TIMBER PHYSICS.

RÉSUMÉ OF INVESTIGATIONS CARRIED ON IN THE U. S. DIVISION OF FORESTRY,

1889 TO 1898.

By FILIBERT ROTH,
ASSISTANT PROFESSOR, NEW YORK STATE COLLEGE OF FORESTRY, CORNELL UNIVERSITY.

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I. THE WORK IN TIMBER PHYSICS IN THE DIVISION OF FORESTRY.

By Filibert Roth,

Late Assistant in the Division of Forestry.

Historical.

As in the case of other materials, exact investigation of the properties of wood did not begin until the latter part of the eighteenth and the beginning of the nineteenth century, when Girard Buffon and Duhamel du Monceau in France, and Peter Barlow, the nestor of engineering in England, laid the foundation for this inquiry by devising suitable methods and working out correct formulæ for the computation of the results. As might be expected, the results of this pioneer work, particularly that of the French investigators, were often contradictory, and have to-day little more than historical value.

Subsequently our knowledge of wood in general, and that of European species in particular, was increased by a number of experimenters. Among these, Chevandier and Wertheim in France, and Nördlinger in Germany, stand out conspicuous. Unfortunately, their apparatus was crude and, in the case of the French workers, the series was too small to satisfy so complicated a problem, while Nördlinger was obliged to content himself with small and few specimens, owing to a want of proper equipment.

In England considerable money was expended from time to time both by Government and private enterprise, but the eagerness of making the matter as practicable as possible led, unfortunately, to much testing of large sizes and to the employment of insufficient (because unsystematic) methods, so that such extreme experiments as those of Fowke and others have really neither furthered science nor helped the practice. In this country the engineering world for a long time relied largely on the results of European testing, and the wood consumers in general depended on a meager accumulation of experience and crude observation concerning most of the fine array of valuable and abundant kinds of timber offered in our markets.

Ignorance and prejudice had their way. Chestnut oak was pronounced unfit for railway ties, and thus millions of logs were left rotting in the woods, though this prejudice had not a single fair trial to support it. "Bled" longleaf, or Georgia pine, was considered weaker and less durable, millers and dealers were obliged to misrepresent their goods, causing unnecessary loss and litigation, and yet there existed not a single record of a properly conducted experiment to substantiate these views. Gum was of no value, Southern oak was publicly proclaimed as unfit for carriage builders, and the views as to the usefulness of different timbers were almost as numerous as the men expounding them.

The engineering world was the first to realize this deficiency, and men like Hatfield, Lanza, Thurston, and others attempted to replace the few antiquated and unreliable tables of older text-books by the results performed on American woods and with modern appliances.

In addition to these efforts of engineers, Sharples, under Sargent's direction, in his great work for the Tenth Census of 1880, subjected samples of all our timber trees to mechanical tests, but, since in these tests only a few select pieces represented each species, the engineering world never ventured to use the results. As regards the rest of the wood testing in our country, it may be said that it generally possessed two serious defects: (1) the wood was not properly chosen, and (2) the methods of testing were defective, especially with respect to the various states of seasoning, wood being tested in almost every state from green to dry, without distinction. This is the more remarkable since the important influence of moisture was recognized and emphasized by both French and German experimenters more than forty years ago.[1]

These facts were fully appreciated by the engineers of our country, as is well shown by the numerous, often emphatic, approvals and recommendations of the timber-physics work undertaken by the Division of Forestry, and by the eagerness with which wood consumers generally seized on all information of this kind as fast as the Division of Forestry could supply the same.

Southern and Northern Oak.

Though fully planned before, the work in timber physics was really begun in order to decide an important controversy as to the relative value of Southern and Northern grown oak.

A representative committee of the Carriage Builders' Association had publicly declared that this important industry could not depend upon the supplies of Southern timber, as the oak grown in the South lacked the necessary qualities demanded in carriage construction. Without experiment this statement could be little better than a guess,[2] and was doubly unwarranted, since it condemned an enormous amount of material, and one produced under a great variety of conditions and by at least a dozen different species of trees, involving, therefore, a complexity of problems difficult enough for the careful investigator, and entirely beyond the few unsystematic observations of the members of a committee on a flying trip through one of the greatest timber regions of the world.

A number of samples were at once collected (part of them supplied by the carriage builders' committee) and the fallacy of the broad statement mentioned was fully demonstrated by a short series of tests and a more extensive study into structure and weight of these materials. From these tests it appears that pieces of white oak from Arkansas excelled well-selected pieces from Connecticut both in stiffness and endwise compression (the two most important forms of resistance).

Results of tests on Northern and Southern white oak made in Washington University Laboratory, St. Louis, Mo., by Prof. J. B. Johnson, 1889.

Test piece.		Bending and cross breaking. Size of test piece 1⅝ by 1⅝ by 24.						Compression.				Shearing.	
		Stiffness.		Ultimate strength.		Resistance to shock.		Endwise.		Transverse.		Longitudinal.	
Where procured.	No.	Range No.	[3]Modulus of elasticity, pounds per square inch.	Range No.	Modulus $\frac{3. W. L.}{2. b. h^2}$ pounds per square inch.	Range No.	Modulus inch-pounds per cubic inch.	Range No.	Modulus pounds per square inch. Size 1⅝ by 5 inches.	Range No.	Modulus pounds per square inch.	Range No.	Modulus pounds per square inch.
A. a. I	1	9	990,000	3	13,760	4	59	6	6,160	1	3,400	3	1,375
	2	5	1,280,000	1	18,500	1	92	7	5,480	3	3,100	1	1,560
Average	......	3	1,135,000	1	16,130	1	76	3	5,820	1	3,250	1	1,468
A. b. II	3	6	1,120,000	8	12,300	6	47	11	4,740	7	2,500	6	....
	4	10	920,000	5	12,700	5	55	9	4,980	4	2,800	7	1,225
Average	......	4	1,020,000	3	12,500	3	51	5	4,860	2	2,650	3	1,225
	5	11	850,000	9	11,400	2	83	8	5,230	5	2,700	4	1,375
	6	7	1,140,000	7	12,300	7	45	10	4,820	8	2,500	2	1,540
Average	......	5	995,000	5	11,850	2	64	4	5,025	3	2,600	2	1,458
B		Size: 1⅝ by 1⅝ by 18 inches.						Size: 1⅝ cube.					
	7	3	1,570,000	6	12,380	9	27	4	6,800	11	2,000	10	860
	8	8	1,100,000	2	14,690	3	82	1	7,800	2	3,200	5	1,260
	9	4	1,385,000	11	11,240	11	19	5	6,800	9	2,300	11	825
Average	......	2	1,351,667	2	12,770	4	43	2	7,133	4	2,500	5	982
	10	1	1,653,000	4	13,030	8	30	3	6,900	6	2,600	8	1,050
	11	2	1,581,000	10	11,590	10	22	2	7,700	10	2,100	9	940
Average	......	1	1,617,000	4	12,310	5	26	1	7,300	5	2,350	4	995

[1] For a more complete history see Bulletin 6 of Division of Forestry.

[2] See Report of the Division of Forestry, 1890, page 209.

[3] Young's modulus of elasticity: $E = \frac{W. L.^3}{4\ D. b. h.^3}$ where W. = total load at center in pounds; L. = length in inches; D. = deflection in inches; b. = breadth in inches; h. = height in inches.

Description of test material and results of physical examination.

Notation as to station, site, and tree	A. a. I. Connecticut upland.	A. b. II. Connecticut lowland.	B. Arkansas.
Number of test piece	1.	3.	
Exposure in tree	North.	Southwest.	
Height in tree	"Butt cut."	"Butt cut."	
Position in tree (with reference to periphery)	Not known.	Not known.	
Size of test material:			
Length	4	4	
Breadth	$1\frac{5}{8}$ inch.	$1\frac{5}{8}$ inch.	
Depth (measured across rings)	$1\frac{5}{8}$ inch.	$1\frac{5}{8}$ inch.	Not specified.
Number of rings			
Width of rings (average)	2.7 millimeters.	1.5 millimeters.	
Summer wood as a whole	80 per cent.	54 per cent.	
Firm bast tissue	60 per cent.	37.5 per cent.	
Space lost by large vessels	14.7 per cent.	24.9 per cent.	
Moisture conditions when tested	Nearly seasoned.	Half seasoned.	
Density	.84	.77	

These particular tests can hardly settle definitely any question. Samples 1 and 2 being selected stock, second growth, can not be used for comparison with samples of B, except to show that for stiffness the unselected Southern stock is superior to the best Northern growth, as also in resistance to endwise compression. The samples 3, 4, 5, and 6 are probably more nearly comparable to samples of B, and here we find the Southern oak very much superior, not only in stiffness and columnar strength, but also in ultimate cross-breaking strength, while for resistance to shock, at least one sample of Southern oak is superior to three samples of forest-grown Northern, and even to one of the best Northern second growth. This piece (No. 8) exhibits, altogether, qualities which render the verdict tenable that Southern oak is not necessarily inferior to Northern oak in any of its qualities.

Beyond this it would not be safe to use these figures for generalizations.

In 1888 the really first beginning in timber physics was made in the form of a preliminary physical and structural examination of a set of trees representing the more important lumber pines of the South and of the lake region, as well as of bald cypress. A comprehensive plan was fully worked out and the mistakes of former methods were carefully avoided. In 1891 a more extensive study of the four great Southern timber pines, the longleaf, Cuban, loblolly, and shortleaf, was begun, and the material was at the same time collected in such a manner as to enable a detailed inquiry into the relative merits of timber bled or tapped for turpentine as compared with unbled timber.

The trees were collected by Dr. Charles Mohr, of Mobile, Ala., an acknowledged authority on the botany of the region, and thus a correct identification was assured. Of each tree entire cross sections as well as the intervening logs were utilized, the former being subjected to examinations into their specific weight (the acknowledged indicator of many valuable technical properties), into the amount of moisture contained, into the shrinkage consequent on drying, and into the structural peculiarities, particularly those structural features which are readily visible and may be utilized in practice for purposes of timber inspection.

The logs were sawed and tested according to definite plans in the well-equipped test laboratory of the Washington University, St. Louis, Mo., under the direction of Prof. J. B. Johnson, a recognized authority in engineering. The first series of test results are embodied in Bulletin No. 8 of the division, where the strength values for the longleaf pine are fully tabulated and discussed. So eagerly was this bulletin sought by wood consumers, that an edition of 5,000 copies was exhausted in a short time.

Bled and Unbled Pine.

In addition, this series of tests together with an extensive chemical analysis and physical and structural examination of material from unbled and bled trees, as well as from trees bled and abandoned for five years, re-enforced by an extended study of bled and unbled timber at various points of manufacture, proved conclusively that the discrimination against bled timber was unwarranted, since the bled timber was neither distinct in appearance, behavior, nor strength.

To avoid error in so important a matter, and also for a comparison of the three most important turpentine trees—the Cuban and longleaf with the loblolly pine—the extensive chemical analyses of Dr. M. Gomberg, of the Michigan University, were repeated and extended by Mr. O. Carr, of the Chemical Division of the Department of Agriculture. This series of additional chemical analyses fully substantiated Dr. Gomberg's work, so that it was safe to announce that: (1) Bled timber is as strong as unbled timber; and (2) that it contains the resinous substances in the same amounts and similarly distributed as the wood of unbled timber, so that it seemed to follow as a simple corollary that bled timber is also as durable as unbled, and hence equal to the latter in every respect.

The importance of this fact was quite fully realized. Trautwine, in his standard work, the Engineers' Pocketbook, at once placed the fact on eminent record, and the lumbermen of the South, as well as all trades journals, spread the welcome news in every paper and at every opportunity.

The work of Mr. Gomberg in determining the distribution of the resin through the different parts of the tree is unique in method and classical in its clear scientific procedure and statement. Since the publication in which it first appeared was at once exhausted, it appears proper to reproduce it in full, leaving out only a few tables, as a part of the most valuable work in timber physics performed under direction of the Division of Forestry:

A Chemical Study of the Resinous Contents and their Distribution in Trees of the Longleaf Pine Before and After Tapping for Turpentine.

[By M. Gomberg.]

Botanists tell us that resins are produced by the disorganization of cell walls and by the breaking down of starch granules of cells. Chemists believe that resins are oxidation products of volatile oils, the change being expressed by formula as follows: $2C_{10}H_{16}+3O=C_{20}H_{30}O_2+H_2O$.

Whatever view be correct,[1] one thing is certain, and that is that the formation of either resins or essential oils requires the presence in the tree of those peculiar conditions which we call vital. The tree must live, must be active, must assimilate carbon dioxide and imbibe moisture, in order that oil of turpentine and rosin be formed.

The heart of the tree is the dead part of it. It does not manufacture any turpentine. A part of the oleoresin in it had been formed when the heartwood was yet sapwood, and remained there after the change from sap to heart had taken place. It is also probable that the heart of the tree acts as a storehouse in which there is deposited a portion of the oleoresin formed in the leaves and sap.

When a tree is tapped for turpentine there are two possible changes that might be supposed to take place: (1) The tree may be considered as placed in a pathological condition, when it will strive to produce a larger amount of oleoresin in order to supply the amount removed. In a few years the energy of the tree will be exhausted and the amount freshly supplied will fall far below the amount of oleoresin drawn off by the tapping. The tapping will then have to be discontinued. The oleoresin in the heartwood will in this case remain untouched. (2) The oleoresin previously stored away in the heart might, by some unknown means and ways, also be directed toward the wound.

If the first change takes place then, the tapping will have little effect upon the chemical composition of the heartwood. If, however, the second condition prevails during tapping, then of course the heartwood will be seriously affected for some time after tapping, and will contain a much smaller amount of oleoresin than it contained before tapping. Moreover, the tapping may affect not only the amount of oleoresin, but also the quality of the new product and the relative distribution of volatile products.

For this reason the chemical side of the problem has been approached by parallel analyses of tapped or untapped trees for their relative amounts of turpentine. It was hoped that by a large series of analyses an average might be obtained showing whether tapped and untapped trees differ from each other in that respect.

CHEMICAL COMPOSITION OF TURPENTINE.

Under the name of turpentine is known an oleoresinous juice produced by all the coniferous trees in greater or less amount. It is found in the wood, bark, leaves, and other parts of the trees. It flows freely as a thick juice from the incisions in the bark. It consists of resin or resins

[1] The one view does not exclude the other.

dissolved in an essential oil; the latter is separated from the former usually by distillation with steam.

There are many varieties of turpentine, corresponding to the different varieties of coniferæ, but only three are commercially important, as they are the source of the three principal oils of turpentine.

(1) The turpentine of *Pinus pinaster* (syn. *P. maritima*), collected in the southern departments of France around Bordeaux. From it is obtained the French turpentine, which yields 25 per cent of volatile oil.

(2) The turpentine from *Pinus palustris*, *P. tæda*, *P. heterophylla*, collected in the southern sea-bordering States from North Carolina to Texas. From them, principally from the first source, is obtained the English or American oil of turpentine, which yields 17 per cent of volatile oil. Formerly the *P. rigida* was also worked for turpentine in the North Atlantic States, but it is now exhausted.

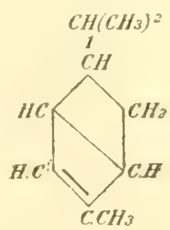
(3) The turpentine from *Pinus laricio* var. *austriaca*, collected mainly in Austria and Galicia. From it is obtained the German turpentine oil, which yields 32 per cent of volatile oil.

The Russian oil of turpentine is obtained from *Pinus silvestris* and *Pinus ledebourii*, by the direct distillation of the resinous wood, without previously collecting the turpentine. It is said to be identical with the German oil of turpentine, but more variable, as it contains products of destructive distillation, both of wood and rosin.

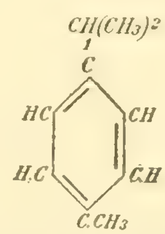
The turpentines from the different sources differ from each other—(1) in their action upon polarized light, (2) in the relative amounts of volatile oil they yield on distillation with steam, and (3) in the nature of the volatile oils they contain.

Colophony.—The rosin in the different varieties of turpentine is practically the same. It is known as common rosin or colophony.[1] It consists chemically of a mixture of several resin acids and their corresponding anhydrides. The chief constituent is abietic anhydride, $C_{44}H_{62}O_4$, abietic acid being $C_{44}H_{64}O_5$. The crystals that are noticed in crude turpentine are the free abietic acid; on melting the thick turpentine, or on distilling the volatile oil, the acid is changed to the anhydride. Colophony is nonvolatile, tasteless, brittle, has a smooth shining fracture, sp. gr. about 1.08. It softens at 80° C., and in boiling water melts completely at 135° C.

The volatile oil.—The second principal constituent of turpentines are the volatile oils. The chief ingredient of the three turpentine oils is a hydrocarbon of the same composition, $C_{10}H_{16}$; nevertheless the three oils have distinct hydrocarbons differing from each other in physical if not in chemical properties. The empirical formula of the hydrocarbon is $C_{10}H_{16}$, and according to the latest researches of Wallach[2] it has the following structural formula:



thus being a dihydro-para-cymene, paracymene being $C_{10}H_{14}$,



[1] Colophon, a city of Iconia, whence rosin was obtained by the Greeks.
[2] Ann. Chem. (Liebig), 239, 49; Ber. d. Chem. Ges., 24, 1515.

The position of this particular terpene, pinene, will be best seen from the general classification of terpenes taken from Wallach.[1]

I. *Hemiterpenes* or *pentenes* of the formula C_5H_8.
II. *Terpenes* or *dipentenes* of the formula $C_{10}H_{16}$.
(1) *Pinene*, obtained from many varieties of turpentine.
(2) *Camphene*, obtained artificially from camphor.
(3) *Fenchene*, obtained artificially from fenchone, a constituent of many fennel oils.
(4) *Lemonene* occurs in orange-peel oil, in oils of lemon, bergamot, cuminin, etc.
(5) *Dipentene*, obtained artificially from pinene. Occurs in Russian and Swedish turpentine.
(6) *Sylvestrene* occurs in Russian and Swedish turpentine.
(7) *Phelandrene* occurs in the oils of bitter fennel and water fennel, elemi, eucalyptus.
(8) *Terpinene* occurs in oil of cardamom.
(9) *Terpinolene*, only slightly known.
III.—*Polyterpenes*, of the formula $(C_5H_8)_n$, as cedrenes $C_{15}H_{24}$ caoutchouc $(C_5H_8)_n$, etc.

The hydrocarbon of the American and French oils of turpentine is pinene. It is dextro-rotatory when obtained from the American turpentine oil, and is known as austro-terebinthene or australene; lævo-rotatory when obtained from the French turpentine oil, and is known as terebinthene. Otherwise the two hydrocarbons agree entirely in specific gravity, boiling point, and behavior toward chemical reagents.

The hydrocarbon of the Russian oil of turpentine is sylvestrene. It is dextro-rotatory, and has a higher boiling point than pinene. The latter boils at 155° to 156° C., the former at 175° to 178° C.

But even the turpentine oils of high grade as found on the market do not consist of pure pinene; especially is this true of ordinary oil of turpentine, which is obtained from the cruder turpentine by a single distillation with steam. Different samples vary from one another considerably in their specific rotatory power as well as their boiling point.

American oil of turpentine has a density of 0.864° to 0.870°. According to Allen[2] it begins to boil at a temperature between 156° and 160° C., and fully passes over below 170° C. "A good sample of rectified American oil will give 90 to 93 per cent of distillate below 165°, the greater part of which will pass over between 158° and 160°",[3] while in the experience of J. H. Long,[4] "In the examination of a large number of pure commercial samples of turpentine oil it was observed that the boiling point was uniformly at 155° to 156°, and that 85 per cent of the samples distilled between 155° and 163°. The distillation is practically complete below 185° C."

Then, again, as found by Long, the vapor densities of many samples of oil are too high to allow the formula $C_{10}H_{16}$ for the entire oil. Fractions of different boiling points show different degrees of specific rotation. All this would indicate that ordinary turpentine oil contains hydrocarbons heavier than pure pinene, $C_{10}H_{16}$. They are probably either isomeric with pinene, but of a higher boiling point, or may belong to the polyterpenes.

Still less do we know of the source of these hydrocarbons. Whether they are produced by the tree simultaneously with pinene, and are therefore to be found in the oleoresin or whether they are all or in part produced by external agencies after the turpentine has been dipped can not be answered. Probably the formation of these other hydrocarbons takes place in both ways spontaneously in the tree and by some influences outside the tree.

Indeed, all terpenes have this property in common that they easily undergo change, from optically active to inactive, from hemiterpenes to terpenes and polyterpenes. The change can be brought about either by heat alone, or by heating the terpenes with salts or acids. So, when a sample of American turpentine oil of +18.6° was heated to 200° C. for two hours it showed an opposite rotation of —9.9°.[5] Pinene heated to 250° to 300° C. is converted into dipentene CH, boiling at 175°, and a hydrocarbon CH, boiling at 260° C.

These illustrations will suffice to show that the transformation of pinene into isomeric and heavier hydrocarbons may occur, at least partially, after the turpentine has been removed from the tree.

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[1] Ann. Chem. (Liebig), 227, 300; Ber. d. Chem. Ges., 24, 1527.
[2] Allen, Com. Org. Anal., 2, 437.
[3] Allen, Com. Org. Anal., 2, 441.
[4] Jour. Anal. and Appl. Chem., 6, 5.
[5] Muspratt's Chemie, 4th ed., 1, 153.

The crude turpentine from *Pinus palustris*, or long-leaf pine, is thus made up of—

(1) Rosin, 75 to 90 per cent; mostly abietic anhydride.

(2) Australene, 25 to 10 per cent; boils at 155° to 156° C.

(3) Some other terpenes of $C_{10}H_{16}$; small portions; kind not known.

(4) Some polyterpenes of $(C_5H_8)_n$; small portions; kind not known.

(5) Cymene (?) $C_{10}H_{14}$; small portions, if any; boils at 175° to 176° C.

(6) Traces of formic and acetic acids; produced probably by atmospheric oxidation during collection of turpentine.

ANALYTICAL WORK.

As both the rosin and the volatile oil are easily soluble in chloroform, ether, carbon disulphide, etc., their separation from wood by any of the above solvents would appear to be an easy matter. But an exact quantitative determination of the volatile oil presents considerable difficulties, and for these reasons: (1) Wood can not be dried free from moisture without driving off some of the volatile hydrocarbons; (2) the ether extract can not be freed entirely from either without some loss of the volatile oil.

If a weighed quantity of wood shavings is exhausted with either, the residue dried at 100° C. and weighed, the total loss thus found will represent:

The moisture = *H*.
The rosin = *R*.
The volatile hydrocarbons = *T*.

It is sufficient to determine two of these factors; the third could then be determined by difference. But as has been mentioned before, the ether extract can not be obtained in any degree

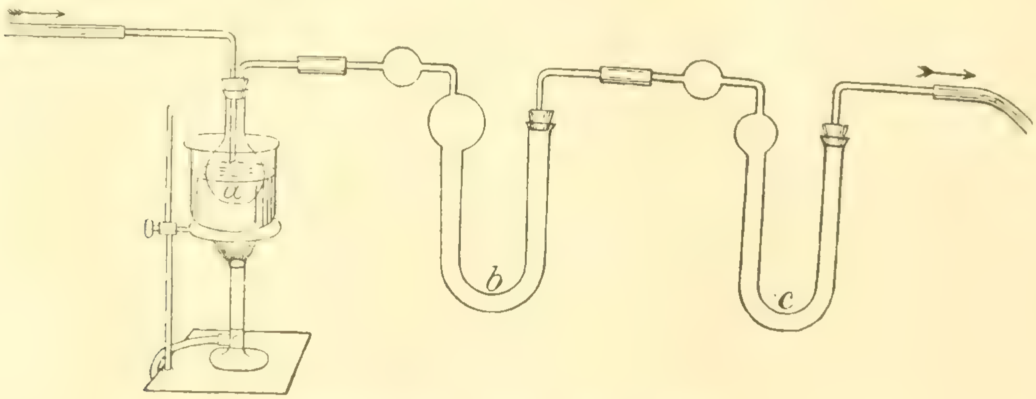


FIG. 85.—Method of chemical analysis of turpentine.

of purity without loss of turpentine. The evaporation of ether in a stream of dry air, as proposed by Dragendorf, for the estimation of essential oils in general, does not give satisfactory results with turpentine oil, as Dragendorf himself observed.

A weighed quantity of a mixture of rosin and oil, made up in about the same proportions as they exist in crude turpentine, was dissolved in a suitable amount of ether. The latter was then evaporated in a current of dry air till the odor of ether was hardly noticeable. The mixture was found to have gained considerably in weight by retaining ether in the thick sirupy oleorosin. It was only by heating at 100° C. for some time that all of the solvent could be driven off, and then the mixture was found to have lost in weight. Repeated trials proved that this method could not be used safely.

An attempt was then made to determine the quantities *H* and *R*, and thus find *T* by difference A weighed quantity of wood shavings was placed in a small flask *a*. The latter was connected on one side with a tray of drying bottles, on the other two $CaCl_2$ tubes *b* and *c*, similar in size and form. The flask is immersed in boiling water and a current of dry air is passed through the whole apparatus for one and one-half hours. The flask is then cooled and air is passed for one and one-half hours longer.

It was thought that while *b* would retain all the moisture and a portion of the volatile compounds, *c* would retain about the same amount of the volatile products only. Gain in weight of

c subtracted from that of b would then give the moisture H. The sample of wood shavings is then exhausted with ether, the latter evaporated, and the residue heated at about 140° to 150° to constant weight; this gives the rosin R. If L be the total loss by extraction with ether, we have

$$L-H+R=T.$$

But it was soon found by experiments upon pure turpentine oil that the two $CaCl_2$ tubes did not retain an equal amount of volatile oil. The quantity retained depended upon many circumstances, the chief one being the amount of moisture already present in the $CaCl_2$ tubes.

Even had the tubes retained quantities of turpentine oil, this method would still have the objection that one of the constituents was to be determined by difference—an objection especially serious when the ingredient to be so determined is small in comparison with the materials to be weighed.

The writer has therefore attempted to make use of a somewhat different principle. A few trials were sufficient to show that the method promised to give satisfactory results. The basis of the method is the same which served for the production of Russian turpentine oil on a large scale, namely, the distillation of the volatile products from the wood itself, without previously obtaining the turpentine. But instead of condensing the volatile products, their vapors are passed over heated copper oxide, whereby they are burned to water and carbon dioxide. Many trials were made with this method upon pure materials and on samples of resinous wood. As the results were found to be entirely concordant and satisfactory, the method was adopted, and by it were obtained the results presented in this report.

DESCRIPTION OF THE METHOD EMPLOYED.

A weighed amount of wood shavings is placed in a straight $CaCl_2$ tube a. The tube is connected on one side by means of a capillary tube with a drier A, which serves for freeing the air from moisture and CO_2. The other end of the tube is connected with an ordinary combustion

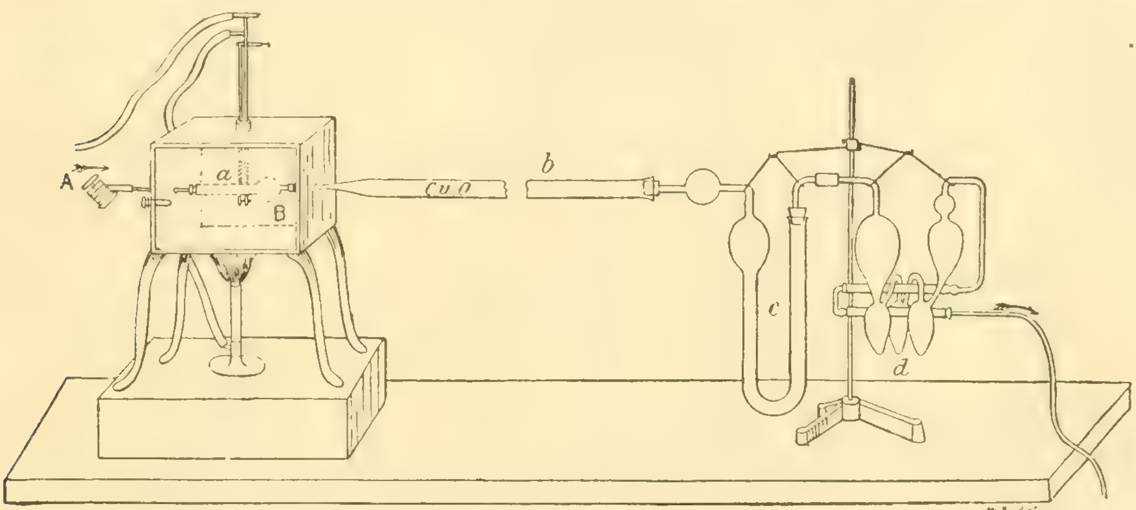


FIG. 86.—Method of distillation of turpentine.

tube b containing granulated CuO. The tube is drawn out at one end as is shown in the figure, and the narrow portion is loosely filled with asbestus wool. The connection is made glass to glass, so that the vapors of distillation do not come in contact with any rubber tubing. The forward end of the combustion tube is connected with a $CaCl_2$ tube c, one-half of which is filled with granulated $CaCl_2$ and the second half with P_2O_5. Then follows a potash bulb d provided with two straight tubes, the first one filled with solid KOH, the second with P_2O_5. The last tube is connected with an aspirator.

All the connections having been made air-tight, the connection between the tube a and the drier A is shut off by means of a clamp and the aspirator turned on. When the combustion tube has been heated to dull redness the burner under the air-bath B is lit and the temperature raised to 110°–120° C. The moisture contained in the tube escapes quite rapidly, carrying with it some turpentine oil. The capillary tube at the other end of A practically checks backward diffusion or any accumulation of condensed vapors. In about fifteen minutes all the moisture appears at the forward end of the combustion tube. The clamp is now opened and a stream of air at the rate of somewhat over one liter an hour is passed through the whole apparatus, while the temperature of the air bath is raised to 155° to 160° C., and kept at that point for about forty-five minutes. Toward the end of the operation the temperature is raised to 165° to 170° C. for ten minutes. Then the light under the air bath is turned off and air aspirated for twenty to twenty-five minutes longer. As the air bath is in close contact with the combustion furnace, the whole length of the tube is kept at a temperature above the boiling point of turpentine oil. In this way a complete distillation is insured.

All the moisture is retained by *c*, while the CO_2 is absorbed in the potash bulb *d*. The gain of weight in *c* represents the moisture originally present in the sample of wood plus the water produced in the combustion of the hydrocarbons. The gain in weight of *d* represents the amount of CO_2, derived from the combustion of the volatile products.

The tube *a* is now transferred to an ordinary Soxhlet's extraction apparatus and exhausted with ether. The latter is distilled off, the residue dried for about two hours at 100° C., and weighed. This represents the amount of rosin in the sample of wood taken.

As has been previously mentioned, the volatile oil of the oleoresin is not pure australene, $C_{10}H_{16} = (C_5H_8)_2$. It probably contains some other hydrocarbons, either of the same formula or belonging to the class of polyterpenes $(C_5H_8)_n$. It is clear that whichever they be their percentage composition is alike in all; they all have C = 88.23 per cent, H = 11.77 per cent. Therefore, so far as the combustion of the volatile terpenes is concerned, they can all be represented by the equation:

$$\underbrace{C_{10}H_{16}}_{136} + 14O = \underbrace{10\ CO_2}_{440}, = \underbrace{8\ H_2O}_{144}$$

In other words, 440 parts of CO_2 are derived from 136 parts of volatile terpenes.

$$440:136 = 1:X;\ X = 0.3091,$$

i. e., 1 part of CO_2 obtained in the combustion represents 0.309 parts of the volatile hydrocarbons.

For every 440 parts of CO_2 produced there are 144 parts of H_2O formed.

$$440:144 = 1:X;\ X = 0.3272,$$

i. e., simultaneously with 1 part of CO_2 there is produced 0.327 parts of H_2O.

Let the weight of the sample taken = W,

Let the weight of CO_2 obtained = W′,

Let the weight of H_2O obtained = W″,

Then—$W' \times 0.309 = T$, the amount of volatile hydrocarbons.

$W' \times 0.327 = H'$, the amount of H_2O corresponding to the volatile hydrocarbons.

$W'' \times - H', = H$ the amount of moisture in the wood.

$\frac{T}{W}$ = per cent of T; $\frac{H}{W}$ = per cent of moisture.

Thus the moisture, the volatile hydrocarbons, and rosin are obtained directly from the same sample. Where many estimations are to be made, it is of course unnecessary to cool down the combustion tube between successive combustions.

The temperature of distillation.—Some experiments were made to determine at what temperature it is safe to conduct the distillation. Although pure turpentine boils at 156–160° C., yet in open air it can be volatilized at a much lower temperature, even on the water bath, without any difficulty. Especially is this the case when the vapors are removed as soon as formed by a stream of air, but it must be remembered that the volatilization of the essential oil directly from the wood might be considerably hindered by the large amount of rosin.

A sample of wood distilled by the method outlined above gave the following results at different temperatures:

	120°	140°	150°	160°	170°
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
T. =	1.09	1.18	1.30	1.26	1.32
H_2O =	11.17	11.33	11.23	......	......

Another sample gave:

	160	180
	Per cent.	*Per cent.*
T	4.00	3.98
H_2O	8.79	....

The results would indicate that the distillation is practically complete at 160°, and that the wood itself does not contribute any CO, by partial decomposion at that high temperature; for, should the latter be the case, higher results might be expected at 180° than at 160°, and then the sapwood would give much higher numbers for turpentine oil than those actually obtained.

Even if this method does not give the absolute amounts of volatile hydrocarbons, yet it certainly gives results very near the truth, and, what is more important, under the same conditions it gives constant results. Therefore, by employing strictly parallel conditions in the analysis of the different samples, results are obtained which can be safely used as indices of comparison of the relative amounts of volatile hydrocarbons in the samples under analysis.

MATERIAL FOR ANALYSIS AND METHOD OF DESIGNATION.

Materials.—Trees No. 52 and 53, abandoned five years.
Trees No. 60 and 61, abandoned one year.
Trees No. 1 and 2, not tapped.
Trees 54–57, abandoned five years.
Trees 58–59, abandoned five years.
Trees 63–65, abandoned one year.
Trees 66–69, abandoned one year.
Trees 17–19, not tapped.

Generally Disk II is 23 feet from ground.
Disk III is 33 feet from ground.
Disk IV is 43 feet from ground.

Method of designation.—It was thought best to make a somewhat detailed analysis of a few bled and unbled trees in order to gain an insight into the quantitative distribution of turpentine in the trees. Each disk was divided into pieces of about thirty rings each, the heart and sapwood being kept separate. The number of the disk is designated by a roman figure, the kind of wood by either *s* for sapwood or *h* for heartwood. The arabic figure which precedes the *h* or *s* designates the number of the piece, counting for the sapwood from the bark; for the heartwood, from the line of division between sap and heart.

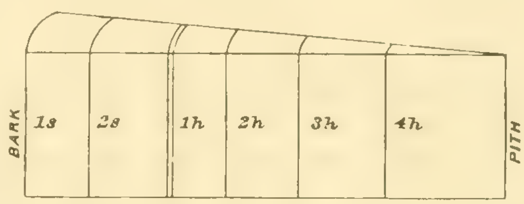


FIG. 87.—Distribution of turpentine in trees. (A piece marked 52 III 2*h* means tree No. 52, disk III, the second piece of the heart.)

Preparation of material.—The first six tables give the results of what might be called "detail" analysis, where each piece of about thirty rings has been analyzed separately. The material for analysis was prepared in the following way: A radial section of the disk, about 1 to 2 inches thick, is selected. A piece of 1 inch is cut off transversely, and the strip is then divided into pieces of about thirty rings each. From the freshly cut transverse surface about 15 grams of thin shavings are planed off and placed in a stoppered bottle. The exact amount used for analysis, usually from 3 to 5 grams, is found by weighing the bottle before and after taking out the portion for analysis.

The second set of tables, VII to XII, inclusive, give the results of "average" analysis. The material for these analyses was obtained by mixing equal quantities of shavings from the corresponding portions of several trees and taking for analysis an average sample of the mixture. The sapwood furnish one analysis and the heart wood was either analyzed as a whole or divided into portions, 1*h* and 2*h*, if of considerable thickness.

NOTES ON TABLES I TO XII.

Each table contains a column "calculated for wood free from moisture," giving the per cent of volatile hydrocarbons and rosin obtained by calculation from results actually found. Objections might be raised to this mode of interpreting the results. It might be said that the moisture in the wood can not be disregarded, because it is as much an essential proximate constituent of wood as the turpentine itself is. But since the analyses were not made soon after the trees had been felled, the moisture found in the samples does not represent the original moisture, nor does it represent equal portions of it in all samples. The numbers given in the column "water" are of course suggestive as to the comparative degree of retention of moisture by the different samples, since the latter were all exposed to about the same influences. But it seemed best to compare the amounts of volatile hydrocarbons and rosin on wood free from that variable constituent; the more so as some time elapsed between the analysis of the first and last samples.

The last column in each table contains the ratio between the volatile hydrocarbons and rosin. This ratio is multiplied by 100, and means that for every 100 parts of rosin as many parts of the volatile hydrocarbons are found as is indicated in the column. This ratio $\left(\frac{T}{R}\right)$ is of little value in cases when the amount of turpentine is small, because a very small increase of the first constituent—an increase within experimental error—will change the quotient considerably. An increase of 0.07 per cent of volatile hydrocarbons in 60, IV, 1*s* will bring up $\frac{T}{R}$ from 7.2 to 10. A decrease of 0.07 per cent in 52, IV, 2*s* will change $\frac{T}{R}$ from 25.20 to about 19. These numbers are therefore of very little significance when applied to the sapwood of all samples, to entire tree 52, and to some parts of trees 60 and 1, all of which show only small portions of turpentine.

DISCUSSION OF RESULTS OBTAINED.

Relation of rosin and volatile hydrocarbon to moisture.—The amount of moisture retained by different samples does not seem to have any direct relation to the amount of oleoresin in these samples. Yet in the same tree, or rather in the different parts of the same disk, there seems to exist something like a relation of the two. This is especially noticeable in tree No. 53. The moisture retained seems to vary inversely with the amount of oleoresin in the sample. Compare, for example, in 53 II, 1*h*, 2*h*, 3*h*; in 53 III, 1*h*, 2*h*, 3*h*, 4*h*; in 53 IV, 2*h*, 3*h*, 4*h*. The piece richest in oleoresin is generally the poorest in moisture. But this is by no means a universal rule. Some trees show about the same per cent of moisture in parts widely differing from each other in the amounts of turpentine, and in many instances a smaller amount of turpentine is associated with a smaller per cent of moisture.

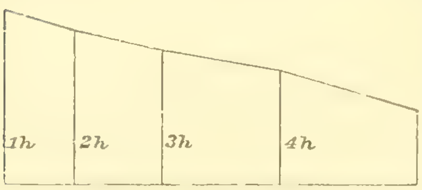


FIG. 88.—Relationship of different parts of same disk.

Sapwood and heartwood.—All the analyses, detail and average, show conclusively that the sapwood is comparatively very poor in turpentine; it is immaterial whether it comes from a rich tree or a poor one, from a tapped tree or an untapped one. The turpentine in sapwood reaches 3 to 4 per cent in very rich trees, as in Nos. 53, 61, and 2; in the remaining trees it is 2 to 3 per cent. Consequently the results obtained for sapwood are not taken into account in the following paragraphs. When differences between trees are spoken of, it applies entirely to heartwood.

The different parts of the same disk show a constant relation in nearly all instances. In most cases 1*h* is the richest, and the heartwood grows poorer as we approach the pith of the tree. In a few cases, as in 1 III and in 1 IV, 1*h* and 2*h* are practically identical, while in some instances, in 2 III, 61 II, 61 III, and 53 II, 1*h* is poorer than 2*h*. In nearly all cases the decline is marked in 3*h*, and 4*h* is usually found to be the poorest part of the disk. This relationship can be represented in a general way by the following curve:

Relation of volatile hydrocarbons to rosin.—As the turpentine in the tree is a solution of rosin in an essential oil, it will follow that the richer a tree is in turpentine the richer it will be in the constituents that go to make up this mixture. One would also expect that the ratio between the volatile hydrocarbons and rosin would be tolerably constant in the different parts of the same tree, but the results of analysis do not indicate it. They show that this ratio increases with the amount of rosin. A part of heartwood having twice as much rosin as another part will contain more than twice as much volatile products as the second part. This is true in a general sense of parts of the same disk, of parts of different disks in the same tree, and parts from different trees. There is no distinction in that respect between bled and unbled trees. This relationship can be formulated in the following way: The crude turpentine from heartwood rich in oleoresin will yield a comparatively larger amount of turpentine oil than the turpentine from heartwood poor in oleoresin.

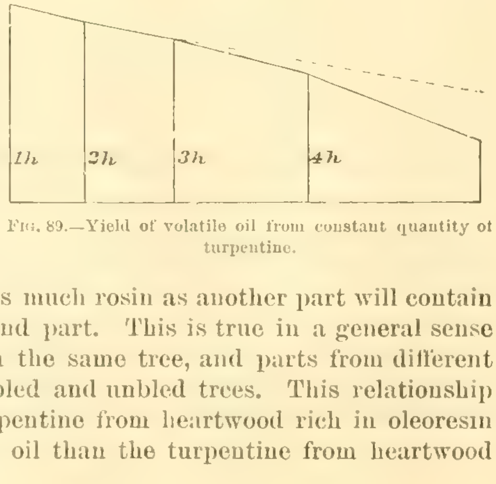


FIG. 89.—Yield of volatile oil from constant quantity of turpentine.

It has been shown that the heartwood grows poorer from $1h$ toward the pith of the tree. It will therefore follow from what has been said in the preceding paragraph that $\frac{T}{R}$ will also grow smaller from $1h$ to the pith. The yield of volatile oil from a constant quantity of turpentine can be expressed in a general way by a graphic illustration similar to that which expresses the yield of total oleoresin from different parts of the disk.

It is difficult to explain satisfactorily this decrease of $\frac{T}{R}$. The two parts of the radial sections that have been the longest exposed to air are $1s$ and the last h. The question naturally arises, May not the decrease of $\frac{T}{R}$ be due to a greater evaporation of volatile hydrocarbons from these two ends? But this can hardly be so. No. 53, II, $4h$ was analyzed at intervals of two months and furnished the following data:

I, Sept. 28.	II, Nov. 27.
H_2O = 11.23	7.24
T = 1.30	1.34
R = 7.96	8.12

Calculated for wood free from moisture:

I.	II.
T—1.30	1.30
R—8.96	8.75

Sufficient experimental data are lacking to prove conclusively that the volatile hydrocarbons do not evaporate to any extent from the heartwood except from freshly cut surfaces of it.

Relation between different disks of the same tree.—There is no constant relation between the different disks of the same tree so far as the amount of oleoresin is concerned. Although the disks do vary from each other, the variation can not be connected with gravitation, by virtue of which the lower disks would contain a larger amount of turpentine than the upper ones; for different trees vary from each other considerably in this respect, the variation being apparent in both bled and unbled trees. If *a*, *b*, *c* stand for the amounts of oleoresin in disks denoted by Roman numerals, the relative magnitudes being represented by the letters in the alphabetic order, then the results of analysis can be condensed in the following table for the trees denoted in Arabic numbers:

	53.	60.	61.	1.	2.
IV......	*a*	*b*	......	*a*	*c*
III....	*b*	*c*	*a*	*c*	*b*
II	*c*	*a*	*b*	*b*	*a*

It is evident that no constant relation as to amounts of oleoresin exists between the disks of the same tree.

Comparison of tree 52 with 53.—These two trees were both supposed to have been sound, healthy trees at the time of felling, and yet they differ from each other as much as two trees could differ. The heartwood of one is very rich in turpentine; that of the other contains comparatively very small quantities—only a trace. How to explain the difference? Previous to felling they had both been tapped for four consecutive years; consequently both must have contained considerable amounts of turpentine. Since the last tapping they stood for five years side by side, both exposed to the same influences. This great difference can not be traced directly to tapping, for the latter, it may be assumed, would have affected both trees equally. The cause of the difference between 53 and 52 ought to be looked for, rather, in the condition of the two trees before tapping. In connection with this it would be interesting to know how much turpentine each tree had yielded when tapped.

Comparison of trees 60 and 61.—There is a decided difference between the two trees. The highest numbers in 60 are 0.84 per cent for volatile hydrocarbons and 5.35 for rosin, while in 61 0.75

and 5.67 are the lowest numbers for the corresponding constituents, the highest being 3.49 and 16.29, respectively. Here again we have two trees of about the same age, under apparently the same conditions of growth, tapped at the same time and abandoned for the same length of time before felling, and yet differing very widely from each other. It is difficult to conceive why tapping should have affected the heartwood of these two trees in such a strikingly different manner. If the assumption is made that the tapping had drained both trees equally, what explanation can be given for the fact that within one year of abandonment one tree is very rich in turpentine while the other has less than one-fourth as much?

Comparison of trees 52 and 53 with 60 and 61.—Compare 53 and 61. Here we have two trees both very rich in turpentine, but while 53 had five years of rest after tapping, 61 had only one year. Had the tapping forced the trees to pour out their oleoresin previously stored up in the heart, we should expect to find in the time of rest the prime factor for the tree in resuming its natural condition; but, on the contrary, results of analysis show that time of abandonment before felling is of little importance. While we can have a tree very rich in turpentine within five years after tapping, we can also have trees rich and poor even within one year, and trees almost totally deprived of turpentine in the heartwood within five years after tapping.

Comparison of 1 with 2.—These two trees had never been tapped, and yet neither is rich in turpentine. No. 2 contains about twice as much turpentine as No. 1, the difference becoming smaller as we go up the tree. The highest numbers for 2 are 1.93 and 14.19 for T and R, respectively, the lowest 0.86 and 5.89, with an average of about 1 and 7. We can say that there is as much difference between untapped trees as there is between trees that have been tapped.

Average analyses.—The average analyses cover 16 trees. Thirteen trees furnish four sets of analyses of tapped trees and 3 trees furnish one set of untapped. The results obtained are summarized in the following table:

Tree No.	II.			III.			Remarks.
	$T.$	$R.$	$\frac{T}{R}\times 100.$	$T.$	$R.$	$\frac{T}{R}\times 100.$	
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*		
54–57	0.93	5.88	15.58	0.58	3.98	14.04	Abandoned 5 years.
57–59	.80	4.06	19.63	.82	4.29	19.10	Do.
63–65	.91	5.32	17.18	....	....	....	Abandoned 1 year.
66–69	.89	4.95	18	....	....	....	Do.
17–19	.64	2.98	21.37	.71	3.21	21.76	Not tapped.

These results show a pretty constant average number for turpentine in tapped trees. The heartwood of untapped trees is poorer in both volatile oil and rosin than that of tapped trees. And here again it is worthy of notice that time of abandonment is of little importance to tapped trees. The trees that had been abandoned for one year are fully as rich as those that had five years to recover from tapping.

Comparison of tapped with untapped trees.—If now the heartwood of tapped trees be compared with that of untapped, one is at a loss as to what conclusions should be drawn from so few analytical data. It is remarkable that the two richest trees and the poorest tree are among those that had been tapped. Of the remaining 19 trees, there is no difference between the 14 tapped and 5 untapped. Whatever differences are found among bled trees are equally found among those that have not been tapped.

Indeed, from the study of the results of analyses the writer is of the opinion that the difference in untapped trees is due to the same cause as the difference in trees that have been tapped. As stated above, the cause of the difference among tapped trees can not be traced directly to tapping; it ought to be looked for, rather, in the condition of the trees previous to tapping.

The difference between trees 52 and 53 can be explained on the following hypothesis: 53 had been a rich tree from early growth and had a large amount of turpentine stored up in the heartwood; 52 for some reason or other had very little stored away. When the two trees were subjected to tapping they gave up whatever turpentine they had in the sapwood and whatever they could produce from season to season, till at the end of four years the production became too small in amount and too poor in quality. The trees were then abandoned. But tree No. 53 had its oleoresin in the heartwood untouched, while No. 52 had hardly any before tapping, and for the same unknown cause did not store away any in the heartwood after the tree had been abandoned.

The explanation offered in the preceding paragraph gains still more probability when trees 60 and 61 are compared with each other and also with 52 and 53. The difference between 1 and 2, the results of average analyses—all these are very suggestive of the theory that the sap, and not the heart of the tree, supplies the turpentine when the tree is tapped. The fact that the heartwood of trees felled one year after tapping is fully as rich or as poor as that of trees felled five years after tapping, seems to the writer of especial significance, for it shows that the richness of the heartwood in a tapped tree is independent of time of rest before felling.

It is a well-known fact that when a pine tree is cut transversely, liquid turpentine immediately appears on the fresh surface of the sapwood, while the heartwood remains perfectly clear. It would seem as if the turpentine in the sap is far less viscid than that in the heart of a tree. It is probable that the turpentine in the sap is richer in volatile hydrocarbons than that in the heart. (A difference of cell structure and manner of existence of oleoresins may also account for this difference in part.—B. E. F.)

It is generally stated that crude turpentine as obtained on a large scale yields from 10 to 25 per cent of volatile oil. This gives $\frac{T}{R}=11.11$ to 30, with an average of over 20. This average is somewhat higher than that for the $\frac{T}{R}$ as found for the turpentine from heartwood of the 21 trees analyzed. Although experimental data are wanting to show conclusively that the difference in the consistency of the oleoresin from sapwood and heartwood is due to a difference in the relative amount of volatile oil, yet it is quite probable that this should be the cause. The oleoresin in the heartwood of trees has been produced for the most part when the heartwood was yet sapwood. Therefore that part of turpentine which is found in the heartwood is the oldest in age and consequently has been exposed the longest to oxidizing influences of air, which gradually replace the water when the sapwood changes to heartwood. It is the same kind of oxidation and of thickening which takes place when crude turpentine is exposed to the air and sun, or when a fresh cut is made in the bark of a tree. It is probably for the same reason that $\frac{T}{R}$ becomes smaller as we approach the pith of the tree, because the parts nearest the pith are the oldest.

It is difficult to conceive how the thick oleoresin of the heartwood could be made to flow toward the incision when a tree is tapped. It is also difficult to explain by what means the tree could change this thick turpentine into a less viscid solution in order that it may flow toward the wound.

One would judge, a priori, from the great difference in the consistency of the turpentine in the heart and sap that only the liquid turpentine will flow when a tree is tapped. Tapping will then have little effect, if any, upon the oleoresin stored up in the heartwood of the tree. A tree whose heartwood is rich in turpentine will remain so after tapping.

The writer is not willing to generalize too hastily from so few results and consider them as a solution of the problem. A large number of analyses, devoid of the possibility of chance selection of samples, is necessary before a positive or a negative answer can be given to the question, does the tapping of trees for turpentine affect the subsequent chemical composition of the heartwood?

But, however few in number the results are, they admit of the following conclusions:

(1) Trees that have been tapped can still contain very much turpentine in the heartwood.

(2) Trees that have been abandoned for only one year before felling can contain fully as much turpentine in the heartwood as trees that have been abandoned for five years.

(3) Trees that have not been tapped at all do not necessarily contain more turpentine in the heartwood than trees that have been tapped.

The following diagram serves to show what proportion of each disk was involved in each of the detail analyses, and the results in each case. The right-hand vertical line represents the pith of the tree, the horizontal lines represent the radical extension of each disk, as numbered by roman number, the position of the disk in the tree being maintained as in nature, IV being the top, II the lower, and III the intervening disk. The subdivisions of radii represent the actual divisions of the disk to scale of one-half natural size, the portions to the left of the heavy subdivision line representing sapwood *s* 1 and *s* 2; the portions to the right heartwood *h*, *h*, divided according to the method as indicated above. The four columns of figures over each disk piece represent results pertaining to that piece; they stand in order from the top for (1) number of rings, (2) volatile hydrocarbons, (3) rosin, (4) ratio $\frac{T}{R}$; (2) and (3) as calculated on wood free from moisture. For instance, for tree No. 53, disk IV, *s*2, we find—

40 = Number of rings.
0.40 = Per cent of volatile hydrocarbons.
3.81 = Per cent of rosin.
$10.37 = \frac{T}{R}$.

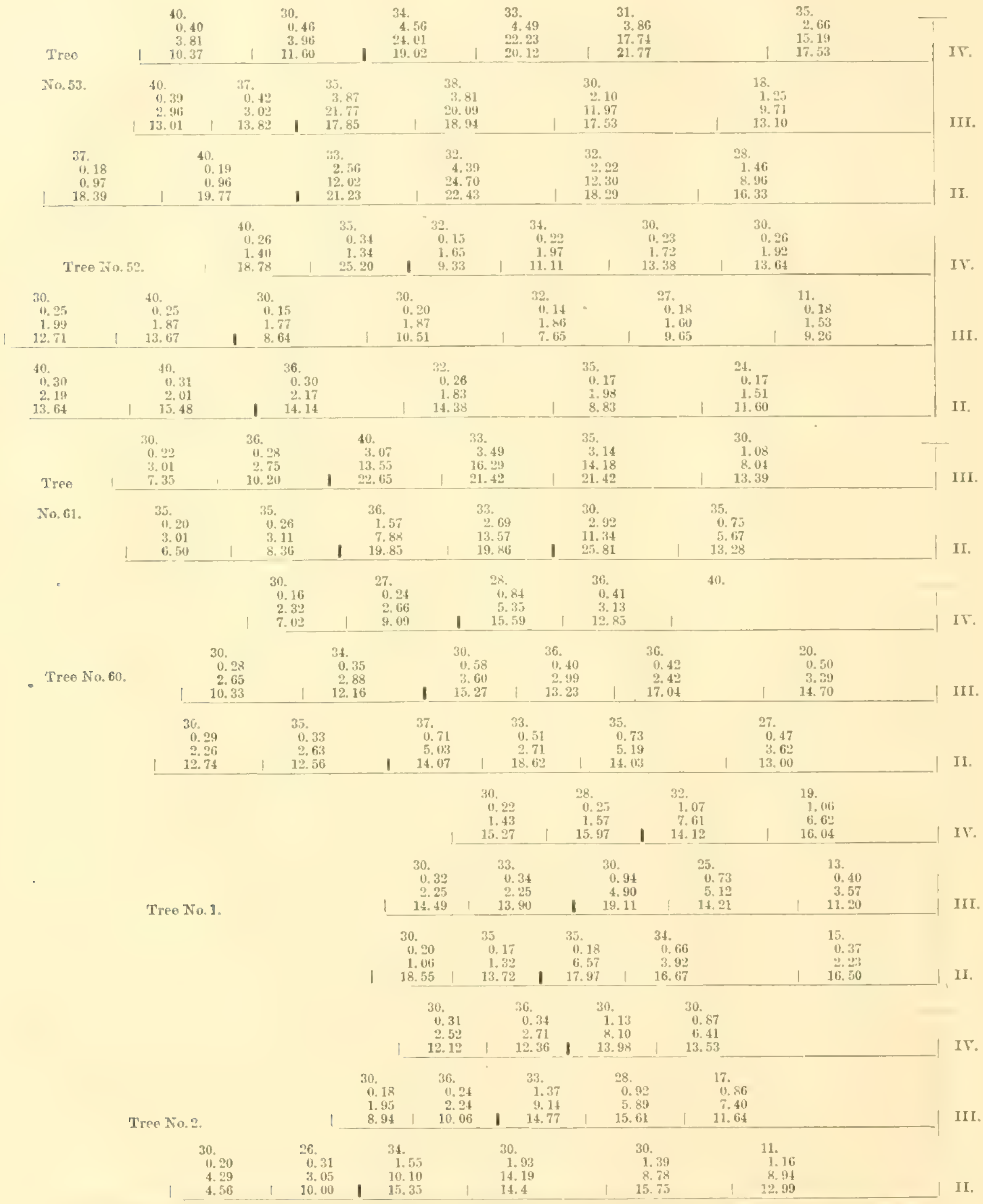


FIG. 90. Diagram of detail analyses, representing radial dimensions of test pieces in each disk. Scale, one-half natural size.

TABLE I.—TREE No. 53.

No. of disk.	Part of disk.	Number of rings.	Width.	Water.	Volatile hydro-carbon.	Rosin.	Calculated on wood free from moisture.		$\frac{\text{Vol. hydroc.}}{\text{Rosin.}} \times 100$
							Volatile hydro-carbon.	Rosin.	
			Cm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
II	1*s*	37	3.3	10.51	0.16	0.87	0.18	0.97	18.39
	2*s*	40	4.0	10.05	0.17	0.86	0.19	0.96	19.77
	1*h*	33	3.0	9.11	2.32	10.93	2.56	12.02	21.23
	2*h*	32	2.9	8.79	4.00	17.83	4.39	24.70	22.43
	3*h*	32	5.0	8.47	2.03	11.26	2.22	12.30	18.29
	4*h*	28	10.0	*11.23	1.30	7.96	1.46	8.96	16.33
III	1*s*	40	2.7	9.08	0.35	2.69	0.39	2.96	13.01
	2*s*	37	2.6	8.90	0.38	2.75	0.42	3.02	13.82
	1*h*	35	3.5	7.89	3.57	20.05	3.87	21.77	17.85
	2*h*	38	4.1	8.04	3.50	18.48	3.81	20.09	18.94
	3*h*	30	5.5	8.55	1.92	10.95	2.10	11.97	17.53
	4*h*	18	7.0	8.79	1.14	8.86	1.25	9 71	13.10
IV	1*s*	40	4.0	8.96	0.36	3.47	0.40	3.81	10.37
	2*s*	30	3.0	8.67	0.42	3.62	0.46	3.96	11.60
	1*h*	34	3.9	8.04	4.20	22.08	4.56	24.01	19.02
	2*h*	33	3.0	7.93	4.13	20.56	4.49	22.33	20.12
	3*h*	31	5.8	8.65	3.53	16.21	3.86	17.74	21.77
	4*h*	15	5.3	9.55	2.41	13.74	2.66	15.19	17.53

*53, II, 4*h* has been analyzed some three weeks earlier than the remaining parts of this tree, hence a large per cent of moisture.

TABLE II.—TREE No. 52.

II	1*s*	40	3.1	9.72	0.27	1.98	0.30	2.19	13.64
	2*s*	40	3.9	9.77	0.28	1.81	0.31	2.01	15.47
	1*h*	36	4.6	8.67	0.28	1.98	0.30	2.17	14.14
	2*h*	32	3.0	8.44	0.24	1.68	0.26	1.83	14.38
	3*h*	35	6.8	8.80	0.16	1.81	0.17	1.98	8.83
	4*h*	24	7.4	8.55	0.16	1.38	0.17	1.51	11.60
III	1*s*	30	3.0	9.12	0.23	1.81	0.25	1.99	12.71
	2*s*	40	3.5	9.00	0.23	1.68	0.25	1.87	13.67
	1*h*	30	3.4	8.44	0.14	1.62	0.15	1.77	8.64
	2*h*	30	3.0	8.51	0.18	1.71	0.20	1.89	10.51
	3*h*	32	4.8	8.37	0.13	1.70	0.14	1.86	7.65
	4*h*	27	6.9	9.35	0.14	1.45	0.15	1.60	9.65
	5*h*	11	5.0	9.21	0.13	1.39	0.14	1.53	9.26
IV	1*s*	40	3.5	8.88	0.24	1.28	0.26	1.40	18.78
	2*s*	35	3.3	8.49	0.31	1.23	0.34	1.34	25.20
	1*h*	32	3.0	9.08	0.14	1.50	0.15	1.65	9.33
	2*h*	34	2.8	8.86	0.20	1.80	0.22	1.97	11.11
	3*h*	30	3.6	8.48	0.21	1.57	0.23	1.72	13.38
	4*h*	30	6.8	8.10	0.24	1.76	0.26	1.92	13.64

TABLE III.—TREE No. 61.

II	1*s*	35	3.0	7.94	0.18	2.77	0.20	3.01	6.50
	2*s*	35	3.0	7.90	0.24	2.87	0.26	3.11	8.36
	1*h*	36	2.8	7.35	1.45	7.30	1.57	7.88	19.85
	2*h*	33	3.2	7.58	2.49	12.54	2.69	13.57	19.86
	3*h*	30	4.5	7.64	2.70	10.46	2.92	11.34	25.81
	4*h*	35	9.5	7.10	0.70	5.27	0.75	5.67	13.28
III	1*s*	30	3.0	7.65	0.20	2.78	0.22	3.01	7.35
	2*s*	36	2.7	7.43	0.26	2.55	0.28	2.75	10.20
	1*h*	40	3.1	7.14	2.85	12.58	3.07	13.55	22.65
	2*h*	33	3.2	7.46	3.23	15.08	3.49	16.29	21.42
	3*h*	35	6.0	7.41	2.91	13.59	3.14	14.18	21.42
	4*h*	30	8.0	7.09	1.00	7.47	1.08	8.04	13.39

TABLE IV.—TREE No. 60.

II	1*s*	30	2.7	9.91	0.26	2.04	0.29	2.26	12.74
	2*s*	35	2.8	9.34	0.30	2.39	0.33	2.63	12.56
	1*h*	37	3.5	8.72	0.65	4.62	0.71	5.03	14.07
	2*h*	33	4.5	9.15	0.46	2.47	0.51	2.71	18.62
	3*h*	35	4.6	8.01	0.67	4.71	0.73	5.19	14.02
	4*h*	27	6.5	8.45	0.43	3.31	0.47	3.62	13.00
III	1*s*	30	3.1	8.74	0.25	2.42	0.28	2.65	10.33
	2*s*	34	2.8	8.60	0.32	2.63	0.35	2.88	12.16
	1*h*	30	3.2	8.68	0.53	3.47	0.58	3.80	15.27
	2*h*	36	4.4	9.02	0.36	2.72	0.40	2.99	13.23
	3*h*	36	4.5	7.73	0.38	2.23	0.42	2.42	17.04
	4*h*	20	6.0	7.73	0.46	3.13	0.50	3.39	14.70
IV	1*s*	30	2.6	7.51	0.15	2.15	0.16	2.32	7.02
	2*s*	27	2.6	7.84	0.22	2.45	0.24	2.66	9.09
	1*h*	28	3.7	7.77	0.77	4.94	0.84	5.35	15.59
	2*h*	36	5.0	8.12	0.37	2.88	0.41	3.13	12.85
	3*h*	40	8.0	7.92	0.26	2.81	0.28	3.05	9.18

Table V.—Tree No. 1.

No. of disk.	Part of disk.	Number of rings.	Width.	Water.	Volatile hydrocarbon.	Rosin.	Calculated on wood free from moisture. Volatile hydrocarbon.	Calculated on wood free from moisture. Rosin.	$\frac{\text{Vol. hydroc.}}{\text{Rosin.}} \times 100$
			Cm.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
II	1*s*	30	2.0	8.67	0.18	0.97	0.20	1.06	18.55
	2*s*	35	3.0	8.77	0.16	1.21	0.17	1.32	13.72
	1*h*	35	3.6	8.56	1.08	6.01	1.18	6.57	17.97
	2*h*	34	6.5	8.39	0.60	3.60	0.66	3.92	16.67
	3*h*	14	3.0	7.67	0.34	2.06	0.37	2.23	16.50
III	1*s*	30	2.8	7.94	0.30	2.07	0.32	2.25	14.49
	2*s*	33	3.0	7.92	0.31	2.23	0.34	2.42	13.90
	1*h*	30	3.8	8.13	0.86	4.50	0.94	4.90	19.11
	2*h*	25	4.2	7.78	0.67	4.72	0.73	5.12	14.21
	3*h*	13	3.5	7.57	0.37	3.30	0.40	3.57	11.22
IV	1*s*	30	2.2	8.33	0.20	1.31	0.22	1.43	15.27
	2*s*	28	2.8	8.12	0.23	1.44	0.25	1.57	15.97
	1*h*	32	5.0	7.94	0.99	7.01	1.07	7.61	14.12
	2*h*	19	5.2	7.73	0.98	6.11	1.06	6.62	16.04

Table VI.—Tree No. 2

No. of disk.	Part of disk.	Number of rings.	Width.	Water.	Volatile hydrocarbon.	Rosin.	Calculated on wood free from moisture. Volatile hydrocarbon.	Calculated on wood free from moisture. Rosin.	$\frac{\text{Vol. hydroc.}}{\text{Rosin.}} \times 100$
II	1*s*	30	3.0	7.65	0.18	3.95	0.20	4.29	4.56
	2*s*	26	2.7	8.19	0.28	2.80	0.31	3.05	10.00
	1*h*	34	3.5	7.31	1.44	9.25	1.55	10.10	15.35
	2*h*	30	5.0	8.11	1.77	13.05	1.93	14.19	14.41
	3*h*	30	6.0	8.16	1.27	8.06	1.39	8.78	15.75
	4*h*	11	4.2	7.88	1.07	8.24	1.16	8.94	12.99
III	1*s*	30	2.7	8.00	0.16	1.79	0.18	1.95	8.94
	2*s*	36	3.0	8.01	0.22	2.06	0.24	2.24	10.06
	1*h*	33	3.2	7.44	1.25	8.46	1.37	9.14	14.77
	2*h*	28	5.5	7.78	0.85	5.44	0.92	5.89	15.61
	3*h*	17	4.8	7.12	0.80	6.87	0.86	7.40	11.64
IV	1*s*	30	2.7	8.20	0.28	2.31	0.31	2.52	12.12
	2*s*	36	3.0	8.08	0.31	2.49	0.34	2.71	12.36
	1*h*	30	3.6	8.10	1.04	7.44	1.13	8.10	13.98
	2*h*	30	7.6	7.81	0.80	5.91	0.87	6.41	13.53

Table VII—Summary of Results of Trees Nos. 54 to 69 and Nos. 17 to 19.

Serial number of trees.	Part of disk.	Disk II. Volatile hydrocarbons.	Disk II. Volatile hydrocarbons (h)	Disk II. Rosin.	Disk II. Rosin (h)	Disk II. $\frac{\text{Vol. hydr.}}{\text{Rosin.}} \times 100$	Disk II. $\frac{\text{Vol. hydr.}}{\text{Rosin.}} \times 100$ (h)	Disk III. Volatile hydrocarbons.	Disk III. Volatile hydrocarbons (h)	Disk III. Rosin.	Disk III. Rosin (h)	Disk III. $\frac{\text{Vol. hydr.}}{\text{Rosin.}} \times 100$	Disk III. $\frac{\text{Vol. hydr.}}{\text{Rosin.}} \times 100$ (h)
		Per cent.		*Per cent.*				*Per cent.*		*Per cent.*			
54, 55, 56, 57	*s*	0.18		1.48		13.14		0.26		1.93		13.33	
	1*h* (h)	1.16	0.93	6.78	5.88	17.14	15.58	0.81	0.58	4.80	3.89	16.82	14.04
	2*h* (h)	0.70		4.97		14.01		0.34		2.97		11.27	
58, 59	s	0.28		1.76		15.76		0.20		1.35		14.14	
	h	0.80		4.06		19.63		0.82		4.29		19.10	
63, 64, 65	*s*	0.18		1.74		70.00		....		....		....	
	1*h* (h)	0.81	0.91	4.35	5.32	18.55	17.18	....		....		....	
	2*h* (h)	1.00		6.29		15.80							
66, 67, 68, 69	s	0.14		1.78		8.00		....		....		....	
	h	0.89		4.95		18.00		....		....		....	
17, 18, 19	*s*	0.14		1.49		9.56		0.11		1.34		8.20	
	1*h* (h)	0.78	0.64	3.48	2.98	22.87	21.37	0.91	0.71	3.63	3.21	25.15	21.76
	2*h* (h)	0.50		2.47		19.82		0.50		2.79		18.36	

Timber Physics Work.

The timber physics work was continued actively and the investigation extended to other kinds of timber, both conifers and hard woods. In 1896 the Division was in position to announce its findings with regard to the mechanical, physical, and structural study of the four principal Southern pines (Circular 12). Based, as these results are, on over 20,000 mechanical tests and over 50,000 weighings and measurements, they may fairly be regarded as final, and thus avoid future discussion and much fruitless and expensive private testing. According to this exhaustive study, the Cuban and long-leaf pine rank foremost among our timber pines, and are fully 20 to 25 per cent stronger than had previously been assumed. It also appeared that the wood of these species varies in strength directly as the weight (little discrepancies being well accounted for by variations in resin contents, which add only to weight and not to strength); that in the same tree the wood varies according to certain definite laws, being heaviest at butt, lightest in top, heavier in the interior, and lighter and weaker in the outer parts of saw-size timber; that thus the age when formed, as well as the position in the tree, exercises a definite influence which is generally far greater than the much-quoted influences of soil, locality, etc. In this latter respect it was clear from the results that the oft-claimed superiority of the timber of certain localities is not substantiated by experiment, but that there is heavy and strong as well as lighter and weaker timber in every locality throughout the range of these species. The all-important effect of moisture was carefully considered throughout the work, and it was established that in general an increase in strength of at least 50 to 75 per cent takes place during ordinary seasoning, so that for all designing of covered work, as in ordinary architecture, this improvement may be depended upon and considered in the proportioning of the timbers.

The manner in which the valuable information was secured and communicated will appear from the following reprint of Circulars 12 and 15, issued in 1896 and 1897:

SOUTHERN PINE—MECHANICAL AND PHYSICAL PROPERTIES.

THE MATERIAL UNDER CONSIDERATION.

The importance of reliable information regarding the pines of the South is evident from the fact that they furnish the bulk of the hard-pine material used for constructive purposes with an annual cut hardly short of 7,000,000,000 feet B. M., which, with the decline of the soft-pine supplies in the North, is bound to increase rapidly.

Although covering the largest area of coniferous growth in the country (about 230,000 square miles), proper economies in their use are nevertheless most needful, since much of this area is already severely culled and the cut per acre has never been very large. Hence the demonstration (a result of the investigations in this Division) that bled pine is as strong and useful as unbled, and the assurance that long-leaf pine is in the average 25 per cent stronger than it is often supposed to be, and therefore can be used in smaller sizes than customary at present, must be welcome as permitting a saving in forest resources which may readily be estimated at from eight to ten million dollars annually, due to this information.

The pines under consideration, often but imperfectly distinguished by consumers in name of substance, are:

(1) The long-leaf pine (*Pinus palustris*), also known as Georgia or yellow pine, and in England as "pitch pine," and by a number of other names, is to be found in a belt of 100 to 150 miles in width along the Atlantic and Gulf coasts from North Carolina to Texas, furnishing over 50 per cent of the pine timber cut in the South—the timber par excellence for heavy construction, but also useful for flooring and in other directions where strength and wearing qualities are required.

(2) The Cuban pine (*Pinus heterophylla*), found especially in the southern portions of the long-leaf pine belt, known to woodsmen commonly as "slash pine," but not distinguished in the lumber market. It is usually mixed in with long leaf, which it closely resembles, although it is wider ringed (coarse grained), and to which it is equal if not superior in weight and strength.

(3) The short-leaf pine (*Pinus echinata*), also known, besides many other names, as yellow pine and as North Carolina pine, but growing through all the Southern States generally north of the long-leaf pine region; much softer and with much more sapwood than the former two, useful mainly for small dimensions and as finishing wood, being about 20 per cent weaker than the long-leaf pine.

(4) The loblolly or old-field pine (*Pinus tæda*), of similar although more Southern range than the short leaf, also known as Virginia pine, much used locally and in Washington and Baltimore, destined to find more extensive application. At present largely cut together with short leaf and sold with it as "yellow pine," or North Carolina pine, without distinction, although sometimes far superior, approaching long-leaf pine in strength and general qualities.

The names in the market are often used interchangeably and the materials in the yard mixed. All four species grow into tall but slender trunks, as a rule not exceeding 30 inches in diameter and 100 feet in height; the bulk of the logs cut at present fall below 20 inches. The sapwood forms in old trees of long leaf (with 2 to 4 inches) about 40 per cent of the total log volume; in Cuban, short leaf, and loblolly 60 per cent and over.

A reliable microscopic distinction of the wood of the four species has not yet been found. As a rule long leaf contains much less sapwood than the other three. The narrow-ringed wood of long leaf (averaging 20 to 25 rings to the inch) usually separates it also from the other three, while the especially broad-ringed Cuban excels usually also by broader summer-wood bands. In the log short leaf and loblolly may usually be recognized as distinguished from the former by the greater proportion of sapwood and lighter color due to smaller proportion of summer wood. The general appearance of the wood of all four species is, however, quite similar. The annual rings (grain) are sharply defined; the light yellowish spring wood and the dark orange-brown summer wood of each ring being strongly contrasted produce a pronounced pattern, which, although pleasing, especially in the curly forms (which occur occasionally), may become obtrusive when massed.

The following diagnosis may prove helpful in the distinction of the wood:

Diagnostic features of the wood.

Name of species.	Long-leaf pine (*Pinus palustris* Miller).	Cuban pine (*Pinus heterophylla* (Ell) Sud).	Short-leaf pine (*Pinus echinata* Miller).	Loblolly pine (*Pinus tæda* Linn.).
Specific gravity of kiln-dried wood. Possible range	.50 to .90	.50 to .90	.40 to .80	.40 to .80
Specific gravity of kiln-dried wood. Most frequent range.	.55 to .65	.55 to .70	.45 to .55	.45 to .55
Weight, pounds per cubic foot, kiln-dried wood. (Average)	36	37	30	31
Character of grain seen in cross section	Fine and even; annual rings quite uniformly narrow; on large logs averaging generally 20 to 25 rings to the inch.	Variable and coarse, rings mostly wide; averaging on large logs 10 to 20 rings to the inch.	Very variable; medium, coarse; rings wide near heart, followed by zone of narrow rings; not less than 4 (mostly about 10 to 15) rings to the inch, but often very fine grained.	Variable, mostly very coarse; 3 to 12 rings to the inch, generally wider than in the short leaf.
Color, general appearance	Even dark reddish yellow to reddish brown.	Dark straw color with tinge of flesh color.	Whitish to reddish or yellowish brown.	Yellowish to orange brown.
Sapwood, proportion	Little; rarely over 2 to 3 inches of radius.	Broad; 3 to 6 inches..	Commonly over 4 inches of radius.	Very variable, 3 to 6 inches of the radius.
Resin	Very abundant; parts often turning into "light wood;" pitchy throughout.	Abundant, sometimes yielding more pitch than long leaf; "bleeds" freely, yielding little scrape.	Moderately abundant, least pitchy; only near stumps, knots, and limbs.	Abundant; more than short leaf, less than long leaf and Cuban, but does not "bleed" if tapped.

The sapling timber of all four species is coarse grained, that of loblolly exceeding the rest in this respect. The grain varies most in the butt, least in the top, is very fine in the outer portions of all old trees. Loblolly in the center of the log frequently shows rings over one-half inch wide, and timber averaging eight rings to the inch is not rare, while short leaf will average 10 to 15 rings to the inch. The greater or less proportion of the sharply defined dark-colored bands of summer wood of the ring furnish the most reliable and ready means of determining quality.

At present distinction is but rarely made in the species and in their use. All four species are used much alike, although differentiation is very desirable on account of the difference in quality. Formerly these pines, except for local use, were mostly cut or hewn into timbers, but especially since the use of dry kilns has become general and the simple oil finish has displaced the unsightly painting and "graining" of wood Southern pine is cut into every form and grade of lumber. Nevertheless, a large proportion of the total cut is still being sawed to order in sizes above 6 by 6 inches, and lengths above 20 feet for timbers, for which the long leaf and Cuban furnish ideal material. The resinous condition of these two pines make them also desirable for railway ties of lasting quality.

MECHANICAL PROPERTIES.

In general the wood of all these pines is heavy for pine (31 to 40 pounds per cubic foot, when dry); soft to moderately hard (hard for pine), requiring about 1,000 pounds per square inch to indent one-twentieth inch; stiff, the modulus of elasticity being from 1,500,000 upward; strong, requiring from 7,000 pounds per square inch and upward to break in bending, and over 5,000 pounds in compression when yard-dry.

The values given in this circular are averages based on a large number of tests, from which only defective pieces are excluded.

In all cases where the contrary is not stated the weight of the wood refers to kiln-dried material and the strength of wood containing 15 per cent moisture, which may be conceived as just on the border of air-dried condition. The first table gives fairly well the range of strength of commercial timber.

Average strength of Southern pine.

Air-dry material (about 15 per cent moisture).

Name.	Compression strength. With grain. Average of all valid tests. Absolute.	Relative.	Compression strength. With grain. Average for the weakest one-tenth of all the tests. Absolute.	Relative.	Compression strength. Across grain. 3 per cent indentation.	Bending strength. At rupture modulus $\frac{3\ Wl}{2\ bh^2}$. Average of all valid tests. Absolute.	Relative.	Bending strength. At rupture. Average for the weakest one-tenth of all the tests. Absolute.	Relative.	Bending strength. At elastic limit modulus $\frac{3\ W_1l}{2\ bh^2}$	Bending strength. Elasticity (stiffness) modulus $\frac{3\ Wl^3}{4\ \Delta\ bh^3}$	Relative elastic resilience.	Tensile strength.	Shearing strength.
	Lbs. per sq. inch.		*Lbs. per sq. inch.*		*Lbs. per sq. inch.*	*Lbs. per sq. inch.*		*Lbs. per sq. inch.*		*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*In.-lbs. per cu. in.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*
Cuban pine	7,850	100	6,500	100	1,050	11,950	100	8,750	100	9,450	2,305,000	2.5	14,300	680
Longleaf pine	6,850	87	5,650	87	1,060	10,900	91	8,800	101	8,500	1,890,000	2.3	15,200	706
Loblolly pine	6,500	83	5,350	82	990	10,100	84	8,100	92	8,150	1,950,000	2.25	14,400	690
Shortleaf pine	5,900	75	4,800	74	940	9,230	77	7,000	80	7,200	1,600,000	2.05	13,400	688

RELATION OF STRENGTH TO WEIGHT.

The intimate relation of strength and specific weight has been well established by the experiments. The average results obtained in connection with the tests themselves were as follows:

	Cuban.	Longleaf.	Loblolly.	Shortleaf.
Transverse strength	100	91	84	77
Specific weight of test pieces	100	94	82	77

Since in the determination of the specific gravity above given, wood of the same per cent of moisture (as is the case of the values of strength) was not always involved, and also since the test pieces, owing to size and shape, can not perfectly represent the wood of the entire stem, the following results of a special inquiry into the weight of the wood represents probably more accurately the weight and with it the strength-relations of the four species.

WEIGHT RELATIONS.

[These data refer to the average specific weight for all the wood of each tree, only trees of approximately the same age being involved.]

	Cuban.	Longleaf.	Loblolly.	Shortleaf.
Average age of trees	171	127	137	131
Number of trees involved	6	22	14	10
Specific gravity of dry wood	0.63	0.61	0.53	0.51
Weight per cubic foot	39	38	33	32
Relative weight	100	97	84	81
(Transverse strength *a*)	(100)	(91)	(84)	(77)

a The values of strength refer to all tests and therefore involve trees of wide range of age and consequently of quality, especially those of longleaf, involve much wood of old trees, hence the relation of weight and strength appears less distinct.

From these results, although slightly at variance, we are justified in concluding that Cuban and longleaf pine are nearly alike in strength and weight and excel loblolly and shortleaf by about 20 per cent. Of these latter, contrary to common belief, the loblolly is the heavier and stronger.

The weakest material would differ from the average material in transverse strength by about 20 per cent and in compression strength by about 30 to 35 per cent, except Cuban pine, for which the difference appears greater in transverse and smaller in compression strength. It must, of course, not be overlooked that these figures are obtained from full-grown trees of the virgin forest, that strength varies with physical conditions of the material and that, therefore, an intelligent inspection of the stick is always necessary before applying the values in practice. They can only represent the average conditions for a large amount of material.

DISTRIBUTION OF WEIGHT AND STRENGTH THROUGHOUT THE TREE.

In any one tree the wood is lighter and weaker as we pass from the base to the top. This is true of every tree and of all four species. The decrease in weight and strength is most pronounced in the first 20 feet from the stump and grows smaller upward. (See fig. 91.)

This great difference in weight and strength between butt and top finds explanation in the relative width of the summerwood. Since the specific weight of the dark summerwood band in each ring is in thrifty growth from .90 to 1.00, while that of the springwood is only about .40, the relative amount of summerwood furnishes altogether the most delicate and accurate measure of these differences of weight as well as strength, and hence is the surest criterion for ocular inspection of quality, especially since this relation is free from the disturbing influence of both resin and moisture contents of the wood, so conspicuous in weight determinations.

The following figures show the distribution of the summerwood in a single tree of longleaf pine, as an example of this relation:

	In the 10 rings next to the bark.	In the 10 rings, Nos. 100 to 110 from bark.	Average for entire disk.	Specific weight.
	Per cent.	*Per cent.*	*Per cent.*	
At the stump	37	52	50	0.73
32 feet from stump	25	38	33	59
87 feet from stump	15	37	26	55

Weight and strength of wood at different heights in the tree.

	Strength of longleaf pine (pounds per square inch).		Specific weight.			Mean of all three species. Relative weight.	Relative strength of longleaf pine. Mean of compression and bending.
	Bending strength.	Compression endwise (with grain).	Longleaf.	Loblolly.	Shortleaf.		
Number trees used	56		22	14	12	48	56
Average age of trees	150 (over)		127	113	131		
Number of feet from stump:							
0			.751	.629	.614		
			106	*106*	*105*	*106*	....
6	12,100	7,350	.705	.595	.585		
	100	*100*	*100*	*100*	*100*	*100*	*100*
10	11,650	7,200	.674	.578	.565		
	96	*98*	*96*	*97*	*97*	*97*	*97*
20	10,700	6,800	.624	.534	.523		
	88	*93*	*89*	*90*	*90*	*90*	*90*
30	10,100	6,500	.590	.508	.496		
	84	*89*	*84*	*86*	*85*	*85*	*86*
40	9,500	6,300	.560	.491	.472		
	79	*86*	*80*	*83*	*81*	*81*	*82*
50	9,000	6,150	.539	.476	.455		
	75	*83*	*77*	*80*	*78*	*78*	*79*
60	8,600	6,050	.528	.470	.454		
	71	*82*	*75*	*79*	*78*	*77*	*76*

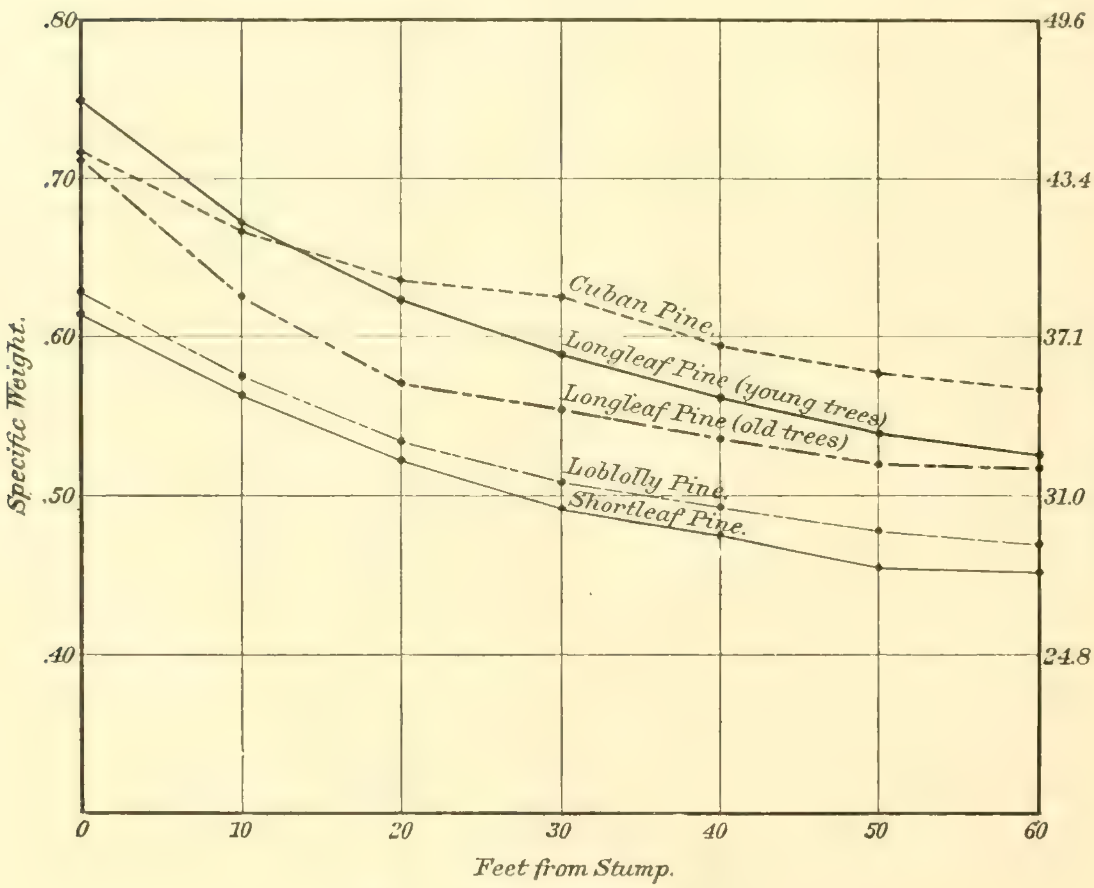


FIG. 91.—Variation of weight with height of tree.

Logs from the top can usually be recognized by the larger percentage of sapwood and the smaller proportion and more regular outlines of the bands of summer wood, which are more or less wavy in the butt logs.

The variation of weight is well illustrated in the foregoing table, in which the relative values are indicated in italics. For comparison the figures for strength of long-leaf pine are added.

Both weight and strength vary in the different parts of the same cross section from center to periphery, and though the variations appear frequently irregular in single individuals, a definite law of relation is nevertheless discernible in large averages, and once determined is readily observable in every tree.

A separate inquiry, avoiding the many variables which enter in the mechanical tests, permits the following deductions for the wood of these pines, and especially for long leaf, the data referring to weight, but by inference also to strength:

1. The variation is greatest in the butt log (the heaviest part) and least in the top logs.

2. The variation in weight, hence also in strength, from center to periphery depends on the rate of growth, the heavier, stronger wood being formed during the period of most rapid growth, lighter and weaker wood in old age.

3. Aberrations from the normal growth, due to unusual seasons and other disturbing causes, cloud the uniformity of the law of variation, thus occasionally leading to the formation of heavier, broad-ringed wood in old, and lighter, narrow-ringed wood in young trees.

4. Slow-growing trees (with narrow rings) do not make less heavy, nor heavier, wood than thriftily grown trees (with wide rings) of the same age. (See fig. 92.)

EFFECT OF AGE.

The interior of the butt log, representing the young sapling of less than 15 or 20 years of age, and the central portion of all logs containing the pith and 2 to 5 rings adjoining is always light and weak.

The heaviest wood in long-leaf and Cuban pine is formed between the ages of 15 and 120 years, with a specific weight of over 0.60 and a maximum of 0.66 to 0.68 between the ages of 40 and 60 years. The wood formed at the age of about 100 years will have a specific weight of 0.62 to 0.63, which is also the average weight for the entire wood of old trees. The wood formed after this age is lighter, but does not fall below 0.50 up to the two hundredth year; the strength varies in the same ratio.

In the shorter-lived loblolly and short leaf the period for the formation of the heaviest wood is between the ages of 15 and 80, the average weight being then over 0.50, with a maximum of 0.57 at the age of 30 to 40. The average weight for old trees (0.51 to 0.52) lies about the seventy-fifth year, the weight then falling off to about 0.45 at the age of 140, and continuing to decrease to below 0.38 as the trees grow older.

That these statements refer only to the clear portions of each log, and are variably affected at each whorl of knots (every 10 to 30 inches) according to their size, and also by the variable amounts of resin (up to 20 per cent of the dry weight), must be self-evident.

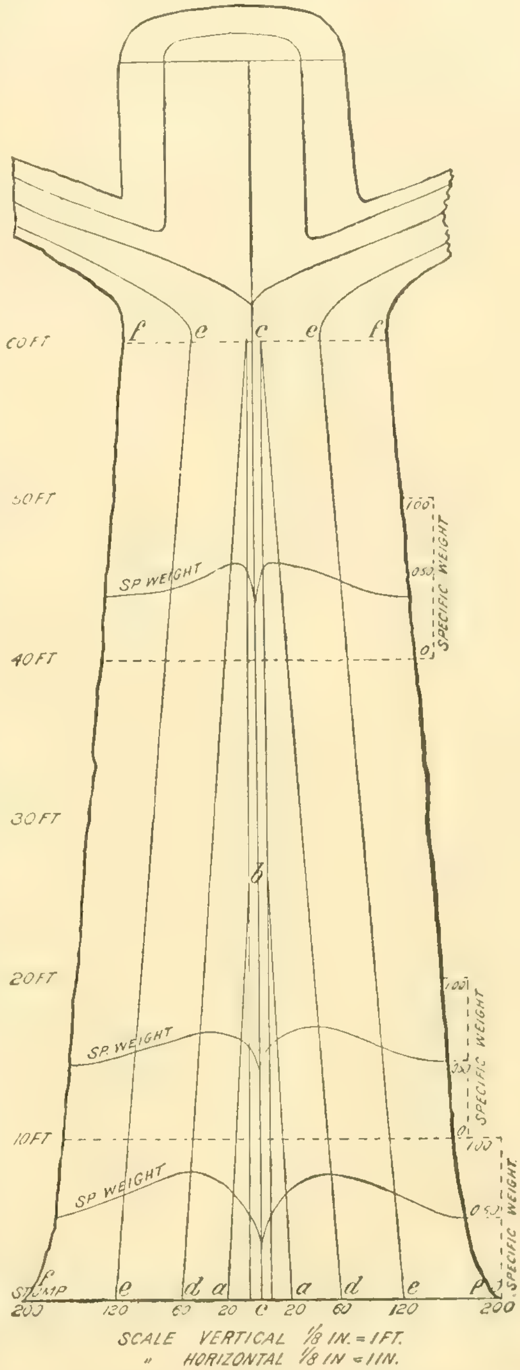


FIG. 92.—Schematic section through stem of long-leaf pine, showing variation of specific weight, with height, diameter, and age, at 20 (*aba*), 60 (*dcd*), 120 (*eece*), 200 (*ffff*) years.

Sapwood is not necessarily weaker than heartwood, only usually the sapwood of the large-sized trees we are now using is represented by the narrow-ringed outer part, which was formed during the old-age period of growth, when naturally lighter and weaker wood is made; but the wood formed during the more thrifty diameter growth of the first eighty or one hundred years—sapwood at the time, changed into heartwood later—was, even as sapwood, the heaviest and strongest.

RANGE OF VALUES FOR WEIGHT AND STRENGTH.

Although the range of values for the individual tree of any given species varies from butt to top and from center to periphery by 15 to 25 per cent and occasionally more, the deviation from average values from one individual to another is not usually as great as has been believed; thus of 56 trees of long-leaf pine, 42 trees varied in their average strength by less than 10 per cent from the average of all 56.

The following table of weight (which is a direct and fair indication of strength), representing all the wood of the stem and excluding knots and other defects, gives a more perfect idea of the range of these values:

Range of specific weight with age (kiln-dried wood).

[To avoid fractions the values are multiplied by 100.]

	Cuban.	Longleaf.	Loblolly.	Short leaf.
Number of trees involved	24	96	60	56
Trees over 200 years old	61	57	....	....
Trees 150-200 years old	63	59	50	....
Trees 100-150 years old	....	60.5	53	51
Trees 50-100 years old	61	62	53.4	55
Trees 25-50 years old	55	61	53	57
Trees under 25 years old	51	55	48	53

Though occasionally some very exceptional trees occur, especially in loblolly and short leaf, the range on the whole is generally within remarkably narrow limits, as appears from the following table:

Range of specific weight in trees of the same age approximately; averages for whole trees.

[Specific gravity multiplied by 100 to avoid fractions.]

Name.	No. of trees.	Age (years).	Single trees.													Average.
Cuban	4	150-200	56	68	62	65	..	..	..	..	..	..	..	..	..	62.5
Cuban	5	50-100	60	58	60	59	67	..	..	..	..	..	..	..	..	60.9
Long-leaf pine	13	100-150	59	66	57	62	66	58	59	57	57	66	59	62	57	60.5
Loblolly pine	10	125-150	51	51	53	51	55	53	54	55	55	52	..	..	..	52.8
Short-leaf pine	12	100-150	45	47	53	47	50	51	55	55	53	51	50	53	..	50.8

From this table it would appear that single individuals of one species would approximate single individuals of another species so closely that the weight distinction seems to fail, but in large numbers—for instance, carloads of material—the averages above given will prevail.

INFLUENCE OF LOCALITY.

In both the Cuban and long-leaf pine the locality where grown appears to have but little influence on weight or strength, and there is no reason to believe that the long-leaf pine from one State is better than that from any other, since such variations as are claimed can be found on any 40-acre lot of timber in any State. But with loblolly, and still more with short leaf, this seems not to be the case. Being widely distributed over many localities different in soil and climate, the growth of the short-leaf pine seems materially influenced by location. The wood from the Southern coast and Gulf region, and even Arkansas, is generally heavier than the wood from localities farther north. Very light and fine-grained wood is seldom met near the southern limit of the range, while it is almost the rule in Missouri, where forms resembling the Norway pine are by no means rare. The loblolly, occupying both wet and dry soils, varies accordingly.

INFLUENCE OF MOISTURE.

This influence is among the most important; hence all tests have been made with due regard to moisture contents. Seasoned wood is stronger than green and moist wood. The difference between green and seasoned wood may amount to 50 and even 100 per cent. The influence of seasoning consists in (1) bringing by means of shrinkage about 10 per cent more fibers into the same square inch of cross section than are contained in the wet wood; (2) shrinking the cell wall itself by about 50 per cent of its cross section, and thus hardening it, just as the cow skin becomes thinner and harder by drying.

In the following tables and diagram this is fully illustrated. The values presented in these tables and diagrams are based on large numbers of tests and are fairly safe for ordinary use. They still require further revision, since the relations to density, etc., have had to be neglected in this study.

Influence of moisture on strength.

Average of all valid tests.	Per cent of moisture.a	Cuban.	Longleaf.	Loblolly.	Shortleaf.
Bending strength	33	8,450	7,660	7,370	6,900
	20	10,050	8,900	8,650	8,170
	15	11,950	10,900	10,100	9,230
	10	15,300	14,000	12,400	11,000
Crushing endwise	33	5,000	4,450	4,170	4,160
	20	6,600	5,450	5,350	5,100
	15	7,850	6,850	6,500	5,900
	10	9,200	9,200	8,650	7,000

Relative values.	Per cent of moisture.a	Cuban.	Longleaf.	Loblolly.	Shortleaf.	Average.
Bending strength	33	100	100	100	100	100
	20	118	116	117	118	117
	15	142	142	138	134	139
	10	181	182	168	160	173
Crushing endwise	33	100	100	100	100	100
	20	132	122	128	122	126
	15	157	154	156	142	152
	10	184	206	206	168	191
Mean of both bending and crushing strength	33	100	100	100	100	100
	20	125	119	122	120	122
	15	149	148	147	138	146
	10	182	194	187	164	182

a 33 per cent green, 20 per cent half dry, 15 per cent yard dry, 10 per cent room dry.

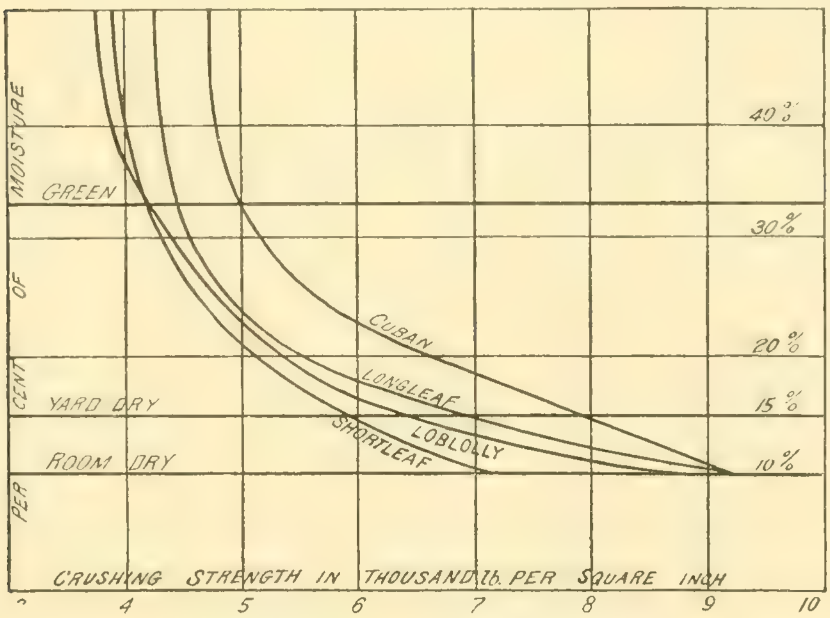


FIG. 93.—Variation of compression strength with moisture.

It will be observed that the strength increases by about 50 per cent in ordinary good yard seasoning, and that it can be increased by about 30 per cent more by complete seasoning in kiln or house.

Large timbers require several years before even the yard-season condition is attained, but 2-inch and lighter material is generally not used with more than 15 per cent moisture.

WEIGHT AND MOISTURE.

So far the weight of only the kiln-dry wood has been considered. In fresh as well as all yard and air-dried material there is contained a variable amount of water. The amount of water contained in fresh wood of these pines forms more than half the weight of the fresh sapwood, and about one-fifth to one-fourth of the heartwood; in yard-dry wood it falls to about 12 to 18 per cent, while in wood kept in well-ventilated and especially in heated rooms it is about 5 to 10 per cent, varying with size of piece, part of tree, species, temperature, and humidity of air. Heated to 150° F. (65° C.) the wood loses all but about $1\frac{1}{2}$ to 2 per cent of its moisture, and if the temperature is raised to 175° F. there remains less than 1 per cent, the wood dried at 212° F. being assumed to be (though it is not really) perfectly dry. Of course large pieces are in practice never left long enough exposed to become truly kiln-dry, though in factories this state is often approached.

As long as the water in the wood amounts to about 30 per cent or more of the dry weight of the wood there is no shrinkage[1] (the water coming from the cell lumen) and the density or specific gravity changes simply in direct

[1] In ordinary lumber and all large size material the exterior parts commonly dry so much sooner than the bulk of the stick that checking often occurs, though the moisture per cent of the whole stick is still far above 30.

proportion to the loss of water. When the moisture per cent falls below about 30 the water comes from the cell wall, and the loss of water and weight is accompanied by a loss of volume, so that both factors of the fraction

$$\text{Specific gravity} = \frac{\text{weight}}{\text{volume}}$$

are affected and the change in the specific gravity no longer is simply proportional to the loss of water or weight. The loss of weight and volume, however, being unequal and disproportionate, a marked reduction of the specific gravity takes place, amounting in these pines to about 8 to 10 per cent of the specific weight of the dry wood.

SHRINKAGE.

The behavior of the wood of the southern pines in shrinkage does not differ materially. Generally the heavier wood shrinks the most, and sapwood shrinks about one-fourth more than heartwood of the same specific weight. Very resinous pieces ("light wood") shrink much less than other wood. In keeping with these general facts, the shrinkage of the wood of the upper logs is usually 15 to 20 per cent less than that of the butt pieces, and the shrinkage of the heavy heartwood of old trees is greater than that of the lighter peripheral parts of the same, while the shrinkage of the heavy wood of saplings is greatest of all. On the whole, the wood of these pines shrinks about 10 per cent in its volume, 3 to 4 per cent along the radius, and 6 to 7 per cent along the tangent or along the yearly rings.

After leaving the kiln the wood at once begins to absorb moisture and to swell. In an experiment with short pieces of loblolly and shortleaf, representing ordinary flooring or siding sizes, these regained more than half the water and underwent more than half the total swelling during the first 10 days after leaving the kiln (see fig. 94). Even in this less than air-dry wood the changes in weight far excel the changes in volume (sum of radial and tangential swelling), and therefore the specific gravity, even at this low per cent of moisture, was decreased by drying and increased by subsequent absorption of moisture. Immersion and, still more readily, boiling, cause the wood to return to its original size, but temperatures even above the boiling point do not prevent the wood from "working," or shrinking, and swelling.

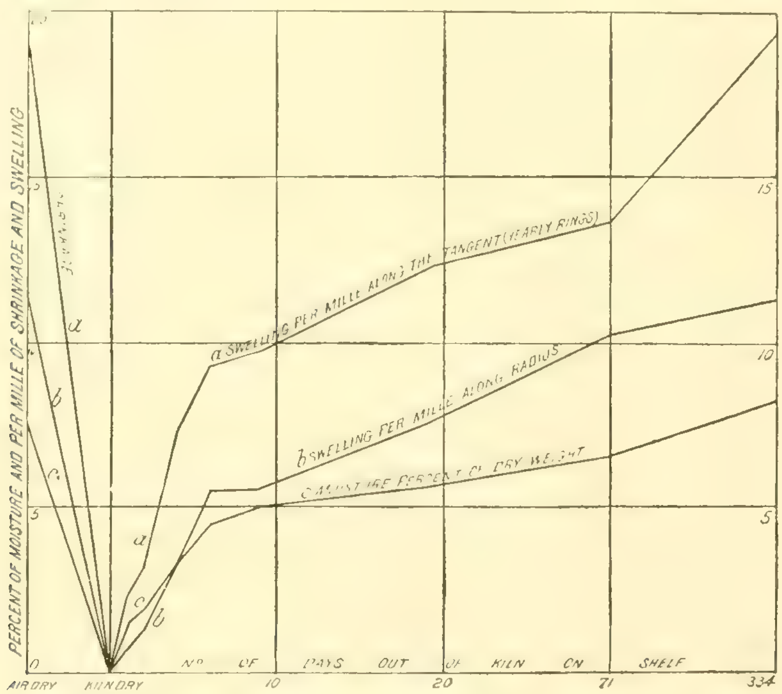


FIG. 94.—Loss of water in kiln drying and reabsorption in air, shrinking, and swelling.

In fig. 94 are represented the results of experiments on the rate of loss of water in the dry kiln and the reabsorption of water in the air. The wood used was of loblolly and shortleaf pine kept on a shelf in an ordinary room before and after kiln-drying. The measurements were made with caliper.

EFFECT OF KILN-DRYING.

Although kiln-drying has become quite universal, opinions are still divided as to its effects upon the strength of the material and other qualities. Many objections and claims as to physical and chemical changes produced by the treatment remain unsubstantiated. The method most widely used and most severely criticised is that of the "blower" kiln, where hot air (180° F.) is forced into the drying room by means of powerful fans. Besides the many, in part, unreasonable and contradictory claims about closing or opening of pores, chemical or physical influence on the sap and its contents, albumen, gum, resin, sugar, etc., substances whose very existence in many cases is problematical or doubtful, the general claims of increased checking and warping, "casehardening," "honeycombing," etc., as well as reduction of strength, are still prevalent even among the very manufacturers themselves. The manner and progress of the kiln-drying may render this otherwise useful method of seasoning injurious. Rapid drying of the heavier hardwoods of complicated structure, especially in large sizes and from the green state, is apt to produce inordinate checking and thus weakening of the material. For Southern pine, however, it is entirely practicable to carry on the process without any injury, as is evidenced by the following experiment, in which wood of Cuban pine in small dimensions (4 by 4) was seasoned in warm air (about 100° F.) and parts of the same scantling were dried at temperatures varying from 150° at the entrance end to 190° F. at the exit:

	Bending strength.		Compression strength.
	Absolute.	At elastic limit.	
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Mean of material not kiln-dried (reduced to 15 per cent of moisture)	12,200	9,070	7,630
Average of kiln-dry material	11,500	9,180	8,550

Well-constructed "blower kilns," where the hot air is blown in at one end and escapes at the other (this latter always the entrance end for the material), are giving satisfaction. The best kiln, however, seems to be one in which ample piping in the kiln itself insures sufficiently high (up to 180° F.), uniform temperature in all parts of the kiln, and where the circulation, promoted by a suction fan, is moderate and under perfect control. In such kilns even timbers of large size can be dried satisfactorily with a temperature not over 150° F.

EFFECT OF HIGH-TEMPERATURE AND HIGH-PRESSURE PROCESSES.

For some time a process employing high temperature under high pressure (temperature over 300° F., pressure 150 pounds) has been discussed and applied, claiming as a result of the treatment (1) increase in strength; (2) increase in durability; (3) absence of shrinkage.

The result of a series of experiments in which a number of scantlings of longleaf pine, one-half treated, the other untreated, is as follows:

	Bending strength.	Compression strength.
	Lbs. per sq. in.	*Lbs. per sq. in.*
Treated	7,770	5,600
Untreated	12,340	7,400

The same difference in favor of the untreated material obtained in every single case.

The chemical analyses performed on wood lying side by side along the same radius, being of the same annual rings and same position in tree, gave the following:

Per cent of rosin and phenols calculated to dry weight of wood.

	Tree No. 475.		Tree No. 476.		Average of both.	
	Treated.	Untreated.	Treated.	Untreated.	Treated.	Untreated.
Rosin:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Sapwood	1.21	2.05	1.22	1.23	1.22	1.64
Heartwood	8.35	10.58	2.23	1.93	5.29	6.26
Phenols:						
Sapwood	0.061	0.083	0.045	0.083	0.053	0.083
Heartwood	0.290	0.180	0.070	0.058	0.180	0.119

It appears that the protective rosin is rather decreased by the treatment, and the antiseptic phenols not increased in an adequate amount to be of value since it requires at least 20 times as much heavy oil in wood impregnation to be effective. It is, however, possible that the change of color due to the process may be accomplished and be produced by the formation of empyreumatic bodies (allied to the humus substances) which may act as preservative against the attacks of fungi.

The claim that the shrinkage of the wood is favorably influenced by the process was not sustained by a series of experiments with oak and pine, which showed that the treated wood absorbs water from air or in the tub, swells and shrinks in the same manner and to about the same extent as the untreated wood.

EFFECT OF IMMERSION ON THE STRENGTH OF WOOD.

The notion frequently expressed is that "soaking wood by floating, rafting, etc., reduces its tendency to decay and shrinkage, but injures its strength." The same was claimed for boiling or steaming preparatory to bending. The last position was disproved by Peter Barlow in the first quarter of this century. The following figures (results of an experiment involving several hundred separate tests) disprove the former assertion.

The soaked wood was kept immersed six months, each piece having its check pieces from the same scantling, which were not subject to the same process, but were tested—one green and one dry. All soaked pieces were seasoned in dry kiln before testing. All values were reduced to 15 per cent moisture.

Loblolly pine.	Bending strength.	Compression strength.
	Lbs. per sq. in.	*Lbs. per sq. in.*
Soaked 6 months, and then dried	10,820	6,780
Not soaked (mean of green and dry tests)	10,570	7,060

EFFECT OF "BOXING" OR "BLEEDING."

"Bleeding" pine trees for their resin—to which only the longleaf and Cuban pine are subjected—has generally been regarded as injurious to the timber. Both durability and strength, it was claimed, were impaired by this process, and in the specifications of many architects and large consumers, such as railway companies, "bled" timber was excluded. Since the utilization of resin is one of the leading industries of the South, and since the process affects several millions of dollars' worth of timber every year, a special investigation involving mechanical tests, physical and chemical analyses of the wood of bled and unbled trees from the same locality were carried out by this division. The results prove concusively (1) that bled timber is as strong as unbled if of the same weight; (2) that the weight and shrinkage of the wood is not affected by bleeding; (3) that bled trees contain practically neither more nor less resin than unbled trees, the loss of resin referring only to the sapwood, and, therefore, the durability is not affected by the bleeding process.

The following table shows the remarkable numerical similarity between the average results for three groups of trees, the higher values of the unbled material being readily explained by the difference in weight:

Longleaf pine.	Number of tests.	Specific weight of test pieces.	Bending strength.	Compression strength.
			Lbs. per sq. in.	*Lbs. per sq. in.*
Unboxed trees	400	0.74	12,358	7,166
Boxed and recently abandoned	390	0.79	12,961	7,813
Boxed and abandoned 5 years	535	0.76	12,586	7,575

The amount of resin in the wood varies greatly, and trees growing side by side differ within very wide limits. Sapwood contains but little resin (1 to 4 per cent), even in those trees in which the heartwood contains abundance. In the heartwood the resin forms from 5 to 24 per cent of the dry weight (of which about one-sixth is turpentine and can not be removed by bleeding), so that its quantity remains unaffected by the process. Bled timber, then, is as useful for all purposes as unbled.

To give an idea how necessary it is that a large series of material be tested before making statements of the strength of wood of any species, we reproduce one of the many tables contained in Bulletin 8, which at the same time exhibits the variation of strength throughout the tree and from tree to tree.

Comparative Strength of Different Trees of Longleaf Pine.

Specimens taken from first 20 feet of tree trunk reduced to 15 per cent moisture. The numbers given in light-faced type are the percentages; the several results are the average of all of that class.

[The tabulated values and averages of tests from butt cuts (from 12 to 20 feet long) of individual trees.]

Local conditions of growth.	1		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Number of tree.	Age.	Dates of cutting and sawing.	Dates of green and dry tests.	Number of sticks tested.	Approximate dimension in inches.	Standard percentage of moisture.	Average specific gravity (not reduced for moisture).	Cross-bending tests. Modulus of rupture per square inch. $f = \frac{3Wl}{2bh^2}$	Cross-bending tests. Modulus of strength at elastic limit per square inch. $f = \frac{3Wl}{bh^2}$	Cross-bending tests. Modulus of elasticity. $E = \frac{3Wl^3}{4\Delta bh^3}$	Crushing strength endwise per square inch.	Crushing strength across the grain per square inch. For 3 per cent distortion.	Crushing strength across the grain per square inch. For 15 per cent distortion.	Tensile strength per square inch (not reduced for moisture).	Shearing strength per square inch.	Per cent each tree is of its group.	Per cent each tree is of its kind.	Per cent each group is of its kind.	Per cent each kind is of the whole, giving each kind equal weight.	Per cent each tree is of the whole.
									Pounds.	*Pounds.*		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*					
Unboxed.	1	182	Nov., 1890	July, 1891					101.4	98.6	103.1	103.9	96.1		107.4	103.7	101.1				
			Feb., 1891	Aug., 1892	7	4x4x60	15	0.753	**12,664**	**9,057**	**2,081,243**	**7,370**	**1,004**	**1,410**	**20,347**	**744**	....	**101.1**	100	96.6	**97.1**
	2	196	Nov., 1890	July, 1891					98.0	97.6	95.2	99.1	95.9		82.2	87.8	94.6				
			Feb., 1891	July, Aug., 1892	6	4x4x60	15	0.76[illegible]	**12,244**	**8,962**	**1,922,260**	**7,031**	**1,002**	**1,327**	**15,564**	**630**	....	**94.6**			**90.9**
	3	183	Nov., 1890	July, 1891					98.9	100.0	108.0	97.0	94.0		107.6	92.6	98.8				
			Feb., 1891	Aug., 1892	4	4x4x60	15	0.729	**12,345**	**9,187**	**2,180,977**	**6,881**	**982**	**1,394**	**20,369**	**664**	....	**98.8**			**94.9**
	4	189	Nov., 1890	July, Aug., 1891					99.3	103.9	84.9	103.0	104.8		102.1	100.9	102.1				
			Feb., 1891	July, Aug., 1892	7	4x4x60	15	0.739	**12,398**	**9,548**	**1,714,700**	**7,311**	**1,095**	**1,741**	**19,332**	**724**	....	**102.1**			**98.1**
	5	226	Nov., 1890	July, 1891					102.4	99.9	108.8	97.1	109.2		100.7	115.0	103.4				
			Feb., 1891	....	24	4x4x60	15	0.762	**12,796**	**9,174**	**2,197,808**	**6,891**	**1,141**		**19,081**	**825**	....	**103.4**			**99.3**
Unboxed.	16	202	Apr., 1891	July, Aug., 1891					95.0	95.2	92.7	102.5	114.8		102.4	85.5	98.1				
			June, 1891	July, 1892	15	4x4x60	15	0.773	**11,616**	**8,506**	**1,826,229**	**7,417**	**1,145**	**1,488**	**18,464**	**742**	....	**98.1**	100		**94.2**
	17	163	Apr., 1891	Aug., Sept., 1891					92.3	95.5	97.2	97.5	102.5		81.7	97.4	94.4				
			June, 1891	July, 1892	6	4x4x60	15	0.753	**11,289**	**8,534**	**1,915,380**	**7,064**	**1,023**	**1,444**	**14,732**	**846**	....	**94.4**			**90.7**
	18	210	Apr., 1891	Aug., Sept., 1891					90.8	88.0	91.9	95.8	85.7		77.5	95.2	89.5				
			June, 1891	July, 1892	3	4x4x60	15	0.734	**11,098**	**7,863**	**1,811,600**	**6,929**	**855**	**1,216**	**13,977**	**827**	....	**89.5**			**86.0**
	19	160	Apr., 1891	Aug., 1891					104.8	103.0	99.6	97.5	79.9		112.0	114.5	101.5				
			June, 1891	July, 1892	4	4x4x60	15	0.698	**12,808**	**9,202**	**1,962,975**	**7,052**	**797**	**1,047**	**20,210**	**994**	..	**101.5**			**97.5**
	20	110	Apr., 1891	Aug., Sept., 1891					117.2	118.2	118.6	106.7	117.1		126.4	107.4	116.5				
			June, 1891	July, 1892	4	4x4x60	15	0.782	**14,326**	**10,555**	**2,338,745**	**7,713**	**1,168**	**1,931**	**22,792**	**933**	....	**116.5**			**111.9**
Boxed five years before cutting.	52	......	Oct., 1891	Nov., Dec., 1891					89.3	91.8	91.9	90.0	83.4		81.8	81.1	87.1				
			Nov., 1891	Jan., July, 1892	40	4x4x60	15	0.661	**11,240**	**8,682**	**1,696,570**	**6,817**	**1,063**	**1,303**	**13,593**	**710**	....	**85.3**	97.9	103.4	**87.5**
	53	192	Oct., 1891	Nov., Dec., 1891					92.2	95.4	81.9	93.0	91.3		79.5	76.8					
			Nov., 1891	Jan., July, 1892	19	4x4x60	15	0.732	**11,606**	**9,020**	**1,512,458**	**7,045**	**1,164**	**1,405**	**13,220**	**672**	**88.8**	**86.9**			**88.1**
	54	180	Oct., 1891	Nov., 1891					101.3	98.7	103.7	96.8	108.9		116.3	103.4					
			Nov., 1891	July, 1892	8	4x4x60	15	0.804	**12,756**	**9,332**	**1,913,175**	**7,332**	**1,388**	**1,866**	**19,340**	**905**	104.1	**101.9**			**104.4**
	55	......	Oct., 1891	Nov., 1891					97.1	102.5	96.5	98.2	94.9		96.1	86.7	**96.6**				
			Nov., 1891	July, 1892	10	4x4x60	15	0.720	**12,221**	**9,694**	**1,781,640**	**7,440**	**1,210**	**1,556**	**15,968**	**759**		**94.6**			**97.0**
	56	......	Oct., 1891	Nov., Dec., 1891					110.4	104.4	112.7	107.6	95.3		110.2	108.8	106.6				
			Nov., 1891	July, Aug., 1892	8	4x4x60	15	0.787	**13,893**	**9,874**	**2,080,875**	**8,172**	**1,214**	**1,598**	**18,327**	**952**	....	**104.4**			**107.1**
	57	......	Oct., 1891	Nov., 1891					103.9	102.8	99.1	99.6	103.8		90.2	106.5	101.6				
			Nov., 1891	Aug., 1892	8	4x4x60	15	0.747	**13,082**	**9,727**	**1,829,862**	**7,551**	**1,323**	**1,742**	**14,996**	**932**	....	**99.5**			**102.0**
	58	......	Oct., 1891	Nov., 1891					100.4	101.0	106.1	104.1	100.0		116.1	105.4	103.9				
			Nov., 1891	Aug., 1892	8	4x4x60	15	0.767	**12,634**	**9,549**	**1,959,075**	**7,884**	**1,274**	**1,639**	**19,306**	**922**	....	**101.7**			**104.3**
	59	......	Oct., 1891	Nov., 1891					105.3	103.6	107.9	110.4	122.3		109.7	111.2					
			Nov., 1891	Aug., 1892	6	4x4x60	15	0.777	**13,253**	**9,798**	**1,992,035**	**8,361**	**1,559**	**1,928**	**18,237**	**1,148**	**111.3**	**109.0**			**111.8**

COMPARATIVE STRENGTH OF DIFFERENT TREES OF LONGLEAF PINE—Continued.

Specimens taken from first 20 feet of tree trunk reduced to 15 per cent moisture. The numbers given in light-faced type are the percentages; the several results are the average of all of that class—Continued.

1			2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
									Cross-bending tests.				Crushing strength across the grain per square inch.								
Local conditions of growth.	Number of tree.	Age.	Dates of cutting and sawing.	Dates of green and dry tests.	Number of sticks tested.	Approximate dimension in inches.	Standard percentage of moisture.	Average specific gravity (not reduced for moisture).	Modulus of rupture per square inch. $f=\frac{3Wl}{2bh^2}$	Modulus of strength at elastic limit per square inch. $f=\frac{3Wl}{bh^2}$	Modulus of elasticity. $E=\frac{3Wl^3}{4\Delta bh^3}$	Crushing strength endwise per square inch.	For 3 per cent distortion.	For 15 per cent distortion.	Tensile strength per square inch (not reduced for moisture).	Shearing strength per square inch.	Per cent each tree is of its group.	Per cent each tree is of its kind.	Per cent each group is of its kind.	Per cent each kind is of the whole, giving each kind equal weight.	Per cent each tree is of the whole.
									Pounds.	*Pounds.*		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*					
Recently boxed.	60	225	Oct., 1891	Nov., Dec., 1891					100.9	101.9	99.6	99.8	103.5		96.7	88.0					
			Nov., 1891	Jan., Aug., 1892	15	4x4x60	15	0.767	13,078	10,148	1,911,106	7,794	1,347	1,582	16,137	834	99.6	101.7			104.3
	61	214	Oct., 1891	Nov., Dec., 1891					103.2	98.8	98.7	97.9	98.3		103.7	99.3					
			Nov., 1891	Jan., Aug., 1892	21	4x4x60	15	0.788	13,376	9,846	1,894,267	7,647	1,280	1,899	17,300	941	99.7	101.8			104.4
	62	......	Oct., 1891	Dec., 1891					105.4	110.3	110.3	98.2	113.5		114.3	84.1					
			Nov., 1891	Aug., 1892	6	4x4x60	15	0.816	13,661	10,988	2,116,550	7,676	1,478	1,804	19,078	797	105.3	107.5			110.3
	63	200	Oct., 1891	Nov., Dec., 1891					86.8	85.7	85.1	92.4	96.9		70.0	88.5					
			Nov., 1891	Aug., 1892	8	4x4x60	15	0.737	11,255	8,536	1,633,450	7,220	1,262	1,711	11,681	839	87.0	88.8	102.1	103.4	91.1
	64	......	Oct., 1891	Nov., Dec., 1891					102.0	108.2	109.5	103.3	97.3		108.4	96.7					
			Nov., 1891	Aug., 1892	8	4x4x60	15	0.835	13,221	10,780	2,100,925	8,069	1,267	1,740	18,089	917	103.8	106.0			108.7
	65	......	Oct., 1891	Nov., Dec., 1891					98.8	97.7	93.8	103.9	100.5		110.5	114.8					
			Nov., 1891	Aug., 1892	8	4x4x60	15	0.843	12,799	9,736	1,798,750	8,041	1,309	1,769	18,442	1,088	101.9	104.0			106.7
	66	91	Oct., 1891	Nov., Dec., 1891					100.2	91.1	93.2	98.9	102.3		90.9	116.7					
			Nov., 1891	Aug., 1892	4	4x4x60	15	0.797	12,981	9,077	1,789,000	7,733	1,332	1,816	15,165	1,106	98.2	100.2			102.8
	67	116	Oct., 1891	Nov., Dec., 1891					102.8	106.3	109.7	106.5	87.6		105.9	112.0					
			Nov., 1891	Aug., 1892	8	4x4x60	15	0.781	13,320	10,585	2,105,212	8,305	1,140	1,583	17,577	1,062	104.5	106.7			109.4
									101.0	101.4	101.2	99.0	102.3		102.9	90.4					
Average of first group, 5 unboxed trees					....	....	....	0.749	12,489	9,186	2,019,398	7,097	1,045	1,468	18,939	717	100.0				
									99.0	98.6	98.8	101.0	97.7		97.6	109.6					
Average of second group, 5 unboxed trees					....	....	....	0.748	12,227	8,932	1,970,986	7,235	998	1,425	18,035	868	100.0				
									98.5	97.4	98.1	98.5	98.9		99.8	96.1					
Average of third group, 8 trees boxed 5 years before cutting.					....	....	....	0.762	12,586	9,459	1,845,711	7,575	1,274	1,630	16,623	875	97.9				
									101.5	102.6	101.9	101.5	101.1		100.2	103.9					
Average of fourth group, 8 trees recently boxed					....	....	....	0.795	12,961	9,962	1,918,657	7,813	1,302	1,738	16,684	948	102.1				
									98.3	96.5	102.9	96.4	88.5		105.2	93.1	96.6				
Average of first and second groups, 10 unboxed trees.					....	....	....	0.749	12,358	9,059	1,995,192	7,166	1,021	144	18,487	793					
									101.7	103.5	97.1	103.6	111.5		94.8	106.9	103.4				
Average of third and fourth groups, 16 boxed trees					....	....	....	0.779	12,774	9,710	1,882,184	7,694	1,288	1,684	16,654	912					
Mean value of boxed and unboxed trees					....	....	....	0.764	12,566	9,385	1,938,688	7,430	1,155	1,565	17,570	853					
Averages of all trees (26)					265	4x4x60	15	0.767	12,614	9,460	1,925,644	7,452	1,185	1,598	17,359	866					

SIZE OF TEST MATERIAL.

The long-standing idea of engineers and other consumers to have wood tested more nearly in the sizes used in ordinary practice led to the adoption of test sizes, generally varying from 3 by 3 inches to 4 by 4 inches. Besides this, special inquiries with different kinds of timber into the relation of large and small tests were instituted to ascertain the correctness of the general dogma which claimed that tests on small pieces could not be utilized, since such pieces for their very size gave higher values of strength. This investigation involved full-size columns as well as beams, and was continued throughout the entire period of the timber-physics work. It led to a number of the most interesting and highly valuable results, as will appear from the following statements:

Selected tests of columns and compression pieces from the same trees compared.

Number of tree.	Length.	Ratio $\frac{l}{d}$	Small pieces (average of whole tree). (a)	Large columns. (b)	Relative value. (a)	(b)	Deflection.	Failure.
	Feet.		*Pounds per sq. inch.*	*Pounds per sq. inch.*			*Inch.*	
239	12	14	6,700	6,100	100	91	0.7	Sheared.
240	12	14	7,000	6,900	100	99	0.1	Compression.
241	12	15	6,900	6,500	100	94	0.7	Do.
309	12	12	6,800	6,500	100	96	0.4	Do.
312	12	16	6,100	6,300	100	103	0.4	Do.

In these columns (nearly one-tenth of all longleaf pine columns tested) the strength was so nearly the same as that of the short pieces that it appears as if flexure had but little to do with the failure, the small differences being amply accounted for by a larger number of defects in the columns. Should this prove true in general for wooden columns as ordinarily designed, the problem would become simply a study of the influence of defects and of proper inspection.

The nature of the failures would also point in this direction:

Of 86 columns 32 failed normally, i. e., in simple compression; 22 were crushed near the end; 14 failed at knots, and 19 by shearing, the rupture usually beginning at or near the ends; a small knot proved sufficient to cause a large column, 20 times as long as its diameter, to fail at 14 inches from the end.

The deflection in the average for all columns (12 to 20 feet long) was only about 1 inch for the maximum load, when, to be sure, destruction had progressed for some time; at the elastic limit the deflection was only about one-half as much. These results would seem to warrant the statement that for pine columns at least, in which the ratio of height to least diameter does not exceed 1 in 20, none of the accepted column formulæ are applicable, the nature of the failure being mostly in simple compression, and depending more on specific defects than on the design of the column.

STRENGTH OF LARGE BEAMS AND COLUMNS.

Owing to the fact that much wood testing has been done on small, select, and perfectly seasoned pieces, usually from butt logs, the values thus obtained seemed to differ very markedly from the results on large timbers usually very imperfectly seasoned, and it was claimed that tests on small sizes always furnished too high values, just as if the differences were due to sizes alone.

While, to be sure, a small piece may be so selected that defects are excluded, the grain straight and in the most favorable position with regard to the load, the assumption of the difference in strength of small pieces from that of large-sized sticks has never been made good experimentally.

Since it appears desirable to compare the results from large beams and columns not only with the average data obtained from the general test series on small 4 by 4 material, but also with the average strength of small pieces cut from the same beams and columns, a special inquiry into the legitimacy of such a comparison was made. This study involved over 100 separate tests, and proved the very important fact that uninjured parts of broken beams and columns do not suffer in the test. The large-sized beams varied from 4 by 4 to 8 by 16 inches.

Tests of large and small beams—Bending strength.

	Small beams, general test series.	Large beams. Total.	Large beams. Beams from which small beams were cut.	Small beams cut from large beams.
Number of tests involved	1,986	127	57	236
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Longleaf	11,300	11,500	9,800	10,100
Loblolly	10,000	10,800	10,300	10,000
Shortleaf	9,300	9,200	8,700	8,700

From the preceding table it would appear that large timbers, when symmetrically cut (i. e., with the center of the log as center of the beam), develop as beams practically the same strength as the average of the small pieces that may be cut from them, and sometimes even higher values; the explanation being that cut in this manner the extreme fibers which are tested in a beam come to lie in that part of the tree which, as a rule, contains the strongest timber.

Results discordant from these may be explained by differences in the degree of seasoning of the outer layers and also by the fact that especially in the northern pineries timbers are often cut from the top logs, which are weaker and more defective.

Test of large and small columns—Compression strength.

	Regular series from same trees as the columns.	Columns (simple compression).	Small pieces cut from columns.
Number of tests involved	949	95	97
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Longleaf	6,600	5,300	7,100
Loblolly	6,800	4,700	6,300
Shortleaf	5,900	4,100	6,200
Cuban	7,400	5,000	8,700

The square columns were mostly 8 by 8 inches, some 10 by 10 inches, a few of larger and also some of smaller dimensions. The ratio of length to width varied from 12 to 27, about one-half being under and the other half over 18 to 1. The compression pieces of the regular series, and those cut from the broken columns, were in general about 4 by 4 by 6 inches.

It will appear from this statement of average results that columns develop only from 62 per cent (in Cuban) to 78 per cent (longleaf) of the compression strength of ordinary short pieces. The explanation may be due to several reasons, natural and mechanical. In a column, unlike a beam, all the fibers are under great strain; hence all the defects, which are by necessity found in every column, influence the results; the flexure of a column under strain is an element of weakness, to which the short compression piece is not subject. In addition the difficulty of determining the average moisture condition of the large timber throughout the cross section and that of the small pieces cut from them afterwards would render this method for columns less satisfactory; a larger number of tests will still be required to establish comparable average conditions in the two kinds of tests. It would, therefore, be unsafe to generalize too hastily from these average figures, at least as to the numerical difference, for there are remarkable individual exceptions. Not only do individual columns show differences in strength 50 per cent and more lower than the compression pieces from the same log, but sometimes they show practically the same or even a higher value of strength, as will appear from the following selected cases, in which the data for the columns are placed in comparison with those obtained on compression pieces from the same tree.

Additional Series on Beams and Columns.

A series more extended as regards beams, involving 68 large and 777 small beams, besides over 1,000 compression tests on the same material on which the beam tests were made, and tests on 6 large columns, has fully confirmed the indications of the previous experiments.

TESTS ON COLUMNS.

The columns were 12 by 12 inches and 8 by 12 inches in cross section, with a length of 132 to 168 inches. From these were cut, as near as possible from the place of failure, two blocks 24 inches long, and these blocks were tested on the same large testing machine (described in Bulletin 6), so that inaccuracies of machinery do not enter into consideration. The results, tabulated as follows, prove conclusively the statement made upon the former more extensive series (see Circular 12), that wooden columns in which the diameter and length are to each other as 1 to 18 or less behave like short blocks and fail in simple compression. The four columns of long-leaf pine exhibit practically the same strength as the short blocks—i. e., within 10 per cent—which, as has been shown above, is within the limits of maximum uniformity.

Strength of large columns and short (24-inch) blocks cut from these columns.

Kind of wood.	Dimensions of columns (inches).			Moisture of wood (per cent).	Modulus of elasticity (pounds).	Compression strength in pounds per square inch.	
						Columns.	Short blocks.
Shortleaf pine	144	12	12	14.2	2,274,000	4,840	6,090
Do	132	12	12	12.9	1,740,000	4,840	5,660
Longleaf pine	168	12	8	30.9	1,628,000	2,940	2,950
Do	168	12	8	32.3	1,570,000	3,170	3,530
Do	156	12	8	40.8	1,764,000	3,030	3,310
Do	156	12	8	29.7	1,776,000	3,710	3,780

BEAM TESTS.

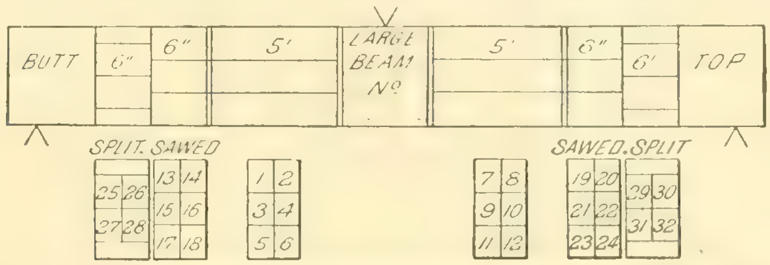
The experiments, of which the following tables contain the principal results, were performed on beams generally 8 by 12 by 192 inches. After breaking the large beam 12 small beams were cut from the uninjured portion of the large beam[1] in such a way that the entire cross section of the large piece was represented by two sets of 6 small beams each. Besides these tests on small beams, the compression strength of part of the material was tested on small blocks, part of which was sawed and part split from portions of the large beam. (See diagram at head of

[1] The legitimacy of using such material for such purpose has been fully established by a long series of experiments. (See Circular 12, Division of Forestry, p. 11.)

table.) To avoid any complications due to differences or changes in moisture, the tests on large and small beams were performed the same day.

Strength of large beams and of small beams, and of compression pieces cut from them.

[Usually 12 small beams cut from the uninjured part of each large beam.]



Kind of wood.	Number of beam.	Strength of large beams.	Average strength of small beams.	Moisture.		Compression, endwise strength.	
				Large beams.	Small beams.	Sawed pieces.	Split pieces.
		Lbs. per sq. in.	*Lbs. per sq. in.*	*Per cent.*	*Per cent.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Oak	1	7,400	8,560	69.5	68.5	3,960	4,120
	2	5,880	8,660	70.3	69.0	4,340	4,700
	3	6,570	6,220	75.3	75.2	3,030	3,190
	4	8,640	8,800	66.6	67.6	4,090	4,460
	5	8,150	7,710	64.8	65.8	3,680	3,750
	6	7,450	6,910	63.0	66.6	3,330	3,330
	8	6,870	6,890	67.4	70.5	3,470	3,190
Shortleaf pine	9	8,300	7,950	48.1	57.7	4,030	4,160
	10	7,440	7,250	42.1	56.3	3,840	3,850
	11	5,110	6,760	38.9	33.3	3,870	3,630
	12	7,360	6,930	35.2	33.5	3,890	3,850
	13	7,320	7,300	37.4	40.6	4,090	3,800
White pine	14	3,110	3,560	84.9	83.6	2,440	2,500
	15	4,280	4,340	43.8	41.2	2,710	2,840
	16	3,770	4,590	50.7	50.5	2,660	2,760
	17	3,460	3,590	60.0	48.6	2,410	2,570
	18	3,990	3,640	42.8	43.0	2,800	2,620
	19	4,040	4,400	62.4	60.4	2,760	2,780
	20	4,410	4,180	53.6	51.8	2,680	2,700
	21	4,900	4,320	50.1	51.0	3,010	2,900
	22	3,860	4,320	50.2	60.8	2,500	2,430
	23	4,660	4,890	52.0	58.2	2,850	2,880
	24	3,960	4,440	76.3	71.5	2,520	2,710
	25	3,920	4,410	53.6	60.5	2,840	2,730
Shortleaf pine	26	4,560	6,290	31.2	30.5	3,660	3,850
	27	4,390	5,610	33.9	36.0	2,830	3,110
	28	6,670	6,830	28.6	28.9	3,540	3,590
	29	7,410	7,630	28.6	29.0	4,450	4,250
	30	6,600	7,160	28.3	28.9	4,200	4,190
	31	5,750	6,000	34.3	35.5	3,630	3,530
	32	6,210	7,500	26.4	27.2	3,940	4,050
	33	7,450	8,390	29.5	30.1	4,350	4,220
	34	7,000	7,800	28.4	29.5	4,070	4,120
	35	6,030	6,740	28.8	29.4	3,810	3,640
	36	6,520	6,890	31.6	31.6	4,320	4,370
	37	7,030	7,890	29.2	29.9	4,380	4,920
	38	7,710	8,510	26.2	25.4	4,500	4,610
	39	8,090	8,210	32.5	31.9	4,550	4,670
	40	7,680	7,980	31.1	32.3	4,290	4,380
	41	7,330	8,230	31.7	31.5	4,680	4,820
Longleaf pine	42	7,290	8,740	30.9	31.2	4,950	5,120
	43	8,850	9,720	28.1	28.9	5,300	5,440
	44	8,040	8,870	26.3	26.9	4,730	5,070
	45	8,090	8,850	25.8	25.4	5,000	5,050
	46	7,620	7,670	32.6	33.9	4,730	4,830
	47	6,710	7,610	33.0	33.4	4,200	4,520
	48	8,480	8,300	29.3	29.3	4,870	4,890
	49	5,630	6,250	34.5	33.7	3,600	3,630
White pine	50	4,900	5,020	87.2	75.7	2,970	3,200
	51	5,300	5,210	71.4	69.6	3,330	3,240
	52	4,810	4,470	77.2	64.7	2,940	3,100
	53	3,610	3,610	54.5	58.2	2,400	2,550
	54	4,440	4,720	97.6	94.9	2,710	2,900
Shortleaf pine	55	6,400	7,610	27.0	27.1	4,340	4,500
	56	6,690	6,880	28.4	26.6	4,050	4,210
	57	6,670	6,990	27.0	26.4	4,100	4,340
	58	7,310	7,490	28.5	26.8	4,100	4,030
White pine	101	5,070	7,200	15.4	16.2	5,410	5,720
	102	6,340	6,890	11.0	11.7	4,920	5,520
	103	7,070	8,750	12.2	10.5	5,140	5,760
	104	4,900	6,680	12.1	8.2	4,360	4,700
	105	6,640	6,890	10.6	11.2	5,450	5,310
	106	6,180	7,650	11.6	11.3	5,190	5,420
	107	6,080	6,090	11.5	11.5	4,810	5,170
	108	5,510	5,810	11.1	10.7	5,100	4,710
	109	6,930	7,300	11.4	10.5	5,330	5,080
	110	5,930	6,010	12.1	11.6	4,600	4,670
	111	4,010	5,040	13.0	13.0	4,270	4,390

OBSERVATIONS AND DEDUCTIONS.

(*a*) The difference between the values for the large beam and the average for the small beams is not at all constant, either in character or quantity; the large beam may be stronger (20 per cent of the cases) or practically as strong—i. e., within 10 per cent (57 per cent of the cases)—or it may be weaker, and vary often considerably from the average (23 per cent of the cases).

Of 696 tests on small beams 235 furnished results smaller than that of the large beam. Again, out of 396 small beams fully 40 per cent were weaker that the large beam, while of another series of 300 only 24 per cent gave lower values.

(*b*) There are in every case some small beams which far excel in strength the large beam; even in such cases, where the average strength of the small beams is practically the same as that of the large beam, some small beams show values 25 to 30 per cent greater than the large beam.

(*c*) In only 6 per cent of the cases each of the small pieces gave a higher result than was obtained from the large beam, but in these cases the latter was evidently defective.

(*d*) In all beams the differences observed between the several small beams themselves are far greater than that between the average value of the small beams and the value of the large beam from which they are cut.

From these observations, which are fully in accord with the observations on the numerous tests of the large general series, it would appear that—

(1) Size alone can not account for the differences observed; and, therefore, also that a small beam is not proportionately stronger because it is smaller, for it may be either stronger or weaker; but that if it is stronger, the cause of this lies in the fact that the larger beam contains weak as well as strong wood, besides other defects, which may or may not appear in the small stick.

(2) Generally, but not always, a large timber gives values nearer the average, since it contains, naturally, a larger quantity as well as a greater variety of the wood of the tree; and, therefore, also—

(3) Small beams, for the very reason of their smallness, containing, as they do, both a smaller quantity and variety of the material, give results which vary more from the average than results from large beams, and, therefore, can be utilized only if a sufficient number be tested; but it also appears that—

(4) To obtain an average value, even a very moderate number of smaller pieces, if they fairly represent the wood of the entire stem, give fully as reliable data as values derived from a large beam.

(5) *Average values derived from a large series of tests on small but representative material may be used in practice with perfect safety, and these averages are not likely to be modified by tests on large material.*

It might be added that both the practicability and need of establishing a coefficient or ratio between results from tests on large and small beams or columns falls away. To deserve any confidence at all, only a large series of tests on either large or small beams would satisfy the requirement of establishing standard values, while a series of small pieces has the preference, not only on account of greater cheapness and convenience in establishing the values, but still more for the reason that only by the use of small, properly chosen material is it possible to obtain a sufficiently complete representation of the entire log.

Before these results, part of which were published by installments, had all been computed and arranged, the results of the work made it possible to publish, for the first time in the English language, a brief exposition of the technical properties of wood in general, which appeared as Bulletin 10 of the Division. This little booklet was copied verbatim several times by different technical journals of this country, was embodied in toto in one of the best works on the materials of engineering, and was even translated into French by one of the foremost publishers of France, besides being used itself as a text-book by several of our largest colleges. In addition to the discussions of the several technical properties of wood, this booklet contains the first attempt in the English language at a key by which our common woods may be safely recognized from their structure alone. The key and some of the tables in this bulletin have been reproduced in an earlier part of this report. By this time, when the work was interrupted by superior orders, there were brought together the strength values for the wood of 32 species, of which 26 were represented by more than 200 tests each (the longleaf pine by over 6,000), 17 of them by over 400 tests per species, and seven by over 1,000 tests. These results were published in full in Circular No. 15 of the Division, from which the following extract is here repeated:

SUMMARY OF MECHANICAL TESTS ON THIRTY-TWO SPECIES OF AMERICAN WOODS.

GENERAL REMARKS.

The chief points of superiority of the data obtained in these investigations lie in, (1) Correct identification of the material, it being collected by a competent botanist in the woods; (2) selection of representative trees with record of age, development, place and soil where grown, etc.; (3) determination of moisture conditions and specific gravity and record of position in the tree of the test pieces; (4) large number of trees and of test pieces from each tree; (5) employment of large and small-sized test material from the same trees; (6) uniformity of method for an unusally large number of tests.

The entire work of the mechanical test series, carried on through nearly six years intermittently as funds were available, comprises so far 32 species with 308 test trees, furnishing over 6,000 test pieces, supplying material for 45,336 tests in all, of which 16,767 were moisture and specific gravity determinations on the test material.

In addition to the material for mechanical tests, about 20,000 pieces have been collected from 780 trees (including the 308 trees used in mechanical tests) for physical examination to determine structure, character of growth, specific gravity of green and dry wood, shrinkage, moisture conditions, and other properties and behavior.

In addition to the regular series of tests, the results of which are recorded in the subjoined tables, special series, to determine certain questions were planned and carried out in part or to finish, adding 4,325 tests to the above number.

Account of test material.

No.	Name of species.	Number of trees.	Number of mechanical tests.	Average specific gravity of dry wood.	Localities and number of trees from each.
1	Longleaf pine (Pinus palustris.)	68	6,478	0.61	Alabama, coast plain (22) *a*; uplands (6); hill district (6); Georgia, undulating uplands (6); South Carolina, coast plain (7); Mississippi, low coast plain (2); Louisiana, low coast plain, gravelly soil (7); sandy loam (6); Texas, low coast plain (6).
2	Cuban pine (Pinus heterophylla.)	12	2,113	.63	Alabama, coast plain (6); Georgia, uplands (1); South Carolina, coast (5).
3	Shortleaf pine (Pinus echinata.)	22	1,831	.51	Alabama, uplands (4); Missouri, low hilly uplands (6); Arkansas, low hilly uplands (6); Texas, uplands (6).
4	Loblolly pine (Pinus tæda.)	32	3,335	.53	Alabama, mountainous plateau (8); low coast plain (6); Arkansas, level flood plain (5); Georgia, level coast plain (6); South Carolina, low coast plain (7).
5	White pine (Pinus strobus.)	17	540	.38	Wisconsin, clay uplands (5); sandy soils (4); sandy loam (5); Michigan, level drift lands (3).
6	Red pine (Pinus resinosa.)	8	412	.50	Wisconsin, drift (5); Michigan (3).
7	Spruce pine (Pinus glabra.)	4	696	.44	Alabama, low coast plain.
8	Bald cypress (Taxodium distichum.)	20	3,396	.46	South Carolina, pine barren (6); river bottom (4); Louisiana, coast plain, border of lake (4); Mississippi, Yazoo bottom (3); upland (3).
9	White cedar (Chamæcyparis thyoides.)	4	354	.37	Mississippi, low plain.
10	Douglas spruce (Pseudotsuga taxifolia.)	......	225	.51	(From lumber yard.)
11	White oak (Quercus alba.)	12	1,009	.80	Alabama, ridges of Tennessee Valley (5); Mississippi, low plain (7).
12	Overcup oak (Quercus lyrata.)	10	911	.74	Mississippi, low plain (7); Arkansas, Mississippi bottoms (3).
13	Post oak (Quercus minor.)	8	256	.80	Alabama, Tennessee Valley (5); Arkansas, Mississippi bottom (3).
14	Cow oak (Quercus michauxii.)	11	935	.74	Alabama, Tennessee Valley (4); Arkansas, Mississippi bottoms (3); Mississippi, low plain (4).
15	Red oak (Quercus rubra.)	7	299	.73	Alabama, Tennessee Valley (5); Arkansas, Mississippi bottom (2). *b*
16	Texan oak (Quercus texana.)	3	479	.73	Arkansas, Mississippi bottom.
17	Yellow oak (Quercus velutina.)	5	222	.72	Alabama, Tennessee Valley (5).
18	Water oak (Quercus nigra.)	4	132	.73	Mississippi, low plain (4).
19	Willow oak (Quercus phellos.)	12	649	.72	Alabama, Tennessee Valley (5); Arkansas, Mississippi bottom (3); Mississippi, low plain (4).
20	Spanish oak (Quercus digitata.)	11	1,035	.73	Alabama, Tennessee Valley (5); Arkansas, Mississippi bottom (3); Mississippi, low plain (3).
21	Shagbark hickory (Hicoria ovata.)	6	794	.81	Mississippi, alluvial plain (3); limestone (3).
22	Mockernut hickory (Hicoria alba.)	4	300	.85	Mississippi, low plain.
23	Water hickory (Hicoria aquatica.)	2	197	.73	Do.
24	Bitternut hickory (Hicoria minima.)	4	100	.77	Do.
25	Nutmeg hickory (Hicoria myristicæformis.)	3	294	.78	Do.
26	Pecan hickory (Hicoria pecan.)	2	172	.78	Do.
27	Pignut hickory (Hicoria glabra.)	3	84	.89	Do.
28	White elm (Ulmus americana.)	2	94	.54	Mississippi, bottom.
29	Cedar elm (Ulmus crassifolia.)	3	201	.74	Arkansas, bottom.
30	White ash (Fraxinus americana.)	3	476	.62	Mississippi, bottom.
31	Green ash (Fraxinus lanceolata.)	1	45	.62	Do.
32	Sweet gum (Liquidambar styraciflua.)	7	508	.59	Arkansas, bottom (3); Mississippi, low plain (4).

a Sixteen of these were bled trees to study the effects of boxing.
b These two should probably be classed as Southern red oak. They were collected before the distinction was finally decided upon.
NOTE.—The values for specific gravity here given refer to "dry" wood of test material—i. e., wood containing variable amounts of moisture below 15 per cent; the moisture effect has therefore not been taken into account, but more careful experiments indicate that its nfluence on specific gravity at such low per cent is so small that it may be neglected for practical purposes.

As will be observed, some species, notably the Southern pines, have been more fully investigated, and the results on these (which have been published more in detail in Circular No. 12) may be taken as authoritative. With those species of which only a small number of trees have been tested this can be claimed only within limits and in proportion to the number of tests.

The great variation in strength which is noticeable in timber of the same species makes it necessary to accept with caution the result of a limited number of tests as representing the average for the species, for it may have happened that only all superior or all inferior material has been used in the tests. Hence we would not be entitled to conclude, for instance, that pignut hickory is 14 per cent stronger than shagbark, as it would appear in the table, for the 30 test pieces of the former may easily have been superior material. Only a detailed examination of the test pieces or a fuller series of tests would enlighten us as to the comparative value of the results.

The following data, therefore, are not to be considered as in any sense final values for the species, except where the number of trees and tests is very large:

Results of tests in compression endwise.

[Pounds per square inch.]

No.	Species.	Number of tests.	Highest single test.	Lowest single test.	Average highest 10 per cent of tests.	Average lowest 10 per cent of tests.	Average of all tests.	Proportion of tests within 10 per cent of average.	Proportion of tests within 25 per cent of average.
	Reduced to 15 per cent moisture.							*Per cent.*	*Per cent.*
1	Longleaf pine	1,230	11,900	3,400	8,600	5,700	6,900	53	90
2	Cuban pine	410	10,600	2,800	9,500	6,500	7,900	61	93
3	Shortleaf pine	330	8,500	4,500	7,600	4,800	5,900	47	90
4	Loblolly pine	660	11,200	3,900	8,700	5,400	6,500	49	84
	Reduced to 12 per cent moisture.								
5	White pine	130	8,500	3,200	6,800	4,000	5,400	49	93
6	Red pine	100	8,200	4,300	8,100	4,900	6,700	54	96
7	Spruce pine	170	10,000	4,400	8,800	5,600	7,300	66	95
8	Bald cypress	655	9,900	2,900	8,500	4,200	6,000	31	74
9	White cedar	87	6,200	3,200	6,000	4,400	5,200	79	99
10	Douglas spruce *a*	41	8,900	4,100	8,100	4,200	5,700	28	65
11	White oak	218	12,500	5,100	11,300	6,300	8,500	40	81
12	Overcup oak	216	9,100	3,700	8,600	6,000	7,300	70	95
13	Post oak	49	8,200	5,900	8,100	6,000	7,100	58	100
14	Cow oak	256	11,560	4,600	9,800	5,600	7,400	51	89
15	Red oak	57	9,700	5,400	9,200	5,500	7,200	36	94
16	Texan oak	117	11,300	5,800	9,800	6,900	8,100	62	98
17	Yellow oak	40	8,600	5,500	8,300	5,800	7,300	58	100
18	Water oak	31	9,200	6,200	9,000	6,300	7,800	75	100
19	Willow oak	153	11,000	4,200	8,700	5,500	7,200	51	88
20	Spanish oak	251	10,600	3,700	9,500	5,100	7,700	61	94
21	Shagbark hickory	137	13,700	5,800	10,900	7,500	9,500	79	97
22	Mockernut hickory	75	12,200	6,200	11,600	8,000	10,100	65	99
23	Water hickory	14	10,000	6,700	9,600	7,000	8,400	71	100
24	Bitternut hickory	25	11,500	7,300	11,200	7,800	9,600	60	100
25	Nutmeg hickory	72	12,300	6,400	11,000	7,100	8,800	79	97
26	Pecan hickory	37	10,500	5,800	10,400	7,300	9,100	51	95
27	Pignut hickory	30	13,000	8,700	12,700	8,900	10,900	72	100
28	White elm	18	8,800	4,900	8,800	5,000	6,500	28	88
29	Cedar elm	44	10,600	6,200	10,100	6,500	8,000	66	95
30	White ash	87	9,600	5,000	8,700	5,700	7,200	48	96
31	Green ash	10	9,800	6,600	9,800	6,600	8,000	29	100
32	Sweet gum	118	8,900	4,600	8,500	5,600	7,100	60	97

a Actual tests on "dry" material not reduced for moisture.

The variation in strength in wood of the virgin forest, as will be seen from the tables, is in some species so great that by proper inspection and selection values differing by 25 to 50 per cent may be obtained from different parts of the same tree, and values differing 100 to 200 per cent within the same species. These differences have all their definite recognizable causes, to find and formulate which is the final aim of these investigations.

The tests are intentionally not made on selected material (except to discard absolutely defective pieces), but on material as it comes from the trees, so as to arrive at an average statement for the species, when a sufficient number of trees has been tested. How urgent is the need for data of inspection as above indicated will appear from the wide range of results recorded.

To enable any engineer to use the data here given with due caution and judgment, not only the ranges of values and the average of all values obtained, but also the proportion of tests which came near the average values, have been stated, as well as the average results of the highest and lowest values of 10 per cent of the tests. With this information and a statement of the actual number of tests involved, the comparative merit of the stated values can be judged. With a large number of tests, to be sure, it is more likely that an average value of the species has been found. The actual test results have been rounded off to even hundreds in the tables.

FACTORS OF SAFETY.

With such lowest standard values, also lowest factors of safety could be employed. As to factors of safety, it may be proper to state that the final aims of the present investigations may be summed up in one proposition, namely, to establish rational factors of safety. It will be admitted by all engineers that the factors of safety as used at present can hardly be claimed to be more than guesswork. There is not an engineer who could give account as to the basis upon which numerically the factors of safety for wood have been established as "8 for steady stress; 10 for varying stress; 15 for shocks" (see Merriman's Testbook on the Mechanics of Materials); or as 4 to 5 for "dead" load and 5 to 10 for "live" load (see Rankine's Handbook of Civil Engineering).

The directions for using these indeterminate factors of safety given in the text-books would imply that the student or engineer is, after all, to rely on his judgment as to the modification of the factor, i. e., he is to add to this general guess his own particular guess. The factor of safety is in the main an expression of ignorance or lack of confidence in the reliability of values of strength, upon which the designing proceeds, together with an absence of data upon which to inspect the material. With a larger number of well-conducted tests, coupled with a knowledge of the quantitative as well as qualitative influences of various factors upon strength, and with definite data of inspection which allow ready sorting of material, the factor of safety, as far as it denotes the residuum of ignorance which may be assumed to remain, as to the character and behavior of the material, may be reduced to a minimum, restricting itself mainly to the consideration of the indeterminable variation in the actual and legitimate application of load.

Results of tests in compression endwise on green wood (above 40 per cent moisture, not reduced).

[Pounds per square inch.]

No.	Species.	Number of tests.	Highest single test.	Lowest single test.	Average of all tests.
1	Longleaf pine	86	7,300	2,800	4,300
2	Cuban pine	38	6,100	3,500	4,800
3	Shortleaf pine	8	4,000	3,000	3,300
4	Loblolly pine	69	5,500	2,600	4,100
7	Spruce pine	71	4,700	2,800	3,900
8	Bald cypress	280	8,200	1,800	4,200
9	White cedar	34	3,400	2,300	2,900
11	White oak	25	7,000	3,200	5,300
12	Overcup oak	45	4,900	2,800	3,800
14	Cow oak	58	4,900	2,300	3,800
16	Texan oak	39	6,000	3,100	5,200
19	Willow oak	49	5,500	2,300	3,800
20	Spanish oak	52	5,100	2,500	3,900
21	Shagbark hickory	22	6,900	3,500	5,700
22	Mockernut hickory	18	7,200	4,500	6,100
23	Water hickory	4	5,600	4,700	5,200
25	Nutmeg hickory	26	5,500	3,700	4,500
26	Pecan hickory	4	3,800	3,300	3,600
27	Pignut hickory	5	6,200	4,700	5,400
32	Sweet gum	6	3,600	3,000	3,300

While the values given in these tables may claim to contain more elements of reliability than most of those published hitherto, much more work will have to be done before the above-stated aim will be satisfied.

In explanation of the table recording tests in bending at relative elastic limits it should be stated that since an elastic limit in the sense in which the term is used for metals, namely, as a point at which distortion becomes disproportionate to load and a permanent injury and set results, can not be readily determined for wood, Prof. J. B. Johnson has proposed to utilize a point where the rate of distortion becomes 50 per cent greater for the amount of load than it was for the initial load, which point can be tolerably accurately determined (see Bull. 8, p. 9). This point he has called the "relative elastic limit." The assumption is that such a point would be near the limit to which the material can be strained without permanent injury, and the strength values obtained at that point would serve for indications of safe loads.

The practical utility of determining this point and the strength values relating to it remains, however, still open for discussion. A comparison of the values obtained for the strength at rupture and at relative elastic limit shows a parallelism which would make it questionable whether much is gained by the use of that point, which in reality lies beyond the limit where practical injury has begun, as indicated by the increased distortion.

We would be inclined to consider that point more serviceable where the curve begins to deviate from the straight line, at which point we may assume no permanent injury has as yet been experienced. This point we may call provisionally the "safe limit."

Objection has been made to utilizing this point because it can not be located with as much nicety and mathematical precision as the point of "relative elastic limit." But even this point is only approximately definable; and since no strength values can claim to be more than approximately correct, it would suffice to determine the safe-limit point and the correspondent strength values also only approximately. This point has the advantage that it lies on the safe side.

Special series of tests to investigate the legitimacy of the use of any of these limits for practical purposes were designed, but have as yet not been taken up, and hence the values in the table on p. 367 are given only as suggestions for what they are worth.

Results of tests in bending, at rupture.

[Pounds per square inch.]

No.	Species.	Number of tests.	Highest single test.	Lowest single test.	Average highest 10 per cent of tests.	Average lowest 10 per cent of tests.	Average of all tests.	Proportion of tests within 10 per cent of average.	Proportion of tests within 25 per cent of average.
	Reduced to 15 per cent moisture.							*Per cent.*	*Per cent.*
1	Longleaf pine	1,160	17,800	3,300	14,200	8,800	10,900	41	84
2	Cuban pine	390	17,000	2,900	14,600	8,800	11,900	46	83
3	Shortleaf pine	330	15,300	5,000	12,400	7,000	9,200	40	79
4	Loblolly pine	650	14,800	3,900	13,100	8,100	10,100	44	84
	Reduced to 12 per cent moisture.								
5	White pine	120	11,100	4,600	10,100	5,000	7,900	43	81
6	Red pine	95	12,900	3,100	12,300	4,900	9,100	28	60
7	Spruce pine	170	16,300	3,100	13,600	5,800	10,000	43	81
8	Bald cypress	655	14,800	2,300	11,700	5,000	7,900	25	69
9	White cedar	87	9,100	3,500	8,400	4,000	6,300	32	78
10	Douglas spruce *a*	41	13,000	3,800	12,000	4,100	7,900	22	58
11	White oak	218	20,300	5,700	18,500	7,600	13,100	39	75
12	Overcup oak	216	19,600	4,900	14,900	6,300	11,300	47	81
13	Post oak	49	16,400	5,100	15,300	7,400	12,300	47	92
14	Cow oak	256	23,000	3,300	12,500	6,500	11,500	32	68
15	Red oak	57	16,500	5,700	15,400	9,100	11,400	46	84
16	Texan oak	117	19,500	8,200	16,900	10,000	13,100	64	86
17	Yellow oak	40	15,000	5,100	14,600	5,700	10,800	28	65
18	Water oak	31	16,000	5,800	15,700	7,200	12,400	40	76
19	Willow oak	153	16,000	3,200	13,800	5,400	10,400	33	70
20	Spanish oak	257	17,300	5,000	15,600	6,900	12,000	40	72
21	Shagbark hickory	187	23,300	5,700	20,300	9,400	16,000	46	84
22	Mockernut hickory	75	20,700	5,300	19,700	7,900	15,200	45	78
23	Water hickory	14	18,000	5,300	17,300	5,400	12,500	21	64
24	Bitternut hickory	25	19,500	7,000	19,300	8,700	15,000	28	60
25	Nutmeg hickory	72	16,600	6,700	15,600	8,100	12,500	40	88
26	Pecan hickory	37	18,300	5,600	18,100	10,300	15,300	38	95
27	Pignut hickory	30	25,000	11,100	24,300	11,500	18,700	43	77
28	White elm	18	14,000	7,300	13,600	7,300	10,300	44	72
29	Cedar elm	44	19,200	6,600	17,300	8,500	13,500	50	86
30	White ash	87	15,000	5,000	14,200	6,300	10,800	37	77
31	Green ash	10	16,000	5,100	16,000	5,100	11,600	20	60
32	Sweet gum	118	14,400	5,100	12,700	6,000	9,500	39	79

a Actual tests on "dry" material not reduced for moisture.

RELATIONS OF WEIGHT AND STRENGTH.

That within the same species the strength of wood varied with the dry weight (specific gravity), i. e., that the heavier stick is the stronger, has been known for some time. That this law of variation held good not only for a given species, but irrespective of species for the four principal pines of our Southern States was indicated in Circular 12 of this Division. This fact becomes the more important in practical application, as the wood of these species of pines so far can not be distinguished at all by its anatomical structure and only with difficulty and uncertainty by other appearances, while in the lumber market substitution is not infrequent. It will therefore be best with these pines, where strength alone is desired, to inspect the material by weight (specific), other things being equal, disregarding species determination.

While this result of the exhaustive series of tests reasonably well demonstrated for these pines may be considered of great practical value, we can now extend the application of the law of relation between weight and strength a step farther, and state as an indication of our tests that probably in woods of uniform structure strength increases with specific weight, independently of species and genus distinction, i. e., other things being equal, the heavier wood is the stronger. We are at present inclined to state this important result with caution, only as a probability or indication, until either the test material and tests can be more closely scanned, or more carefully planned and minutely executed series of detail tests can be carried on to confirm the truth of what the wholesale tests seem to have developed.

In the following two diagrams the average strength of the different species in compression endwise and bending, as found in the preceding tables, has been plotted with reference to the dry weight as given in preceding table.

Considering that these tests and weight determinations (especially the latter) were not carried on with that finesse which would be required for a scientific demonstration of a natural law, that other influences, as crossgrain, unknown defects, and moisture conditions may cloud the results, and that in the averaging of results undue consideration may have been given to weaker or stronger, heavier or lighter, material, the relaxation is exhibited even by this wholesale method with a remarkable degree of uniformity bordering on demonstration.

An exception is apparent in the oaks in that they do not exhibit this relation of weight and strength with reference to other species, and also with less definiteness among the various species of oak in themselves. The structure of oak wood being exceedingly complicated and essentially different from that of the wood of all other species under consideration, it may reasonably be expected that it will not range itself with these.

Results of tests in bending, at relative elastic limit.

[Pounds per square inch.]

No	Species.	Number of tests.	Highest single test.	Lowest single test.	Average of highest 10 per cent of tests.	Average of lowest 10 per cent of tests.	Average of all tests.	Proportion of tests within 10 per cent of average.	Proportion of tests within 25 per cent of average.	Modulus of elasticity (average of all tests).
	Reduced to 15 per cent moisture.							*Per cent.*	*Per cent.*	
1	Longleaf pine	1,160	13,500	2,400	11,100	5,400	8,500	43	81	1,890,000
2	Cuban pine	390	12,900	2,200	11,500	5,600	9,500	42	83	2,300,000
3	Shortleaf pine	330	11,900	2,900	9,700	4,800	7,200	48	81	1,600,000
4	Loblolly pine	650	12,700	3,100	10,800	5,400	8,200	46	85	1,950,000
	Reduced to 12 per cent moisture.									
5	White pine	130	10,000	4,100	8,200	4,500	6,400	58	85	1,390,000
6	Red pine	95	11,300	3,100	10,300	4,500	7,700	38	73	1,620,000
7	Spruce pine	170	13,700	3,000	11,200	5,000	8,400	51	82	1,640,000
8	Bald cypress	655	12,000	2,200	9,900	4,200	6,600	25	66	1,290,000
9	White cedar	87	8,200	3.400	7,390	4,000	5,800	44	86	910,000
10	Douglas spruce *a*	41	13,700	2,800	9,600	3,400	6,400	32	56	1,680,000
11	White oak	218	15,700	4,400	14,100	6,100	9,600	37	73	2,090,000
12	Overcup oak	216	11,600	4,000	9,500	5,400	7,500	47	91	1,620,000
13	Post oak	49	10,600	5,100	9,600	6,000	8,400	34	76	2,030,000
14	Cow oak	256	14,200	3,400	11,600	5,000	7,600	50	95	1,610,000
15	Red oak	57	14,500	5,100	13,600	5,600	9,200	15	49	1,970,000
16	Texan oak	117	12,000	5,900	11,400	7,800	9,400	62	94	1,860,000
17	Yellow oak	40	11,800	4,900	11,100	5,100	8,100	35	75	1,740,000
18	Water oak	31	11,800	4,500	11,400	5,500	8,800	40	84	2,000,000
19	Willow oak	153	13,100	2,700	10,000	4,300	7,400	42	81	1,750,000
20	Spanish oak	257	13,500	5,100	11,600	6,600	8,600	41	80	1,930,000
21	Shagbark hickory	187	16,100	5,400	14,200	7,700	11,200	50	89	2,390,000
22	Mockernut hickory	75	15,400	4,300	14,600	7,800	11,700	39	83	2,320,000
23	Water hickory	14	11,900	4,100	11,800	4,800	9,800	21	86	2,080,000
24	Bitternut hickory	25	14,300	7,500	14,000	7,600	11,100	44	84	2,280,000
25	Nutmeg hickory	72	12,200	4,200	11,200	6,400	9,300	46	93	1,940,000
26	Pecan hickory	37	15,000	5,800	14,400	7,900	11,500	65	89	2,530,900
27	Pignut hickory	30	17,500	7,400	16,400	8,300	12,600	40	83	2,730,000
28	White elm	18	9,700	5,300	9,600	5,400	7,300	33	71	1,540,000
29	Cedar elm	44	10,700	4,700	10,100	5,800	8,000	57	91	1,700,000
30	White ash	87	14,500	3,600	10,400	5,200	7,900	43	83	1,640,000
31	Green ash	10	13,200	3,200	13,200	3,200	8,900	40	70	2,050,000
32	Sweet gum	118	11,000	3,500	10,100	5,100	7,800	46	82	1,700,000

a Actual tests on "dry" material not reduced for moisture.

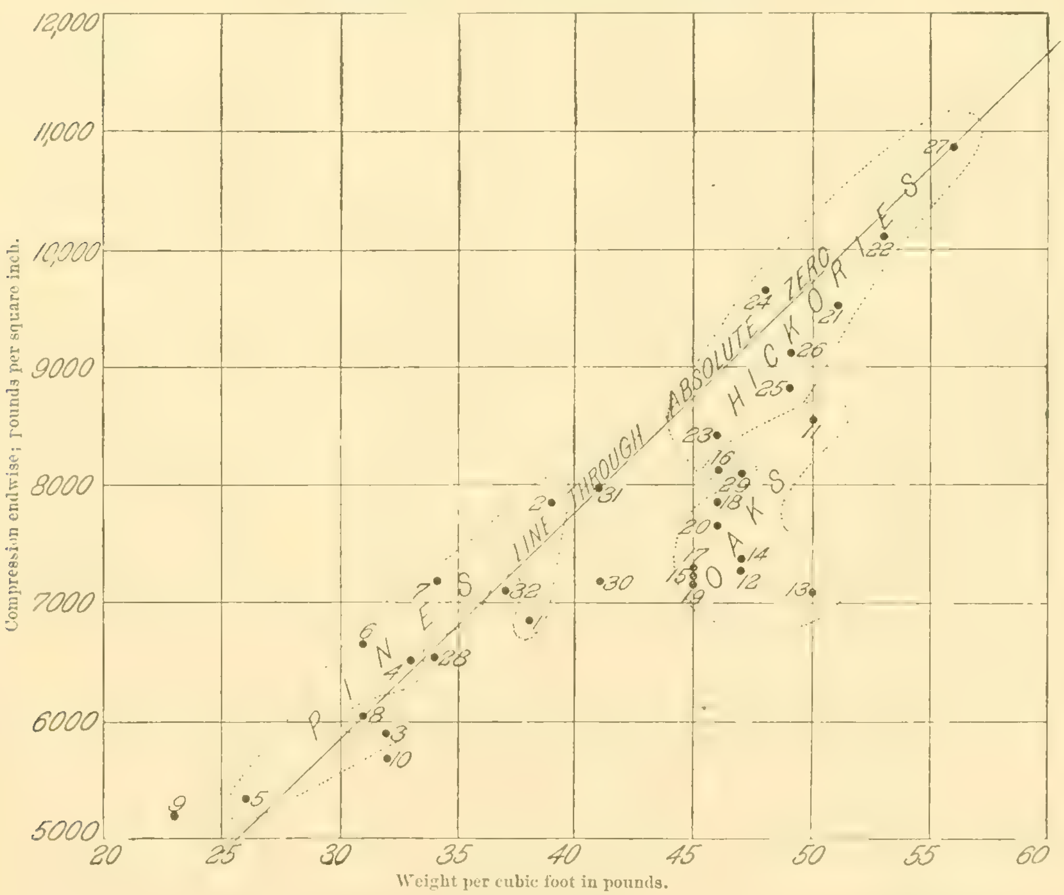


FIG. 95.—Relation of strength in compression endwise to weight of material. The figure at each point indicates the species thereby represented.

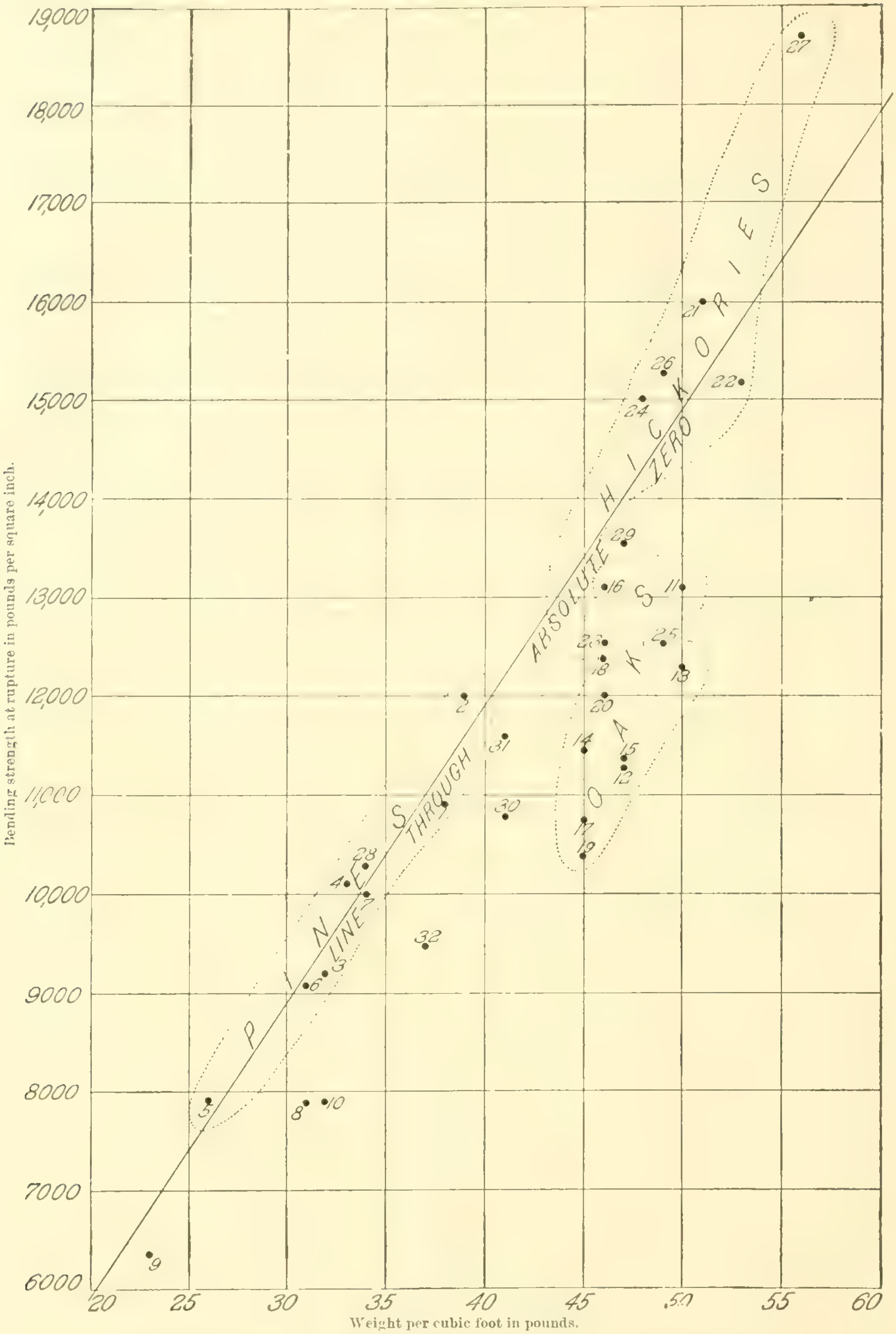


FIG. 96.—Relation of weight to bending strength at rupture. The figure at each point indicates the species thereby represented.

In addition, the difficulty of seasoning oak without defects or even securing perfect material may have influenced the results of tests so as to cloud the relationship with the genus.

If further close study, supplemented by additional series of tests carefully devised to investigate this relationship, should uphold the truth of it, this result may be set down as the most important practical one that could be reached by these tests, for it would at once give into the hands of the wood consumer a means of determining the relative value of his material as to strength and all allied properties by a simple process of weighing the dry material; of course with due regard to the other disturbing factors like crossgrain, defects, coarseness of grain, etc.

Results of tests in compression across grain (a) and shearing with grain.

[Pounds per square inch.]

No.	Species.	Number of tests.	Compression across grain.	Shearing with grain not reduced for moisture.	No.	Species.	Number of tests.	Compression across grain.	Shearing with grain not reduced for moisture.
	Reduced to 15 per cent moisture.					*Reduced to 12 per cent moisture—Continued.*			
1	Longleaf pine	1,210	1,000	700					
2	Cuban pine	400	1,000	700	16	Southern red oak	117	2,000	900
3	Shortleaf pine	330	900	700	17	Black oak	40	1,800	1,100
4	Loblolly pine	690	1,000	700	18	Water oak	30	2,000	1,100
					19	Willow oak	153	1,600	900
	Reduced to 12 per cent moisture.				20	Spanish oak	255	1,800	900
					21	Shagback hickory	135	2,700	1,100
5	White pine	130	700	400	22	White hickory	75	3,100	1,100
6	Red pine	100	1,000	500	23	Water hickory	14	2,400	1,000
7	Spruce pine	175	1,200	800	24	Bitternut hickory	25	2,200	1,000
8	Bald cypress	650	800	500	25	Nutmeg hickory	72	2,700	1,100
9	White cedar	87	700	400	26	Pecan hickory	37	2,800	1,200
10	Douglas spruce *b*	41	800	500	27	Pignut hickory	30	3,200	1,200
11	White oak	218	2,200	1,000	28	White elm	18	1,200	800
12	Overcup oak	216	1,900	1,000	29	Cedar elm	44	2,100	1,300
13	Post oak	49	3,000	1,100	30	White ash	87	1,900	1,100
14	Cow oak	256	1,900	900	31	Green ash	10	1,700	1,000
15	Red oak	57	2,300	1,100	32	Sweet gum	118	1,400	800

a To an indentation of 3 per cent of the height of the specimen.

b Actual tests on "dry" material not reduced for moisture.

Having fully established the great influence of moisture on the strength of wood, the practitioner still needed information as to the rate and manner of drying and as to the way in which moisture is distributed during seasoning. Several thousand moisture determinations were made and it was established beyond doubt that moisture is generally least abundant at the ends, is quite evenly distributed throughout the length, but is not always uniform in different parts of the same cross section, often varying in this respect within astonishing ranges, so that the use of timber in a half-seasoned condition, and where uniform seasoning can not be obtained by the material, requires that these facts be duly considered in designing.

Tests of Maximum Uniformity.

Both in this country and abroad small differences in strength values were often interpreted as deciding for or against any given material. This same problem arose also in every case where many results were to be compiled, and it seemed especially desirable once for all to find just how much uniformity could be expected of wood materials. From a large series of well-selected quarter-sawed pieces representing several kinds of pine, cypress, and hardwoods it was found that even contiguous blocks, 2½ inches long, may differ by as much as 2 to 4 per cent in conifers and as much as 13 per cent in oak, and that in a scantling only 6 feet long the butt might differ from the top by 10 to 20 per cent in conifers and over 35 per cent in oak. This extremely valuable set of results throws much light upon discussions of the past, and is well suited to show that many boastful claims rested on very flimsy and entirely unreliable differences, such as might well be accounted for by a little more extended examination of materials. It will also assist in judging test results in the future and help to avoid useless controversy and prejudice. The following more fully illustrates the results of this series:

Scantlings of air-dry material, 6 to 10 feet long, of white pine, longleaf pine, tuliptree (poplar), and white oak, and of perfectly green material of loblolly pine and cypress, fresh from the saw, were cut partly into blocks 2 by 2 by 2¾ inches, but mostly into cubes of 2¾ inches. All material was quarter sawed, carefully prepared, and in all cases treated alike, either perfectly green or dried together at the same temperature. Altogether 529 tests in endwise compression were made, namely, 100 on white pine, 72 on longleaf pine, 99 on loblolly pine, 40 on white oak, 115 on tuliptree (poplar), 103 on cypress.

From these tests the following table of averages is derived, together with fig. 97:

Average of tests for maximum uniformity.

Name.	Moisture.	Average strength of all pieces.	Greatest difference in strength between adjoining pieces.		Greatest difference in entire scantling, i. e., 6-10 foot piece.
	Per cent.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Per cent.*	*Per cent.*
White pine (Pinus strobus)	8	4,900	190	3.8	18
Longleaf pine (Pinus palustris)	7.8	10,800	380	3.5	10
Tuliptree (poplar) (Liriodendron tulipifera)	8	6,010	480	8.3	20
White oak (Quercus alba)	Yard dry.	8,300	1,110	13.4	37
Loblolly pine (Pinus tæda)	125 + (green).	2,670	130	4.8	20
Cypress (Taxodium distichum)	125 + (green).	4,090	70	1.8	15

It will be observed that green cypress excelled in its uniformity; that green loblolly proves not more uniform than dry white and longleaf pine; that wood of the conifers far excel even the tuliptree (poplar) with its uniform grain and texture; and that oak, as might be expected, is the least uniform. It will also be noticed that even in one and the same short scantling (6 to 10 feet) of select quarter-sawed longleaf pine differences of 10 per cent may occur, and that in all others these differences were even greater.

Incidentally in this and the following experiment a small number of the blocks were thoroughly oven-dried (to about 2 per cent moisture), and it was found that the strength of both cypress and loblolly was increased by about 150 per cent during drying, so that wood at 2 per cent is about two and one-half times as strong as perfectly green or soaked material; and also that drying from 8 to 10 per cent to the lowest attainable moisture condition (1 to 2 per cent) still adds about 25 per cent to the strength of the wood.

In the following diagram and table a part of the results are presented in detail:

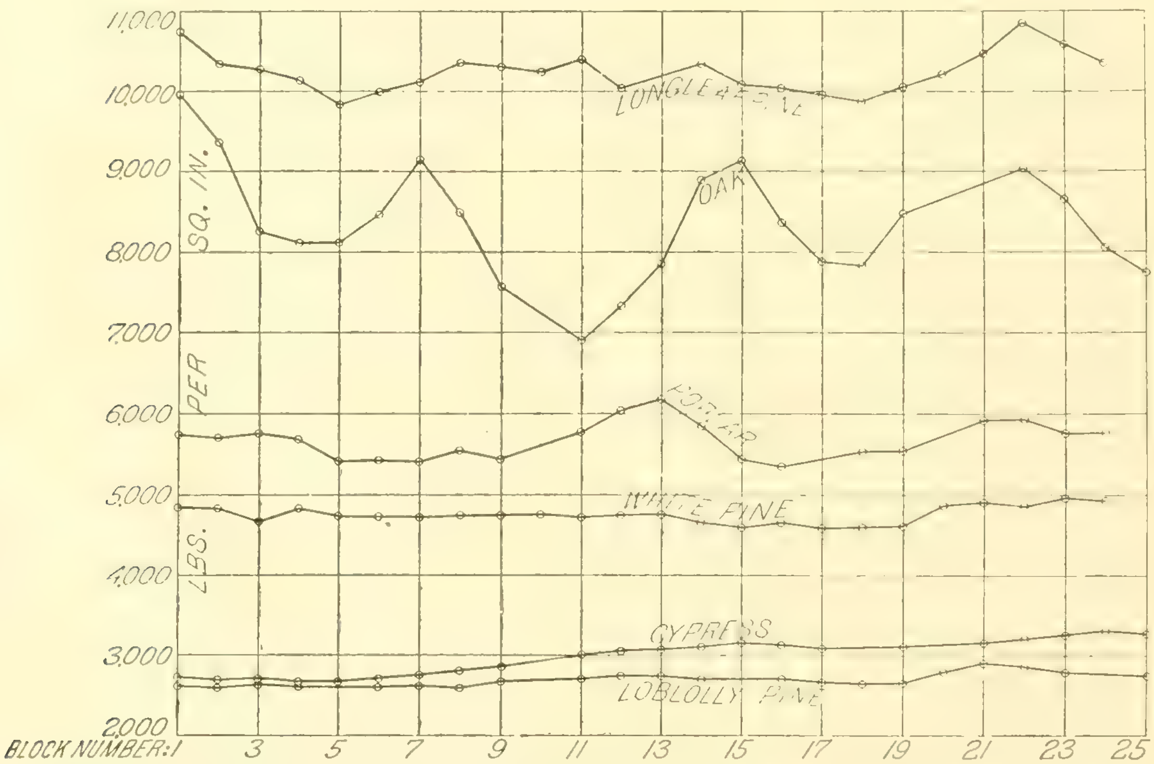


FIG. 97.—Strength of contiguous blocks, showing maximum uniformity of select quarter-sawed material in compression endwise.

Strength of contiguous blocks of the same scantling, select material, in compression endwise.

[Dimensions generally, 2.76 by 2.76 by 2.76 inches.]

Number of blocks.	Kind of wood. White pine (8 per cent moisture).	Longleaf pine (8 per cent moisture).	Loblolly pine (125+ per cent moisture).	Cypress (125+per cent moisture).		Tulip-tree (8 per cent moisture).	Oak (air dry).
	Pounds per square inch.						
1	4,850	11,580	[illegible]	2,720	4,170	5,740	9,970
2	4,860	11,530	[illegible]	2,700	4,190	5,700	9,370
3	4,690	11,310	[illegible]	2,720	4,170	5,770	8,260
4	4,840	11,060	2,450	2,680	4,180	5,700	8,120
5	4,760	8,250	a 5,700	2,680	4,200	5,430	8,12[illegible]
6	4,720	10,740	2,600	2,720	4,180	5,430	8,[illegible]
7	4,730	11,180	2,680	2,770	4,230	5,420	9,15[illegible]
8	4,760	11,220	2,640	2,820	....	5,560	[illegible]
9	4,750	10,980	2,720	2,870	....	5,440	7,[illegible]
10	4,770	11,130	a 6,970	....	....	a 7,070	....
11	4,730	11,510	2,770	3,020	4,230	5,770	6,9[illegible]
12	4,760	11,490	2,730	3,070	4,180	6,030	7,3[illegible]
13	4,770	11,320	2,780	3,099	4,130	6,170	7,870
14	4,670	11,220	2,800	3,120	4,160	5,840	8,90[illegible]
15	4,600	11,320	a 5,840	3,170	4,160	5,440	9,[illegible]
16	4,660	11,340	2,880	3,140	4,160	5,360	8,[illegible]
17	4,590	11,470	2,870	3,090	4,110	....	7,[illegible]
18	4,600	10,790	2,870	....	4,090	5,530	7,840
19	4,610	10,740	2,860	3,120	4,070	5,530	8,480
20	4,880	11,030	a 6,480	....	....	a 6,880	....
21	4,920	11,110	2,760	3,170	....	5,920	....
22	4,870	11,450	2,760	3,220	....	5,930	9,030
23	4,970	12,250	2,720	3,270	....	5,770	8,660
24	4,910	12,760	2,640	3,320	....	5,780	8,060
25	....	10,740	a 7,050	3,270	....	6,120	7,740
26	5,070	10,350	2,680	....	....	6,480	7,580
27	4,940	10,280	2,650	3,320	....	6,310	8,100
28	5,020	10,150	2,650	3,370	....	6,220	8,710
29	5,110	9,860	2,780	3,420	....	6,310	8,[illegible]
30	5,020	10,000	a 7,320	....	....	a 7,420	....
31	4,950	10,120	2,730	3,490	....	6,340	7,2[illegible]
32	4,820	10,370	2,780	3,520	....	6,360	7,510
33	4,950	10,320	2,720	3,570	....	6,040	7,510
34	4,900	10,250	2,660	3,620	....	....	8,080
35	5,040	10,400	a 5,360	3,640	....	6,2[illegible]	9,030
36	5,160	10,050	2,610	....	....	6,490	8,790
37	5,120	10,050	2,560	....	....	6,610	8,640
38	5,100	10,350	2,580	....	....	6,220	8,7[illegible]
39	5,230	10,100	2,580	....	....	6,19[illegible]	8,78[illegible]
40	5,280	10,030	a 5,220	....	....	a 7,300	....
41	5,260	9,970	2,620	....	....	6,010	....
42	5,280	9,880	2,600	....	....	6,1[illegible]	....
43	5,300	10,050	2,640	....	....	6,170	....
44	5,310	10,220	2,610	....	....	6,010	....
45	5,300	10,470	a 6,440	....	....	6,49[illegible]	....
46	5,350	10,860	2,6[illegible]	....	....	[illegible]	....
47	5,400	10,590	2,620	....	....	6,[illegible]	....
48	5,360	10,350	2,600	....	....	[illegible],860	....
49	5,560	11,150	2,680	....	....	6,110	....
50	5,510	10,970	a 6,440	....	....	a 7,920	....
51	5,070	10,890	2,710	....	....	6,210	....
52	5,150	10,790	2,750	....	....	6,27[illegible]	....
53	5,020	10,970	2,760	....	....	6,[illegible]	....
54	4,770	11,040	2,720	....	....	6,420	....
55	4,770	10,940	a 6,850	....	....	6,4[illegible]	....
56	4,920	10,970	2,710	....	....	6,170	....
57	4,950	10,840	2,680	....	....	6,440	....
58	4,840	10,710	2,660	....	....	6,[illegible]	....
59	4,860	10,890	2,660	....	....	6,310	....
60	a 6,460	10,710	a 7,030	....	....	a 7,540	....

a Dried to about 2 per cent moisture before testing.

As was indicated at the outset and is fully explained in Bulletins 6 and 8, the plan of this investigation also included among the objects to be sought the establishment of the following:

(1) The relative value of each species.

(2) The outward signs or physical and structural properties, easily used in inspection.

(3) The relation of the properties among themselves; and

(4) Their relation to the conditions under which the wood is formed, such, for instance, as the age of the tree when wood is laid on, influences of soil, climate, etc.

As has been explained, some of these relations were more or less fully determined, at least, qualitatively; nevertheless, the relation of the several forms of resistance, as well as the mutual relations of the properties in general, seemed to escape observation in the manner of inquiry generally pursued. It became clear before long that these laws must be established by special series, planned each to seek answer to some specific question. Several of these were carried out, and, though little more was accomplished than to find proper ways, the study of these results, amplified by the large ordinary series, led to several interesting discoveries, the most important of which is the discovery of the relation between the strength in cross bending at elastic limit and the compression endwise, this latter being equal to the fiber stress of the former. Though still requiring special experiments to become convincing, it is fair to state at this point that a great deal of useless testing will be saved in the future, since the test in compression is by all means the simplest, the selection and treatment of the material for it the easiest, and the result the most satisfactory. The importance of this discovery by Mr. S. T. Neely is such that a reprint of Mr. Neely's discussion here will be found justified.

Relation of Compression-endwise Strength to Breaking Load of Beam.

In testing timber to obtain its various coefficients of strength, the test which is at once the simplest, most expedient, satisfactory, and reliable is the "compression-endwise test," which is made by crushing a specimen parallel to the fibers. All other tests are either mechanically less easily performed, or else, as in the case of cross-bending, the stresses are complex, and the unit coefficient can be expressed only by reliance upon a theoretical formula, the correctness of which is in doubt. It would, therefore, be of great practical value to find a relation between the cross-bending strength, the most important coefficient for the practitioner, and the compression strength, when the study of wood would not only be greatly simplified and cheapened, but the data could be applied with much greater satisfaction and safety.

The consideration of such a relation resolves itself naturally into two parts, namely, a study of the relation ot the internal stresses in a beam to the external load which produces them, and a study of the relation of the internal stresses in a beam to the compression-endwise strength of the material of which the beam is made.

The first relation has been a subject of study for more than two centuries, and from the time of Galileo down to the present day the theory of beams has been gradually evolved. Within recent years several eminent physicists and engineers have given a true analysis of both the elastic and ultimate strength of a beam, a clear exposition of which is made by Prof. J. B. Johnson in his work on Modern Framed Structures. He points out that the "ordinary equation" for obtaining the extreme fiber stresses, when the external load and dimensions of the beam are given, is not applicable to a beam strained beyond its elastic limit; and he follows this statement with a discussion of the true distribution of internal stresses in a beam at time of rupture, and with a "Rational equation for the moment of resistance at rupture," devised by M. Saint-Venant, which really does connect the extreme fiber stress in a bent beam with the compression-endwise strength and also with the tension strength. Professor Johnson's final conclusion, however, is that for practical use the "ordinary formula" may be applied to a beam at rupture, providing the fiber stress involved is obtained from cross-bending tests; and this is the present practice among engineers.

RELATION OF INTERNAL STRESSES.

Assume for the discussion of the relation of internal stresses to external load the simple conditions of a beam of rectangular cross section loaded at the middle.

Regarding the distribution of internal stresses, it must be agreed that the neutral plane lies in the center of the beam so long as the beam is loaded within the elastic limit; this follows from the fact that the modulus of elasticity is the same whether derived from compression tests or from tension tests (i. e., $E_c = E_t$), as proved by experiments of Nördlinger, Bauschinger, Tetmayer, and others.

Since the distortion of any given fiber in the beam is proportional to its distance from the neutral plane, the distribution of stresses in a longitudinal section of a beam loaded up to its elastic limit may be represented by the following diagram, in which the vertical scale represents increments of distortion and the horizontal scale the fiber stresses.

In this diagram the angle a = angle b, since $E_c = E_t$; and furthermore, since these latter quantities are each equal to the modulus of elasticity obtained from cross-bending tests (according to the same authorities), this angle a (or b) can be obtained by platting the results of the cross-bending test itself.

It is a well-established fact that the tension strength of wood is much greater than the compression strength, and also, as shown by the German experimenters quoted, that the elastic limit in either case is not reached until shortly before the ultimate strength. Furthermore, it seems reasonable to suppose, and is essential to the construction of the above diagram, that the true elastic limit of the beam (shown on the strain diagram of a beam at the point where it ceases to be a straight line) is reached at the same instant that the elastic limit of the extreme compression fiber is reached; for when the loading is continued beyond this latter condition the line OC must begin to curve upward (since the proportion of load to distortion on that side begins to increase more rapidly), while the line OT continues in its original direction. Therefore, in order to maintain the equilibrium, the whole distribution of stresses will necessarily be changed, the position of the neutral axis will be lowered, and these changes will, of course, show an effect on the deflection of the beam.

Now, even at rupture the proportionality of fiber distortion to distance from neutral axis is maintained (because a plane cross section will always remain a plane), and therefore the distribution of internal stresses just at the point of rupture can be represented by a diagram similar to fig. 99, in which, as before, the vertical scale represents increments of distortion and the horizontal scale fiber stresses. The fibers on either side of the neutral plane are under stresses which vary from zero at the neutral plane to the maximum stress in the extreme fiber, changing in proportion as the increments of load in the test machine vary. Therefore, the distribution of stresses on the compression side of the neutral plane will be shown by an ordinary strain diagram for compression, and on the tension side by a similar tension-strain diagram. Unfortunately there are no reliable diagrams of these kinds now on record. The compression pieces tested have usually been too short to afford reliable measurements of distortion, and, owing to structural and mechanical difficulties, satisfactory tension tests seem to be impossible.

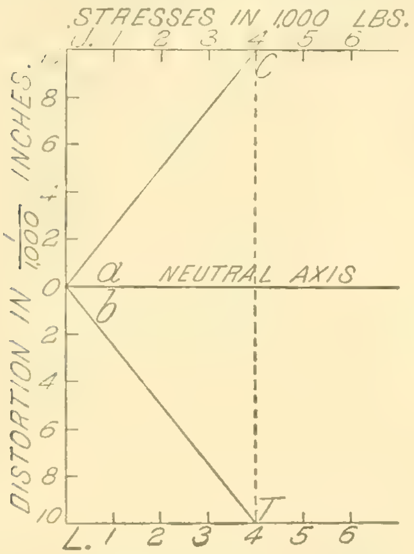


FIG. 98.—Relation of fiber stresses and distortions.

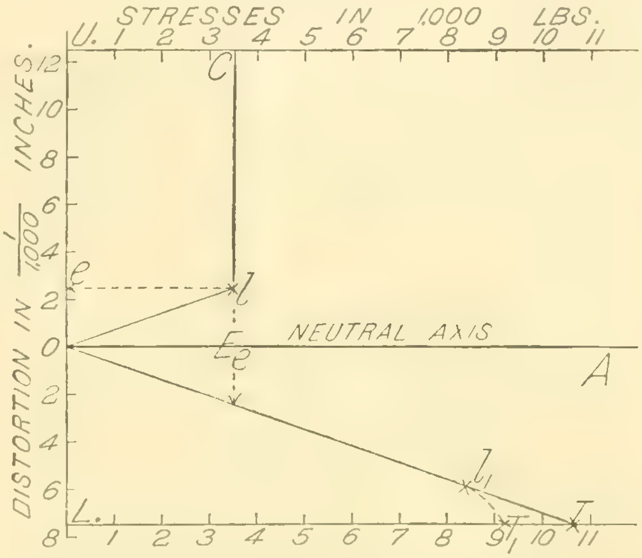


FIG. 99.—Distribution of internal stresses in a beam at rupture.

Experience in testing, however, has taught that when a piece of green wood is tested in compression it will undergo a great distortion after the maximum load has been applied without actually breaking down—in fact, while sustaining the same load. A piece tested in tension, on the other hand, breaks suddenly as soon as the maximum load is applied. A beam in failing may, therefore, sustain an increasing load long after the extreme compression fiber has been loaded to its ultimate strength; the fibers on the compression side continue to be mashed down, while the neutral plane is lowered and the stress in the tension fiber increases until, very often in practice, the beam "fails in tension." With these facts and observations before us it is possible to construct a diagram so that it will represent, approximately, at least, the distribution of internal stresses in a beam at rupture. (See fig. 100.)

In this figure OA represents the position of neutral plane at time of rupture, OU the distortion in the extreme compression fiber, UC the stress on same fiber, OL the distortion in extreme tension fiber, and LT the stress on that fiber.

It can readily be seen that the manner of breaking will influence slightly the form of this diagram. If the beam fails in compression before the tension fiber reaches its elastic limit the line OT will be straight as shown, otherwise the line will assume some such position as Ol_1T_1 (diagram 99), in which l_1 is the elastic limit in tension.

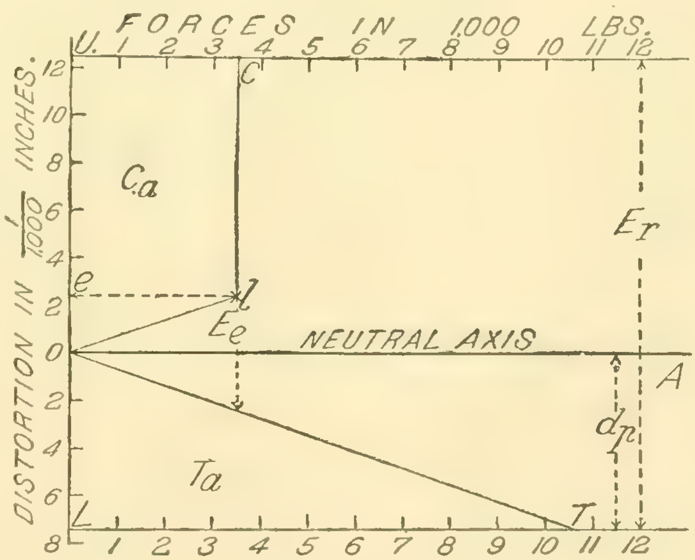


FIG. 100.—Position of neutral axis and internal stresses at rupture of beam.

From the approximate distribution of internal stresses their relation to the external load may be determined. The two fundamental equations—(1) that the sum of internal stresses on the tension side equals the sum of internal stresses on the compression side, and (2) that the sum of the external moments equals the sum of the internal moments—apply at the time of rupture as well as at the elastic limit. From (1) it follows that area OUCl = area OLT, and the position of the neutral plane at rupture is thereby fixed. If now the line LU be assumed to represent the depth of the beam in inches instead of indicating the distortion of the fibers, the sum of the internal moments about the point O is found by multiplying the area of either the compression or tension diagram by the sum of the distances of their respective centers of gravity from the neutral plane. By putting this sum equal to the moment of the external load about the same point O the first relation is established.

RELATION OF CRUSHING-ENDWISE STRENGTH.

The second relation (that of crushing-endwise strength to internal stresses) was touched upon in discussing the first, when it was stated: (1) That the true elastic limit of the beam is probably reached at the same instant that the extreme fibers on the compression side reach their elastic limit in compression. (2) That this latter limit lies close to the ultimate compression-endwise strength (so close that former experimenters have been unable satisfactorily to separate them). (3) That a piece of green wood will stand a great deal of distortion after the ultimate load is applied before actually failing. And to these statements may be added the evident fact (4) that the stress on any fiber on the compression side can not exceed the compression-endwise strength of the material. (5) Finally and most important it appears from (1) and (2), but especially from an examination of the several thousand test results on the several species of conifers made by the Division of Forestry, that the extreme fiber stress at the true elastic limit of a beam is practically identical with the compression-endwise strength of the material. (This last observation, which was forced upon the writer by its continual repetition in the large series of tests under review, lies at the basis of this discussion.) The observation of this identity makes the distribution of internal stresses appear more simple than was hitherto assumed, and the desired relation between compression and cross-bending strength capable of mathematical expression.

DEVELOPMENT OF FORMULÆ.

From these considerations the distance UC in fig. 100, which represents the ultimate compression-endwise strength of the material, becomes practically equal to the distance *el*, which represents the compression strength at the true elastic limit, and hence the line IC straight and vertical; and if OT is taken as straight, the diagram will be made up of simple geometric figures, as in fig. 100.

The line LU will represent the total fiber distortion at time of rupture, and is equal to the sum of the amounts by which the extreme compression fibers shorten and the extreme tension fibers elongate.

Let a test in which the following quantities have been observed and recorded be considered:

Let P_r = the external load at rupture (pounds).
Δ_r = the corresponding deflection of the beam (inches).
C = compression-endwise strength of the material (pounds).
E = modulus of elasticity (pounds).
d = depth of beam (inches).
b = breadth of beam (inches).
l = length of beam (inches).
Δ_e = deflection at true elastic limit.

Then, based upon the above statements, by means of formulas derived from the geometric relations of the diagram and the fundamental equations of equilibrium, the following quantities can be calculated:

Let E_e = total fiber distortion due to bending at true elastic limit (inches).
E_r = total fiber distortion due to bending at rupture = LU (inches).
d_p = distortion in extreme tension fiber at rupture = LO (inches); also the proportional distance of neutral plane from tension side of beam.
d_r = real distance of neutral plane at rupture from tension side of beam (inches).
d_e = real distance of neutral plane at rupture from that fiber on compression side which has just reached the elastic limit, in inches = Oe.
T = stress in extreme tension fiber (pounds).
T_a = sum of forces on tension side = area OLT (pounds).
C_a = sum of forces on compression side = area OUC*l* (pounds).
d_t = distance of center of gravity of tension area from neutral plane (inches).
d_c = distance of center of gravity of compression area from neutral plane (inches).
M_r = sum of the internal moments about the point O (inch-pounds).

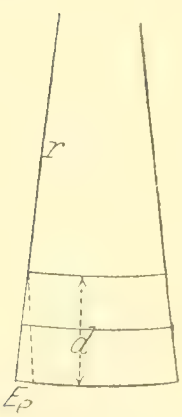


FIG. 101.—Fiber distortion in unit length of beam, at elastic limit.

The formulas connecting these quantities are derived as follows:

To find E_e let fig. 101 represent a portion of the beam one unit in length bent to its elastic limit; then,

$$\frac{E_e}{1} = \frac{d}{r},$$

where r is the radius of curvature, but from fundamental formulas true at elastic limit

$$\frac{1}{r} = \frac{m}{EI} = \frac{Pl}{4EI} = \frac{12\Delta_e}{l^2} \therefore (1)\ E_e = \frac{12\Delta_e d}{l^2}.$$

Since this involves only geometric relations, it is true also at rupture (since the beam preserves its original form).

$$(2)\ E_r = \frac{12\Delta_r d}{l^2}.$$

To find d_p and T:

Since the sum of stresses on the tension side = sum of stresses on compression side,

$$\text{the area OLT} = \text{area OUC}l \therefore \frac{d_p}{2}\text{T} = (E_r - d_p)\,\text{C} - \frac{E_e\text{C}}{4} \text{ and } \text{T} = \frac{d_p\text{C}}{\frac{1}{2}E_e}$$

from the similar triangle OLT and O*el* (fig. 100),

$$\therefore \frac{d_p^2 C}{E_e} = (E_r - d_p)\, C - \frac{E_e}{4} C,$$

whence,

(3) $d_p = \sqrt{E_r \times E_e} - \frac{E_e}{2}$,

and after d_p is found, T can be obtained:

(4) $T = \frac{d_p C}{\frac{1}{2} E_e}$.

Now, when the vertical line LU is assumed to represent the real depth of the beam in inches $= d$, every vertical measure will be changed in the ratio $\frac{d}{E_r}$ (see fig. 102); whence,

(5) $d_r = \frac{d}{E_r} d_p$

(real distance of neutral plane from tension side).

(6) $d_e = \frac{1}{2} \frac{d}{E_r} E_e$

($\frac{1}{2}$ because E_e total distortion, while d_e is the distance on one side of the neutral plane).

The area OLT would then become:

(7) $T_a = \frac{d_r T}{2}$, and the area OUCl =

(8) $C_a = (d - d_r)\, C - (\frac{d_e}{2} \times C)$

(C_a must equal T_a).

The distance of centers of gravity would be:

(9) $d_t = \frac{2}{3} d_r$,

(10) $d_c = \frac{d - d_r}{2} + \frac{d_e}{4}$,

and the sum of internal moments.

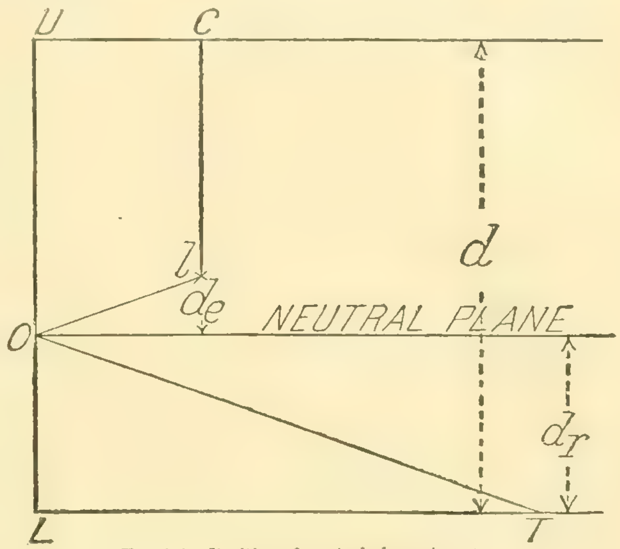


FIG. 102.—Position of neutral plane at rupture.

(11) $M_r = (C_a d_c + T_a d_t) b$, and since $C_a = T_a$, hence $M_r = C_a (d_c + d_t) b$.

But since the sum of internal moments equals the sum of external moments:

$$\frac{P_r l}{4} = M_r = C_a (d_c + d_t) b.$$

And since P_r is the breaking load of the beam, and C_a involves only the compression endwise strength and lineal dimensions, we have a formula directly connecting the breaking load of a beam with the compression strength.[1]

Application of these formulæ.—Unfortunately no tests have been made to study the application of these formulæ directly and in particular. The tests on beams published in this circular were made for a different purpose. For the purpose of ascertaining the correctness of the formulæ only the tests made on large beams have been utilized, since in these the deflections were specially accurately measured. In addition to the quantities to be calculated already given in this discussion, the fiber stress at the true elastic limit is also calculated, and called S_e, to be compared with C, and the load producing it, P_e, is also set down as an observed quantity. If the modulus of rupture, R, has already been calculated by the "ordinary formula," S_e can be obtained from the relation $\frac{S_e}{R} = \frac{P_e}{P_r}$ and

(12) $S_e = \frac{P_e}{P_r} R$.

The modulus of elasticity at true elastic limit E_e is recomputed as a check, and of course is:

$$(13)\ E_e = \frac{S_e}{\frac{1}{2} E_e}.$$

Since P_e is an arbitrary quantity within certain limits, and can not be determined with any degree of accuracy, S_e will be found to differ more or less from C. For these reasons, however, C is a more reliable value for the true elastic limit than S_e itself, and in the formulæ is used as such; for instance, E_e is the fiber distortion produced by the same load which produces a fiber stress = C, not by the load which produces S_e.

The following table exhibits the results of applying the formulæ to the data from these tests:

[[1] The factors $d_c + d_t$, within such limits as the cross-bending strength is constant, are constants; they will have to be ascertained by actual experiment for each species and quality, and might then be expressed as a proportion of the depth. In the material used, pine as well as oak, it appears to be about 3/5. The material on which this relationship has been mainly studied was green wood, and it may be questioned whether the factors d_c and d_t would remain the same in material of all moisture conditions. There is no logic which would lead us to expect a difference greater than the limits of "maximum uniformity," i. e., 10 per cent. A few comparisons of data obtained from material of other species with varying moisture percentage indicate that a difference does not exist.—B. E. F.]

Relation of results observed and calculated by usual methods and results calculated by Neely's formulæ.

Kind of wood.	Original number of beam.	Data observed and calculated by usual methods. Compression endwise strength.	Bending strength.	Load at rupture.	Modulus of elasticity.	Deflection at rupture.	Dimensions of beams. Length.	Depth.	Breadth.	Load at true elastic limit.	Deflection at true elastic limit.	Actual sum of external moments about point O at rupture.	Results calculated by Neely's formulæ. Sum of internal moments about point O at rupture.	Bending strength at true elastic limit.	Total fiber distortion due to bending. At elastic limit.	At rupture.	Modulus of elasticity at true elastic limit.	Distortion in extreme tension fiber at rupture.	Real distance of neutral plane at rupture. From tension side of beam.	From that fiber on compression side which has just reached elastic limit.	Stress at rupture of extreme tension fiber.	Sum of forces for unit width of beam. On tension side.	On compression side.	Distance from neutral plane of center of gravity. Of tension area.	Of compression area.
		C	R	P_r	E	Δ_r	l	d	b	P_e	Δ_e	$\frac{P_r l}{4}$	M_r	S_e	E_o	E_t	E_e	d_p	d_r	d_e	T	T_a	C_a	d_t	d_c
		Lbs. per sq. in.	Lbs. per sq. in.	Lbs.	1,000 lbs.	Inches.	Inches.	Inches.	Inches.	Lbs.	Inch.	Inch pds. 1,000.	Inch pds. 1,000.	Lbs.	Inches.	Inches.	1,000 lbs.	Inches.	Inches.	Inches.	Lbs. per sq. in.	Lbs.	Lbs.	Inches.	Inches.
Shortleaf pine	12	[illegible]	7,560	28,000	**1,711**	3.10	192.0	11.87	7.87	13,000	1.02	**1,344**	**1,334**	*3,420*	0.0039	0.0120	**1,752**	0.0049	4.85	3.86	9,700	23,400	23,300	3.23	3.99
Do	28	[illegible]	6,670	23,500	**1,483**	6.24	216.0	11.9	8.2	13,500	1.80	**1,269**	**1,350**	*3,780*	0.0055	0.019	**1,373**	0.0075	4.70	3.44	9,810	25,053	22,760	3.13	4.03
Do	9	[illegible]	8,300	32,800	**1,630**	6.16	192.0	12.0	8.0	19,000	1.50	**1,574**	**1,541**	*4,800*	0.0059	0.0240	**1,630**	0.0089	4.45	1.47	12,200	27,100	27,400	2.97	4.14
Do	10	[illegible]	7,440	29,400	**1,340**	4.31	192.0	12.0	8.0	17,000	1.39	**1,411**	**1,392**	*4,200*	0.0054	0.0168	**1,400**	0.0068	4.86	1.93	9,800	24,000	24,000	3.24	4.05
Do	13	[illegible]	7,320	29,800	**1,540**	4.06	192.0	12.1	8.1	17,000	1.36	**1,430**	**1,460**	*4,180*	0.0053	0.0158	**1,570**	0.065	5.00	2.01	9,920	24,800	25,010	3.33	4.03
Do	29	[illegible]	7,410	24,500	**1,703**	4.86	216.0	11.75	7.9	16,000	1.92	**1,323**	**1,410**	*4,800*	0.0058	0.0150	**1,703**	0.0064	5.01	2.27	9,820	24,600	24,900	3.34	3.94
Do	33	[illegible]	7,470	26,400	**2,017**	3.36	216.0	12.06	8.0	16,000	1.48	**1,425**	**1,394**	*4,520*	0.0046	0.0104	**2,000**	0.0047	5.45	2.84	8,350	22,700	22,600	3.63	[illegible]
Do	[illegible]	[illegible]	7,710	27,240	**1,718**	5.57	216.0	12.0	7.95	16,000	1.77	**1,470**	**1,571**	*4,530*	0.0055	0.0172	**1,670**	0.0069	4.90	1.92	11,300	27,600	27,600	3.26	4.03
Longleaf pine	43	[illegible]	8,850	33,550	**1,715**	4.90	216.0	12.3	8.1	20,000	1.97	**1,811**	**1,887**	[illegible]	0.0062	0.0155	**1,718**	0.0067	5.32	2.46	11,500	30,500	30,500	3.54	4.10
White pine	51	[illegible]	5,300	18,700	**1,320**	3.75	216.0	12.1	7.95	12,000	1.69	**1,009**	**1,085**	*3,400*	0.050	0.0116	**1,340**	0.0051	5.30	2.40	6,780	18,000	18,000	3.53	4.05
Red oak	3	[illegible]	6,570	25,800	**1,646**	7.94	192.0	12.0	8.0	9,000	1.50	**1,238**	**1,255**	*2,300*	0.0059	0.9310	**1,642**	0.0106	4.10	1.14	11,000	22,500	22,200	2.73	4.23
Do	4	[illegible]	8,640	31,500	**1,825**	5.93	216.0	12.25	8.0	20,000	1.90	**1,701**	**1,675**	*5,480*	0.0060	0.0187	**1,828**	0.0076	4.98	1.96	11,330	28,100	28,100	3.32	4.13
Do	8	[illegible]	6,870	26,000	**1,485**	6.70	216.0	12.25	8.37	14,000	1.71	**1,404**	**1,437**	*5,700*	0.0050	0.0200	**1,480**	0.0075	4.60	1.73	10,400	23,900	23,600	3.07	4.21

NOTE.—Columns of figures in same distinctive type to be compared one with the other.

In order to see how far the formulæ may be applicable to beams of the same material the data obtained on the small beams cut from one of the large beams were subjected to scrutiny, basing the calculations on the data from the adjoining compression block. The calculated result compared with the actual breaking load showed a most convincing similarity, as will be apparent from the table herewith presented:

Strength of small beams, calculated by Neely's formulæ from compression strength, on the assumption that the relative position of the neutral plane at rupture is the same as found in large beams.

[Shortleaf pine, large beam No. 13, special series.]

Number of beam.	Data observed in testing. Dimensions of beams. Length.	Depth.	Breadth.	Bending strength as calculated by ordinary formula.	Compression endwise.	Observed load at rupture.	Results calculated by Neely's formulæ. Load at rupture, as calculated by Neely's formula, from compression strength.	Bending strength at true elastic limit.	Real distance of neutral plane at rupture. From tension side of beam.	From that fiber on compression side which has just reached elastic limit.	Stress at rupture of extreme tension fiber.	Sums of forces for unit width of beam. On tension side.	On compression side.	Distance from neutral plane of center of gravity. On tension area.	On compression area.	Sum of internal moment about point O at rupture.	Load at true elastic limit.	Deflection at true elastic limit.
	l	d	b	R	C	P	P_r	S_e	d_r	d_e	T	T_a	C_a	d_t	d_c	M_r	P_e	Δ_r
	Inches.			Lbs. per sq. in.		Lbs.		Lbs. per sq. in.	Inches.		Lbs. per sq. in.	Lbs.	Lbs.	Inches.		Inch pounds.	Lbs.	Inch.
2	50	3.51	3.56	7,350	**4,430**	**4,300**	**4,708**	**3,760**	1.46	1.23	10,517	7,677	7,719	0.97	1.18	58,760	2,200	0.296
3	50	3.75	3.37	7,910	**4,610**	**5,000**	**5,310**	**4,430**	1.56	1.31	10,979	8,564	8,552	1.04	1.26	66,380	2,800	0.391
4	50	3.55	3.60	7,790	**4,560**	**4,710**	**5,057**	**3,969**	1.48	1.24	10,885	8,055	8,026	0 99	1.19	63,216	2,400	0.413
5	50	3.49	3.50	8,230	**4,070**	**4,680**	**4,203**	**4,220**	1.45	1.22	9,675	7,014	7,061	0.97	1.17	52,535	2,400	0.345
6	50	3.58	3.54	7,750	**4,150**	**4,690**	**4,571**	**4,296**	1.49	1.25	9,894	7,371	7,376	0.99	1.20	57,144	2,600	0.356
7	50	3.53	3.50	7,810	**4,160**	**4,540**	**4,420**	**4,129**	1.47	1.23	9,943	7,308	7,290	0.98	1.18	55,248	2,400	0.431
8	50	3.56	3.54	7,470	**3,870**	**4,470**	**4,578**	**4,178**	1.48	1.25	9,164	7,381	6,840	0.99	1.20	57,222	2,500	0.440
*a*9	50	3.52	3.54	5,130	**3,880**	**3,000**	**4,169**	**3,078**	1.47	1.23	9,274	6,816	6,751	0.98	1.18	52,118	1,800	0.328
10	50	3.52	3.45	7,510	**3,680**	**4,280**	**3,854**	**3,860**	1.47	1.23	8,796	6,465	6,403	0.98	1.18	48,177	2,200	0.387
11	50	3.47	3.52	6,370	**3,750**	**3,600**	**3,312**	**3,893**	1.44	1.21	8,926	6,427	6,485	0.96	0.87	41,400	2,200	0.372
12	50	3.48	3.54	6,580	**3,540**	**3,760**	**3,697**	**3,395**	1.45	1.22	8,415	6,101	6,124	0.97	1.17	46,219	1,940	0.300

a Failed, due to knot.

NOTE.—Columns of figures in same distinctive type to be compared one with the other.

On the whole, it is in no way boastful to assert that this work has already furnished practical data enough to more than pay the expenses incurred ten times over; that its fruits are not half gathered, and that for more than a quarter of a century its results will serve as a basis for the user of wood and as the guide to the teacher and experimenter.

DEVELOPMENT OF THE SCIENCE OF TIMBER PHYSICS AND METHODS EMPLOYED IN THE INVESTIGATION.

Since the elaborate plan and methods of this study of our woods denotes an entirely new departure in timber investigations, at least in our country, it is only fitting to place the credit for its conception, for the elaboration of the plan, the organization of the work, and the persistent prosecution of the same in spite of many drawbacks and lack of support. This credit belongs to Dr. B. E. Fernow, chief of the Division of Forestry. The plan was first foreshadowed in his second report (1887, p. 37) as chief of that division, and the word "timber physics" was there used for the first time, and the essentials of the future plan were there discussed. In a small tentative manner the first steps to put it in operation were made in 1888. In the report for 1889 we read:

> The investigations into the technology of our timbers and especially into the conditions upon which the qualities of our timbers depend—for which Mr. Roth of Ann Arbor has begun preliminary studies—has also made but slow progress for lack of means.

In the report for 1890 we find, besides an account of the tests on Northern and Southern oaks referred to before, the statement that "by the increase of appropriations the forest technological investigations referred to in former reports have become possible on a scale which was hitherto unattainable," and a description of the plans is given. But the first fuller statement of the development of the investigation and its methods was not published until 1892, in Bulletin 6, in which Mr. Fernow described the aims, objects, and methods at length.

In the report for 1890 the following language is used:

TIMBER TESTS.

While the use of wood pulp and other substitutes may displace in many ways the use of wood in its natural state, there will always be desirable qualities inherent in the latter that make its use indispensable. Hence the desirability of knowing the qualities of our timbers and, if possible, of knowing the conditions under which the wood crop will develop the desirable qualities.

Much work and useful work is done in the world by the rule of thumb. All such work is not reliable and certainly not economical. With the need of greater economy in production, the need of more accurate measuring arises, and with that the need of more specific knowledge of the materials to be measured.

Wood is one of the materials which has been measured by the rule of thumb longer than others. Iron and other metals used in the arts have their properties much more accurately determined than wood material. Especially in the United States, when we speak of quality of our timbers, it can only be in general terms; we lack definite data.

One difficulty in determining reliably the qualities of our timbers lies in the fact that living things are rarely precisely alike. Every tree differs from every other tree, and the material taken from the one has a different value from that taken from the other of the same species. Yet every tree has some characteristics in common with all those grown under similar conditions. But even these common properties differ in degree in different individuals. Individual variation tends to obscure relationship.

The factors which determine the quality of timbers are found directly in the structure of the wood, and it is possible from a mere ocular examination to judge to some extent what qualities may be expected from a given piece of timber, although even in this direction our knowledge is very incomplete, and but few definite relations between structure and quality, or between physical and mechanical properties, are established. We know that the width of the annual rings, their even growth, the closeness of grain, the length, number, thickness, and distribution of the various cell elements, the weight, and many other physical appearances and properties of the wood influence its quality, yet the exact relation of these is but little studied. Conjectures more or less plausible, suppositions, and a few practical experiences preponderate over positive knowledge and results of experiments. Again we know, in a general way, that structure and composition of the wood must depend upon the conditions of soil, climate, and surroundings under which the tree is grown, but there are only few definite relations established. We are largely ignorant as to the nature of our wood crop, and still more so as to the conditions necessary to produce desirable qualities, and since forestry is not so much concerned in producing trees as in producing quality in trees, to acquire or at least enlarge this knowledge must be one of the first and most desirable undertakings in which this Division can engage.

Accordingly a comprehensive plan has been put into operation to study systematically our more important timber trees.

It will at once be understood that as long as the qualities are to be referred to the conditions under which the tree is grown, the collection of the study material must be made with the greatest care, and the material must be accompanied with an exhaustive description of these conditions. Since, further, so much individual variation seems to exist in trees grown under seemingly the same conditions, a large number must be studied in order to arrive at reliable average values. For the present it has been decided to study the pines, especially the white pine and the three Southern lumber pines.

In selecting localities for collecting specimens, a distinction is made between station and site.

By station is understood a section of country (or any places within that section) which is characterized in a general way by similar climatic conditions and geological formation. Station, then, refers mainly to the general geographical situation. Site refers to the local conditions and surroundings within the station, such as difference of elevation, of exposure, of physical properties and depth of the soil, nature of subsoil, and forest conditions, such as mixed or pure growth, open or close stand, etc.

The selection of characteristic sites in each station requires considerable judgment.

On each site five full-grown trees are to be taken, four of which are to be representative average trees; the fifth or "check" tree, however, should be the best developed tree that can be found on the site. Some additional test trees will be taken from the open and also a few younger trees. The trees are cut into varying lengths, and from each log a disk of 6-inch height is secured, after having marked the north and south sides and noted the position of the log in the tree.

The disks are sent for examination of the physical and physiological features to the Michigan University, while the logs, and later on special parts of the disks are to be sent to the test laboratory of the Washington University of St. Louis. Here, for the first time, a systematic series of beam tests will be made and compared with the tests on the usual small laboratory test pieces. Such tests with full-length beams in comparison with tests on small specimens promise important practical results, for a few tests have lately developed that large timbers seem to have but little more than one-half the strength they were credited with by standard authorities, who relied upon the tests on small specimens.

From the "check" tree mentioned before only clear timber is to be chosen, in order to ascertain the possibilities of the species and also to establish, if possible, a relation between such clear timber and that used in general practice, where elements of weakness are introduced by knots and other blemishes.

An authority on engineering matters writes regarding this work:

"Inasmuch as what passes current among engineers and architects as information on the strength of timber is really misinformation, and that no rational designing in timber can be done until something more reliable is furnished in this direction, the necessity for making a competent and trustworthy series of such tests is apparent. This is a work which the Government should undertake if it is to be impartial and general."

A careful record of all that pertains to the history and conditions of the growth from which the test pieces come, and of their minute physical examination, will distinguish these tests from any hitherto undertaken on American timbers.

The disk pieces will be studied to ascertain the form and dimensions of the trunk, the rate and mode of its growth, the density of the wood, the amount of water in the fresh wood, the shrinkage consequent upon drying, the structure of the wood in greatest detail, the strength, resistance, and working qualities of the wood, and lastly, its chemical constituents, fuel value, and composition of the ash.

In Bulletin 6 we are introduced to the science of "timber physics" in the following language:

Whenever human knowledge in any particular direction has grown to such an extent and complexity as to make it desirable for greater convenience and better comprehension to group it, correlate its parts, and organize it into a systematic whole, we may dignify such knowledge by a collective name as a new science or branch of science. The need of such organization is especially felt when a more systematic progress in accumulating new knowledge is contemplated. In devising, therefore, the plans for a systematic and comprehensive examination of our woods it has appeared desirable to establish a system under which is to be organized all the knowledge we have or may acquire of the nature and behavior of wood.

To this new branch of natural science I propose to give the name of "timber physics," a term which I have used first in my report for 1887, when, in devising a systematic plan of forestry science the absence of a collective name for this class of knowledge became apparent.

While forest biology contemplates the forest and its components in their living condition, we comprise in timber physics all phenomena exhibited in the dead material of forest production.

The practical application of timber or wood for human use, its technology, is based upon the knowledge of timber physics, and under this term we comprise not only the anatomy, the chemical composition, the physical and mechanical properties of wood, but also its diseases and defects, and a knowledge of the influences and conditions which determine structure, physical, chemical, mechanical, or technical properties and defects. This comprehensive science, conceived under the name here chosen, although developed more or less in some of its parts, has never yet been dignified by a special name, nor has a systematic arrangement of its parts been attempted before. It comprises various groups of knowledge derived from other sections of science, which are neither in themselves nor in their relations to each other fully developed.

While plant physiology, biology, chemistry, anatomy, and especially xylotomy, or the science of wood structure, are more or less developed and contribute toward building up this new branch of science, but little knowledge exists in regard to the interrelation between the properties of wood on one side and the modifications in its composition and structure on the other. Even the relation of the properties of various woods, as compared with each other, and their distinct specific peculiarities are but little explored and established. Less knowledge still exists as to the relation of the conditions which surround the living tree to the properties which are exhibited in its wood as a result of its life functions. Suppositions and conjectures more or less plausible preponderate over positive knowledge derived from exact observation and from the results of experiments. Still less complete is our knowledge in regard to the relation of properties and the methods and means used for shaping or working the wood.

The close interrelation of all branches of natural science is now so well recognized that I need not remind my readers that hard and fast lines can not be drawn whereby each field of inquiry is confined and limited; there must necessarily be an overlapping from one to the other. Any system, therefore, of dividing a larger field of inquiry into parts is only a matter of convenience; its divisions and correlations must be to some extent arbitrary and varied according to the point of view from which we proceed to divide and correlate.

There are two definite and separate directions in which this branch of natural science needs to be developed, and the knowledge comprised in it may be divided accordingly. On one side it draws its substance largely from the more comprehensive fields of botany, molecular physics, and chemistry, and on the other side it rests upon investigations of the wood material from the point of view of mechanics or dynamics. In the first direction we are led to deal with the wood material as it is, its nature or appearance and conditions; in the second direction we consider the wood material in relation to external mechanical forces, its behavior under stress.

The first part is largely descriptive, concerned in examining gross and minute structures, physical and chemical conditions and properties, and ultimately attempting to explain these by referring to causes and conditions which produce them. This is a field for investigation and research by the plant physiologist in the laboratory in connection with studies of environment in the forest. The second part, which relies for its development mainly upon experiment by the engineer, deals with the properties which are a natural consequence of the structure, physical condition, and chemical composition of the wood as exhibited under the application of external mechanical forces. It comprises, therefore, those studies which contemplate the wood substance, with special reference to the uses of man, and forms ultimately the basis for the mechanical technology of wood or the methods of its use in the arts.

The correlation of the results of these two directions of study as cause and effect is the highest aim and ultimate goal, the philosophy of the science of timber physics. Timber physics, in short, is to furnish all necessary knowledge of the rational application of wood in the arts, and at the same time, by retrospection, such knowledge will enable us to produce in our own forest growth qualities of given character.

Conceived in this manner it becomes the pivotal science of the art of forestry, around which the practice both of the consumer and producer of forest growth moves.

The first part of our science would require a study into gross and minute anatomy, the structure of the wood, form, dimensions, distribution, and arrangement of its cell elements and of groups of structural parts, not only in order to distinguish the different woods, but also to furnish the basis for an explanation of their physical and mechanical properties. We next would class here all investigations into the physical nature or properties of the wood material, which necessarily also involves an investigation into the change of these properties under varying conditions and influences. A third chapter would occupy itself with the chemical composition and properties of woods and their changes in the natural process of life, which predicate the fuel value and durability as well as the use of the wood in chemical technology.

Although, philosophically speaking, it would hardly seem admissible to distinguish between physical and mechanical properties or to speak of "mechanical" forces, for the sake of convenience and practical purposes it is desirable to make the distinction and to classify all phenomena and changes of nonliving bodies, or bodies without reference to life functions, into chemical, physical, and mechanical phenomena and changes. As chemical phenomena or changes, and therefore also conditions or properties, we class, then, those which have reference to atomic structure; as physical phenomena, changes, and properties those which refer to and depend on molecular arrangement, and as mechanical (molar) changes and properties those which concern the masses of bodies, as exhibited under the influence of external forces, without altering their physical or chemical constitution.

There is no doubt that this division is somewhat forced, since not only most or all mechanical (as here conceived) changes are accompanied or preceded by certain alterations of the interior molecular arrangement of the mass, but also many physical phenomena or properties, like density, weight, shrinkage, having reference to the mass, might be classed as mechanical; yet if we conceive that physical phenomena are always concerned with the "quantity of matter in molecular arrangement" and with the changes produced by interior forces, while the latter are concerned rather with the "position of matter in molecular arrangement" and with changes under application of exterior forces, the distinction assumes a practical value.

Our conception of these distinctions will be aided if we refer to the physical laboratory as furnishing the evidence of physical phenomena and to the mechanical laboratory as furnishing evidence of mechanical phenomena.

These latter, then, form the subject of our second or dynamic part of timber physics, which concerns itself to ascertain mainly by experiment, called tests, under application of the laws of elasticity, the strength of the material and other properties which are exhibited as reactions to the influence of applied stresses, and those which need consideration in the mechanical use of the material in the various arts.

Having investigated the material in its normal condition, we would necessarily come to a consideration of such physical and chemical conditions of the material as are abnormal and known as disease, decay, or defects.

Finally, having determined the properties and their changes as exhibited in material produced under changing conditions or differing in physical and structural respects, it would remain the crowning success and goal of this science to relate mechanical and physical properties with anatomical and physiological development of the wood substance.

The subject-matter comprised in this branch of applied natural science, then, may be brought into the following schematic view:

TIMBER PHYSICS, OR THE SCIENCE OF WOOD.

I.—Wood structure or xylotomy.

(*a*) *Exterior form.*

Here would be described the form development of timber in the standing tree, differentiated into root system, root collar, bole or trunk crown, branches, twigs; relative amounts of material furnished by each.

(*b*) *Interior structural appearance;* differentiation and arrangement of groups of structural elements.

Here would be described the gross structural features of the wood, the distribution and size of medullary rays, vessels, fibro-vascular bundles, as exhibited to the naked eye or under the magnifying glass on tangential, radial, and transverse sections; the appearance of the annual rings, their size, regularity, differentiation into summer and spring wood, and all distinguishing features due to the arrangement and proportion of the tissues composing the wood.

(*c*) *Minute anatomy or histology;* differentiation and arrangement of structural elements.

Here the revelations of the microscope are recorded, especially the form, dimensions, and structure of the different kinds of cells, their arrangement, proportion, and relative importance in the resulting tissues.

(*d*) *Comparative classification of woods,* according to *structural* features.

(*e*) *Laws of wood growth* with reference to structural results.

Discussion of the factors that influence the formation of wood in the standing tree.

(*f*) *Abnormal formations.*

Burls, bird's eye, curly, wavy, and other structural abnormities and their causes.

II.—Physical properties, i. e., properties based on molecular (physical) constitution.

(*a*) *Exterior appearance.*

Such properties as can be observed through the unaided senses, as color, gloss, grain, texture, smell, resonance.

(*b*) *Material condition.*

Such properties or changes as are determined by measurements, as density or weight, water contents and their distribution, volume, and its changes by shrinkage and swelling.

(c) *Classification of woods* according to *physico-technical* properties, i. e., such physical properties as determine their application in the arts.

III.—Chemical properties, i. e., properties based on atomic (chemical) constitution.

(a) *General chemical analysis of wood* (qualitative and quantitative).

Here would be discussed the chemical constitution of different woods and different parts of trees and their changes due to physiological processes, age, conditions of growth, etc.

(b) *Carbohydrates of the wood.*

Here would be more specially discussed cellulose and lignin, cork formations, organic contents and their changes, and such properties as predicate the fuel value of woods, their manufacture into charcoal, their food value, pulping qualities, etc.

(c) *Extractive materials.*

A knowledge of these underlies the application of wood in the manufacture of tan extracts, resin, and turpentine, tar, gas, alcohol, acids, vanillin, etc.

(d) *Antiseptic materials.*

A knowledge of those chemical properties which predicate durability and underlie processes of increasing the same.

(e) *Mineral constituents.*

A knowledge of these in particular will establish the relation of wood growth to mineral constituents of the soil and also serve as basis for certain technical uses (potash).

IV.—Mechanical properties, i. e., properties based on elastic conditions exhibited by the aggregate mass under influence of exterior (mechanical) forces.

(a) *Form changes without destruction of cohesion*, commonly called elasticity, flexibility, toughness.

(b) *Form changes with destruction of cohesion*, commonly called strength (tensile, compressive, torsional, shearing), cleavability, hardness.

V.—Technical properties, i. e., properties in combination.

Here would be considered the woods with reference to their technical use, their application in the arts, which is invariably based upon a combination of several physical or mechanical properties.

VI.—Diseases and faults.

Here would be treated the changes in structure and properties from the normal to abnormal conditions, due to influences acting upon the tree during its life or upon the timber during its use.

VII.—Relation of properties to each other.

Here would be discussed the connection which may be established between structure, physical, chemical, and mechanical properties, and also between these and the conditions of growth under which the material was produced. The philosophy of the entire preceding knowledge would here be brought together.

To contribute toward this important branch of human knowledge and to help in the building of its foundation, the work undertaken by the Division of Forestry described in this bulletin was designed by the writer; and, in order to build with a knowledge of what has been done before on this structure, a brief review of the progress in the development of timber physics seemed advisable.

This historical review is then given. From this we deem it appropriate to quote the portion which refers to efforts in the United States up to the time of the writing to establish data regarding the mechanical properties of our timber:

AMERICAN WORK.

While it may be possible to work out the general laws of relation between physical and mechanical properties on material of European origin, for practical purposes we can not rely upon any other data than those ascertained from American timbers, and so far as dependence of quality on conditions of growth are concerned this truth is just as patent. Although in the United States probably more timber has been and is being used than in any other country, but little work has been done in the domain of timber physics.

Among the earliest American experiments falling in the domain of timber physics may be cited those of Marcus Bull to determine "the comparative quantities of heat evolved in the combustion of the principal varieties of wood and coal used in the United States for fuel," made in the years 1823 to 1825 and published in 1826. Here the experiments of Lavoisier, Crawford and Dalton, and Count Rumford on similar lines are discussed and followed by an able series of experiments and discussion on American woods and coals.

The only comprehensive work in timber physics ever undertaken on American timbers is that of Mr. T. P. Sharples, in connection with the Tenth Census, and published in 1884, Vol. IX, on the Forests of North America. Comprehensiveness, however, has been sought rather in trying to bring under examination all the arborescent species than in furnishing fuller data of practical applicability on those from which the bulk of our useful material is derived. "The results obtained," the author says, "are highly suggestive; they must not, however, be considered conclusive, but rather valuable as indicating what lines of research should be followed in a more thorough study of this subject."

Not less than 412 species were examined in over 1,200 specimens. The results are given in five tables, besides four comparative tables of range, relative values, averages, etc. The specimens were taken "in most cases from the butt cut and free from sap and knots;" the locality and soil from which the tree came are given in most cases, and in some its diameter and layers of heart and sapwood; determinations were made of specific gravity, mineral ash per cent, and from these data fuel values were calculated.

The specimens tested were "carefully seasoned." For transverse strain they were made 4 centimeters (1.57 inches) square, and a few of double these dimensions, with 1 meter (3.28 feet) span.

One table illustrates "the relation between the specific gravity and the transverse strength of the wood of species, upon which a sufficient number of tests has been made to render such a comparison valuable." This table seems to show that in perfect specimens weight and strength stand in close relation. A few tanning determinations on the bark of a few species are also given.

The object of the work as stated, namely, to be suggestive of a more thorough study of the subject, has certainly been fully and creditably attained. Of compilatory works, for use in practice and for reference, the following, published in the United States, may be cited:

De Volson Wood: Resistance of Materials (1871), containing rather scanty references to the work of Chevandier and Wertheim.

R. G. Hatfield: Theory of Transverse Strain (1877), which, besides other references, contains also twenty-three tables of the author's own test on white pine, Georgia pine, hemlock, spruce, white ash, and black locust, on sticks 1 by 1 inch by 1.6 feet in length.

William H. Burr: The Elasticity and Resistance of Materials of Engineering, third edition, 1890, a comprehensive work, in which many references are made to the work of various American experimenters.

Gaetano Lanza, in Applied Mechanics, 1885, lays especial stress on the fact that tests on small select pieces give too high values, and quotes the following experiments on long pieces. He refers to the work of Capt. T. J. Rodman, United States Army, published in Ordnance Manual, who used test pieces 2¾ by 5¾ inches and 5 feet length, without giving any reference to density or other facts concerning the wood; and to Col. Laidley's United States Navy test (Senate Ex. Doc. 12, Forty-seventh Congress, first session, 1881), who conducted a series of experiments on Pacific slope timbers, "white and yellow pine," 12 feet long and 4 to 5 by 11 to 12 inches square, giving also account of density and average width of rings.

Lastly, the author's own experiments, made at the Watertown Arsenal for the Boston Manufacturers' Mutual Fire Insurance Company, on the columnar strength of "yellow pine" and white oak, 12 feet long and 6 to 10 inches thick, are brought in support of the claim that such tests show less than half the unit strength of those on small pieces. Data as to density, moisture, or life history of the specimens are everywhere lacking.

R. H. Thurston, Materials of Engineering, 1882, contains, perhaps, more than any other American work on the subject, devoting, in Chapters II and III, 117 pages to timber and its strength, and in the chapter on Fuel several pages to wood and charcoal, and the products of distillation. It also gives a description of some twenty-five kinds of American and of a few foreign timber trees, with a description of the structure and their wood in general; directions for felling and seasoning; discusses briefly shrinkage, characteristics of good timber, the influence of soil and climate on trees and their wood, and of the various forms of decay of timber, methods of preservation and adaptation of various woods for various uses, much in the same manner as Rankine's Manual of Civil Engineering, from which many conclusions are adopted. The author refers, besides foreign authorities, to the following American investigators:

G. H. Corliss (unpublished?) is quoted as claiming that proper seasoning of hickory wood increases its strength by 15 per cent.

R. G. Hatfield is credited with some of the best experiments on shearing strength, published in the American House Carpenter.

Prof. G. Lanza's experiments are largely reproduced, also Trautwine's on shearing, and some of the author's own work on California spruce, Oregon pine, and others, especially in torsion, with a specially constructed machine, an interesting plate of strain diagrams accompanying the discussion.

In connection with the discussion by the author on the influence of prolonged stress, there is quoted as one of the older investigators, Herman Haupt, whose results on yellow pine were published in 1871 (Bridge Construction).

Experiments at the Stevens Institute of Technology are related, with the important conclusion that a load of 60 per cent of the ultimate strength will break a stick if left loaded (one small test piece having been left loaded fifteen months with this result).

In addition the following list of references to American work in timber physics is here inserted, with a regret that it has not been possible to include all the stray notes which may be in existence but were not accessible. Those able to add further notes are invited to aid in making this reference list complete:

Abbott, Arthur V. Testing machines, their history, construction, and use. With illustrations of machines, including that at Watertown Arsenal. Van Nostrand's Magazine, 1883, vol. 30, pp. 204, 325, 382, 477.

Day, Frank M., University of Pennsylvania. The microscopic examination of timber with regard to its strength. Read before American Philosophical Society, 1883.

Estrada, E. D. Experiments on the strength and other properties of Cuban woods. Investigations carried on in the laboratory of the Stevens Institute. Van Nostrand's Magazine, 1883, vol. 29, pp. 417, 441.

Flint, ——. Report of tests of Nicaraguan woods. Journal of Franklin Institute, October, 1887, pp. 289-315.

Goodale, Prof. George L., Harvard University. Physiological Botany, 1885, chapters 1, 2, 3, 5, 8, 11, and 12.

Ihlseng, Magnus C., Ph. D. On the modulus of elasticity in some American woods, determined by vibration. Van Nostrand's Magazine, 1878, 19.

—— On a mode of measuring the velocity of sounds in woods. Read before the National Academy of Science, 1877; published in American Journal of Science and Arts, 1879, vol. 17.

Johnson, Thomas H. On the strength of columns. Paper read at annual convention of American Society of Civil Engineers, 1885. Transactions of the Society, vol. 15.

Kidder, F. E. Experiments at Maine State College on transverse strength of southern and white pine. Van Nostrand's Magazine, 1879, vol. 22.

——— Experiments with yellow and white pine. Van Nostrand's Magazine, 1880, vol. 23.

——— Experiments on the strength and stiffness of small spruce beams. Van Nostrand's Magazine, 1880, vol. 24.

——— Influence of time on bending strength and elasticity. Journal of Franklin Institute, 1882. Proceedings Institute of Civil Engineering, vol. 71.

Lanza, Gaetano, professor Massachusetts Institute of Technology. Address before American Society of Mechanical Engineers, describing the 50,000-pound testing machine at Watertown Arsenal and tests of strength of large spruce beams. Journal of Franklin Institute, 1883.

——— Report of Boston Manufacturers' Mutual Fire Insurance Company of tests made with Watertown machine on columns of pine, whitewood, and oak of dimensions used in cotton and woolen mills. See summary and tables of same in Burr's Elasticity and Resistance of the Materials of Engineering, p. 480.

Macdonald, Charles. Necessity of government aid in making tests of materials for structural purposes. Paper read before the American Institute of Mining Engineers. Van Nostrand's Magazine, 1882, vol. 27, p. 177.

Norton, Prof. W. A., Yale College. Results of experiments on the set of bars of wood, iron, and steel after a transverse set. Experiments discussed in two papers read before the National Academy of Science, 1874 and 1875. Published in Van Nostrand's Magazine, 1887, vol. 17, p. 531.

——— Description of machine used is given in proceedings of the A. A. A. S., eighteenth meeting, 1869.

Parker, Lieut. Col. F. H., United States Ordnance Department. Report of tests of American woods by the testing machine, United States Arsenal, Watertown, under supervision of Prof. C. S. Sargent, for the Census Report, 1880. Senate Ex. Doc. No. 5, Forty-eighth Congress, first session, 1882–83.

——— Report of experiments on the adhesion of nails, spikes, and screws in various woods, as made at Watertown Arsenal. Senate Ex. Doc. No. 35, Forty-ninth Congress, first session, 1883–84, and in report on tests of metals and other materials for industrial purposes at Watertown Arsenal, 1888–89.

——— Also in report on tests of iron, steel, and other materials for industrial purposes at Watertown Arsenal, 1886-87, pp. 188, 189.

——— Report on cubic compression of various woods, as shown by tests at Watertown Arsenal, 1885–86, in report on tests of metals, etc., for industrial purposes.

Philbrick, Professor, Iowa University. New practical formulas for the resistance of solid and built beams, girders, etc., with problems and designs. Van Nostrand's Magazine, 1886, vol. 35.

Pike, Prof. W. A. Tests of white pine, made in the testing laboratory of the University of Minnesota. Van Nostrand's Magazine, 1885, vol. 34, p. 472.

Rothrock, Prof. J. T., University of Pennsylvania. Some microscopic distinctions between good and bad timber of the same species. Read before American Philosophic Society.

Smith, C. Shaler, C. E. Summary of results of 1,200 tests of full-size yellow-pine columns. See W. H. Burr's Elasticity and Resistance of the Materials of Engineering, pp. 485–490.

Thurston, Prof. R. H., Cornell University. The torsional resistance of materials. Journal of Franklin Institute, 1873, vol. 65.

——— Experiments on torsion. Van Nostrand's Magazine, July, 1873.

——— Experiments on the strength, elasticity, ductility, etc., of materials, as shown by a new testing machine. Van Nostrand's Magazine, 1874, vol. 10.

———. The relation of ultimate resistance to tension and torsion. Proceedings of Institute of Civil Engineers, vol. 7, 1878.

———. The strength of American timber. Experiments at Stevens Institute. Paper before A. A. A. S., 1879. Journal of Franklin Institute, vol. 78, 1879.

———. Effect of prolonged stress upon the strength and elasticity of pine timber. Journal of Franklin Institute, vol. 80, 1880.

———. Influence of time on bending strength and elasticity. Proceedings A. A. A. S., 1881. Proceedings Institute of Civil Engineers, vol. 71.

Watertown Arsenal. Summary of results of tests of timber at, in Ex. Doc. No. 1, Forty-seventh Congress, second session. See Burr's Elasticity and Resistance of Materials of Engineering, pp. 486 and 535.

Wellington, A. M., C. E. Experiments on impregnated timber. Railroad Gazette, 1880.

Organization and Methods.

Although in the course of the investigations many minor and some more important changes in methods became necessary, the general plan was in the main adhered to. We consider it, therefore, desirable to restate from the same bulletin such portions as will explain the methods pursued. The work at the test laboratory at St. Louis, Mo., was described in full by Prof. J. B. Johnson, in charge, and the methods in the examination of the physical properties of the test material by the writer.

There are four departments necessary to carry on the work as at present organized, namely:

(1) The collecting department.

(2) The department of mechanical tests.

(3) The department of physical and microscopic examination of the test material.

(4) The department of compilation and final discussion of results.

The region of botanical distribution of any one species that is to be investigated is divided into as many stations as there seem to be widely different climatic or geological differences in its habitat. In each station are selected as many sites as there seem widely different soils, elevations, exposures, or other striking conditions occupied by the species. An expert collector describes carefully the conditions of station and site, under instructions and on blanks appended to this report. From each site five mature trees of any one species are chosen, four of which are average representatives of the general growth, the fifth, or "check" tree, the best developed that can be found. The trees are felled and cut into logs of merchantable size, and from the butt end of each log a disk 6 inches in height is sawed. Logs and disks are marked with numbers to indicate number of tree and number of log or disk, and their north and south sides are marked; their height in the tree from the ground is noted in the record. The disks are also weighed immediately, then wrapped in oiled paper and packing paper, and sent by mail or express to the laboratory, to serve the purpose of physical and structural examination. Some disks of the limbwood and of younger trees are also collected for other physical and physiological investigations, and to serve with the disks of the older trees in studying the rate of growth and other problems.

The logs are shipped to the test laboratory, there sawed and prepared for testing, carefully marked, and tested for strength.

The fact that tests on large pieces give different values from those obtained from small pieces being fully established, a number of large sticks of each species and site will be tested full length in order to establish a ratio between the values obtained from the different sizes. Part of the material is tested green, another part when seasoned by various methods. Finally, tests which are to determine other working qualities of the various timbers, such as adapt them to various uses, are contemplated

The disks cut from each log and correspondingly marked are examined at the botanical laboratory. An endless amount of weighings, measurings, countings, computings, microscopic examinations, and drawings is required here, and recording of the observed facts in such a manner that they can be handled. Chemical investigations have also been begun in the Division of Chemistry of the Department of Agriculture, the tannic contents of the woods, their distribution through the tree and their relation to the conditions of growth forming the first series of these investigations.

It is evident that in these investigations, carried on by competent observers, besides the main object of the work, much new and valuable knowledge unsought for must come to light if the investigations are carried on systematically and in the comprehensive plan laid out. Since every stick and every disk is marked in such a manner that its absolute position in the tree and almost the absolute position of the tree itself or at least its general condition and surroundings are known and recorded, this collection will be one of the most valuable working collections ever made, allowing later investigators to verify or extend the studies.

This significant prophetic language also occurs in this connection, which has finally been realized by the discovery of the relation between compression and beam strength:

> By and by it is expected that the number of tests necessary may be reduced considerably, when for each species the relation of the different exhibitions of strength can be sufficiently established, and perhaps a test for compression alone furnish sufficient data to compute the strength in other directions.

WORK AT THE TEST LABORATORY AT ST. LOUIS, MO.

SAWING, STORING, AND SEASONING.

On arrival of the logs in St. Louis they are sent to a sawmill and cut into sticks, as shown in fig. 103.

In all cases the arrangements shown in Nos. 1 and 2 are used, except when a detailed study of the timber in all parts of the cross section of the log is intended. A few of the most perfect logs of each species are cut up into small sticks, as shown in Nos. 3 and 4. The logs tested for determining the effects of extracting the turpentine from the Southern pitch pines were all cut into small sticks.

In all cases a "small stick" is nominally 4 inches square, but when dressed down for testing may be as small as 3½ inches square. The "large sticks" vary from 6 by 12 to 8 by 16 inches in cross section.

All logs vary from 12 to 18 feet in length. They all have a north and south diametral line, together with the number of the tree and of the log plainly marked on their larger or lower ends. The stenciled lines for sawing are adjusted to this north and south line, as shown in the figures. Each space is then branded by deep dies with three numbers, as, for instance, thus: 25 2 4, which signifies that this stick was number 4, in log 2, of tree 25. A facsimile of the stenciling is recorded in the log book, and the sticks there numbered to correspond with the numbering on the logs. After sawing, each stick can be identified and its exact origin determined. These three numbers, then, become the identification marks for all specimens cut from this stick, and they accompany the results of tests in all the records.

The methods of sawing shown in Nos. 2 and 4 are called "boxing the heart;" that is, all the heart portion is thrown into one small stick, which in practice may be thrown away or put into a lower grade without serious loss. In important bridge, floor, or roof timbers, the heart should always be either excluded or "boxed" in this way, since its presence leads to checking and impairs the strength of the stick.

After sawing, the timbers are stored in the laboratory until they are tested. The "green tests" are made usually within two months after sawing, while the "dry tests" are made at various subsequent times. One end (60 inches) of each small stick is tested green, and the other end reserved and tested after seasoning. The seasoning is hastened in some cases by means of a drying box. The temperature of the inflowing air in this drying box is kept at about 100° F., with suitable precaution against checking of the wood, and the air is exhausted by means of a fan. The air is, therefore, somewhat rarefied in the box. The temperature is at all times under control. It operates when the fan is running, and this is only during working hours.

The mechanical and moisture test are then made according to known methods.

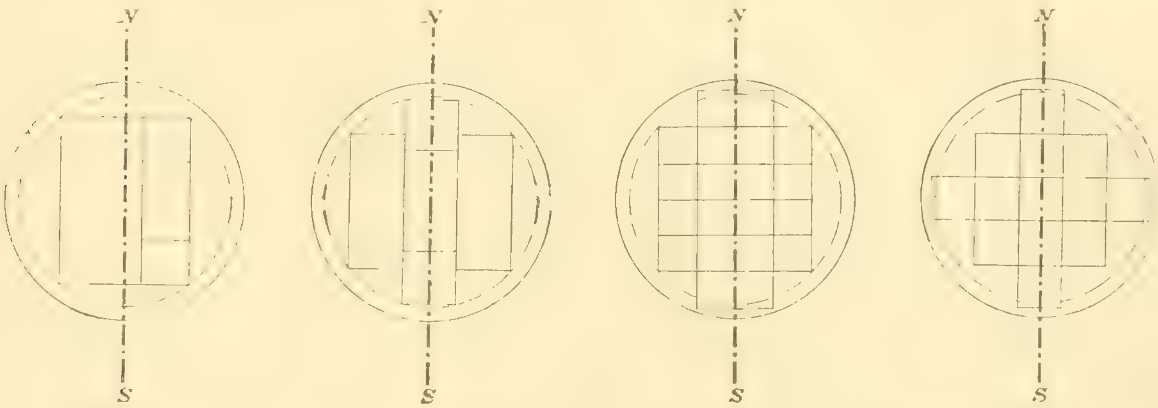


FIG. 103.—Method of sawing test logs.

EXAMINATION INTO THE PHYSICAL PROPERTIES OF TEST MATERIAL.

The physical examination consists in ascertaining the specific weight of the dried material, and incidentally the progress and amount of shrinkage due to seasoning; the counting and measuring of the annual rings, and noting other microscopic appearances in the growth; the microscopic investigation into the relation of spring and summer wood from ring to ring; the frequency and size of medullary rays; the number of cells and thickness of their walls; and, in short, the consideration of any and all elements which may elucidate the structure and may have influence upon the properties of the test piece. The rate of growth and other biological facts which may lead to the finding of relation between physical appearance, conditions of growth, and mechanical properties are also studied incidentally.

SHAPING AND MARKING OF THE MATERIAL.

The object of this work being in part the discovery of the differences that exist in the wood, not only in trees of different species or of the same species from various localities, but even in the wood of the same tree and from the same cross section, a careful marking of each piece is necessary. The disks are split, first into a north and south piece, and each of these into smaller pieces of variable size. In one tree all pieces were made but 3 cm. thick radially, in another 4 cm., in still others 5 cm., while in some trees, especially wide-ringed oaks, the pieces were left still larger. In the conifers the outer or first piece was made to contain only sapwood. Desirable as it appeared to have each piece contain a certain number of rings, and thus to represent a fixed period of growth, it proved impracticable, at least in the very narrow-ringed disks of the pines, where sometimes the width of a ring is less than 5 mm. (0.2 inch).

Some of the disks were split to a wedge shape from center to periphery, so that each smaller piece not only represents a certain period of growth in quality, but also in quantity, thus simplifying the calculations for the entire piece or disk. Other pieces were left in their prismatic form, when to calculate the average density of the entire piece the density of each smaller piece is multiplied by the mean distance of this smaller piece from the center, and the sum of the products divided by the sum of the distances.

Each piece is marked, first by the number of the tree, in Arabic; second, by the number of the disk, in Roman numbers; and if split into small pieces, each smaller piece by a letter of the alphabet, the piece at the periphery in all cases bearing the letter *a*. Besides the number and letters mentioned, each piece bears either the letter N or S, to indicate its orientation on the north or south side of the tree. To illustrate: 5—VII N *a* means that the piece bearing the label belongs to tree 5 and disk VII comes from the north side of the tree, and is the peripheral part of this disk piece. From the collector's notes the exact position of this piece in the tree can readily be ascertained.

The entire prisms sent by freight are left in the original form, unless used for special purposes, and are stored in a dry room for future use.

WEIGHING AND MEASURING.

The weighing is done on an apothecary's balance, readily sensitive to 0.1 gram with a load of more than 200 grams. Dealing with pieces of 200 to 1,000 grams in weight, the accuracy of weighing is always within 1 gram.

The measuring is done by immersion in an instrument illustrated in the following design: *V* is a vessel of iron; *S* represents one of two iron standards attached to the vessel and projecting

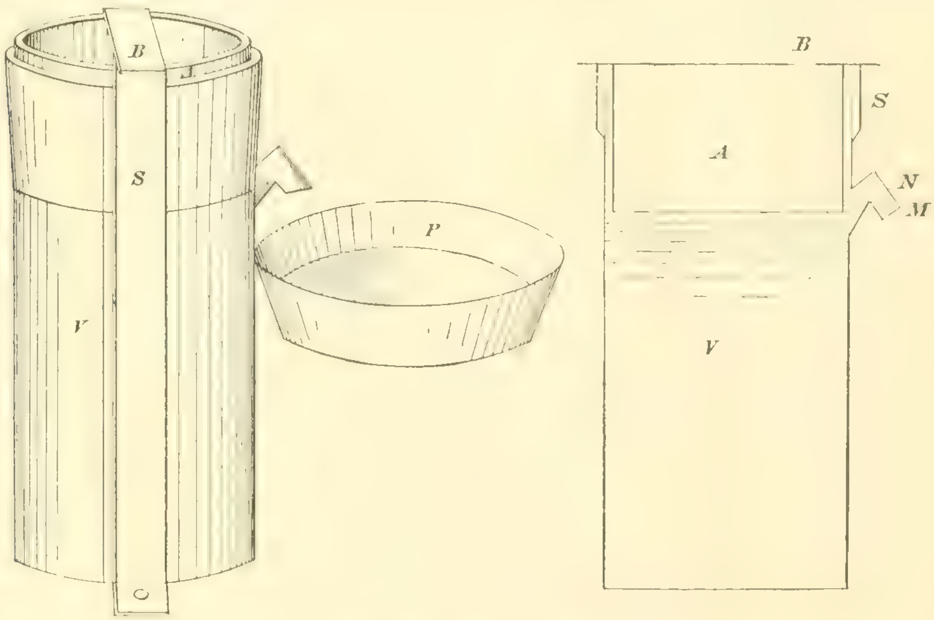


FIG. 104.—Apparatus for determining specific gravity.

above its top; *B* is a metal bar fastened to the cup *A*, which serves as guard to the cup and prevents it going down farther at one time than another by coming to rest on the standards *S*. The cup *A* dips down one-sixteenth to one-eighth of an inch below the edge of the knee-like spout. In working, the cup is lifted out by the handle which the bar *B* forms, water is poured into the vessel until it overflows through the spout, then the cup is set down, replacing the mobile and fickle natural water level by a constant artificial one. Now the instrument is set, the pan *P* is placed under the spout, the cup is lifted out and held over the vessel, so that the drippings fall back into the latter, the piece of wood to be measured is put into the vessel and the cup replaced, and pressed down until the bar *B* rests on the standards *S*. This is done gently to prevent the water from rising above the rim of the vessel. This latter precaution is superfluo us where the cup fits closely, as it does in one of the instruments thus far used. The pan with water is then weighed, the pan itself being tared by a bag of shot. The water is poured out, the pan wiped dry, and the process begins anew. To work well it takes two persons, one to weigh and record. The water pan is a seamless tin pan, holding about 1,500 cc. of water and weighing only 144 grams. The temperature as well as density of the water are ascertained, the latter, of course, omitted when distilled water is used. To maintain the water at the same temperature it requires frequent changing.

DRYING.

After marking, the pieces are left to dry at ordinary temperature. Then they are placed in a dry kiln and dried at 100° C.

The drying box used is a double-walled sheet-iron case, lined with asbestus paper, and heated with gasoline. The air enters below and has two outlets on top. The temperature is indicated by a thermometer and maintained fairly constant.

After being dried, the pieces of wood are weighed and measured, in the same way as described for the fresh wood, and from the data thus gathered the density, shrinkage, and moisture per cent are derived in the usual manner.

The formulæ employed are:

$$(1)\ \text{Density of fresh wood} = \frac{\text{Weight of fresh wood.}}{\text{Volume of fresh wood.}}$$

$$(2)\ \text{Density of dry wood} = \frac{\text{Weight of dry wood.}}{\text{Volume of dry wood.}}$$

$$(3)\ \text{Shrinkage} = \frac{\text{Fresh volume} - \text{dry volume.}}{\text{Fresh volume.}}$$

$$(4)\ \text{Moisture in wood} = \frac{\text{Fresh weight} - \text{dry weight.}}{\text{Fresh weight.}}$$

In presenting these values they are always multiplied by 100, so that the density expresses the weight of 100 cm.^{3} of wood; thus the shrinkage and the amount of moisture become the shrinkage and moisture per cent.

SHRINKAGE EXPERIMENTS.

To discover more fully the relations of weight, humidity, and shrinkage, as well as "checking" or cracking of the wood, a number of separate experiments were made. A number of the fresh specimens were weighed and measured at variable intervals until perfectly dry. Some dry pieces were placed in water and kept immersed until the maximum volume was attained. Without describing more in detail these tests and their results, it may be mentioned that in the immersed pieces studied the final maximum volume differed very little, in some cases not at all, from the original volume of the wood when fresh; and also that in a piece of white pine only 15 cm. long and weighing but 97 gs. when dry, it required a week before the swelling ceased.

To determine the shrinkage in different directions a number of measurements are made in pieces of various sizes and shapes. In most cases pins were driven into the wood to furnish a firm metal point of contact for the caliper. A number of pieces of oak were cut in various ways to study the effect of size, form, and relative position of the grain on checking.

WOOD STRUCTURE.

The most time-robbing, but also the most fascinating, part of the work consists in the study of the wood as an important tissue of a living organism; a tissue where all favorable and unfavorable changes experienced by the tree during its long lifetime find a permanent record.

GENERAL APPEARANCE.

For this study all the specimens from one tree are brought together and arranged in the same order in which they occurred in the tree. This furnishes a general view of the appearance of the stem; any striking peculiarities, such as great eccentricity of growth, unusual color, abundance of resin in any part of the stem, are seen at a glance and are noted down.

A table is prepared with separate columns, indicating—

(1) Height of the disk in the tree (this being furnished by the collector's notes);

(2) Radius of the section;

(3) Number of rings from periphery to center;
(4) Number of rings in the sapwood;
(5) Width of the sapwood; and
(6) Remarks on color, grain, etc.

The results from each disk occupy two lines, one for the pieces from the north side and one for those of the south side. The radius is measured correct to one-half millimeter (0.02 inch), and the figures refer to the air-dry wood.

To count the rings, the piece is smoothed with a sharp knife or plane, the cut being made oblique, i. e., not quite across the grain, nor yet longitudinal. Beginning at the periphery, each ring is marked with a dot of ink, and each tenth one with a line to distinguish it from the rest. After counting, the rings are measured in groups of ten, twenty, thirty, rarely more, and these measurements entered in separate subcolumns. In this way the rate of growth of the last ten, twenty, or thirty years throughout the tree is found, also that of similar periods previous to the last; in short, a fairly complete history of the rate of growth of the tree from the time when it had reached the height of the stump to the day when felled is thus obtained. Not only do these rings furnish information concerning the growth in thickness, but indicating the age of the tree when it had grown to the height, from which the second, third, etc., disks were taken, the rate of growth in height, as well as that of thickness, is determined, any unfavorable season of growth or any series of such seasons are found faithfully recorded in these rings, and the influence of such seasons, whatever their cause, both on the quantity and on the quality or properties of the wood, can thus be ascertained.

In many cases, especially in the specimens from the longleaf pine, and from the limbs of all pines, the study of these rings is somewhat difficult. Zones of a centimeter and more exist where the width of the rings is such that the magnifier has to be used to distinguish them. In some cases this difficulty is increased by the fact that the last cells of one year's growth differ from the first cells of the next year's ring only in form and not in the thickness of their walls, and therefore produce the same color effect. Such cases frequently occur in the wood of the upper half of the disks from limbs (the limb supported horizontally and in its natural position), and often the magnifier has to be reenforced by the microscope to furnish the desired information. For this purpose the wood is treated as in all microscopic work, being first soaked in water and then sectioned with a sharp knife or razor and examined on the usual slide in water or glycerin.

The reason for beginning the counting of rings at the periphery is the same which suggested the marking of all peripheral pieces by the letter *a*. It is convenient, almost essential, to have, for instance, the thirty-fifth ring in Section II represent the same year's growth as the thirty-fifth ring in Section X. The width of the sapwood, the number of annual rings composing it, as well as the clearness and uniformity of the line separating the sapwood from the heartwood, are carefully recorded. In the columns of "remarks" any peculiarities which distinguish the particular piece of wood, such as defects of any kind, the presence of knots, abundance of resin, nature of the grain, etc., are set down.

When finished, a variable number, commonly 3 to 6 small pieces, fairly representing the wood of the tree, are split off, marked with the numbers of their respective disks, and set aside for the microscopic study, which is to tell us of the cell itself, the very element of structure, and of its share in all the properties of wood.

The small pieces are soaked in water, cut with a sharp knife or razor, and examined in water, glycerin, or chloriodide of zinc. The relative amount of the thick-walled, dark-colored bands of summer wood, the resin ducts, the dimensions of the common tracheids and their walls, both in spring and summer wood, the medullary rays, their distribution and their elements, are the principal subjects in dealing with coniferous woods; the quantitative distribution of tissues, or how much space is occupied by the thick-walled bast, how much by vessels, how much by thin-walled, pitted tracheids and parenchyma, and how much by the medullary rays; what is the relative value of each as a strength-giving element; what is the space occupied by the lumina, what by the cell walls in each of these tissues—these are among the important points in the study of the oaks.

Continued sections from center to periphery, magnified 25 diameters, are employed in finding the relative amount of the summer wood; the limits of the entire ring and that of spring and

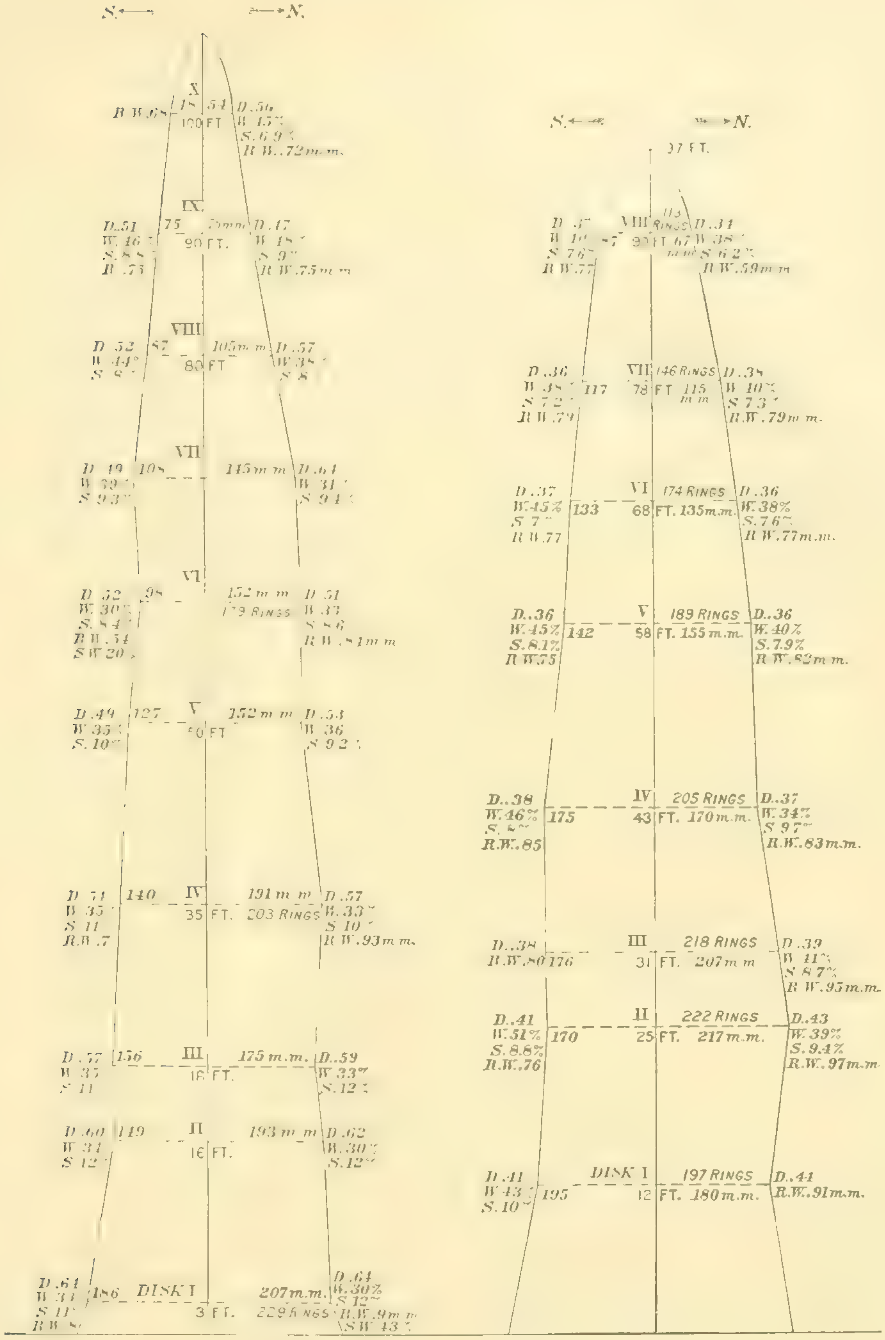


Fig. 105.—Result of physical examination. (Sample.)

Longleaf pine (*P. palustris*), tree 3.	White pine (*P. Strobus*), tree 116.
Locality: Wallace, Ala.	*Locality:* Marathon County, Wis.
Site: Upland forest, quite dense.	*Site:* Grown in dense mixed forest.
Soil: Sandy.	*Soil:* Sandy, with sandy subsoil.

Legend.

D. Denotes density or specific gravity of the dry wood.
W. Denotes percentage of water in the fresh wood, related to its weight.
S. Denotes percentage of shrinkage in kiln drying.
R. W. Denotes width of ring (average) in millimeters (25 mm. = 1 inch).
S. W. Denotes percentage of summer wood as related to total wood.
Roman numbers refer to number of disk, placed in position of disk.

Height is given in feet from the ground; scale, 10 feet = 2 inches.
Radius, north and south (dotted line), in millimeters; scale, 10 mm. = 0.1 inch.
Median line represents the pith.
Right-hand numbers relate to north side, left-hand numbers to south side.
Outer lines represent outlines of trees.

summer wood are marked on paper with the aid of the camera, and thus a panorama of the entire section is brought before the eye. The histology of the wood, the resin ducts, the tracheids and medullary rays, their form and dimensions, are studied in thin sections magnified 580 diameters and even more. Any peculiarity in form or arrangement is drawn with the camera and thus graphically recorded; the dimensions are measured in the manner described for the measurement of the summer wood, or with the ocular micrometer. In measuring cell walls the entire distance between two neighboring lumina is taken as a "double wall," the thickness of the wall of either of the two cells being one-half of this. The advantage of this way of measuring is apparent, since the two points to be marked are in all cases perfectly clear and no arbitrary positions involved. The length of the cells is found in the usual way by separating the elements with Schultze's solution (nitric acid, chlorate of potassium). All results tabulated are averages of not less than ten, often of more than one hundred, measurements.

In the attempt to find the quantitative relations of the different tissues, as well as the density of each tissue, various ways have been followed. In some cases drawings of magnified sections were made on good, even paper, the different parts cut out, and the paper weighed. In other cases numerous measurements and computations were resorted to. Though none of the results of these attempts can be regarded as perfectly reliable, they have done much to point out the relative importance of different constituents of the wood structure, and also the possibility and practicability, and even the necessity, of this line of investigation.

INSTRUCTIONS AND BLANK FORMS, WITH ILLUSTRATIVE RECORDS.

Instructions for the Collection of Test Pieces of Pines for Timber Investigations.

A.—OBJECT OF WORK.

The collector should understand that the ultimate object of these investigations is, if possible, to establish the relation of quality of timber to the conditions under which it is grown. To accomplish this object he is expected to furnish a very careful description of the conditions under which the test trees have grown, from which test pieces are taken. Care in ascertaining these and minuteness and accuracy of description are all-important in assuring proper results. It is also necessary to select and prepare the test pieces exactly as described and to make the records perfect as nearly as possible, since the history of the material is of as much importance as the determination in the laboratory.

B.—LOCALITIES FOR COLLECTING.

As to the locality from which test trees are to be taken, a distinction is made into station and site.

By station is to be understood a section of country (or any places within that section) which is characterized in a general way by similar climatic conditions and geological formation. "Station," then, refers to the general geographical situation. "Site" refers to the local conditions and surroundings within the station from which test trees are selected.

For example, the drift deposits of the Gulf Coast plain may be taken for one station; the limestone country of northern Alabama for a second. But a limestone formation in West Virginia, which differs climatically, would necessitate another station. Within the first station a rich, moist hummock may furnish one site, a sandy piece of upland another, and a wet savannah a third. Within the second or third station a valley might furnish one site, the top of a hill another, a different exposure may call for a third, a drift-capped ledge with deeper soil may warrant the selection of another.

Choice of stations.—For each species a special selection of stations from which test pieces are to be collected is necessary. These will be determined, in each case separately as to number and location, from this office. It is proposed to cover the field of geographical distribution of a given species in such a manner as to take in stations of climatic difference and different geological horizon, neglecting, however, for the present, stations from extreme limits of distribution. Another factor which will determine choice is character of soil, as dependent upon geological formations. Stations which promise a variety of sites will be preferably chosen.

Choice of site.—Such sites will be chosen at each station as are usually occupied by the species at any one of the stations. If unusual sites are found occupied by the species at any one of the stations it will be determined by special correspondence whether test pieces are to be collected from it. The determination of the number of sites at each station must be left to the judgment of the collector after inspection of the localities; but before determining the number of sites the reasons for their selection must be reported to this office. The sites are characterized and selected by differences of elevation, exposure, soil conditions, and forest conditions. The difference of elevation which may distinguish a site is provisionally set at 500 feet; that is, with elevation as the criterion for choice of stations the difference must be at least 500 feet. Where differences of exposure occur a site should be chosen on each of the exposures present, keeping as much as possible at the same elevation and under other similar conditions. Soil conditions may vary in a number of directions, in mineral composition, physical properties, depth, and nature of the subsoil. For the present, only extreme differences in depth or in moisture conditions (drainage) and decided difference in mineral composition will be considered in making selection of sites.

Forest conditions refer, in the first place, to mixed or pure forest, open or close stand, and should be chosen as near as possible to the normal character prevailing in the region. If what, in the judgment of the collector, constitutes normal conditions are not found, the history of the forest and the points wherein it differs from normal conditions must be specially noted.

C.—CHOICE OF TREES.

On each site five trees are to be taken, one of which is to serve as "check tree." None of these trees are to be taken from the roadside or open field, nor from the outskirts, but all from the interior of the forest. They are to be representative average trees—neither the largest or best nor the smallest or worst, preferably old trees and such as are not overtopped by neighbors.

The "check tree," however, should be selected with special care, and should represent the best-developed tree that can be found, judged by relative height and diameter development and perfect crown.

The distance between the selected trees is to be not less than 100 feet or thereabout, yet care must be exercised that all are found under precisely the same conditions for which the site was chosen.

There are also to be taken six young trees as prescribed under E.

If to be had within the station, select two trees from 30 to 60 years old or older, which are known to have grown up in the open, and two trees which are known to have grown up in the forest, but have been isolated for a known time of ten to twenty years.

D.—PROCEDURE AND OUTFIT.

The station determined upon, the collector will proceed to examine it for the selection of sites. After having selected the sites, he will at once communicate the selection, with description and justification, to this office, negotiate with the owners of the timber (which might be done conditionally during the first examination) for the purchase or donation of test trees; and the latter arrangements completed, without waiting reply from this office, he will at once proceed to collect test pieces on one of the sites in regard to the selection of which he is not in doubt.

To properly carry out the instructions, the following assistants and outfit may be required:

(1) Two men[1] with ax and saw; a boy also may be of use.

(2) Team, wagon, and log trucks for moving test pieces and logs to station.

(3) Frow or sharp hacking knife for splitting disks. Heavy mallet or medium-sized "maul" to be used with frow.

(4) A handsaw.

(5) Red chalk for marking. (A special marking hammer will be substituted.)

(6) Tape line and 2-foot rule or calipers.

(7) Tags (specially furnished).

(8) Tacks (12-ounce) to fasten tags.

(9) Wrapping paper and twine.

(10) Franks for mailing test pieces (specially furnished).

(11) Shipping tags for logs.

(12) Scales, with weight power not less than 30 pounds.

(13) Barometer for ascertaining elevations.

(14) Compass to ascertain exposures.

(15) Spade and pick to ascertain soil conditions.

(16) Bags for shipping disks.

E.—METHOD OF MAKING TEST PIECES.

(a) *Mature trees.*

(1) Before felling the tree, blaze and mark the north side.

(2) Fell tree with the saw as near the ground as practicable, avoiding the flare of the butt and making the usual kerf with the ax opposite to the saw, if possible, so as to avoid north and south side. If necessary, square off the butt end.

(3) Before cutting off the butt log mark the north side on the second, third, and further log lengths.

(4) Measure off and cut logs of merchantable length and diameters, beginning from the butt, noting the length and diameters in the record.

Should knots or other imperfections, externally visible, occur within 8 inches of the log mark, make the cut lower down or higher up to avoid the imperfection.

(5) Continue measuring the full length of the tree and record its length. Note also distance from the ground and position on the tree (whether to the north, south, west, east) of one large sound limb. Mark its lower side and saw it off close to the trunk and measure its length and record it, the limb to be utilized as described later.

If the tree after felling prove unsound at the butt, it will be permissible to cut off as much or as little as necessary within the first log length. If sound timber is not found in the first log, the tree must be discarded. Only sound timber must be shipped. Any logs showing imperfections may be shortened. Be careful to note change in position of test pieces.

(6) Mark butt end of each log with a large N on north side. Saw off squarely from the bottom end of each log a disk 6 inches long, and beyond the log measure cut off disks every 10 feet up to 2-inch diameter. Place each disk

[1] Only men familiar with felling and cutting timber should be chosen.

on its bottom end, and after having ascertained and marked the north and south line on top end. Split the disk with a sharp hacking knife and mallet along this line. Split from outside of the west half of the disk enough wood to leave a prism 4 inches thick. Split from the east half two wedges with one plane in the south-north line and with their wedge line through the heart of the disk; the outer arc to be about 4 inches.

Mark each piece as split off on top side with number of the tree (Arabic), the serial number (Roman) of the disk in the tree, beginning with No. 1 at butt log, and with a distinct N or S, the north or south position of the piece as in the tree.

Write the same data on a card and tack it to the piece to which they belong. Whenever disk pieces are small enough for mailing, leave them entire. Whenever they can not be shipped by mail, leave disks entire, wrap in paper, and ship by express.

(7) Weigh each piece and record weight in notebook, using the same marks as appear on the pieces.

(8) Wrap each piece in two sheets of heavy wrapping paper and tie securely.

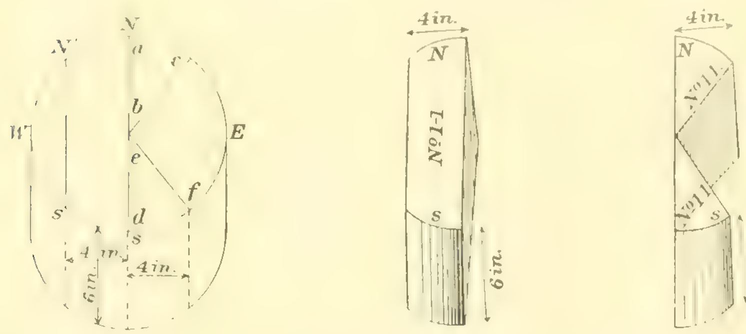
(9) Mark on the newly cut bottom end of each log with a heavy pencil a north and south line, writing N on the north and S on the south side of the log, large and distinct. Also mark centrally with an Arabic number on each log the number of the tree in the series, and with a distinct Roman number the serial number of the log in the tree, counting the butt log as first.

Tack to the butt end of each log securely a card (centrally), on which is written name of tree, species, locality from which tree is taken, denoted by the letter corresponding to that used in the notebook, number of tree, and section. This card or tag is intended to insure a record of each log in addition to the marking already made.

(10) *Limb wood.*—Having, as before noted, selected a limb, measured and recorded its distance from the butt and position on the trunk, and marked its lower side and sawed it off close to the latter, now take a disk 6 inches long from the butt end and others every 5 feet up to 2-inch diameter at the top. Number these consecutively with Roman number, calling the butt disk No. 1. Note by letters L and U the lower and upper side, as the limb appeared on the tree, and place the (Arabic) number of tree from which the limb came on each. Enforce the record by cards containing the same information, as done in case of other disk pieces.

Weigh and wrap and mail in the same manner as the other pieces.

(11) *Check trees.*—From the "check tree," which is to be the very best to be found, only three disks or three logs are to be secured, from the butt, middle, and top part of the tree Absolutely clear timber, free from all knots and blemishes, is to be chosen. The disk pieces are to be of the same size, and to be secured in the same manner as those described before; the logs to be not necessarily more than 6 feet; less if not enough clear timber can be found.



Note the position of each piece in the tree by measuring from the butt cut to the butt end of the piece.

Prepare and mark all pieces in the same manner as those from other trees, adding, however, to each piece a × mark to denote it as coming from the "check tree."

(12) *Young trees.*—Select six trees from each site approximately of following sizes: Two, 6-inch diameter, breast high; two, 4-inch diameter, breast high; two, 2-inch diameter, breast high. Mark north and south sides and chop or saw all close to the ground and cut each tree into following lengths: First stick, 2 feet long; second stick, 4 feet long; the remaining cuts 4 feet long up to a top end diameter of about 1 inch. Cut from the basal end of each log a disk 6 inches long. Mark and ticket butt end of each log as in case of large trees. Mark a north and south line on *top* end of each disk, with N and S at extremities to denote north and south sides; and also ticket with same data as given on large disk pieces. Weigh and wrap as before. Of these trees only the disk pieces are to be mailed.

F.—SHIPPING TEST PIECES.

Ship all pieces without delay. To each log tack securely a shipping card (furnished), so as to cover the marking tag. The logs will go to J. B. Johnson, St. Louis, Mo. The disks and other pieces are to be mailed to F. Roth, Ann Arbor, Mich., using franks, securely pasted, for mailing, unless, as noted before, they must be sent by express.

Mail at once to the above addresses notice of each shipment, and a transcript of notes and full description to this office, from which copies will be forwarded to the recipients of the test pieces.

If free transportation is obtained from the railroad companies, special additional instructions will be given under this head.

G.—RECORDS.

Careful and accurate records are most essential to secure the success of this work. A set of specially prepared record sheets will be furnished, with instructions for their use. A transcript of the record must be sent to this office at the time of making shipment; also such notes as may seem desirable to complete the record and to give additional explanations in regard to the record and suggestions respecting the work of collecting. Original records and notes must be preserved, to avoid loss in transmission by mail.

FORM OF FIELD RECORD.

(Folder.)

Name of collector: (Charles Mohr.) Species: Pinus palustris.

STATION (denoted by capital letter): A.

State: Alabama. County: Escambia. Town: Wallace.

Longitude: 86° 12′. Latitude: 31° 15′. Average altitude: 75 to 100 feet.

General configuration: Plain—hills—plateau—mountainous. General trend of valleys or hills ....

Climatic features: Subtropical; mean annual temperature, 65°; mean annual rainfall, 62 inches.

SITE (denoted by small letter): a.

Aspect: Level—ravine—cove—bench—slope (angle approximately).

Exposure: .... Elevation (above average station altitude): 125 feet.

Soil conditions:

(1) Geological formation (if known): Southern stratified drift.

(2) Mineral composition: Clay—limestone—loam—marl—sandy loam—loamy sand—sand.

(3) Surface cover: Bare—grassy—mossy. Leaf cover: Abundant—scanty—lacking.

(4) Depth of vegetable mold (humus): Absent—moderate—plenty—or give depth in inches.

(5) Grain, consistency, and admixtures: Very fine—fine—medium—coarse—porous—light—loose—moderately loose—compact—binding—stones or rock, size of..............................

(6) Moisture conditions: Wet—moist—fresh—dry—arid—well drained—liable to overflow—swampy—near stream or spring or other kind of water supply ....

(7) Color: Ashy-gray.

(8) Depth to subsoil (if known): Shallow, 3 to 4 inches to 1 foot—1 foot to 4 feet, deep—over 4 feet, very deep—shifting.

(9) Nature of subsoil (if ascertainable): Red, ferruginous sandy loam; moderately loose, or rather slightly binding; always of some degree of dampness; of great depth.

Forest conditions: Mixed timber—pure—dense growth—moderately dense to open.........................

Associated species: None.

Proportions of these..

Average height: 90 feet.

Undergrowth: Scanty; in the original forest often none.

Conditions in the open: Field—pasture—lawn—clearing (how long cleared): In natural clearings untouched by fire, dense groves of second growth of the species.

Nature of soil cover (if any): Weeds—brush—sod.

(Inside of folder.)

STATION: A. SITE: a. SPECIES: P. palustris. TREE No. 3.

POSITION of tree (if any special point notable not appearing in general description of site, exceptional exposure to light or dense position, etc., protected by buildings, note on back of sheet): In rather dense position.

ORIGIN of tree (if ascertainable): Natural seedling, sprout from stump, artificial planting.

DIAMETER breast high: 16 inches.
HEIGHT to first limb: 53 feet.
AGE (annual rings on stump): 183.

HEIGHT of stump: 20 inches.
LENGTH of felled tree: 110 feet 4 inches.
TOTAL height: 111 feet 8 inches.

No. of disk.	Distance from butt.	Weight of combined disk pieces.	Remarks.
	Feet.	*Pounds.*	
I................	0	27	Crown touching those of nearest trees to the N. and NE. Open toward SW.
II	13	20	
III................	19	20	
IV................	32	18	
V................	47	16	
VI................	57	14	
VII................	67	17	
VIII................	77	14	
IX................	87	9½	
X................	97	6	

No. of log.	Distance from butt.	Length of log.	Diameter, butt end.
	Ft. In.	*Ft. In.*	*Inches.*
I......	8 0	12 4	16¾
II......	13 8	5 4	14½
III......	19 8	12 4	14
IV......	32 8	14 4	13½
V......	47 8	9 4	12¾
VI......	57 8	9 4	11⅛
VII......	67 8	9 4	9¾
VIII......	77 8	9 4	8½

LIMBWOOD:

DISTANCE from butt: POSITION on trunk: TOTAL length:

NUMBER of disks taken:

NOTE.—As much as possible make description by underscoring terms used above. Add other descriptive terms if necessary.

SAMPLE RECORDS OF TESTS.

CROSS BREAKING TEST.

Mark, {116. 1. 3.} White pine.
Length, 60.0 inches.
Height, 3.74 inches.
Breadth, 3.75 inches.

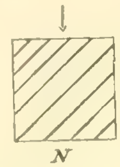
Strength of extreme fiber,

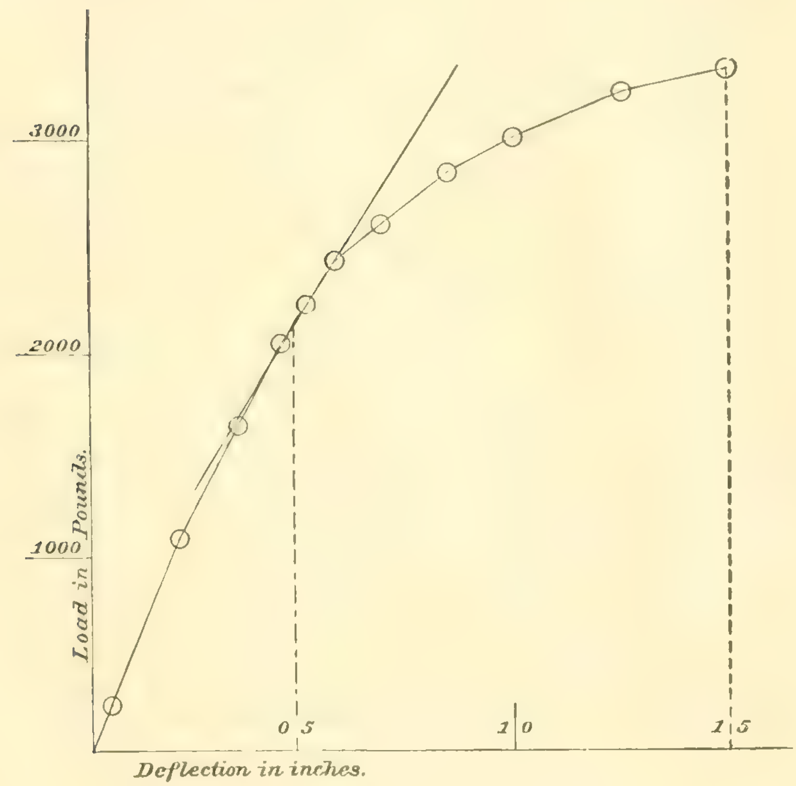
where $f=\frac{3}{2}\frac{W\,l}{b\,h^2}$=5,660 pounds per square inch.

Modulus of elasticity =1,320,000 pounds per square inch.
Total resilience =3,460 inch-pounds. El. Res., 550.
Resilience, per cubic inch =4.11 inch-pounds. El. Res., 0.65.

[Number annual rings per inch=19.]

July 18, 1891.	Load.	Deflection.	Micrometer.	Remarks.
h. *m.*				
4 24	.200	.042	0.757	
25	1,000	.211	0.926	
26	1,600	.300	1.065	
27	2,000	.454	1.169	
28	2,200	.511	1.226	
29	2,400	.595	1.310	
31	2,600	.690	1.405	
33	2,800	.853	1.568	
35	3,000	1.015	1.730	
37	3,200	1.276	1.991	
40	3,300	1.521	2.236	Maximum load.





CROSS BREAKING TEST.

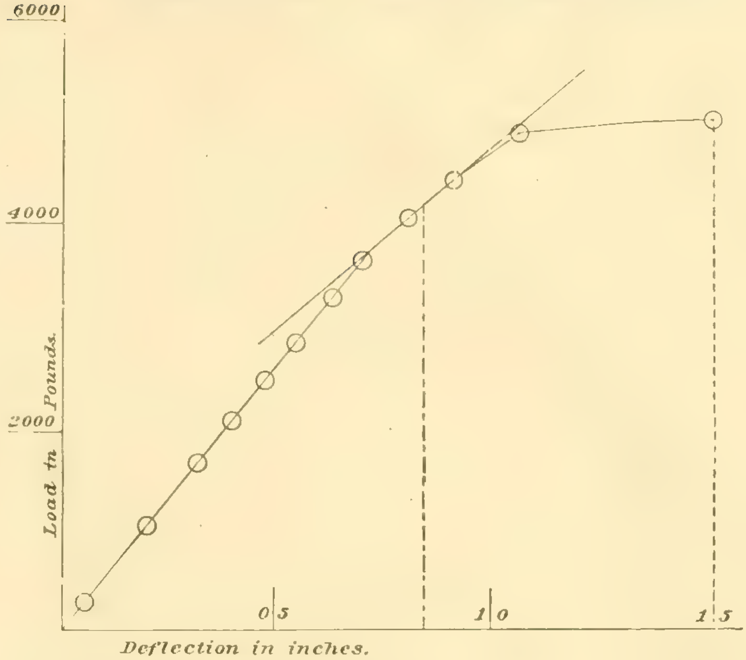
Mark, {3. 3. 1.} Longleaf pine.

Length, 60.0 inches.
Height, 3.50 inches.
Breadth, 3.72 inches.

Strength of extreme fiber;
where $f=\frac{3}{2}\frac{Wl}{bh^2}$=10,230 pounds per square inch.
Modulus of elasticity =1,760,000 pounds per square inch.
Total resilience 5,110 inch-pounds. El. Res., 1,780.
Resilience, per cubic inch =6.54 inch-pounds. El. Res., 2.28.

[Number annual rings per inch=23.]

July 20, 1891.	Load.	Deflection.	Micrometer.	Remarks.
h. m.				
2 58	200	.042	0.958	
3 0	1,000	.208	1.124	
1	1,600	.324	1.240	
2	2,000	.404	1.320	
3	2,400	.481	1.397	
4	2,800	.558	1.474	
5	3,200	.640	1.556	
6	3,600	.721	1.637	
7	4,000	.815	1.731	
8	4,400	.926	1.842	
9	4,800	1.074	1.990	
13	5,180	1.544	2.460	Maximum load



FINAL RECORD OF TIMBER TESTS.

Mark.	Percentage of moisture.	Cross bending test. Dimensions. Length.	Height.	Breadth.	Time.	Load.	Deflection.	Strength per square inch. (f)	Modulus of elasticity. (e)	Resilience in inch-pounds per cubic inch. (r)
		Inches.	*Inches.*	*Inches.*	*Min.*	*Pounds.*	*Inches.*	*Pounds.*	*Pounds.*	
Longleaf pine: 3 / 3 / 1	16.8	60.0	3.50	3.72	15	5,180	1,544	10,230	1,760,000	6.54
White pine: 116 / 1 / 3	54.3	60.0	3.74	3.75	16	3,300	1,521	5,660	1,320,000	4.11

Mark.	Crushing endwise. Dimensions. Height.	Cross section.	Area.	Crushing load.	Strength per square inch.	Crushing across grain. Dimensions. Height.	Cross section.	Area.	Crushing load.	Strength per square inch.
	Inches.	*Inches.*	*Sq. in.*	*Pounds.*	*Pounds.*	*Inches.*	*Inches.*	*Sq. inch.*	*Pounds.*	*Pounds.*
Longleaf pine: 3 / 3 / 1	8.1	3.46 / 3.72	12.87	77,700	6,040	3.73	3.47 / 3.93	13.63	10,400	760
White pine: 116 / 1 / 3	7.6	3.73 / 3.73	13.91	48,400	3,480	3.72	3.72 / 3.93	14.62	5,200	360

Mark.	Tension tests. Size of reduced section.	Area.	Breaking load.	Strength per square inch.	Shearing tests. Total shearing area.	Breaking load.	Shearing strength.
	Sq. inch.	*Sq. inch.*	*Pounds.*	*Pounds.*	*Sq. inch.*	*Pounds.*	*Pounds.*
Longleaf pine: 3 / 3 / 1	2.38 / .41	0.976	11,400	11,680	4.14 / 3.97	2,280 / 2,580	551 / 650
White pine: 116 / 1 / 3	2.52 / .45	1.134	11,200	9,880	4.16 / 4.02	1,700 / 1,600	409 / 398