U. S. DEPARTMENT OF AGRICULTURE.
FORESTRY DIVISION.
BULLETIN No. 6.

TIMBER PHYSICS.

PART I.

PRELIMINARY REPORT.

1. NEED OF THE INVESTIGATION.
2. SCOPE AND HISTORICAL DEVELOPMENT OF THE SCIENCE OF "TIMBER PHYSICS."
3. ORGANIZATION AND METHODS OF THE TIMBER EXAMINATIONS IN THE DIVISION OF FORESTRY.

COMPILED BY
B. E. FERNOW,
CHIEF OF FORESTRY DIVISION.

PUBLISHED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1892.

CONTENTS.

ILLUSTRATIONS AND PLATES

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF FORESTRY,
Washington, D. C., February 1, 1892.

SIR: I have the honor herewith to submit for publication the first of a series of bulletins which are to record the results of an extensive investigation into the nature of our important woods, especially their mechanical and technical properties, and the dependence of these upon structure and physical condition and upon the conditions under which the wood was grown.

The present bulletin is entirely preliminary in its nature. Its object is to serve as a basis for the work which is to follow and is partly begun. It discusses the need, object, and scope of the investigation, gives references to the work which has preceded the present investigations, and explains the methods pursued in these latter, including the forms of record and illustrations of the machinery in use.

Respectfully,

B. E. FERNOW,
Chief of Forestry Division.

Hon. J. M. RUSK,
Secretary.

TIMBER PHYSICS.

NEED OF THE INVESTIGATION.

INTRODUCTORY.

Scientific research is satisfied with its results without any reference to their practical application. Increase of knowledge is its self-sufficient aim. Whether this may in the end bring us an increase of power to control nature's forces or to utilize them to better advantage is not the concern of science, and yet all increase of this power has come directly or indirectly from such scientific research. Acknowledgment of ignorance, then, from a scientific point of view, is sufficient to establish the need of an investigation. From a practical and economic point of view, however, it would still remain necessary to point out whether and why the need is a pressing one and what direct benefits may be expected from such an investigation.

It will be admitted by all who have to handle wood in building, engineering, and manufacturing, that our knowledge regarding the properties of our various timbers is not very satisfactory, and that while attempts more or less systematic have been made to determine these properties, and knowledge gained from experience exists among those who have handled certain classes of woods for certain purposes, there does not exist much reliable published information for general use.

It is also a well-known fact that from this ignorance of the value of our varied timber wealth. and its special adaptation to particular uses, large quantities of valuable material have been wasted. Everybody is familiar with the waste of our fine black walnut timber for fence rails, posts, and firewood. Until twelve or fifteen years ago many million feet of hemlock were left to rot in the woods, after the bark had been taken for tanning purposes, or this timber was not cut at all because its value for building purposes was not understood or was underrated.

In Alabama, along the Louisville and Nashville Railroad, a few years ago a large amount of chestnut oak was felled for the tan bark alone, the wood of the trees being allowed to rot, because railroad people did not know its value for railroad ties. The Division of Forestry, by a little circular, called their attention to the superiority of this timber for tie purposes, and now the wood is utilized, and thus for this region alone a saving of from $40,000 to $50,000 annually was effected, or more than three to four times as much as the annual appropriations for the Division of Forestry.

Even now many thousand cords of this valuable wood are lost there and in other regions when the bark is taken for tanning purposes, while the wood itself, which contains as much and more tannic acid per cord than the bark, is left unused, because it can not be profitably transported in its original form. Presently a new wealth will be developed for the tanners, where it was not looked for.

Our railroad system requires annually 80,000,000 ties, costing the railroad companies about $30,000,000. Their life in the average may be computed at six and one-half years. There are means of doubling their life easily by using only the more durable kinds, paying proper attention to the handling of the ties and by impregnation with fungus-resisting materials or by other processes. Such increase of durability may be obtained by an expenditure of, say, $20,000,000, by which an annual saving of more than $5,000,000 would be effected, or 25 per cent on the additional outlay. These figures are extremely conservative and the advantage might readily be doubled. We could multiply such examples of wasteful practice in every direction, arising at least in part from lack of knowledge.

It would be impossible to estimate the direct and indirect losses which the country suffers from our ignorance as to the true values and strength of our building timbers. Such losses occur by using kinds unsuited for given purposes, or by employing either more or else less timber than necessary. Engineers and architects are fully aware of this deficiency in our knowledge, which approaches "a state of ignorance" remarkable to contemplate when it is considered that timber has always been a foremost building material.

To make good this assertion a résumé of some hundred letters received by the Department from leading engineers, scientific societies, and others is appended to this report, which, while strongly favoring the thorough investigation of our timbers, are of interest also as showing the multiplicity of directions in which the work would be of benefit.

Not only are our engineers' tables, giving values of strength, uncertain, unreliable for practical use, based upon European timbers, etc., but probably not one in a hundred engineers or architects, who specifies timber for work, is capable of determining whether a given stick of timber is or is not capable of doing the duty it is designed to do. Even if he recognizes the species of timber, which he rarely can do with accuracy, he would fail to recognize any relation between the appearance or structure of the material and its expected or desired quality. And if he be better informed than the majority it will be only through dearly-bought experience. Empiricism in this branch of engineering still reigns supreme.

It is only six years ago that Prof. Lanza showed that tests made on small specimens, and on which our tables for engineers' use are based, may give results more than twice as high as those made on full-sized sticks; and although a factor of safety of 4 may have been applied in the specification, when it is found that material may have actually a strength 50 per cent less than that given in the tables, we may often strain our material, without knowing it, to its full capacity and feel safe in so doing.

The following statement, which occurs in one of the letters referred to, may serve as an illustration. Mr. D. H. Burnham, engineer of construction for the World's Columbian Exposition, writes:

> When I was appointed engineer of construction, World's Columbian Exposition, August 1, I found it necessary to make changes in most of the buildings because I did not dare to use as high unit stress in timber as was used by my predecessor, although he claimed to be perfectly safe in his strains, and brought forward authorities—Trautwine and others—to prove his statements.

Inquiries from woodworkers in all branches show that the same lack of reliable knowledge exists with regard to the adaptation of woods to technical purposes. Especially are the ideas as to the relation of properties to structure, physical condition, locality of growth, etc., entirely at variance and lacking a sound basis derived from accurate observation and research. It would then appear that from a practical point of view the need for an investigation exists, the more so since our forest resources begin more decidedly to show the signs of lavish wastefulness, and proper economy would dictate a more careful employment of our wood materials.

Lastly, since we are beginning to plant forests and since foresty does not concern itself with the production of wood simply, but is to produce wood of given quality, we need this knowledge in order to proceed intelligently in the selection of plant material with reference to locality and in order to be able to control in a measure the quality of the product.

It is of interest to inquire why our ignorance exists and has prevailed so long, and to find out what is necessary in order to remove it.

There is one important factor of difference between other materials of construction and timber. It is the factor of life. Life means variety, change, variability. Each individual differs from every other in its development, and each part of the individual differs from its other parts in structure, and hence in qualities. Each living tree of the same species, therefore, converted into building material offers a different problem as to its properties, especially its strength, and each stick taken from a different part of the tree shows different quality.

This endless variability it is that has kept us in ignorance as to the capability of our timbers. While, by experience, we have learned that these differences exist, and even learned to find some relations between physical appearances, anatomical structure, and mechanical properties, the enormity of the enterprise has baffled investigators and deterred them from carrying on, in a systematic and comprehensive manner, such tests and examinations as would furnish us not only with reliable data as to the range of capacity of our timbers, but also as to the exact relation of their properties to their structure and physical condition.

In order to establish fully for any one species the possibilities of its adaption to our use, it is necessary to test a very large number of specimens. In order to formulate laws of relation between physical condition, anatomical structure, and mechanical properties, each test specimen must be carefully examined. In order to establish laws of relation between the physical and mechanical qualities and the conditions under which the specimen has grown, it is necessary to perform the testing and the examination on a large number of specimens of known origin.

Almost all the investigations made in this line are deficient in one or more or all of those points. Not only have there been few tests made on a sufficient quantity of material to allow generalization, but rarely have there been sufficient data furnished regarding the nature and origin of the test specimens to enable us to form a judgment.

Whatever laws of interrelation between physical structure and mechanical properties have been established or indicated, we owe almost entirely to European investigators on European timbers. Our engineers' tables are mainly made up from European sources, and while the extensive tables of the Tenth Census, prepared by Prof. C. E. Sharples, give us an indication as to the relative values of our many species, they can hardly claim to furnish data for practical application; in fact the author himself distinctly disclaims this. Anyhow, no attempt has been made to find out the causes of variation in properties or even to give data from which argument might proceed or a relation between properties and structure might be inferred.

It is to supply this absolute gap in our knowledge—which causes thousands and millions of dollars of waste annually—that the Forestry Division has entered upon a comprehensive and systematic investigation which has become known under the name of "the Government timber tests."

This investigation, the most comprehensive of the kind ever undertaken anywhere, in this country or in Europe, differs from all former attempts in similar direction in this, that it starts out with the fullest recognition of three facts:

(1) That in order to establish reliable data as to mechanical properties of our timbers, it is necessary to make a very large number of tests, by which the range as well as average capabilities of the species is determined.

(2) That in order to enable us to make the most efficient practical application of the data thus obtained, it is necessary to know the physical and structural conditions of the test material and bring these into relation with the best results.

(3) That in order further to deduce laws of relation between mechanical properties and the physical and structural conditions, as well as the conditions under which the material was produced, it is necessary to work on material the history of which is thoroughly known.

Briefly, then, to solve the problems before us, it is necessary to make our tests on a large number of specimens of known origin and known physical condition. While the tests in themselves appeal at once and first to the engineer, inasmuch as, by their great number, they will furnish more reliable data regarding the capabilities of the various timbers, the chief value and most important feature of the work lie in the attempt to relate the mechanical properties to the structure of the material and to the conditions under which it was produced.

We are not only concerned to know that a stick of this species of tree will bear a given load but we want to be able to tell why this stick of the species will bear so much and why the other stick of the same species will bear only half as much; why the timber grown in this locality is found generally superior to that of the same species grown in another locality, etc.

When we have established such knowledge, then it will be possible for an engineer not only to specify his timbers intelligently, but also to inspect them and to know whether or not they come up to his specifications. To be sure, we are not now quite without some knowledge regarding these matters, although few users of wood seem aware of it. But not only is this knowledge scanty, it is not quite certain or capable of general application, and the results and deductions of one investigator may often be found contradicted by another or by the same authority after further investigation. We know that there are differences in quality, at least for some timbers, in sticks from different parts of the tree: not only the heartwood differs from the sapwood, but also the butt log from the top log.

While some experiments would lead us to believe that specific weight is a fair expression of the strength of timber of the same species, yet it would be hazardous to rely upon this factor without regard to other physical conditions and structural features of the timber.

Such "ring-porous" woods as the oaks and ash show the greatest strength and elasticity when their annual rings are wide, while the slow-grown mountain oak seems to excel in stiffness. From conifers, on the other hand, according to Hartig, the slow-grown timbers seem to exhibit superior quality; hence those from rich soils are not desirable. This again has appeared doubtful, or at least true only within unknown limits, from Bauschinger's experiments, who showed that tensile strength in pines was independent of the total width of the annual ring, but dependent on the ratio between the spring wood and summer wood.

That wet soil produces brittle, dry or fresh soils tough timber, is believed but needs proof. Contrary to general opinion, the time of felling seems to be without influence on the strength of pines. The degree of seasoning, on the other hand, seems to increase the strength, although it would still have to be found out whether the manner and rapidity of seasoning may not change this result. Toughness or capacity for bending without rupture, on the contrary, is claimed to be inversely proportionate to seasoning.

Carriage-makers claimed "that the white oak when grown in the South loses its peculiar toughness, by which it excels in the North." We have shown by actual tests that this is not the case, and claim the exact opposite from physiological reasons.

ABSTRACTS OF LETTERS.

The following abstracts of letters from engineers, scientific societies, and others, regarding the timber studies and tests instituted in the division of Forestry, received by the Department of Agriculture, are given in this connection as showing the interest manifested in the subject under consideration. The high professional standing of the writers, together with their strong expressions regarding the importance and value of the investigation and the diversity of interests involved in this work, form the best argument that could be given for the need of the investigation. For ease in following the arguments adduced, the letters have been grouped under general headings in *italics* expressive of the main ideas therein contained.

(1) The information now available regarding the value, properties, and adaptations of our timbers is scanty in amount and unreliable in character.

O. Chanute, consulting engineer, president Am. Soc. C. E., Chicago, Ill.:

As a civil engineer of some forty years of practice I have become aware how little is really known concerning the conditions under which the best results can be secured from commercially useful timbers, and I am glad that your Department has begun its investigations with the southern pines and oaks, which must hereafter largely be drawn upon to supply the place of similar woods now being exhausted in the North. The value of such investigations depends so largely upon the competency of the men who are intrusted with them that it was undoubtedly wise for Congress to start with a small appropriation, so that something might be known of the probable results before expending any considerable sums. From my personal knowledge, however, of the thoroughness of Mr. B. E. Fernow, and Prof. J. B. Johnson, of St. Louis, I am convinced they will accomplish valuable results, and I hope you will recommend sufficient appropriation by Congress to enable us to know within a year what practical results are to be expected from the investigation. I, for one, shall be very glad to place at the disposal of your Department, without charge, any information which I have thus far gathered, and I think that the experience gained by those who have handled certain classes of woods, for certain purposes, will be also freely at your disposal.

M. H. Rogers, chief engineer, Denver and Rio Grande Railway Company, Denver, Colo.:

When the fact is considered that the information published on this subject at present, even in our most advanced works on engineering, is very meager and unsatisfactory, more especially since such tests as have been made are with reference to the superior specimens of the different species of woods and that a great many of our native timbers are omitted altogether, but little further argument is needed to show the advisability of such investigations by the Department. Since the work will be conducted by experts under the direction of the Government, the results will be most satisfactory and become an invaluable standard for engineers and others in the construction of all works wherein wood forms an important part.

J. D. Hawks, chief engineer, Michigan Central Railroad Company, Detroit, Mich.:

I have been engaged for twenty years on various railroads in the United States and Canada, and during that time have found a great lack of reliable information about timber. Questions are continually arising as to the lasting qualities and the strength of different timbers. I know from the numerous inquiries from railroad officers that others are bothered by this lack of precise information. * * * It is a very expensive matter for us to be compelled to learn the facts as to strength and lasting qualities of all these timbers by experience. If the Government would undertake these tests for the people it would be a very great assistance, not only to the railroads, but to other users of timber, as well as those who have timber to sell.

L. L. Randolph, engineer of tests, Baltimore and Ohio Railroad Company, Baltimore, Md.:

The information which exists upon this subject is extremely meager, being made up from the incomplete work of a number of different investigators, who have been hampered by lack of means from going into the subject as deeply as they wished and the importance of the subject demands. We are using in many cases more timber than should be used, on account of a lack of knowledge of its strength and other properties, and in some cases are running risks which should not be taken, relying on incomplete investigations. The investigations made by the Board appointed to test iron and steel have been so very valuable to the engineers of the country that it has shown all the very great necessity for similar work on timber.

H. S. Jacoby, professor of graphics and bridge engineering, Cornell University, Ithaca, N. Y.:

I was interested quite recently in a brief description, in one of the engineering papers, of the series of tests which your Department has inaugurated relative to the strength of American timbers. In my class work in structural details I am constantly reminded of the very meager knowledge concerning the strength of even a few species of woods that is now available in the designing of wooden structures. Such investigations made with special care, on an extensive plan, are essential to economy in design.

J. C. Bland, Am. Soc. C. E., consulting engineer, Colorado Springs, Colo.:

I beg to say that the value to the engineering public, the railways, and the public at large will in my judgment be incalculable. Your intention to extend the tests to full-sized pieces as used in bridge construction is particularly admirable, such results being meager at present, as indeed are even reliable tests on small sized specimen pieces; also your purpose of determining the influence of continued services on pieces of bridge construction of known length of service, will, when carried out, put us in possession of highly valuable data now confined to the very few who have had opportunity to make such observations. It is not hard to see how this point affects the safety of the traveling public. In this part of the country we are compelled to use Oregon Fir for our best wooden bridges and trestles, the native pine being deficient in transverse strength, as well as short-lived, and concerning neither timber do we know much in a scientific way. Oak as a rule behaves badly in this climate; hence your purpose to determine "how far do climatic and soil conditions influence quality" is another point from which I expect valuable information. I can not state forcibly enough the very great value which I think such work as you intend undertaking will have.

James Dunn, chief engineer, Atchison, Topeka and Santa Fé Railroad Company, Topeka, Kans.:

The knowledge of the physical properties of American timber is very limited, particularly as refers to timber of the same variety growing in different localities and under different conditions, and the result of the tests will be of very great value to engineers, architects, and builders.

F. C. Osborn, chief engineer, King Iron Bridge and Manufacturing Company, Cleveland, Ohio:

I wish to urge upon you the importance of this investigation both in regard to consumers of timber and to engineering profession as well. * * * The data that are at present at hand in regard to strength of American timbers in various positions are very meager, and the large amount of timber used in connection with structures of importance makes it very desirable that some satisfactory results should be arrived at in regard to the strength of the same.

F. W. Skinner, Am. Soc. C. E., New York City:

There is a great scarcity of such data available for engineers, and as a bridge engineer I heartily appreciate its value and hope that it will be fully supported.

The Phœnix Bridge Company, engineers and builders of bridges, viaducts, etc., Phœnixville, Pa.:

We hope that these investigations may be continued until we have complete data in regard to the timbers used in construction. At present this information is very meager and the investigation undertaken by the Department of Agriculture will be watched with great interest. In the line of bridge construction the information secured by these tests will be particularly valuable.

(2) *The results of European tests, which form the principal basis of our engineers' tables, are inapplicable to timber grown here.*

G. Lindenthal, chief engineer North River Bridge Company, New York City:

There has not been so far an elaborate and continuous investigation of American timbers such as is now pursued by the Forestry Division, and the meagerness of data relating to the subject has been repeatedly the cause of great vexation and embarrassment to engineers. * * * The absence of authentic and reliable knowledge of the physical properties of American timbers has been the cause of great losses, by reason of incorrect application and design, mistaken judgment in the preservation of such timbers, and of their strength and durability. * * * The information engineers possess from similar tests in Europe naturally can not be applied to the timbers grown in this country, and we ought not to be behind in this respect the information of the "Old Country."

Thomas Egleston, professor of metallurgy, School of Mines, Columbia College, New York:

As a member of the committees of all the engineering societies of the United States, and at one time chairman of the committees of the American societies of mining, civil, and mechanical engineers in charge of this subject, I urged at great length the consideration of this subject by a commission to be appointed by the United States Government. It is one of the most important subjects connected with engineering, and I congratulate you on having undertaken a work whose results must be of such very great importance to the engineering profession in all parts of the world. I am also glad to see by the circular that you intend to do some work on the botanical side of the subject. During the time that I was working with the United States test commission, the extraordinary fact was brought out that at that time all the formulæ used in engineering for testing the strength of woods were based on the tests of a small column of Dantzic Oak of a variety which does not grow in the United States, and that these tests were altogether valueless. By stating the botanical name of the wood and the conditions under which it grew, these tests will become permanently valuable in the profession.

Thomas M. Cleeman, past president Engineers Club, Philadelphia, Pa.:

When the English formula of Mr. Hodgkinson, their greatest authority, was shown by Mr. Smith's experiments on large pillars to give results double what should be given, as stated in Trautwine's Pocket Book, engineers felt a longing for full, accurate, and modern experiments, on large sizes, that they might not be in any doubt as regards the strength of their work. The only method that will secure the information required is for the Government to seek it in the manner proposed. It is just such work that will keep it more in touch with the mass of the people.

G. Bouscaren, consulting engineer, Cincinnati, Ohio:

As one especially interested in the results of these investigations, I may be pardoned for expressing my appreciation of the same and the anxiety which I feel to see them carried out to the end and without any curtailment of the programme, which is admirably conceived. Timber is used as structural material in the United States to a much larger extent than in any other country, but American engineers and architects are still dependent in a large degree for a knowledge of its strength on experiments made by European investigators. These experiments do not generally agree, for the reason that they were made on timbers growing under different conditions of climate and soil, often cut from trees of different varieties and age, and treated in a different manner by the several experimenters. This simple statement of facts should suffice to show the great and urgent need of the work inaugurated by you, the results of which shall form a true scientific basis for a most important branch of the engineering art.

(3) *Experiments made on small and selected specimens give unreliable data for use in the case of large timbers.*

William H. Burr, vice-president Company of Constructing Engineers, New York:

It is true that a considerable number of examinations and tests have heretofore been made under the auspices of the Government, but almost or quite entirely on small and specially prepared specimens, quite different in character from the pieces of the same material used in engineering practice and in the entire field of structural operations. There are at present few results of investigations made under conditions which fit them to serve practical purposes. * * * Permit me to say, therefore, that I trust you will encourage, in every legitimate and proper manner, this physical and mechanical investigation of the different varieties of American timber; and I can confidently assure you that the engineering and building portion of the public will be served in a most efficient and valuable manner thereby.

John C. Trautwine, jr., C. E., Philadelphia, Pa.:

I beg to express my appreciation of the value of such experiments, and especially the importance of having them conducted on the most liberal scale. It is especially desirable that the tests should be made upon full-sized pieces, so as to approximate as nearly as possible to the conditions of actual service. Anything short of this would keep these experiments down to the level of tests made in the past and rob them of their crowning advantage.

Louis De Coppet Berg, architect, Trinity Building, New York:

I beg to say that I deem these tests of the utmost importance to architects and engineers. You will remember that up to within a few years ago we were using constants for the strength of timber which were proven by Prof. Lanza's limited tests on full-sized timbers to be utterly beyond the strength of the beams. These constants were derived from tests on small specimens, made by Hatfield and others, and if it had not been for the large factor of safety used many accidents would have happened. A series of tests such as you propose will give us an intimate knowledge of the action of our American timbers in large sizes when under strain, and will not only enable us to calculate more accurately and safely the strength of our buildings, but will prove a great economy to all builders in allowing us to use smaller factors of safety, which can safely be done where the actual strength and behavior of the timber are accurately known.

Rudolph Hering, M. Am. Soc. C. E., M. Inst. C. E., M. Can. Soc. C. E., New York City:

We need much more information regarding the qualities of timber for constructive purposes, and private enterprise can not give us results as extensive or impartial as can be obtained through the aid of the Government. It is true that we possess a great deal of information on the subject already, and for the most common cases in practice we are tolerably satisfied with the existing information as to tensile, compressive, and transverse strength of test pieces of the common timbers of our country. But we are lacking reliable information regarding such qualities in large beams as actually used in structures. We are not always safe in applying the results of small test pieces to large beams. We have likewise very imperfect knowledge concerning the durability of all the varieties of American timbers with reference to the conditions of growth, climate, moisture, and temperature. I should consider that in this direction particularly the benefits arising to the country from increased knowledge on the subject would be very large.

E. L. Corthell, C. E., Chicago, Ill., and Broadway, New York:

In my profession as a civil engineer I have, with others of my profession, felt the necessity of much more extensive and thorough tests of timber than have ever yet been made, at least in our country. The rules that have been given us in the books for the use of timber have been found to be, in many cases, unreliable, for the reason mainly that the experiments and tests have been made on small specimens instead of full-sized sticks. I have recently had my attention called to this while making an examination of the Massachusetts Institute of Technology, where tests are now being made on full sizes of timber with results varying in almost every instance from accepted formulæ. I therefore desire to express my interest in the work which you have undertaken, which, as I understand it, is an elaborate investigation of the physical properties of our timbers. This investigation, as I understand it, relates to the conditions of growth as well as to the uses of the timber. This is a work in which the entire country must necessarily be interested, for the works which we, as engineers, are building for commerce are for the use of the public, and it is of the greatest importance that when we use timber in bridges, buildings, and other works we use it properly and within safe limits of strain. Our General Government should not hesitate a moment in giving your Department all the funds it requires to make and to continue to make the most thorough investigations and tests of American timbers.

R. D. McCreary, engineer, Western New York and Penn. Railroad Company, Buffalo, N. Y.:

The data until recently relied upon by engineers in proportioning wooden structures were based in the main upon comparatively crude experiments with small and imperfect specimens of the various kinds of timber, and not upon the sizes nor the varying conditions of timber used in practice, and resulted in large factors of safety to cover known and unknown defects in the material used. A larger knowledge of the value of timber under the practical conditions of construction is much needed, and in my judgment your investigations and tests should be continued until this end is fully attained.

John R. Freeman, engineer department of inspections, adjustments, and surveys, Boston, Mass.:

For many years engineers have been using data derived wholly from extremely small specimens of selected woods, and the few tests which have already been made on large-sized sticks would indicate that the large sizes of timber, such as are commonly used in engineering structures of importance, will withstand scarcely half so great a breaking strain as our old data would indicate. I most earnestly hope that at the coming session of Congress such more liberal appropriations will be earnestly sought as will enable the work to be pushed vigorously forward.

Henry B. Seaman, C. E., 10 West Twenty-ninth street, New York City:

Constructors are in the greatest need of a series of tests of this kind, and the results will be invaluable to all who have occasion to use wooden structures, and to trust property or life to their safety. The engineering profession has for years used data obtained from small specimen tests, trusting to a judicious factor of safety to cover the deficiencies of experiment. More recent tests on large specimens, however, indicate that our former results were of little value, and in many cases have led to the use of timber strained dangerously near the breaking limit. That we may at last obtain definite and authoritative knowledge upon this subject is a source of congratulation, and the progress of the experiments will be watched with the greatest interest.

J. B. Davis, assistant professor civil engineering, University of Michigan, Ann Arbor, Mich.:

I hope now to see results from tests of commercial shapes and sizes, bought in the open market, substituted in our text-books and works of reference for those derived from plaything sticks (splinters really) chosen from the choicest spot in the best piece to be found.

(4) A better knowledge of the physical properties of woods will result in greater economy in the use of material, and less forest waste.

G. H. Thomson, engineer of bridges, New York Central Railroad, Am. Soc. C. E., M. I. C. E.:

The value of timber, viewed commercially alone, possibly may be well known, but the structural properties, durability, and suitability for the various purposes, etc., are not fully ascertained, so that consumers of large quantities of timber can not always construct timber work with ultimate economy, not knowing all the premises which should govern a conclusion involving large expenditures in timber. A better knowledge of the physical properties of woods would result in greater economy and less forest waste, a desideratum worthy of national consideration.

E. D. Meier, C. E., and president of Heine Safety Boiler Company, St. Louis, Mo.:

Having frequently been at a loss to determine just what strains timbers of various kinds may be safely called upon to bear, and having in fact been several times obliged to make hasty and crude tests of my own, I take the liberty to write you in hopes that you may find means to continue the very thorough tests you have begun. There are few things of so general value to all classes of the community, both those who build structures and those who live or travel over them, as a thorough knowledge of the timber which enters into their construction. We have, through the efforts of the War Department, a tolerably thorough knowledge of structural materials, composed mainly of steel or iron. But there are, and always will be, a large number of structures in which the engineer and the builder are obliged to rely mainly on timber. There are in this country some excellent examples of large timber spans in bridges which have stood the test of a century's travel, but in examining them we are struck very forcibly by the fact that an immense saving in material might have been effected had their builders been able to obtain a complete and accurate knowledge of the physical properties of the timbers they were obliged to use.

Edward Bates, engineer, Chicago, Milwaukee and St. Paul Railway Company, Chicago, Ill.:

Having in my charge something over 100 miles of wooden bridges, besides wooden buildings of all classes, I am competent to express an opinion that these tests will be extremely useful to engineers and others engaged in timber construction, and would like, as far as I can, to emphasize my opinion as to their importance. I venture to add the suggestion that to make the work complete all of the information obtainable regarding the different processes for the preservation of timber should be added. The question of using our timber supply to the best advantage and preserving it to the country is so important that I make no apology for this letter.

J. J. R. Croes, Am. Soc. C. E., M. Inst. C. E., New York City:

While I had a general idea regarding the work being done in this direction by your Department, I was not aware that so thorough and systematic an examination of the properties of timber had been undertaken, and I am greatly impressed with the value of these investigations to all who are interested in knowing the relative value for structural purposes of the different kinds of timber in the United States. I beg leave to urge the necessity, from an economic point of view, of having sufficient appropriations made by Congress to enable the work to be carried to completion on the scale on which it has been begun.

L. L. Buck, C. E., 18 Broadway, New York:

It seems to be eminently a proper function of our Government to pursue the investigation exhaustively as proposed. The cost will not be excessive compared to the value gained by authoritative information thus laid before the people. Moreover, such information will in time repay the expense of obtaining it, by removing an important cause of destruction, to wit, that of cutting large quantities which, after being culled over, net but a small portion of high-class material; while a far greater portion might have been found good if cut at the proper time and age.

Benjamin Douglas, bridge engineer Michigan Central Railroad, Detroit, Mich.:

A knowledge of the results of such tests will be of great value to engineers and builders, and particularly those made with large pieces—those showing the relation existing between the strength of large and small pieces cut from the same tree, and the influence of continued service. A thorough knowledge of the properties of timber would lead to considerable economy in its use, and this will be of constantly increasing importance in the future as timber grows more scarce.

J. E. Watkins, curator, section of transportation and engineering, Smithsonian Institution, Washington, D. C.:

To me, in common with other civil engineers of America, the need for an exact knowledge of the physical properties of American timber is apparent. * * * I earnestly trust that sufficient appropriation will be obtained from the next Congress to insure a continuation of the good work already begun. A more complete knowledge of the subject will grow in economic value as our American forests are depleted. Had this matter been taken up fifty years ago millions of feet of timber which have been wasted might have been saved.

H. I. Miller, Supt., Pittsburg, Cincinnati, Chicago and St. Louis Railroad Co., Louisville, Ky.:

Our useful timbers are being rapidly depleted, and if scientific research will assist in a better knowledge of their uses it will unquestionably prolong the time during which we will have these timbers in this country.

Lewis Kingman, Am. Soc. C. E., chief assistant engineer Atchison, Topeka and Santa Fé Railroad:

I consider this a very important work, and believe that the time and money expended will be appreciated, and that it will result in the economical use of an immense amount of timber which is now recklessly used and destroyed.

Alfred P. Boller, C. E., New York City:

I sincerely trust that the work will continue on the broad scale laid out, that the intelligent and economical use of timber may be spread broadcast among the people.

R. Montfort, chief engineer Louisville and Nashville Railroad Company, Louisville, Ky.:

Our information as to strength and other properties of timber is by no means complete. A full knowledge of the properties of the different timbers will insure their more intelligent and economic use, and will be beneficial not only to railroads, but to all industries engaged in the use of timber.

(5) *The proposed investigation will be of special interest to engineers, railroad companies, and all engaged in building operations.*

G. B. Nicholson, chief engineer Cin., New Orleans and Tex. Pac. Railway Co., Cincinnati, Ohio:

The present knowledge of the properties of timber amounts to a state of ignorance, and the cost of investigation has precluded individuals from undertaking it. I speak in behalf of the civil engineers, but I might add that a perfect knowledge of our timbers will be of benefit to the country at large, as civil engineers take an important part in the planning and building of works on which vast sums are annually expended by the people. I respectfully ask that your estimates to Congress will call for an appropriation large enough to prosecute vigorously this eminently useful work.

J. J. McVean, chief engineer Saginaw Valley and St. Louis Railroad, Grand Rapids, Mich.:

These tests and examinations will be of inestimable value to engineers, architects, and builders, as well as to the public generally, and if properly carried out and continued for a sufficient length of time to insure accurate results, they will be a gseat saving to consumers of timber as well as a source of profit to owners of timber land.

Robert Fletcher, Am. Soc. C. E., prof. civil engineering, Dartmouth College, Hanover, N. H.:

I have the honor to urge upon your attention the value and importance of the investigation now being made through the Forestry Division on the physical properties of American timbers. As a member of the engineering profession, I beg to emphasize the necessity of a far better knowledge than we now possess concerning the strength, durability, and adaptation to structural and other purposes of available sorts of timber, and also of the various conditions affecting their useful properties. The knowledge desired by the engineering profession is only to be had satisfactorily from tests of full-sized specimens under conditions of actual practice. Such tests are generally beyond the means and facilities possessed by individuals or firms, especially, in view of the time and expert attention which they demand.

William P. Shinn, C. E., late president Am. Soc. C. E., Pittsburg, Pa.:

I think it of very great and growing importance to the people at large that this investigation of the properties of our native woods should be made general, systematic, and thorough. To the engineering profession especially its results will be of incalculable advantage.

George W. Cooley, C. E., Am. Soc. C. E., Minneapolis, Minn.:

The importance of a comprehensive system of tests on all timber entering into the various details of construction can not be overestimated, and the engineering profession should cooperate with the Department in every way necessary to obtain full and accurate data on this most important subject. When it is considered that the safety of millions of lives and vast amounts of property depend upon the stability of timber structures, it appears that it is of the utmost importance that the absolute strength of all material entering into such construction should be accurately determined.

Engineering News, D. McN. Stauffer and A. M. Wellingford, editors, New York City:

As the editors of a journal prominently identified with the advancement of engineering interests in the United States, we can not too much commend the good work inaugurated by your Department in commencing an elaborate and complete scientific investigation into the properties of American timber. But as these experiments, to be really useful, must be on a scale and occupy time that puts them out of the reach of individuals, we sincerely trust that the wisdom of our legislators will ably second your own efforts to continue them to a proper end. * * * The information gained by a complete and scientific investigation of all American timber will be of inestimable value to engineers, and all concerned in the production or use of timber. This information will not only be essential to the safe and economical use of timber in construction, but it will undoubtedly vastly broaden the available supply of useful material for general or specific purposes.

W. Kiersted, Am. Soc. C. E., consulting engineer, Kansas City, Mo.:

I beg leave to say that I am in full sympathy with the work, and trust the necessary measures may be taken to carry it through to completion. The scale on which it is proposed to make the tests can not but be fruitful in valuable results of a kind that are in great demand by those interested in structural work where timber is used. Doubtless every civil engineer will rejoice that these scientific investigations are being made on so extensive a scale and under Government auspices, as it should be.

Charles M. Heald, manager Chicago and Western Mich. Railway, etc., Grand Rapids, Mich.:

As a manager of railway properties, I consider such information of almost incalculable benefit in aiding our engineering department to obtain a more accurate knowledge of the relative strength of material entering into the construction of bridges, and for this reason, if for nothing else, I should favor an appropriation by the Government to assist you in carrying out to the fullest extent the tests you are now engaged in making, and hope you will be successful in securing sufficient aid to enable you to proceed with the work and carry it to a satisfactory conclusion. I shall be glad to assist in this matter by carrying, upon application from you, free of expense, upon the lines under my charge, any timber which you may desire to secure in our territory for test purposes.

Arthur Beardsley, C. E., professor of engineering, Swarthmore College, Swarthmore, Pa.:

The value of the information to be obtained from these tests is so inestimably great to all engaged in the work of construction, whether as architects, engineers, or builders, in any of the many arts and trades employing timber, that one wonders that they have not been undertaken on so comprehensive a scale long before this; and it is to be hoped that you may meet with every encouragement in the work, until we shall have, through this means, such a thorough knowledge of all of these properties of our American woods as will enable those who use them in the various arts and trades to do so with the greatest economy and certainty as to the results.

S. Whinery, C. E., Cincinnati, Ohio:

I desire to call your attention to the great importance of a proper series of tests of American timber, such as have been inaugurated in the Forestry Division of your Department. While some investigations have been made in this line, they have not been conducted in a thorough and systematic manner and under the same conditions, and consequently are neither complete nor comparable. I do not think your Department could render a greater service to the engineers, architects, builders, and all others interested in the use of timber, than to carry out the scheme proposed for a complete series of tests of all American timber used in industrial and engineering work, and I hope that Congress may make the necessary appropriations to enable you to proceed with the same.

Joseph Wood, general manager Pennsyvania Company; E. B. Taylor, general superintendent of Transportation Pennsylvania Lines, West Pittsburg; A. B. Starr, superintendent Pennsylvania Company; J. Becker, chief engineer Illinois and St. Louis Railway Company, Pittsburg, Pa.:

We, the undersigned, members of the American Society of Civil Engineers, beg leave to urge upon you the necessity and importance of continuing the investigation of the physical properties of American timbers as related to their conditions of growth and the uses to which they are put. Such investigations would be of the greatest value, not only to engineers, architects, and builders, but to all users of timber and to the public generally. We understand that the work has been started with but limited appropriations, but we trust that you will see your way clear to arrange for its prosecution with greater energy, to the end that some final results may be reached at as early a date as possible. From the character of the work a certain time must elapse before getting such results, but unless carried on without interruption a great deal of what is already achieved will be lost, besides putting off the day when this valuable information will be disseminated.

Engineers' Club, of Philadelphia, Howard Murphy, secretary, Philadelphia, Pa.:

At the last meeting of the Engineers' Club, of Philadelphia, it was ordered that the secretary be requested to express to you its appreciation of the great importance of the extensive tests of timber recently undertaken by your Department, and the hope that such appropriations may be granted as will enable the work to be carried out upon the grand scale projected, and thus insure for it the desired degree of usefulness.

R. C. Morris, chief eng'r Nashville, Chattanooga and St. Louis Railway Co., Nashville, Tenn.:

These examinations will prove of inestimable value to engineers, architects, builders, railroads, lumber manufacturers, and dealers, and to the public generally. There is certainly a great demand for such scientific investigations. During the practice of my profession, I have often felt the necessity and importance of the information these examinations and tests will supply. Hence I beg to urge upon you the necessity and importance of this work.

L. L. Randolph, engineer of tests, Baltimore and Ohio Railroad Company, Baltimore, Md.:

This information would be extremely valuable to the engineers of the country, and would in the end save the people at large much money. As you are aware, investigations of this character have to be paid for, and it frequently happens that engineers in different parts of the country simply duplicate each other's tests, with the result that the information gained costs four or five times as much as it should. Of course this increases the cost of the building or whatever work is being done, and this again comes out of the pockets of the people at large.

D. C. Humphreys, prof. applied mathematics, Washington and Lee University, Lexington, Va.:

I am glad to see that your Department has commenced what I hope will be a complete, elaborate, and exhaustive test of the physical properties of American timbers. Such an investigation is very much needed and the resulting knowledge will be of incalculable value to engineers in designing structures in wood.

S. W. Robinson, professor of mechanical engineering, Ohio State University, Columbus, Ohio:

I consider the testing, as outlined, to be of highest importance to engineers, builders, furniture manufacturers, etc., and would urge such aid as can be given it.

H. G. Kelley, resident engineer St. Louis Southwestern Railway Company, Texarkana, Tex.:

I desire to express my deep interest in this work. The value of it will be incalculable, not only to the railrods but to the building interests of the country. The professional knowledge of the qualities of the different timbers in the various parts of the country is now almost a purely professional experience, which, at best, is a very uncertain factor for the engineer and builder. I shall take great pleasure in furnishing all the assistance I can to such agents or experts as may be sent out by the Department, and will, at all times, consider it a pleasure to give such information, either personally or by mail.

C. H. Benzenberg, city engineer, Milwaukee, Wis.:

These examinations will prove of inestimable value to all engineers, builders, architects, manufacturers, and the public in general, and the labors of your Department in this direction will certainly be most heartily appreciated by all those interested in the same. The great expense incident to a thorough set of tests extending over a number of years has prohibited most engineers or manufacturers, or even railroad companies, from entering into the subject to any great extent, and hence it is most gratifying to know that the Government has commenced this work, which will be of the greatest importance to all concerned.

Amory Coffin, chief engineer Phœnix Iron Works, Phœnixville, Pa.:

Referring to the investigation of the physical properties of American timbers, recently begun in the Forestry Division of the Department of Agriculture, I beg to express to you my high appreciation of the value of the results sought to be obtained. I heartily trust that you will urge upon the proper authorities the importance of this work, in order that the information desired may at an early date be available for the use of the engineers, architects, builders, and general public of our country.

H. W. King, secretary King Iron Bridge and Manufacturing Company, Cleveland, Ohio:

I trust, as this investigation would be of great value to engineers and builders and the public generally, that you will succeed in securing the necessary appropriation from Congress for this purpose. In fact I do not see how you can have any trouble in getting it, when the information is so necessary to every one.

J. H. Hinton, lumber dealer, Lumberton, Miss.:

The tests of timber, as carried on by Professor Johnson, of St. Louis, we think a very important work, and one that is bound to result in much good to the building trades, as well as to railroad interests. I trust you will use your influence to secure a liberal appropriation.

D. H. Burnham, engineer of construction, World's Columbian Exposition, Chicago, Ill.:

Such an investigation as this will be of the greatest value to the engineers and architects, and the value will be increased in proportion to the rapidity with which the work is done and the results are published. We need such investigations and need them now. Professor Lanza's tables, published recently, show that the old stress used for timber was much too high, but we need additional and still more extended investigations. When I was appointed engineer of construction World's Columbian Exposition, August 1, I found it necessary to make changes in most of the buildings because I did not dare to use as high unit stress in timber as was used by my predecessor, although he claimed to be perfectly safe in his strains and brought forward authorities—Trautwine and others—to prove his statements. I earnestly hope that Congress will make a liberal appropriation for this purpose, and that speedily.

J. T. Fanning, M. A. S. C. E., consulting engineer, Minneapolis, Minn.:

Permit me respectfully to urge upon your Department the importance of continuing the elaborate investigations and experimental determinations of the properties of American timbers, as already inaugurated in the Forestry Division, under your direction. The experience of designers of architecture and engineering structures teaches that the results will prove of inestimable value.

George H. Pegram, M. Am. Soc. C. E., civil and mechanical engineer, St. Louis, Mo.:

I do not know of any work of more importance to engineers than the timber investigations and tests, now being conducted by the Government. As the timber is cut off and the selection becomes more and more restricted, a more thorough knowledge becomes almost imperative.

C. M. Bolton, chief engineer Richmond and Danville Railroad Company, Atlanta, Ga.:

Information to be derived from these tests will be exceedingly valuable, especially to civil engineers and railroads. I will be very glad if you will have my name put on your list for the reports of tests that will be from time to time issued.

E. B. Codwise, M. Am. Soc. C. E.; C. E., Kingston, N. Y.:

The results of this investigation will prove of great value to all engineers, architects, and others engaged in the erection and care of timber structures. * * * I would urge upon you the great importance of the work, and trust that you may obtain the necessary appropriations for its speedy completion.

Samuel M. Gray, consulting engineer, Providence, R. I.:

The general practical value of the results of these tests to all engineers and mechanics using timber for construction of different works can not be overestimated.

Oberlin Smith, Am. Soc. C. E.; Am. Soc. Mechl. E.; Am. I. M. E.; Bridgeton, N. J.:

I think I only agree with the great majority of practical engineers in believing that this is a subject of vast importance to the industries of the country, as knowledge obtained in such a sytematic and thorough mannner is of infinitely more value, as well as very much cheaper, than can be the results of haphazard experiments by individuals. I hope that the Congressional committee in charge of the matter may be brought to see of how great consequence are experiments of this kind, and that they should be made in the most thorough manner possible that their results may settle once for all many puzzling questions that afflict the engineer as well as the manufacturer, merchant, and user of all kinds of timber in every form.

B. T. Morse, civil engineer and architect, inspector of buildings, Cleveland, Ohio:

Such investigations, examinations, and tests as are proposed to be made by the Forestry Division of the Department of Agriculture will be, in my judgment, of great value to architects, engineers, builders, and the public generally.

A. Fteley, chief engineer aqueduct commission; vice-president Am. Soc. C. E., New York City:

The engineering and other building professions are very much in need of the tests of timber, and an appropriation to that end would, in my judgment, be useful and timely.

W. L. Cowles, chief engineer Youngstown Bridge Company, Youngstown, Ohio.

There can be no doubt that this work will be of the greatest practical benefit to all parties engaged in occupations which involve the use of timber, and it is very important that our knowledge of the properties of different timbers should be as thorough as possible. We trust that increased appropriations may be secured to engage in this work.

H. V. Hinkley, office engineer, Atchison, Topeka and Santa Fé Railroad Co., Topeka, Kans.:

If these tests are carried on as suggested, they can not fail to be of vast benefit to the engineering profession, to the bridge and building fraternity, and to railroads especially. I heartily recommend the tests for your hearty cooperation.

J. A. L. Waddell, constructing bridge engineer, Kansas City, Mo.:

I indorse most heartily the action taken by the Department of Agriculture in this matter. The results of the proposed tests, in my opinion, would be of incalculable value to the members of the engineering profession, as well as to many others.

(*6*) *The work is of greatest practical benefit and its importance can not be overestimated.*

John MacLeod, constructing engineer, Am. Soc. C. E., Louisville, Ky.:

As an engineer in active practice of general constructive work, and representing a large clientage whose interests will be greatly affected by the investigations and tests being made by the General Government as to the physical properties of American timbers, I beg to be allowed to express my appreciation of the great value of this work to all who have to do with timber in any of its multifarious forms, of the admirable organization and methods for carrying on the investigations, and of the ability and special qualifications of the gentlemen selected for the work, which is a guaranty that it will be exhaustive and the results reliable. Scientific investigations and tests of American timber are a national need, second only in importance to similar tests of iron and steel, and there is a growing want in every department of construction of the information that these investigations will develop, and nothing should be allowed to retard the work.

Thomas Rodd, chief engineer Pennsylvania lines west of Pittsburg, Pittsburg, Pa.:

Such investigations would be of the greatest value not only to engineers, architects, and builders, but to all users of timber and to the public generally. I understand that the work has been started with but limited appropriations, but I trust that you will see your way clear to arrange for its prosecution with greater energy, to the end that some final results may be reached at as early a day as possible. From the character of the work a certain length of time must elapse before getting such results, but unless carried on without interruption a great deal of what is already achieved will be lost, besides putting off the day when this valuable information will be disseminated.

P. C. Ricketts, professor mechanics, Rensselaer Poly. Inst.; M. Am. Soc. C. E., Troy, N. Y.:

I write to express my opinion as to the very great value of this work to the people generally. Such experiments necessarily can not be carried on by private individuals, and the results obtained far exceed in value any outlay that might be necessary in making the determinations. I hope that the work will be pushed forward to a rapid completion.

R. H. Thurston, director Schools of Mech. Eng. and Mech. Arts, Cornell University:

This work is regarded, I am sure, by all engaged either in scientific or commercial work, in which the nature, properties, and constructive values of our timber trees are a matter of consequence, as one of the most important and directly useful schemes of scientific investigation ever yet undertaken, and all will be very much gratified that so extensive and satisfactory a work has been undertaken by such competent authorities. Its value to the whole country is likely to prove vastly more than commensurate with its cost and with the time expended upon it. This is not an individual opinion only, but is that of competent judges throughout the world, as is witnessed by the still earlier action of the probably best organized forestry department in the world, that of the Prussian Government. No other country has even approximately the number and variety of timber trees possessed by the United States; and in no other part of the world is the complete study of their useful qualities so important. The rapid extinction of pine timber in the older sections formerly possessing large areas of pine lands, the imperative necessity of finding suitable substitutes, and the even more imperative necessity of finding promptly a way to inaugurate the replacement of this lost forest, as a matter of sanitation and climatic regulation, and of making this substitution by cultivating the best timber trees, are facts which sufficiently well indicate the vital importance of the work already undertaken by your Department.

C. J. H. Woodbury, vice-president Boston Manufacturers' Mutual Fire Insurance Company:

By way of introduction, I would say that, although an officer af an insurance company, we confine our business entirely to underwriting upon manufacturing property, and my duties largely pertain to the numerous questions of engineering involved in these matters. The only method of floor construction found feasible in our mills has been to construct such floors of very heavy timber, because iron is not so well suited for that, as its anvil-like rigidity causes the machinery to hammer itself to destructive results. The use of timber in mill work has been largely based upon precedent, and but very little has been done outside of my own work on the matter of properly organizing and formulating such results and methods. I do not know how I can call your attention to the importance of a careful investigation upon the physical properties and strength of timber for mill work in other ways than to say that by the method of slow-burning construction in vogue in this country mills are built at a cost of 75 cents for every square foot of floor, while the corresponding method of building mills in use in England involves a cost of about $1.50 per square foot of floor. The fire hazard of the American mill is also much less, such mills being insured at a cost of about one-fifth of 1 per cent; whereas the cost of insuring the corresponding English mill largely exceeds this.

J. W. Andrews, assistant chief engineer Omaha, Kansas Central and Galveston Railroad Co.:

Learning that your Department has begun a series of tests of American timber, I beg to tender my wishes for a full and elaborate investigation into the physical properties of our woods and their uses. With railroad men the economic value of such tests will be incalculable, because of the great ignorance on this subject, which often leads to serious results, not only in railroad bridges, but in large buildings. Many serious accidents and much loss of human life might be averted if engineers and mechanics knew precisely the value, in strength and durability, of the various woods in structural uses.

George F. Swain, professor of civil engineering, Mass. Institute of Technology, Boston, Mass.:

I desire to express in the strongest terms my appreciation of the work which you have inaugurated, and to bear my testimony to the great value which the results will have for all persons interested in building or having to do with the use of timber. I think that you and your Department are to be congratulated upon having been the first to enter upon a work of great importance, and I sincerely trust that nothing may interfere with its successful prosecution.

A. G. Compton, professor applied mathematics, College of the City of New York, New York:

My attention has been called to the investigation into the properties of American timbers now being conducted by the Department of Agriculture, and I write to express to you my sense of the great value which such a work may have if conducted in a thoroughly scientific spirit. I hope the undertaking will receive hearty support.

W. G. Curtis, general manager Southern Pacific Company, San Francisco, Cal.:

Our attention has been called to the comprehensive timber tests recently inaugurated in the Forestry Division of the Deportment of Agriculture. Without doubt such tests will be of great benefit to the scientific world, as well as to the public generally, and we think it important that the investigations be vigorously prosecuted and carried to final conclusions at an early date.

William B. Jenkins, receiver New Orleans and Northwestern Railway Co., Natchez, Miss.:

Such a work will be invaluable to the engineers, architects, builders, railroad companies, lumber manufacturers and dealers, and to the public generally. But few tests have been made of Southern timbers, whilst the Southern States are full of the most valuable and durable kinds of wood, all suitable for building purposes. Tests of these timbers, giving weights and strength, will fill a want long felt. In many instances an engineer has to refer to an English authority for information in regard to building timbers. Railroad classifications are based upon such information as can be obtained only by approximation. Consequently this work, when completed, will be in great demand.

John J. Ganahl, president Ganahl Lumber Company, St. Louis, Mo.:

We consider it of very great importance for the Government to make the necessary appropriations for obtaining the required tests by scientific investigations, to ascertain the strength and durability of the different kinds and qualities of our forest products. We trust that you will use every opportunity for obtaining the necessary funds to make the desired tests, to enable us to give the information wanted to our customers in order to guide them to use the proper kind of lumber in the construction of the different classes of buildings.

R. E. Kelley, sec. Texas and Louisiana Lumber Manufacturers' Association, Beaumont, Tex.:

The members of this association are taking a deep interest in the tests of American timbers now being made under the supervision of the Department over which you so ably preside, and trust to see them prosecuted to an early completion. They feel that great advancement has been made in recent years in determining the relative value of timbers, but they are also cognizant of the fact that much remains to be done, and they hope for advantageous results from the investigations now being made by the Forestry Division of your Department. If you will indicate how this association may be of service in promoting the investigations it will readily extend you all the assistance in its power.

Coleman Sellers, Am. Inst. C. E., consulting engineer, Philadelphia, Pa.:

I apprehend that Congress has not fully appreciated the importance of this work, which bears upon so many industries in the United States and is of such vital importance. I have had occasion to seek for information in this direction lately, and have met with so much difficulty in finding what I wanted that I sincerely hope that the work will go on, and that publications will be made from time to time by you that will give users of wood the fullest information in regard to the resources of our country in this direction.

W. W. Coe, chief engineer Norfolk and Western Railroad Company, Roanoke, Va.:

I note with great pleasure that this work has been commenced, and believe that an investigation of this matter will be very useful and instructive. Personally I shall be glad to aid in any way in my power in furtherance of such investigation, and will take pleasure in recommending to our company that they afford means for obtaining and transporting specimens, should it be desired by the Department.

M. G. Howe, receiver Houston, East and West Texas Railway Company, Houston, Tex.:

Having had many years' experience in the use of timber in the construction and operation of railroads, I fully appreciate the importance of the proposed work, both to the railroad interests and to the general public, and feel that I can not urge too strongly the necessity of continuing this work in a practical way.

L. M. Haupt, A. M., C. E., University of Pennsylvania, Philadelphia, Pa.:

The work will be of inestimable value to the country in furnishing correct data to engineers and architects, and I trust that Congress will exercise a wide liberality in this matter of so great utility by making a liberal appropriation for its continuance.

C. Palmer, engineer Chicago and Northwestern Railway Co., Am. Soc. C. E., Escambia, Mich.:

In view of the extensive use of timber in important structures, no reasonable expense should be spared to make the tests exhaustive and reliable.

(7) *Such a work must be carried on by the Government, because it is too difficult and expensive to be undertaken by private parties.*

Robert Moore, chief engineer St. Louis Merchants' Bridge Terminal Railway, St. Louis, Mo.:

Allow me to express my sense of the great value to engineers and all users of timber of the investigation now in progress under your direction, and my strong wish that nothing may interrupt it until fully completed. It is a work of a kind which can not be done by any private individual or corporation, and when once done in the manner in which it has now been begun will be done for all time.

Theo. Cooper, C. E., mechanical engineer, 35 Broadway, New York, N. Y.:

The study and investigation of the characteristics, properties, and capabilities of the great variety of timber of our country is a most desirable work. It would not be possible to have such investigations, requiring many years of careful observations, work, and record, undertaken by private means or through the personal action of isolated investigators. The benefits of such researches would be immediately felt by the whole people, equally by the laborer and the capitalist. As the benefit would be for no one class, but for the whole people, it is, in my opinion, a proper field for governmental action.

George S. Lacey, vice-president and general manager Keystone Lumber and Improvement Company, Bogue Chitto, Miss.:

I can not too highly recommend to your favorable consideration this scheme, believing that it is a step in the right direction. The Southern Lumberman's Association (of which I have the honor of being vice-president) have contributed $500 to aid in furthering the same object, but this whole matter is one that can be reached only by such action and expenditure of money as the General Government could afford. The diversity of our forest products is so immense that no one party or persons engaged in but one line can attempt to intelligently enter on this field with any idea of its investigations being comparatively of any good.

J. P. Frizell, chief engineer board of public works, Austin, Tex.:

While much legislation has lately been enacted and great expenditures have been authorized for objects the propriety of which is the subject of fierce and bitter contention, there can be no question in any well-informed mind as to the propriety of liberal expenditures for such objects as this; to procure information for the people which, from the nature of the case, they can not procure for themselves.

W. S. Pope, president Detroit Bridge and Iron Works, Detroit, Mich.:

It is plain that such investigations can be thoroughly and authoritatively made only by the General Government, and as every citizen is more or less interested, it seems an eminently proper branch of governmental work.

Horace Andrews, city engineer, Albany, N. Y.:

I can urge the utility of such tests with great confidence, and can see no way in which a complete series of tests can be made without Government aid. Data as to the strength of metals are more easily obtained by private enterprise and necessity, but no exhaustive experiments on the strength of American timber can be expected from private sources.

Chauncey Ives, chief engineer Cumberland Valley Railroad, Chambersburg, Pa.:

The tests should be made of full-sized pieces as used in bridges and buildings, and this can only be done by the Government, as no private individual or individuals could afford the expense. The result of such investigations would be of the greatest advantage to all classes of citizens, as well as to engineers, architects, railway companies, etc.

Charles M. Jervis, president and engineer Berlin Iron Bridge Company, East Berlin, Conn.:

The field is so large that no private party can furnish the means to conduct the investigation in regard to the physical properties of American timber, and as it is of the greatest importance to engineers and architects that the work be continued, we request that you will urge upon Congress the advisability of making an extra appropriation for this purpose.

M. L. Holman, Am. Soc. C. E.; Am. Soc. M. E., etc., St. Louis, Mo.:

A complete investigation should be made and the results formulated for the use of architects and engineers. As this work can be carried on by the United States Government only, I have the honor to request that you will endeavor to have the investigation continued and the results published.

William Cain, professor of engineering and mathematics, University of North Carolina, Chapel Hill, N. C.:

I regard these tests as the most valuable to the engineer that could be undertaken at this time. Tests on iron and steel are counted by the thousand; but very few satisfactory tests have been made on timber, nor probably will be, until the Government steps in and makes an exhaustive investigation.

(8) *Public money could hardly be expended for a better object, or for one so likely to secure valuable results.*

Walter Katte, chief engineer New York Central and Hudson River Railroad Company, New York; Am. Soc. C. E., M. I. C. E., Great Britain; M. West'n Soc. C. E.:

I think there can be but one opinion in regard to the very great importance of such investigations as are contemplated, and of their immense benefit and usefulness to all parties, and especially to those engaged in the use of timber for manufacturing and constructive purposes. Personally, I would be very glad indeed to see these labors completed at the earliest possible date, in order that the valuable information derived from them may be furnished for use at the earliest possible time. I can hardly conceive of an expenditure of public money for a better object, or for one so likely to return the most valuable results, in which such a large proportion of the citizens of this country are directly and financially interested.

C. C. Martin, chief engineer and superintendent New York and Brooklyn Bridge, Brooklyn, N. Y.:

Tests have been made, from time to time, which possess some value, but nothing to compare with the complete series that Mr. Fernow proposes. In my judgment, no better use could be made of money than in ascertaining the physical qualities of American timbers. The building and engineering industries would be immensely benefited thereby. The plan laid out is an excellent one.

James Christie, Am. Soc. C. E.; Am. Soc. Mech'l Engrs.; A. A. A. S., Pencoyd, Pa.:

The growing scarcity and increased cost of our timbers render it important that their use should be governed by a more accurate knowledge of their physical properties than that which has been heretofore possessed. Increased knowledge of the subject will tend to prevent much misapplication and waste of valuable material. If Congress can be prevailed upon for liberal aid, I am sure its action will be fully appreciated and it will be a crowning act for the present honored administration.

C. L. Strobel, chief engineer Keystone Bridge Company of Pittsburg, Pa., Chicago, Ill.:

The determination of the strength and other qualities of timber, with reference to its use in constructions, is preëminently a Government work, and I think that the means at the disposal of the Government can not be put to a more useful purpose. Private enterprise is not interested to any great degree in doing such work, as the public will receive the principal benefit, in greater security to life and limb and in greater economy. Such tests as have been made are incomplete, and the proportions adopted by different engineers vary widely. Considerable discussion and difference of opinion has only recently been evolved in connection with the unit strains to be allowed for the wood constructions of the World's Fair buildings. While many engineers, in the light of future investigation, will probably be found to err on the safe side, no doubt others will be shown to have erred in the other direction.

W. F. Allen, secretary, American Railway Association, 24 Park Place, New York City:

I have the honor to inform you that at a meeting of the American Railway Association, held at the Hotel Brunswick in this city on Wednesday, October 14, 1891, the following preamble and resolutions were unanimously agreed to:

Whereas the American Railway Association, representing 166 railroad companies, operating about 125,000 miles of railroad, feels a deep interest in the "timber tests" now being conducted by the Department of Agriculture: Therefore,

Resolved, That in the opinion of this association this work is one which earnestly recommends itself to the favorable consideration of Congress.

Resolved, That the secretary be directed to furnish a copy of this resolution to the Hon. Jeremiah Rusk, Secretary of Agriculture.

(9) *Expressing admiration of the organization and method of the investigation as planned by the Division of Forestry, and urging ample appropriations by Congress for prosecuting the proposed investigation to a proper completion.*

Charles B. Dudley, chemist, Pennsylvania Railroad Company, Altoona, Pa.:

I should like to say that I most heartily approve of making these tests, and also of the plan which has been outlined and is being carried out in actually doing the work. There is very great need of careful accurate study of the value of our woods, and no one appreciates this necessity more than those who constantly use our native woods in construction. I sincerely hope that Congress will be so liberal in its provisions for this work that it will go on as speedily as possible. I have the pleasure of Mr. Fernow's acquaintance, and regard him as in every way competent to carry on such a system of tests as has been inaugurated. If I can assist in any way in securing the necessary funds to bring about the result desired, I hope you will not fail to command me.

C. N. Brown, professor of civil engineering, Ohio State University, Columbus, Ohio:

These tests will be of inestimable value to all engineers, and I hope that they may be carried out according to the plans of the Department. I hope that you may be able to prevail upon Congress to make such appropriations as will permit the work being pushed with vigor.

J. B. White, president Southern Lumber Manufacturers' Association, Grandin, Mo.:

The Southern Lumber Manufacturers' Association is composed of the largest manufacturers of lumber in nine of the Southern States, and they recently donated $500 to aid Professor Johnson in purchasing a machine to make experimental tests of Southern woods. The work will be of inestimable advantage to the Southern States, especially as their financial resources must largely come from the forests which occupy such a large proportion of their domain. If Congress can be prevailed upon to increase the annual expenditure for this purpose, it will result greatly to the prosperity of the lumber States South. I wish to urge upon you the necessity and importance of this work.

C. B. Davis, hydraulic and sanitary engineer, Chicago, Ill.:

I desire to urge the great importance of this work, of its vigorous prosecution, and of the necessity and desirability of a liberal appropriation being made at the earliest date possible.

J. W. Schaub, engineer Detroit Bridge and Iron Works, Detroit, Mich.:

The company with which I am connected is engaged in the designing and building of bridges and similar engineering structures, in which timber is used to a considerable extent, and we are thus brought to appreciate the desirability of a more extended knowledge of the various properties thereof. * * * As every citizen is more or less directly interested, it seems an eminently proper branch of governmental work. I heartily recommend, therefore, liberal appropriations for the purpose.

W. Howard White, consulting and executive engineer, 74 Wall street, New York:

I trust that the work already done on the testing of United States timber as to physical properties will be continued by appropriations from the next Congress. I am myself engaged upon a set of tables intended to facilitate the correct proportioning of the various parts of wooden buildings. At the base of the calculations upon which these tables are made lies the correct factor of strength to be used; and the satisfactory use of such tables depends therefore upon the satisfactory determination of this factor.

P. H. Griffin, president New York Car Wheel Works, Buffalo, N. Y.:

My attention has been brought to the proposed Government timber tests, and being impressed with the importance and value of the work, I trust Congress will see fit to make the necessary appropriations to carry it out. I deem the result one of great benefit to the public.

George E. Mann, city engineer, Buffalo, N. Y.:

Being aware that the limited appropriation for the investigation of American timbers delays the obtaining prompt and valuable results, I write to urge the recommendation for a larger appropriation and such as the importance of the work demands.

SCOPE AND HISTORICAL DEVELOPMENT OF THE SCIENCE OF "TIMBER PHYSICS."

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 them 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 is 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 comprising 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 *condition;* 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 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 purpose 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 abnomities 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 its 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, its manufacture into charcoal, its 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. In this I have followed largely the excellent résumé by Dr. W. F. Exner in Lorey's Handbuch der Forstwissenschaft.

HISTORICAL.

The first important and exhaustive work was that of PARENT, published in the Mémoires de l'Académie des Sciences in the years 1707 and 1708, being "investigations into the strength of oak and fir." The idea of elasticity, so important in the application of timbers, was not even known to him. A work memorable in this first period of scientific efforts in this direction was produced by MUSCHENBROECK in 1762 (Introductio ad philosophiam naturalem), discussing especially the differences of strength in the different parts of the same tree. Although not a sufficient number of satisfactory experiments were conducted to prove his deductions fully, they were remarkably clear and in the main correct. The celebrated naturalist, BUFFON (Oeuvres, Vol. x), occupied himself in a comprehensive manner with a determination of the mechanical properties of oak wood. In 1780 appeared the often-cited work of DUHAMEL DUMONCEAU, Traité de la Conservation et de la Force, which contains a number of references to the properties of timber.

These three authors are almost the only ones who occupied themselves with the determination of density and strength in the different parts of the same tree and of the influence of soil conditions on these properties. The contradictions in their views and deductions, however, left these important questions undecided. Only the authors of later periods gave any thought to the study of elasticity. Among these were GIRARD (Traité Analytique de la Résistance des Solides, 1798), who experimented on oak columns, and PERRONNET (Mémoires sur les pieux et les pilotis, 1782). The latter found that a continuous even load increases the depth of deflection, which he argues could not be the case without a change in elasticity, by losing part of its energy. At the end of the last and the beginning of this century a number of recognized men of science have determined by experiment, for a large number of timbers of different kinds and locality, the density, the strength, and the coefficient of elasticity. Notable among these are BELIDOR (Architecture hydraulique, 1782), RONDELET (Art de batir), BARLOW (Essay on the strength of timber, 1817), EBBELS, and TREDGOLD in various works.

CHARLES DUPIN published in the Journal de l'École Polytechnique, Vol. 10, 1815, an extensive work on the mechanical properties of wood (Expériences sur la flexibilité, la force, et l'élasticité des bois). He investigated the nature of the elastic curve, the position of the neutral plane (*fibre invariable*), and he corrected the formulas which express the relations of the size of test pieces and the applied loads to the resulting deflections.

BEVAN occupied himself especially with the determination of the modulus of elasticity, derived from experiments in torsion. (Philosophical Transactions, 1829.)

SAVART utilized tone vibrations of wooden plates in order to determine the differences of elasticity and the position of its axes. These plates were cut from a piece of beech, in various directions. He supposed three axes, one parallel to the fibers, the second in the direction of the radius, the third tangential to the annual ring. He found that if the resistance against cross bending in the direction to the tangent is taken as unity, the resistance in the direction of the radius is 2.25, that in the direction of the fiber is 16. (Mémoires de l'Académie des Sciences, 1830.)

The same question was discussed by WHEATSTONE in the Philosophical Transactions, in 1833. He says:

When a plate is cut out so that the fibers run parallel to one of the side faces the axes of the greatest and smallest elasticity are rectangular to each other and parallel to the sides. If the plate has the shape of a rectangle, the sides of which are inversely proportional to the squares of their resistance to bending, both kinds of vibrations parallel to the sides, although these may vary in length, become synchronous, and its consistency furnishes a resulting figure with lines parallel to the diagonal.

Hence, by finding experimentally the relative length that these sides should have, the relation of the coefficients of elasticity in two directions perpendicular to each other may be found.

PONCELET, in his Mécanique Industriel, 1839, enters into a very detailed discussion on the elasticity of timbers and especially on experiments into the resistance to torsional forces. He derived from the experiments of Minard, Desormes, and Ardent the conclusion that for the first load the elongations are proportional to the straining forces, and he calculates from these elongations the coefficients of elasticity.

According to EATON HODGKINSON (Combes, Exploitation des Mines), a shortening by 0.0027 of the original length of a rectangular (not bent) prism alters the elasticity considerably.

HAGEN (Poggendorf's Annalen, Vol. LVIII, p. 125) has investigated the elasticity of several kinds of timber by crossbending of sticks, which were cut in the one case in the direction of the fiber, and in the other case perpendicularly to the same, and did not find any great difference between the heart and sap wood; but he recognized that the coefficient of elasticity decreases considerably when the wood contains much water.

In the year 1845 two Italian physicists, PACCINOTTI and PERI (Il Cimento, Vol. III), published a very precise and detailed investigation into the elasticity of timbers, in which the various methods for the determination of the coefficient of elasticity were compared and their value examined. They operated according to the three methods of tension, flexion, and torsion, with cubic blocks of 27 to 36 millimeters side. In the experiments with flexion they employed different methods of fastening or support. They measured the elastic as well as the permanent elongations, the angles of torsion, the ordinates corresponding to the different points of the stick during its deflection with an increasing load. In the second part of their work, Paccinotti and Peri compare the numerical results of their experiments with the figures which were calculated by the known formulas, and attempt to find a relation between the density and the coefficient of elasticity for the timbers experimented upon.

They arrived at the following conclusions:

(1) The elasticity allows in the different parts of the wood changes in dimension, which are in proportion not only to the first load but also to those which come near that load which produces rupture, provided care is taken to differentiate from the elastic changes those permanent ones which are due to the softness of the material or to the continuity of the load.

(2) The curves of deflection which the sticks assume when fastened securely at one end differ under otherwise equal conditions from those which the same sticks form when both ends are supported; this must be ascribed to the reaction of the fiber in the two opposite branches formed in the latter method of support. The same theory, however, may serve for the purpose of deriving the two kinds of curves, provided that in the integration of the respective differential equations care is taken to properly determine the constant (the value of which depends on the degree of the invariability of the fastening or insertion of the sticks experimented upon).

(3) The differences which appear in the determination of the coefficient of elasticity disappear almost entirely if by this expression is understood the quotient $E_1 = \frac{E}{G}$, in which E denotes the common term for the coefficient of elasticity and G the specific gravity.

(4) The coefficient of elasticity E_1, although there are some differences in the various species of wood, is in general equal to 2,000 for the square millimeter of transverse cut.

(5) The coefficient of elasticity can be determined not only by tension but also by flexion and torsion, but with these different methods different values are found, and to reduce these to the same value it will be necessary in each case to determine a constant coefficient dependent upon the method of operation.

(6) The easiest method for the determination of the coefficient of elasticity is that in which the stick is supported at both ends and is loaded at equal distance from the two points of support (center).

The observations of Paccinotti and Peri are as exact as it was possible to make them without the application of the kathetometer. The authors, however, also neglected to consider the part of the tree from which the experimental pieces were taken and the degree of seasoning at the time of experiment. It is known that the elasticity is not the same in all parts of the tree and changes considerably with the amount of moisture, and this is especially variable in such small sticks as the authors used; so that the result of these experiments are not entirely capable of comparison or generalization.

Reviewing the results of investigations obtained in this field up to the middle of our century, we find that great progress was made in the methods and the exactness of the reasoning, but the results were often contradictory and unsatisfactory. Recognizing this, two French scientists, one a forester, the other a technologist, CHEVANDIER and WERTHEIM, undertook a far-reaching investigation. The timbers for experiment were taken from a locality of the Western Vosges Mountains, France, the local conditions of which were thoroughly known to the experimenters. In a forest comprising about 10,000 acres sufficiently numerous variations of site and kinds of timber were found. The same exactitude was used in the selection, the description, and the preparation of the test pieces as in the experiments themselves, for which all the necessary means of satisfactory quality were at their disposal. Chevandier and Wertheim published their work, the fruit of many years of labor, which had been executed with a degree of perfection never before attained, in the year 1848, as a monograph entitled Mémoires sur la propriété mécanique du bois.

The following questions were to be determined by the authors:

(1) What effect does a gradually increasing load produce upon timbers, according to what laws do the resulting changes of form progress, and what methods are applicable to the determination of the mechanical properties of the timbers?

(2) Do the mechanical properties of the wood vary—

(*a*) with the orientation, *i. e.*, according to the position in the tree in relation to the points of the compass;

(*b*) with the degree of moisture;

(*c*) with the position in the tree in relation to the distance from the axis to the circumference at the same height;

(*d*) with the position in the tree according to the height from the ground?

(3) In what relation do the mechanical properties of wood stand in the direction of the fiber and in the direction perpendicular to the same respectively at varying heights from the ground?

(4) What influence does the age of trees exert?

(5) What influence do the width of annual rings (rate of growth), the exposure, and the soil conditions show?

(6) What relations exist between the several mechanical properties of the timbers to each other?

(7) What average values can be considered proper to express the mechanical qualities of timber and what conclusions result therefrom for the practice?

The results of the experiments of these two scientists belong to that class of data which we employ even to-day. The authors first review the history of these investigations, which we have here given, recording in a table the results of experiments by their predecessors, and in eighteen additional tables the results of their own work. Here for the first time we find a rather full record of the history and nature of the test material. Regard is taken of the moisture per cent in four stages of seasoning; fresh, partly dried, well seasoned, and kiln-dry. These authors also tested larger logs (up to 26 feet in length). They also employed the method by sound vibrations to determine the coefficient of elasticity, and finally correlated their results with a view to answering the above questions.

These two men, without doubt, must be considered the fathers of the new science of Timber Physics, and while their conclusions may not be accepted as having settled all the questions, because even they lacked many data of record, etc., they pointed out the road along which we must travel, and helped to level it. Yet it has remained largely untraveled until our time.

Twelve years after Chevandier & Wertheim's publication there appeared in Germany the most comprehensive work in this line of investigations, containing the fullest discussion of all the known and assumed facts regarding wood, its properties and application, by Dr. H. NÖRDLINGER, professor of forestry and Oberförster at Hohenheim, Würtemberg. The means for his long-continued experiments and accumulation of data were furnished by the direction of the Forest Academy at Hohenheim and the Minister of Finance of his State. The first fruit of his studies appeared in the year 1860, in the standard work entitled The Technical Properties of Timber, for Forest and Civil Engineers, Technologists, and Manufacturers.

For the mechanical properties Nördlinger largely relied upon the work of Chevandier & Wertheim, but with great assiduity he himself filled out the deficiencies which existed, to make a universal treatise on the subject possible. He added a description of the anatomical structure of the various timbers, in the expectation that many properties and their variations might be derived and explained from the anatomy. Besides, he treated upon grain, color, luster, transparency, odor, capacity for heat, capacity for evaporation and for imbibition of water and vapor, specific gravity, hardness, cleavability, shrinkage, swelling, warping, elasticity, flexibility and toughness, strength, chemical composition, fuel value, natural durability, and faults of timber. This comprehensive book, even to-day, after more than a quarter of a century, must be consulted by him who would drink at the fountain head. All the compilatory treatises on the technical qualities of timbers published since, at least in German, are based more or less on Nördlinger's work, none bringing quantitatively more new material.

Of these publications the following, not of encyclopædic or entirely compilatory nature, are worthy of mention:

Tables of the Results of a series of Experiments on British Colonial and other Woods, prepared by FRANCIS FOWKE, was published in 1867 after a long series of experiments on rather crude principles. This enormous work has done little service for science.

In the same year (1867) a revised edition of PETER BARLOW'S Strength of Materials (originally in 1817) was published in London, which records many older experiments, besides the author's own, and is a book full of solid, highly interesting, and reliable information.

CARL V. JENNY, professor at the Imperial Technological High School at Vienna, carried on his work upon a comprehensive plan at the expense of the Hungarian Government. Only a part of the work was published in 1873. He experimented upon the elasticity and strength of compression as opposed to pressure, shearing strength parallel to the fiber, and the tensile elasticity and tensile strength of tension on Hungarian timbers, the history of which were known as regards locality of their growth, soil, site, and the width of the annual rings.

A considerable number of experiments into the mechanical properties of timber grown in Bohemia were made by CARL MIKOLASCHEK at the instance of the Forest Experiment Station at Vienna. From the many results published in 1879 in the Mittheilungen aus dem Forstlichen Versuchswesen Oesterreichs general laws were not deduced, but the results present reliable data.

After this time the periodical literature of the day contains a great many essays and more or less valuable records of experiments.

As of special influence upon the development of this branch of science, two studies of greater extent, both appearing in the year 1883, require mention. Methods and Results of the Examination of Swiss Building Timbers, by L. TETMAJER, professor at the Swiss Polytechnical School at Zurich, and Investigations into the Elasticity and Density of Spruce and Pine Building Timber, by J. BAUSCHINGER, professor of Technical Mechanics and Graphical Statics at Munich.

In the first-mentioned work the author proposes a method, which deserves attention, of determining the "quality" of timber for building purposes by the "working capacity of cross-bending strength." There were thirty-one trees used for the examination, twenty-two test pieces being taken from each, and a thorough description of the locality, site (especially elevation above sea level), age, and appearance of the wood, was given.

Bauschinger, whose work is published in Mittheilungen aus dem Meschanisch-technischen Laboratorium der königl. Technischen Hochschule in München, Vol. IX, and a continuation of it in 1887, Vol. XVI, proposed mainly to find out the influence of the site and of the time of felling upon the elasticity and strength of the most important (European) conifers. From four different sites respectively, four pines and spruces of the age of 90 to 100 years were taken, which were grown under similar conditions of site, perfectly healthy and without flaws. Two trees each on every site were cut in the month of August, 1881, and two in the following winter (December and January). The sticks were made specially long (250 cm. span = 9 feet, and about 20 cm. square = 62 sq. in. cross-section) and were tested for flexion, tension, compression, shearing. Besides, on one stick of each tree, specially prepared for the purpose, an investigation was made into the relation of the mechanical (elasticity and strength) and the physical (density and humidity) properties, in order to render the results from other experiments comparable.

Bauschinger found that winter-felled wood of these conifers was 25 per cent stronger than the summer felled, if they are both used immediately after felling, but that this difference passes away with seasoning. He claims a direct proportion between strength and density (or weight of the dry fiber), which he ventures to formulate thus:

Crushing strength per cubic inch = 6.35 D − 0.635, where D denotes density of wood with 15 per cent moisture, calculated upon the dry wood. He considers crushing tests, using test pieces 6 inches high, as the most satisfactory for timber.

Altogether the work of Bauschinger ranks as one of the best and most careful researches in this direction, and has to some extent served as a basis for the work now proposed on American timbers. Further illustrations of the results of Bauschinger's work will be found further on in this bulletin.

Although not undertaken for the purpose of determining any relation of mechanical and physical properties of timbers, we may here mention, on account of careful methods, the tests performed by DAVID KIRKALDY, of London, commented upon in an interesting publication entitled Illustrations of David Kirkaldy's System of Mechanical Testing, by Wm. G. Kirkaldy, 1891.

It is interesting and gratifying to note here that almost simultaneously, but without knowledge of the fact, both the Governments of Prussia and of the United States in the present proposed timber investigations conceived the necessity of more careful, painstaking, and comprehensive work in timber physics than has been attempted before.

With the careful and circumspect manner which characterizes all the Government work of Prussia, before engaging fully upon the main work, a preliminary investigation into methods was determined upon in 1884, when a special commission was charged by the Minister for Agriculture, Public Lands and Forests to determine upon a working plan.

The results of this preliminary investigation, in which three pine trees were most carefully investigated, were published in 1889 as a report by M. Rudeloff, first assistant of the Royal Technical Experiment Station, at Berlin. Upon the basis of this investigation a plan for the execution of the principal work has been elaborated. Although this preliminary work was not known to the writer when devising similar work for American timbers, it appears that in the main the working plans resemble each other closely with the one exception, namely, that the need of practically applicable results has here been kept in the foreground. We have not spent time to arrive at satisfactory methods before proceeding to the main work, but expect to improve the methods as the work proceeds, meanwhile accumulating valuable and useful data.

In regard to the mechanical properties which adapt wood to building, construction, and engineering purposes generally, there exists since Chevandier and Wertheim a considerable, rich, and varied mass of results of experimentation. *We have, however, hardly found more than the methods of investigation and a few examples to illustrate them. To satisfy scientific inquiry more fully will require a considerable amount of mental and pecuniary effort, which should be systematically carried on after a well-digested plan like that now inaugurated in the Forestry Division, and not be dependent on accidental opportunity.*

The knowledge of other groups of properties is in some respects still further removed from the goal that it is desirable to reach. The least has been done with regard to the scientific development of technology. While HARTIG, at Dresden, has taught how to test wood-working machines with reference to their effectiveness, nobody yet has tried to determine quantitatively the working qualities of wood in such a manner that the expenditure of energy necessary in their working could be determined beforehand; nobody has yet discussed the connection of these degrees of quality with the mechanical and physical properties and with the structure and chemistry of wood.

CARL KARMARSH, the celebrated technologist, who raised descriptive technology to the rank of a science, laid the foundation for the discussion of all technical properties which stand in relation to the working and use of wood in the industries in his celebrated standard work, Handbuch der mechanischen Technologie (Handbook of Mechanical Technology), 1st ed., 1837; 5th ed., 1875; last edition, enlarged by H. Fisher in 1888. In this work elasticity and even strength are considered of less moment than density, hardness, cleavability, change of volume, which are of so much account in shaping and in keeping in shape wood structures. The main merit of his work lies in the comprehensive representation of all the reliable old and new data and in bringing to gether the experiences which had accumulated in the mechanical, physical, and chemical treatment of woods and in regard to their properties. His followers, EGBERT HOYER (Lehrbuch der vergleichenden mechanischen Technologie, 1878), FRANZ STÜBCHEN-KIRCHNER (Karmarsch-Heerens technisches Woerterbuch), third edition, 1886, and Prof. A. LEDEBUR (Die Verarbeitung des Holzes auf mechanischem Wege, 1881), could use already the work of the foresters and botanists, Nördlinger, Dr. Julius Wiesner, Dr. R. Hartig, Theodor Hartig, etc. A good compilatory work on the properties of wood, much used and cited in technical circles, is RUDOLPH GOTTGETREU'S Physische und chemische Beschaffenheit der Baumaterialien (Physical and Chemical Qualities of Building Materials), third edition, Berlin, 1880.

An entirely modern idea of the part which the properties of wood play in technological regard is presented by Ledebur, who separates them into "working properties" (Arbeitseigenschaften) and "technological properties" (Gewerbseigenschaften).

In addition to these authors who developed timber physics in the mechanical direction, a number of botanists must be mentioned who made a specialty of the study of wood in its anatomy, physiology, and histology, with the use of the microscope.

Dr. JULIUS WIESNER, of Vienna, gave a new form to this branch of investigations and placed it on a scientific basis. His main works in this field are, Einleitung in die technische Microscopie (Introduction into Technical Microscopy), Vienna, 1867, and Die Rohstoffe des Pflanzenreichs (The raw materials of the Vegetable Kingdom), Leipzig, 1873. In the latter work for the first time in an extensive manner were given the characteristics for the discrimination of the different kinds of wood, their physical properties and their use, and many current misconceptions were shown up and permanently removed.

Dr. J. MOELLER, distinguished by his excellent "Contributions to the Comparative Anatomy of Wood," and by other studies, published in 1883 his very valuable monograph, Die Rohstoffe des Tischler-und Drechsler-Gewerbes, I Theil, das Holz (Raw Materials of the Carpenters' and Turners' Industry, part I, Wood), in which were discussed in an apt manner botanical as well as technical points.

The following botanists also furnished various contributions: Boehm, R. and Th. Hartig, Hoenel, Reinke, Rossmann, Unger, Sanio, Schacht, Weiss, Willkomm, and many others.

Nördlinger, too, enriched the literature, after the appearance of his main work, with special studies, *e. g.*, Der Holzring als Grundlage des Baumkörpers (The Annual Ring as basis of the body of the tree), Stuttgart, 1872. R. HARTIG investigated green and dry weight, etc., the water contents and the shrinkage of pine timber (Berlin, 1874), and published in 1885 the excellent monograph Das Holz der deutschen Coniferen (The Wood of the German Conifers). J. SACHS published his investigation into the Porosität des Holzes (Porosity of Wood), Würzburg, 1877, etc.

In an appendix will be found in addition a list of works which serve the needs of the practice immediately and the popularization of the science, containing many valuable data, besides references to articles bearing on the science of timber physics.

By far the greater part of the work has been done by German investigators, although valuable sporadic additions have been made by French, English, and American workers.

Of English publications which treat broadly on the subject in connection with other matters Professor RANKINE'S Manuals of Civil Engineering, of Applied Mechanics, and of Machinery and Millwork and TREDGOLD'S Carpentry are perhaps best known.

One of the newest and best publications on the general subject of testing is that of W. C. UNWIN, The Testing of Materials of Construction, London, 1888, which besides a general discussion on the properties of material and of methods and machinery for testing, devotes fourteen pages to timber especially, in which Bauschinger's and Professor Lanza's experiments are discussed at length.

In addition there may be mentioned, besides the references made in the foregoing historical account, THOS. LASLETT'S Timber and Timber Trees, London, 1875. Tests on large beams were made by LYSTER, engineer in chief of Mersey Docks and Harbor Board, recorded in Engineering, London, volume 19, 1875, and by MCCLURE, CLARK, and GRAHAM; references to these are found in Burr's Elasticity and Resistance of the Materials of Engineering.

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 aborescent 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 tests 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, U. S. Army, published in Ordnance Manual, who used test pieces 2⅞ by 5¾ inches and 5 feet length without giving any reference to density or other facts concerning the wood; and to Col. Laidley's U. S. Navy tests (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 investigations:

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 on the influence of prolonged stress by the author, 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, vol. 30, 1883, 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, vol. 29, 1883, pp. 417, 441.

Flint, ——. Report of tests of Nicaragua 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, 19, 1878.

——. 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, vol. 17, 1879.

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, vol. 22, 1879.

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

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

——. 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 to 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, vol. 27, 1882, 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 Sciences, 1874 and 1875. Published in Van Nostrand's Magazine, vol. 17, 1887, p. 531.

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

Parker, Lieut. Col. F. H., U. S. 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, Prof., Iowa University. New practical formulas for the resistance of solid and built beams, girders, etc., with problems and designs. Van Norstrand's Magazine, vol. 35, 1886.

Pike, Prof. W. A. Tests of white pine, made in the testing laboratory of the University of Minnesota. Van Nostrand's Magazine, vol. 31, 1885, 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, vol. 65, 1873.

———. 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, vol. 10, 1874.

———. 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.

CONCLUSION.

While it may appear from this brief review of investigations and publications that our knowledge of timber physics is not quite barren, yet we are only at the outstart of exact investigation, and especially for our American timbers even the first practically applicable reliable data are lacking, not to speak of laws of interrelation between physical and mechanical properties or conditions of growth. We find them here altogether a wide field for scientific investigation, promising results of highest practical value.

ORGANIZATION AND METHODS OF THE TIMBER EXAMINATIONS IN THE DIVISION OF FORESTRY.

The timber examinations recently begun under the direction of the Division of Forestry have for their object to determine more precisely than has ever been done the mechanical, physical, and chemical properties of the most important American timbers and the relation of these properties to each other. Besides more reliable data regarding the properties of our principal timbers, there is to be gained from this investigation a means of determining quality by the examination of physical appearance and structure, and of establishing an interrelation between quality and conditions of growth.

To define the objects of the work more in detail, some of the questions which it is expected ultimately to solve may be formulated as follows: What are the essential working properties of our various woods and by what circumstances are they influenced? How does age, rapidity of growth, time of felling, and after-treatment change quality in different timbers? In what relation does structure stand to quality? How far is weight a criterion of strength? What macroscopic or microscopic aids can be devised for determining quality from physical examination? What difference is there in wood of different parts of the tree? How far do climatic and soil conditions influence quality? In what respect does tapping for turpentine affect quality of pine timber?

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 devoloped 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 arduous work of collecting has been done hitherto chiefly by Dr. Charles Mohr, of Mobile, Ala., and has been confined so far mainly to the collection of pines and oaks from Alabama, of which during the year one hundred and forty-nine trees were collected. In addition, twenty-two trees of white pine from Wisconsin were collected.

The logs are shipped to the test laboratory at St. Louis, in charge of Prof. J. B. Johnson, and are there sawed and prepared for testing, carefully marked, and tested for strength, as described further on. Up to the time of writing some twenty-six hundred tests have been made.

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.

I consider it my duty to state here that through the energy and devoted interest of Professor Johnson alone has it been possible to carry this work into execution, since he provided by personal and private endeavor the entire outfit of the test laboratory, and with much financial risk organized the testing work.

The disks cut from each log and correspondingly marked are examined at the botanical laboratory of the University of Michigan, at Ann Arbor, by Mr. Filibert Roth, who has prepared himself for this work, requiring great care and painstaking, by several years' preparatory studies. 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.

Although the work as now organized has been carried on for hardly a year, the number of definite problems which present themselves and are destined to be solved by it is quite astonishing. Besides the general examining and testing species by species, there become, therefore, necessary special series of investigations. For instance, the influence of seasoning on the strength of timber will form such a special series presently to be undertaken. The influence on the quality of the wood of tapping the Southern longleaf pine for turpentine is a series on which we are now engaged, and a brief résumé of the most important results of which has been published.

The influence of the length of service upon construction members will form another series as material can be obtained. Altogether there is opened up an almost endless field of useful work, the richest mine of unexplored knowledge, the importance of which can hardly be overestimated, for after all, though we in the United States are slow to realize it, wood is our most important material of construction, and increased knowledge regarding it must affect, directly or indirectly, every conceivable interest.

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.

(Written by Prof. J. B. Johnson.)

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 Figs. 1 to 4.

In all cases the arrangements shown in Figs. 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 Figs. 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.

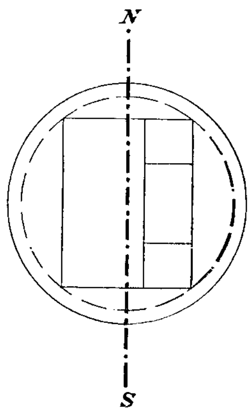


Fig. 1.

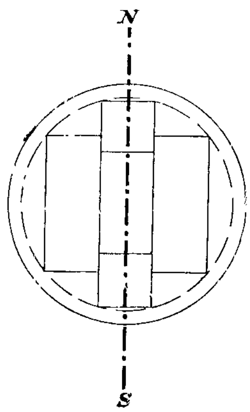


Fig. 2.

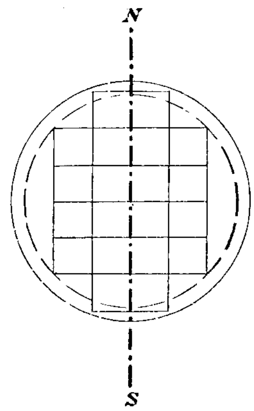


Fig. 3.

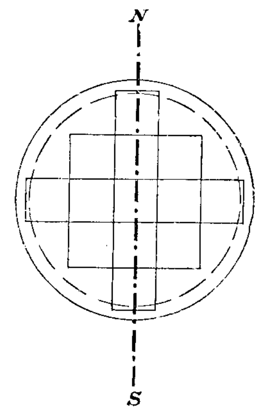


Fig. 4.

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: $\overset{25}{\underset{4}{2}}$, 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 Figs. 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 the drying box shown on Plate I. 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 LABORATORY.

The testing laboratory is the basement story of the gymnasium building of Washington University. Its dimensions are 71 by 46 feet, with one corner partitioned off, as shown on the floor plan, Plate I. The net area used for laboratory purposes is 2,500 square feet. All the apparatus suspended from the ceiling, as shafting, steam pipes, exhaust fan, etc., is shown in dotted lines.

The apparatus pertinent to the timber tests consists of a 1,000,000-pound column-testing machine; one 100,000-pound beam-testing machine, one 100,000-pound universal testing machine, of Riehlé's "Harvard" pattern; one small portable beam machine, one 6-horse power Brayton coal-oil engine, one 4-horse power steam engine, one planer and one lathe, for ironwork; one planer, one band saw, and one cutting-off saw, for shaping and dressing wood specimens; suitable scales, drying ovens, etc., for the moisture and specific gravity tests; the drying box with its steam coils and exhaust fan, and all the necessary appliances, benches, tools, desks, etc., including a Thatcher's slide rule for making the computations. The timber is stored in various parts of the room not otherwise utilized. Ultimately a warehouse will have to be obtained for storing the broken specimens.

The cross-breaking tests.

Large beams.—The large beams are tested on the large beam-testing machine shown on Plate II. The base of this machine consists of two long-leaf pine sticks (*Pinus palustris*), 6 inches by 18 inches by 24 feet long, with a steel plate three-fourths of an inch by 18 inches by 20 feet long, all bolted up as one beam. The power is applied by hydraulic pressure upon a plunger below, to the crossheads of which are attached the two side screws, on which the upper crosshead is moved by sleeve nuts and spur gearing. The beam to be tested rests on pivots at the ends, placed on top of the base beam, and the upper crosshead is moved down by means of the gearing until the central pivot attached to it comes in contact with the beam, or rather with the distribution blocks placed on the beam at this point. The test then begins, the power originating in a double-plunger pump, operated by hand or by steam power in another part of the room.

To prevent the pivots or "knife-edges" from crushing into the timber, it is necessary to make the contact at both ends and center, first upon a cast-iron plate, then through longer wooden blocks to the timber. The center block is curved somewhat on the lower side, to allow for a considerable deflection in the beam when nearing its maximum load.

In the tests of all beams, both large and small, the load is put on at the same uniform rate, so as to eliminate the time effect, which is very great in timber tests. The load on the small beams is increased at such a rate as to produce an increase in the deflection of one-eighth inch per minute without any pause until rupture occurs. This causes rupture in from ten to fifteen minutes time. The load is read off when it reaches certain even amounts, and an observer notes the corresponding deflection without stopping the test. The time required for the large beam tests is about the same, the deflection rate being greater when the total deflection is expected to be greater, as is the case with 4 by 8 inch sticks 12 feet long. The deflections of the large beams are observed upon a paper scale, graduated to inches and tenths, glued to a piece of mirror, which is tacked to one side of the stick at the center. A fine thread is stretched, by means of a rubber band, over nails driven into the side of the stick above the end supports on the line of the neutral axis. This string or thread is moved about an inch away from the surface of the timber, and all parallax, or error of reading from an oblique position of the eye, is avoided by keeping the eye where the thread and its image in the mirror coincide and form one and the same line. The readings are taken to inches and hundredths by estimating the tenths of the graduation spaces on the scale.

The loads are weighed on the large universal testing machine in another part of the room. This is done by having both machines connected up to the same pump, blocking the weighing machine so that the load on its plunger is transmitted to the scales and weighing beam, and then pumping into both machines. The plungers are exactly of the same diameter; they have similar leather cup packing, and hence the error of this method is simply the difference in the friction of the two plungers in their packing rings. To test the accuracy of this method, and to determine the error, if any, at any time, a nest of calibrating springs, shown on Plate II, was made and tested first on the Emery machine at the United States Arsenal, at Watertown, Mass. The loads were found which corresponded to given deflections, or in other words the stress diagram of these springs up to a 30,000-pound load, which corresponds to a little more than one inch elastic deflection. By repeating this test on the 100,000-pound universal or weighing machine, and then on the large beam machine, and plotting the stress diagrams obtained from each, not only can these machines be compared with each other, but both can be compared or calibrated with the Emery machine at the Watertown Arsenal.

In Fig. 5 the three curves corresponding to the three machines are given. They are so nearly coincident that it is shown that not only is the universal 100,000-pound Riehlé machine correctly graduated, but that the method used of weighing the loads on the beam machine by means of the universal machine results in no appreciable error. This test can be applied at any time, and proof

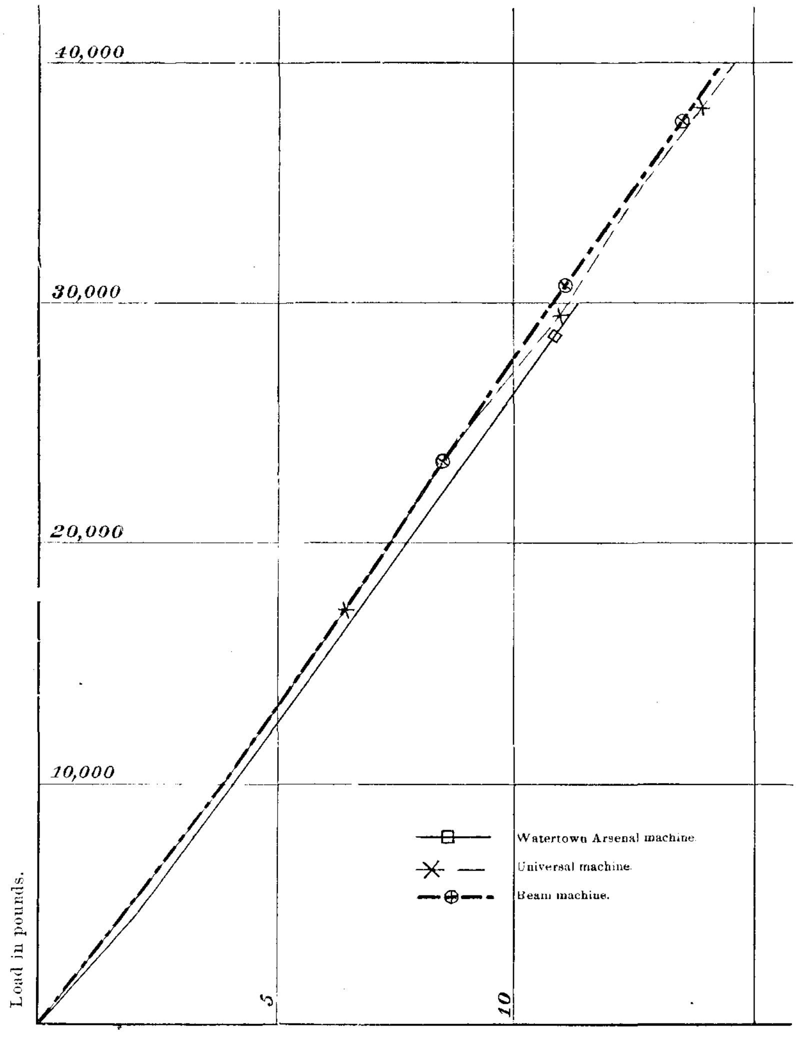


FIG. 5.—Standardizing tests with calibrating springs.

readings have been made at frequent intervals. The beam machine is greatly simplified by thus dispensing with all attached weighing apparatus, which would be greatly in the way in the handling of large beams sometimes weighing over 1,000 pounds.

Small beams.—The small beams which are nominally 4 inches square and 60 inches long between supports are tested on the small beam-testing machine, shown on Plate III. This machine was designed originally for testing cast-iron beams, the load at one end or one-half the load at the center being weighed on a pair of ordinary platform scales. The deflections are read off to thousandths of an inch upon a micrometer screw held in the top iron crossbeam. By this means a rigid connection is obtained, through parts not under stress, from the end supports to the center bearings. The movement of the center with reference to the ends is therefore obtained, regardless of the absolute movement of the parts. The load is put on by the hand wheel and power screw, and the weighing beam kept in balance by putting on overweights and moving the poise. Three men are required to make this test. One moves the power screw, which has one fourth inch pitch, so as to make one revolution every two minutes, and he continues this uniform motion till rupture occurs. Another keeps the scales balanced and calls off the even hundreds of pounds. Another keeps the micrometer screw in contact with the head of the power screw, reads it for certain even hundred-pound loads called off, and records the time of each such reading to the nearest minute, the load, and the corresponding reading of the micrometer screw. Here also the end and center bearings are protected by iron plates large enough to prevent any appreciable distortion from lateral compression.

After rupture occurs the stick is bored for samples from which to obtain the moisture tests, and the uninjured ends sawed off and used for the remaining tests, as described below.

The moisture test.

The borings are taken from two holes, 20 inches from each end, and at about one-third the width of the stick, from either side. These borings are first weighed on a delicate balance, then placed in a drying oven, at a temperature of 212° F., until they have reached a nearly constant weight, when they are reweighed. The dry weight is taken as the basis on which to compute the percentage of moisture. Thus, if the original weight is twice the final weight, then there was as much water as woody fiber in the stick, or one-half or 50 per cent of the original weight was water. But when computed on the basis of the dry weight there would be 100 per cent of water. The advantage of computing the percentage on the dry weight is that it furnishes a constant basis of comparison, whereas if computed on the actual or wet weight the basis on which the percentage would be computed would vary with every change in the amount of moisture.

The specific gravity.

The specific gravity is found by taking one of the end pieces, usually 4 by 4 by 8 inches, measuring carefully its lateral dimensions by calipering them at the middle points of the sides at the central section, measuring the length in a similar manner, and taking the product of these three dimensions as the volume. From the total volume and the actual total weight the weight per unit volume or per cubic foot is found, and from this the specific gravity, which is the weight per cubic foot divided by the weight of a cubic foot of distilled water. It must be understood that all the small (4 by 4 inch) beams are planed up true and rectangular before testing, and that all the crosscuts are made by a power saw so adjusted as to cut truly at right angles to the sides. The volume can therefore be very accurately computed from the dimensions as above described.

The tension test.

The tension test piece is cut from one end of the broken beam. It is 16 inches long, 2½ inches wide, and 1½ inches thick. Its thickness at the center is reduced by cutting out with a band saw circular segments, leaving a breaking section of some 2½ inches by three-eighths inch. This specimen is then placed between the plain wedge-shaped steel grips, and pulled, the same as a bar of iron, in the Universal Machine, shown on Plate IV. This simple method has been found very satisfactory in practice, and is fully illustrated on Plate V. For this test care is taken to cut the specimen as nearly parallel to the grain of the wood as possible, so that its failure will occur in a condition of pure tension.

The endwise compression test.

Most of these tests are made on sticks 4 inches square by 8 inches long, the ends having been cut perfectly true and at right angles to the sides. They are tested in the Universal Machine, the compression continuing until the stick has been visibly crushed and has passed its maximum load. The crushing usually manifests itself over a plain section, by crushing down or bending over all the fibers at this section, which may be either a right or an oblique section. The section of failure, however, is seldom at the very end. The slightest source of weakness may determine its position, as a very small knot for example, for knots are a source of weakness in compression as well as in tension.

Some tests are made on columns 40 inches long by 4 inches square on the large beam machine, but these usually fail the same as the short blocks, and not by bending sidewise.

Compression across the grain.

Specimens 4 inches square and 6 inches long are tested in compression across the grain. An arbitrary limit of distortion, namely, 3 per cent of the height, has been chosen as a reasonable maximum allowable distortion in practice. This limit is indicated in the test by the ringing of an electric bell, and the load then on the specimen is called the compressive strength across the grain. The same limit has also been found to be very near the maximum load in lateral compression, which is also determined.

The shearing tests.

Since timber fails by shearing, or splitting, oftener than any other way this test becomes a very important one. The specimen is taken 2 inches square and 8 inches long, and rectangular holes mortised 1 inch from each end, and at right angles to each other, as shown on Plate V. The specimen is then pulled, in the Universal Machine, by means of suitable stirrups and keys, as shown in the plate. The ends are kept from spreading or splitting by putting on small clamps with just enough initial stress in them to hold them in place. After one end shears out, two auxiliary hoops or stirrups are used to connect the key which sheared out to a pin put through the hole at the center of the specimen as shown. The other end is then sheared, and two results are obtained on planes at right angles to each other. In this way the shearing strength is determined on two planes at right angles to each other.

Tests of full-sized columns.

No set of experimental tests of timber would be complete without numerous tests on full-sized columns. This requires a machine of not less than 1,000,000 pounds capacity, capable of crushing to failure columns from 12 to 14 inches square and at least 30 feet long. Such a machine has been built expressly for this work, and is shown on Plate VI. It is capable of exerting a compressive force of 1,000,000 pounds on a length of 36 feet or less. The sides or tension members of this machine are made of four long-leaf yellow pine sticks (*Pinus palustris*), from Georgia, each 8 by 12 inches and 45 feet long. The power is applied by the same hydraulic pump which operates both the large beam machine and the 100,000-pound universal machine. The loads are weighed on this latter machine the same as for the beam tests. The plunger in the column machine has just ten times the area of that in the weighing machine, and hence the loads in the column tests are just ten times those indicated on the weighing beam, with a slight correction for the friction differential, which has not yet been determined. The tail block is of cast iron, resting in a spherical socket, which is carried on a car, and which can be held by struts resting in slots in the timber. The outer ends of these struts are kept from spreading by means of tiebars, as shown, and the whole combination can be moved forward or back so as to make the distance between face plates any even number of feet from two to thirty-six. The spherical socket in the tail block will produce an accurate adjustment of the end bearings at the beginning of the test, but after the load is on it is thought that this joint will remain rigid, the same as a solid block, especially if precautions are taken to increase the frictional resistance between these bearing surfaces. This spherical socket is provided to eliminate the effects of unequal shrinkage in the side timbers, or any unequal compression in the bearing sockets, and not to serve as a round-end bearing for the column. When long columns are tested, a part of their weight will be supported by means of lines and pulleys, so as to make the test correspond to a vertical load in actual practice.

Significance of results.

From the cross-breaking tests are obtained the cross-breaking modulus of rupture, the modulus of elasticity, or measure of the stiffness, and the elastic resilience, or measure of the toughness.

The loads and their corresponding deflections are plotted as rectangular coördinates, and the modulus of elasticity and the elastic resilience are obtained from a study of this strain diagram.

The following is an example of the record made for every beam test. This is a record of a test made on a 4 by 8 inch stick of long-leaf pine, 12 feet long, which was placed on supports 140 inches apart.

CROSS-BREAKING TEST.

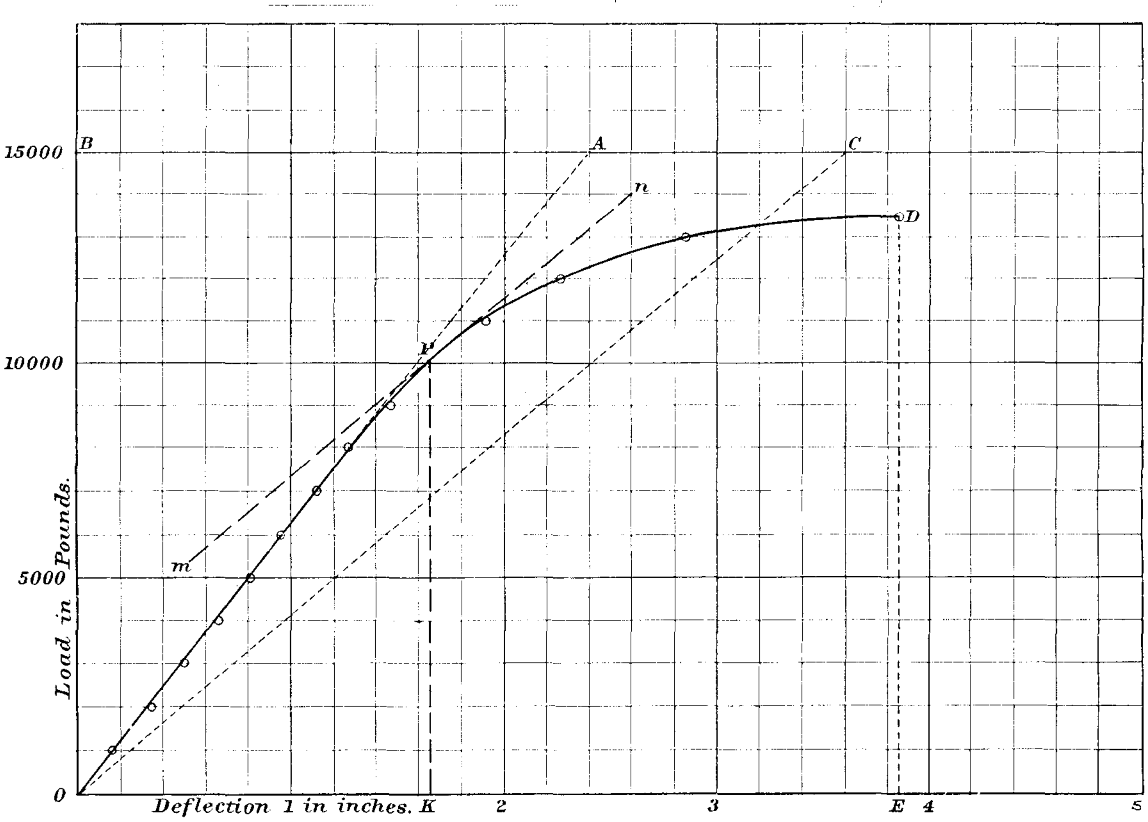
Mark $\begin{cases} 16 \\ 3 \\ 1 \end{cases}$

Length, 140.0 inches.
Height, 8.04 inches.
Breadth, 4.02 inches.

Strength of Extreme Fiber,
where $f = \frac{3 W l}{2 b h^2} = 10{,}910$ pounds per square inch.
Modulus of Elasticity = 2,070,000 pounds per square inch.
Total Resilience = 35,440 inch-pounds.
Resilience, per cub. in. = 7.83 inch-pounds.
Total Elastic Resilience = 8,650 inch-pounds.
Elastic Resilience, per cubic inch = 1.91 inch-pounds.

[Number of annual rings per inch = 14.]

August 27, 1891.		Load.	Deflection	Scale reading.	Remarks.
h.	*m.*				
1	58	1,000	0.17	11.02	
	59	2,000	0.34	11.19	
	59	3,000	0.50	11.35	
2	00	4,000	0.66	11.51	 
	00	5,000	0.82	11.67	
	01	6,000	0.96	11.81	
	02	7,000	1.13	11.98	
	02	8,000	1.27	12.12	
	03	9,000	1.46	12.31	N
	03	10,000	1.65	12.50	Butt end. Top end.
	04	11,000	1.93	12.78	
	05	12,000	2.27	13.12	
	07	13,000	2.85	13.70	
	09	13,500	3.85	14.70	Maximum load.



The observed data are given in the columns headed "Time," "Load," and "Scale Reading." These results are recorded on this sheet in ink as they are observed. The result in the "Deflection" column is computed from the scale reading. It is placed next to the column of "Loads" for convenience in plotting the strain diagram, which is done on the ruled squares at the bottom of each sheet. These plotted results fall in all cases on a true curve, similar to the one shown on p. 36. The total area of this curve, *O. D. E.*, properly evaluated by the scales used, represents the total number of foot-pounds or inch-pounds of work done upon the stick before rupture occurred. This is called the *Total Cross-breaking Resilience* of the stick, and when divided by the volume of the stick in cubic inches it gives approximately the total cross-breaking resilience of the stick in inch-pounds per cubic inch of timber.

A better criterion of toughness, or resistance to shock, is some definite portion of this strain diagram area, as *O P K*, for example. This amount of resilience or spring can be used over and over again, and is a true measure of the toughness of the timber as a working quality. To locate the point *P*, the following arbitrary rule has been followed:

Draw a tangent to the curve at the origin, as *O A*. Lay off $A\ C = \frac{1}{2}\ B\ A$, and draw *O C*. Draw *m n* parallel to *O C* and tangent to the curve. Take the point of tangency as the point *P*, and draw *P K*. The area *O P K* is then called the *Relative Elastic Resilience.**

There is no "elastic limit" in timber as there is in rolled metals. In this respect it is like cast iron. The point *P* is the point where the rate of deflection is 50 per cent more than it is at first, and usually falls on that part of the curve where it begins to change rapidly into a horizontal direction or where the deflection begins to increase rapidly. The areas of these curves are measured with a planimeter and reduced to inch-pounds. Thus, if 1 inch vertically represents 5,000 pounds, and 1 inch horizontally represents 1 inch deflection, then 1 square inch represents 5,000 × 1 = 5,000 inch-pounds. If the area *O P K* is 1.73 square inches, then the corresponding resilience is 8,650 inch-pounds. This means that a weight of 100 pounds, falling 86.5 inches, or 1,000 pounds falling 8.65 inches, would have strained the beam up to the point *P* or it would have deflected it 1.66 inches, and the beam would have been then resisting with a force of 10,000 pounds, since *P* falls on the 10,000-pound line. If this result—8,650 inch pounds—be divided by the number of cubic inches in the stick between end bearings, the result is the true *Relative Resilience in Cross-breaking* in inch-pounds per cubic inch. This result is independent of the dimensions of the test specimen, and is therefore a true measure of the quality of timber which is usually known as toughness. It depends, as toughness in the usual understanding does, on both the strength and the deflection; in fact, it is very nearly the half-product of the strength developed and the deflection produced at this particular point *P*. It is probably the nearest quantitative measure of the toughness that can be arrived at.

The strength of the extreme fibre is computed by the ordinary formula—

$$f = \frac{3\ W\ l}{2\ b\ h^2} \quad \ldots \quad (1)$$

where f = stress on extreme fibre in pounds per square inch,
W = load at center in pounds,
l = length of beam in inches,
b = breadth of beam in inches,
h = height of beam in inches.

At the time of final rupture this formula by no means represents the actual facts. It assumes that the neutral plane remains at the center of the beam till rupture occurs, which is far from correct. In green timber, where the crushing strength is greatly reduced by the presence of the sap, the crushing resistance is only about one-third as much as the resistance to tension, so that the stick invariably begins to fail on the compression side. This causes the neutral plane or plane of no stress to be lowered, and at the time of final rupture this plane may be from one-fourth to one sixth the depth from the bottom side of the beam. The value of f computed by this formula from a cross breaking test, therefore, will always be intermediate between the crushing strength

* This term has been coined to define this particular portion of the resilience which will be used for comparing the relative elasticity or toughness of different timbers.

and the strength in tension. Thus the crushing strength of a given stick was found to be 5,820 pounds per square inch, while the tensile strength was 15,780 pounds; the cross-breaking strength was found by this test to be 10,900 pounds.

The modulus of elasticity is computed from the formula—

$$E = \frac{W l^3}{48 D I} = \frac{W l^3}{4 D b h^3} = \frac{W}{D} \cdot \frac{l^3}{4 b h^3} \quad . \quad . \quad . \quad . \quad (2)$$

where E = modulus of elasticity,

and W, l, b, and h as in eq. (*1*)
D = deflection of beam.
I = moment of inertia of the cross-section $= \frac{1}{12} b h^3$ for rectangular sections.

To find this modulus, a tangent line is drawn to the strain diagram at its origin, as $O A$, and the cördinates of any point on this line used as the W and D from which to compute E.

The modulus is thus seen to vary directly as the load and inversely as the deflection, hence it is a true measure of the stiffness of the material. It is the most constant and reliable property of all kinds of engineering materials,* and is a necessary means of computing all deflections or distortions under loads.

In using the modulus of elasticity of timber for computing deflections, it must be remembered that in this case the time effect is very great (it is nearly zero in metals) and that this factor can only be used to compute the deflection for temporary loads. The deflection of floor or roof timbers, for instance, under constant loads is a very different matter, as it increases with time.

Relation between strength and stiffness.

In Fig. 6 is shown the relation found by Professor Bauschinger† between the modulus of elasticity (stiffness) and the cross-breaking strength, from tests on pine, larch, and fir timber. Although the results show a wide range, there is evidently a general relation between these two quantities, as indicated by the straight line drawn through the plotted points. The algebraic expression of the law shown by this line, rendered into pounds per square inch, is, in round numbers—

$$\text{Cross-breaking strength} = 0.0045 \text{ Modulus of Elasticity} + 450. \qquad (3)$$

If it should be found that there is such a law for all kinds of timber, then there may be derived an equation of this form, but with different constants, for each species.

Relation between strength and weight.

In Fig. 7 is shown the relation between the crushing strength and the specific gravity, when both are reduced to the standard percentage of moisture, which was taken at 15 per cent.

These results are also taken from Professor Bauschinger's published records of tests on Pine, Larch, and Fir timbers, and they conclusively show that the greater the weight the greater the strength of the timber. The law here is a well-defined one, so far as these timbers are concerned. When rendered into English units (pounds per sq. in.), the equation of this line is:

$$\text{Crushing strength} = 13800 \text{ specific gravity} - 900. \qquad (4)$$

when the timber contains but 15 per cent of moisture. This equation would also vary in its constants for each species of timber.

---

* The wide range of values of the modulus of elasticity of the various metals, found in published records of tests, must be explained by erroneous methods of testing.

† See Pl. II, vol. 16, of Professor Bauschinger's Reports of Tests made at Government Testing Laboratory at Munich.

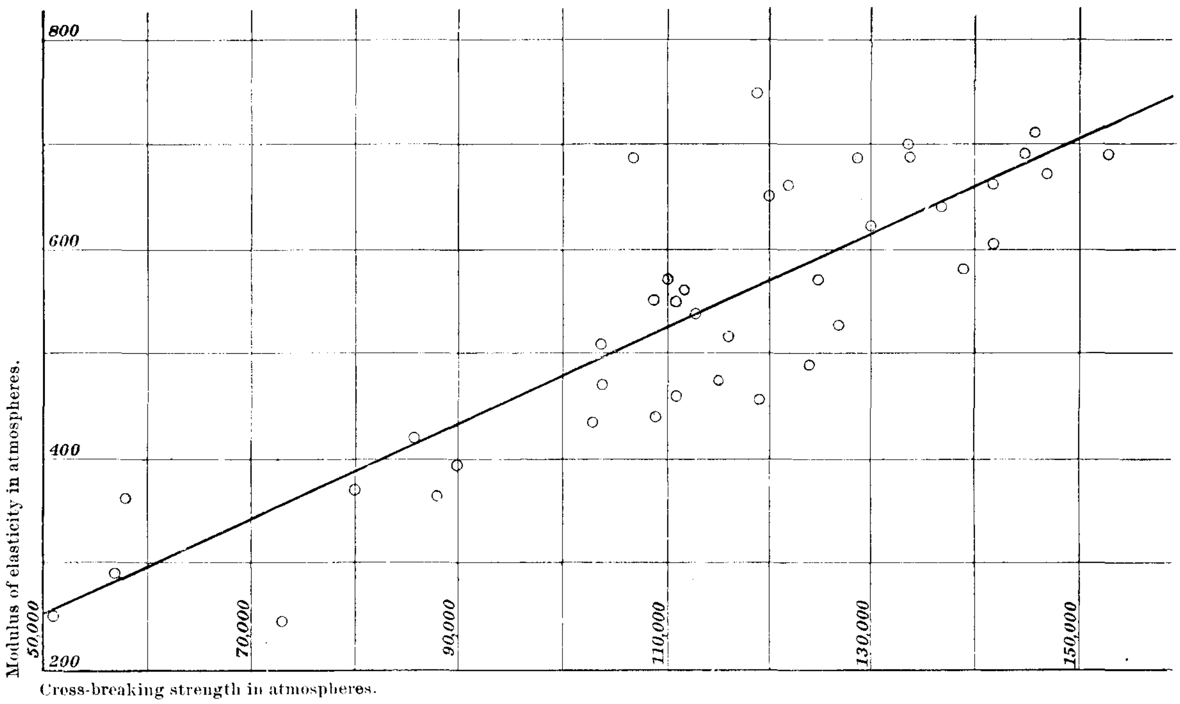


FIG. 6.—Relation between cross-breaking strength and modulus of elasticity or stiffness for Pine, Larch, Spruce, and Fir timber. (After Bauschinger.)

[Cross-breaking strength = 0.0045 modulus of elasticity + 450.]

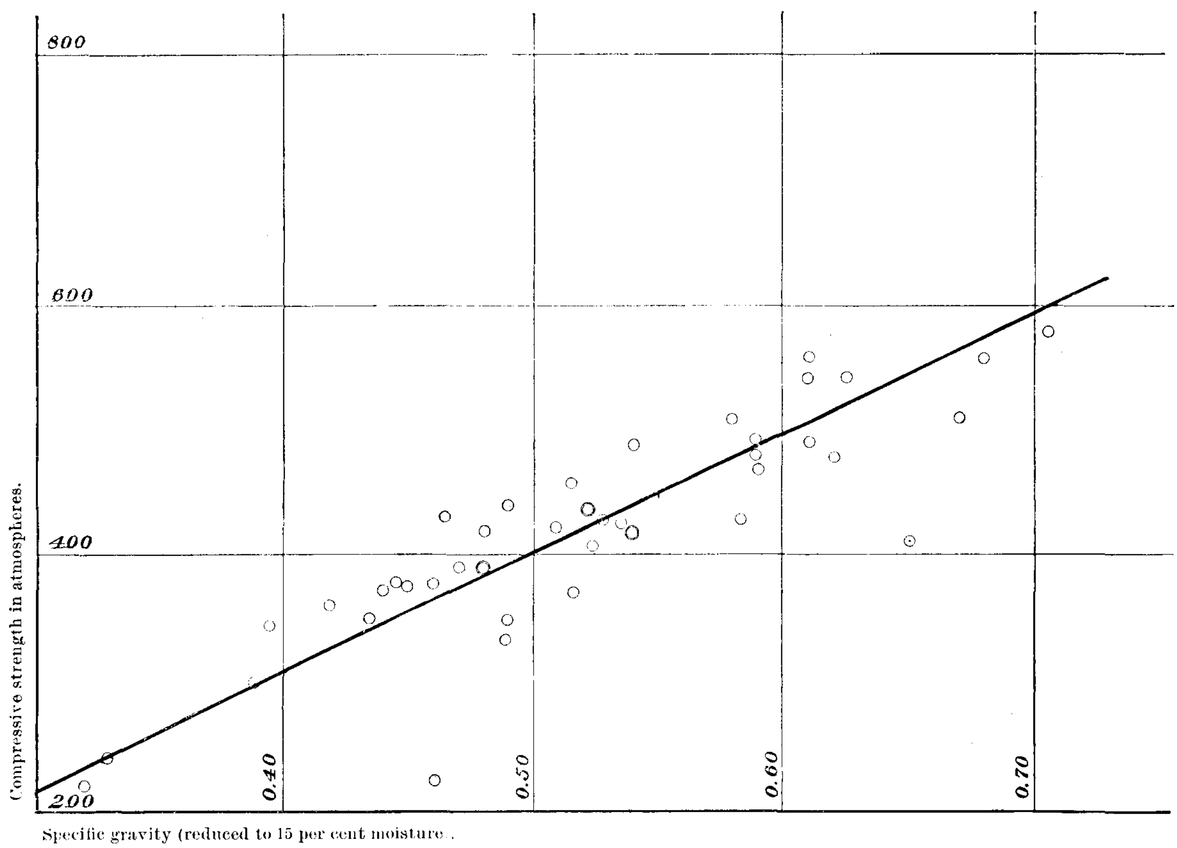


FIG. 7.—Relation between compressive strength and specific gravity or weight for Pine, Larch, Spruce, and Fir timber. (After Bauschinger.) [Compressive strength = 13,800 specific gravity — 900.]

Relation between the compressive strength and the percentage of moisture.

In Fig. 8 are plotted some very careful tests by Professor Bauschinger to show the relation between the percentage of moisture and the crushing strength.

There is no question but the crushing and the shearing strength are both greatly reduced by moisture. The crushing test also gives a very fair indication of the strength of the timber in all other ways. In this instance four sticks were taken and sections tested first green, or having an average of 37 per cent of moisture when computed on the wet weight, or 59 per cent of moisture when computed on the dry weight, as is the practice in the tests made by this Department. The sticks were then dried until there was an average of 14.6 per cent moisture on the wet weight, or 17 per cent of the dry weight. The remaining portions of the sticks were further seasoned until there remained but 8.2 per cent moisture computed on the wet weight, or 9 per cent moisture on the dry weight, and then tested. This is a smaller percentage of moisture than out-door lumber ever reaches, as the ordinary humidity of the external air will usually maintain at least 10 per cent of moisture in all kinds of timber.

When these three groups of results are plotted, and the most probable curve drawn through them, there is seen to be a remarkable increase in the crushing strength when the percentage of moisture falls below fifteen or twenty. The variation in strength above that limit is very small. Professor Bauschinger has published a great many such curves, all showing the same general law. This curve illustrates the necessity for finding the percentage of moisture for every test of strength made.

Professor Bauschinger has published very few tests showing the relations between the cross-breaking strength and the moisture, but Fig. 9 is a reproduction of such results as he has given.

When the percentage of moisture sinks as low as 10 there appears a wide variation of strength, not satisfactorily explained. There would seem to be a law of dependence, however, but less marked than in the case of compressive strength.

Relation between specific gravity and moisture.

In Fig. 8 the "specific-gravity" curve shows the relation between the specific gravity and the percentage of moisture. At first the specific gravity diminishes rapidly as the percentage of moisture is reduced, but when this has been reduced to 15 per cent the specific gravity changes very little for any further reduction in moisture. This shows that the shrinkage is insignificant until the timber becomes nearly dry, when it swells and shrinks almost directly with the percentage of moisture, so that the weight of a unit volume, which is a measure of the specific gravity, remains nearly constant. This curve is also only one of a great many similar ones given by Professor Bauschinger.

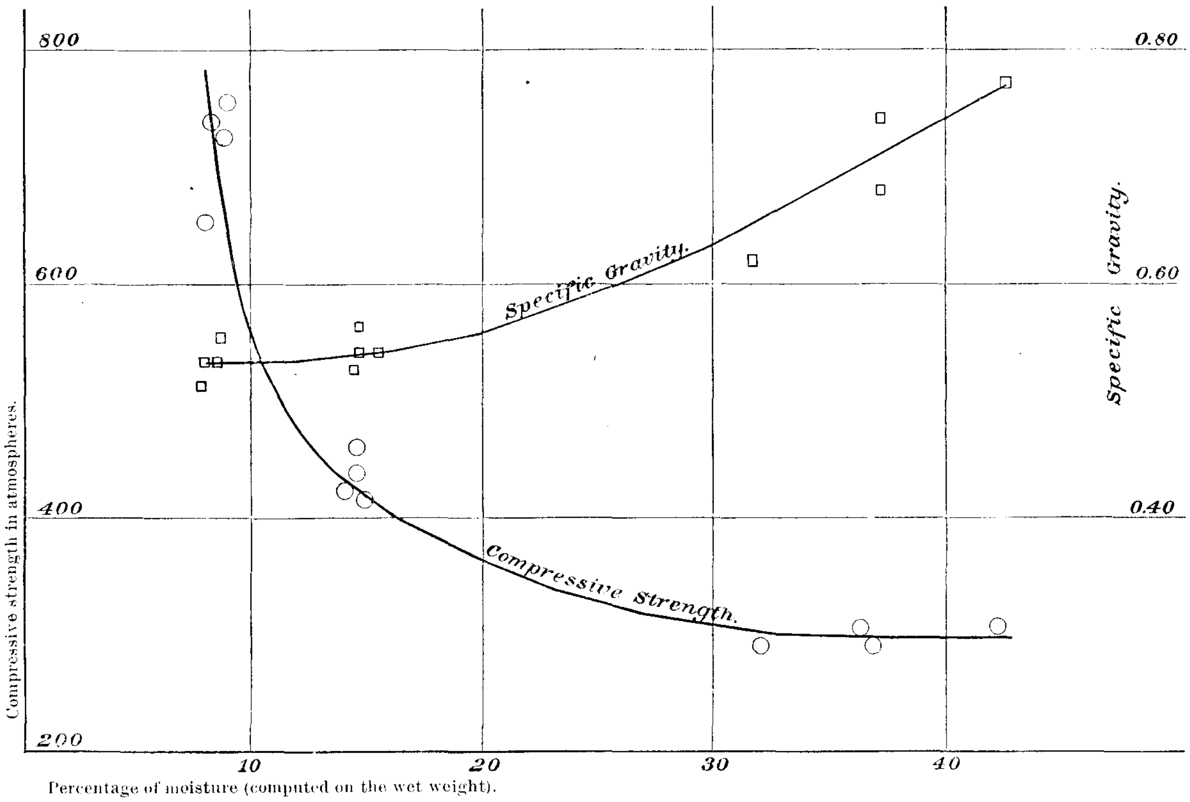


FIG. 8.—Variation of compressive strength and of specific gravity for varying percentages of moisture. Results on Scotch Pine timber. (After Bauschinger.)

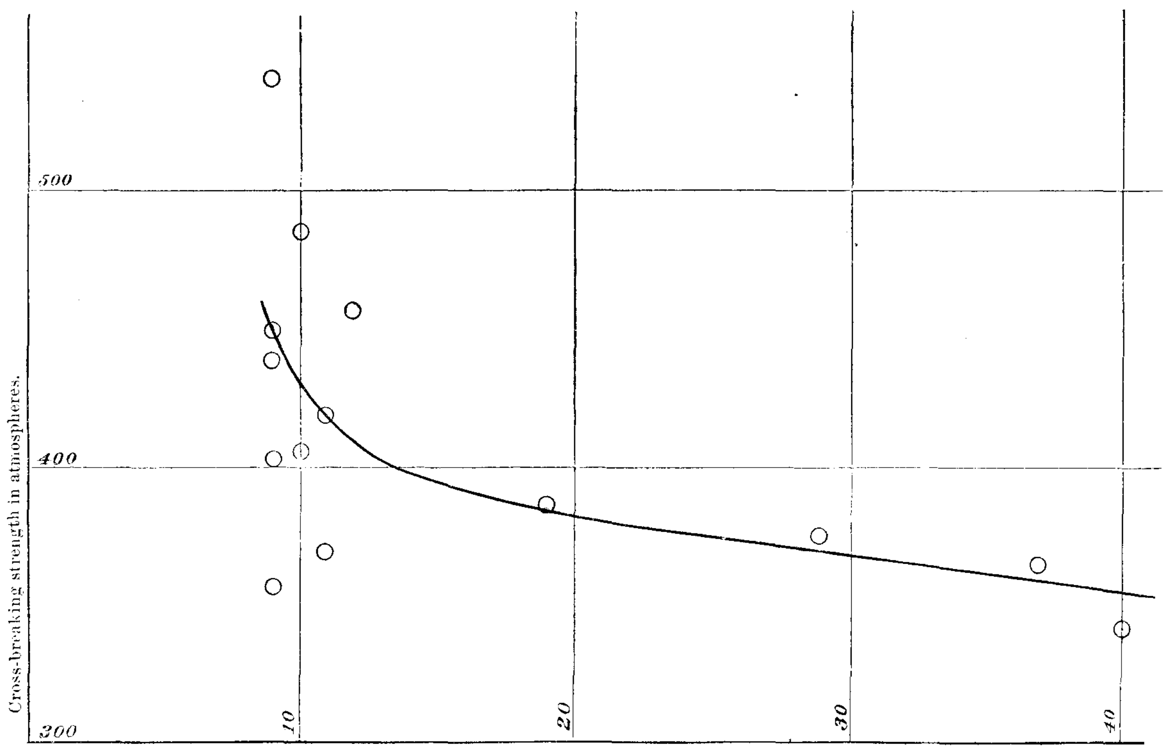


FIG. 9.—Relation between cross-breaking strength and percentage of moisture for Pine, Larch, Spruce, and Fir timbers. (After Bauschinger).

EXAMINATION INTO THE PHYSICAL PROPERTIES OF TEST MATERIAL.

(Written by FILIBERT ROTH.)

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.

CONDITION OF THE MATERIAL ON ARRIVAL.

The specimens sent by mail, and in double wrapper, oiled paper inside, have arrived in all cases in very good condition. The journey from Alabama to Michigan occupies from two to four days, and only in exceptional cases are the wrappers worn. To determine the effect of the wrapper as a preventive against evaporation, several pieces were allowed to remain in their original wrapper, and were thus weighed from time to time.

The following figures refer to a half disk of *Pinus palustris*, consisting almost entirely of sapwood:

Date.	Weight of piece, including wrapper.	Remarks.
Oct. 24	1,607	Wrapper rubbed off at one corner.
Oct. 26	1,600	Placed on a shelf 10 feet from a steam-heating coil.
Oct. 30	1,572	After weighing to-day a damp cloth was placed over the piece.
Oct. 31	1,572	Cloth remained, but was not remoistened; it therefore became dry and was removed.
Nov. 2	1,568	The piece felt moist and was covered with mold.
Loss (2.2 per cent)	39	
Dec. 12	1,330	
Loss (17.2 per cent)	.277	

During the same time a piece of the same disk and weighing 823 grams at first, was left without a wrapper in an unheated room and lost 298 grams, or 36.1 per cent. These figures show that the wrapper alone reduces the evaporation to a minimum, which may well be left out of consideration, and also that if this wrapper is reinforced by dampened cloth, a precaution always observed during the time of working up the specimens, the evaporation ceases entirely.

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. For it would not be sufficient to add the densities of the several pieces, and divide this sum by the number of pieces, in which case the central (prismatic) pieces would inordinately influence the result.

For instance, a given prism gave for the four sections from periphery to center the following values:

Section.	Density.	Mean distance from center.	Product.
a	0.60	14	8.40
b	0.50	10	5.00
c	0.40	6	2.40
d	0.30	2	0.60
Total....	1.80	32	16.40

The density from simple addition would be $\frac{1.80}{4}=.45$, while the method as used will give $\frac{16.40}{32}=.51$.

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 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 further 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 superfluous 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.

In constructing the apparatus, care should be had that the point *N* is higher than the point *M*; if this is not the case, some air, slightly compressed by a closely-fitting cup, suddenly finds an outlet, and carries some water along with it. The accuracy of this instrument is very considerable and easily tested; its management is simple, its construction easy. Previously two ways had been tried. In one case a similar vessel about 15 cm. diameter had been used, having a graduated glass tube on the outside communicating with the vessel. The readings, made with a magnifier, were facilitated by a float. A rise of 1 mm. requiring about 17 cub. cm. would have to distinguish one-seventeenth of a millimeter. Without further discussing the difficulties of this method, it may be stated that it proved by no means satisfactory. The second way was to allow the water to flow over a broad, short and steep spout with a clean, sharp edge, and then to weigh the water, as is done at present. This gave much better results than the method just described, but it is a slow method; the water requires too long to arrange its level, and any slight shock or disturbance readily vitiates the experiment.

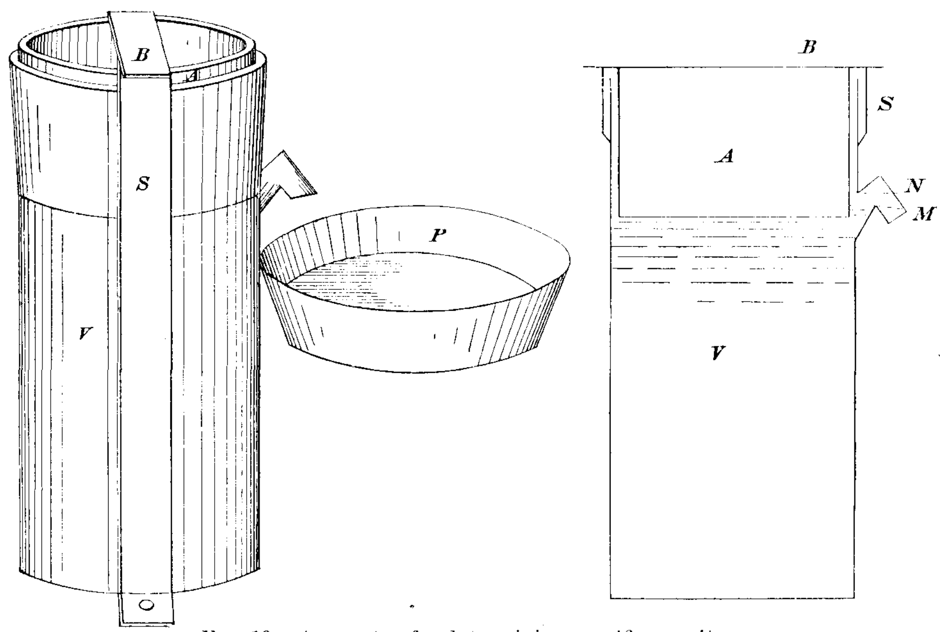


Fig. 10.—Apparatus for determining specific gravity.

DISCUSSION OF VARIOUS METHODS TO ASCERTAIN VOLUME.

Having described the mode of doing, the application of the method of measurement by immersion for porous bodies like wood requires some consideration. The fact that it has been, and is to-day, extensively employed by the best of experimenters is certainly a recommendation, but can not serve as an argument for its accuracy, and it appeared necessary, therefore, to resort to special experiments. Before describing these experiments and their results, a consideration of the objections and their justification from a general standpoint may not prove amiss. The objection of inaccuracy of the apparatus ceases at once with an instrument whose accuracy can be demonstrated any moment, and expressed in grams or parts of such. Not so with the more common objection that "wood soaks up water while the measuring is going on." This statement generally appears to express two more or less clear notions, one implying a swelling of the wood on imbibing water, and thus a change of dimensions during the process of the experiment; the other a soaking of water into the cell cavities analogous to the rushing of water into the capillary tubes of plaster of Paris, and thus a decrease of water in the vessel and a consequent inaccuracy of the experiment. The correctness of the first of these two notions, experiment alone could establish; that of the second necessitates a consideration of general wood structure. A piece of pine wood, for instance, resists the passage of water in a radial direction even when under considerable pressure, less so in a tangential direction, and, of course, very much less longitudinally. In a radial direction it is a process of soaking from cell to cell, often, in split wood commonly through the thick cell walls of the summer wood, and even the medullary rays, owing to the small radial dimension of their elements seem not to improve the conductivity to any great extent. This is quite different in a tangential direction where every element possesses dotted pits. But these pits are guarded by membranes, and any one who has watched a thin section freshly cut from a dry stick with its many persistent air bubbles, appreciates why water does not pass readily through wood across the grain. In a longitudinal direction, the lumina, or pores are opened. Here each lumen acts as a capillary tube, and once moist is as eager to take up water as a capillary tube of the same dimensions in plaster of Paris. In pine wood the greatest length of these tubes is about 6–7 mm. Assuming that the cells are cut in such a manner that the average length of the tube exposed by the section is one-half of the total length, or 3–5 mm., also that the capillary attraction is such that it equals a pressure of one-half atmosphere, then the air contained in each cell will be reduced to three-fourths f its original volume, allowing one-fourth of the tube to be filled with water. In the case assumed then, water would fill the tubes for about $\frac{3}{4}$–1 mm., and if these tubes occupy three-fourths of the entire cross section (the other one-fourth being tube, or cell wall) the water at each cross section crowded into the wood, amounts to a sheet less than 1 mm. thick and $\frac{3}{4}$ of the cross section in extent. Actually this maximum is probably never attained.

Returning to the experiments, the above conclusions were largely verified, but not all.

To determine the behavior of wood as regards swelling, a piece of white pine was carefully dressed, measured with a micrometer caliper of Darling, Browne and Sharpe, 12 inch, with vernier accurate to one-fiftieth of a millimeter $\left(\frac{1}{1282}\text{ inch}\right)$.

The width measured was 4.528 cm. The piece was then measured by immersion, wiped, and measured with the caliper, which had been left set. The caliper still fitted at the particular place which had been marked with pencil. The piece was then immersed for one minute; the caliper still fitted so perfectly that no difference in friction on sliding it up and down could be observed. The same was true after an additional immersion of two minutes and then one of five minutes. The piece of wood was then left to dry and was again measured forty-five minutes later. The width had changed from 4.528 to 4.532 cm. during the fifty minutes since the time of first immersion.

This simple experiment shows what might have been expected, that the imbibition by the cell-walls, on which swelling depends, is too slow a process ever to interfere in measurements.

To study the rush of water into the wood, numerous weighings on different woods, including pine, both hard and soft, white wood, and oak were made.

The agreement in their behavior is such that the following illustrations may serve the purpose of showing the effects. A piece of dressed white pine was weighed when dry, then it was measured by immersion, not to obtain the volume but to make the time of immersion that commonly requisite to do the work. The results stand thus:

	Grams.
Weight when dry	82.2
After first immersion	83.9
After second immersion	85.7
After third immersion	86.2
After fourth immersion	86.5
After fifth immersion	86.6
After sixth immersion	86.6
After seventh immersion	86.8
After eighth immersion	87.1
After ninth immersion	87.1

After each immersion the piece of wood was wiped with a damp cloth, a process which removes the drippings, but also aids in perfectly moistening the wood. Of two pieces of white wood molding, one was given a coat of linseed oil, the other left unoiled; the following figures describe their behavior:

Weight.	Oiled piece.	Not oiled.
Dry	112.5	112.5
After immersion and wiping	115.0	115.2

A neatly dressed piece of white pine was measured with caliper and its dimensions in centimeters found to be as follows:

	One end.	Middle.	Other end.
Width (one side)	4.528	4.520	4.504
Width (other side)	4.480	4.476	4.464
Height (one side)	4.538	4.530	4.524
Height (other side)	4.524	4.538	4.508
Average length	15.380		
Average width	4.495		
Average height	4.527		
Volume ... cm^3	312.965		
Volume by immersion	309.700		
Difference ... cm	3.265		

After 8 minutes of immersion:
Volume by immersion: 310.8, first trial.
Volume by immersion: 310.9, second trial.

The surface area of this piece is in round figures 318 cm^2, of which 40 fall to the ends. If the difference, 3.26 cm^3 of water, were evenly distributed over this area, the sheet of water soaked or rushed in would be but 0.01 cm., or 0.1 mm., or 0.004 inch thick.

Again, the end surface is 40 cm., the density of the piece about 0.40; setting the density of wood substance at about 1.56, one fourth of this surface is cell-wall, the other three fourths cell-lumen. According to the calculations set forth above, the sheet of water drawn into the cut lumina of the cells is less than 1 mm. thick. This when spread over three-fourths of the 40 cm^2, or 30 cm^2, would account for nearly 3 cm^3 of water.

In a third experiment, on a piece of fresh oak wood, the volume by immersion was found to be:

720 cubic centimeters	First trial
729 cubic centimeters	Second trial
730 cubic centimeters	Third trial
730 cubic centimeters	Fourth trial
730 cubic centimeters	Fifth trial

These experiments show that the water in filling all crevices and pores does not proceed uniformly; that its progress depends on variable circumstances, of which the form and dimension of the cavities and the existence of a film of air are probably the most important. They also indicate that, whether fresh or dry, the water adapts itself to the configuration of the wood, a cover sheet is formed which adheres to the wood and is held there by a capillary attraction, but that the water does *not* rush into the wood in a manner analogous to that observed in inorganic porous bodies. In every case the measurement of the caliper is greater than that found by immersion.

The question now arises, is the measurement by immersion, with its variable factors, sufficiently reliable or should the volume be determined by the caliper? To decide this question it is necessary to examine the latter method itself. In doing so we may ask, is it more accurate, and is it practicable? Turning back to the caliper measurements recorded above, we find that in a soft, well-dressed piece of wood the dimensions varied very considerably. The height, for instance, was on one side 4.524 at one end, 4.538 at the middle, and only 4.508 at the other end. Comparing this with measurements made on machine-planed pieces of molding, etc., it was found that the latter varied as much—in some cases even more. None were free of the wavy outline so characteristic of machine planing. The end surface produced by a saw-cut requires no mention, for every one is familiar with its appearance. To be reliable, then, much more accurate work in dressing would be requisite.

The practicability of this method is limited to pieces which can first be accurately dressed; fresh woods, checked pieces, etc., are thus excluded. The time requisite to determine the volume can easily be estimated when we consider that fifteen measurements, each requiring the use of the magnifier and the delicate adjustment of the micrometer instrument and nine arithmetical processes, were requisite to find the volume of one piece of wood.

From the above we see that the caliper measure is preferable only if the piece is dressed and dressed perfectly. As it is, the caliper measures the wood only at its projections, the water presses too deep into the cavities. Hence the difference, and the necessary choice between them. Both ways furnish variable results, these depending in the case of the caliper on accuracy of dressing and precision in the management of a delicate instrument, and involving the danger of too complicated computation. In the case of the measurement by immersion the variations depend on the nature, form, and size of the piece of wood, but the method is relatively free from the danger of error accompanying the use of delicate instruments, inaccuracy of reading, and complicated computation.

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 asbestos 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.

The reason for choosing the temperature at 100° C., or the boiling point of water, is the fact that experimenters generally have used this particular temperature, and for the sake of comparableness of results the continuance of this practice is desirable. To judge from the experiments so far made, this temperature is taken somewhat too high. Prof. Bauschinger, of Munich, describes similar experiments where the wood at this temperature first grew lighter and finally increased again in weight. The same thing has been observed in our work, but neither the cause nor the nature of the process has as yet been determined. Moreover, the wood is brought too near the burning point and danger from conflagration is great. Besides these two chief objections it may be argued that wood in all ordinary uses is never subject to temperatures much above 60° C.

To determine the difference in humidity of wood dried at different temperatures, and to obtain moisture-coefficients corresponding to the different temperatures, some experiments were made on the wood of the white pine and that of the longleaf pine. For one of these, pieces of sapwood, split nearly as thin as matches, were used. These were tied in loose bundles, weighed, then placed in the oven to dry.

The following figures contain the principal results:

	P. palustris.	P. Strobus.
	Grams.	*Grams.*
Weight before placing in kiln	73.5	35.4
Dried at 60 to 62° C.	68.4	33.3
Dried at 80 to 82° C.	67.5	32.8
Dried at 100 to 105° C.	66.9	32.5

From these results the humidity expressed as percentage of dry wood dried at varying degrees is:

	P. palustris.	P. Strobus.
	Grams.	*Grams.*
At ordinary temperature (about 25° C)	9.8	8.1
Dried at about 60° C.	2.2	2.4
Dried at about 80° C.	.8	.9
Dried at about 100° C.	.0	.0

Though this problem is by no means solved by these few experiments, it is clear that a lower temperature than 100° C. would have served just as well, and also that wood dried at 80° C. (a much safer temperature) is nearly as dry as that dried at 100° C.

MOISTURE EXPERIMENTS.

In connection with these experiments in drying at different temperatures a series of experiments on the shavings of the sapwood of white pine and longleaf pine were made; one to determine the amount of moisture which shavings of this kind are capable of taking up, another to determine the daily changes going on in the humidity of wood. For the first of these, air-dried shavings of sapwood were suspended in a saturated atmosphere for three months. To prevent fungous growth a little carbolic acid was added to the water and the vessel hermetically closed and placed in a dark room where a very uniform temperture prevails. At the end of three months the shavings were taken out, weighed at once, and then left to dry. After a few days they were placed in a kiln and dried at 100° C., and it was found that for each 100 cm³ of dry wood substance there had been absorbed in—

P. palustris .... 40 cubic centimeters of water.
P. Strobus .... 45 cubic centimeters of water.

which represents the water capacity of the sapwood of these two species.

The following figures illustrate the daily changes of humidity in shavings of sapwood:

The weather was clear, and the temperature of the atmosphere rose each day to about 28° C. (80° to 85° F.). The shavings were on a plate in a clean, well-ventilated room.

	Humidity in shavings of—	
	P. palustris.	P. Strobus.
	Per cent.	*Per cent.*
July 11, 7 a. m	9.03	8.51
1 p. m	8.77	8.23
4:30 p. m. (temperature 84° F.)	7.72	7.52
9 p. m	8.24	7.66
July 12, 8 a. m. (warm night)	8.50	8.23
10 a. m. (94° F.)	8.37	8.23
1:25 p. m	7.18	6.95
3:25 p. m	7.31	6.95
8 p. m	7.57	7.38

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:

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

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

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

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

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 were 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.

Since the shrinkage of the entire piece is a resultant change of form and dimensions of the individual cells, a study of the behavior of the cell elements themselves during shrinkage was undertaken. Portions of thin sections of the wood of *P. Strobus* and *P. palustris* were magnified

580 diameters and drawn with the camera lucida. The sections were then allowed to dry under the cover glass, to avoid any warping, and were again drawn, when dry, with every part occupying as nearly the same position in the field as the shrunken condition would allow. One cell was exactly superposed and served as a starting point. No difficulty was experienced in drawing the dried section; the picture agreed with the section on removal of cover glass, and also after adding glycerine to the dried section. Left in glycerine a few weeks, the original picture could be superposed (with the camera) almost, but not quite perfectly. Whether this fact is due to a difference in swelling of wood in water and glycerine is not yet ascertained.

The results so far obtained from this study are in perfect agreement with the general theory of shrinking. Thick walls shrink more than thin walls. The change of form and dimension of lumina, on the other hand, was found to be variable; some lumina changing their dimensions very markedly others scarcely or not at all. Lumina with circular cross-section appear to have changed less than those with a compressed, slit-like cross-section; in general the change was more apparent in the summer wood than in the spring wood.

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 reinforced 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 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 the 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 described 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 10 to 20 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 assistance and outfit may be required:

(1) Two men * with axe 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 hand saw.

(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 axe 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 on its bottom end, 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. (See figures on opposite page.)

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.

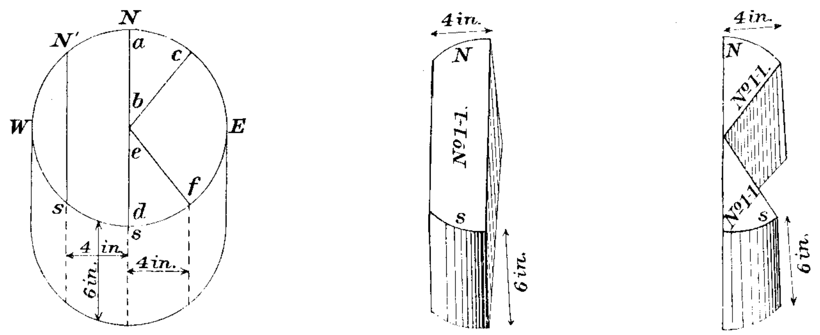
* Only men familiar with felling and cutting timber should be chosen.

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 lumber 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 the 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.	No. of log.	Distance from butt.	Length of log.	Diameter, butt end.
	Feet.	*Pounds.*			*Ft. In.*	*Ft. In.*	*Inches.*
I....................	0	27	Crown touching those of nearest trees to the N. and NE. Open toward SW.	I......	8 0	12 4	16¾
II....................	13	20		II......	13 8	5 4	14½
III....................	19	20		III......	19 8	12 4	14
IV....................	32	18		IV......	32 8	14 4	13½
V....................	47	16		V......	47 8	9 4	12¼
VI....................	57	14		VI......	57 8	9 4	11⅛
VII....................	67	17		VII......	67 8	9 4	9¾
VIII....................	77	14		VIII......	77 8	9 4	8⅕
IX....................	87	9½					
X....................	97	6					

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.

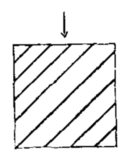
SAMPLE RECORDS OF TESTS.

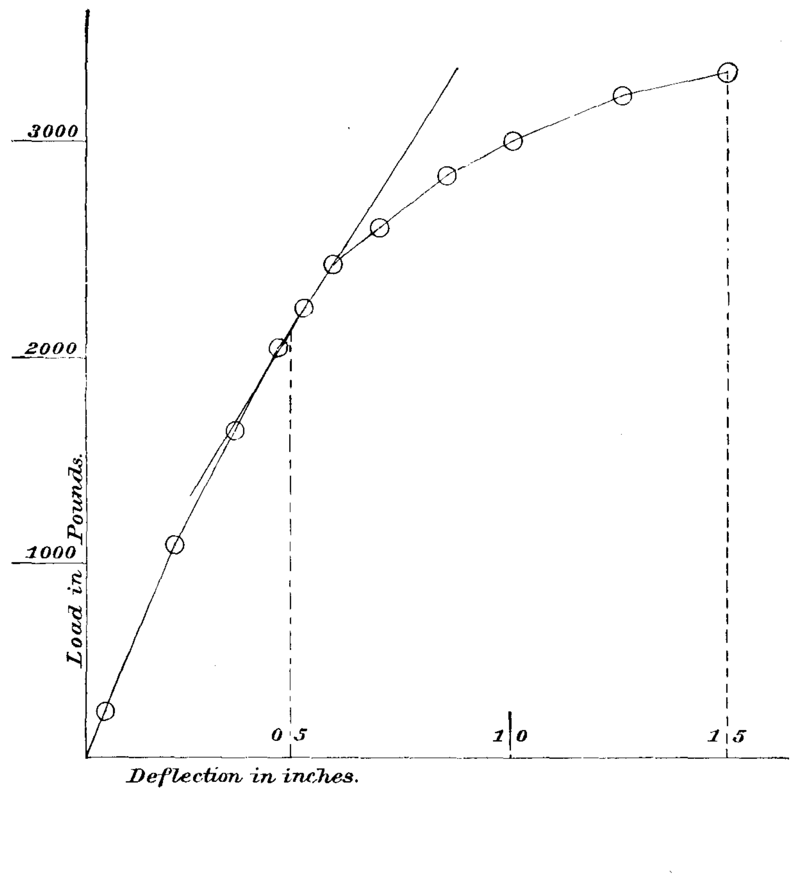
CROSS-BREAKING TEST.

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 clasticity =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	*N*
37	3,200	1.276	1.991	
40	3,000	1.521	2.236	Maximum load.



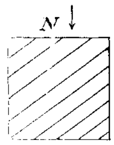
CROSS-BREAKING TEST.

Mark, { 3. 3. 1. } Long-leaf pine.

Length, 60.0 inches.
Height, 3.50 inches.
Breadth, 2.72 inches.

[Number annual rings per inch = 23.]

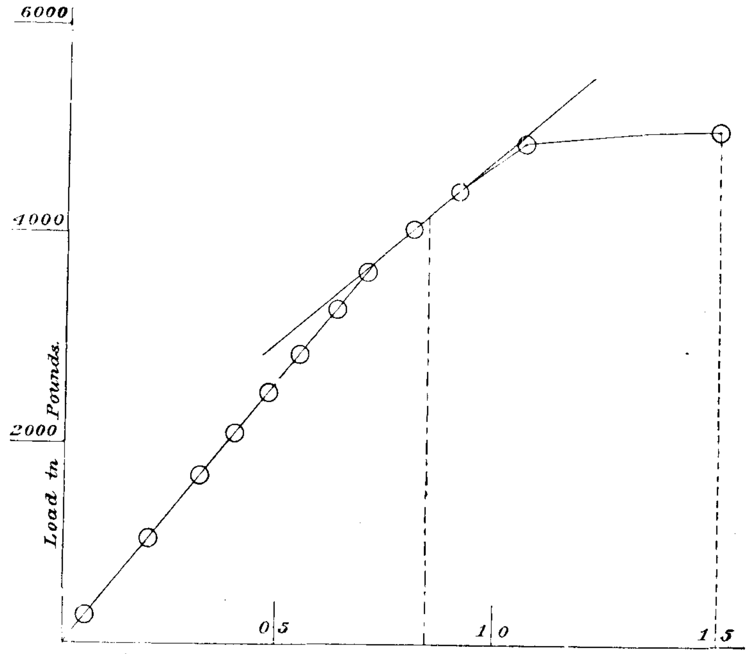
July 20, 1891.		Load.	Deflection.	Micrometer.	Remarks.
h.	*m.*				
2	58	200	.042	0.958	
3	0	1,000	.208	1.124	
	1	1,600	.324	1.240	
	2	2,000	.404	1.320	
	3	2,400	.481	1.397	
	4	2,800	.558	1.474	
	5	3,200	.640	1.556	
	6	3,600	.721	1.637	
	7	4,000	.815	1.731	
	8	4,400	.926	1.842	
	9	4,800	1.074	1.990	
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



Strength of extreme fiber,

where $f = \frac{3}{2}\frac{W\,l}{b\,h^2}$ = 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. E. Res., 2.28.



Deflection in inches.

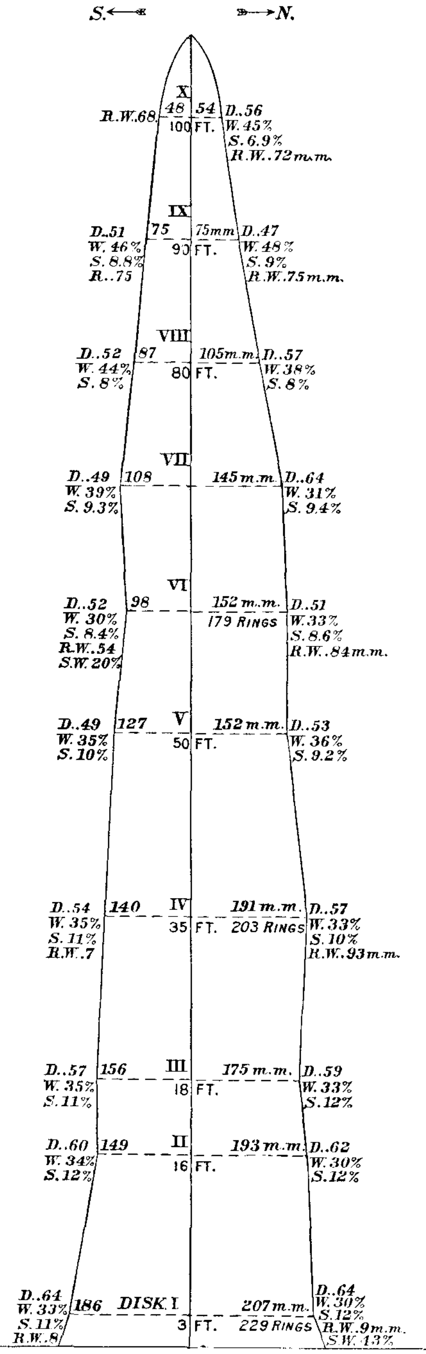
FINAL RECORD OF TIMBER TESTS.

Mark.	Percentage of moisture.	Cross-bending tests. Dimensions. Length.	Height.	Breadth.	Time.	Load.	Deflection.	Strength per square inch. (*f*)	Modulus of elasticity. (*e*)	Resilience in inch-pounds per cub. inch. (*r*)
		Inches.	*Inches.*	*Inches.*	*Min.*	*Pounds.*	*Inches.*	*Pounds.*	*Pounds.*	
Long-leaf 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

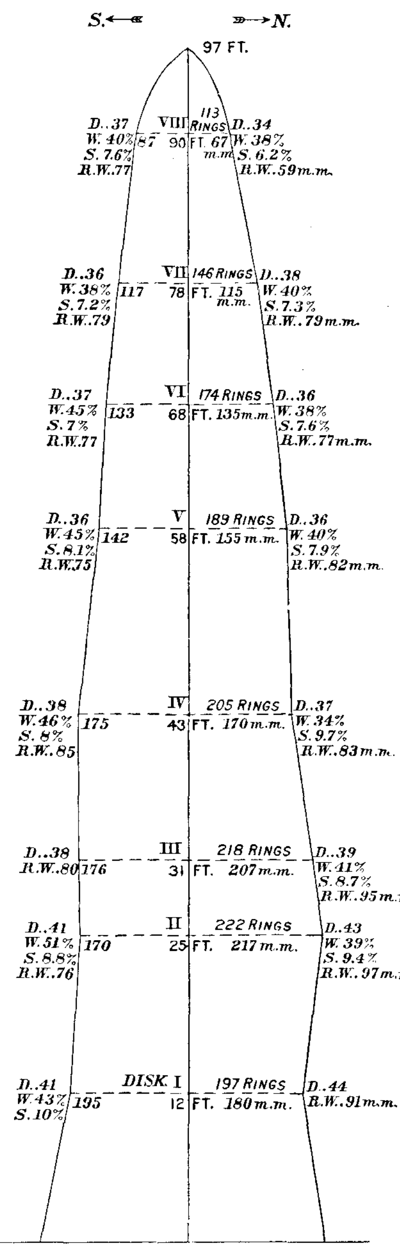
Mark.	Crushing endwise. Dimensions. Height.	Cross section.	Area.	Crushing load.	Strength per square inch.	Crushing across grain. Dimensions. Height.	Cross section.	Area.	Crushing load.	Strength per square inch.
	Inches.	*Inches.*	*Sq. in.*	*Pounds.*	*Pounds.*	*Inches.*	*Inches.*	*Sq. in.*	*Pounds.*	*Pounds.*
Long-leaf 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. in.	*Sq. in.*	*Pounds.*	*Pounds.*	*Sq. in.*	*Pounds.*	*Pounds.*
Long-leaf 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

RESULT OF PHYSICAL EXAMINATION. (Sample.)



LONG-LEAF PINE (*P. palustris*), *tree 3.*
Locality: Wallace, Alabama.
Site: Upland forest, quite dense.
Soil: Sandy.



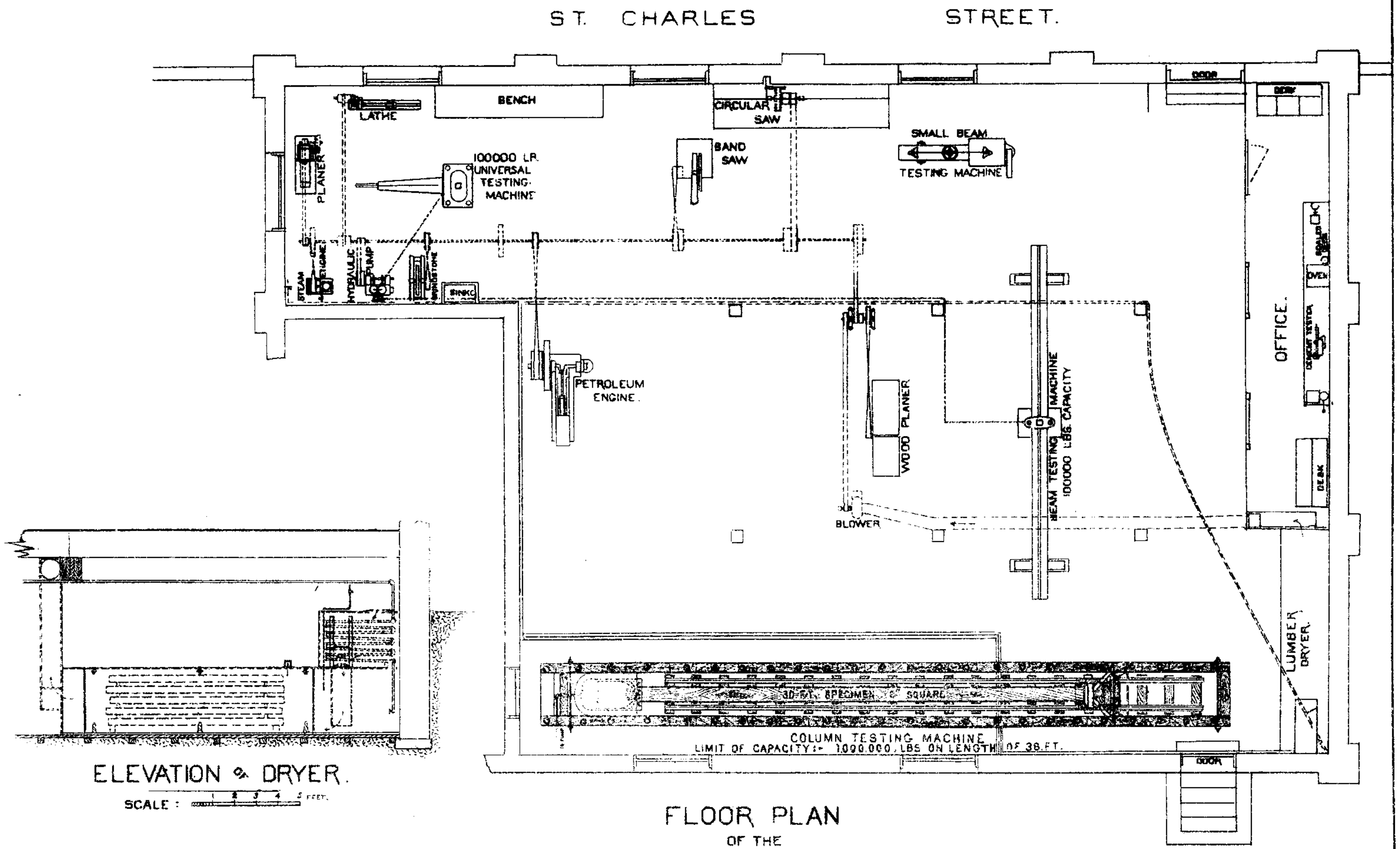
WHITE PINE (*P. Strobus*), *tree 11.*
Locality: Marathon County, Wisconsin.
Site: Grown in dense mixed forest.
Soil: Sandy, with sandy subsoil.

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 milimeters (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.

CLASSIFIED INDEX.



ELEVATION of DRYER.

SCALE: 1 2 3 4 5 FEET.

FLOOR PLAN
OF THE
WASHINGTON UNIVERSITY TESTING LABORATORY.
ST. LOUIS, MO.

SCALE:

PLATE I.

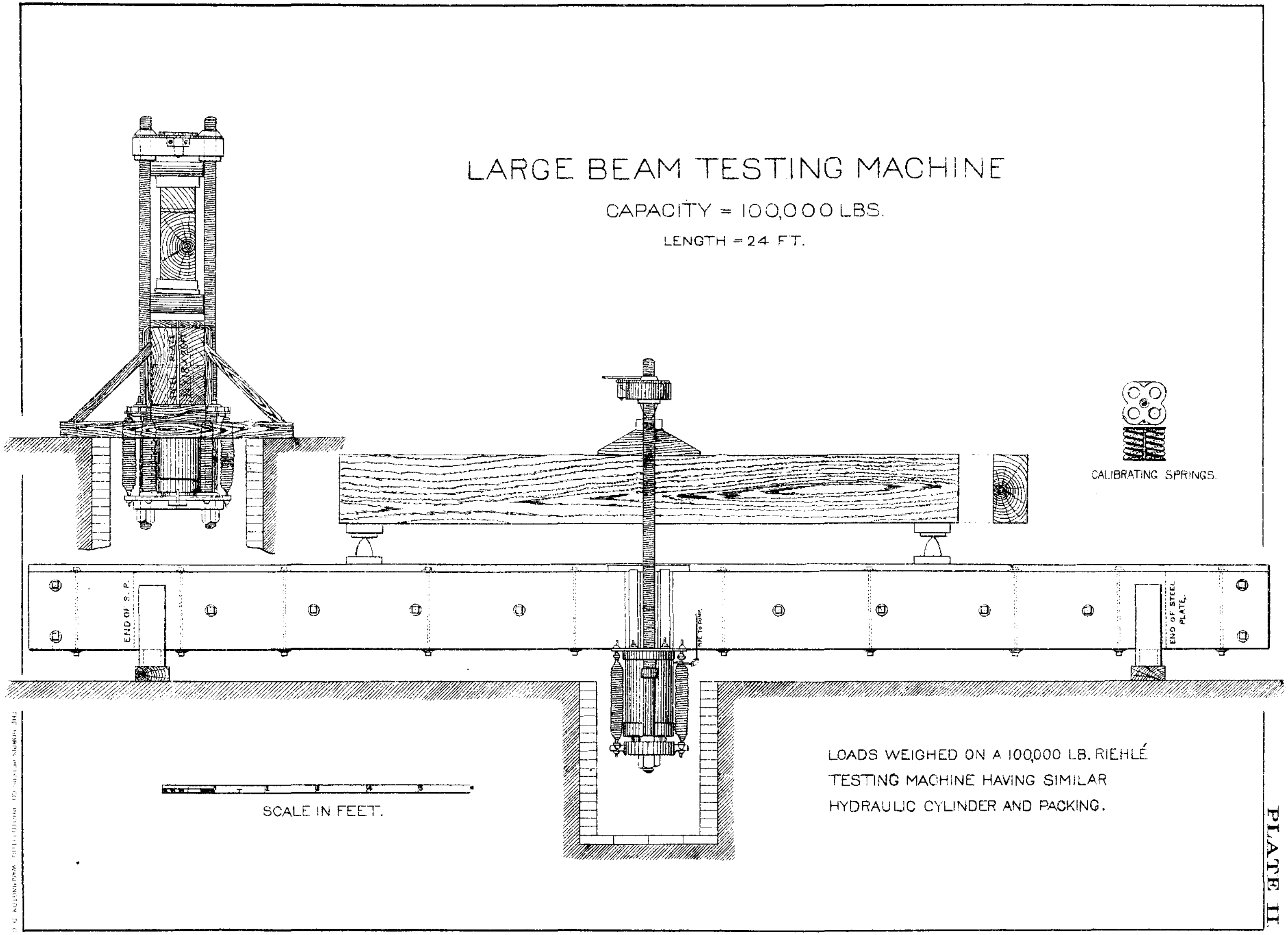
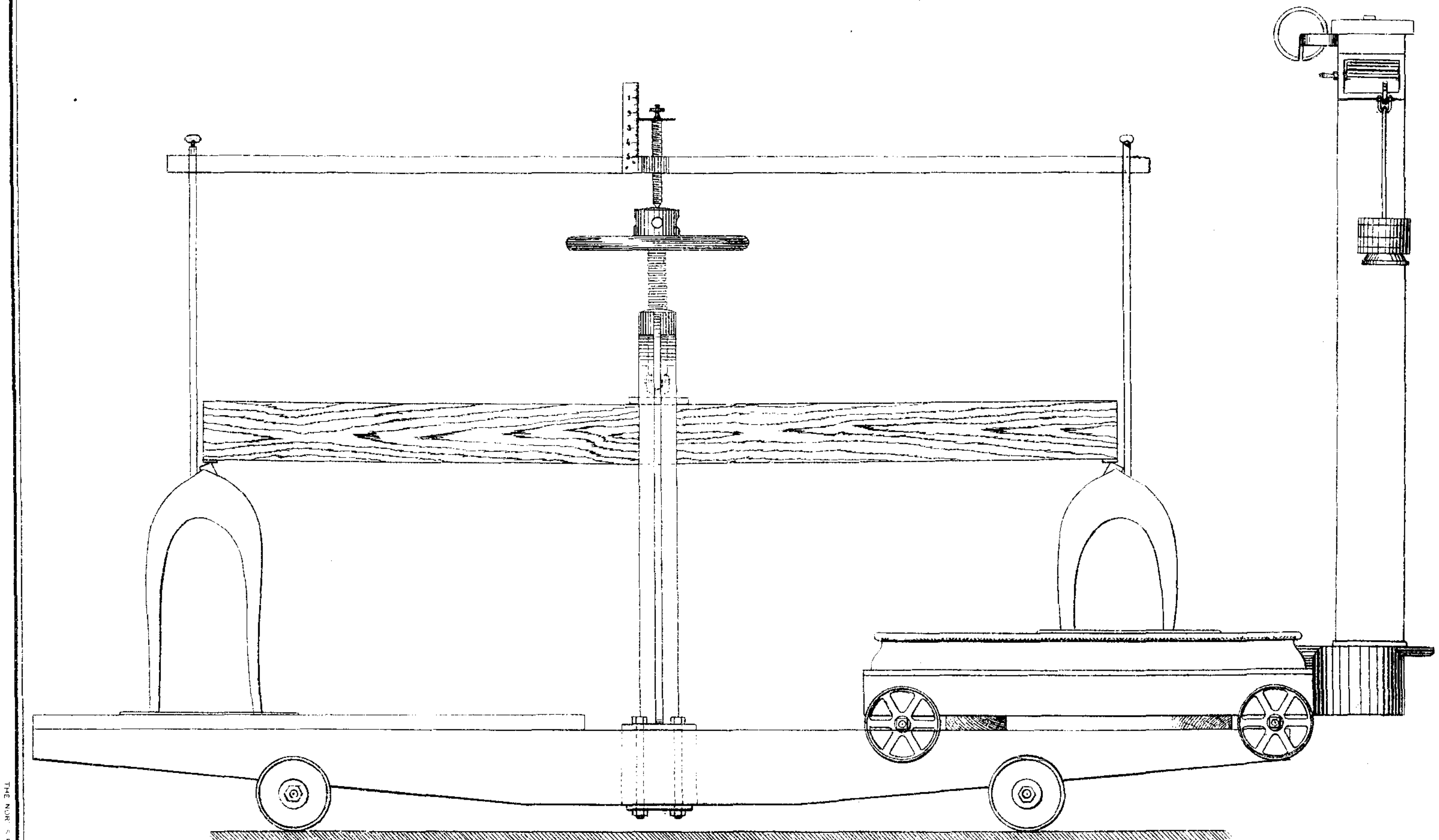

LARGE BEAM TESTING MACHINE
CAPACITY = 100,000 LBS.
LENGTH = 24 FT.
CALIBRATING SPRINGS.
END OF S.P.
END OF STEEL PLATE.
LOADS WEIGHED ON A 100,000 LB. RIEHLÉ
TESTING MACHINE HAVING SIMILAR
HYDRAULIC CYLINDER AND PACKING.
SCALE IN FEET.

PLATE II.

PLATE III.



SMALL BEAM TESTING MACHINE.

CAPACITY—6000 LBS. ON LENGTH OF 5 FEET.

MICROMETER READS TO 0.001 INCH.

SCALE IN INCHES.

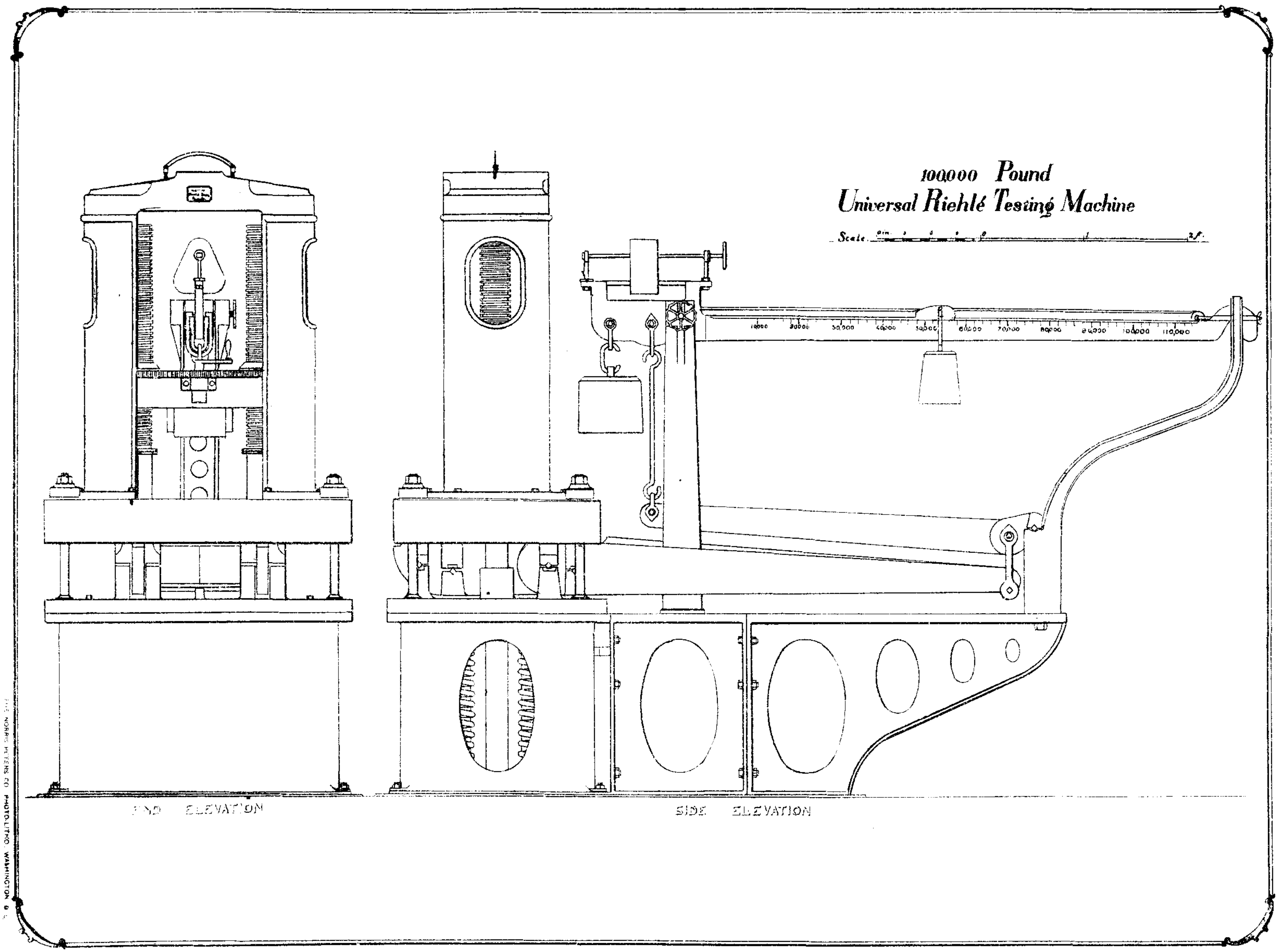
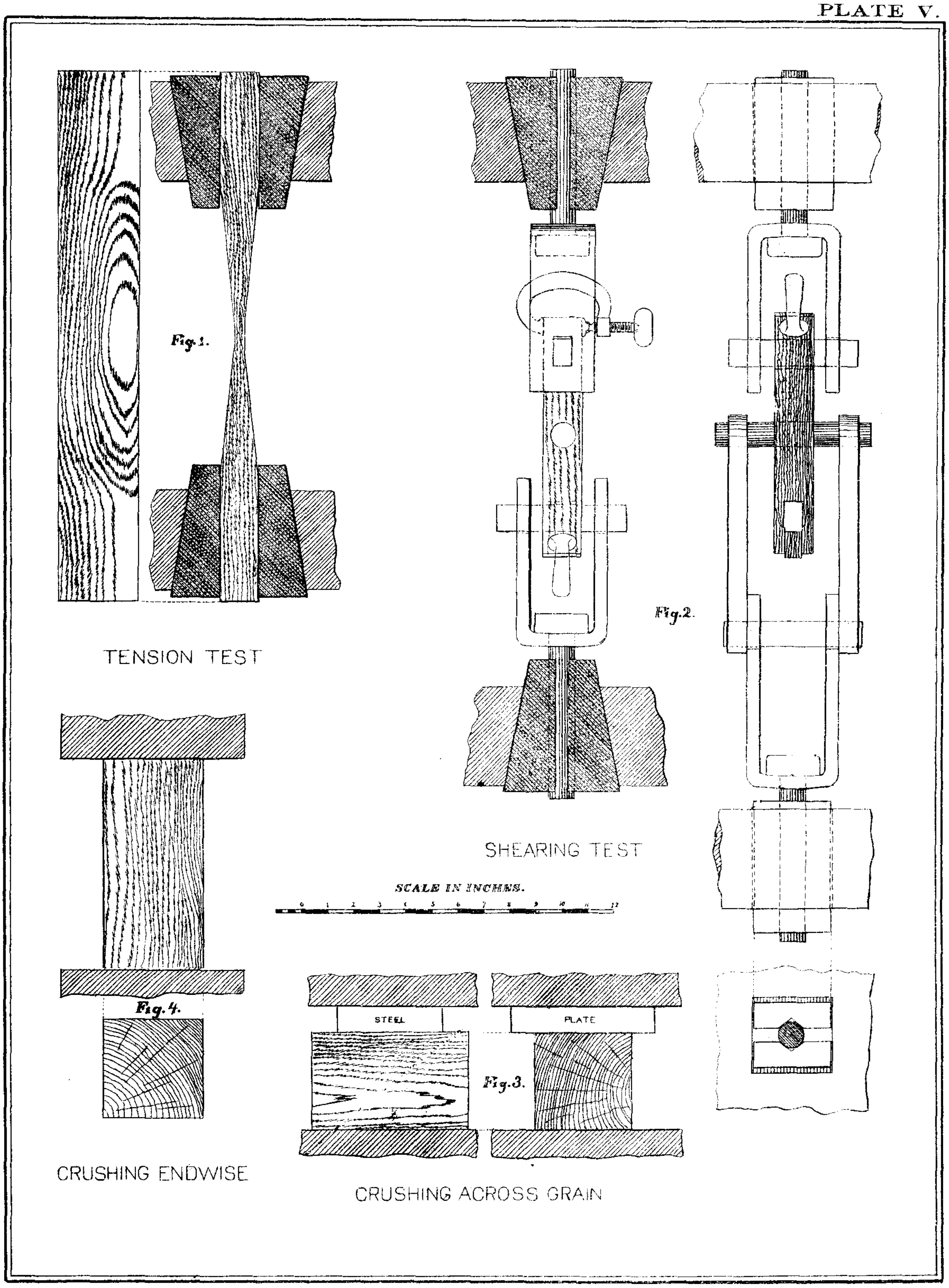


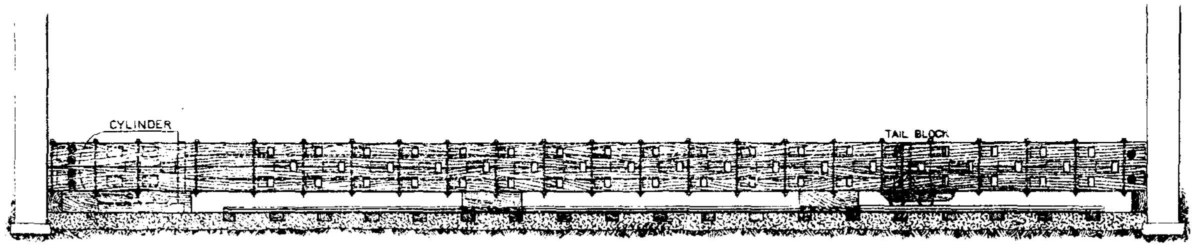
PLATE IV.

THE NORRIS PETERS CO. PHOTO-LITHO. WASHINGTON D.C.

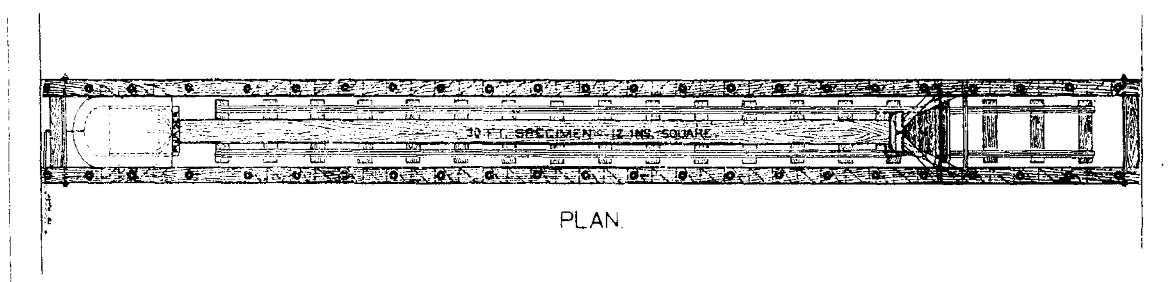
PLATE V.



THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D.



ELEVATION.



PLAN.

COLUMN TESTING MACHINE.

LIMIT OF CAPACITY :– 1,000,000 LBS. ON LENGTH OF 36 FT.

SCALE :- 2 3 4 5 6 7 8 9 10 FEET

PLATE VI.