DEPARTMENT OF AGRICULTURE.
FORESTRY DIVISION.
BULLETIN NO. 1.

REPORT

ON THE

RELATION OF RAILROADS TO FOREST SUPPLIES AND FORESTRY:

TOGETHER WITH

APPENDICES

ON THE

STRUCTURE OF SOME TIMBER TIES, THEIR BEHAVIOR, AND THE CAUSE
OF THEIR DECAY IN THE ROAD-BED; ON WOOD PRESERVATION;
ON METAL TIES; AND ON THE USE OF SPARK ARRESTERS.

COMPILED BY THE CHIEF OF THE FORESTRY DIVISION.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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LETTER OF TRANSMITTAL.

FORESTRY DIVISION, DEPARTMENT OF AGRICULTURE,
Washington, D. C., May 30, 1887.

SIR: I have the honor to submit for publication as a special bulletin, prepared under your instructions, a collection of reports, illustrating the Relation of our Railroads to Forest Supplies and Forestry, and pointing out on a practical basis how an economy in the use of forest supplies by the railroads can be effected.

Respectfully,

B. E. FERNOW,
Chief of Forestry Division.

Hon. NORMAN J. COLMAN,
Commissioner.

CONTENTS.

APPENDICES.

INTRODUCTORY.

The following Reports, written mostly by experts, form a more or less exhaustive account of what the railroads of our country have done or are doing to deplete our forests, and show how the wastefulness in the use of material, which is in danger of great diminution if not exhaustion, may be checked, to some extent, by increasing its durability through the employment of preserving processes; by substituting, where admissible on financial grounds, other material; by observing conditions in its use hitherto largely overlooked; and, lastly, by insuring a continuance of supply through active forestry work on the part of railroad companies and in other ways.

Considering the wasteful manner of getting out railroad timber, it can be fairly estimated that to build our present railroad system more than one hundred million acres, or one-fifth of our present forest area, were stripped during the last fifty years, and the next fifty will very likely call for more than double that amount, judging from the accelerated development which is probable and the requirements for renewal.

While railroads have done much for the growth and development of our country, they are also responsible for much of the hindrance to reform in the use of our forest resources. The rapid extension of our railroad system has brought within reach of markets distant forest areas, where, to make lumbering profitable in the absence of home consumption for the inferior grades of material and leavings, wasteful and destructive methods of utilization have to be employed.

While, therefore, directly and indirectly, railroad enterprises have contributed largely to a considerable reduction (if not destruction) of forest supplies, it might be presumed that, depending as they do on these supplies and being by their own continuous character most deeply concerned in their continuation, the railway companies would feel a special interest in forest preservation.

With this view the following reports have been prepared as aids to a proper appreciation of our wood material and its economical use.

The report of Mr. M. G. Kern has been written after much correspondence with railroad managers. Extracts from this correspondence are appended, with the design of showing whatever objections have been raised to the practicability of railroad companies engaging in active forestry.

I would call particular attention to the original work of Mr. P. H. Dudley, the study of which will prepare one for a more critical estimate of the processes employed for wood preservation, so ably presented by Col. Henry Flad, to which also some notes have been appended taken from a paper kindly prepared by Mr. Howard Constable, C. E. These papers are intended to appeal and give information to the business or unprofessional man who may be interested in the subject, and who is frequently the motive power of operations conducted by professional men. It should be added, that while it has been the custom to describe the different processes of wood preservation, coupling each with the use of certain antiseptics, or, *vice versa*, to speak of antiseptics as necessitating the employment of certain processes; and though in the main Colonel Flad has followed this customary treatment of the subject there is no good reason for continuing such strict classification: the practical man will observe the practical expedients of all the processes and select and combine them to meet the requirements of his special case, cutting away from the hampering influence of mere precedent, and adopting the best means to an end, thus carrying out what Mr. Constable is pleased to call the "American idea of wood-preserving processes."

In connection with these papers I would also refer the reader to a very valuable report on wood-preservation made by a committee of the American Society of Civil Engineers to that body at its annual convention in June, 1885.

A new interest in the line of wood-preserving processes has been added in the economical applications of wood-creosote oil, made from the Southern pine, a report on which was kindly prepared by Capt Wm. H. Bixby, U. S. A.

Particular attention is called to the reference table for comparing annual charges, prepared by the writer, which does away with all cumbersome calculations hitherto practiced even by engineers.

The notes on metal ties, prepared in this office, though perhaps not exhaustive, will furnish nevertheless ready references for the use of engineers, and give cumulative evidence of the practicability and desirableness of this substitute for wooden ties. While the treatment of this subject from the railroad engineer's point of view may seem at first sight not germane to the work of the Forestry Division, I think it cannot be denied that forest preservation must be indirectly but most effectively and practically promoted among this class of consumers by just such a presentation of the experiences, so far had, with a substitute for what involves one of the most wasteful and destructive uses of our forest resources.

With the improvement which has been made in the laws and in their execution, regarding fires set by locomotives, providing a more ready method for the collection of damages, the use of spark arresters has been considerably extended, and the two papers on the subject of this means of preventing fires, prepared by well-known railroad engineers, and prefaced by Mr. N. H. Egleston, it is hoped, may weigh sufficiently with companies not yet provided with those contrivances to induce their adoption in order to avoid one cause of useless forest devastation.

B. E. F.

THE RELATION OF RAILROADS TO FOREST SUPPLIES AND FORESTRY.

By M. G. Kern, *Agent of the Department.*

A discussion of the relation of the railways to the forests of America may be preceded appropriately by a glance at the origin and growth of the railroad system.

The year 1825 will be always memorable in American history for the completion of the first great work of internal improvement in the United States, the Erie Canal, constituting a navigable water-way between the Hudson River and Lake Erie, through which the vast territory tributary to the Northern Lakes was opened to the commerce of the world by a channel far more advantageous to American interests than that offered by the Saint Lawrence River.

The completion of this work decided forthwith the question of supremacy amongst Atlantic seaports, and to New York harbor henceforth the products of the newly-opened empire of agriculture and production floated to find their outlets into the world's commerce.

Aroused to unprecedented exertion to counterbalance the advantages gained by New York, the commercial and shipping interests concentrated around Chesapeake Bay united in undertaking a railway to connect the tide-water of the bay with the Ohio River, necessitating the passage of the Allegheny Mountains, which was quite impracticable by means of a canal.

On July 4, 1828, the citizens of Baltimore assembled to break ground for the inauguration of this work, the magnitude of which, and its electrifying influence on the entire country, could not be fully foreseen on that memorable day.

In 1830 the Baltimore and Ohio Railway, in the earliest stage of its growth, extended 23 miles west of the city of Baltimore, and was operated for the first two years by horse-power.

The invention of the locomotive, following soon afterward, gave the impetus which brought into existence the giant railway system, to which is due, in great measure, the rapid commercial, social, and political development of the North American continent.

The new system of transportation, as well as new inventions in the construction of the railway track, rolling-stock, and machinery were rapidly adopted, so that in a few years the principal Atlantic States were in railroad communication with each other.

The increase of railway mileage from 1830 to 1840 was 2,795 miles, and the mileage of 1850 was reported as 9,021 miles.

LAND-GRANT ROADS.

Up to this time the railways were constructed and equipped by the people, unaided by the Government, State or Federal; but in consideration of the benefit accruing from them to the country at large, and desiring to extend these motors of civilization over the young and sparsely-settled States of the Union, Congress adopted a new policy, of momentous importance to the internal improvements of the Union. The year 1850, therefore, on account of this precedent established by Congress, may be regarded as the second epoch in the construction of the railways of the United States.*

Although at first the grants were made to the several States, they were in all cases transferred as speedily as possible to railroad companies which were chartered by them to construct the lines upon the general route specified in the act of Congress by which the lands were granted.

The enormous increase of mileage constructed during the ensuing decade speaks eloquently, not merely for the object aimed at by Congress in making so magnificent a grant from the public domain, but likewise of the indefatigable energy of the American people.

The mileage of railways in 1860 was 30,635 miles, being an increase over 1850 of 21,614 miles. In the decade from 1860 to 1870, embracing the turbulent time of the civil war and its consequences, the question of railway construction assumed of necessity an aspect different from that of a time of peace and prosperity. In order to strengthen the integrity of the Union, Congress determined upon the construction of a system of railways connecting the Atlantic and Pacific States, making, however, the grants and concessions necessary for the consummation of so grand a project, not to the several States but to corporations organized directly for this purpose.

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* "In the case of the Illinois Central and Mobile and Ohio Railroads it granted to States in aid of railroad construction, upon specified routes, six sections of public lands of 640 acres each, for every mile of road built, to be taken by the odd numbers within 6 miles of the proposed route, provision being made that under certain circumstances the grant may be enlarged to apply to odd sections within 15 miles on either side, so as to make up the full amount intended to be granted. Many of the grants were subsequently further enlarged to apply to sections of odd numbers within 20 miles of the line. Upon the sections of public land of even numbers within the limits of the grant the price was raised from $1.25 to $2.50 per acre."—(Poor's Manual of the Railroads, 1876.)

The construction of the Pacific railways and their connecting links, vigorously pursued during this decade, naturally swelled the increase to a great extent; much activity in construction was necessary also to rebuild and to enlarge the systems of the Southern States, greatly damaged by the chances of the war.

The mileage in 1870 was 52,914 miles; an increase over 1860 of 22,279.

The mileage in 1880 was 93,349.

The mileage at the close of 1886 was 137,615.

From reports which have been received by the publishers of Poor's Manual of Railroads in regard to work done or in progress, it is evident that, unless some serious convulsion should appear to disarrange and defeat plans, not less than 12,000 miles of new road will be constructed during the present year, so that at the close of 1887 we shall have 150,000 miles of road or 187,000 miles of railway track.

The public lands have been granted in aid of seventy-eight railroads, the first grant having been made in 1850 to the States of Illinois, Alabama, and Mississippi, for the purpose of aiding the construction of the Illinois Central and the Mobile and Ohio River roads, making a continuous line of railway from Chicago to Mobile. The granting of land directly to railroad companies rather than to States for the benefit of railroads, began with the grant to the Union Pacific Company in 1862.

The grants made to all the roads are estimated by the Commissioner of Public Lands to involve 197,203,808 acres, being only 5,000,000 acres less than the entire area of the thirteen States which originally composed the Union. Of this vast amount of land there had been certified or patented to the aided railroads, up to the 7th of March of the present year (1887), 49,178,877 acres, and at the close of the last fiscal year (1886) selections of land by the companies amounting to 16,571,300 acres in addition were awaiting examination and the decision of the proper officers of the Government. Of the land-grant roads there were completed on the 30th of June, 1886, as appears on the books of the General Land Office, 17,724 miles, distributed in the States and Territories as follows:

States.	Miles.	States.	Miles.	States.	Miles.
Alabama	901. 43	Indiana	241. 35	Nebraska	768. 52
Arkansas	602. 24	Iowa	1, 547. 64	Nevada	446. 00
Arizona	383. 00	Kansas	1, 485. 65	New Mexico	167. 00
California	1, 037. 91	Louisiana	530. 00	Oregon	325. 80
Colorado	208. 60	Michigan	1, 045. 01	Utah	225. 00
Dakota	410. 98	Minnesota	2, 144. 11	Washington	463. 60
Florida	639. 97	Mississippi	384. 00	Wisconsin	973. 50
Idaho	90. 00	Missouri	625. 75	Wyoming	500. 00
Illinois	707. 00	Montana	780. 00		
				Total	*17, 724. 06

In many cases the roads aided have received new names since the grants were made to them or they have lost their names by being merged in other roads, so that their original names do not appear in our ordinary lists of roads. In some cases projected roads to which lands were granted have been abandoned, and consequently the grants have lapsed. In other cases claims to large amounts of land have been rendered invalid because of the failure to complete the roads within the time stipulated in the grants, and the question of the forfeiture of this land is now awaiting decision.—N. H. E.

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* Later information from the Commissioner of Railroads shows that on the 1st of May, 1887, the length of the land-grant roads, completed and in operation, had increased to 17,978 miles.

GEOGRAPHICAL RELATION OF RAILROADS TO THE FOREST AREA.

With the railway map of to-day before us, a brief consideration may properly be given to the physical characteristics of the country in reference to the distribution of the forests, from which the most indispensable material of construction has to be drawn. The vast area of country lying east of the Rocky Mountains presents the two opposite extremes of forest and treeless plain.

The States bordering on the Atlantic coast from north to south, together with the interior and Middle States, are forest territory, in which settlement and civilization could gain a foothold only by the use of the ax. The forest extended from the Northern Lakes to the Gulf of Mexico, but midway in the Mississippi Valley was met by the treeless prairie. The change, however, was not abrupt, but gradual, both forest and prairie dovetailing deeply into each other. The middle ground, extending from Minnesota to Texas, is a territory peculiarly favored by the hand of nature, possessing the fertility and ease of culture of a prairie, together with an abundance of timber and protection from the inclemencies of the climate of the plains of the West, on which trees flourish only along the water-courses.

On the Pacific slope the greatest forest area is again found in the North, extending in many ramifications through the mountain ranges. The area of treeless territory, however, is equally large, especially in the southern half of this section.

At the time when the railways were undertaken, it is evident that an abundance of material for construction existed throughout the timbered district, and that no real value was placed on the material, which, though indispensable, was everywhere encumbering the ground. In the construction of roads over widely-extended treeless plains, the supply had of necessity to be brought from great distances at a corresponding cost.

Considering the stupendous amounts of timber already withdrawn from native forests, the annual demands of railways now in operation, and the increase of mileage from year to year, it becomes necessary to take a more accurate survey of the fields of demand and supply, unbiased by the popular delusion of the inexhaustible forest wealth of America. This necessity is no longer either to be ignored or lightly treated as in the past.

DEMANDS OF THE RAILWAY SYSTEM.

For construction.—Assuming 187,500 miles of track * in the United States, and taking 2,640 ties for each mile, the number of ties in use would be 495,000,000, each tie containing an average of 3 cubic feet;

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* In considering the relation of the railways to the forests, it is important to bear in mind the distinction between the length of *road* and the length of *track*. These often differ greatly from each other. For example, the length of the New York

the amount of timber imbedded under the entire mileage and undergoing a constant process of decay is, therefore, 1,485,000,000 cubic feet.

Bridge- and trestle-work, timber and poles for piling, cannot be estimated with the same accuracy, as roads vary indefinitely in topography and material of bridge construction in use, whether wooden or iron, piling or stone masonry. As a rule, wooden structures are employed in the first stage of construction of new roads, to be replaced as soon as practicable by more permanent material. The roads of the older States are, therefore, more substantially built than a majority of southern and western roads, in which a far greater percentage of timber is employed in construction than on the great trunk lines of the Eastern and Middle States. On many southern roads, running through low and swampy districts, piling is used to a great extent, but accurate figures cannot be given as to the timber used for this purpose. An average of 2,000 cubic feet per mile is considered approximately correct by engineers consulted on this subject.* Therefore, 187,500 miles of track contain 375,000,000 cubic feet of bridge and trestle timber.

As with the preceding items of bridge and trestle construction, it is alike impossible to make a correct estimate as to the quantity of timber used per mile for station-houses, buildings for all purposes, and platforms, all requiring large amounts of timber. The amount of timber used in track construction proper is, therefore,—

	Cubic feet.
Ties for 187,500 miles	1,485,000,000
Bridge and trestle timber	375,000,000
Total	1,860,000,000

It can be safely assumed that for every cubic foot ready for use, $1\frac{2}{3}$ cubic feet of round timber is required.† Therefore the amount of round timber

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Central and Hudson River Railroad is 442 miles; but it has four tracks from Albany to Buffalo, besides 551 miles of sidings, making in all 2,043 miles of track to be furnished with ties, bridge timber, etc. So the length of the Pennsylvania road from Jersey City to Pittsburgh is 445 miles; but the road having a double track throughout and 449 miles of siding, the whole length of the track to be supplied with ties, &c., is 1,339 miles. A careful comparison of the length of roads and the length of their tracks, so far as the latter are reported, warrants the conclusion that 25 per cent. should be added to the reported length of our railroads as a whole in order to represent fairly the additional demand for rails, ties, etc., made by double tracks and sidings, or turn-outs.—N. H. E.

* The Chicago, Saint Paul, Minneapolis and Omaha Company report their timber-work for piling, trestles, bridges, and culverts on 1,600 miles of road as being 1 foot to every cubic yard of earth-work. Earth-work on 1,600 miles amounts to 15,000 cubic yards per mile. Two per cent. of its entire length is in bridges of all kinds. The average duration of wooden culverts and pile and trestle bridges was eight to ten years; of truss-bridges, nine to eleven years.

† That the allowance here made for the waste of the forests in preparing ties or other timber for market is fully warranted, and the waste often much larger, may be seen from the following extract from a trustworthy lumber journal:

"There is no branch of the lumber industries where there is more waste of raw material than in making ties. Each tie is split from clear wood, and it takes about necessary to yield the above product may be estimated at 3,100,000,000 cubic feet.

Telegraph Poles.—Each mile of railway requiring thirty telegraph poles, the total number of poles in use on 137,615 miles of railway at the close of 1886 was 4,128,450, and, making due allowance for double rows along many sections of road, can be safely estimated at 5,000,000, with an average content of 10 cubic feet each, amounting to 50,000,000 cubic feet of pole timber.

In consideration of the steady increase of mileage during the last decade, it is is safe to anticipate a yearly addition of 5,000 miles of track, creating annually an additional demand for 13,200,000 ties, and 10,000,000 cubic feet of bridge and trestle timber, together with corresponding amounts of construction timber and telegraph poles.

To this may appropriately be added a very large amount, incapable of exact estimate, used in fencing the roads, together with timber incidentally employed for track construction.

The above figures, though they may be in certain points more or less exact, give, nevertheless, an approximate idea of the amount of timber cut for the construction of the American railway system; an amount obtainable only on a continent supplied more lavishly with forest wealth than any other portion of the globe.

Maintenance.—While no general rule can be laid down as to the lasting quality of timber imbedded under the track and used in bridges and trestle-work, subject, as it is, to the endless variety of conditions of soil and climate in different sections of the country, nevertheless it may be safely assumed that seven years is the limit of the average usefulness of ties of the best kinds of hard-wood and four years for those of the soft-woods.

Bridge and trestle timber and telegraph poles may be assumed to last ten years.

Therefore, the seventh part of 495,000,000 ties, in round numbers equal to 70,714,286, is required each year for the maintenance of a safe

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35 feet of clear lumber to make a merchantable tie. Redwood will average about 50 per centum of clear and suitable wood for ties. When to this is added the percentage of 'culls' that are arbitrarily rejected by the inspectors on behalf of the railroads at the owner's expense, it will be found that each tie represents about 75 feet of good merchantable lumber in the standing timber destroyed for it. Placing the market price of the Redwood lumber at $25 per 1,000 feet, each tie represents $1.87½ worth of lumber. In the light of these figures, it conclusively appears that the present ruling rate of Redwood railroad ties (35 cents) is grossly inadequate. The remedy lies with the owners of the lands from which the ties are cut. If they will combine, and agree that they will no longer sacrifice their timber and their work as they have been doing, but will insist on being paid at least as much approximately as the lumber represented by the ties is worth, they can control the situation. It would be far better for them to sell their lands at a small profit, and get into some more profitable occupation, than to go on for years, and at the end find themselves without either timber or money to compensate them for their wasted endeavors. The railroads must have the ties, and land-owners are foolish if they do not compel the payment of a fair price for them."—B. E. F.

track, together with one-tenth of the timber used in bridges, trestles, and pilings, and of telegraph poles in use along railroads, giving the following figures:

	Cubic feet.
70,714,286 ties (at 3 cubic feet each), equal	212,142,858
Bridge and trestle timber	37,500,000
Telegraph poles, 500,000	5,000,000
Total demand for maintenance	254,642,858

To this must be added the amount of material required for the construction of new roads, assumed above at 5,000 miles annually, being:

	Cubic feet.
13,200,000 ties	39,600,000
Bridge and trestle timber	10,000,000
150,000 telegraph poles	1,500,000
Total	51,100,000

Demands for maintenance	254,642,858
Demands for new construction	51,100,000
Total	305,712,858

which may safely be considered as equal to 509,521,430 cubic feet of round timber.

This amount of timber, required for the specific purposes mentioned above, is cut principally in those sections of the wooded area of the United States where the kinds of trees demanded are most abundant, and where facilities for transportation encourage their felling. Heavily wooded districts, remote from existing lines of communication, have thus far escaped the attack of the relentless woodman's ax, and form a reserve for future years, when new railway lines will extend into the dark shades of these forests to carry off the timber wealth still remaining in many sections of the land. In many of the older and more populous States of the Union the forests are already thin and meager, and many tracts reported as forest lands are simply wastes of brush and fire-wood.

Amidst the endless diversity in the location of forests and the prevalence of various kinds of timber, it is impossible to estimate with accuracy the area necessary for the production from year to year of the great amount of timber required by the railways. Estimates, to be worth more than guesses, must be based on established data, which unfortunately are but few in the forestry practice of the United States.

The number of ties obtainable from an acre of forest land is very variable. The same is true of the yield of timber on pine and cypress lands, from which are mainly derived the timbers of large dimensions for bridge construction. Trees suitable for telegraph poles are indigenous only in certain few regions, but the number of poles cut on many an acre is quite often very large.

Assuming an average yield of 300 ties per acre, 70,714,286 ties, the number demanded annually for maintenance of the present mileage of track, would require a forest area of 235,714 acres, and 5,000 miles of new road annually built would require an area of 44,000 acres to be cut over for railroad construction, in all amounting to 2,797,140 acres in one decade alone. Although 300 ties per acre may be considered too high an average for a large portion of the forests of the United States, which have been culled for the best tie-timber for many years past, yet it can be readily seen that with a smaller average per acre, a much greater area will necessarily be cut over each year. If the frequent estimate of 100 ties per acre be taken, the area drawn upon annually will be 839,142 acres, and the necessary reserve for ten years will be 8,391,420 acres.

On the other hand, assuming an average yield per acre of 3,000 cubic feet of "dimension" timber and lumber, together with 500 telegraph poles per acre, the area needed for yearly maintenance will be, for,—

	Acres.
"Dimension" timber and lumber	12, 500
Telegraph poles	1, 000
	13, 500
And adding area necessary for ties	235, 714
We have a total of	249, 214

to serve the maintenance of our railways.

The area needed for annual new construction would appear to be:

	Acres.
Ties	44, 000
"Dimension" timber and lumber	3, 333
Telegraph poles	300
	47, 663

RECAPITULATION.*

	Acres.
Annual maintenance of 187,500 miles of track, with 137,615 miles of telegraph lines, requires	249,214
Annual new construction of 5,000 miles	47, 633
Total	296, 847

Quality of timber required.—The speed and weight of railway traffic demand unconditionally the selection of the best timber. The necessity of imbedding the cross-ties in earth ballast, by which a constant process of decomposition of the woody fiber is induced, requires the

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* This appears rather as a hand-to-mouth calculation, which does not take into consideration the continuous existence of the railroads and of their requirements of wood supplies. Calculating upon present conditions, which require the production of wood at the rate of more than 500,000,000 cubic feet of round timber annually, it would be necessary to arrive at some idea of what forest area could produce such an amount continually as its accretion. A yearly average production of 50 cubic feet per acre for large areas, with a long period of time and tolerably well-stocked forest, can be assumed as a reasonable result. From this it would appear, that to supply continuously the present demand of wood for railway construction would necessitate a reserve of not less than 100,000,000 acres of well-stocked thrifty forest.—B. E. F.

most lasting timber. Railway companies use, therefore, the best timber obtainable within a reasonable distance from their lines.

In consequence certain pre-eminently valuable kinds are required in the greatest quantities, and adding to this the general preference given to young and thrifty timber, possessing the greatest toughness and elasticity, it can be readily seen that the time may not be far distant when the wonted supply of those kinds will become exhausted. Many millions of young trees of the White Oak tribe are cut annually, each of which make but one tie. When one locality is exhausted, this scene of slaughter of the most valuable young timber is simply shifted to another. The careful selection of the best material makes the waste throughout necessarily large.

Telegraph poles, required to be straight, smooth, and lasting, are made of Chestnut and Red and White Cedar timber, which abounds principally in the Northeastern and Atlantic States. Tennessee, Arkansas, and Texas likewise, furnish large quantities of this material. Preference is given, however, to Cedar poles grown on the barren uplands rather than to those grown on the sandy lowlands of the Southern States.

"Dimension" timber for bridge construction, lumber for stations, and material for car-building naturally belong to the lumber trade and command the ruling prices obtaining in that industry. It is noteworthy in this connection that, while prices are on the ascendency in the latter, the value of ties is comparatively stationary, lower even to-day in certain sections than ten or fifteen years ago.

Adequacy of supply.—Railways built through timbered districts encounter little difficulty in procuring the needed supply of construction timber, in the selection of which they have had an almost unlimited choice. The abundance and cheapness of wood has exercised a great influence in the shaping of the modes of construction in vogue in a country in which for several generations past the inhabitants have been busily engaged in clearing the land of the timber. Are we to wonder at the accounts of proverbial waste in the earlier days of the country, a popular policy simply unavoidable under circumstances controlling those pioneer periods? But would it be wise to cling to the traditions of the past, refusing to judge impartially the necessities of the future, in which the demands for forest products will ever be on the increase?

The agencies employed in supplying the enormous quantities of ties required by the railway system determine, to a great extent, the amount and price of material offered in the market. In many parts of the country the cutting and hauling of ties to railway stations is performed mostly by the farmers, to whom this labor is a source of ready cash and employment of spare time. Owing to this mode of supply an abundance of material is steadily offered, giving railways full control in the selection of the best quality and in the price paid, while by a regulation of the rates of freight they can prevent an undue export to the treeless sections of the country, or check materially the lumber industry of certain localities. In this way prices are kept down and a show of seeming abundance is maintained which does not in the least prove the supply to be adequate, but merely shows that the great number of people engaged in this industry are willing to haul ties to the railways over distances steadily increasing as the timber nearest the lines is cut off. Immense quantities of tie-timber are thus cut down and delivered to the railways at prices below its real value. At the time the leading lines west of the Missouri River were constructed, extensive tracts of White Oak timber were laid waste in the Western States. And the same process is going on throughout the White Cedar regions of the North, from which immense quantities of ties are thrown on the lumber market. These channels of supply, based solely on considerations of monetary profit, will continue to bring to market the forest wealth of many sections of the land, but in many instances, and at a time not far distant, nature's bountiful supply will be exhausted, and the reckless system of forest clearing will of necessity be a thing of the past. Many parts of the country, once well supplied with valuable timber, have passed through the process of "improvement," but to-day feel quite keenly the loss sustained in former years.

Aside from railway supply, a notable diminution of forest wealth is beginning to be felt by many industries depending for raw material on certain valuable kinds of timber. Approaching scarcity is plainly indicated by steadily advancing prices, and by the difficulty already experienced in the manufacturing centers of obtaining the desired materials. Railway managers acknowledge quite candidly that the present condition of the supply cannot last for an indefinite period, as many leading centers of production are now practically exhausted, necessitating transportation over far greater distances than heretofore.

The discussion of substitutes for wood in railroad construction thus becomes a subject of great interest to the railway world, as it can be predicted with certainty that necessity will soon force the roads traversing the treeless plains to seek a substitute for the wooden tie. The modern steel tie, which thus far has given great satisfaction on European railways, will undoubtedly find extensive adoption in the railway system of America. There are, however, two expedients, already widely discussed and experimented with in this country, by which this pressure upon the most valuable forest products may be sensibly relieved. The one relates principally to railway interests; the other appeals to the intelligence and enterprise of the people at large. They are, first, the adoption of means of preservation by which many kinds of timber heretofore rejected in railway construction, and therefore still in great abundance in many sections, may be made valuable; second, the planting and cultivating of the most valuable timber trees on a scale commensurate with future demands. In support of this proposal to substitute various timbers hitherto but sparingly used in track construction, reference may be made to the experience of European railways with beech, which, together with closeness of fiber to hold spikes, combines the requisite hardness to withstand the concussion of heavy traffic, but lacks durability when in contact with the ground subject to excessive changes in dryness and moisture. When properly treated with an antiseptic the tie, which in its natural state lasts but five or six years, is made to last from ten to twelve.

The same treatment is applied to various inferior kinds of pine, transforming them into valuable material, while in their natural condition they are almost useless for railroad construction. In consequence of the rapid increase of railroads in European countries, and their comparatively small timber resources, these precautionary measures of economy have there been forcibly demanded, and they have also attracted the attention of American railway companies, some of which have experimented quite extensively with the leading processes of timber preservation in vogue in Europe.

The great abundance and cheapness of timber in this country hitherto has made the economy of any expensive preserving process quite doubtful, while the dishonesty with which contracts for preservation have been fulfilled, in many instances resulting in the protection of only an outer shell surrounding the speedily decaying heart, has proved a great impediment to real progress.

The question, however, is only postponed to a time, not far distant, when the price of first-class tie-timber will show a marked increase. It is obvious that the lines in timbered sections, within cheap and easy reach of all the road material needed by them, have no immediate interest in the question of the preservation of the very product in the carrying traffic of which they are principally engaged, and no inducement could lead them to engage in enterprises for which there is neither real nor immediate necessity. The case, however, is entirely different with lines in sparsely wooded districts from which the most available timber has already disappeared, and where forebodings of coming deficiency of home supply are already sensibly felt; yet it concerns more especially the lines on the open plains which depend exclusively on remote forest districts for their supply of timber. On the proverbially fertile soils of these broad prairies soft-wood timbers can be encouraged to grow with great—quite often with wonderful—rapidity, thus securing an abundant supply for track construction and for many mechanical purposes, provided the texture of the wood can be sufficiently strengthened, and made more durable by a process of preservation, the expense of which does not prohibit its general adoption.

Correspondence recently had on the subject with managers and engineers of leading western roads, a résumé of which will be found in the appended summary of correspondence, establishes the fact that the attention of various lines is being prominently directed to this important subject, and also that the Union Pacific Railway is erecting preserving works at Omaha, Nebr., for the special purpose of treating the soft-woods for ties and piling, while the Atchison, Topeka and Santa Fé Road has established extensive works at Las Vegas, N. Mex., operated under the Wellhouse tannin process. *

The necessity of timber culture.—The satisfactory results of forest-tree culture attained by the early settlers of the bleak prairies of the West and Northwest have demonstrated beyond a doubt that timber trees, so indispensable to the homestead on the treeless plain, as material for construction, for fencing, and for fuel, can be raised by each farmer willing to devote to them, for the few years of their earliest growth, the same care and culture that he is accustomed to give to a crop of corn. Tree culture has become a legitimate branch of agriculture, and is practiced by every intelligent farmer from the shores of the Arkansas River to the northmost prairie of Dakota. Well may it be said that in this instance necessity has been the mother of invention, but it has likewise been the faithful teacher of arboriculture.

Belts and groves planted a few decades ago have already furnished abundant material for house construction and for the most pressing economic wants, lending to the prairie farm a manifest protection from the hardships of an open treeless country.

With these gratifying evidences of success before the public, the question suggests itself, why should not railway timber be raised as well as wood material needed by the farmer?

This question has already been extensively agitated, and a few instances can be pointed out where planting has been actually begun. In the majority of cases, however, decisive action has been deferred to a more convenient time, which amidst the constant pressure of the operating service of the railways has not yet come. The indifference of many railroad managers to plans for the preservation of the needed timber supply is easily accounted for when the present abundance of material is taken into consideration on the one hand, and on the other, that the length of time required to grow timber to a size suitable for track construction prevents the existing administrations from inaugurating enterprises in timber culture the full fruition of which is not likely to come during their time of holding the reins of management. The uncertainty of eventual success, owing to the ever-present danger of destructive fires, depredations and unlawful acts of the community, necessitating an extra service for guarding the forests, is likewise a grave objection to a policy apparently within easy reach and control of the great railway corporations, which, as a rule, own large tracts of land capable of producing great quantities of timber.

It is much to be regretted that at the time of the passage of the land-grant acts the necessity of an American system of forestry was but little foreseen, as a clause might justly have been inserted in the act,

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* The subject of wood preservation is treated at greater length in Appendix 2 (p. 66), to which reference may be had for further information.

restricting railways that accepted the valuable grants of the public domain from wasting the forest lands received from the Government, and binding them to a perpetual maintenance of a certain forest area to supply their future wants, either reserved from the primitive forest or established by a system of planting and forest culture.

Could the voice of immortal Evelyn, who two centuries ago aroused the people of old England to a full realization of the value of their forests, have been heard in the American Congress of 1850, or had the wonderful results of his early teachings, visible in all European countries, been heeded at the time, the land-grant acts of Congress would have proved a greater blessing to America than they have been.

To sum up briefly the results of the agitation in favor of timber culture by railway companies, it can be stated that, while the imperative necessity of such a movement is freely acknowledged by those best informed in regard to the demands of the present and the outlook of the future, little disposition on the part of the railway companies to enter practically into such an enterprise has so far manifested itself. And it is equally clear that so long as a new departure in forest culture is asked or expected from the heads of the operating service, to whom appeals have in greater part been made, no enterprise on a scale even distantly proportioned to the magnitude of the issue can reasonably be expected, and this mainly from the fact that the service must be managed in accordance with conditions existing for the time being and as they will appear on the yearly balance-sheet of every corporation. Present expediency and restriction of expenditures outweighs, therefore, all possible advantages of the certain future.

The managers of various leading railways, especially those of the Western Plains, formerly called the "Great American Desert," have accorded liberal encouragement to tree culture and home forestry, by establishing experimental stations and nurseries in various sections of their lines, designed to show the possibility of tree culture, to attract settlement, and in consequence to promote the sale of lands granted to them by the Government. As soon as those objects were successfully accomplished the companies withdrew from this inviting field of arboriculture, leaving it to the energy of the settler. It is gratifying that one instance denoting broader views of the necessity of forest culture can be reported—that of the extensive plantation established in Crawford County, Kansas, by Mr. H. H. Hunnewell, of Massachusetts, president of the Kansas City, Fort Scott and Gulf Railway. This far-seeing railroad manager and liberal friend of horticulture has caused two sections of prairie land to be planted, in greater part with the hardy Western Catalpa, one section belonging to the above-named corporation, the other his private property. The success attending this timely enterprise, conducted by one of the honored pioneers of American forest culture, Robert Douglas, of Illinois, has so far exceeded the most sanguine expectations that it must be regarded as a landmark in the future development of this great interest.

The trees were cultivated for four successive years, until they had attained sufficient size to fully shade the ground and suppress the growth of weeds. The closeness of their stand is forcing a straight and upward growth with but few lateral branches, which in time will be removed by a natural process.

This brief statement indicates the fundamental requisites of success in timber culture. Proper preparation of the soil, intelligent cultivation of the growing trees until large enough to take care of themselves, and close planting to secure height-growth and straightness of stem, the plan pursued by nature herself in rearing mighty forests. To this is to be added the necessity of selecting the most valuable kinds for the object in view.

Considering the history of the plantation in its relation to the corporation to which it owes its existence, it will be seen that three conditions favored its rise and development, which, under circumstances lacking these favorable influences, would never have taken place, or like former attempts, would have resulted in failure. To illustrate: a man largely interested in railway property, and conversant with the aboricultural topics freely agitated in the United States, issues the order for a plantation. At first his subordinates attempt to execute this order, but soon become disgusted with a work so utterly foreign to the operating service of a railroad. Thus the project is in danger of being dropped. But an ardent pioneer of forest culture steps forward to save so far-reaching an enterprise, hoped for these many years, shoulders the financial risk involved, and performs the work under a great sacrifice of his personal comfort, assisted, however, by the hearty co-operation of the executive officers of the road.

The conditions indispensable to every similar enterprise are, that the order come from the financial headquarters; that there be unerring, sound judgment in the execution of the work, and good-will and co-operation on the part of the executive officers of the respective roads, without which, though well planned and conducted, the work may be greatly impeded by delays, and even practically fail.

In the report of the Department of Agriculture for 1885 there will be found an account of this forest tract, together with one of the growth of the trees planted in three successive years, and of the financial aspect of the enterprise, given by the manager of the plantation, and by the general manager of the Kansas City, Fort Scott and Gulf Railroad; by which it is plainly demonstrated that railway corporations can contract with reliable parties for the planting, cultivation, and care of extensive forest tracts at very moderate prices, thus relieving the executive officers from all cares and responsibilities incident to arboricultural enterprises, in the successful management of which, as a rule, they have no experience, and consequently no desire to enter into them.

Time only can develop the full result of this pioneer enterprise. Whatever success may attend it in after years, these stately blocks of young and thrifty trees, sprung up as if by magic on a treeless prairie, and the lesson in arboriculture imparted by their future development will be of undeniable value to the country at large, demonstrating not merely the possibility of successful timber growth on open, stormy plains, but also the advantages gained by stocking idle and otherwise unproductive lands with valuable seedling trees which will develop into majestic forests.

The time cannot be far distant when the attention of capitalists investing so lavishly in railway properties will be directed towards a closer investigation of this financial question, and when once convinced of the feasibility of timber culture from a financial point of view, the step towards action will not appear so problematic as it must necessarily be before the hard crust of doubt and the uncertainty of eventual success is broken by actual experience, gained by the liberal investments of the comparatively few far-seeing and philanthropic pioneers of American forest culture.

Railway corporations are deeply interested in the perpetuity of suitable material for the maintenance of their thousands of miles of track. The leading managers of the railways of the sparsely-timbered sections cannot fail to see the advantages to accrue in future years from a general interest in favor of timber culture aroused amongst the owners and tillers of the soil; a forward movement which can be most effectually promoted by making the people of every section along the various lines familiarly acquainted with the value and ease of culture of certain kinds of timber, in which not only the railways, but the people at large, are most prominently interested.

No more effectual mode of arousing this interest can be suggested than that of railway corporations planting in various suitable localities along their lines specimen groves or blocks of such kinds of timber trees as are worthy of the greatest possible dissemination amongst the agricultural people. Let this timely enterprise, entailing but comparatively small outlay, and within the reach of nearly every corporation, be conducted in accordance with the best arboricultural knowledge and experience of the day, and above all let the young plantations be properly cultivated until able to take care of themselves, and be protected as far as possible from destructive fires, and success can be looked for with certainty. Let it be remembered, too, in this connection, that a few successful, well-paying orchards, planted in early days, have done more service in the rise and spread of American fruit culture than all the combined efforts of authors and orators on horticultural topics.

SUMMARY OF CORRESPONDENCE WITH RAILROAD OFFICERS.

During the year 1886 a circular was directed to railroad companies, chiefly those located in the western part of the country, for the purpose of obtaining information in regard to the consumption of timber for the construction of their roads, the extent to which they were engaged in the cultivation of timber for railroad building, or in the planting of trees for wind-breaks and as a protection from snow-drifts; and, in general, as to the prospect of an adequate supply of timber for railroad purposes in the future.

Replies to the circular were received from the following companies, thirty-five in all, viz: Atlantic and Pacific (New Mexico); Burlington, Cedar Rapids and Northern; Chicago, Burlington and Quincy; Chicago and Alton; Chicago and Eastern Illinois; Chicago and Northwestern; Chicago, Saint Paul, Minneapolis and Omaha; Central Iowa; Cincinnati, Indianapolis, Saint Louis and Chicago; Cincinnati, Wabash and Michigan; Denver and Rio Grande; Detroit, Lansing and Northern; Hannibal and Saint Joseph; Illinois Central; International and Great Northern; Kansas City, Fort Scott and Gulf; Little Rock, Mississippi River and Texas; Louisville and Nashville; Louisville, New Orleans and Texas; Louisville, New Albany and Chicago; Michigan Central; Missouri Pacific; Mobile and Ohio; Nashville, Chattanooga and Saint Louis; New York, Pennsylvania and Ohio; Northern Pacific; Pennsylvania Railroad; Pensacola and Atlantic; Pittsburg, Cincinnati and Saint Louis; Saint Louis, Alton and Terre Haute; Saint Louis and San Francisco; Southern Pacific; Terre Haute and Indianapolis; Union Pacific; Wabash, Saint Louis and Pacific.

These roads have 45,787 miles of track in operation. In their construction 16,668,423 ties have been used, at an average cost of 35.6 cents each.

The average number of new ties required annually for each mile, to replace decayed ones, is 365; the average duration of ties is 7.2 years.

To the question, "Has your road made any efforts or experiments in timber culture?" ten of the companies reply affirmatively.

The Illinois Central Company report that they planted some Larches in 1872, that they gave them very little attention, and the greater portion of them died.

The Kansas City, Fort Scott and Gulf Railroad Company are distinguished above all other railroad companies of the country for the extent and systematic manner in which they have engaged in tree-planting. A full account of their plantation is given elsewhere in reports from this division.

The Northern Pacific Railroad Company report that experiments have been made with Box-Elder, Cottonwood, Ash, and Willow, but do not give the result.

The Burlington and Missouri River Railroad Company have planted some timber trees, chiefly for protection from snow-drifts in cuts. The trees planted were Honey Locust, Cottonwood, Box-Elder, Maple, Ash, Willow, and some evergreens. Wherever the trees were properly cared for they have grown well. In some places they have been injured by fire.

The Atchison, Topeka and Santa Fé Company report as follows:

"About the time of the construction of our line, in 1870-'72, in the State of Kansas, four or five experimental nurseries or plots of ground, planted with young trees, were started at different points along our line, from 200 to 300 miles west of the Missouri River. All the hardy trees common to Eastern Kansas and Western Missouri were grown from the seeds, and for five or six years were carefully cultivated. After that time they were left to care for themselves. They made good growth and seemed perfectly at home in what was then a treeless country. Since that time settlers have fully occupied the ground, and many of them have grown trees in great numbers. Our aim, principally, was to show the new settlers what trees were suitable to plant in this section of country."

The Missouri Pacific Company report:

"In Mississippi County, Missouri, 250,000 Catalpa plants are in cultivation by the railway company, and the experiment promises satisfactory results; but sufficient time has not elapsed since planting to speak with certainty."

The Southern Pacific Railroad Company make the fullest report of any. They say: "In the year 1877 it was determined by the directors to try the experiment of tree-culture through the various sections of country traversed by the line of railroad controlled by the company, with the following objects in view:

"(1) To demonstrate the capability and value of the land.

"(2) To test the value of certain woods for railroad purposes, and the practicability of their economic cultivation.

"(3) To remove the sterile and forbidding appearance of the stations and section houses in the treeless plains and valleys, by surrounding them with fruit and shade trees.

"It was determined to carry this work on under the Superintendent of track, and it was specially put in my charge, with instructions to make the current expenses as small as possible.

"My first effort was directed towards the culture of the rapidly growing varieties of the Eucalyptus on the margin of the right of way, where it was available, with a view to utilize the growth and to test the economic value of the wood.

"For this purpose some thousands of tree-plants were purchased in the nurseries of Oakland and Hayward and planted along the right of way of the lines running through Alameda County, California. The total number planted in this way was about 44,000, mostly *Eucalyptus globulus*, but including also a good number of *E. amygdalina* and *E. rostrata*. To anticipate this experiment as a test of the wood, about a thousand telegraph poles were procured, of the young growth of the *Eucalyptus globulus* or Blue Gum, and also 226 fair-sized railroad ties. The telegraph poles were placed in the line along the San Pablo and Tulare Railroad. The railroad ties were placed in the track near Rose Creek, Nevada, on the Truckee division, Central Pacific Railroad. This point was selected because it was found that there the destruction of ties by rot was extremely rapid. Mr. Vandenburg's report of the test of the Eucalyptus for telegraph poles showed that while they were strong and tough, and bore up the wire well under all circumstances, yet they did not last well, as they were inclined to rot in the ground, and just at the surface of the ground were attacked by the larvæ of some large beetle. The Eucalyptus ties placed in the sandy soil of Rose Creek very quickly showed a tendency to check or crack in an extraordinary manner, so that in some cases it was found difficult to find a place on them suitable to hold a spike; otherwise the ties were very strong and lasted well. After being four years in the track, Roadmaster Browning reported 'no sign of decay.' After being six years in the track, slight signs of rot were reported, and two out of two hundred and twenty-six were removed for being split. After seven years in the track, two inches of rot was reported, and seventy-three were taken out of the track. This would show the Blue Gum ties comparing in durability with best Yellow Pine, which is our best second-class tie.

"The trees planted along the track in Alameda County showed great thriftiness of growth, and in a few years demonstrated that wood could be produced in this way with surpassing rapidity. In four years some of the trees had reached a height of 24 to 26 feet and a diameter of 8 to 10 inches. At this point it was deemed expedient to terminate the experiment, and the trees were cut down and used for engine wood.

"In 1877 Mr. C. P. Huntington sent a box of Catalpa seed (*C. bignonioides*), with a strong recommendation that it be tested with a view to cultivate a plantation for tie-timber. The wood of the Catalpa is coarse-grained and light, but it has the reputation of being the most durable under ground of all timber. Cases are quoted of its lasting, buried in the ground, eighty years and upwards without showing signs of rot. (Ohio Agricultural Report, 1871.) The Goshen Branch, just built at this time, passed through a treeless region where the land was moist and very fertile, hence it was deemed a good place for the Catalpa experiment, and a parcel of land, fifteen acres in extent, was selected for that purpose in the town of Hanford, Tulare County, California. This tract was planted with Catalpa trees raised from the seed sent out by Mr. Huntington. The trees were set out 8 feet apart, north and south. They throve remarkably well, growing almost as rapidly as the Eucalyptus trees about San Francisco Bay. But in the course of time the company received what was thought to be a very advantageous offer for this land, and it was sold. Though the experimental grove was thus taken out of our hands, it yet continues to flourish, and I learn from the report of the company's agent that these trees, which are now seven years old, have attained a height of from 50 to 60 feet and are from 8 to 12 inches in diameter. They have now, therefore, reached a size when some of the trees might be cut for ties. They were planted 326 to the acre. If one-fourth of these could be cut for ties, and by splitting them through the center, as is suggested, four ties be made from a tree, this ground may be considered to bear already a very valuable crop.*

"It was considered that the most important work in hand was that of planting out about the stations and section houses. To have a cheap and convenient source from which to procure tree-plants it was determined to establish two nurseries, one in the northern, the other in the southern portion of California. For the first a block of land belonging to the company was selected in the town of Chico; for the second locality we took a portion of the right of way situated between Sumner Station, California, and the Kern River. The strong clay soil of Chico was relied on to produce the plants of the Catalpa, Locust, Walnut, Poplar, and certain fruit trees, while the sandy soil and hot climate of the Kern River valley was expected to produce the different varieties of the Eucalyptus, Acacia, and Pepper Trees, and certain trees of arid habitat.

"From these sources we soon had an abundant supply of tree-plants. In the spring of 1877 the whole of the country east of Tulare Lake and south of the present town of Tulare was an unoccupied waste, used only sparingly for pasture. With a view of demonstrating that this treeless waste could be made fit for homes, a half section of land was selected in the midst of this area at a point just south of Tipton. This was inclosed with a fence and planted with Eucalyptus and Acacia trees, and for their maintenance an effort was made to get an artesian well, which resulted successfully. A good flow of water was obtained at a depth of 403 feet. Stimulated with this water the tree-plants grew fairly well and presented the appearance of a grove.

"The example was followed by settlers, who bought land and soon were sinking artesian wells and making homes throughout this section, showing that one object of the experiment had been accomplished. We soon found, however, that the Blue Gum was too susceptible to frost to thrive permanently at Tipton. Each winter biting, frosty air pours down from the mountains out of the cañon of Deer Creek on to this particular tract, thus killing the tender Blue Gums in spite of their strong summer growth.

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*Irrigation has been extensively carried on in this region, and its summer climate is undoubtedly more humid than is generally the case in the interior valleys of California. However this may be, the Catalpa trees planted along the company's lines at all the principal stations in California have not thriven well, apparently being ill-adapted to the long warm and rainless seasons.

"The nurseries at Chico and Sumner (Kern River) furnish tree-plants, and each spring during the period adapted to planting they were distributed along the lines of railroad and planted about the stations and section houses.

"In some localities, notably in Nevada, great difficulty was found in making the trees live. This resulted partly from the altitude and severe climate, and partly from selecting trees ill-adapted to the locality. It is true, we know, that Cottonwood and Quaking Aspen and the like would flourish at the most difficult points, but it was deemed worth while to try what could be done with more durable species and with fruit trees. In this way it was not by once planting, but by many times planting, that the stations in the treeless wastes were gradually embowered. Often, after trees were well started, the carelessness of an employé would allow them all to die off again.

"The situation of Kern River was found to be excellent for a nursery, but for the sake of economy it was abandoned in favor of Tipton, where the plantation and nursery could be consolidated. Most of the trees planted out along the Southern Pacific, as far east as El Paso, were raised in this nursery from the seed.

"In extending the tree-planting through Arizona and New Mexico an unexpected difficulty was encountered. We had looked for trouble from heat and drought, but we found the most serious trouble to arise from frost. We never expected to find, as our meteorological observations now show, a minimum temperature of 8° and 10° for stations in Arizona.

"In consequence of this lack of sufficient data, the trees sent to that section for several seasons have been frost-bitten. As the first experience of this kind was thought unusual and exceptional, the same kinds were tried again. I believe I can now report that the present stations throughout California are sufficiently supplied with living trees, so that, with reasonable care, the beauty and advantage to be derived from them will be constantly on the increase."

To the question, "Have you planted trees for wind-breaks, as a protection against snow-drifts, and with what success?" thirty-four, or most of the companies from whom reports were received, reply emphatically, "No."

The Northern Pacific Railroad Company says: "Yes; but it will take two years to determine with what success."

The Burlington and Missouri River Company say, "We do not consider that our trees planted for snow protection are a very great success. In the winter, when protection is needed, the foliage is all off, and the railroad 'right-of-way' being narrow the trees must necessarily be too close to the road to make an efficient snow-break."

The Chicago, Saint Paul and Minneapolis Company report good success, but give no particulars.

The report from the Missouri Pacific Company objects to the planting of trees for wind-breaks or as a protection from snow on account of their obstructing the view at highway crossings, and because it would involve the expense of purchasing land on either side of the road so that the trees might be set further apart than they can be with the ordinary width of road. It is alleged that where the road is only 100 feet wide rows of trees on either side, instead of protecting from drifts, cause the snow to lodge there and become more troublesome than it would be without the trees.

To the question, "Have plantations along your line been materially damaged by fire?" twenty-two companies have made reply. The general tenor of these replies would indicate that the losses by fire are not great.

The Louisville and New Albany Company say: "We have had very little damage by fires to forests, and do not think this would in any way discourage tree-planting."

An officer of the Hannibal and Saint Joseph Railroad Company says, "I am not aware that any plantations along the line have been materially injured by fire, nor do I consider fire a danger sufficient to discourage tree-planting."

Report from the Burlington and Missouri River road says: "Private groves along our road have not been seriously damaged by fire, and they do well in nearly every case; private parties being better able to take care of trees than the railroads, having them near by where they can be constantly looked after, and not endangering them by fire, as the railroads necessarily must do in running their trains, and are not so liable to have them burned."

An officer of the New York, Pennsylvania and Ohio road says: "I would advise to make the plantations at some distance from the railway. Fires are frequent near the railway.

The Louisville and Nashville Company report: "Trees and hedges have been injured by fire along the line of railroad."

The Michigan Central Railroad report says: "The damage is serious where grass is allowed to grow; otherwise not."

The Union Pacific Railway Company report that the damage done by prairie fires has been discouraging, but in that proportion as the land becomes occupied by settlers the danger of fire is diminished.

To the inquiry whether the companies would be willing to expend a small amount annually in tree-planting, the general tenor of the replies is in the negative. Some would be willing to engage in experimental planting if others would unite with them, but few, if any, roads seem to be impressed with a sense of the importance of undertaking the work of planting for their own benefit.

From the Pennsylvania Railroad Company comes this reply, which may be taken as a specimen of the general feeling on the subject: "To this question I would answer yes, if I were the company. But, considering that about twenty-five years would be needed to get White Oak large enough for ties, it is hardly probable the importance of timber culture will be recognized sufficiently to even spend a small amount, say $500 per year, systematically for this."

The Wabash, Saint Louis, and Pacific Company says: "The company would probably consent to make a small expenditure annually in furtherance of tree-culture. Timber has heretofore been so abundant and cheap that there has been but little necessity for taking the matter into consideration and giving it any attention. It is of great importance and should not be longer delayed."

To the inquiry whether the lands along the lines of railway are too valuable to be profitably devoted to tree-planting, while some roads report much of the land as being of high value, they generally agree that there is a sufficient quantity of inferior value which might be more profitably used for the cultivation of trees than for any other purpose. The Louisville and New Albany Company say, for instance, "Our line is mostly through cultivated lands, but there are many tracts that would be just the thing for tree-culture, while of no value for any other purpose." The Union Pacific Company say that there is an abundance of land fit for tree-culture along the company's lines, but it would not be advisable to plant and cultivate at the company's expense, for they cannot even protect from thieves the small patches of timber on the streams that were formerly found in many sections of their grant.

To the question, "Would not tree-planting by railways be facilitated if each road had in its employ an officer sufficiently acquainted with the relative value of trees and modes of planting to superintend all work of this kind ordered by the managers?" the replies are almost unanimously in the affirmative. Most of the companies think such an officer would be indispensable, while a few think the existing officers of the roads could manage the business

Appendix 1.

STRUCTURE OF CERTAIN TIMBER-TIES; BEHAVIOR AND CAUSES OF THEIR DECAY IN THE ROAD-BED;

TOGETHER WITH EXPERIMENTS ON THE ADHESION OF SPIKES.

By P. H. DUDLEY, C. E.

The extensive railway system of the United States will this year require 60,000,000 ties for repairs, and as the lines are yearly extended the number required for this purpose will be increased. Expressed in board measure this represents approximately 2,160,000,000 feet, a large quantity, though, for our great country, only comparatively so; for could the supply be cut indiscriminately, and from all kinds of timber, our forests would continue to meet the demand for years to come. But the supply is limited to special kinds of woods, and ties are cut chiefly from trees 10 to 12 inches in diameter and from thirty to sixty years old. This is one of the serious phases of the question; for this consumption of young and thrifty trees reduces the future supply of timber faster than would otherwise be the case.

In the Eastern and Middle States the supply of timber adjacent to railways has been largely exhausted, ties for these roads coming from forests some distance away; and, with the price constantly advancing, how they will procure ties a few years hence is a serious question with railroad officials. But few railroad companies are in position to grow their future supply of timber, and if they were, it would be twenty-five years before they could derive much benefit from such a course.

CHECKING UNNECESSARY CONSUMPTION OF TIMBER BY PRESERVATION OF TIES.

The railway companies can at once take more effective measures to increase the durability of the ties they must use, and thus to check the present consumption of such great quantities of timber. In former years many efforts were made in this country to preserve ties by artificial processes; but the cost was so great and timber so cheap, while the results were only partially successful, that for the time being all methods for the preservation of ties were abandoned. But at present the case is different. In many localities timber is two or three times as expensive as it formerly was. Chemicals are much cheaper and money bears a lower rate of interest, so that, upon the score of economy alone, it will now be expedient to do what was unwarranted a few years ago. Little inquiry was made as to why so many of the preserving processes failed.

THE DECAY OF TIMBER AND TIES DUE TO THE GROWTH OF VARIOUS KINDS OF FUNGI.

In dry situations, as in roofs of buildings, or when submerged in mud and water, seasoned wood will last for centuries; but it decays in places where it is warm and moist (from 40° to 120° Fahr.). Formerly the decay of timber was generally ascribed to slow combustion (Liebig's Eremacausis), but it is now known to be due to various kinds of fungi, the presence of many of which microscopical investigations have demonstrated.

As regards the relative position of the fungi in the scale of plant-life, it is perhaps only necessary to say they are a great group of plants of low organization, destitute of chlorophyll, and bearing neither leaves nor flowers. Instead of seeds they produce microscopic spores, which are freely disseminated by wind and water. They are dependent chiefly upon higher plants for their nutriment, appropriating the already elaborated material found in the tissues of these hosts. Nearly 50,000 species of fungi have been described, many of which grow on or in the wood of trees.

A large number of the measures formerly adopted to prevent and check decay, especially that of unseasoned wood, by confining the moisture, were the most effective in causing the fungi to grow, inducing, it is believed, the decay of the wood. Thus it is a well-known fact that painting green timber will hasten rather than retard its decay; the paint, by retaining the moisture, furnishes a necessary condition for the germination of the inclosed spores. This also is probably the explanation of the failure of so many of the other preserving processes. The chemicals, or other substances used, formed an exterior coating* like paint, thus retaining the moisture and allowing the fungi to grow on the inside, causing the so-called "dry-rot." If the timber be thoroughly seasoned, an exterior protection from moisture is sufficient to prevent decay. The rotting in four or five years of many of the earlier wooden bridges, which were painted before they were seasoned, is familiar to all railroad men, while those unpainted lasted much longer. So, too, unpainted covered wooden bridges were found to be the most durable, from the fact that the timber was kept so dry as to preclude the attacks of fungi. The timber, if not too large, became thoroughly seasoned, and in that condition was practically indestructible.

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* See Carbolineum as a Protection against the Decay of Wood, p. 104.

Ties should be seasoned.—Simply seasoning ties would add much to their durability. They should be piled so as to have a free circulation of air under and about each tie. The top of the pile should be inclined so as to shed water. As soon as the trees are felled the bark should be removed in order to facilitate the seasoning of the wood. Large timber for switch-stands, trestles, floor beams, and stringers for bridges should be seasoned under cover to prevent the sun from seasoning only an exterior layer, thereby preventing the escape of moisture from the interior and inducing interior decay. Station platforms of timber should have a circulation of air under them, otherwise they are quite liable to be attacked by some of the fungi. In many cases spruce planks in these structures have decayed in less than two years.

The appearance of some of the fungi present upon and in piles of timber is, perhaps, familiar to all track managers, but we have been taught so long that this is simply the accompaniment of decay, instead of being its inducing cause, that such effective measures to prevent rotting have not been taken as might have been and will now be adopted since the cause is better understood.

Preservation of ties.—In most cases thorough and proper treatment will preserve ties so as to double their life as far as decay is concerned; but the method that is most suitable for one kind of wood may not answer for another of different characteristics. This will be more apparent upon examining the structure of the woods illustrated. To be successful the conditions of each case must be considered; not only the kind of wood, but whether it is seasoned or not, and what the final surroundings are where it is to be used. For railway ties, we can say in general that the treatment must be such as will do one of two things: keep the wood dry; or, if it is to be used in a position where it will be moist, the antiseptic must be sufficient to check all fungous growth or fermentation, to do which the cells of the wood must be thoroughly impregnated. The success of Dr. Boucherie's first process of forcing a solution of copper sulphate through the green wood was due to the complete impregnation of the wood-cells. But this plan of treatment requires much care and skill to be effective. The late Dr. Hough, in Vol. IV. of the Report on Forestry, p. 165, says:

> "Upon the Flushing Railroad Burnettized ties were used in building the pile-work near Flushing village in 1868, the timber being green Spruce 12 by 12 (inches), sawed and used as stringers, from 4 to 10 feet above the level of salt-marsh meadows. They appeared to have been thoroughly treated to the heart. There being some deficiency in the supply the work was completed with White Pine stringers (not Burnettized) of the same dimensions as the Spruce. Upon repairing the pile-work the Burnettized timber was found decayed in the heart, leaving a shell of from 1 x 3 inches, while the Pine was comparatively sound, some portions being merely sap-rotten an inch or so deep on the outside.
>
> "The roadmaster then in charge, and who writes apparently without the least interest or prejudice, considers the Burnettized timbers unsafe for railroad structures on account of its decaying at the heart and leaving a shell that is sound, which would naturally lead employés to regard the timber safe for trains after it had reached a

degree of weakness that was altogether dangerous within. He thinks that this process has a tendency to produce dry-rot, especially of Pine or soft-wood.

"It would, however, be unfair to draw conclusions from American experience, and perhaps it would be just to attribute some, at least, of the failures that have followed to the inexperience of workmen and to the superficial and imperfect manner in which these processes have been applied."

The last sentence explains the matter. The fault was not in the antiseptic but in the manner of its application; the heart-wood was not impregnated with a sufficient quantity to protect it from the fungi.

STRUCTURE OF THE WOODS UNDER CONSIDERATION.

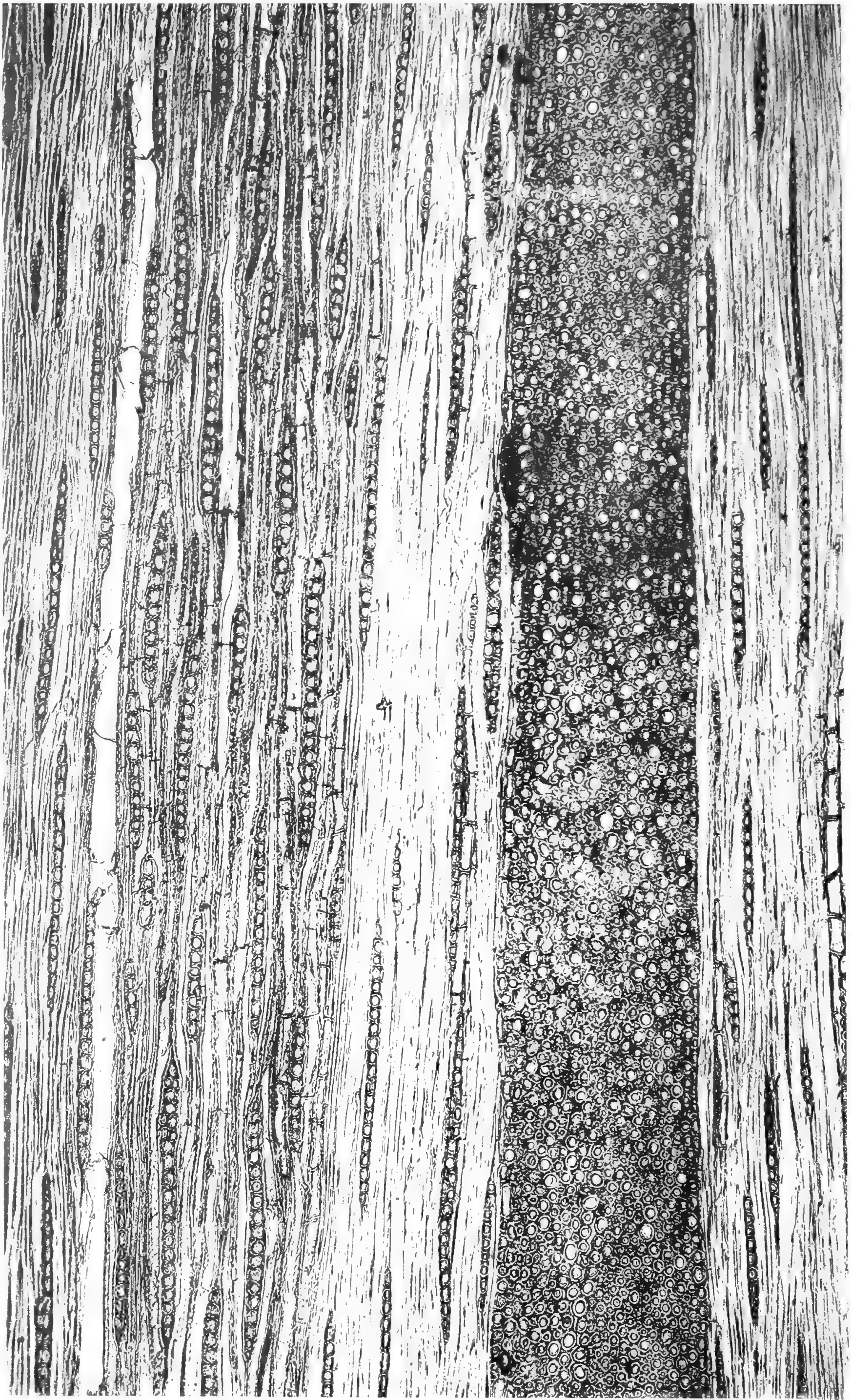
In the following pages will be considered the structure and nature of some timbers with reference to their use as railway ties, and their special requirements in regard to preserving processes; namely those which form the bulk of our wood supply for railway purposes—White Oak, Chestnut, Cedar, Yellow Pine, Hemlock, and Tamarack or Larch.

The oak and chestnut belong to the Angiosperms, and the cedar, yellow pine, hemlock, and tamarack, to the Gymnosperms, all of the latter having the general characteristics and structure of the Coniferæ, but differing from each other in detail. In the first two the cell-structure is entirely unlike that of the last four, being far more complex and highly differentiated, the inner portion of each annual layer having from one to three concentric rows of large ducts, while smaller ones are distributed through the entire layer.

All these trees are Exogens or outside growers, and if we look at a transverse section of any of them of the natural size we see it is composed of a series of annual rings, each representing a distinct period of active growth, generally only one ring forming each season, but often varying in thickness. For instance, in the White Oak (*Quercus alba, L.*) a layer of a poor season's growth may not have the full number of the hard, dense fibers which give hardness to the wood. To some extent this is true also of the chestnut. In the other woods under consideration each layer will have more nearly its proper proportion of the different fibers, though the layer may be thin. Through each annual ring pass the medullary rays, which extend from the bark to the pith, and if a small section be magnified the general characteristics of the entire layer are seen; if the section be taken from the sap-wood the structure is not so complete as in heart-wood, and the cell contents are not the same. In the mechanical destruction of ties the ease or difficulty with which the rings separate has much to do with the wearing capacity and consequent durability of the ties. This feature differs in all the woods under consideration, and will be specifically treated for each one.

PHOTOMICROGRAPHS OF THE MAGNIFIED STRUCTURE OF THE WOODS.

The photomicrographs accompanying this report are all enlarged to one scale, namely, 100 diameters, and by employing the metric scale in making a measurement, and dividing by 100, the natural size of

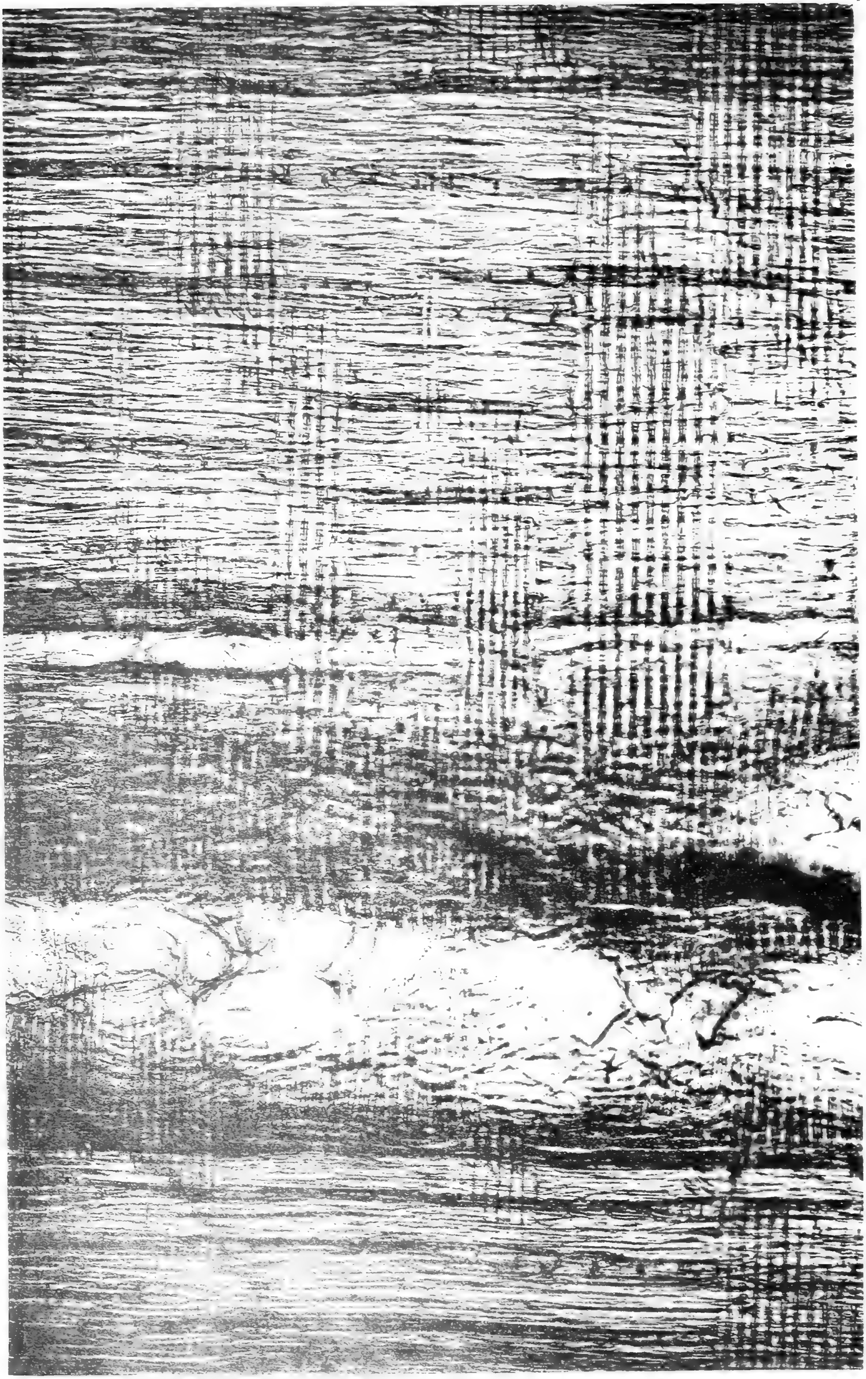


Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

251. Quercus Alba, Linnaeus; White Oak.

Tangential Section x 100 Diameters.

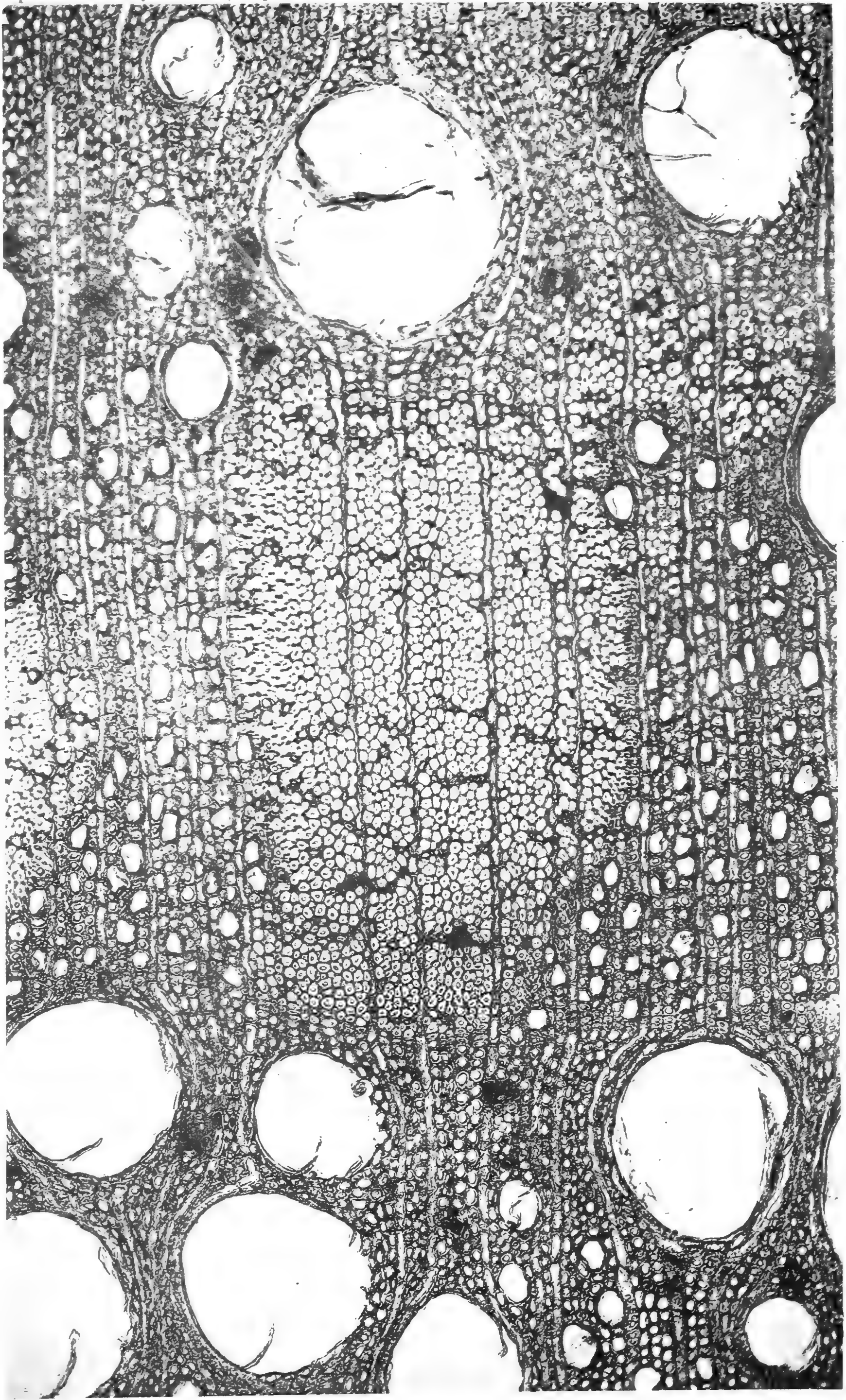


Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

251. Quercus Alba, Linnaeus; White Oak.

Radial Section x 100 Diameters.



Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

251. Quercus Alba, Linnaeus; White Oak.

Transverse Section x 100 Diameters.

a cell or the thickness of its wall can be obtained. For this amplification the field of the objective covers an area of the specimen equal to one-tenth of an inch in diameter, which is enlarged to 10 inches, the photomicrograph being taken from the portion thus viewed with the same amplification retained. To show the entire structure of the wood a photomicrograph of three different sections is required, *i e.*, transverse, tangential, and radial. In the transverse section the cells are cut across, showing some in their largest diameter, while others are cut at varying portions of their length, and, therefore, show different diameters. All of these transverse sections are so arranged that the top of the page points to the center of the tree, and the bottom of the page to the outside of the bark. The lines running down the page indicate the medullary rays, which extend outward through each layer of wood as it is formed. The views of the other sections will be understood from the special description under each species.

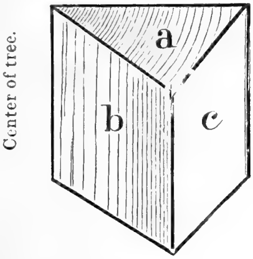


Diagram illustrating sections: *a*, transverse section; *b*, radial section; *c*, tangential section.

WHITE OAK, *Quercus alba*, L. No. 251.*

The photomicrograph of the transverse section of the White Oak is from an annual ring of medium thickness, and a striking feature in its appearance is the concentric circle of ducts in the early spring growth of wood; in the thick rings sometimes there are two or three rows of ducts, the third one being of smaller size than the others. The first row forms in the spring as the leaves are opening. The largest duct in the illustration is round and .013 of an inch in diameter; some are smaller, and others flattened or elliptical. Except when first forming these ducts are never open, as usually stated, but are filled with delicate tissue.† This tissue is so delicate and its cells so large that in cutting the sections it is more or less removed by the section-knife. It is, however, quite durable, for in decaying ties this tissue in the ducts is still intact after many of the surrounding wood-cells are decomposed. During growth, fluids pass through this tissue by osmotic

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* The botanical names are those used by Prof. Sargent in his report on the "Forest Trees of North America," Vol. IX., of the Tenth Census; the numbers refer to those used in that work.

† *Tyloses*, a peculiar cell-structure found in the ducts of many of our timber trees.

action. Surrounding these ducts are small cells, which are termed tracheids, having minute thin places in their sides; the middle lamella of the cell, however, is not visibly perforated. Some cells containing starch are also intermingled with these tracheids. If the tree is not vigorous or the season favorable for a large growth there are only a few other cells formed, and the annual layer will be narrow and imperfect; and if the entire wood is made up of such rings it has a low specific gravity, is "brash" and not strong. Such wood is not suitable for wheel-pieces of car-trucks, and when used for ties the rails wear down into it as they do on chesnut ties. In an annual layer of vigorous growth large bundles or masses of hard, dense fibers are seen just outside of the concentric circles of ducts, and when fully formed extend through the outer part of the layer. These fibers vary in diameter from .006 to .0075 of an inch. Such bundles or masses of hard fibers give to this wood its peculiar hardness and toughness, making it so valuable for railroad ties. The medullary rays run through the bundles and at frequent intervals are intersected by cells running parallel to the axis of the tree, thus connecting radiating bundles of medullary rays, and dividing a mass of hard fibers into small rectangles. On either side of a mass of hard fibers will be seen a series of small flattened ducts about .001 of an inch in diameter, surrounded by small tracheids and some of the small wood-fibers. In this transverse section only single lines of the medullary rays are seen, but large bundles do occur, and a portion of an end view of one will be seen in the tangential section. Near the top and bottom of the illustration can be seen the lines where the annual layer joins others. The illustration of the radial section shows it to have been made through a mass of dense fibers, exposing also the exterior and interior of one of the large ducts. The single rows of cells running down the page are the medullary rays. This view shows also the firmness and solidity of the wood. The hard fibers running across the page give but little indication of where they join or interlace. One of the ducts shows the surrounding tracheids and also the cells of the medullary rays crossing the duct.

In the tangential section, as already stated, are seen the ends of the cells composing one of the great bundles of medullary rays so common to this wood; but few of the cells are as large as .001 of an inch in diameter, most of them being much smaller. On either side of this are the hard, dense, woody fibers, interspersed with small bundles of medullary rays of a single row of cells superimposed one above the other. From the views of the structure of this wood it is seen to be one of considerable hardness and density.

Specific Gravity.—For the heart-wood, this ranges from 0.65 to 0.90. In Vol. IX., of the Tenth Census, Professor Sargent reports the average of thirty-one pieces, dried at 100° centigrade, as 0.7470. Ties will never be found as dry as this, and in general the average will be much higher.

In wet places oak ties often become water-soaked and will sink when thrown into the water.

Change of sap-wood to heart-wood.—The sap-wood of the White Oak changes to heart-wood in ten to fifteen years, much earlier than that of some of the other oaks. This is a valuable feature, as ties are cut mostly from small timber of the proper size and flattened on two sides, leaving the sap-wood on the remaining sides. In many cases the bark is not removed, but it should be at the time of felling the tree, especially if the temperature be about 50° or 60° F. If the wood is cut during active growth the sap furnishes a good medium for the growth of various ferments, which, if special care is not taken to prevent their growth, will affect the sap-wood and eventually the heart-wood. When such fermentation has taken place and is afterward checked by drying, the wood is discolored and is called "dozy," and will rot quickly when placed in the road-bed subject to conditions of warmth and moisture.

NOTE.—The controversy as to the influence of the time of felling on the durability of the wood cannot yet be said to be definitely closed. The most recent investigations under this head, published by Professors Hartig, Poleck, and Dr. Lehmann, would indicate that the question cannot be answered generally, but that the answer is dependent on different conditions in each special case.

The "dry-rot" fungus (*Merulius lacrymans*, Schum.) being found to be the principal destroyer of the wood used in building, Professor Poleck was induced to examine the mineral constituents of timber felled in the winter and in the summer with regard to the requirements of this fungus, and was led to state that the summer-felled timber affords a better supply of nourishment to the fungus than that felled in winter, the former being five times as rich in potash and eight times as rich in phosphoric acid as the latter. The experiments which confirm this view were conducted with blocks of timber inclosed in casks. Unfortunately, later on, Professor Poleck discovered that the timber procured for him, purporting to be winter-felled wood, was in reality raft-timber; and he has ascertained that timber which has been immersed in water is no longer liable to the attacks of "dry-rot," the effect of the water being to dissolve out slowly the albumen and salts, thus depriving the fungus of the necessary nutriment for its development. So much so is this the case that in Alsace it is customary to specify that only raft-timber shall be employed.

In opposition to the theory of Professor Poleck a number of experiments were carried on by Professor Hartig. In the first place he shows that at the end of April the sap has not risen in the timber, and that no mineral matter can have been stored up in the wood-cells which were not present at the beginning of the winter, and that the true summer-felled timber must, if anything, be poorer in mineral salts than that felled in the winter. His analyses confirm this view, showing 8.42 per cent. of phosphoric acid in winter wood as opposed to 5.89 per cent. in summer-felled wood; and while Professor Poleck insists upon the necessity of phosphoric acid for the growth of the fungus, Professor Hartig lays most stress upon the presence of ammonia or potash salts as being essential.

Professor Hartig's experiments made with pine and fir, felled for the purpose and stored in a specially constructed cellar, are most elaborate and minute, the general result being that both summer- and winter-felled damp fir and pine (two kinds of woods behaved alike) lost equally in weight. When, however, dry winter wood was contrasted with wet winter wood, the results were astonishingly different. In the case of fir the dry wood lost 11 per cent. in weight, while the wet wood lost 23.1 per

THE GREAT VALUE OF WOOD DETERMINED BY LONG EXPERIENCE.

The wood of the White Oak is the one most desired by railroad companies for ties. In the primitive forests the growth was very general in those sections of the country where railroads were constructed, and its great value has been fully demonstrated by long experience. The demand for ties of this wood has been so imperative that large extents of territory once covered by this valuable timber have long since been denuded; what remains is so scarce and valuable that few companies are now able to obtain a supply of second-growth for ties.

The oak holds a spike with great tenacity, and thus the rail is firmly fastened to the tie, a feature the importance of which is entirely overlooked by people who have not had practical experience in the matter. The wearing down of ties under the rails is not due alone to the ease of indentation, but largely to abrasion. The softer the wood the less firmly the spike is held, and if there is more or less looseness of the rails an abrasion takes place more rapidly than when they are held firmly to the tie. This fact has been determined by practical tests. Alternate ties under the same rail have been bolted to the rail, and the abrasion was less rapid on them than on those which were spiked. I am well aware of the prevailing opinion in the New England States, where the Chestnut is so extensively used for ties, that were they to attempt to change to oak ties they could not draw the spikes to make the adjustments in their rails, but would break off the heads of the spikes in the trial. Against this opinion, however, we have the experience of the main lines, with a large mileage and tonnage. They prefer the White Oak, experiencing but little trouble in drawing spikes, and they would not use any other wood, except that its scarcity and cost have compelled them in many cases to do so.

Durability.—White Oak ties last from six to ten years. Seven years' duration is considered good under heavy traffic on rails with a 4-inch base. Longer wear of course is had under broad faces of 8 to 10 inches. The moisture which collects around the spikes and under the rails eventually softens the injured fibers, and fermentation is set up in two to three years, depending upon local conditions of moisture and heat combined, the most rapid fermentations occurring in localities where the warm season is the longest. The decay of the ends and central

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cent.; but in the case of pine the loss in the dry wood was 13.3 per cent., while in wet wood it was only 13.6 per cent.

Comparative experiments with heart-timber of fir and pine, as contrasted with the outside planks, showed that while in the fir the heart was destroyed more rapidly than the outside layers the reverse was the case in the pine.

Very unexpected results were obtained when the wood was in contact with various substances, as sand, coal-dust, ashes, garden-mold, etc., from which it would seem that clear sand is worse for filling-in between the joists than a mixture of sand and plaster, while dry rubbish from old buildings is better filling material than coal-dust

The question, then, of the best time of felling, as regards the lasting qualities of timber, cannot yet be considered as settled, and the matter of handling timber after felling is the point of most importance.—B. E. FERNOW.

portions of White Oak ties as a rule follows closely upon that under the rails, especially that portion of the tie which is surrounded by or underneath the ballast. In gravel ballast, oak ties decay more rapidly under the ballast than in the fully exposed parts. In most localities the decay of the oak is retarded by imbedding the tie in the ballast as little as is compatible with the stability of the track. The layers of wood under the rails separate from each other by the breaking-through of the tracheids between the large ducts, yet not as readily as in the Chestnut, but the massive bundles of medullary rays of the oak to some extent check the breaking or crushing of the tracheids, and offer considerable resistance to the undulation of the rails and consequent abrasion of the ties. The apparent injury to the White Oak ties by spiking is not as great as it is to the other woods under consideration, but it is sufficient to shorten, to some extent, the life of ties used. Boring holes for the spikes would prevent much checking of the wood, and a proper-sized hole would increase the adhesion of the spike, as shown by tests.*

Time of cutting White Oak for ties.—The season of cutting affects the heart-wood much less than it does the sap-wood. Great care must be taken of timber cut from April to July, as the large amount of sap elaborated at this time furnishes a favorable condition for the development of fungi, first involving the sap-wood and then the heart-wood. For a like reason care must also be taken of timber cut from July to November, as the sap-wood is liable to be affected; but timber cut in winter is less liable to attacks of fungi at once, from the fact that as a rule the temperature is too low for such growths, and the wood is more likely to get partly seasoned than if cut in the summer.†

PRESERVATION.

This has been accomplished by "Kyanizing" and "Burnettizing" and by the use of copper sulphate. But the treatment must be long-continued to insure full penetration into the wood; otherwise it will be a failure.

FUNGI.

The sap-wood of White Oak ties in the ground is quickly attacked by *Polyporus versicolor*, Fr., the fungus often being found fruiting on timber in the main tracks. The past season I have found it growing to some extent upon the heart-wood of this class of ties, showing that under favorable conditions it can destroy the heart- as well as the sap-wood.

Dædalia quercina, Pers., is often found growing on the sap-wood of these ties, and destroys them with considerable rapidity.‡ *Polyporus applanatus*, Fr., attacks the heart-wood, and is very destructive, though

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* See Table VI. on Adhesion of Spikes, p. 58; also note and tables on p. 62.

† See foot-note, p. 37.

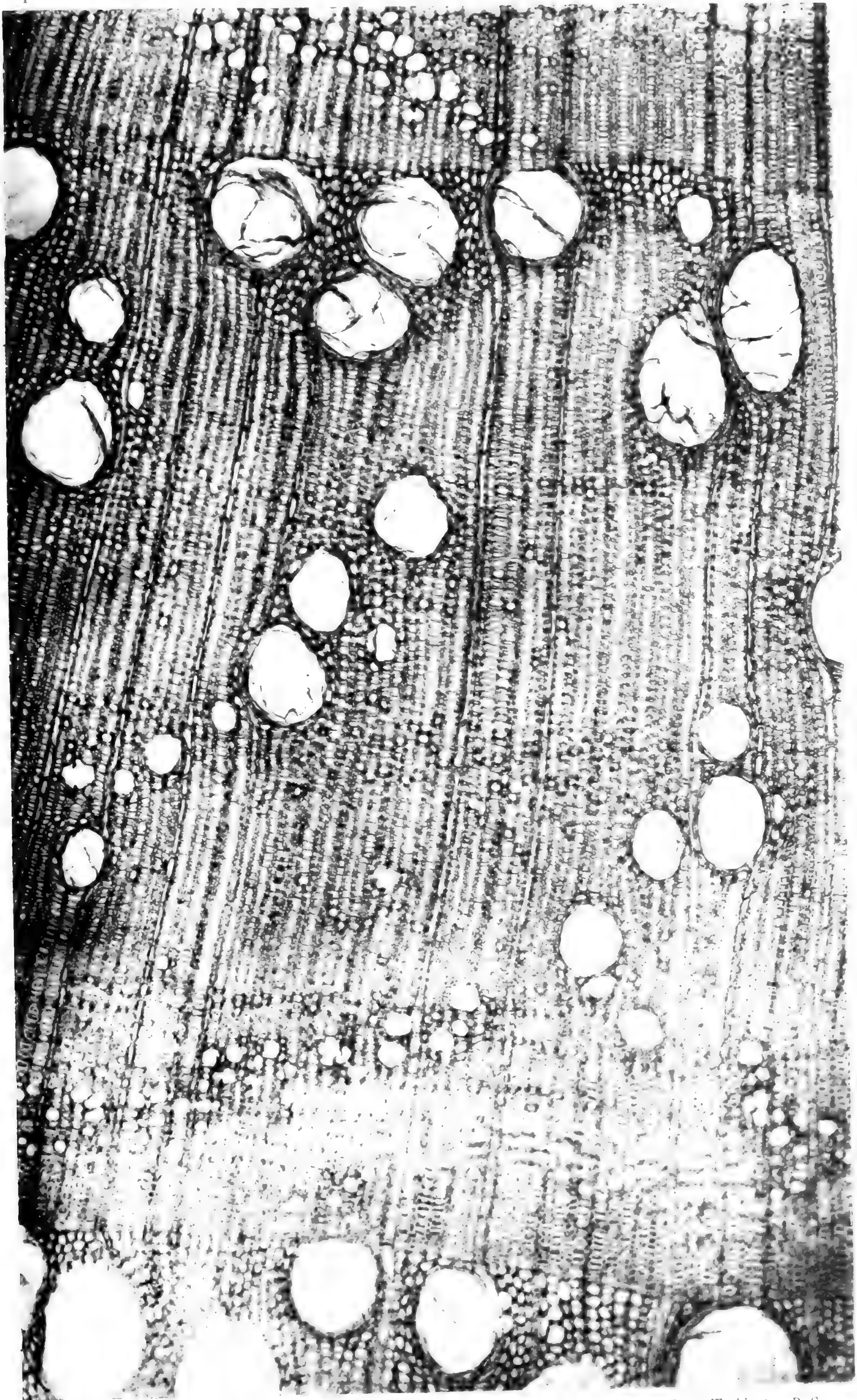
‡ Prof. Charles H. Peck thinks it cannot be *quercina*, as he has not been able to find any specimens of this species.

it is rarely found fruiting in the main tracks. *Lenzites vilas*, Pk., is often found upon the White Oak ties of bridges.

CHESTNUT, *Castanea vulgaris*, var. *Americana*, A. D C., No. 290.

Each annual ring of wood, as seen in the photomicrograph of the transverse section, has one concentric circle of ducts, at least in the interior portion of each ring, and in other specimens a second and sometimes a third occurs. Botanists recognize only one species; but in regard to structure and color of the wood two varieties are discernible. In one of the sections, taken from a tree grown near New York City, the effect of climatic conditions upon the character of the cells formed is readily traced.

In order to show an entire section of this ring (from the second growth wood, the most desirable for ties) three plates of the size of the one presented (7 by 7½) would be required. The section of this ring was taken from near the heart of the tree, and exhibits the characteristic structure, though the ducts are only about one-third the usual size. The wood from which the photomicrographs of the other sections were taken is most suitable for ties. Surrounding the ducts and growing with them are tracheids, which have a lumen from one-half to two-thirds the size of the cell; but in some of the annual rings (from the same piece of wood) only a few of the tracheids are seen with a large lumen beyond the first row of ducts; there are also found tracheids with a small lumen and some fibers making up the rest of the ring, while in an adjacent ring the tracheids may form many rows beyond the ducts, the wood-fibers usually completing the ring. Wood formed of rings of the latter character is stronger and has a greater specific gravity than wood which is formed of annual rings, as first described. Under the microscope the distinction between the two grades is easily made; for in the wood composed mostly of fibers there are numerous cells, which in the alburnum (except in active growth) contains starch. The heavy lines of cells running down the page represent the medullary rays, which in this wood are mostly in single rows, the cells being placed one above the other. The medullary rays bend around the ducts, their cells being slightly flattened and curved. In the wood-fibers the medullary rays are intersected at right angles by numerous rows of cells which contain starch, as described above. In the radial section the cells crossing the page are those of the medullary rays, while on the left are seen the numerous tracheids which surround the ducts. On the right of the page are the longitudinally arranged wood-cells and traces of some of the smaller ducts. The ends of the medullary rays are seen to be composed of cells in single rows, and very numerous. The cells of this wood contain considerable tannin, and their size, with a comparatively large lumen, shows that the wood has a low specific gravity, ranging from 0.36 to 0.56, the former occurring in large trees grown in dense forests, while the latter is frequently found in small

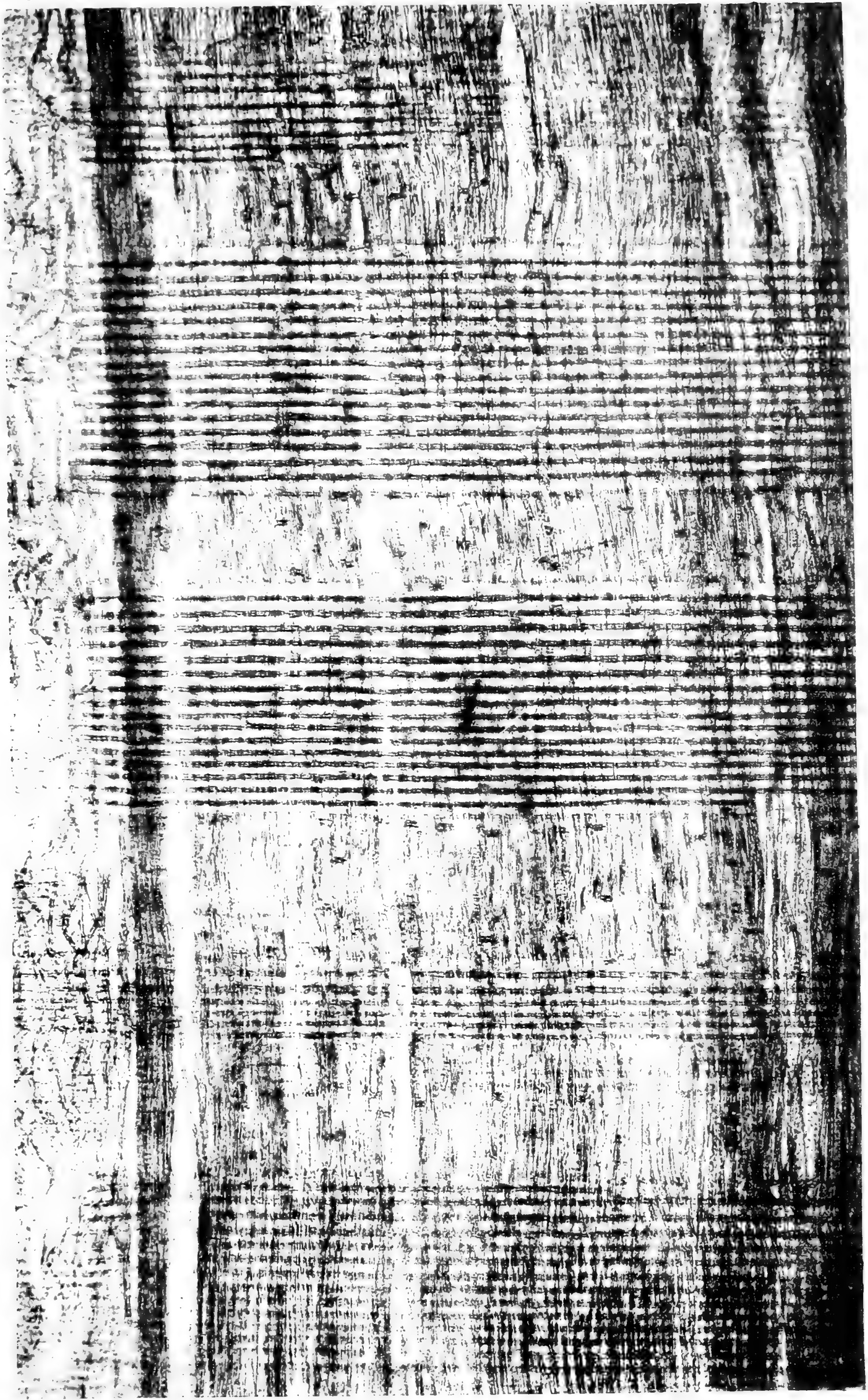


Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

290. CASTANEA VULGARIS, VAR. AMERICANA, A. DECANDOLLE; CHESTNUT.

Transverse Section x 100 Diameters.

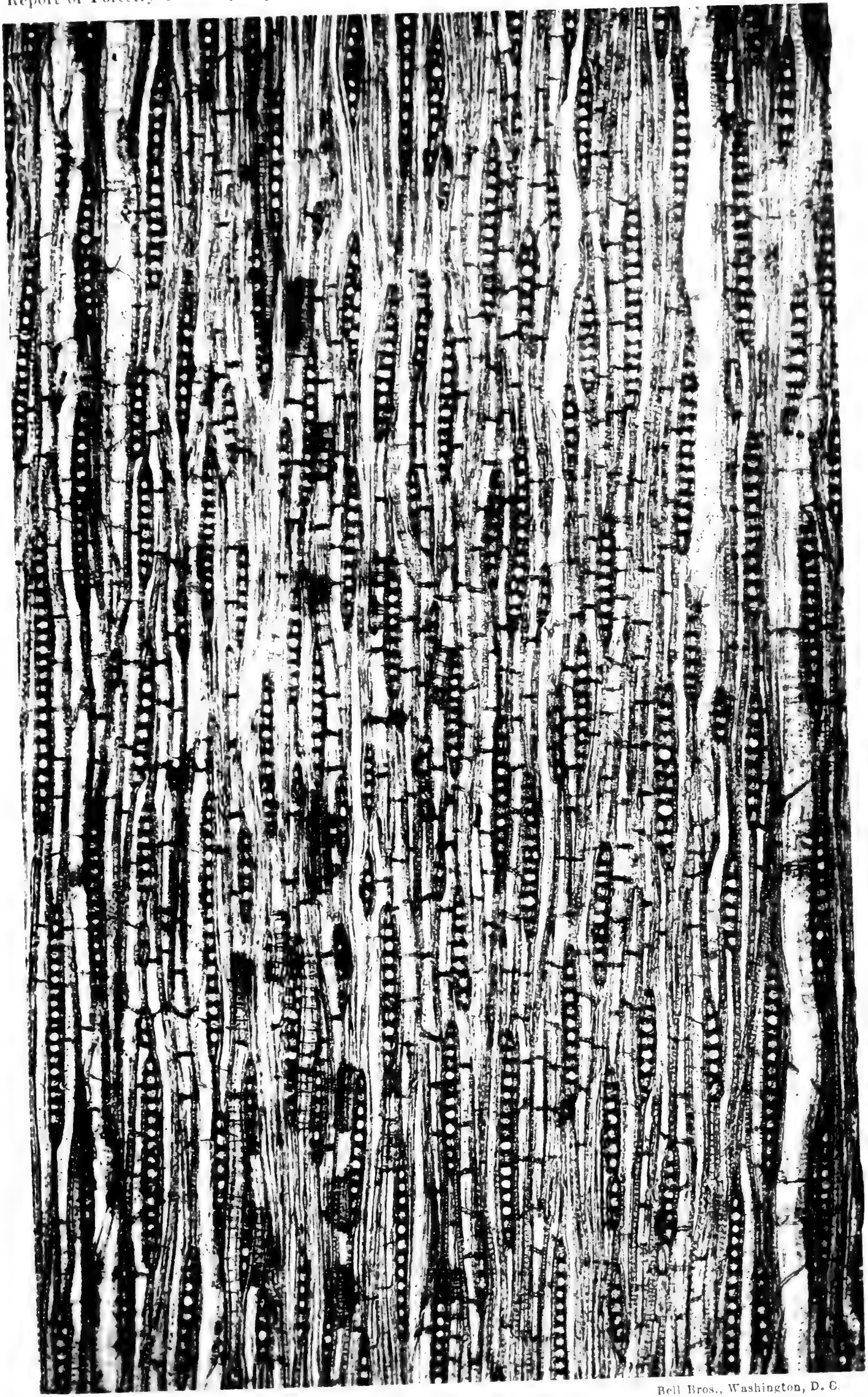


Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

290. CASTANEA VULGARIS, VAR. AMERICANA; A. DECANDOLLE; CHESTNUT.

Radial Section x 100 Diameters.



Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

290. CASTANEA VULGARIS, VAR. AMERICANA, A. DECANDOLLE; CHESTNUT.

Tangential Section x 100 Diameters.

trees having large leaf areas and growing in open woods, as second-growth timber.

Change of sap-wood to heart-wood.—In large trees this change takes place in from ten to fifteen years, while in younger trees, growing in the New England States, the change is completed sooner, usually in four to six years. This is important, as the majority of ties are cut from small timber, and flattened only on two sides, the sap wood forming but small portions of the faces of the ties.

Durability of Chestnut ties.—Chestnut wood is far more durable in contact with the soil than any other species considered in this paper, except, possibly, the White Cedar. But as soon as iron comes in contact with the longitudinally arranged fibers of the unseasoned wood, its durability is decreased, and decay is likely to commence, especially around the spikes. After a few years ties of sound Chestnut are found to decay from the surface downward, and rapidly in the vicinity of the spikes and under the rails. In most soils, if the ties remain in the track over six or eight years, the ends and central portions above the ground become affected, while the portions under the ballast are sound. The order of decay is the reverse of that of White Oak, Yellow Pine, and Hemlock, and the body of the ties lasts longest when fully imbedded in the ballast.

Chestnut is a soft wood, and in ties which have been removed from the track after four to six years' service, on account of cutting under the rails and injuries from spiking, the ends and centers are found so sound that the opinion has been quite general that Chestnut ties do not decay under ordinary service, but that the failure is due to the mechanical destruction of the wood-layers under the rails. After having the opportunity during the past two years of examining many thousand Chestnut ties, removed from the tracks, I find this opinion needs important modification. Cut out a section of a tie which has had four years of service under fair traffic, and incipient decay is found to have commenced in all of the layers which have been loosened, except three or four under and next to the rail, as here the air dries the wood too rapidly for fermentation to be set up at once; but the fermentation which takes place under these layers soon renders the fibers soft and brittle and capable of furnishing but little support to the rails. It is a well-known fact that the rapidity of abrasion increases with the age of service, which would be expected after an investigation. Could we find ties where the injury to the wood-fibers from the spiking did not show, the affected spot would be V-shaped, the included angle being larger for a broad- than for a narrow-faced tie. This effect can be noticed in Figure 1 (page 61), though that of the spike is included on one side, the dark portion representing the injury. In Fig. 2 the injury is shown extending from the spike along the fibers. In Chestnut ties the spikes soon discolor the wood in immediate contact, and after this has taken place fermentation is more easily set up in the discolored wood than in the uncolored portions. The injury to ties of this wood by the spikes is twofold, mechanical and chemical, both favoring decay around the spikes and under the rails. Boring holes for the spikes would add to the durability of Chestnut ties, and without much detriment to the adhesion of the spikes after two or three years of service.

Under traffic as heavy as that of the Boston and Albany Railroad, the Chestnut tie generally fails by the rails cutting into the face; but, excepting at the entrance of the great yards, this does not occur to a marked extent until the fermentation mentioned has taken place around the spikes and under the rails.

When the rings of wood are in a tangential position to the rails they separate by the breaking of the tracheids to a depth of from one to three inches. Those rings which are cut through and present their edges to the surface, separate and become filled with sand, which is crushed into the wood by the passing of trains, and the sand will be found between the third and fourth layers under the rails. In such cases the fibers are between " the upper and nether mill-stone," and are abraded very rapidly, reciprocal action or abrasion also taking place at the base of the rails.

The decay of Chestnut ties is usually very slow, and on ties affected before they are placed in the road-bed the decay is generally upward.

Preserving Chestnut ties.—But few experiments have been made in preserving this wood for ties, on account of its natural durability. Those experiments made with corrosive sublimate hardened the fiber and increased the wearing capacity.

FUNGI.

The fungi which I have found on Chestnut ties in the New England States are as follows:

Polyporus versicolor, Fr.; very common on posts also.
Polyporus hirsutus, Fr.
Polyporus pergamenus, Fr.; on ties with the bark on.
Polyporus sulphureus, Fr.; without doubt very common.
Polyporus spumeus, (?) Fr.; on ties removed from the track.
Agaricus Americana, Pk.
Agaricus sublateritius, Fr.; very common.

WHITE CEDAR, *Chamæcyparis sphæroidea*, Spach. No. 329.

This tree is found from " Southern Maine, near the coast, to Northern Florida, and along the Gulf Coast to the valley of the Pearl River, Mississippi," * reaching a height of 75 to 80 feet, and sometimes with a trunk 3 feet in diameter, generally growing " in deep, cold swamps." *

In the New England States this tree is a very slow grower, in the majority of cases, the annual layers ranging from 1-32 to 1-16 of an inch; some exceed this width, but in several ties measured they did not ex-

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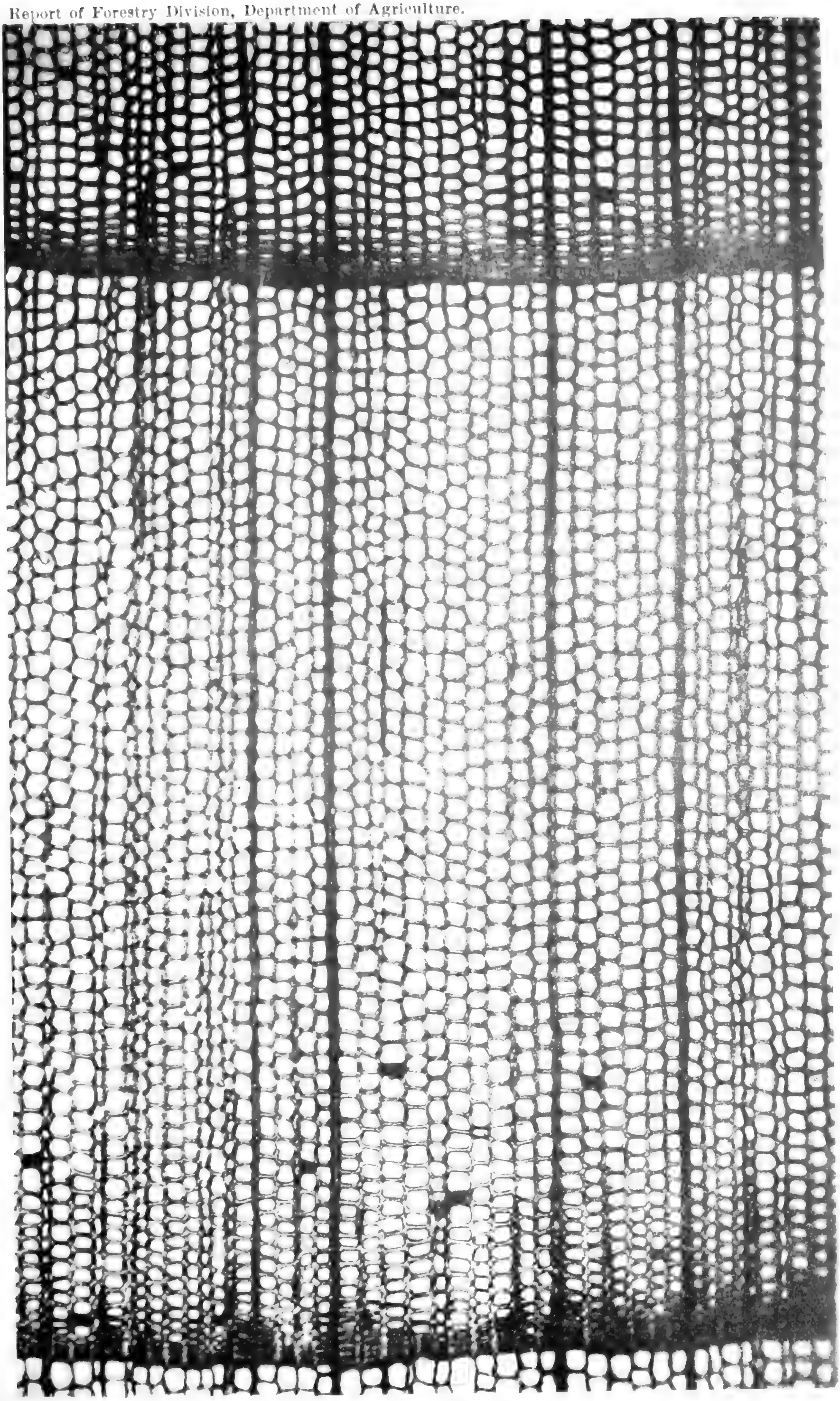
* C. S. Sargent, Vol. IX., Census Report, 1880.

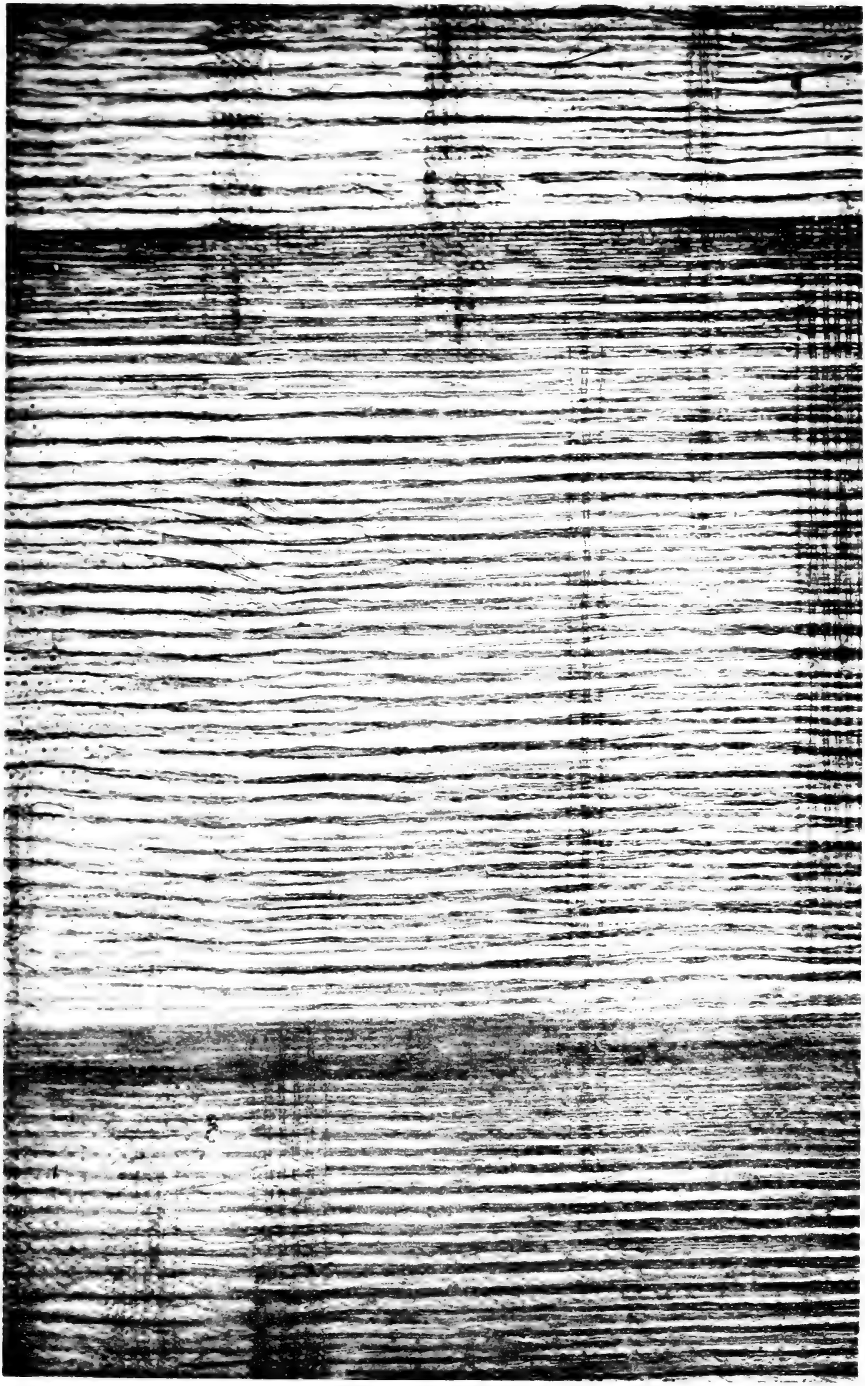


Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

329. Chamaecyparis Sphaeroidea, Spach.; White Cedar.

Transverse Section x 100 Diameters.



Photomicrograph by P. H. Dudley.

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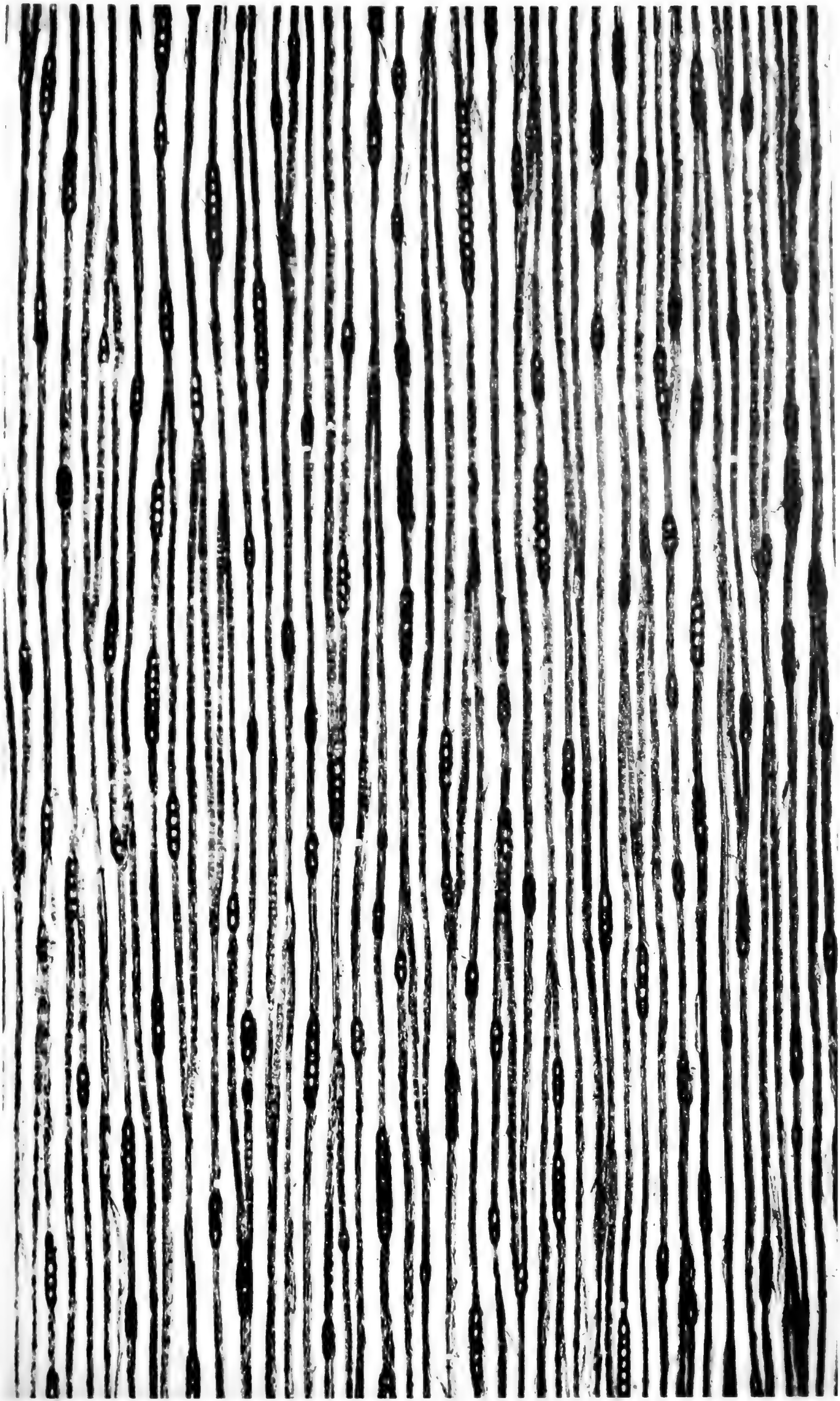
329. CHAMAECYPARIS SPHAEROIDEA, SPACH.; WHITE CEDAR.

Radial Section x 100 Diameters.



Photomicrograph by P. H. Dudley. Bell Bros., Washington, D. C.

329. CHAMAECYPARIS SPHÆROIDEA, SPACH.; WHITE CEDAR.

Tangential Section x 100 Diameters.

ceed 1-32 of an inch 2 inches from the center. The wood is very light, weighing only from 19 to 22 pounds per cubic foot.*

In the photomicrograph of the transverse section the cells are seen to be of nearly one size throughout the entire layer, being only slightly compressed in the fifth to the tenth row of cells of the latest growth in each ring. The walls of the tracheids are of nearly uniform thickness throughout the ring. In this wood there are no resin-ducts; there are, however, special resin-cells represented by a few black rectangular spots near the outer portion of each ring. This feature is common to all the cedars I have examined, and also to the Sequoias. The diameter of the tracheids is the smallest of any of the Conifers under consideration, being only 0.0013 to 0.0015 of an inch, the lumen ranging from 0.0011 to 0.0013 of an inch. The medullary rays are very delicate, and in this view hardly show a trace of an opening.

The radial section was taken from a specimen of narrower layers than those of the transverse section. The longitudinally arranged cells of the tree are represented horizontally on the page. The lenticular markings are very small and close together, especially near the ends of the cells. The chain-like appearance of the small resin-cells shows for a short distance in the lower annual layer. The cells of the medullary rays, which are not abundant, run down the page, and, being very small and generally filled with resinous products, are not easily affected by fungi. The great delicacy of the medullary system is seen in the tangential section; it is found to be composed of only single rows of cells, which are superimposed one above the other. Often but a single cell is found, yet bundles of two, three, or four cells are very common; those of six are interspersed at great intervals in this section, and now and then a larger bundle occurs. I have found the medullary system to be very delicate in all the cedars, which, in addition to the presence often of resinous matter, perhaps in a measure accounts for the slow lateral spread of the spots of decay in this wood.

The impression made on one who for the first time sees ties of this wood, now being received by the railroad companies, would not be as favorable as that in the case of those who have had a large experience in their use. Out of many thousands which I saw just received by railroad companies this spring, not 10 per cent. were perfectly sound: yet, when put in the ground, they will last from eight to ten years.

Some ties would have a decayed center, while others would have only five to ten small spots; but as long as there was sufficient room for spiking the ties were considered good, as they decay in the ground so slowly that their mechanical destruction under the traffic is accomplished before they are completely rotted.

From its great durability this wood is well adapted for railroads of moderate passenger and freight traffic. The ties with a 7- to 8 inch face, 7 inches thick and 8 feet long, have this spring cost from 30 to 35 cents, while Chestnut ties of the same size cost 55 to 65 cents in the vicinity of

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* See Table II., Specific Gravity, p. 53.

Boston, Mass. The sap-wood on the ties is only one-half to three-quarters of an inch thick, and quite generally the former. Sixteen or seventeen of these ties are put under a rail 30 feet long. It is the softest and lightest of all the woods considered in this report, but it is found to be most durable in service, and, because of its small medullary rays, when in the ground does not absorb proportionately as much water into its wood-cells as the Hemlock or Chestnut, and after three or four years' service is not cut into as rapidly as are the two latter kinds of ties. The logs of this wood which have been buried in the swamps of New Jersey for hundreds of years, when cut, rise and float, showing that they are not "water-logged."

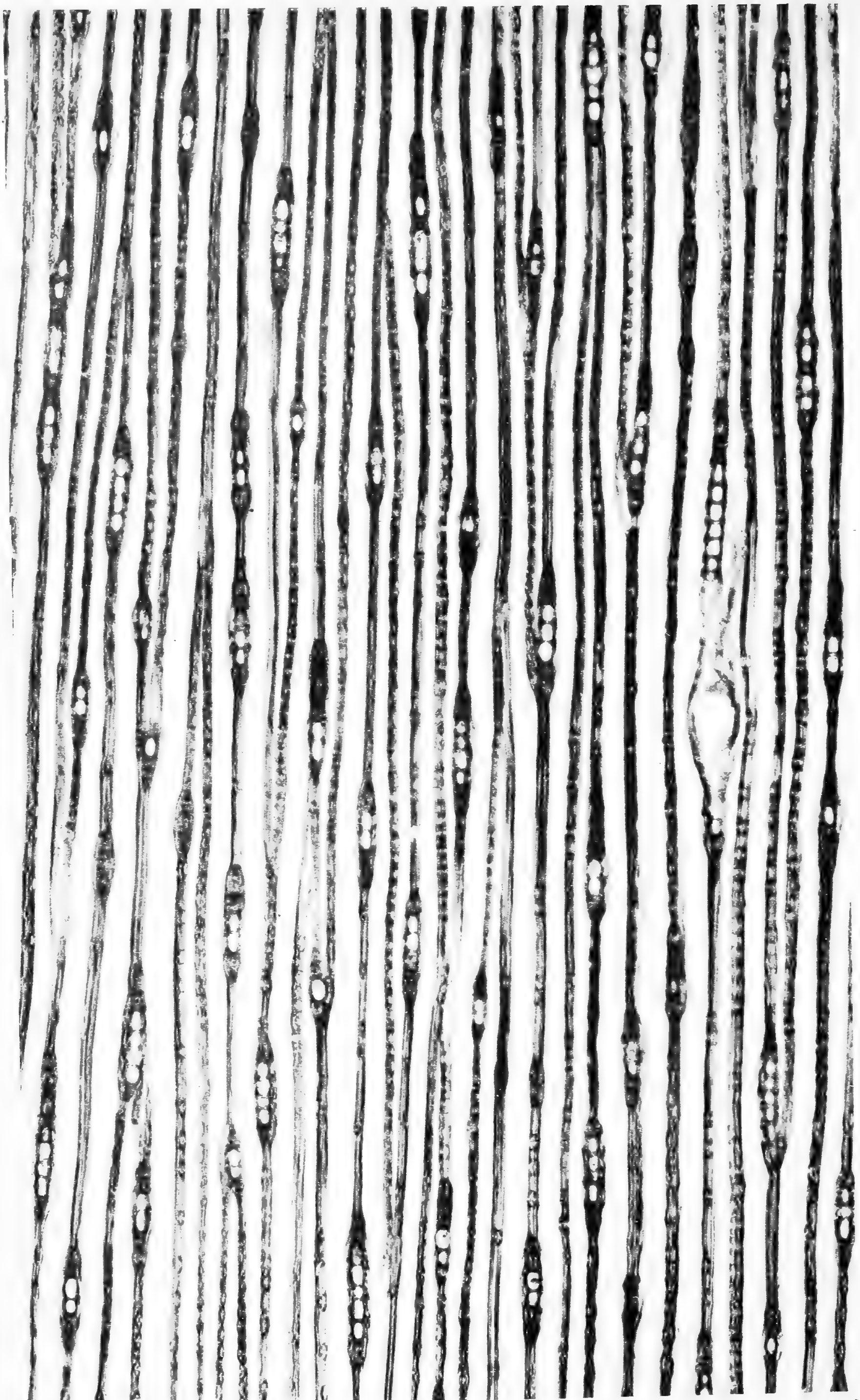
This tree has an abundance of small limbs which shoot out near the ground and do not die until the limbs and foliage above them shut out the necessary supply of light for growth; then they become dry, but do not decay rapidly; when they break off it is close to the trunk, the wound being healed over at once, as in many other trees; but it requires from ten to thirty years to close over the projecting stub.

In many cases spores of higher fungi (*Hymenomycetes*) and the *sporidia* of some species of the *Sphæriacei* find lodgment on the bark of the broken limbs, and finally a growth is extended to the heart-wood. But on account of limited supply of air the decay thus set up is very slow, and it follows up and down the wood-cells, spreading laterally very little. Thus the decayed tissue may extend considerable distance in the timber and yet not exceeding one-half or an inch in diameter. If the wound finally becomes closed and the air supply cut off, all fungous growth is checked, if not fully arrested.

Durability.—On account of its softness and natural durability, this wood has not been treated to any extent to preserve it for ties. The spikes do not hold in it as well as in some of the harder woods, yet it is very valuable for the above-mentioned traffic, and its use is on the increase. The rings do not separate as freely as those of the Yellow Pine, and the cutting down of the fibers is due largely to abrasion; the spikes draw, and from the looseness of the rails, together with the sand and grit between them and the ties, the fibers are crushed by the passing of every train. Could the rails be kept tightly spiked, the cutting would not proceed so rapidly. For a trunk-line freight traffic the White Cedar tie is too soft for the present 65-pound rail with only a 4¼- to 4½-inch base. In order to save the Chestnut ties for their curves, roads of light traffic are now commencing to replace these on their tangents with Cedar.

FUNGI.

The species of fungi that attack this wood are but little known. In searching for them on the Boston and Maine Railroad, from Boston to Portland, I found specimens in fruit of only *Agaricus campanella*, Batsch, which has a tawny pubescence at the base. *Agaricus melleus* Vahl., has been said to attack this wood, but I have never been able to find it either on the prostrate trunks or on the ties.

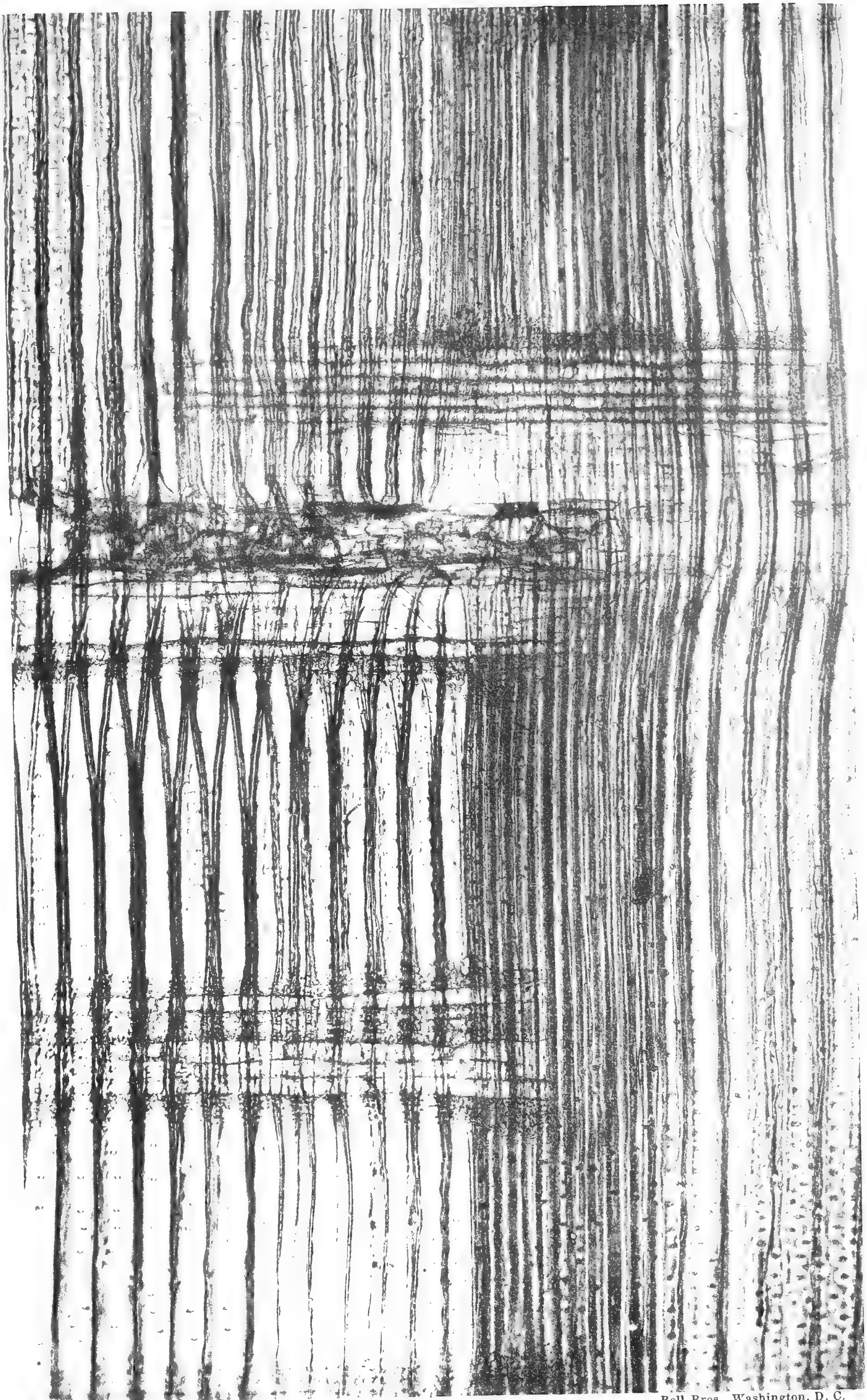


Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

380. PINUS PALUSTRIS, MILLER; LONGLEAF PINE.

Tangential Section x 100 Diameters.

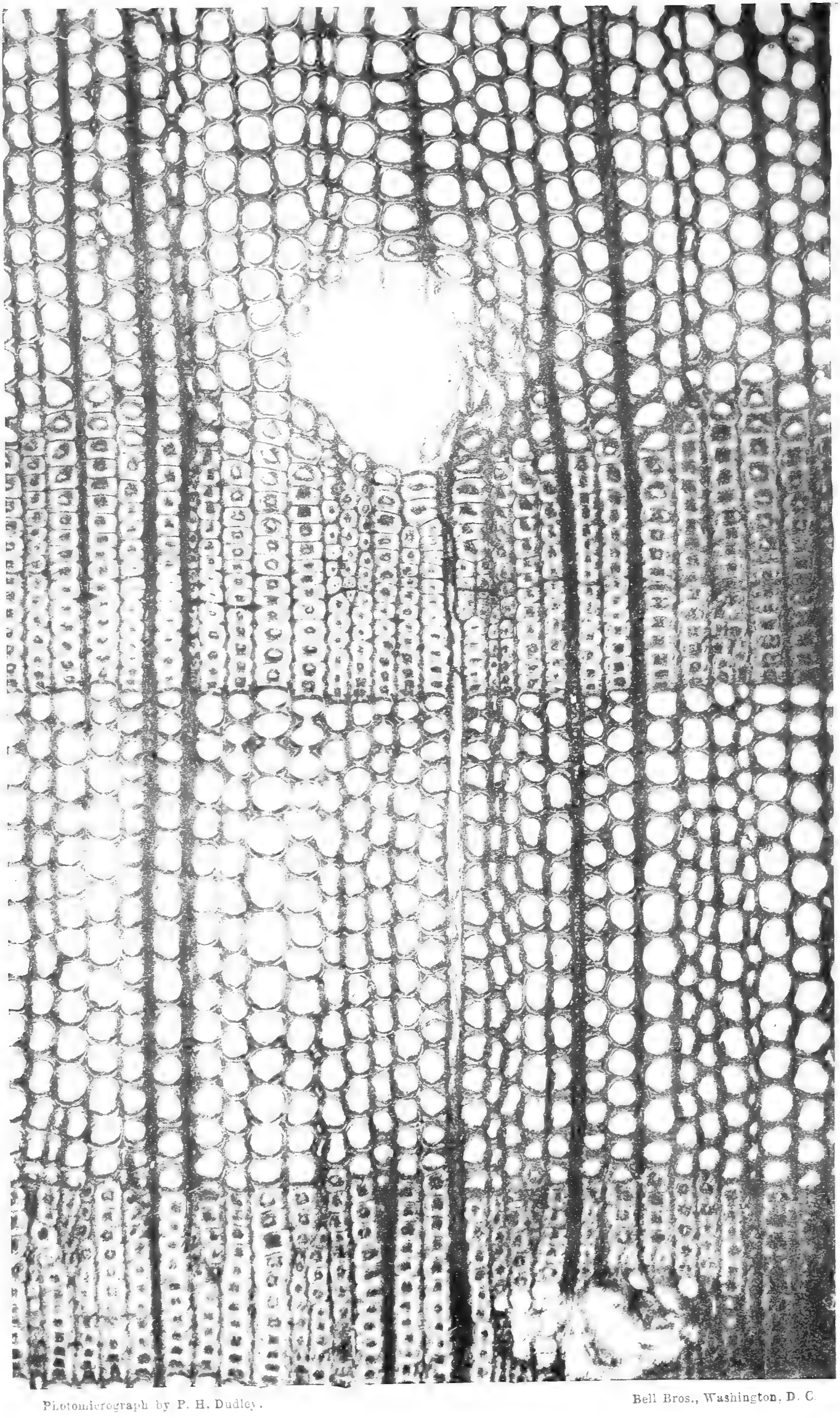


Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

380. Pinus Palustris, Miller; Longleaf Pine.

Radial Section x 100 Diameters.



Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

380. Pinus Palustris, Miller; Longleaf Pine.

Transverse Section x 100 Diameters.

LONG-LEAVED OR YELLOW PINE, *Pinus palustris*, Mill. No. 380.

The striking appearance of the structure of this wood, as seen in the transverse section, consists in the strongly marked zones of different cells in each layer of growth. At the present time satisfactory distinctive names have not been given to these two classes of wood-cells or tracheids. I shall use the term thin- and thick-walled tracheids to distinguish them. The former grow in the first part of the season, and the latter during the summer; but the line of demarkation between them is sharp, not being a gradual merging as in most of the other Conifers. In some trees, each layer is made up of about equal portions of the thin- and thick-walled tracheids, though these layers may vary in thickness from one-thirty-second to one-fourth of an inch; in other trees, the layer of thin-walled tracheids is the thickest, and, as a rule, such wood is of less specific gravity than that with thicker layers. The size of the wood-cells in different individuals is not the same, and this feature also affects the specific gravity.

In selecting a piece from which to make an illustration to show an entire annual ring, we are obliged to take one of less than medium thickness in order to get it on the page. In a luxuriant growth a larger one might be selected which would show only one class of tracheids. Measurements from these photomicrographs will give average results for this wood. The largest of these walls measures .003 by .0025 of an inch, with a lumen of .0025 by .002 of an inch; the thick ones are .002 by .001 of an inch, with a lumen of .0006 by .0004. Many rows of cells of the same size are seen running parallel to the medullary rays, usually single, sometimes double, but rarely in threes.

The thick-walled tracheids are nearly quadrangular, and some of them tabular, and the same number of concentric rows occupy only about one-half as much in width of the ring as would the same number of rows of thin-walled tracheids; the former give the hardness and great elasticity to the wood. It has been generally stated that the thick-walled tracheids contain the most of the resinous matter; this applies only to the volume, as by weight I found that practically they contain equal amounts. The large openings which inclose the tissue of the resin canals are prominent features in the transverse section of this wood. Smaller canals occur in the medullary rays, and if they were wider they could be readily traced in the illustration; one appears in this photomicrograph. The two systems of resin-canals are connected.

The heavier lines of cells running up and down the page are the medullary rays with their canals; and, though numerous, the cells are not strong, the annual rings of wood being quite easily separated from each other when under severe service, or in the sun. Thick layers can be readily separated with a knife, from sections one-half to three fourths of an inch in width. The separation of the thick- from the thin-walled tracheids in the same layer is far more difficult, the latter breaking off in short sections.

The lenticular markings on the tracheids are more abundant near the ends of the cells than in the center, and the appearance of swellings on the walls of the smaller cells, parallel to the medullary plates, is due to the cross-section of the lenticular markings.

The walls of each cell are composed of three layers—an inner one, quite thin and surrounding the lumen; then a thick one, and, lastly, a thinner one, which is so delicate that between the adjacent cells it appears as one wall; but, in some woods, is known to consist of two different layers for each cell and is believed to be so in all; its division can be seen in the transverse section of the Tamarack.*

In the radial section the longitudinally arranged cells are seen with their lenticular markings. It is generally stated that in the duramen the lamella between the domes of each one of these markings becomes broken, so that there is a free communication between the cells; this is not the case: the delicate membrane is pushed over to one side in the direction of the exit of the sap, and may be found by the highest grade of objectives. When it is covered with resinous products the passage of heavy fluids is much impeded and this is one of the reasons why, without special treatment, it is so difficult to secure the penetration of preserving fluids in this wood. These cells can be filled with any antiseptic (creosote combined with an oil, etc.), but it is a question of time, heat, and vacuum.

The walls of the more open or larger cells are seen to be some distance apart; the white space shows their cavities, with the lenticular markings appearing in the background as it were, or in this class of tracheids in plains parallel to those of the medullary rays. The dark upright bands shown in the photomicrograph represent the thick walled tracheids. The lenticular markings in these are generally on the walls which lie in planes at right angles to those of the medullary rays and are much smaller in diameter. The lines crossing the page represent the medullary rays, the upper one showing a resin-duct in longitudinal section, the cells of which are very delicate. The marginal cells of the medullary rays are decidedly irregular, and are more or less serrated; the center rays have two to four thin places opposite each cavity of the tracheids; but in the transverse section, where the latter are in contact with the medullary rays, it can be seen that the inner and next lamella are not continuous; the same feature occurs in the White Pine.

In the tangential section are seen the openings of the medullary rays, which, except those inclosing the resin canals, are of single rows of cells, one to eight being superimposed one above the other in the bundles; the marginal cells are the darker spots above and below the central portion of each bundle. In these sections the lenticular markings are seen to be very abundant on the cell-walls. The interlacing of the tracheids is also well shown. On the right is seen an opening of a resin-canal in the medullary system. In the duramen the medullary cells are more or less filled with resinous products, which makes it difficult to force fluids through these rays into the central portion of the stick; and in the ground, too, the moisture penetrates longitudinally much

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* See transverse section *Larix Americana*, p. 51.

faster than in an opposite direction through the medullary rays. As before stated, the cells of the medullary rays are not strong; in all cases spiking the ties separates each layer longitudinally from three-fourths to one inch on each side of the spike, and in many ties the checks extend much farther.

DURABILITY AND FUNGI.

Ordinary specimens of Yellow Pine contain from eighteen to twenty per cent. of resinous matter, which is supposed to add much to the durability of the wood. But this does not seem to be the case when the wood is put in the ground, or in the road-bed as ties. In such situations it is rapidly destroyed by the fungus *Lentinus lepideus*, Fr., an Agaric. I have found this so general over a great extent of territory that I am inclined to think it is a fungus peculiar to the heart-wood of this timber, especially when the latter is in exposed situations. I have found *Trametes pini*, Fr., on dock-timbers a few times, but more often on ties. The mycelium of the latter is yellowish, a color that distinguishes it from the clear white mycelium of the former fungus. Long-continued warmth and moisture facilitates the growth of the mycelium of *Lentinus lepideus*, and, consequently, rapid destruction of the wood. I have samples of Yellow Pine ties from the Panama Railway which were rotted in two years, while in the Southern States they last from four to six years; in the Middle States, from five to eight years. Formerly the first Yellow Pine ties used on the New York railways lasted from ten to fourteen years. The reason given why the present ties do not last longer is that they are now made from timber of "tapped" trees. This, however, is not the sole reason, especially in road-beds where Yellow Pine ties were formerly used, and where the mycelium of its injurious fungus remains from former decayed ties in the road-bed and is ready to attack the new summer-laid ties. The rational procedure from these observations would be, to replace the unsound ties by such of another wood as are not affected by the same fungus.

When the Yellow Pine wood can be kept comparatively dry, it is very durable; this is shown by the ties not decaying quickly where the upper surface remains dry, but still does not always indicate what has taken place on the inside or underneath. Upon raising the track, many unsound ties are found, which on the surface did not indicate the presence of decay. In the vicinity of Albany, N. Y., Yellow Pine ties in cinder ballast (from locomotives) are rotted by their specific fungus much faster than they are in gravel ballast. As before stated, the layers of wood are checked in driving the spikes, and, moisture thus being admitted, fermentation takes place and the layers separate under the rails, frequently throughout the entire length of the tie. The mycelium of *Lentinus lepideus* often follows the checks, and the decay is thus hastened.

Under severe service it is not uncommon to see the ends of many ties of this wood split and crushed, offering but little support to the rails, with the spikes loose. The fermentation, which precedes the growth of the fungus mentioned, softens the thin-walled tracheids first; then often larvæ, from one-sixteenth to one-eighth of an inch in length, bore through and through the softened cells, while the harder tissues are left undestroyed until the decay is farther advanced; and thus what seems to be a sound tie from above, is but a series of shells. *Sphæria pilifera* (Fr.) grows in great abundance on the sap-wood of Yellow Pine, discoloring the wood with its dark threads. The abundance of the *perithecia** of this fungus on sawed lumber gives the surface a dark moldy appearance; drying, however, checks the growth, but it is again set up as soon as moisture and warmth are present, and, if the timber be still unaffected, these same conditions will be favorable to fermentations and the consequent decomposition of the sap-wood. This is readily noticed in the floors of freight-cars, the sap-wood rotting in one or two years; thus it would seem advisable never to use sap-wood in situations where heat and moisture are liable to occur.

Preservation.—Creosote and other antiseptics can be made to penetrate the heart-wood only quite slowly, so that in many cases the resulting treatment is rather superficial. A recent examination of several thousand cubic feet of timber of this wood, which had been creosoted, showed this to be the case, a superficial exterior protection only. In several places the fungus *Trametes pini* (Fr.) was growing on the wood as though it had not been treated, the mycelium having developed under the superficial coating. In this case the treatment was too short, resulting in a penetration only of one-eighth to three-sixteenths of an inch in depth. I have examined many ties treated with creosote, where the penetration was ample to protect them, showing that the treatment can be such as to thoroughly impregnate them, but it is a matter of time and pressure. I have also examined many of the so-called "vulcanized" ties, which, after three years of service, did not show any decay. It may be, however, that seasoning of the ties of this wood is, on the whole, a matter of first importance to insure longer life.

HEMLOCK, *Tsuga Canadensis*, Carrière. No. 387.

This wood, once very abundant, and still covering a large tract of country, has been extensively used for ties, and will of necessity be substituted for other woods which are now becoming scarce. Professor Sargent,† gives its distribution as follows:

> "Nova Scotia, Southern New Brunswick, valley of the Saint Lawrence River to the shores of Lake Temiscaming, southwest to the western border of Northern Wisconsin; south through the Northern States to New Castle County, Delaware, Southeastern Michigan, Central Wisconsin, and along the Alleghany Mountains to Clear Creek Falls, Winston County, Alabama (Mohr.)."

The photomicrograph of the transverse section indicates that the wood is soft, though harder than that of the White Cedar. The zone of thick-walled tracheids in the outer portion usually forms from one-fifth to one-fourth of the ring; where the two classes of cells join in the

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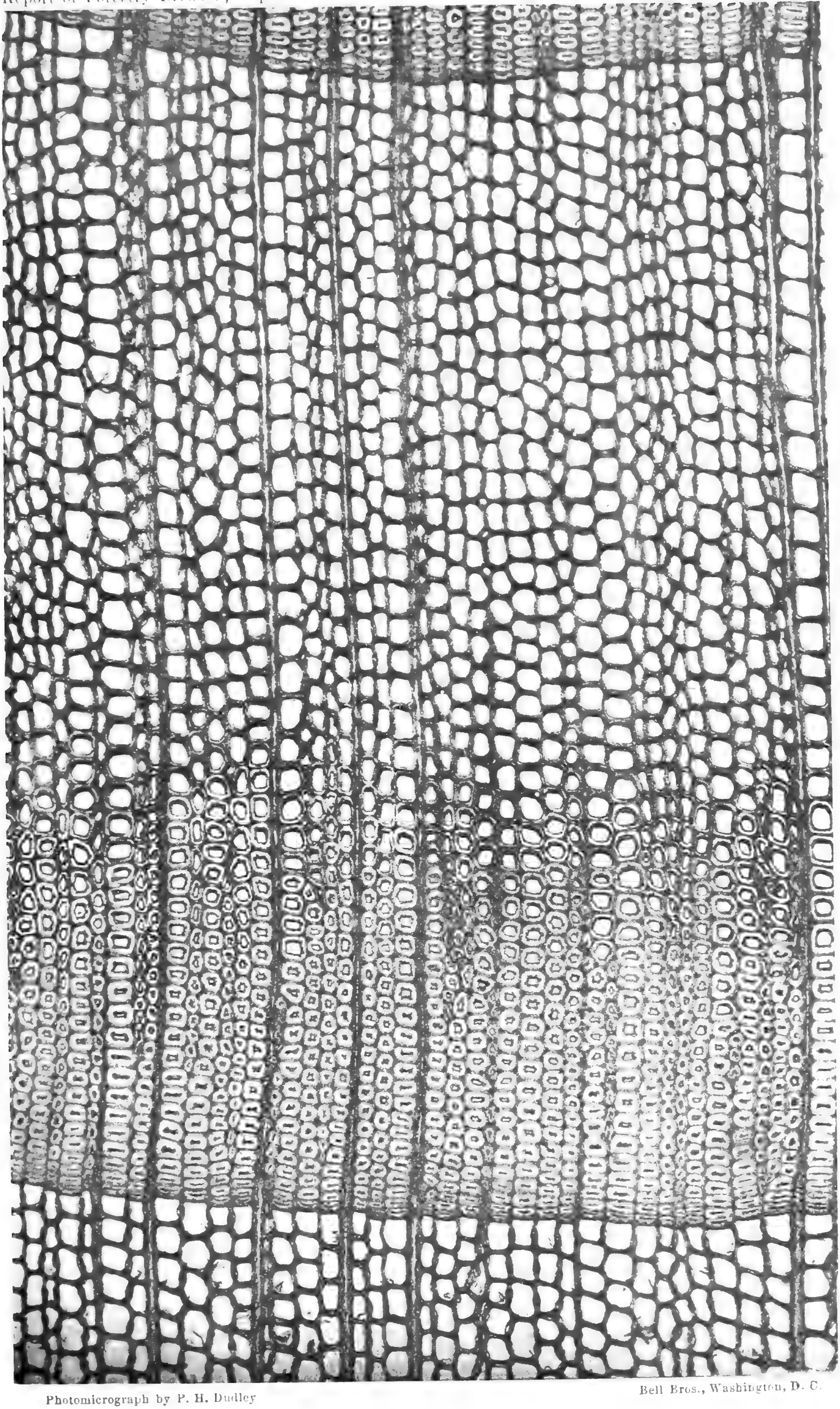
* Beak-like protuberances containing spores.

† "Forest Trees of North America," Vol. IX. of Tenth Census Report, 1880.

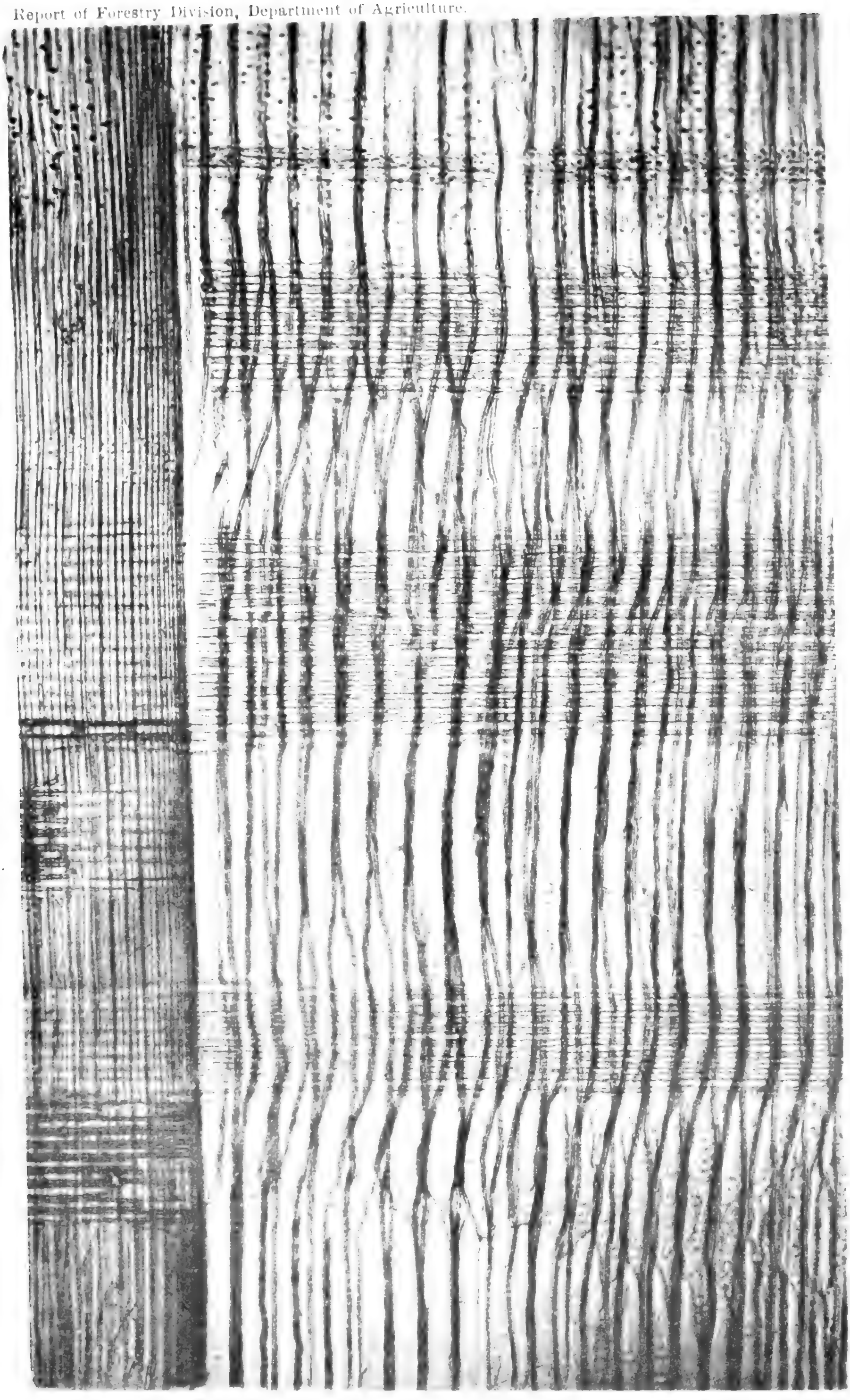


Photomicrograph by P. H. Dudley

Bell Bros., Washington, D. C.

387. TSUGA CANADENSIS, CARR; HEMLOCK.

Transverse Section x 100 Diameters.

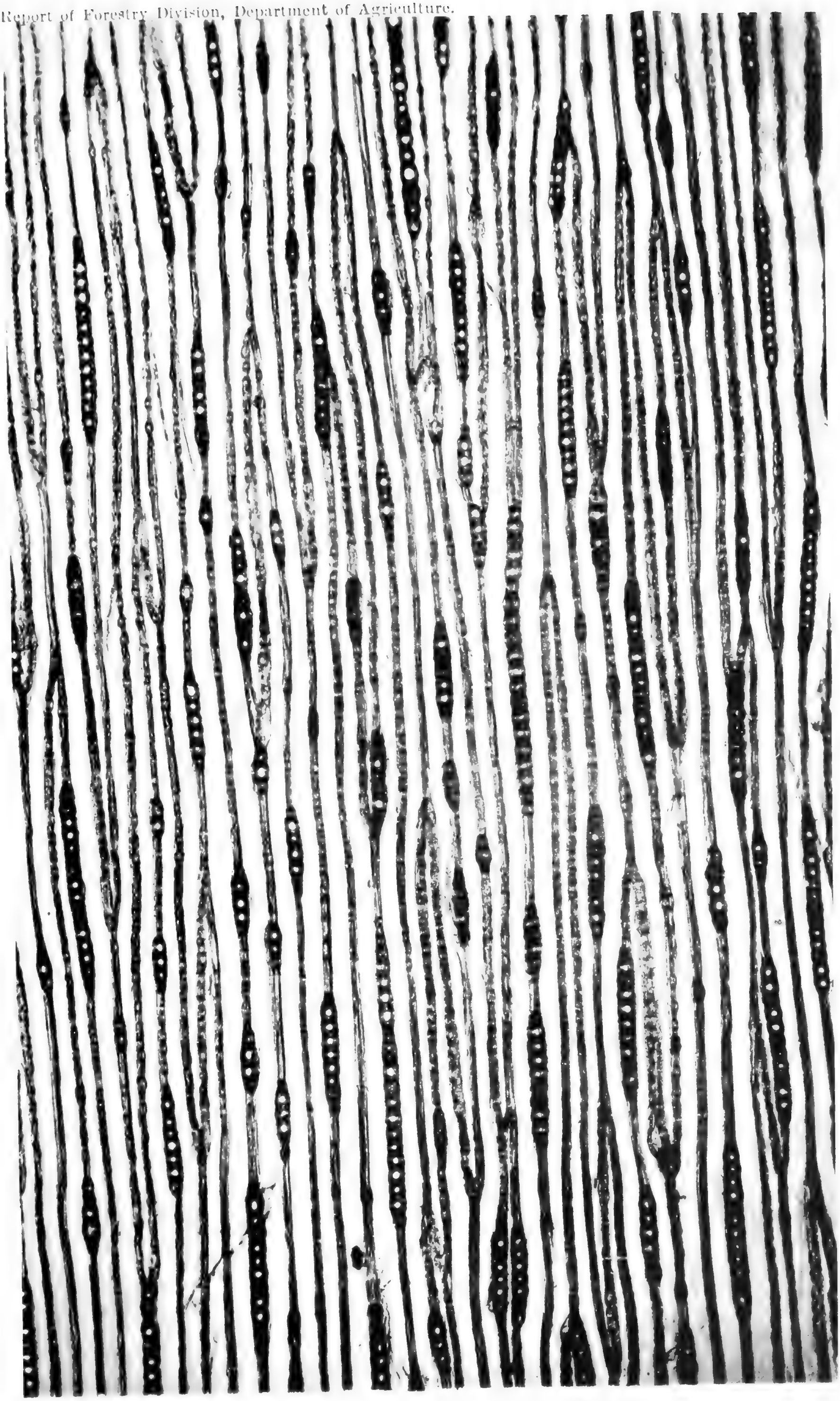


Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

387. TSUGA CANADENSIS, CARR; HEMLOCK.

Radial Section x 100 Diameters.



Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

387. TSUGA CANADENSIS, CARR; HEMLOCK.

Tangential Section x 100 Diameters.

same ring there is a gradual merging and not a sharp line of demarcation, as in the Yellow Pine (*Pinus palustris*) or in the Tamarack (*Larix Americana*). The thick-walled cells in this wood are of a different character from those of the two woods just mentioned; the cells are not as strong, the lumen being proportionately larger. The thin-walled tracheids, though not so large as those of the Yellow Pine, are generally quadrangular, and have the same proportionately large lumen, and the corners of the cells not being thickened they are crushed more easily. Like the thin walled ones of the Yellow Pine, both classes of tracheids are "brash," and in breaking snap off quite short. So far as I have observed, the so-called "Yellow Hemlock" has a greater proportion of thick-walled tracheids in each layer than the "White Hemlock."

The lines running down the page represent the medullary rays, and occur only in lines of cells of single width. The absence of resin-canals in this wood is in marked contrast to the Yellow Pine or Tamarack.

In the White Cedar the dark and apparently solid cells shown in the transverse section are those of the longitudinally-arranged special resin-cells; but none of these have as yet been found in the Hemlock, the resinous matter in this wood being much less abundant than in the other Conifers considered. In the transverse section what appears as small cells are those cut off near their tapering ends, and the swelling of the walls on the side in a plane parallel to that of the medullary rays is due to the cross-section of the lenticular markings; in the radial section these will be seen to be smaller and rounder than those of Yellow Pine or Tamarack, but larger than those of the White Cedar. For a long time it has been the opinion that in the mature cell there is a free opening in the lenticular markings, the middle lamella breaking away. This is not found to be the case when examined with the highest grade of objectives. In the large cells the lamella becomes crowded to the opening of the dome on the side where the sap is making its exit, and must be looked for with great care, while in some of the thick-walled cells it retains its central position and is readily seen. In the radial section the structure of the longitudinally-arranged cells is clearly shown, the harder, dense portion of the ring being seen on the left of the page. The lines running across the page represent the medullary rays. Above the upper row are seen the ends of the tracheids slightly rising as they approach the outer portion of the ring.

In the tangential section the ends of the medullary rays are seen to be in single rows, the cells being superimposed one above the other. In a few instances only a single cell occurs, while in others there are two, three, and as many as twenty. These cells, as seen in the radial section, are short and easily parted, not binding the wood together firmly, as in the White Oak. The lenticular openings are abundant on the cell-walls parallel to the medullary plates.

Durability.—The Hemlock is not a durable wood in contact with the ground, and ties decay in about four years. The structure of the wood readily admits of treatment by antiseptics, but it must be thoroughly done; such a treatment that practically will keep every fiber of the wood dry; or, if not thus protected, the antiseptic must be of sufficient strength to prevent any fermentation from being set up. A portion of the wood left unprotected and put in the ground would still be liable to attacks, and decay would soon follow in other parts. Mere exterior protection is one of the best ways to start internal decay, the so called "dry-rot," as timber does not decay unless moisture is present. We have an abundance of proof that Hemlock ties well treated will last for fifteen or twenty years. I have a piece of Hemlock wood which was "Kyanized" in 1847, and has been in the ground until this year, 1886, and is generally sound. The experience of railroad companies in using treated Hemlock ties is so extended in this country that the efficacy of such a plan no longer admits of doubt as to its practicability or expediency. On the Chicago, Rock Island and Pacific Railroad some "Burnettized" Hemlock and Tamarack ties were put in the road-bed in 1866, and in 1882, after sixteen years of service under heavy traffic near Chicago, about 75 per cent. of them were still in the track, and the rails not cutting into them any more than they would into White Oak ties. Several other roads have had similar results. Since 1881 the Eastern Railroad, of Massachusetts, has "Kyanized" (by a simple bath in a 1-per cent. solution of an antiseptic) many thousand Hemlock ties, at a reported cost of 11 to 12 cents per tie, and they are employing the process at the present time. Treating Hemlock by either of the processes mentioned hardens the fiber of the wood. Effective creosoting preserves the timber, but does not harden the fiber as do other treatments. Charring the exterior of Hemlock, as is done for some woods in France, would be but a partial protection, as fermentation might still take place internally.*

FUNGI.

The fungi that attack this wood are numerous, and the following is a list of those so far observed:

Agaricus meleus, Vahl.
Agaricus campanella, Batsch.
Agaricus porrigens, Pers.
Agaricus succosus, Pk.
Agaricus rugosodiscus, Pk.
Agaricus epipterygius, Scop.
Paxillus atrotomentosus, Fr.
Lenzites sepearia, Fr.
Stereum radiatum, Pk.
Polyporus lucidus, Fr.
Polyporus benzoinus, Fr.
Polyporus epileucus, Fr.
Polyporus Vaillantii, Fr.
Polyporus subacidus, Pk.
Polyporus medullapanis, Fr.
Polyporus pincola, Fr.
Polyporus abietinus, Fr.
Polyporus borealis, Fr.

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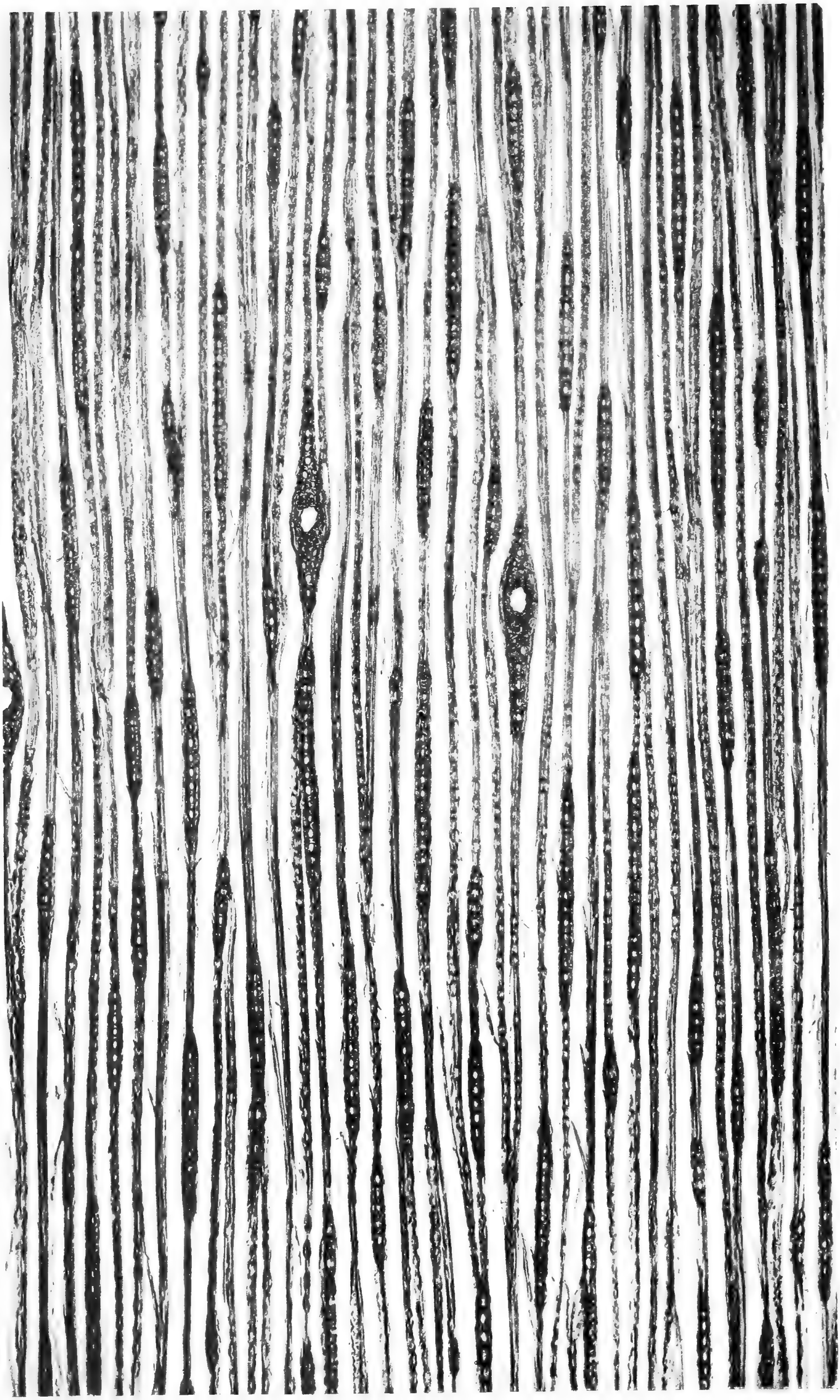
* Since writing the above I have obtained a piece of one of the ties "Kyanized" by the Eastern Railroad Company, put down in 1881 and taken up in the fall of 1886; it is perfectly sound, and, while under very heavy traffic, the wood is not cut into over three-eighths of an inch under the rail.

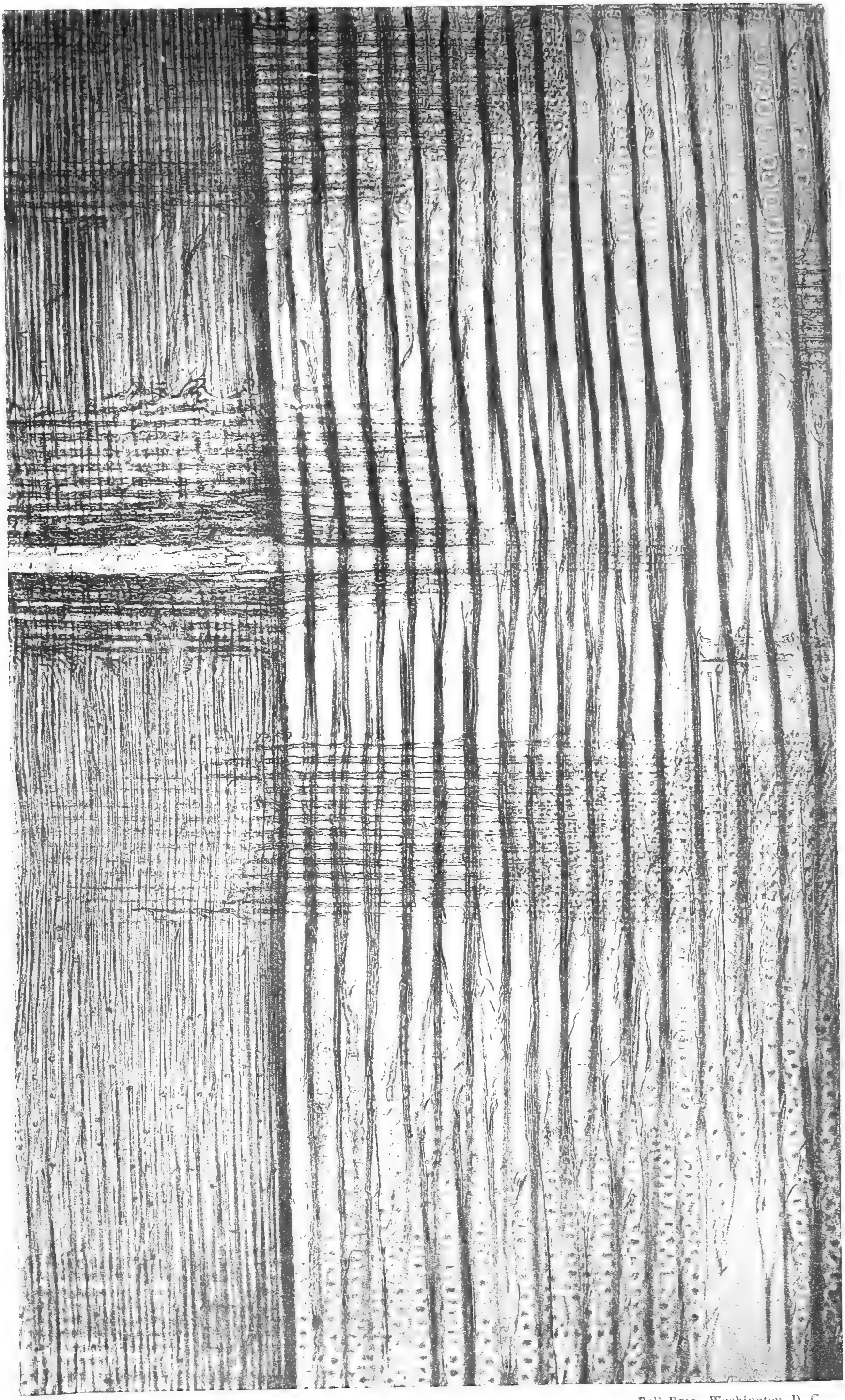


Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

401. Larix Americana, Michaux; Tamarack.

Tangential Section x 100 Diameters.

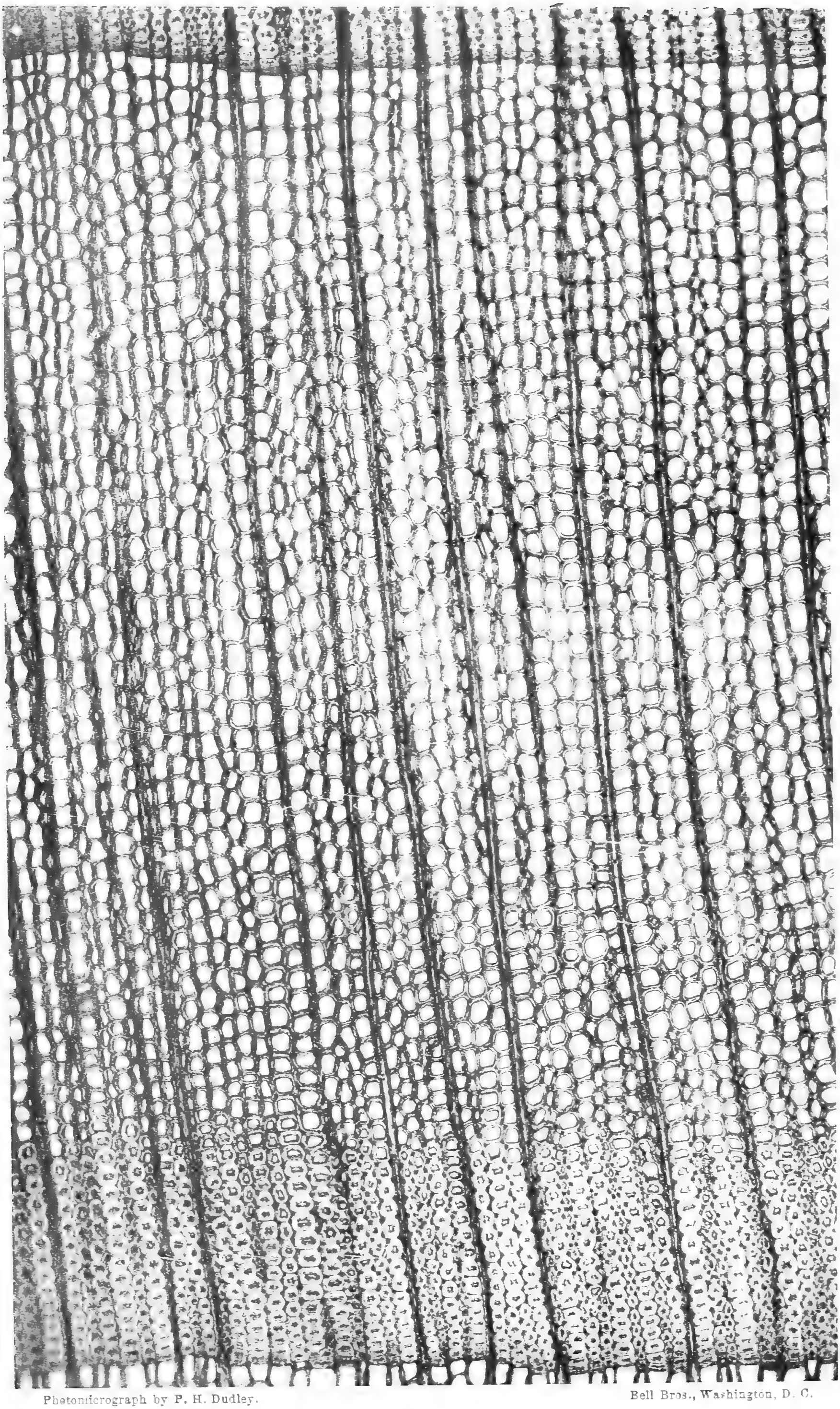


Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

401. LARIX AMERICANA, MICHAUX; TAMARACK.

Radial Section x 100 Diameters.



Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

401. Larix Americana, Michaux; Tamarack.

Transverse Section x 100 Diameters.

TAMARACK, *Larix Americana*, Michx. No. 401.

The photomicrograph of the transverse section shows a zone of hard, dense, nearly solid tracheids, which form from one-sixth to one-third of the annual ring, and, like those of *Pinus palustris*, have a sharp line of demarcation where the two classes join in the ring. These two species of trees attain their greatest development in opposite portions of the country: the Tamarack in the North, and the Yellow Pine in the South. The resin-canals in the former are confined to the zone of thick-walled tracheids, and are usually near the outer portion of the ring. The cells which form the exterior portion of the canal are much thicker and firmer than those in *Pinus palustris*, and the area of the canal is also much less. Generally two canals are in close proximity, but without any apparent connection.

The thin-walled tracheids in different trees vary somewhat in size, ranging from 0.0025 of an inch to 0.002 of an inch in diameter in a radial direction, and from 0.002 to 0.0015 of an inch in a longitudinal direction. The lumen measures from 0.001 of an inch to 0.0013 of an inch, the walls being much thicker than those of some other woods, a feature which gives this wood greater wearing qualities.

In many parts of the transverse section the division between the lamellæ joining the cells can be seen, something that cannot be made out in any of the other Conifers. The medullary rays are quite numerous and of considerable size, showing their cavity quite clearly with this magnifying power. The lenticular markings on the cells are most abundant near the ends, and less frequent in the middle, and the swelling of many of the walls parallel to the medullary rays is due to the cross-section of such markings. This peculiarity of the markings is also seen in the radial section.

In the radial section the lines crossing the page represent the medullary rays, the walls of which are very thick and strong, the thin places in them being very small. In the central ray is seen a longitudinal section of one of the resin-canals of the medullary system. In the tangential section the medullary rays are seen to be cells arranged in single rows, usually from six to eighteen cells superimposed one above the other, except in those rays inclosing a resin-canal. The thickness of the walls is very apparent, and of great importance in preventing decay.

The quality of the wood of this tree is such that it deserves to be more widely known and more extensively used for ties than it has been; yet where its growth is abundant adjacent to their lines, a few railroad companies have employed it for ties. But it was only in a few localities, where the timber was thus situated, that these ties were found recently put in. Each annual ring has a zone of hard, dense tracheids, which render it capable of sustaining the heaviest freight traffic; its durability, too, is another feature of great importance.

Preservation and Fungi.—This wood is easily treated with antiseptics to prevent decay, especially with sulphate or acetate of iron; and ties so treated have lasted over thirty years under heavy traffic. These ties were originally 9 feet long, having been moved under the rails three times, and were destroyed only by continued spiking. The sap-wood did not show evidence of decay exceeding one-eighth of an inch in depth; while the wood within was sound and bright. Untreated Tamarack ties last from five to eight years.

The decay was not uniform; in most cases it was from the outside inward, the sap-wood being destroyed first; in others the decay was from the bottom upward. Unfortunately, however, these observations are somewhat incomplete, as the history of the ties could not be satisfactorily traced.

The fungi which grow on this wood are *Polyporus pinicola*, Fr., and *Polyporus abietinus*, Fr.

WESTERN LARCH, *Larix occidentalis*, Nuttall. No. 402.

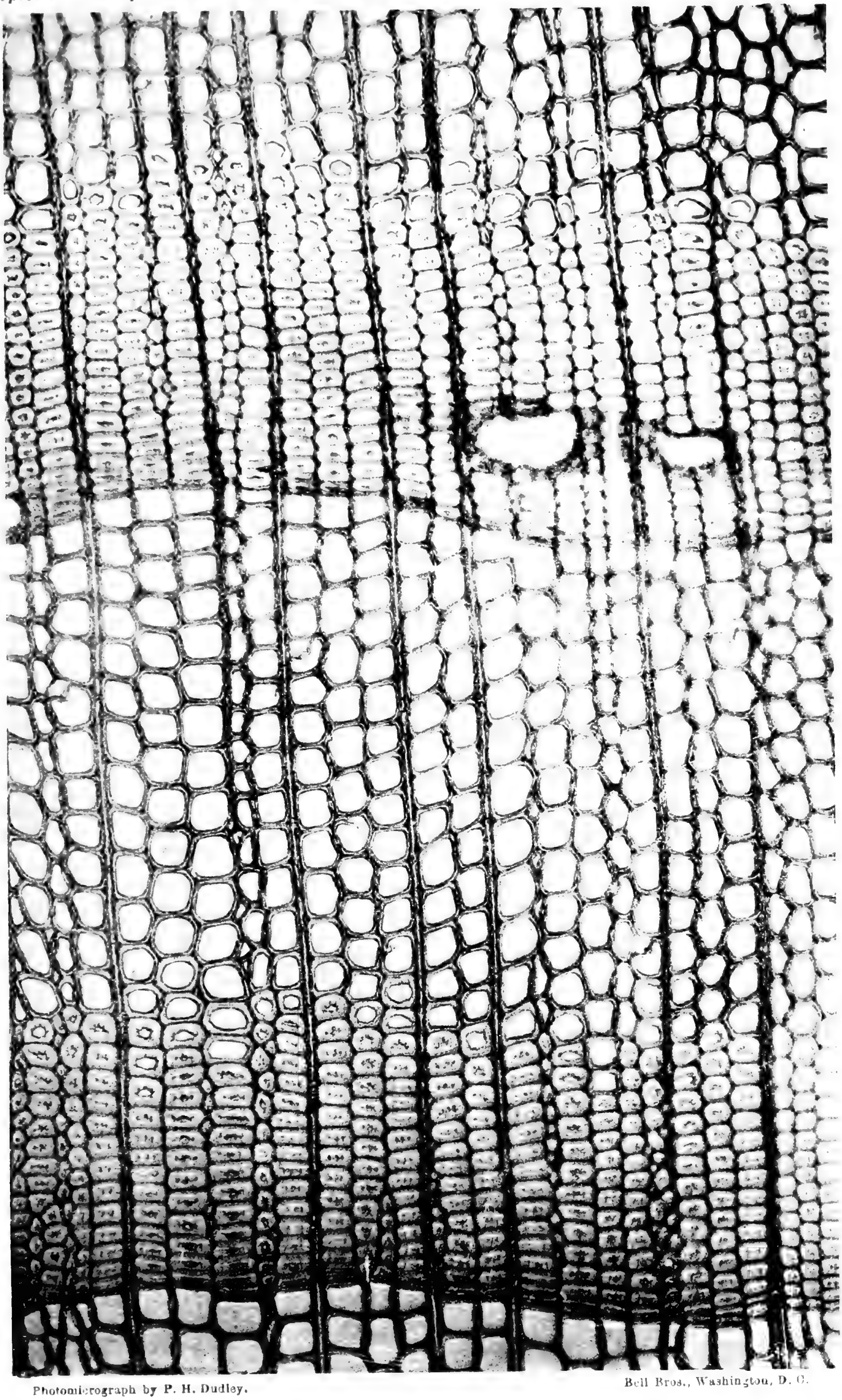
The photomicrograph of the transverse section shows this to be a much harder and more dense wood than that of the preceding species; the thin tracheids are larger and nearly rectangular, the largest of them measuring .0025 of an inch, with a lumen .002 x .002 of an inch, the walls of which are comparatively thick.

The decidedly tabular thick-walled tracheids measure .002 x .0013 of an inch, the lumen being very small, in many cases only a trace of a cavity; and, comparatively speaking, the thick-walled cells comprise a greater number of rows than the thin-walled ones, a feature which gives to this wood increased hardness, strength, and elasticity over the preceding species. The line of demarcation between the two classes of tracheids in the same layer is distinct and sharp.

The number and form of the resin-canals is quite similar to those of the common Tamarack. In the radial section the lenticular markings are not so frequent; generally but one row is found on the side of the thin-walled tracheids, where, in the preceding species, there are commonly two rows. The medullary rays are in broad bands, with a structure almost identical with that of the Tamarack. In the tangential section the medullary rays are in single rows, except when inclosing a resin-canal; but the cells are larger and more conspicuous than in the preceding species.

TABLE I.—*Comparative average number of fibers in a square of wood $\frac{1}{100}$ of an inch on a side, or $\frac{1}{10000}$ of the area of a square inch.*

No.	Woods.	Remarks.
251	White Oak	268 small fibers in the dense masses.
290	Chestnut	150 " " " " " Great variation in different specimens of this wood.
329	White Cedar	110 thick tracheids; 70 thin tracheids.
380	Yellow Pine	60 thick tracheids; 30 thin tracheids.
387	Hemlock	86 thick tracheids; 38 thin tracheids.
401	Tamarack	116 thick tracheids; 33 thin tracheids.
402	Western Larch	54 thick tracheids; 24 thin tracheids.



Photomicrograph by P. H. Dudley.

Bell Bros., Washington, D. C.

Larix Occidentalis; Europæan Larch.

Transverse Section x 100 Diameters.

The above figures would vary, to some extent, for different specimens, but they give an approximate idea of the minuteness of the cellular structure, and are thus very instructive.

TABLE II.—*Specific Gravity.*[*]

No.	Woods.	Minimum.	Maximum.	Average.	Weight per cubic foot.
251	White Oak	0.6006	0.8670	0.7470	46.35
290	Chestnut	0.3829	0.4720	0.4504	28.07
329	White Cedar	0.2990	0.4527	0.3322	20.70
380	Yellow Pine	0.5191	0.9325	0.6999	43.62
387	Hemlock	0.3343	0.5191	0.4239	26.42
401	Tamarack	0.5389	0.7779	0.6236	38.86
402	Western Larch	0.5897	0.8340	0.7407	46.16

TABLE III.—*Chemical Analysis.*

No.	Woods.	Hydrogen.	Carbon.	Oxygen.	Ash.	Specific gravity.
251	White Oak	6.59	50.44	42.73	0.24	0.7635
290	Chestnut	5.75	48.73	41.69	0.83	0.7143
380	Yellow Pine	7.41	58.61	33.72	0.26	0.7414
380	Yellow Pine	7.26	56.19	36.30	0.15	0.8469
380	Yellow Pine	6.70	52.70	40.32	0.28	0.6236
380	Yellow Pine	6.85	52.99	39.88	0.28	0.8988
380	Yellow Pine	6.83	54.78	38.15	0.24	0.8988
380	Yellow Pine, thick tracheids	6.22	49.13	44.65	....	....
380	Yellow Pine, thin tracheids	6.13	49.81	44.06	....	....
387	Hemlock	5.91	52.38	41.23	0.48	0.4097
401	Tamarack	6.03	51.91	41.79	0.24	0.7024

For the analysis of the thin- and thick-walled tracheids the wood was well air-seasoned; they were then separated, each class weighed, and dried at 100° C. The loss of water and volatile hydrocarbons for the thick-walled tracheids was 10.48 per cent., and for the thin-walled, 11.38 per cent. Both were next treated with ether to extract the resinous matter, the thick-walled cells yielding 19.59 per cent., and the thin ones, 20.97 per cent. The tracheids were then burned in oxygen, giving the respective results as previously stated. Contrary to what was hoped, the percentages do not explain or throw much light on the difference in physical properties of the two classes of tracheids.

TABLE IV.—*Longitudinal crushing Strength in Relation to Specific Gravity.*

No.	Woods.	Average of specimens.	Crushing strength per square inch.	Specific gravity.	Ratio.
251	White Oak	8	7,458	0.7516	9,923
290	Chestnut	4	5,804	0.4439	13,075
329	White Cedar	3	3,697	0.3429	10,781
380	Yellow Pine	5	9,081	0.7228	12,564
387	Hemlock	6	5,549	0.4246	13,086
401	Tamarack	4	8,297	0.6197	13,888
402	Western Larch	5	9,991	0.6420	15,560

[*] From Tenth Census Report, Vol. IX., 1880.

Tests upon the crushing strength (tensile and transverse) of different specimens of the same species of wood show that there is a quite constant ratio between each and the specific gravity, thus agreeing with what has been stated as to the presence or absence of certain dense cells in the microscopical structure of the layers. So that one who is skilled, with the aid of a miscroscope, can make a very close estimate of the comparative suitability of different pieces of wood for definite purposes. As a case in point, a railroad company, doing a heavy freight business, being able to buy cedar ties for one-third the cost of oak, for this reason put them down, but only to find that after they had injured one set of rails these ties were too soft for their heavy traffic. A microscopical examination of the timber would have enabled one to predict what the result would be and to save the expensive trial.

Table IV. shows the ratios between the longitudinal crushing strength and the specific gravity of the woods under consideration. The ratios are obtained by dividing the crushing weight per square inch by the specific gravity, which gives a ratio representing the crushing weight of a square inch having a specific gravity of one. The average for White Oak, as given in the table, is 9,923 pounds, which for practical purposes might be called 10,000 pounds. If we compare oak grown south of the fortieth parallel, the result will be 10 per cent. higher.

Having another piece of oak, the specific gravity of which is 0.6578, and wishing to know its approximate crushing weight, we obtain it by multiplying its specific gravity by 10,000, which gives 6,578 pounds. The same method applies to other woods.

Comparing one wood with another, taking White Oak as unity, the comparative crushing strength of Chestnut is 1.3 per unit of specific gravity; White Cedar, 1.07; Yellow Pine, 1.25; Hemlock, 1.3; Western Larch, 1.55; Tamarack, 1.38. The crushing strength given in the table is for blocks eight diameters in length. For larger ones the strength would be less. In using them a factor of safety must be adopted most suitable for the work. The table gives data which, to a great extent, can be used to determine the proper size of columns of one wood to be substituted for another, by giving the proper dimensions and retaining approximately the same factor of safety, a matter which has been neglected in too many cases.

TABLE V.—*Resistance to Indentation.**

[Pressure in pounds per square inch for indentations of one twenty-fifth of inch.]

No.	Woods.	Pressure.
251	White Oak	2,974
290	Chestnut	1,446
329	White Cedar	878
380	Yellow Pine	2,637
387	Hemlock	1,359
401	Tamarack	1,265
402	Western Larch	2,271

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*From the Tenth Census Report, Vol. IX., 1880.

These tests were made upon small pieces of wood, about 1½ inches in width. It is difficult to combine them so as to represent the proper relations of the layers of wood in a tie. These tests were also made upon dry wood. Made upon actual ties, containing the same percentage of moisture as those in the ballast, the results would be modified; Chestnut would not show so high, and Cedar would be reduced but little; Hemlock would be lower, as also the Yellow Pine; and after three years' decay the results would be still further modified. The Hemlock would show marked depreciation, also the Yellow Pine; the Cedar would be quite uniform, while the Oak and Chestnut would show some reduction.

Experience shows that, with the exception of White Cedar, if the fibers can be protected from becoming softened, they are sufficiently hard to sustain from twice to three times as much traffic as they do when untreated.

Length and size of ties.—For a 4-foot 8½-inch guage the majority of railroads use a tie 8 feet long; some 8½ feet long, and a few 9 feet.

Specifications call for a 6-, 7-, and 8-inch face for the flatted ties; and some roads call for joint-ties with a 10-inch face. In depth the dimensions vary from 6 to 7 inches. The Chestnut ties now being bought are required to be 7 inches deep. A few roads use Cedar ties only 6 inches deep, but most of the recent ones are 7 inches. With Chestnut and Cedar ties this is perhaps advisable, but with other woods, owing to the manner of decay, it is doubtful whether anything is gained.

Most of the Yellow Pine ties which reach the North are rectangular and uniform in size. The New York Central and Hudson River Railroad Company use a tie 9½ by 6½ inches and 8 feet long; sixteen of these are put under a 30-foot rail, making the space between each one narrow for tamping such deep ties, and requiring more time and care to do the work. But of course the track remains very firm after it is put up.

RECAPITULATION.

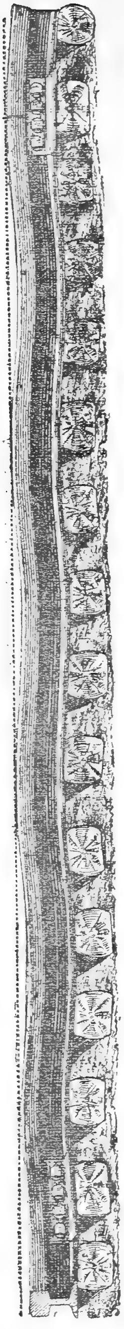
Destruction of ties.—Railroad ties in service are injured, destroyed, and rendered unserviceable by three principal causes:

(1) Mechanical disintegration of the layers, and the abrasion of the fibers under the rails.

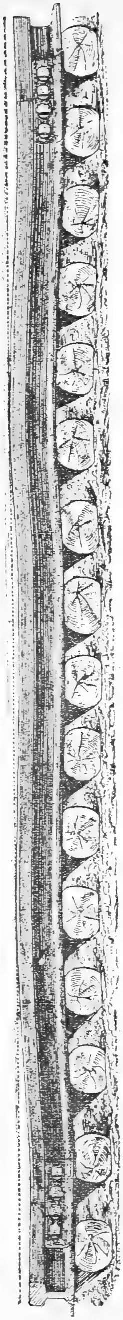
(2) Injury to the wood by spiking and respiking.

(3) General decay of the wood, induced by fungi.

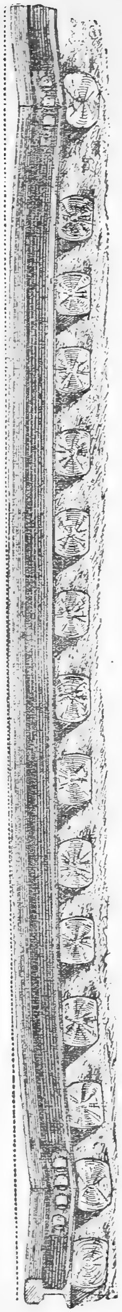
In regard to the first cause, extensive examinations show that there is more or less up-and-down movement of the rails under all passing trains. This is true to some extent of tracks laid with even the heaviest and stiffest rails that are used at the present time, but the undulation of such tracks is greatly reduced.



No. 1. Represents the long waves which are found to take place, more or less, in the best surfaced tracks under the weight of the cars; the deflections are only from $\frac{1}{8}$ to $\frac{3}{16}$ of an inch, the rails returning quite to surface upon passage of the cars.



No. 2. Represents the first form of permanent set in rails, low at the joints and center and high at the quarters.



No. 3. Represents the second form of permanent set in rails, low at the joints and high in the center.

Figure 1 is intended to represent the general appearance of the undulations in the surface of the rails as they take place under the wheels of passing trains. The lighter the rail and lower the standard of track maintained, the greater these undulations become. After they have taken place, and have been allowed to continue, the rails soon acquire a permanent set, and are found to be like those represented in No. 2. If the labor is inadequate to maintain the track under the service, the rails soon take the form shown in No. 3, which will be recognized as being a common type of a permanent set in rails, though rapidly disappearing in the best maintained tracks.

In both the latter forms the rails will be found loose on the ties under the spikes, and are pressed down by every pair of wheels that passes them. The ties not only have to sustain the load upon the wheels, but also to receive the dynamic shock of the falling rail and load; and, as a consequence, there is a very rapid abrasion of the ties and a chafing-out of the throat of the spikes. The softer the wood the faster will be the cutting.

The inspection of thousands of miles of railroad track each year has given me excellent opportunities of studying this phase of tie-destruction. The sections of many of the steel rails which are in the tracks are too light for the present traffic, and must soon be worn out, and the ties are cut down with great rapidity. The section of our rails are being made heavier, but not as much with reference to stiffness as is desirable. So far as I know, the stiffest section in proportion to the weight of any rail yet used, is the 80-pound section, designed and now used by the New York Central and Hudson River Railroad Company, and under heavy traffic it shows a decided advantage over the lighter and weaker sections.

It will be unnecessary to remark upon the other two statements, as they have already been sufficiently considered.

ADHESION OF SPIKES IN TIES OF VARIOUS WOODS.

In the following experiments the White Oak and Chestnut ties used were taken from the Boston and Albany Railroad track, near Allston, Mass. The Cedar tie was green, having been cut in the spring, and the tests were made on it in August. It had not been in service, nor had the Yellow Pine or Hemlock. The Oak tie and one of the Chestnut ties had been in the track only two years and three months, and they were of good sound second-growth timber. The other Chestnut tie had been in service four years and three months. The results obtained from these experiments are of far more practical value than if from new ties.

Maj. F. H. Parker, commanding officer of the Watertown Arsenal, kindly allowed the testing-machine to be used to make the tests, which were conducted by Mr. James Howard, C. E., in charge of the machine, a fact of itself guaranteeing the care used in making the experiments. The Boston and Albany Railroad Company sent Mr. John Twigg, an experienced spiker, to drive the spikes in the ties, the conditions of every-day practice being maintained as nearly as possible. When the ties were taken out of the track a spike was left in each end, as originally driven, and great care was taken not to disturb them in removing the ties from the track. This gave an opportunity of seeing whether the adhesion increased or decreased by age of service.

After the spikes were drawn the ties were cut into blocks and split, exposing the spike so as to show the injury to the wood-fibers, which is very marked in all cases. A blunt or poorly-pointed spike driven into the White Cedar broke the wood down in masses, so as to reduce the adhesion of the spike from 40 to 50 per cent. from that obtained with a sharp-pointed spike; the latter did not break down but cut through the fibers. In most woods driving the spike checks the fibers for some distance on either side of the spike. In oak the adhesion was increased 40 to 50 per cent. by boring a ½-inch hole for a $\frac{9}{16}$-inch square spike. The experiments show conclusively that the same kind of spike is not the most suitable for all woods.

TABLE VI.—*Adhesion of Spikes in Ties.*

[Chestnut tie in service two years and three months under 72-pound rail 4½ inches high.]

Number of test.	Length of spike.	Length driven into tie.	Tension in pounds on spike.								Remarks.
			Pounds to start spike.	At ¼ inch.	At ½ inch.	At 1 inch.	At 1½ inches.	At 2 inches.	At 2½ inches.	At 3 inches.	
1	5.50	4.50	1,496	1,185	954	630	......	......	......	......	Spike drawn in track and redriven in same hole.
2	5.50	4.80	3,166	2,716	2,305	1,814	1,072	......	......	......	Spike as driven by railroad company when tie was put in track.
3	5.25	4.40	3,118	2,200	2,000	1,720	......	......	......	......	New Boston and Albany Railroad spike, good point, driven into solid wood.
4	5.50	4.60	3,572	2,305	2,036	1,560	......	......	......	......	New New York Central and Hudson River Railroad spike driven into solid wood.
5	5.50	5.00	2,886	2,960	2,548	1,100	......	......	......	......	Spike as driven by railroad company, corroded and bent; broke out piece of wood in drawing.
6	5.50	4.60	1,700	1,924	1,550	1,140	......	......	......	......	Old spike redriven in old hole.
[Chestnut tie in service four years and three months; cut under rail.]											
7	5.50	4.40	2,794	1,700	¾ in. 1,430	1,280	......	......	......	......	Spike as driven by railroad company; wood under rail brittle and soft four to five layers down.
8	5.50	4.40	2,265	1,706	1,240	950	......	......	......	......	Spike driven into wood under rail two hours before test; fermentation commenced under fourth layer of wood.
9	5.70	4.80	3,200	2,548	2,390	2,150	......	......	......	......	Spike driven into sound wood.
10	5.30	4.60	2,280	1,030	1,020	880	......	......	......	......	Spike as driven by railroad company; corroded, scales separate, and remain in wood.

TABLE VI.—*Adhesion of Spikes in Ties*—Continued.

[Yellow Pine, 4 by 8 inches; cut in winter of 1886.]

Number of test.	Length of spike.	Length driven into tie.	Tension in pounds on spike.								Remarks.
			Pounds to start spike.	At ¼ inch.	At ½ inch.	At 1 inch.	At 1½ inches.	At 2 inches.	At 2½ inches.	At 3 inches.	
11	5.50	4.80	3,290	1,390	1,210	1,014	740	......	......	......	New York Central'and Hudson River Railroad spike driven tangentially to layers; after yielding fell to 1,500.
12	5.50	4.80	3,195	1,650	1,250	840	......	......	......	......	New York Central and Hudson River Railroad spike; pull fluctuated between 1,300 and 2,200, until spike was drawn to ¼ of an inch.
13	5.00	4.40	3,110	1,750	1,460	1,280	......	......	......	....	Boston and Albany spike.
14	5.50	4.65	2,650	1,200	1,050	995	890	820	......	......	½-inch hole bored full length of spike.
15	5.50	4.70	3,010	1,500	1,550	1,300	980	760	......	......	7/16-inch hole bored full length of spike.
16	5.50	4.70	3,250	2,400	1,900	1,400	1,020	880	......	......	⅜-inch hole bored full length of spike.
34	½-inch Lag-screw	3 in. of screw	2,850	3,510	2,590 ⅜-in., 2,960	940	......	......	......	......	Lag-screw driven in same block with spike hammer.
[Yellow Pine, 4 by 8 inches, seasoned nine years.]											
17	5.50	4.50	3,340	2,240	2,040	1,860	1,480	920	......	......	
18	5.70	5.00	3,640	2,595	2,600	2,560	1,980	1,500	920	......	At 3 inches, 310; sudden drop to 2,700.
19	5.60	4.80	3,445	2,110	2,080	1,790	1,380	940	235	......	At 3½ inches, 180.
20	5.40	3.00	1,870	1,320	1,050	560	......	......	......	......	
[White Cedar]											
22	5.50	4.90	2,305	2,190	2,010	1,640	1,240	760	390	......	Sharp-pointed spike.
23	5.50	4.70	1,460	1,170	1,080	830	......	......	......	......	½-inch hole bored full length of spike.
24	5.50	4.70	1,755	1,360	1,250	1,050	840	680	......	......	⅜-inch hole bored full length of spike.
26	5.60	5.00	1,320	1,150	1,010	680	620	530	420	......	Blunt-pointed spike had broken the wood.
21	⅝ (Lag-screw)	3.40 2.80	2,200 1/16-in. 26.10	2,080	840	480	380	290	......	......	½-inch hole bored.
25	⅝ (Lag-screw)	3.40 2.80	2,825	1,950	1,150	580	......	......	......	......	Spike was drawn 3/16 of inch at 2,700; ⅜-inch hole bored.
[White Oak, fine quality, in service two years and three months.]											
27	5.50	4.70	4,490	3,490	2,910	2,150	1,620	1,220	710	460	Spike as driven by railroad company.
28	5.50	4.60	3,360	2,700	2,220	1,280	670	......	....	.....	Old spike redriven in old hole thirty hours before test.
29	5.60	4.70	4,330	3,260	3,040	2,880	2,250	1,830	1,420	920	New spike in solid wood.
30	5.70	4.90	6,595	5,695	5,480	4,800	4,250	3,300	2,400	1,120	½-inch hole bored full length of spike.
31	5.70	4.80	3,370	2,380	2,140	......	......	...	...	....	Old spike redriven thirty-one hours before test.
32	6.00	5.30	3,965	3,180	2,900	2,150	......	......	......	......	Spike as driven by railroad company.
33	5.60	5.00	5,970	⅜-in., 4,800	4,580	3,900	3,390	2,480	1,820	830	Suddenly drew to ¼-inch at first load; experiment repeated to confirm experiment 30.

TABLE VI.—*Adhesion of Spikes in Ties*—Continued.

[Dry Hemlock tie, cut in winter of 1886; spikes driven seventy-five days previous to tests.]

Number of test.	Length of spike.	Length driven into tie.	Tension in pounds on spike.								Remarks.
			Pounds to start spike.	At ¼ inch.	At ½ inch.	At 1 inch.	At 1½ inches.	At 2 inches.	At 2½ inches.	At 3 inches.	
				$\frac{5}{16}$					2½ in.	3 in.	
35	5. 50	4. 90	3, 110	2, 000	2, 100	1, 800	1, 750	1, 300	950	540	Spike driven in ⅜-inch hole; yields suddenly and stops.
36	5. 50	4. 75	3, 390	2, 060	1, 900	1, 700	1, 280	1, 060	880	420	Spike driven in ½-inch hole; yields suddenly and stops.
37	5. 00	4. 25	3, 690	1, 800	1, 650	1, 080	820	420	......	......	Spike driven into solid wood.
38	5. 50	4. 55	3, 280	1, 850	1, 600	1, 050	880	810	......	......	Spike driven into solid wood; yields suddenly at start.
39	⅝-in. Lag-screw	3. 20	3, 580	2, 580	1, 900	910	520	280	......	......	⅜-inch hole bored; size of screw, ½-inch; fibers of wood are sheared off.
40	⅝-in. Lag-screw	3. 25	4, 290	3, 600	1, 280	900	510	380	......	......	½-inch hole bored; size of screw, ½-inch; fibers of wood are sheared off.

The table giving the adhesion of spikes shows some important features, a part of which will be new to the general railway public.

In Chestnut of second-growth the tension necessary to start an ordinary $\frac{9}{16}$-inch square spike, 5½ inches long, and driven home upon a rail, ranges from 3,000 to 3,600 pounds. After being drawn one-half an inch, the adhesion is diminished to only about two-thirds of these amounts, and at 1 inch is reduced to about one-half. This is of great importance when blocking up the track in winter, as a spike slightly redrawn will still hold.

A spike redriven in an old hole holds about 50 per cent. of the amount that it will when first driven, unless the ties have been in service over three years. In the test of the second Chestnut tie it will be noticed that the adhesion of the spike has decreased with the length of the service.

Experiment No. 8 shows that the adhesion of a spike driven into wood under the rails, after fermentation had taken place, is much decreased, as might be expected.*

In Yellow Pine the resinous matter forced out of the fibers by the compression produced in driving the spike lubricates the latter so that the adhesion is not as great as it should be according to the specific gravity of the wood; and after the spike is started the adhesion decreases rapidly. This feature has been noticed when the rails are raised up on thick shims, the spikes holding but little in the ties, and being easily displaced.

The fibers of the wood are broken and bent down, so that they do not close up tightly to the body of the spike, as in Chestnut and Oak ties.

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* See Figs. 1 and 2, p. 61.

Experiments 14, 15, and 16 show the results of boring holes for the spikes. The $\frac{1}{2}$ inch hole seemed too large; the $\frac{7}{16}$-inch hole showed an improvement; while the $\frac{3}{8}$-inch one gave the best results.

Experiments 17 to 19, inclusive, are instructive, and correspond to spikes driven into dry bridge ties; showing also the increased adhesion gained by driving spikes tangentially to the layers of wood; of course, ties ballasted would not be as dry as this timber.

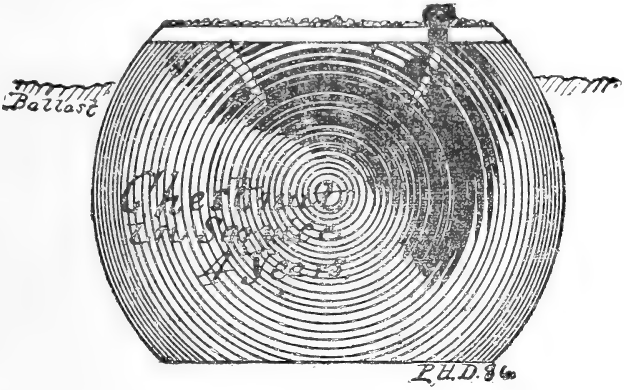

Fig. 1. Cross-section of a tie showing the effect of spiking.

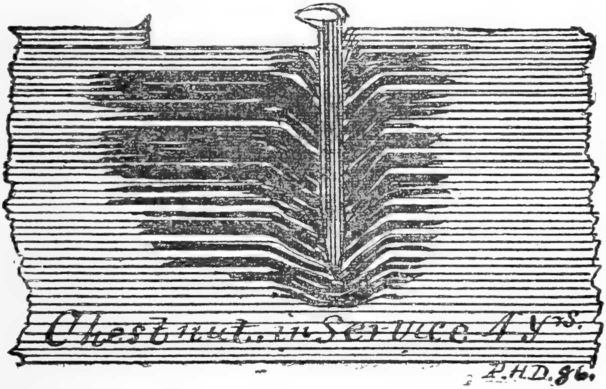

Fig. 2. Longitudinal section of a portion of a tie showing the effect of driving a spike.

White Cedar gives the most irregular results. No. 22 is good, and probably above the average results; No. 26 was in the same tie, but the spike was blunt and tore the wood, leaving but little in front and back of the spike; such results are common in practice. Nos. 23 and 24 show the improvement over No. 26 gained by boring holes; the adhesion was increased as the spike was drawn out at different lengths.

The White Oak tie holds a spike firmly, not giving up its hold rapidly as it is drawn out. Boring holes increases the adhesion* and materially lessens the checking of the layers and injury to the wood-fibers.

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* See experiments No. 30 and 33, p. 59.

In the tests of the Hemlock tie the spikes were driven tangentially to the layers of wood, and at the start the adhesion ranged from 3,280 to 3,690 pounds, but when drawn one-fourth of an inch decreased nearly one-half. The fibers were too much injured to cover and press the spike firmly. Boring holes increased the resistance, as shown when the spike was drawn out to various lengths, the fibers not being injured so much.

NOTE ON ADHESION OF SPIKES.

By B. E. Fernow.

More extensive experiments on the adhesion of spikes were recently published in the "Organ für das gesammte Eisenbahnwesen." The writer comes to the conclusion that by boring holes for the spikes not only is there effected a saving of probably 50 per cent. in spikes, but also a large saving in ties, especially in oak ties, in which, by driving the spikes, the tendency to check is aggravated more than in pine. As set forth in the above report, spiking breaks down the fibers around the spikes, thus inducing earlier decay and at the very places where most resistance is required; and frequent respiking wears out the tie mechanically sooner than in any other way; the bending, too, of the spikes when driven, increases these evils. Unless such mechanical wear is counteracted, it becomes doubtful whether impregnating ties can be considered the right economy.

In these experiments 170 ties, laid down as they came, were bored on one rail-side, and not on the other; the driving of spikes was then done as in practice. After having started the spike (with a regular spike-puller) to 1 inch, a grapple connected with a balance was attached to the rail and weights added to the balance until the rails suddenly gave way; the grapple drawing perpendicularly, and all other forces being ingeniously counterbalanced, the adhesion alone was determined.

Boring-bits of different sizes were used, and the holes were made 4 and 5 inches deep. The conclusions arrived at are recorded as follows:

(1) Adhesion differs greatly in ties of the same kind, as well as in the same tie.

(2) Even the four spikes in each tie show considerable difference of adhesion.

(3) Adhesion is sometimes greater with the inner, sometimes with the outer spikes; sometimes when holes are bored, sometimes when not; sometimes in holes of a larger, sometimes in those of a smaller diameter.

From all of which it appears that generalization on a small number of experiments can be done only with caution. Not only the boring, but also the quality and kind of tie, the seasoning, the temperature and weather in general, the places into which the spikes are driven, whether driven more into the heart-wood or into the sap-wood; the closeness, too, of the contact with the foot of the rail requires consideration in determining the adhesion of the spike for practical purposes. Yet, from the average results represented in the seven tables, the following important conclusions can be drawn:

A. For Oak.

(1) In ties with good, tough, dense fibers the adhesion was found to be greater when holes of $\frac{7}{16}$ or even $\frac{1}{2}$ an inch were bored than when this was not done.

(2) In quickly-grown oak ties the reverse was the case, but the difference was insignificant (−67.2); and as such ties split and check more easily, boring of these also must be considered advantageous.

(3) The friction due to presence of water in the tie (influence of the weather) exerts greater resistance to displacement than the friction of the spikes against the rails.

(4) In a $\frac{3}{8}$-inch hole the average adhesion was slightly less than when the ties were not bored (—24).

(5) Only in holes of small diameter was the average adhesion less than when not bored, while with an increase of the diameter of the hole the adhesion increased (−136 : +112.8 : +144).

(6) The most favorable results were given by a $\frac{7}{16}$-inch hole (1 : 35.4). The largest-sized hole gave not much less favorable results (1 : 31.8).

(7) If the common four-cornered wedge-pointed spike is to be used in unimpregnated oak ties, it is best to use a boring-bit of the same size as the spike.

(8) The results of experiments with 200 spikes on 50 ties would allow the conclusion that new oak ties, unimpregnated, and with square, wedge-pointed spikes, show the same average adhesion whether bored or not; though the boring is recommended, nevertheless, for other advantages.

These results would probably have a like bearing for impregnated ties.

B. For Pine.

(Probably for other coniferous woods and Chestnut.)

(1) By using a boring-bit from $\frac{5}{16}$ inch in size upward, the adhesion was increased; the best results were given by a $\frac{3}{8}$-inch hole (1 : 13.5); and a $\frac{7}{16}$-inch hole was not much less favorable (1 : 10.5).

(2) When the hole was increased to 5 inches in depth there was a decrease of adhesion, though only insignificant.

(3) In pine ties the *place* where the spike is driven is of greater importance than in hard-wood ties, the adhesion diminishing according as the spike has more hold in the sap-wood than in the heart-wood.

(4) Experiments with 400 spikes on 90 ties allow the conclusion that boring increases the adhesion, especially when the bit used is of the same size as the spike.

The following is a résumé of the tables, giving the results of experiments:

Table I.—*Hungarian Oak; dry when the spikes were drawn.*

Bore, $\frac{7}{16}$ inch diameter; pounds to draw spike	3,624.0
No hole bored; pounds to draw spike	3,691.2
Average	3,657.6

Difference, —66.8; diff. : aver. :: 1 : 54.4.

Table II.—*Same Oak; wet when spikes were drawn.*

Bore, $\frac{3}{8}$ inch diameter; pounds to draw spike	4,399.2
No hole bored; pounds to draw spike	4,423.2
Average	4,411.2

Difference, —24.0; diff. : aver. :: 1 : 183.8.

Table III.—*Silesian Oak; wet when spikes were drawn.*

Bore, $\frac{3}{8}$ inch diameter; pounds to draw spike	4,104.0
No hole bored; pounds to draw spike	4,240.8
Average	4,172.4

Difference, —136.8; diff. : aver. :: 1 : 30.5.

Bore, $\frac{7}{16}$ inch diameter; pounds to draw spike	4,044.0
No hole bored; pounds to draw spike	3,931.2
Average	3,987.6

Difference, +112.8; diff. : aver. :: 1 : 35.4.

Bore, $\frac{1}{2}$ inch diameter; pounds to draw spike	4,648.8
No hole bored; pounds to draw spike	4,504.8
Average	4,576.8

Difference, +144; diff. : aver. :: 1 : 31.8.

Table IV.—*Pine; impregnated; dry.*

Bore, $\frac{5}{16}$ inch diameter; pounds to draw spike	1,876.8
No hole bored; pounds to draw spike	2,197.2
Average	2,028.0

Difference, —302.4; diff. : aver. :: 1 : 6.7.

Bore, $\frac{3}{8}$ inch diameter; pounds to draw spike	1,843.2
No hole bored; pounds to draw spike	1,711.2
Average	1,777.2

Difference, +111; diff. : aver. :: 1 : 13.5.

Bore, $\frac{7}{16}$ inch diameter; pounds to draw spike	2,054.4
No hole bored; pounds to draw spike	1,867.2
Average	1,960.8

Difference, +187.2; diff. : aver. :: 1 : 10.5.

Table V.—*Pine; not impregnated; dry.*

Bore, $\frac{5}{16}$ inch diameter; pounds to draw spike	1,696.8
No hole bored; pounds to draw spike	1,572.0
Average	1,634.4

Difference, +124.8; diff. : aver. :: 1 : 13.7.

Bore, ⅜ inch diameter; pounds to draw spike	1,545.6
No hole bored; pounds to draw spike	1,615.2
Average	1,580.4

Difference, —69.6; diff.: aver. :: 1 : 22.7.

Bore, $\frac{7}{16}$ inch diameter; pounds to draw spike	1,593.6
No hole bored; pounds to draw spike	1,646.4
Average	1,620.0

Difference, —52.8; diff.: aver. :: 1 : 30.7.

Bore, $\frac{7}{16}$ inch diameter (without rail); pounds to draw spike	1,737.6
No hole bored (without rail); pounds to draw spike	1,802.4
Average	1,770.0

Difference, —64.8; diff.: aver. :: 1 : 27.4.

(TABLE VI.—*Beech.*)*

TABLE VII.—*Pine; impregnated; wet; depth of hole bored,* 5 *inches.*

Bore, ⅜ inch diameter; pounds to draw spike	1,715.7
No hole bored; pounds to draw spike	2,028.6
Average	1,872.2

Difference, -312.9; diff.: aver. :: 1 : 5.98.

(Not bored and without rail; pounds to draw spike	1,772.4)
Bore $\frac{7}{16}$ inch diameter; pounds to draw spike	1,673.7
No hole bored; pounds to draw spike	1,911.0
Average	1,792.4

Difference, —237.3; diff.: aver. :: 1 : 76.

(Not bored and without rails; pounds to draw spike	1,629.6)
Bore, ½ inch diameter; pounds to draw spike	1,785.0
No hole bored; pounds to draw spike	1,824.9
Average	1,805.0

Difference, —39.9; diff.: aver. :: 1 : 45.2.

(Not bored and without rail; pounds to draw spike	2,053.8)

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*The results obtained from experiments with beech ties were unsatisfactory and not of sufficient value to be introduced.

Appendix 2.

WOOD PRESERVATION.*

By HENRY FLAD, C. E., *Saint Louis, Mo.*

Wood is made up of small fibers, the various forms of which constitute its cell-structure. Air occupies the cells not filled with sap.

The woody fiber in all kinds of wood is composed of the same elements, and in nearly the same proportions. It consists of 52.4 parts of carbon, 5.7 parts of hydrogen, and 41.9 parts of oxygen.

Differences in the strength of timber are due to differences in structure, or in the form and disposition of the fibers. The specific gravity of the fiber is about 1.5.

The sap consists mainly of water, and of the so-called extractive substances, such as vegetable glue, gum, gallic acid, coloring matter, sugar, albumen, etc. Besides these substances, which are found in greater or smaller quantities in almost every kind of sap, that of some kinds of wood contains special ingredients; oak contains tannin, the coniferous woods contain resin, essential oils, etc.

The quantity of sap contained in wood varies considerably in different kinds and at different seasons of the year. Freshly cut wood contains from 18 per cent. of sap (in Hornbeam) to 52 per cent. (in Black Poplar). The variation of sap at different seasons is illustrated by the observation that ash, cut in January, was found to contain 29 per cent. of sap, and 39 per cent. when cut in April.

When wood is thoroughly air-dried it still contains from 16 to 20 per cent. of water, and when air-dried wood is exposed for a time to a tem-

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* In this paper notes signed with the initials H. C. are to be credited to Mr. Howard Constable, C. E., of New York city, who had kindly prepared a separate paper on the same subject, but to avoid unnecessary repetitions, his paper has been divided and used as foot-notes along with this Report.

perature of 277° F., the quantity of water is reduced to $\frac{1}{4}$ or $\frac{1}{5}$ of what was left in the air-dried wood.

NOTE.—The following table exhibits the weight of 1 cubic foot each of different kinds of air-dried wood and the space in a cubic foot, or 1,728 cubic inches, of air-dried wood occupied respectively by fiber, sap, and air, assuming the specific gravity of fiber at 1.5.

	Weights of 1 cubic foot.				Space occupied by fiber, sap, and air.		
	Pounds.	Per cent. of water.	Weight of water.	Weight of fiber.	Fiber. Cub. in.	Sap. Cub. in.	Air. Cub. in.
White Oak	53. 3	16	8. 5	44. 8	830	161	662
Yellow Pine	34. 4	17	5. 8	28. 6	530	161	1, 037
White Pine	26. 1	17	4. 4	21. 6	400	125	1, 203
White Beech	45. 2	18. 5	8. 4	36. 8	681	233	814
White Elm	36. 2	18. 5	6. 7	29. 5	546	186	996
Sweet Gum	39. 6	19	7. 6	32. 0	592	211	925
Yellow Poplar	33. 0	19. 5	6. 4	26. 6	493	177	1, 058
Sycamore	33. 4	20	6. 7	26. 7	494	186	1, 054

The weight of water per cubic foot, as given in the third column of the above table, and the weight of fiber per cubic foot of lumber in the fourth column, were calculated from the observed percentage of water contained in the wood, as given in the second column.

In air-dried wood from one-third to nearly two-thirds of the volume is occupied by air, which might be replaced with some liquid if the air were removed, or partly replaced if the air were compressed. [Knapp's "Technology."]

DECAY OF WOOD.

The woody fiber by itself does not seem liable to decay; but the sap contained in it under favorable conditions undergoes fermentation, and fungi attack and destroy the fiber.

Fermentation, however, cannot take place except in the presence of air, of moisture, and of a temperature above the freezing point (32°), and below 150° F. If any one of these conditions is lacking, decay is impossible.

But if wood is to be exposed to conditions favorable to decay, special precautions and means can and should be adopted to prolong its usefulness. The sap being the prime cause of decay, it is plain that timber should be cut at a season when it contains the least quantity of it and the least amount of organic matter, viz, during winter.

It is stated on good authority that wood of proper character and age, cut during January and then air-dried, resisted decay for fifteen and sixteen years; whereas timber of the same kind, cut at different age and season, lasted only four years.*

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*NOTE.—On this point, see note on page 37. Experience has shown that wood cut in August, if properly seasoned, will last as long as that cut in winter. The manner of after-treatment will decide mostly for or against the practice of summer cutting. If no precautions are taken as to proper seasoning, the winter cutting is decidedly preferable.—B. E. F.

It is also evident that the total or partial removal of the sap from wood will retard its decay. But even if all sap were removed decay would naturally set in, if the entrance into the cells of air and water containing spores is permitted, or if no means are adopted to prevent their growth when introduced.

To prevent air and water from entering the wood its cells may be filled with some substance not liable to decay. To prevent organic life from springing up in the wood cells, antiseptics are introduced into them in the form of solutions, which act as poisons on all kinds of spores and bacteria.

NOTE.—There is no doubt whatever that wood can be preserved, successfully and to commercial advantage, to a much greater extent than is generally believed.

To experts in this field little need be said; they are aware of its extent, what has been accomplished, and the possible advantages. They know that the preservation of wood has been carried on in England and in several countries of Europe for a great many years on a very extensive scale and with the most satisfactory results, several processes being in use whose efficiency has been thoroughly established. Experience in this country has not been satisfactory, owing to a want of appreciation of certain conditions, very different from those found abroad. Among these it is noticeable that we have usually green timber to treat instead of seasoned wood, and that in some localities timber is yet too plentiful, and consequently cheap, to admit a preserving process being employed to commercial advantage. In some cases again experiments have not been satisfactory, owing to the great distances to which wood had to be transported for treatment and then to be sent back.—H. C.

METHODS OF TREATMENT.

The methods which are used, either simply or in combination with each other, in the preservation of wood, are,—

(1) Steeping in water or in antiseptic solutions.

(2) Forcing a current of water or of antiseptic solution longitudinally through the ducts of the wood, either by pressure or by suction—the Boucherie process.

(3) Steaming in closed vessels.

(4) Removing air and vapors from the cells by creating a vacuum around the wood in a closed vessel, and then injecting the antiseptic solution into the wood by applying pressure to the solution.

(1) *Steeping.*—When wood is steeped in running water its sap is diluted and gradually displaced. This is the cause of the greater durability of rafted lumber as compared with that which has not been submerged in water.

But the process is necessarily slow, and if the water in which the wood is submerged contains sediment, the process is impeded.

Steeping is also used for impregnating wood with antiseptic solutions. To allow such solutions to enter the wood the latter should first be freed from water, either by air-drying or by exposing it to heated air in kilns. Steeping requires much time (from one to two or three weeks) and can never effect a thorough impregnation of the wood. The structure of wood is such that, while it offers but slight resistance to the flow of liquids through its longitudinal ducts, it is very difficult, even, under great pressure, to force any liquid from the surface to its center, at right angles to the direction of the fibers. But the entrance of any preserving liquid through the ducts and other cells is resisted by the sap remaining in the wood and by the air which fills the cells not occupied by sap, so that steeping, as generally carried out, causes the antiseptics to penetrate but a short distance from the surface of the wood.

It is evident, therefore, that wood which is to be preserved by this method of impregnation should be fully framed to the exact form in which it is to be used before it is treated.

Steeping may sometimes be useful as a process preparatory to others.

(2) *The Boucherie Process.*—About 45 years ago Boucherie, a French chemist, conceived the idea of impregnating wood with a preserving fluid, by introducing it into a living tree through a groove cut around its surface near the ground, from which it was to arise, together with the sap, through the cells of the wood.

But this was soon found impracticable, and in 1841 Boucherie patented a process for preserving wood by forcing a solution of sulphate of copper through the cells of the wood under hydrostatic pressure applied at one end of freshly cut and unbarked logs, so as to remove the sap and replace it by the solution of copper. Since then impregnation with sulphate of copper has been generally known as the "Boucherie process," although this term is more properly applied to the method of impregnation invented by him, which may also be used in connection with other preservatives as well as with copper.

To secure the ready percolation of the fluid through the cells of the wood it is necessary that the sap of the wood to which the process is to be applied should possess the greatest possible degree of fluidity. This it has during the first months of the year. Timber cut during the autumn may also be used, although the sap at that season is more viscous and less readily removed. During the spring and summer the sap contains so much gummy extractive matter that it is not fit for treatment by this process. The timber is treated in the form of round logs, with the bark left on. The treatment should be applied as soon as possible after the timber has been cut. When exposed to the action of the atmosphere, even for a short time, the sap will solidify and greatly retard the process. It is customary, therefore, to cut the logs of somewhat greater length than that ultimately required, and to saw off a few inches from the ends just before subjecting the logs to the process.

Logs which are placed in clear water immediately after they are cut will remain for some time in proper condition for treatment. If the logs are intended for railroad ties they may be cut of suitable length to make either one or two ties, and the mode of introducing the solution varies accordingly. Logs cut for single length treatment are placed (with a slight inclination) in a row on skids, and fastened to the latter by clamps. Along each row of logs runs a pipe, connected with an elevated tank which contains the antiseptic solution. Around the periphery of the end of the log nearest the pipe a greased rope is then laid and pressed against it by a plank which is drawn tight against the log by clamps.

Thus a cylindrical chamber is formed into which the solution is admitted by a rubber hose connecting the pipe with the chamber. The admission of the solution may be stopped by clamping the hose. When the solution is first admitted the air contained in the chamber is allowed to escape through a small opening near the top of the chamber, and then the solution enters the open ducts in the wood, pushing the sap before it, and finally escapes at the opposite end, where the mixture of sap and solution drips into a trough placed along and under the ends of the logs.

When logs cut to double lengths are to be treated, after having been placed on the skids they are sawed very nearly but not quite through in the middle. Wedges are then used to raise them at the middle so as to open the saw-cut wide enough to admit the introduction of a greased rope, which is placed around the circumference of the cut. The wedges are then taken out to allow the cut to close up, and thus to compress the rope and to form a close chamber. The solution enters this chamber through a short tube driven into a hole which is bored slantingly a few inches from the cut, through the end of one of the logs. Rubber hose leads from the hole in the log to the pipe. The air is allowed to escape from the chamber by using a pin to make a small hole at the top of the greased rope, which is then plugged. Of course two troughs have to be placed along and under the outside ends of the logs, where the liquid leaves the logs. The troughs carry the escaping solution to a tank, where it is restored to its normal strength. But as the solution in passing through the logs is mixed with the sap it will, even if the scum is removed with ladles and the fluid filtered through woolen cloth, soon become impregnated with foreign substances to such an extent that it cannot be safely used any longer.

This may be remedied to some extent by filtration. At the foot of the trestle carrying the tanks are placed as many filtering tanks as there are tanks on the trestle. The filtering tanks are closed by covers, which can be readily raised when the filtering material is to be introduced, and then closed and firmly anchored to the tank.

The fluid delivered by the troughs is pumped into one of the upper tanks, from which it is conducted by a pipe to the bottom of a filtering tank, whence, under a head due to the elevation of the tank, it passes upward through the filtering material and through a pipe starting from the cover of the filtering tank to a pump which raises it again to a second tank on top of the trestle. There the solution is brought to the normal strength and then starts on a new round. Such filters have to be cleaned daily.

It would appear that a cheaper, if not more expeditious, method of preventing the adulteration of the solution could be found by passing only clear water through the logs at the beginning of the treatment, continuing this process until the sap has been removed, and only then introducing the antiseptic solution. The water, after passing through the logs, would be allowed of course to run to waste.

The removal of the sap might, perhaps, be expedited and made more complete by using a weak solution of borax, instead of pure water, at the beginning of the operation.

In France, where the Boucherie process was for many years used exclusively for impregnating wood with sulphate of copper, the rule was to continue the treatment until every portion of the end from which the solution escaped showed the proper reaction when tested with ferro-cyanide of potassium. It was also a rule not to stop the operation until the solution escaping from the end, when tested by chemicals, showed a strength of two-thirds of the original solution, the wood retaining almost all the sulphate of copper at the beginning of the treatment, and gradually less, so that the solution flowing from it showed a corresponding increase in strength. The time required for thoroughly impregnating wood by this process was found to vary with the state of the atmosphere, with the dimensions of the log, and with the quality of the timber. A humid and mild atmosphere was the most favorable, while dry and cold weather retarded the process. During freezing weather operations had to be suspended.

As to the influence of dimensions on the time required for treatment, it may be assumed that the time required is directly proportional to the diameter of the log and to the square of its length. It may also be assumed as being inversely proportional to the hydrostatic pressure applied.

Timber in which the annual rings do not differ much in width, such as beech and hemlock, is more readily impregnated than timber in which the heart is much more compact than the sap-wood, as in oak. No attempt should be made to treat timber which is not perfectly sound throughout its whole section and length.

With fresh-cut beech logs intended for ties it took on an average about forty-eight hours to complete the impregnation. Logs of greater length and of other kinds required as much as one hundred hours for treatment. In cases where the impregnation was found not to be completed at the end of one hundred hours it was customary to reverse the position of the logs and to force the solution through in the opposite direction.

This process has been most extensively used in France, and to a smaller extent in Austria and Germany. In England it has never been applied, because nearly all timber used there is introduced from abroad. In the United States it has been used, so far as I am aware, in but few instances.

Yet its use insures, probably, a more thorough impregnation than any of the other methods employed at present. It does not injuriously affect the strength of the wood, and requires a comparatively small outlay for plant. It can be started almost anywhere within a short time.

Its drawbacks are that it can be carried on only during a comparatively brief season; that it takes considerable time, although less than the steeping process; and that it cannot be applied to square timber.

Considering that the large quantity of air which even fresh-cut wood contains must necessarily obstruct the passage of the solution through the log and prevent the fluid from reaching every portion of the wood; considering, moreover, that in pushing the solution through the ducts by pressure it was exposed to waste at every point where the ducts reached the surface, and that such leaks were difficult to stop, I concluded to make an experiment to see whether better results could not be attained by reversing the Boucherie process, and applying suction instead of pressure for passing the antiseptic solution through the logs. Instead of using an elevated tank, I employed two small closed vessels, in one of which a partial vacuum was kept up, while the other was being emptied of the sap and solution delivered into it by the pipe, which passed along the ends of the logs, and which was connected with the vacuum tanks, and by small rubber hose with the chambers formed at the head of each log. The caps, in this case, consisted of a thin, flexible metal ring, with sharpened edges. One edge was driven in near the circumference of the cut, and when firmly fixed, the disk, 2 to 4 inches thick, which had been cut from the end of the log to prepare it for treatment, was driven into the other edge of the metal ring. This wooden bottom of the chamber was made air-tight by smearing clay or tallow over the outside face.

A small knob fixed to the circumference of the metal ring contained a short tube, to which the rubber hose was attached by merely slipping it over the end of the tube. A cock in the short tube served to permit or to stop the exhaustion of the air from the chamber at the end of the log. The log was always placed so that the suction end was at a higher elevation than the end at which the solution entered the log. The introduction of the solution was managed in two different ways. In one, a chamber, identical with that at the suction end, was formed at the other end of the log, and the solution introduced into this chamber from a trough running along and 4 feet above the lower ends of the logs. This arrangement gave pressure at one end and suction at the other, thus greatly expediting the operation. Cuts of the fibers at the surface of the log, such as would be produced by chopping off branches, through which the air might be sucked, were readily detected and could be quickly stopped by rubbing clay or tallow into them. When the cock in the pipe connecting the suction chamber with the main pipe vas opened, the first result was that the air contained in the cells of the wood was drawn into the suction chamber, and thence into the main suction pipe and vacuum tank, thus forming a vacuum inside the ducts of the log, which caused the sap and the solution from the lower chamber to follow in a solid column and gradually to fill the wood with the antiseptic solution.

Another method was to place the logs in a triangular tank in such a manner that the lower end of the log, to which in this case no chamber or cap was fixed, would be completely submerged in the solution. When the cock controlling the connecting pipe was opened the air and sap contained in the log were exhausted from it and the cells gradually filled with the solution. In some cases the tank was first filled with water for the purpose of washing out the sap before the antiseptic solution was used.

The antiseptic generally used was sulphate of copper, because its presence or absence can be determined constantly by the application of a solution of ferrocyanide of potassium, and the experiments were instituted mainly for the purpose of ascertaining how long a time was required to thoroughly impregnate the logs.

With sound logs, of 12 to 20 inches diameter, cut into lengths of 8 feet, it was found that the wood was thoroughly impregnated in from five to eight hours. This was ascertained by sawing the log in two after it had been treated and testing the whole surface of the cut with the reagent.

But when the logs were not perfectly sound the impregnation was imperfect.

A small experimental station was afterwards erected near Charleston, in Southeast Missouri, where it was intended to test the commercial value of the process, and a number of large logs, mostly Sweet Gum, were impregnated. But as this kind of timber contains a great deal of sap wood, and as most of the large logs show incipient decay at the center, the results were not nearly as favorable as those which had been attained by the previous experiments with logs cut from other kinds of timber of smaller diameter, sound and of uniform texture.

The experiments were interrupted by the illness of my son, who had charge of the work, and a season of high water, which kept the ground at the works, and for miles around, submerged for several months, induced me to discontinue the experiment altogether.

But I believe that under proper condition the method just described will cause a more thorough impregnation of wood than can be secured by any other, without the necessity of an expensive plant and without injury to the strength of the timber.

I believe also that it might be used to good advantage in works where now steeping alone is relied upon, with a view of expediting the process and of impregnating the timber not only near the surface, but also deeper. The timber, when submerged in the antiseptic solution, might be fitted at one end with a metal cap, as heretofore described, and the fluid sucked through the timber by exhausting the air and liquid from the cap. Square timber, even if of large dimensions, might thus be treated, the metal ring in that case being made of the same form as the section of the timber, and in dimension ½ or 1 inch smaller than that section. To effect complete saturation the fibers of the wood would have to be straight and parallel to the sides of the timber, but by applying the process to both ends a thorough impregnation of the inner portion of the timber would, in most cases, be obtained, while the parts near the surface would be impregnated by steeping.

In describing at such length two processes which are not used, I have been influenced by the consideration that, while neither of them can ever find general application, there are undoubtedly locations and circumstances in which preservation by a process requiring but slight outlay for plant is the only one feasible; and, so far as I am aware, a full description of these processes has never been furnished in any of the American publications treating on the subject of the preservation of timber.

(3) *Steaming.*—When fresh timber is placed in a closed vessel and steam admitted into the latter, the first effect will be to expel the air, a tap provided for that purpose being left open. When the air has been driven out this tap is closed, and, more hot steam being admitted, the temperature of the timber and of the sap contained therein rises gradually. When the temperature in any part of the timber rises to 167° Fahr., the albumen which is generally considered the ingredient in the sap most favorable to decay becomes solid. The air expands and a portion of it leaves the cells. The water contained in the cells is gradually transformed into steam, and the water of condensation, together with a great portion of the extractive ingredients of the sap, is driven from the wood and collects at the bottom of the boiler, whence it is from time to time drawn off by a tap. The steam admitted should not have a pressure greater than about 20 pounds (corresponding to a temperature of about 260° Fahr.).*

To coagulate all the albumen it is, of course, necessary that every part of the timber should be heated; but heat enters rather gradually and slowly from the surface to the interior. Experiments made by introducing Rose's metal into holes bored into the timber from the surface, which afterwards were plugged, showed that after three hours' steaming, the heat required for coagulating albumen had penetrated only to a depth of 3 to 4 inches. It is evident, therefore, that if all the albumen in the wood is to be coagulated the time during which the timber is steamed must be regulated according to its dimensions.

With timbers of considerable length and of large cross-section, it may be necessary to continue the process for six and eight hours or more.

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*It would probably be even better to restrict the temperature of the steam to 240°, or 10 pounds pressure, to prevent injurious effects to the strength of the wood where bridge timbers are to be preserved, although the process would take more time.

But such long-continued steaming will soften the fibers, weaken their coherence, and reduce the strength of the timber. Experiments made in Hanover show that the ultimate strength of Burnettized wood was reduced by one-fourth to one-tenth, and its elastic limit by one-seventh. Some part of this reduction was probably due to the action of the antiseptic used—chloride of zinc; but there can be little doubt that it was also partly due to the steaming.

Steaming has some other unfavorable features. A portion of the albumen, although coagulated, remains behind and partially stops up the cells, hinders the free circulation of steam and sap, and ultimately the entrance of the antiseptic solution. The process, moreover, does not fully remove the viscid ingredients of the sap, which, next to albumen, are most favorable to decay, while it deprives the wood completely of the essential oils and of tannic acid, which are to some extent preventives of decay; and, finally, unless the process be followed by some process of drying, as by superheated steam, and by application of the vacuum process (which will be described hereafter), it leaves a considerable quantity of water of condensation in the wood, making it incapable of impregnation with at least one of the best antiseptic substances (heavy oil of tar), and hindering complete impregnation with other preservatives.

That a considerable quantity of water remains in the wood after simple steaming, was proved by experiment, when it was found that of the water introduced into the vessel in the form of steam only two-fifths to four-fifths were removed from the boiler as water of condensation, so that from one-fifth to three-fifths remained in the wood.

(4.) *The Vacuum Process.*—In 1838 Burnett patented a method of preparing timber for receiving the preserving fluid, by placing the timber in a closed vessel and then using an air-pump for removing the air and vapor from the cells of the wood. He next filled the vessel with the antiseptic fluid, and applied a pressure as high as 150 pounds per square inch, by compressing the air above the solution. From the use of compressed air his was named the pneumatic process, and it retained that name even after the use of compressed air had been abandoned, and the pressure was directly produced by pumps.

This process, preceded by steaming and vacuum, is the one now almost universally used.

The timber to be treated is placed on cars, which are then pushed into a boiler, 6 to 8 feet in diameter, and from 60 to 110 feet long, of sufficient strength to safely bear an internal pressure of 150 pounds, and a collapsing pressure of 12 or 15 pounds. The boiler is then closed, and steam admitted under a pressure of 10 or 20 pounds. Steaming is kept up, as heretofore stated, for from three to eight hours, and is followed by exhausting the air and vapor still contained in the wood for from one to three hours, until the vacuum becomes constant on the stoppage of the pumps. The antiseptic solution is then admitted to the boiler, and when the latter is filled with the liquid, force pumps are employed to force the solution into the cells of the wood under a pressure of 100 to 150 pounds. The pressure is kept up until, on stoppage of the pumps, it remains nearly constant; say from three to sixty hours, according to quality, kind, and dimensions of the timber.

The cars with the timber on them are then removed from the boiler and a new charge introduced.

NOTE.—Many seem to be under the impression that the effect of the vacuum in drawing out the sap and air is unlimited, and the same as regards the pressure in forcing the preservative into and through the wood. We have no doubt that the vacuum and pressure are of great benefit, but to what extent the complete impregnation of the wood is affected by the amount of air that may be in the wood-cells remains to be settled by farther investigation, and more precise information would be useful. In green and rafted timber the sap is in a more or less liquid form, and the log may thus be so full of moisture as to contain a minimum amount of air, and steaming can be of benefit only by making the sap more fluid, the moisture of the steam being of no advantage. The heat also expands what air there is in the wood and thus drives out some of the moisture. With such timber it probably would be better to apply dry heat rather than by direct steaming, and thus add heat without extra moisture, for if we get a stick of timber thoroughly water-soaked, the wood-cells are full of water and there is no place into which to force the preserving fluid.—H. C.

ANTISEPTICS USED IN THE PRESERVATION OF WOOD.

Out of the great number of substances which, during the last sixty years, have been proposed for preserving wood from decay, or rather for prolonging the period of its usefulness, only four have stood the test applied, and are now employed for that purpose.

1st. Heavy oil of tar (creosote oil, dead oil).

2nd. Bichloride of mercury (corrosive sublimate).

3rd. Chloride of zinc.

4th. Sulphate of copper.

In addition to these some substances are employed for preventing the gradual removal of these antiseptics from the wood by exposure to atmospheric influences, such as chloride of tannin, glue, tannin, and sulphate of lime.

(1.) *Heavy Oil of Tar.*—The heavy oil of tar is the product of the distillation of coal-tar between the temperatures of 480° and 760° Fahr.

It generally contains from 5 per cent. to 10 per cent. of cresylic acid, the remainder consisting of heavy oil and naphthaline in varying proportions. An analysis of the oil, as imported from England and used at the works at Slidell, La., gave 9.75 per cent. of carbolic and cresylic acid, 12.50 per cent. of naphthaline, and 77.75 per cent. of heavy oil.

At 65° Fahr. it weighs about 9 pounds per gallon, and boils at a temperature of 265°. It has great antiseptic qualities, and being insoluble in water, has the advantage over all other substances used for the preservation of wood, in that when applied in proper manner, it forms a coating to the woody fiber, which prevents water and air from coming in contact with it. Being insoluble in water, it cannot be removed by immersion in water. It is, moreover, the only substance which will permanently protect timber against destruction by the *Teredo navalis* and other parasites.

Impregnation with heavy oil of tar, or creosoting, as it is sometimes called (from the fact that creosote was considered the active preservative principle), was patented in England by Bethell, in 1838.

The method of treatment proposed by him was to remove the air from the wood, to heat the oil to about 120° Fahr., and to inject it into the wood by pressure. To admit of proper impregnation, the wood should be freed from water so far as possible. In England, air-dried wood is readily procured, which being placed in a closed vessel in which a vacuum has been established, can be easily prepared for the reception of the oil. In this country, where the wood generally has to be impregnated soon after it has been cut, and when steaming has to be resorted to for driving out the sap, special means must be adopted to remove the water of condensation from the wood, after steaming, if the treatment is to be successful.

As to the quantity of oil required to preserve the wood, it may be said that the useful effect of the impregnation is proportional to the quantity of oil injected into a given volume of wood. If all the void spaces in the wood could be filled, it would take from one-half to two-thirds of a cubic foot, or from 35 pounds to 50 pounds of the oil for each cubic foot of timber. The practical limit would probably vary from 25 to 50 pounds per cubic foot, according to the kind of timber used.

But impregnation to such an extent would be altogether too expensive, and the quantity is therefore limited to what has proved by experience to be adequate for preservation under the conditions in which the wood is to be used. From 5 to 7 pounds per cubic foot is at present considered sufficient for railroad ties; about 10 pounds per cubic foot for bridge timbers; and for protecting piles used in marine structures, from 18 to 20 pounds per cubic foot are considered necessary according to the experience of American and French engineers, while English engineers consider 10 pounds per cubic foot sufficient protection for timber and piles in marine works.

The value of creosoting as a preservative against decay is shown by long experience. In England it is almost universally used for preserving railroad ties. Creosoted ties have been found perfectly sound after they had been in the ground for twenty-two years. In this country, creosoting was first applied in 1865 by Hinckley, on the Old Colony Railroad, for the preservation of piles; but the treatment was very imperfect, as the oil did not penetrate to a depth of more than one-quarter to one-half an inch below the surface. The piles were also trimmed and cut after treatment, thereby exposing untreated surfaces.

Yet in 1878, when these piles were examined, 200 of them were still found standing, although not in a sound condition. Some railroad ties (hemlock), which had been creosoted and placed in the track at the same time, were found to be perfectly sound.

Creosoted Cypress ties, which had been laid in the track of the Central Railroad of New Jersey in 1876, on an examination made in 1883 by L. L. Buck, were reported to be sound, not much worn, and in all probability good for ten or twelve years' longer service.

In 1885, Mr. J. W. Putnam examined creosoted piles and bridge timbers, which had been in use on the line of the New Orleans and Mobile Railroad for nine years, and found them all sound; the piles had successfully resisted the attacks of the *Teredo*.

Some failures are reported in this country, but in every instance they can be shown to have resulted from imperfect treatment.

Creosoting works are established at Boston, New York, Pascagoula, Miss., Slidell, La., and Bayou Bonfauca, on the New Orleans and Northeastern Railroad.

Creosoting is undoubtedly the most effective means of preserving wood, and the only obstacle to its universal introduction consists in its being more expensive than any of the other systems of preservation.

(2) *Bichloride of Mercury.*—The use of bichloride of mercury (corrosive sublimate) for the preservation of wood was patented and introduced in England by John Howard Kyan, in 1833, and was soon very extensively applied. It coagulates albumen, and is the strongest antiseptic among metal salts; it is also very poisonous. Its solution attacks iron, consequently tanks, pumps, tools, pipes, etc., for holding it must consist of wood or India rubber, or must be coated with coal-tar. It is soluble in water, and by using hot water a solution can be obtained of 1 part of bichloride of mercury and 6 parts of water. When it is to be used for the impregnation of timber the concentrated solution is diluted with the addition of water. The strength of the solutions used in impregnation has differed greatly. On the Boston railroads, where this antiseptic has been largely used for the preservation of railroad ties and sleepers, the strength of the solution was 1 part of bichloride of mercury to 150 parts of water, and the quantity absorbed by 100 cubic feet of dry pine

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NOTE.—In France all ties are impregnated, preferably with creosote, the cost per tie being as follows:

Cost of tie.	Cost of creosoting.	Total cost.
Oak ......$1 00 to $1 18	20 to 40 cents.	$1 20 to $1 35
Beech ... 67 to 77	40 to 45 cents.	1 07 to 1 20
Spruce .. 35 to 40	15 to 20 cents.	50 to 58

The average duration of ties has been found to be as follows: Oak, not impregnated, lasted on the average 14 years. Oak, creosoted, lasted 18 years. Beech, creosoted, lasted 8 to 10 years. Spruce, creosoted, lasted 12 years.—B. E. F.

wood, in the form of ties, was found to be 6.6 pounds; by 100 cubic feet of oak, 5.5 pounds; and 5 pounds by 100 feet of pine moderately dry, containing a large amount of resin.

On the Eastern railroads the strength of the solution at first was 1 in 240 parts, and at present a solution of 1 in 99 is used. The timber is said to absorb about 2.6 pounds per cubic foot, while Mr. J. B. Francis states that in the Lowell works the wood is found to absorb about 6 pounds of sublimate per 100 cubic feet. In England solutions have sometimes been used containing 1 pound in 46, but without securing as good absorption as was obtained with weaker solutions, since only 2.2 pounds per 100 cubic feet were attained, it being probable that some of the sublimate was precipitated in the pores near the surface, stopping them sufficiently to partly prevent the entrance of the solution to the inside of the wood.

The impregnation of wood with corrosive sublimate has always been carried on by steeping. In Germany wooden tanks, from 20 to 35 feet long and from 4 to 5 feet in height, are used. The rule observed as to the length of time of immersion has been to leave ordinary railroad ties ten days in the tanks, lumber five days, bridge timbers fifteen days. In some works the rule is to steep pine ties for eight days, and oak ties for fourteen days.

At Lowell, Mass., where this process was introduced by Jas. B. Francis, C. E., in 1848, and has been carried on (with an interruption of twelve years, 1850 to 1862) up to this time, the steeping is performed in wooden tanks 50 feet long, 7½ feet wide, and 4 feet deep. The rule laid down by Mr. Francis for the duration of steeping is, that the timber should be kept immersed a length of time depending on its least thickness, one day being allowed for each inch in thickness, and one day in addition, whatever the thickness. This makes the time of immersion for a 6-inch timber seven days. At the works of the Eastern Railroad at Portsmouth, Me., tanks 69 feet by 9½ wide, and 6 feet deep, built of granite laid in cement, are used. The inside of these tanks is coated with coal-tar, applied hot. Ties 6 inches thick, according to H. Bissell, M. M. W., Eastern Railway, require one week; 12-inch timber, two weeks. The time of immersion is, therefore, nearly the same at all works. The difference in the quantity of sublimate absorbed (2.6 pounds per 100 cubic feet at Portsmouth, against 6 pounds per 100 cubic feet at Lowell and in Germany) could be due probably only to the fact that the timber treated at Portsmouth was not air-dried.

Bichloride of mercury being a very active poison, great care in handling it is plainly indicated. In Baden it was considered necessary to take extra precaution against the poisoning of the workmen, and some prejudice was created against this mode of preservation on this account; but the experience in this country on this point is somewhat reassuring. Mr. Francis states that, in an experience in Kyanizing, extending over more than thirty years, he has known no case where the men operating with it have been made ill. He says that men working over the tank in which the corrosive sublimate was being dissolved in hot water sometimes complained, but that he never knew any man to be seriously affected. He mentions, however, that in Kyanized timber an efflorescence of the sublimate has sometimes been observed, which might be injurious to cattle, if licked off from timber to which they have access. This might be prevented to some extent if the precaution used in Germany was adopted, of washing with hot water the surface of the timber when treated, and before being exposed. Mr. Bissell corroborates the statements of Mr. Francis. He states that the man in charge of preparing the solution has, in a few instances, been nauseated for a short time by inhaling vapor arising from the solution; but that he believes this would have been prevented by a little more carefulness, and that the men handling the timber never suffered any injury, although frequently careless.

The testing of a solution of the sublimate, as to its strength, can readily and accurately be performed. A graduated test tube being filled with it, a solution of iodide of potassa is added, which precipitates the oxide of mercury as a red powder, which by the further addition of the solution of iodide of potassa is again dissolved, so as to leave a clear liquid. The change in color can be accurately observed, and the numbers on the graduated test tube can be so arranged that the man in charge can read off the weight of bichloride of mercury to be added to bring the solution to its proper strength.

There is ample testimony as to the efficiency of bichloride of mercury as a preservative of wood. The railroad ties of the Baden Railroad, impregnated with it, lasted from twenty to thirty years. Mr. Francis states that in 1850 he put up a fence of Kyanized spruce lumber, which is still perfect, not a single piece having been removed during the thirty-five years, and only part of the wood which was under ground having decayed. The Pawtucket Street Bridge, built in 1849 of northern White Pine (Kyanized), did not require any repair until 1882, a period of thirty-three years. Kyanized timbers were used in nine spans of the Burr truss bridge, at Georgetown, which stood from 1840 to 1862, and failed, not from the decay of its timbers, but from bad construction. The Blackstone River Bridge, on the New York and New England Railroad, a Pratt truss built of Kyanized timber in 1848, when taken down in 1876, after twenty-eight years' service, was found but slightly decayed. Two bridges on the Philadelphia and Reading Railroad, built in 1850 of Kyanized timber, proved sound after twenty years.

The experience in this country as to Kyanized ties is not as favorable as in Baden. This may be due to two causes. On the Baden Railroad the ties and all other timbers are air-dried during two or three weeks after impregnation and before being laid, which precaution is probably not observed in this country, and the road-bed in which the ties of the Baden Railroad were laid consisted of a very dry gravel, which allowed all rain-water to run off at once. But even on other German roads the success of Kyanizing has been remarkable, and the failures which are recorded were due in many cases to imperfect impregnation.

Still, from the experiments of Mr. Francis, it seems to be certain that Kyanizing will give better results when the timber is exposed to air than when placed underground. This results very likely from the sublimate being gradually dissolved and washed out. It might be prevented probably by first drying the treated timber and then giving it a coating of dead oil, on the ends at least.

(3) *Chloride of Zinc.*—The use of chloride of zinc for the preservation of timber was patented by Burnett, in England, in the year 1838.

Chloride of zinc is prepared by dissolving metallic zinc in hydrochloric acid. In its most concentrated form it contains 32 per cent. of zinc, but generally only 25 per cent. The specific gravity of a solution of this strength is about 1.6. It is sometimes made from zinc skimmings, and is then liable to contain free hydrochloric acid and chloride of iron; the first, like nearly all free acids, reduces the strength of the timber, while the second reduces the value of the solution as an antiseptic.

Chloride of zinc has the greatest affinity for wood fiber, and is hygroscopic, both being qualities which increase its value as a preservative. It is also a very strong antiseptic. Burnett at first recomnended to use a solution of 1 part (by volume) of concentrated chloride of zinc to 59 parts (by volume) of water. In Germany stronger solutions were frequently used, 1 in 30, 1 in 24, and in one case even 1 in 14 parts. But it was found, as in the case of corrosive sublimate, that by using these stronger solutions the quantity of zinc absorbed by the wood was not proportionally increased, because such solutions would not so readily enter the cells, and that some portions of the timber received an excessive amount of the zinc chloride, while others received little or none. The presence of an excess of chloride of zinc, moreover, seems to injure the fiber, causing brittleness in the wood, and to prevent these consequences the strength of the solutions on German railroads has been reduced to 1 in 50, or 1 in 60.

In this country solutions of 2 in 100 and 3 in 100 were used at first (Erie Railway Company). On the Philadelphia and Western Railroad the solution used contained 5 or 6 in 100; on the Philadelphia and Reading Railroad, 3¾ in 100; on the Havre de Grace Bridge, 1.12 in 100. At present the solutions generally used have a strength of 1.9 or 2 in 100. The strength of solutions is generally measured by the areometer; but the specific gravity of the solutions of zinc chloride changes so rapidly under changes of temperature that errors are unavoidable, unless proper corrections for temperature are made.

The weight of concentrated chloride of zinc, which was absorbed from a solution of a strength of 1 in 60, was found to be as follows on the railroads of Hanover, Germany:

100 cubic feet of Oak absorb 22 pounds of concentrated chloride of zinc.

100 cubic feet of Beech absorb 106 pounds of concentrated chloride of zinc.

100 cubic feet of spruce absorb 50 pounds of concentrated chloride of zinc.

At the works lately built at Las Vegas, N. Mex., with a solution containing 1.5 parts of concentrated chloride of zinc in 100 parts (by volume)—

Hewn ties absorb 33 per cent. of solution (by volume), or 49 pounds of concentrated chloride of zinc in 100 cubic feet.

Sawed ties absorb 17 per cent. of solution (by volume), or 24 pounds of concentrated chloride of zinc in 100 cubic feet.

Piles 40 feet long, 17 inches at the butt, 12 to 14 per cent., or 16 pounds of concentrated chloride of zinc in 100 cubic feet.

With a solution of a strength of 2 in 100, the absorption would be 75 pounds, 32 pounds, and 21 pounds per 100 cubic feet, respectively.

The efficiency of the chloride of zinc in preserving wood is well attested.

On roads in Hanover 169,000 ties (Burnettized oak) lasted, on an average, 19.6 years.

On the Rhine Emden Railroad 161,515 Burnettized Fir ties lasted, on an average, 22.8 years; 81,000 Beech ties, on the Hanover Railroad, lasted, on an average, 14.8 years; while, when left untreated, the average duration of oak ties in Germany is 14 to 16 years; of fir ties, 7 to 8 years, and of Beech ties 2½ to 3 years.

As to the success of this mode of preservation in this country, the following facts may be mentioned: Of 2,000 Burnettized ties laid on the Chicago, Rock Island and Pacific Railroad in 1866 (pine, Tamarack, and cedar, and the greatest part Hemlock), when examined in 1881 by M. Alexander, roadmaster, 75 per cent. were still found present in the track, and in such condition that they might do good service for 2 or 3 years longer.

L. L. Buck reports that in 1882 he examined a lot of Burnettized ties laid in 1866 and 1868, consisting of Maple, Beech, and Hemlock, and found them, with few exceptions, in a good state of preservation, and more particularly the Hemlock ties. He expresses the opinion that, although in the ground for 16 years, they would probably last from 7 to 8 years longer.

R. M. Chaffee, president of the Union (horse) Railroad at Cambridge, Mass., states that of a lot of Burnettized spruce sleepers laid in that railroad, many were found in good condition after 28 years' service.

A truss bridge of 8 spans, built for the Chicago, Rock Island and Pacific Railroad of Burnettized timber in 1860, was still in fair condition in 1882.

Where Burnettizing failed, it was due to improper treatment. The fact alone that 22 out of 48 German railroad companies, who preserve their ties, use this antiseptic might be accepted as a proof of its efficiency as a preservative.

(4) *Sulphate of Copper.*—Sulphate of copper (blue vitriol) had long been known as a strong antiseptic; but was first used for the preservation of wood by Boucherie, in the year 1838. When used for this purpose it should be free from deleterious admixtures, among which the most common, and at the same time most injurious to wood, is sulphate of iron; for sulphate of iron is easily decomposed, and the free sulphuric acid resulting therefrom attacks and weakens the wood fiber.

The solution of sulphate of copper recommended by Boucherie consisted of 1 part (by weight) of sulphate of copper to 100 parts (by weight) of water.

The increase of timber in weight by impregnation with sulphate of copper was found by Boucherie, when his method of treatment was used, to be as follows per 100 cubic feet: pine, 140 pounds; oak, 145 pounds; Hemlock, 320 pounds; Beech, 540 pounds.

But this increase in weight does not express the weight of dry sulphate of copper taken up by the wood, nor the weight of the diluted solution of sulphate of copper absorbed.* The weight of dry sulphate of copper absorbed by Beech was found to be 32 pounds in 100 cubic feet of wood, and this is the weight of dry sulphate of copper which 100 cubic feet of this kind of wood is required to contain (1.1 pounds per tie of 3.5 cubic feet), under the specifications of the French engineers.

When the Boucherie process of impregnation is used, the weight of sulphate of copper required per cubic foot may be set down at 40 pounds per 100 cubic feet, to make allowance for loss in antiseptic resulting from his mode of treatment. Impregnation with solutions of sulphate of copper has been carried on by almost every known method of treatment, viz: by steeping, by the Boucherie process, and by vacuum and pressure.

One disadvantage in the use of this antiseptic consists in the fact that boilers, pipes, pumps, and tools used in carrying on the process must consist of copper, because contact with iron decomposes the sulphate of copper. This, of course, largely increases the cost of the necessary plant.

Another respect in which treatment with sulphate of copper is inferior to treatment with chloride of zinc, at least in preserving railroad ties, may be found in the fact, that when ties treated with sulphate of copper are placed in the track, the iron rails and spikes coming into contact with the sulphate of copper will decompose the latter, producing free sulphuric acid, which attacks the fiber and injures the strength of the timber. In some cases the endeavor has been made to prevent this by

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* Boucherie found that in 23 hours 3,060 liters of solution entered into a Beech log 15 meters long and averaging 0.9 meters in diameter, or about ⅓ of its total volume.

covering the ties, where they touched the rails, with coal tar, and by using galvanized spikes. Sulphate of copper is less hygroscopic than chloride of zinc, and ties treated with it are more liable to crack.

There is one point, however, in which it is superior to chloride of zinc, and which is of very great importance, when the treatment is to be effected under contract. While it is difficult to control the strength of a solution of chloride of zinc used in impregnation, or to find by chemical analysis the actual quantity of zinc contained in the timber after impregnation, both of these operations can be performed with great accuracy, and without much expenditure of time or money, when sulphate of copper is used. There can be less cheating, and, therefore, the success of the treatment as a means of preservation is more fully assured. To show the efficiency of the sulphate of copper in prolonging the life of wood, it may be stated that, according to German experiments, 60,000 fir ties which had been merely steeped in a solution of sulphate of copper lasted on an average 13.9 years; that 36,000 ties of the same kind of timber, which had been boiled in a solution of this same antiseptic, and laid on the Berlin, Potsdam and Magdeburg Railroad, lasted on an average 14 years; and that 111,000 fir ties, impregnated with sulphate of copper under pressure, averaged 16 years of usefulness; while unimpregnated fir ties used in the same railroads lasted only from 7 to 9 years. It may, therefore, safely be assumed that the durability of such ties would be doubled by proper treatment with sulphate of copper.

The use of sulphate of copper has been nearly abandoned in France, but is still carried on by some of the German railroads.

In this country it has been used only in connection with the Thilmany process, which will hereafter be described. One obstacle to its use may have been found in the fact that sulphate of copper formerly cost much more than chloride of zinc; but the price of copper has declined so much of late that the difference in cost has been greatly reduced.

NOTE.—The outfit for the Boucherie process is light and inexpensive, as well as that for Kyanizing, consisting of tanks in which to mix and store the preserving liquid and troughs to receive the sap; or, with the latter process, tanks in which to soak or steep the timber. The Burnettizing process and the Bethell process must prepare the wood by steaming, etc., and require iron cylinders, a steam boiler, and pumps. But the usual form can be modified, as Colonel Flad has indicated, by using two or more smaller cylinders with boiler and pumps, all attached to trucks or arranged to be easily handled, and with all pipe connections so arranged as to be made or broken readily.

The advantages of a movable plant have received less attention and have been tested less than they deserve. The transportation of timber is of course a considerable item of expense. A plant of moderate size could be taken to the various sources of supply from which the timber comes or to the most economical distributing points, and thus the cost of transportation, in one direction at least, would often be saved.—H. C.

METHODS AND SUBSTANCES USED TO RETAIN ANTISEPTICS.

The heavy oil of tar, being insoluble in water, will not be removed from timber which has been impregnated with it, even if the timber is permanently submerged in water. But the metallic salts at present used in wood preservation, bichloride of mercury, chloride of zinc, and sulphate of copper, being injected into the wood in the form of aqueous solutions, are of course liable to be dissolved again by moisture and eventually to be removed when the timber is exposed to the action of water. Experiments made by chemists seem to prove that a portion at least of the sulphate of copper and of chloride of zinc combines with the fiber of the wood and cannot be removed again; but all that has not been fixed by such combination may, in the course of time, be removed from the wood when permanently immersed in water. Metallic salts should, therefore, not be used when wood is exposed to the constant action of water, and it would be desirable to adopt means for preventing even the gradual, but much slower, removal of the salts by rain and moist air, although the favorable results with wood which had not received such extra protection leaves some doubt as regards its economical value.

The methods which are now used for preventing the "washing out" of the metal salts are: (1) The Thilmany process; (*a*) with sulphate of copper; (*b*) with sulphate of zinc. (2) The Wellhouse process. (3) The zinc-gypsum process. (4) The zinc-creosote process.

1. *The Thilmany Process.*—Thilmany, in 1869, took out a patent for a method of preservation by which the wood was first to be impregnated with sulphate of copper and then to be immersed in a bath of chloride of barium. An interchange of the constituents of these two salts, if brought together in the proper proportions, would leave the timber impregnated with chloride of copper and sulphate of barium, which latter, being insoluble in water and in all acids, was expected to fill up the pores of the wood so as to prevent the removal of the chloride of copper by water entering from the outside.

The process was first tried at Cleveland, Ohio, with blocks for wood pavement. As far as I am informed, the wood was treated with sulphate of copper by the Boucherie process and then immersed in a bath of chloride of barium. In 1881 I took up and examined some of the elm-wood blocks which had been thus treated and laid down in Saint Clair street in 1870, and found them perfectly sound after eleven years' exposure on the street.

Works were erected at Defiance and Milwaukee, where the timber and ties were treated with the Thilmany preservatives by steaming, vacuum, and pressure. But the results were not very favorable. At Defiance a solution of 1.5 in 100, and later one of 2 in 100, was injected with a pressure of 80 to 100 pounds until all the pores of the wood (as Mr. Thilmany says) were charged with the solution, when the boiler was filled with a

1½ per cent. solution of chloride of barium. It is hard to conceive how the second solution could enter the pores already filled with the solution of sulphate of copper, and where the chloride of barium reached the first solution it left chloride of copper, the value of which as an antiseptic is uncertain, and some sulphate of barium inside of the wood, which could do neither good nor harm. The treatment of the paving blocks at Cleveland was evidently more rational, because by the Boucherie process the wood was well impregnated with sulphate of copper, and the soaking in chloride of barium only produced an interchange near the ends, where the formation of the insoluble sulphate of barium was of the greatest benefit in stopping up the pores to some extent, and if not preventing, at least impeding, the ingress of water and the washing out of the sulphate of copper from the inside.

Mr. Thilmany later used sulphate of zinc, instead of copper, in connection with chloride of barium, but the process does not appear any more rational. If the interchange of the chemicals throughout the lumber could occur, it would leave the wood impregnated with chloride of zinc and sulphate of barium; but as such a complete interchange is impossible, part of the sulphate of zinc would undoubtedly remain unchanged, and as its antiseptic powers are not established, the result as to preservation must be uncertain.

2. *The Wellhouse Process.*—Another device for preventing the removal of the zinc chloride has been invented by Mr. Wellhouse and is extensively used. It is based on the fact that glue and tannin, brought together in proper proportions, will form a substance resembling leather. The timber is steamed in the usual manner, inclosed in a vacuum, then impregnated by pressure with a solution consisting of chloride of zinc and glue, and afterwards subjected to a bath of tannin under pressure. The impregnation with glue, it is claimed by the president of the company using this process, will destroy all tannic acid within the wood. But the benefit derived from this chemical combination is not apparent, since tannin is rather a preservative than otherwise. The bath of tannin, the president further states, precipitates the glue remaining in the outer pores of the wood, retaining a greater percentage of chloride of zinc in the wood than would be the case if it were simply Burnettized. But while the latter claim may be substantially correct, it remains to be seen whether the introduction of an uncombined organic substance into the inside pores will prove favorable to preservation.

The question whether the zinc tannin process gives better results than the ordinary Bethell process will be decided within a few years, as a number of works for treating ties by this process have lately been constructed by the Atchison, Topeka and Santa Fé Railroad at Las Vegas, N. Mex., and by the Union Pacific Railroad at Laramie, Wyo., and the process is also used for preserving ties for several railroad companies at the Chicago works of the company.

The works, at Santa Fé, which have within a year been erected on the plans and partly under the supervision of Mr. O. Chanute, C. E., are constructed and operated in accordance with all the requirements of the best modern practice. At the Las Vegas works an accurate and full record is being kept of all the operations and of all expenditures, more complete than has ever been approached, so far as I know, in this or probably any other country, and which, when published in full, will give more trustworthy information as to the cost of wood preservation than has heretofore been obtainable.

The data contained in these reports, which have been kindly furnished to me through Col. Edgar T. Ensign, forestry commissioner of Colorado, have been very useful in determining the comparative cost of the several processes now in use for the preservation of wood.

Whether the use of glue and tannin in connection with the zinc chloride will prove a success or not, the works erected under Mr. Chanute's directions, and the methodical system of operating them initiated by him, will do as much for the proper preservation of timber by mineral salts as Andrews, at Boston, and J. W. Putnam, in the South, have done for the proper application of the creosoting process.

3. *The Zinc-gypsum Process.*—The process was patented by Mr. Hagen, of Saint Louis, and is used by the American Wood Preserving Company. In this process the timber is impregnated with a solution containing both chloride of zinc and gypsum. When the water of the solution evaporates the gypsum crystallizes and is expected to stop up the pores of the wood, and thus prevent the washing out of the zinc-chloride. The question arises, whether a substance soluble in water to some extent like gypsum can be expected to permanently stop up the pores of the wood against the ingress and egress of water. It seems hardly possible that the gypsum would answer the purpose. The best that can be said for this process is, that if the addition of gypsum does no good it cannot do harm, and that if the wood is impregnated thoroughly with a solution of chloride of zinc and gypsum it will last as well at least as wood simply Burnettized.

4. *The Zinc Creosote Process.*—A process has lately been proposed by Mr. Jas. T. Card, President of the Wood Preserving Works at Chicago, Ill., viz: To impregnate the timber first with chloride of zinc, and after partially removing the moisture from the wood to inject dead oil through the outer portions of it, thereby securing, as Mr. Card states, "all the benefits derived from the oil when lumber comes into contact with the ground, as well as insuring thorough treatment of the wood, through chloride of zinc, which is protected by the oil surrounding it, thus preventing its being chemically changed or washed out."

The process seems rational, and would probably answer a good purpose, if the necessary time and money can be spared to thoroughly dry the timber after impregnating it with zinc chloride. and before injecting the oil.

COST OF PRESERVATION.

In order to make a fair comparison of the cost of treatment with the different antiseptics now in use, I will assume that the same kind of timber and the same form, viz, that of hard railroad ties, each containing 3.5 cubic feet, is to be treated, and that the quantity of antiseptic solution used, and the strength of the solution, are to be in conformity with the best practice, as developed by experience in plants of given size.

a. Creosoting.—Assuming that two injection cylinders are to be used, each 100 feet long and 6 feet in diameter, the total volume of each cylinder will be 2,800 cubic feet, and it will have a capacity of nearly 1,400 cubic feet of timber (making allowance for volume of cars and interstices). The total plant required would cost, say, $80,000. If it takes twelve hours for a run, 5,600 cubic feet, or 1,600 ties (of 3.5 cubic feet each), can be treated per day; or, say, 500,000 ties, or 1,750,000 cubic feet, can be treated in a year.

Taking the interest on capital (including repairs and renewal) at 10 per cent., the item of interest on plant will be $8,000, or 1.6 cents per tie.

Assuming the proper quantity of dead oil at 7 pounds per cubic foot, or 24.5 pounds per tie, and the cost of the oil at 0.8 cents per pound, the cost of material will be 19.6 per tie.

The cost of labor and fuel chargeable to treatment alone, judging from the accounts kept at Las Vegas, may be taken at about $15 per run, or, as 400 ties are treated at once, 3.75 cents per tie, or 1.07 cents per cubic foot of timber. The total cost of creosoting a tie would be, therefore:

	Per tie.	Per cubic foot.
	Cents.	*Cents.*
Interest on capital..	1.6	0.46
Material	19.6	5.6
Labor and fuel......	3.75	1.07
Total	25.00	7.1

The cost of transporting the ties to and from the works would of course have to be added, and profit, if the work is done by contract.*

I may mention, that the above price for the dead oil is smaller than has been generally assumed, this because lately I have been offered dead oil at ⅓ of a cent per pound. At that price the cost of creosoting would be only about 14½ cents per tie.

If piles or timber were to be creosoted and impregnated with 20 pounds per cubic foot, it would take about sixty hours for a run, and the

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* See note of cost of creosoting in France on page 78.

total number of runs per annum would be 240 (with 2 cylinders); the number of cubic feet of timber treated per annum, 350,000; the labor and fuel per run, $60, and the total cost of treating 1 cubic foot of timber: Interest on plant, $\frac{8000}{350000}$=2.3 cents per cubic foot; material (20 pounds at 0.8 cents), 16.0 cents; labor and fuel, 4.3 cents; total, 22.6 cents, or about $19 per 1,000 feet B. M.

b. Kyanizing.—If the impregnation is to be carried out in the ordinary way, by steeping, and if the works are to be of sufficient capacity to treat 250,000 ties per annum, or, say, 800 ties, equal to 2,800 cubic feet of timber per day, and if the steeping is to be continued for 7 days, there must be tank-room for, say, 20,000 cubic feet of timber. Allowing 1.3 cubic feet of tank-room for 1 cubic foot of timber, the total capacity of the tanks required will be 26,000 cubic feet, and if tanks 50 feet long, 7.5 feet wide, 5 feet deep are used, about 14 tanks will be required.

The plant would cost probably $10,000, and on 250,000 ties the charge for interest on plant would be (at 15 per cent. in repair and renewal) 0.6 cents per tie.

If 0.06 pound of bichloride of mercury is used per cubic foot, or 0.21 pound per tie (of 3.5 cubic feet), and the sublimate costs 50 cents per pound, the cost of material is 50 x 0.21=10.5 cents per tie. Labor and fuel would be about 3.5 cents per tie, and the total cost of Kyanizing:

	Per tie.	Per cubic foot.
	Cents.	*Cents.*
Interest on capital	0.6	0.17
Material	10.5	3.00
Labor and fuel	3.5	1.00
Total	14.6	4.17

Bridge timber would have to be steeped during two weeks, instead of one, and as, therefore, only half so much lumber could be treated as in the case of ties, the interest on capital would be doubled, the cost of material and labor remaining the same; the cost of treatment per cubic foot would, therefore, be increased only about one twenty-fifth, and would be 4.34 cents per cubic foot.

c. Chloride of Zinc.—If ties are to be impregnated by steaming, vacuum, and pressure, the cost of plant required (in connection with two injecting reservoirs) is about $40,000. Assuming the time used for one run at 10 hours, 60 runs could be made per month with each cylinder, or 120 runs with the two cylinders, or 1,450 runs per annum. Taking 400 ties per run, the total number of ties which could be treated in a year would be 580,000, equal to, say, 2,000,000 cubic feet of timber. Allowing 10 per cent. interest on cost of plant will give $4,000, or $\frac{400000}{580000}$=0.69 per tie, or 0.2 per cubic foot. The cost of concentrated chloride of zinc (specific gravity 1.5) is about $2.60 per cubic foot. If the solution has a strength, 1 in 60, 1 cubic foot of it will cost 4.3 cents, and if the wood takes up 33 per cent. (by vol.) of the solution per cubic foot, it will require $\frac{1}{3}$ cubic foot of the weak solution, costing 4.3, $\frac{260}{180}$=1.44 cents per cubic foot of lumber, or 5 cents per tie. Labor, at $10 per run, will cost $14,500 or 0.72 cent per cubic foot, or 2½ cents per tie. The total cost of this mode of preservation will, therefore, be:

	Per tie.	Per cubic. foot.
Interest on plant	0. 69	0. 2
Material	5. 04	1. 4
Labor and fuel	2. 52	0. 7
Total	8. 25	2. 3

d. Zinc Tannin.—If, in addition to chloride of zinc, glue and tannin are used, the cost of material is increased by 2.5 cents per tie, and the cost of labor and fuel $\frac{1}{5}$, or 0.5 cents per tie, making the total cost 11.25 cents per tie, or 3.2 cents per cubic foot.

e. Sulphate of Copper.—If a solution of sulphate of copper, 1 in 100, was to be injected by the same process, the change in cost would be in interest on plant and cost of material. As such works would cost about $60,000, the item of interest would be increased by one-half. As to cost for materials, sulphate of copper can now be bought at 7 cents per pound. Adding 99 pounds of water, 100 pounds, or 1.5 cubic feet of, the solution will cost 7 cents, or 1 cubic foot, 4.6 cents.

Again, if one-third cubic foot of the solution be injected, the cost of material per cubic foot of wood will be 1.5 cents, and the cost per tie, 5.25 cents. The total cost of preservation would then be:

	Per tie.	Per cubic foot.
Interest	1. 05	0. 3
Material	5. 25	1. 5
Labor and fuel	2. 5	0. 7
Total	8. 80	2. 5

f. Solutions of Chloride of Zinc, or Sulphate of Copper, injected by the Boucherie Process.—To treat 800 ties per day with zinc direct (pressure) by the Boucherie process, would require an investment of capital of about $5,000. The interest on this sum, at 20 per cent. (including repairs and renewal), would be $1,000, or on 250,000 ties, 0.4 cents per tie.

The quantity and cost of the chloride of zinc and sulphate of copper would be the same as when treated by the modern process, plus one-quarter for loss of solution from treating round sticks and from leakage. The labor would be 3½ cents per tie, and the total cost:

ANTISEPTIC.

	Chloride of zinc.	Sulphate of copper.
	Per tie.	*Per tie.*
Interest	0. 40	0. 40
Antiseptic	6. 25	6. 56
Labor	3. 50	3. 50
Total	10. 15	10. 46

If the impregnation is to be produced by suction, the cost of plant will be $12,000, the cost of the antiseptic the same as before, and the cost of labor also the same, since, although it requires two men to attend to the same number of logs which one man can attend to in the direct Boucherie process, the treatment is completed in half the time.

The cost of preservation by this method is, therefore, as follows:

ANTISEPTIC.

	Chloride of zinc.		Sulphate of copper.	
	Per tie.	Per cubic foot.	Per tie.	Per cubic foot.
Interest, repairs, and renewal, 20 per cent	0. 96	0. 28	0. 96	0. 28
Antiseptic	6. 25	1. 80	6. 56	1. 90
Labor	3. 50	1. 00	3. 50	1. 00
Total	10. 71	3. 08	11. 22	3. 18

Recapitulation of cost of preservation of railroad ties with different antiseptics and methods.

[Volume of ties, 3.5 cubic feet.]

Antiseptics.	Method of treatment.	Total cost.	
		Per tie.	Per cubic foot.
1. Dead oil	Modern method	25. 00	7. 13
2. Bichloride of mercury	Steeping	14. 60	4. 17
3. Chloride of zinc	Modern process	08. 25	2. 30
4. Chloride of zinc and tannin	Modern process	11. 25	3. 20
5. Sulphate of copper	Modern process	08. 80	2. 50
6. Chloride of zinc	Direct Boucherie	10. 15	2. 90
7. Sulphate of copper	Direct Boucherie	10. 46	3. 00
8. Chloride of zinc	Boucherie (suct.)	10. 71	3. 08
9. Sulphate of copper	Boucherie (suct.)	11. 22	3. 18

As before stated, these estimates do not embrace the hauling of ties to and from the works. If the ties are destined for a new road just built, the preservation of ties by processes 2, 6, 7, 8, 9, in which the plant can be moved from one place to another, saves the carrying of the ties to distant works for treatment. No. 2, however, requires seasoned wood, and does not, therefore, offer as great advantage as the others. The entire cost of this transportation might, in some cases, amount to 5 or even 10 cents per tie.

CONCLUSION.

By Howard Constable, C. E.

The practicability and economy of wood-preservation have been brought in question often, because the processes have been conducted by dishonest contractors or have been based upon some unwarrantable theory rather than upon any scientific principles. Nevertheless many successes have been achieved, and improvements have been made in the details of treatment and in mechanical contrivances to meet the conditions peculiar to this country. The follwing table* of experiments, in addition to those mentioned by Col. Flad, is certainly encouraging.

Both here and abroad the durability of wharf and other timber subject to severe exposure has been and can be at least doubled. The durability of piles and other timber subject to the attacks of the sea-worm *Teredo* can be prolonged three or four times. The possible economy resulting from the use of treated Hemlock ties, instead of White Oak in their natural condition, has been estimated by Mr. O. Chanute as follows: For a road with about 2,000 miles of track, containing about 5,000,000 ties, $250,000 in first cost every twelve years, and $250,000 each year in the average charge for renewal of ties. Some moderate-sized roads use as many as 400,000 ties a year, and have to get from one-quarter to one-half of them from other territory than their own, which, of course, results in the railroads putting great obstructions to the shipping of ties out of their own region, and necessitates going to great distances for the extra supply.

A few are familiar with all these facts, but the majority, and the economists or business men, frequently realize them only partially, and do not appreciate the importance of the subject to themselves. We shall be accomplishing much if we aid in giving these persons a comprehensive and clear idea of it in its general bearings.

One of the first things to be clearly understood is that the field of wood-preservation is a very large one, embodying many natural and artificial conditions somewhat different in each particular locality and case. Every one cannot preserve wood with advantage. It cannot yet be done cheaply enough for ties on a new road in a heavily wooded district, any more than we could use stone for depots in such a region

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* See p. 98.

Nor is there any "cure-all" process by which any wood for any and every purpose can be preserved. Piles, which are cut to pieces by the *Teredo* within two years, require different treatment from ties to be placed in an ordinary road-bed, as the method of handling and transporting perishable freight must differ from that of ordinary freight, necessitating more care and expense. Any system to be adapted to a variety of work and to give promise of economical results must have the harmonious co-operation of all concerned in its operations and faithful attention to details. Each one in any way connected with the work should have a general understanding of it, and a precise knowledge of his own particular duties and the limits to be observed. If this is not the case the purchasing agent may contract for timber quite unsuited to the purpose for which it is procured; the superintendent may overlook the importance of ample facilities of operation; the engineer may not comprehend the degree of treatment required, and the inspector and workmen may become careless and so ruin the work.

The need of intelligent co-operation is here emphasized because it has been neglected frequently and caused processes in themselves good to be attended with unsatisfactory results.

If a business man—the president, perhaps, of some company—thinks the subject of wood-preservation may have in it some benefit for him, or those whom he represents, his main inquiries are, What does it amount to? Will it pay? Will it make a conspicuous item of economy? How will it affect our policy and dealings with others? Is it practicable in our case?

The manager asks somewhat the same questions, but inquires further, What are the conditions and necessities in our case? What is the best process and its cost? What are the conditions for success? What facilities have we? What rules shall be laid down?

The engineer or foreman in charge wishes to know what precisely is the composition of each ingredient, what is the order and time of each step in the process, what are the requisites and facilities, and what standard must be exacted in order to insure success.

Thus it becomes plain how the physical and commercial divisions of the subject interlace and require to be in accord. In order to select a process and lay down rules for the guidance of all connected with it, it is necessary to decide what purpose and exposure the wood is to be subject to, then to ascertain accurately all the conditions which prevail in the special case, and to determine the length of life that should be secured. Questions like the following will come up naturally and almost necessarily for answer: What is the name, quality, and cost of the wood to be used; its use and exposure; nature of soil and water; average length of life; sources of injury, such as *Teredo*, notching and framing, cutting by the rail, etc.; destroyed by what? Cost of renewals. Available woods for treatment. Cost of the same. Probable quality and condition. Receiving point. Distributing point. Location for preserving-works. Capacity of plant. Cost of plant. Cost of operating.

I may be permitted to quote from the recent and very instructive report on the preservation of timber, made in 1885, by a committee of the American Society of Engineers, after a careful and protracted examination of the subject:

"In view of the differing cost of the various antiseptics used, and of the price of timber in this country, where it is still much cheaper than in Europe, we believe that the method to be selected for preserving wood, if any, depends almost wholly upon its proposed subsequent exposure.

"If the timber is to be exposed, in sea water, to the attacks of the *Teredo navalis* and *Limnoria terebrans*, there is but one antiseptic which can be used with our present knowledge. This is creosote or 'dead oil,' and the amount of it necessary depends upon the activity of the *Teredo*, or rather upon the length of time during the year when the temperature of the water renders them active.

"In our northern harbors, probably 10 to 12 pounds of creosote to the cubic foot of timber are sufficient, but in southern seas it is probably necessary to inject from 14 to 20 pounds per cubic foot.

"Whether it will pay to do this depends upon so many local circumstances in each case that this cannot well be discussed here. If the timber is to be exposed in a very wet situation, creosoting is also the best process to use. It will cost from $10 to $20 per 1,000 feet, b. m., or 35 to 60 cents per tie.

"The selection of the oil, as well as the quantity, is of importance. It was formerly believed that the antiseptic properties of dead oil arose from the presence of carbolic and cresylic acid, but a very able paper by Mr. S. B. Boulton, the leading authority on creosoting in England, read before the British Institution of Civil Engineers in 1884, seems to establish the fact that the preserving properties of dead oil, aside from the mechanical effect in keeping out moisture, are chiefly due to 'acridine,' or one of the alkaloids or bases now known to exist in creosote oils.

"If the exposure is to be that of a railroad tie, creosoting is doubtless the most perfect process to use; but in view of the expense, it may be preferable to use a cheaper process, dependent somewhat upon the location, as away from the seaboard creosote is not available, and transportation is expensive."

"Sleepers of Baltic Fir, unprepared, 9 feet long and 10 x 5 inches, generally cost, in England, about 90 cents each, unloaded, grooved, and piled; and creosoting adds about 24 cents to this. So that the sleeper costs about $1.14 ready to go into the track, and is there laid with a chair under the double-headed rail, so that the latter does not cut into the wood. These sleepers, therefore, last 18 to 20 years, while in this country they would probably be cut into by our foot-rail in from 12 to 16 years; and, moreover, as the first cost of our ties, of corresponding timber, say hemlock or mountain pine, is only from 25 to 35 cents, we cannot afford to spend an equal sum in preserving them; and creosoting is notoriously more expensive here than in England.

"With our present knowledge, and as a result of this investigation, we believe that Burnettizing is the advisable process to use for ties at present in this country. This, if well done (and it is nearly useless to do it otherwise), will cost 20 to 25 cents per tie, and a discussion of the economical results to be expected therefrom will be found in Appendix No. 17.

"Good results may be accomplished with sulphate of copper, but not only does this salt render wood brittle (more so, it is believed, than chloride of zinc), but as the copper attacks iron vessels, its use necessitates preserving cylinders of copper, and requires an expensive plant.

"The great defect of all mineral salts is that they are easily soluble in water, and so wash out in time, and leave the timber unprotected. Hence the many attempts to patent some method of retaining them in the wood. What these may be worth must be determined by time, but the desirable combination for this country would seem to be the impregnation of the inside of the tie with some metallic salt to poison the germs of decay, and a thin coat of creosote outside to repel the intrusion of moisture.

"If the timber is to be exposed in a comparatively dry situation, as in bridges, a trestle, or a fence, the results of this investigation indicate that Kyanizing is a good process to use. It does not seem to impair the strength of the timber as much as Burnettizing, and the latter accordingly is not recommended for those parts of structures (chords, ties, etc.) which are to bear tensile strains.

"Kyanizing costs about $6 per 1,000 feet, b. m., and success with it cannot be expected unless the work be well done. Caution will need to be observed in carrying it on, as corrosive sublimate is a violent poison.

"*Conditions of success.*—Your committee will therefore attempt to state the principal conditions to be observed to achieve success, so far as they have been disclosed by this investigation.

"(1) Select the appropriate process, in view of the subsequent intended exposure of the timber.

"(2) Select the more open-grained, porous, and sappy varieties of wood to operate upon.

"Antiseptics penetrate but little into the dense structure of White Oak, Burr Oak, and Yellow or Heart Pine, and are of doubtful utility for White Pine, Chestnut, or Spruce, while they readily impregnate and preserve the following varieties of wood: Hemlock, Sweet Gum, Mountain Pine, Loblolly Pine, Black Oak, Red Oak, Gray Oak, Water Oak, Beech, Poplar, Ash, Sour Oak, Cottonwood, Maple.

"The cheap woods, on the contrary, can be made to outlast the best woods in their natural state by a thorough artificial preparation.

"For railroad ties it will be advisable to select the harder kinds of wood to guard them against cutting into by the rails, especially upon curves. Preservation, however, materially adds to the natural hardness of timber, and it is found to resist cutting by the rail, under ordinary traffic, from 12 to 16 years.

"(4) Extract the sap and water, as far as practicable, before injecting the preservative. It is obvious that a liquid solution cannot be forced in unless there is a place for it, and yet most of the failures of valuable methods can be traced to neglect of this obvious requirement. Timber must be well seasoned either naturally or artificially before the antiseptic is injected, except in the case of the Boucherie process, which can only be applied to freshly cut logs.

"The Europeans operate, as has been stated, upon timber which has been cut and seasoned six months or more, and hence they find little trouble in injecting the solutions. In this country we must operate chiefly upon green or freshly cut timber, and hence must resort to steaming, if we use the pressure method of injection. Very good results are acomplished by steaming, but the work must be well done, and at such heat and pressure as not to injure the fiber.

"(5) Put in enough of the antiseptic to accomplish the desired result, and make sure that its quality and strength are such as neither to injure the fiber of the wood nor to leave it unprotected.

"(6) After the wood is prepared allow it to dry as much as practicable before using. Its durability will be materially increased by getting rid of surplus moisture.

"(7) Let there be no undue haste in carrying on the work. This is sure to result in unsatisfactory preparation.

"(8) In laying prepared ties or timber in the track protect them from moisture or water, as far as practicable, by draining the road-bed.

"(9) Contract with none but reliable parties. As an inspection subsequent to the doing of the work, short of chemical analysis, does not establish the fact whether it has been well done, and the results cannot be detected for some years, there will always be a great temptation to do bad or careless work under contracts. The safe course, therefore, for those who decide to have timber preserved is either:

"(*a*) To do the work themselves, under the supervision of experts;

"(*b*) To contract it at a sufficient price to honest and skillful parties, keeping an inspector at the works to note the daily working when the magnitude of the order will warrant it; or,

"(*c*) Contract the work on such terms that the profits shall depend upon the results accomplished in preserving the wood against decay.

"*Will it pay?*—The question as to whether it will pay to preserve timber against decay seems to have been answered very positively in the affirmative in Europe. There seems to be, indeed, no longer any question there about it; preservation is looked upon as quite a matter of course, and public works which fail to avail of it are alluded to as neglecting an important economy.

"In this country, preservation of wood (except in an experimental way) has been the rare exception, but the time has probably arrived when, in many sections, an economy of 20 to 50 per cent. a year can be obtained in the maintenance of timber structures and cross-ties by preparing them artificially to resist decay, while in other sections timber is still too cheap to warrant spending money to preserve it.

"This depends upon the price. Thus, where a White Oak tie costs 25 cents and lasts eight years, if we spend 25 cents in preparing it so that it will last sixteen years, we but double the life as well as the cost, and save only the expense of taking the old tie out and placing the new tie in the track at the end of the first eight years, if the price of the ties in the meanwhile continues the same.

"If, however, the Oak tie costs 75 cents, and we can substitute a Hemlock tie, which unprepared would last three and a half years, and cost 30 cents, and by preparing it extend its life to twelve years, at an additional cost of 25 cents, or even more, we then have a notable economy, both in first cost and in duration.

"In the case of piles, which are cut off by the *Teredo* in one or two years, as occurs in our southern harbors, the case is plain. They must be creosoted, or great waste and increased expense will result. In cases where they last eight to ten years, as in some northern sections, it will depend partly upon the value of the structure which the piles sustain whether it will pay to creosote them or not.

"In the case of bridges and trestles, much will depend upon the exposure, and the cost of maintenance, as well as upon the proximate exhaustion of suitable timber in the vicinity, and upon contemplated permanent renewals; while in the case of buildings, platforms, floors, &c., the ordinary wear from traffic will also have to be taken into account.

"The most important factor will be the exposure (wet or dry) and consequent rate of decay. Thus all brewers find it very economical to preserve their floors; and mills, bleacheries, dye-houses, &c., largely resort to artificial preparation of timber because of their exposure to slopping of water, and consequent moisture in heated apartments.

"The engineers and managers of the several works, therefore, will have to figure up for themselves, in view of the local circumstances of their case and the present and prospective price of timber, whether the economy of artificial treatment is sufficiently attractive to induce them to resort to it.

"The great consumers of timber are the railroads, and the managers of such enterprises have to be governed by a good many considerations, both of finance and of expediency, besides those of eventual economy.

"Hitherto, aside from the past cheapness of timber, the principal objections to its preparation against decay have been the lack of information as to what results could be confidently expected, and the conflicting claims of the promoters of various modes of treatment, each of whom represented his process as absolutely the best under all circumstances.

"Railroad managers naturally want to obtain immediate returns. They do not like to burden the revenues of the current year for the benefit of future administrations, and they are with reason jealous of every dollar that goes out now, even if it promises to save $2 or $3 in the future; yet, now that close competition requires every possible economy to be availed of, that railroads must more largely depend upon saving money in their maintenance, in order to continue or to resume their dividends, and that companies in good standing can obtain new capital for expense-saving appliances at 4½ or 5 per cent. a year, the time has probably arrived, in view of advancing prices and scarcity of timber, when some leading railroads will take steps to preserve it.

"Privy Councillor Funk estimates that in 1878, out of sixty millions of sleepers on the German railroads, twenty-five millions were impregnated, and that even with the extraordinary length of life stated for unprepared ties (13.6 years for Oak and 6.1 for Fir and Pine), had the remaining thirty-five millions of ties been impregnated there would have been a resulting economy of about $1,000,000 a year, or some 33 per cent. on the cost of renewals.

"This estimate is understood as having resulted in a material extension of tie-preserving in Germany, notwithstanding the fact that metallic ties have already been largely introduced in that country.

"As regards the latter, a simple calculation shows that the time has not yet arrived when they can profitably be introduced in this country. They will cost, laid in the track, about $2.50 each, and were they to last forever (the estimated life in Germany is twenty to forty years) the interest on the cost, at 5 per cent., would be 12½ cents a year a tie, or more than the annual charge of an unprepared White Oak tie, costing 77 cents in the track, and lasting seven years.

Record of Successful American Experiments in Wood-preservation.

No.	Locality.	Year.	Process.	Material treated.	Subsequent exposure.	Results.	Authority.
1	Vermont Central Railroad	1856	Bethell	Hemlock ties	Railroad track	Success, 1882	J. W. Hobart.
2	Chicago, Rock Island and Pacific Railroad	1860	do	Timber	Howe truss	do	Hugh Riddle.
3	do	1866	do	Ties	Railroad track	Success	M. Alexander.
4	Lehigh and Susquehanna Railroad	1867	do	do	do	Success, 1882	L. L. Buck.
5	New Orleans	1872	Boiling	Paving-blocks	Paving	do	T. Forstall.
6	East River bridge	1872	Steaming	Plank	Caisson	do	F. Collingwood.
7	Boston	1872	do	do	Floor	do	Blake Manufacturing Company.
8	Galveston	1874	do	Pine blocks	Stable	do	W. E. Gregory.
9	New Orleans and Mobile Railroad	1876	do	Piles	Teredo	do	J. W. Putnam.
10	Bound Brook Railroad	1876	Hayford	Ties	Railroad track	do	E. R. Andrews.
11	New Orleans and Mobile Railroad	1876	Steaming	Timber	Bridges	do	J. W. Putnam.
12	Delaware Bay	1878	do	Pine blocks	Teredo	do	W. Ludlow.
13	Philadelphia and Reading Railroad	1878	do	Ties	Railroad track	do	W. Lorenz.
14	Charlestown, Mass	1879	Thilmany	Spruce plank	Sidewalk	Success to 1882	S. G. White.
15	Hudson River Railroad	1869	Hamar	Ties	Railroad track	do	E. W. Vanderbilt.
16	Alexandria	1840	Steeping	Timber	Bridge	Success to 1862	W. R. Hutton.
17	Lowell Canal Company	1848	do	do	Bridges	Continued success	J. B. Francis.
18	Philadelphia and Reading Railroad	1850	do	Pine timber	do	do	J. D. Steele.
19	Blackstone Bridge	1854	do	do	Bridge	do	W. H. White.
20	Saint Louis, Mo	1879	Burnettizing	Gum blocks	Pavement	do	H. Constable.

REPORT ON WOOD-CREOSOTE OIL.

By William H. Bixby,
Captain of Engineers, U. S. A.;
Member of the American, British, and French Societies of Engineers;
Member of the American and British A. A. S.

The Southern Pine (*Pinus palustris*, Linn.) has already made a brilliant record for itself in the past through its valuable products in the shape of turpentine, pitch, tar, and rosin; but there remains for it a much more brilliant career in the future through its newer products wood-creosote oil and pine-leaf fiber, the oil being used mainly for preserving lumber, and the fiber for the manufacture of pillows, mattresses, and carpet matting.

The wood-creosote oil industry is at present carried on in the South mainly by the Carolina Oil and Creosoting Company, and Creosote-Lumber and Construction Company, of Wilmington, N. C., and the following description of the products and processes is based upon the practice of the latter manufactory.

Creosote is a general name applied to the oil products obtained by the destructive distillation of wood, coal, and other carbonaceous fuels after the temperature has risen above 200° or 300° F. If obtained by the distillation of coal, or coal-tar, this creosote is termed "dead oil," or coal-tar creosote-oil; if obtained from the distillation of wood, or wood-tar, it is termed wood-creosote oil.

Heavy resined, "fatty pine" wood, subjected to a heat of from 200° to 760° F., within closed iron cylinders, yields by distillation and condensation: (1) a wood-gas; (2) a small amount of wood naphtha; (3) a large amount of pyroligneous acid; (4) a large amount of wood-creosote oil; (5) a small amount of wood bitumen; and (6) a large amount of charcoal. Nine cords of good wood will yield a few gallons of naphtha and bitumen, 14 barrels of oil, 10 barrels of acid, and 168 barrels of charcoal.

The wood-creosote oil produced by this process is a dark, brownish, black oil, slightly heavier than water (3° to 4° Baumé), with a strong creosote odor, and possessing valuable antiseptic properties. Upon analysis it is found to contain about 5 per cent. of tar acids, about 15 per cent. of lighter oils, and 80 per cent. of heavy oils, which are insoluble in ether, fresh, brackish, or salt-water. This oil is an efficient poison to minute animal and vegetable life, and possesses an odor apparently intensely disagreeable to such life; it thoroughly repels moisture, and its tar-acids possess the power of coagulating albuminous and other fermentable matter. When properly prepared for such use it has been found to be an excellent insecticide to be employed on trees and smaller plants, especially for the destruction of larvæ attacking rose bushes, as also for destroying vermin on animals, in the cracks of floors, and in wooden buildings, and one of the best possible oils for preserving lumber and piling.

Experience in England* and in the United States† is unanimous in agreeing that creosoting is the only reliable method, so far tried, for preserving timber when exposed to salt water (and the *Teredo* worm), or to alternations of wetting and drying by either fresh or salt water. This experience also shows that the preservation of the timber is due mainly to those creosote oils which require over 400° F. for their volatilization, and that the pure creosote (with less tar-acids and with less light-oils) gives the best results.

Wood-creosote oil is much less expensive, and in many ways much more valuable, than the ordinary dead oil or coal-tar creosote oil heretofore used for such purposes as the preservation of timber. Wood-creosote oil contains all the acids needed to properly coagulate the albumen and sap which may be left in the timber, and to thoroughly destroy and prevent all further animal and vegetable life; it is of such nature that it will penetrate the wood both deeply and thoroughly; it contains a large proportion of insoluble matter, and especially of those oils which volatilize only under a heat of over 400° F.; and being derived from wood, it is especially adapted to use with wood.

In all these particulars, as well as in its less cost,‡ the resinous wood-creosote-oil is superior to the bituminous coal-tar creosote-oil (or dead oil), and, dollar for dollar, it will give far superior results in the preservation of timber from destruction and decay.

Applied with an ordinary brush to wooden or metal surfaces of all kinds, two coats of this oil (with an interval of two months between the applications) will effectually preserve these surfaces from wet and dry-rot, from rust, and from the attacks of worms and insects. Forced into the wood by hydraulic pressure, this oil will fill all the pores of the wood and extend its coagulating and antiseptic effects entirely through the wood to its very center. The good results obtained by the use of this wood-creosote oil have been thoroughly tested by the experience of five years in Mr. Mark's ship-yard, at Charleston, S. C., and at Mr. W. H. Northrop's bath-house, at Greenville Sound, near Wilmington, N. C., both places being such that untreated wood is badly damaged in a

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* See Proceedings of Institution of Civil Engineers for 1885.

† See Proceedings of American Society of Civil Engineers for 1885.

‡ It is to be regretted that the cost of treating wood with this wood-creosote oil has not been given, so as to admit of a comparison on a financial basis with the processes outlined by Colonel Flad. An effort to obtain the same has so far proved unsuccessful.—B. E. F.

single season by rot and by the ravages of the *Teredo*. A log treated with this oil, and driven into salt-water, at Key West, Fla , in October, 1885, by the United States engineers, in February, 1887, was found to be untouched by the *Teredo*, although untreated logs were attacked by it in six weeks after they were driven. Similar results were obtained at about the same time by the United States engineers at Charleston, S. C., and at Pensacola, Fla.

The comparative invulnerabilty to fire possessed by wood that has been treated with this oil has been proved at the burning, in the fall of 1886, of the Atlantic and North Carolina Railroad wharf, at Morehead City, N. C., where the creosoted fender-piles remained almost without damage by the fire, while the wharf and shed next to them were burned down entirely. Live coals and ordinary flames are unable to kindle any fire in wood impregnated with this wood-creosote oil.

The pyroligneous acid produced during or just before the distillation of the wood-creosote oil is a light-colored, vinegar-like liquid, slightly heavier (4° to 7° Baumé) than water, and also slightly heavier than the wood-creosote oil. This pyroligneous acid, in its crude and undiluted state, is an excellent and inexpensive disinfectant, immediately arresting putrefaction and preventing any further development of the disagreeable and unhealthy odors arising therefrom. It is equally if not more efficacious than carbolic acid, as well as being free from odor, which makes that acid so disagreeable (at least to many), and it is nearly or quite as efficacious as corrosive sublimate, and is free from the poisonous qualities of this chemical. It is an excellent remedy for skin diseases in animals; makes good vinegar and alcohol, and is said to preserve meats for an indefinite time. As a disinfectant it has been used in large quantities and with great success in the streets, stables, privies, etc., of Wilmington, N. C., under direction of the city authorities.

The charcoal produced by this process is one of fine quality and of remarkably even texture, well adapted for use in the smelting of iron, as well as for ordinary fuel. When finely pulverized (as at the Wilmington works) it can be advantageously used in the place of lamp-black in the manufacture of paints for the preservation of wood, as also for the preservation and insolation of metals.

As will be seen from the above the most important product of the distillation of pine wood is the wood-creosote oil, and the most important use (commercially) of this oil is as a preservative of timber and lumber.

The general features of the process of distillation and subsequent use of this oil are as follows:

Ordinary "light wood" (or "fatty pine" wood) is cut up into sticks of about 4 feet in length, and about five cords of these sticks closely packed inside of a large cylindrical iron retort. The doors of this retort are then closed and hermetically sealed. A fire is then built in the furnace under the retort, and the heat and flames are directed as uniformly as possible all around the outside of the retort. As the temperature inside the retort increases from 100° to 700° F., the liquid and some of the solid portions of the wood are converted into gas and vapor, and pass out of the retort through a copper "worm" inclosed in a cold-water tank and are collected in the form of wood-gas, naptha, acid, and oil. When the oil ceases to run, the fires under the retort are put out, the bitumen is drawn off through a tube coming from the bottom of the retort, and the latter is then allowed to cool off. As soon as possible, therefore, the doors of the retort are opened and the charcoal raked out. The operation is thus finished, and the retorts are ready for a fresh charge.

Timber and lumber which is to be treated with this oil must be first prepared to receive it. Timber is taken directly from the river by large derricks, is landed on the wharf, is stripped of its bark, and then exposed to the sun for a week or ten days to dry. At the end of this time it is placed (one stick at a time) on trucks, is rolled into the carbonizing cylinder, is there exposed from about ten to twenty minutes to an intense radiated heat, and is then withdrawn charred to a depth of one-fourth of an inch, thoroughly dried to a depth of three-fourths of an inch, and thoroughly heated to a depth of several inches.

The carbonizing cylinder consists of a wrought-iron cylindrical tube about 21 feet long by 28 inches in diameter, set in a brick furnace, fired at the side and midway of its length, the cylinder being brought to a proper and uniform heat by means of a wood fire, the heat and flames of which pass by vertical and horizontal flues along and all around the cylinder. The cylinder is further provided with a small railroad track and iron carriage on the inside, for the convenient handling of the timber. Sawn lumber is not usually charred, but is sometimes kiln-dried or semi-charred; the objection to the charring being that it destroys the sharp edges of the lumber. The charring or carbonizing of the process, therefore, consists in taking the timber and subjecting it to a dry radiant heat within the suitable cylindrical surfaces in such manner as to drive out of the timber most of its sap and albuminous matter (ordinarily about five pounds to the square foot), drying the inside of the timber, charring its outside, and leaving the wood with its pores open and in condition to be completely filled with the wood-creosote oil thereafter applied to it.

Charred timber, once thoroughly carbonized, will not crack under subsequent exposure to the sun and air. If further properly treated with wood-creosote oil, it will withstand all attacks of atmosphere, moisture, and animal life, and will last for years anywhere.

This process for carbonizing and creosoting timber is such that it does not injure the fiber of the interior of the wood. It is one of the simplest, cheapest, quickest, most effective, and most successful processes so far known for artificially seasoning and preserving wet or green timber, in cases where the want of time or money do not allow a thorough natural seasoning of at least six months' exposure to the atmosphere. Although other and improperly applied methods of dry-heating and after-creosoting may render timber brittle under the pile-driver, none of the timber so far carbonized and wood-creosoted has proved objectionable from this cause. On the contary, the wood-creosote restores the toughness and elasticity to the charred wood, so that this method has given great satisfaction wherever used, as, for example, at Aspinwall, Panama, under the Panama Canal Company; and at Charleston, S. C., under the Northeastern Railroad Company; in both cases under circumstances extremely unfavorable to the life of the timber.

After the wood has been carbonized or kiln-dried, it is loaded upon trucks, which, with their load, are rolled into the creosoting cylinders, respectively of 65, 75, and 90 feet in length, each with a diameter of 6 feet. The doors of the creosoting cylinder are then closed for from four to fifteen hours, during which time the temperature within the cylinder is raised by dry heat to from 140° to 160° Fr., a vacuum of from 9 to 24 inches is kept up by means of a vacuum-pump, and the sap, albumen, and other impurities are thus thoroughly extracted from the wood and pumped out of the cylinder.

The vacuum-pump is then stopped and a force-pump put to work, by which the cylinder is filled with hot wood-creosote oil, under a pressure of from 65 to 100 pounds per square inch, this pressure being constant from four to eight hours, according to circumstances. By this part of the process from eight to twenty pounds of oil are forced into each cubic foot of wood. The pressure is then relaxed; the unabsorbed oil is then run off into outside tanks, the doors of the cylinders opened, and the impregnated timber, still on its trucks, is rolled out.

This treatment with wood-creosote oil, as above described, has been favorably reported upon (March 18, 1886) by a special board of United States Navy officers; and the wood so treated has had an extensive use already upon the Government wharf at Charleston, S. C., at the jetties at Port Eads in the M. T. and E. P. Inclined Railway at Cincinnati, Ohio, as well as in many other less important places and structures.

Treatment with this oil is especially valuable to wood that is to be used in the construction of bath-houses, wharves, docks, quays, piers, railroad bridges, railroad trestles, wooden pavements, flats, lighters, scows, ship spars and masts, ship decks and bottoms, or used in railroad cross-ties, foundation sills for houses, piazzas, porches, floors, fence-posts, and telegraph poles. No cases have yet been discovered where either rot or *Teredo* has attacked wood that was thoroughly impregnated with this wood-creosote oil.

ADDENDA.

By B. E. F.

In the experiments recently made by Dr. Boehme, to ascertain the relative effect on impregnated and natural wood, samples of various treatment demonstrated that impregnated wood absorbed much less water than the natural wood. Increase in volume in consequence of absorption of water was less in the impregnated than in the natural samples.

Tests of the bending strength of the samples showed that those impregnated were stronger by 15 per cent. Resistance to compression was greater by about 22 per cent. in the case of the impregnated samples.

It would appear of interest to state here that by creosoting the strength of the timber is also increased. The following results confirming this view are taken from some experiments which were submitted to the British Civil and Mechanical Engineers' Society some time ago. The sizes of the pieces tested were 2 feet 6 inches by 2 inches by 1½ inches; the pressure was applied midway between supports 2 feet apart.

	Series No. 1.—Six pieces of Memel fir, not creosoted, weighing 9¼ pounds.	Series No. 2.—Six pieces of Memel fir, creosoted, cut out of the same plank as preceding, weighing 13½ pounds.	Series No. 3.—Six pieces of Scotch fir, not creosoted, weighing 9 pounds.	Series No. 4.—Six pieces of Scotch fir, creosoted, cut out of the same sleeper as the preceding, weighing 16½ pounds.
	Cwt.	*Cwt.*	*Cwt.*	*Cwt.*
No. 1 broke with	12½	12	15	16
2	10½	12	14	14
3	10½	11	12½	14½
4	11½	11	13	17½
5	11	11½	13½	14
6	10	12½	14	16
Average....	11	11⅔	13⅔	15⅓

Summary of Average Results.

	Cwt.
Memel fir not creosoted	11
Memel fir creosoted	11⅔
Scotch fir not creosoted	13⅔
Scotch fir creosoted	15⅔

CARBOLINEUM AS A PROTECTION AGAINST THE DECAY OF WOOD.

According to F. Engel, Government surveyor of buildings, painting wood with carbolineum as a protection against the weather and rot gives favorable results. The Imperial Government surveyor of buildings also confirms this statement in a certificate under date of January 19, 1885, in which he states that on the imperial roads wood-work used in underground construction during the years from 1870 to 1885, when painted with carbolineum, had no decay up to date of certificate.

For the sake of experiment, two pieces of pine wood, taken from the same plank, were thus treated: The first was painted with carbolineum, while the second was left in its natural state, and both placed in the ground under the same conditions. At the end of three years the painted specimen was found to exhibit no signs of decay, but the unpainted one was in a rotten state.

The district surveyor of buildings inclines very favorably to the use of carbolineum on buildings in the water, and on sluice-gates, dam-barriers, piles, posts, especially when the wood is kept wet or dry, or by turns wet and dry.

It is found that carbolineum is cheaper than the semi-fluid tar. For an area of six square meters one kilogram of carbolineum is ordinarily used; and its superiority over tar is shown by the fact that even the largest manufacturers, where tar is a by-product, and the use of which costs nothing, are coming to use carbolineum.

It is best and most advantageous to paint with hot carbolineum, for in this state it is more fluid than when unboiled, and for this reason penetrates into all cracks and openings, at the same time dissolving any resin or oil present; it also disinfects more energetically in a warm state than in a cold one. In warm weather, and on wood when the surface is not buried in the earth, it is necessary to give a thicker coating of the unheated oil, especially as it can be repeated after a while. Wood that is not completely air-dried must always be treated with hot carbolineum. All the wooden posts of bridges that are exposed to changes of wet and dry, as well as their gravel-covered layer of planks, are painted with two coats of hot carbolineum. All knotty wood surfaces must be very carefully treated, applying only so much as will be readily absorbed. The knotty surfaces of wood being the places where the ducts open, these are thus the very localities where the decay and destruction from lower organisms begin, and it is on this account that they must receive special protection. One kilogram of carbolineum (which comes in casks of about two hundred kilos. each), costs 0.3 marks=7 cents.

ANNUAL CHARGES FOR TIES.

By B. E. Fernow.

There appears to have been some difficulty experienced by engineers in coming to a conclusion as to how different processes ought to be compared in regard to the annual charge, which must vary according to the difference of the initial cost of the ties and the difference in the number of years that they will last, and, in addition, to the frequency at which the expense of renewal recurs. The difficulty, it seems, need not exist at all, and can be removed by the application of simple mathematical formulas and mathematical deductions, and put into a form which will allow a ready comparison of the annual charge for ties of different prices and varying conditions. For this purpose the following tables have been constructed, which give answer in a convenient manner to many questions that may be put in connection with the matter of charges.

From Table I. we find, for instance, if we pay 40 cents for a tie, the life of which is six years, making the annual charges 7.88 cents, that we can afford to pay 15 cents per tie in addition for a process that will lengthen its life to nine years; or, if we pay 25 cents for a preserving process, making the initial cost 65 cents, the life of the tie must be increased to at least eleven years in order that it may not increase the annual charge. Or if an oak tie, lasting eight years, can be bought for 50 cents, it would be cheaper to buy hemlock at 30 cents, though it may last but five years.

The formula used in the construction of Table I. is that for the capitalization of regular annual rents, and, by transposition, assumes the form, $r=\frac{\mathrm{R}\ 1.0\ p^{n}}{1.0\ p^{n}\ \ 1}0.0\ p$, in which r=rent or annual charges; R=capitalized rent; p=rate of interest; ^{n}=the number of years for which the charge is to run; and $1.0\ p=\frac{100+p}{100}$. p is taken at 5 per centum, but as the table is intended only for purposes of comparison, the rate of interest is really irrelevant, except to allow a statement of the amount of saving or increased expenditure effected.

In this table no account is taken of the reduction in annual charges due to the less frequent expenditure for renewal with ties of longer duration. For this a separate calculation and addition are necessary, for which the figures are given in Table II.

For the expense of renewal occurring in stated but not at yearly intervals, the formula for the capitalization of intermittent rents is applicable, which by transposition appears as $r=\frac{\mathrm{R}}{1.0\ p^{n}-1}0.0\ p$. For each cent of such expense, then, the amount which appears under the year at which renewal becomes necessary should be added to the annual charge found in Table I. Example: An oak tie costing 50 cents in the road-bed, and lasting eight years, would make an annual charge of 7.74 cents; the extra expense for renewal every eight years, at 10 cents per tie, would increase this annual charge by $0.105\times10=1.05$ cents, or total annual charge equal to 8.79 cents. The same tie, by creosoting, made to last sixteen years, in order to keep the annual charge the same, may cost 90 cents, for annual charge due to cost of renewal $0.042\times10=0.42$ cents. Charge on cost of 90 cents,
8.30 cents,
8.72 cents, the total annual charge,

TABLE I.—*For computing Annual Charges.*

Initial Cost.	Years of duration.																	
	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	16.	18.	20.	22.	24.	26.	28.	30.
	Cents.	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*
30 cents	6.93	5.91	5.18	4.64	4.22	3.89	3.61	3.38	3.19	3.03	2.76	2.56	2.40	2.27	2.17	2.08	2.01	1.95
35 cents	8.08	6.89	6.04	5.41	4.92	4.53	4.21	3.93	3.72	3.53	3.22	2.99	2.80	2.65	2.53	2.43	2.34	2.27
40 cents	9.23	7.88	6.90	6.19	5.62	5.18	4.81	4.49	4.25	4.04	3.69	3.42	3.20	3.03	2.89	2.78	2.68	2.60
45 cents	10.39	8.86	7.76	6.96	6.32	5.82	5.41	5.04	4.78	4.54	4.15	3.84	3.61	3.41	3.26	3.12	3.01	2.92
50 cents	11.54	9.85	8.63	7.74	7.03	6.47	6.01	5.60	5.32	5.05	4.61	4.27	4.01	3.79	3.62	3.47	3.34	3.25
55 cents	12.70	10.84	9.49	8.51	7.73	7.12	6.61	6.15	5.85	5.55	5.07	4.70	4.41	4.17	3.98	3.82	3.68	3.57
60 cents	13.85	11.82	10.35	9.28	8.43	7.72	7.21	6.71	6.38	6.06	5.53	5.12	4.81	4.55	4.34	4.16	4.01	3.90
65 cents	15.00	12.81	11.22	10.06	9.14	8.41	7.81	7.26	6.91	6.56	5.99	5.55	5.21	4.93	4.70	4.51	4.35	4.22
70 cents	16.16	13.79	12.08	10.83	9.84	9.06	8.41	7.82	7.44	7.07	6.45	5.98	5.61	5.31	5.07	4.86	4.68	4.55
75 cents	17.31	14.78	12.94	11.61	10.54	9.71	9.01	8.37	7.98	7.57	6.91	6.41	6.01	5.69	5.43	5.21	5.02	4.87
80 cents	18.47	15.76	13.81	12.38	11.25	10.36	9.62	8.93	8.51	8.08	7.37	6.83	6.41	6.06	5.79	5.55	5.35	5.20
85 cents	19.62	16.75	14.67	13.15	11.95	11.00	10.22	9.48	9.04	8.58	7.83	7.26	6.81	6.44	6.15	5.90	5.69	5.12
90 cents	20.97	17.73	15.53	13.93	12.65	11.65	10.82	10.04	9.57	9.09	8.30	7.69	7.21	6.82	6.51	6.25	6.02	5.85
95 cents	21.93	18.72	16.39	14.70	13.35	12.30	11.42	10.59	10.10	9.59	8.76	8.12	7.62	7.20	6.89	6.59	6.36	6.17
100 cents	23.08	19.70	17.26	15.48	14.06	12.95	12.02	11.15	10.64	10.10	9.22	8.54	8.02	7.58	7.25	6.94	6.69	6.50
105 cents	24.24	20.69	18.12	16.25	14.76	13.59	12.62	11.70	11.17	10.60	9.68	8.97	8.42	7.96	7.61	7.29	7.03	6.82
110 cents	25.39	21.67	18.98	17.02	15.46	14.24	13.22	12.26	11.70	11.11	10.14	9.40	8.82	8.34	7.97	7.63	7.36	7.15
115 cents	26.54	22.66	19.85	17.80	16.17	14.89	13.82	12.81	12.23	11.61	10.60	9.82	9.22	8.72	8.38	7.98	7.70	7.47
120 cents	27.70	23.64	20.71	18.57	16.87	15.53	14.42	13.37	12.76	12.12	11.06	10.25	9.62	9.10	8.70	8.33	8.03	7.80
125 cents	28.85	24.63	21.57	19.35	17.57	16.18	15.02	13.92	13.30	12.62	11.52	10.68	10.02	9.48	9.06	8.68	8.37	8.12
Add for each additional 5 cents	1.154	0.985	0.863	0.774	0.703	0.647	0.601	0.560	0.532	0.505	0.461	0.427	0.401	0.379	0.362	0.347	0.334	0.325

TABLE II.—*For computing Annual Charge of Renewal.*

Cost of Renewal.	Year of Renewal.																	
	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.
	Cents.	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*
1 cent	0.317	0.232	0.181	0.147	0.123	0.105	0.09	0.079	0.07	0.063	0.051	0.042	0.039	0.03	0.026	0.023	0.019	0.017	0.015
10 cents	3.17	2.32	1.81	1.47	1.23	1.05	0.90	0.79	0.70	0.63	0.51	0.42	0.39	0.30	0.26	0.23	0.19	0.17	0.15
12 cents	3.80	2.78	2.17	1.76	1.48	1.26	1.08	0.95	0.84	0.76	0.61	0.50	0.47	0.36	0.312	0.28	0.23	0.20	0.18
15 cents	4 76	3.48	2.72	2.21	1.85	1.58	1.35	1.19	1.05	0.95	0.77	0.63	0.59	0.45	0.39	0.35	0.29	0.26	0.225
20 cents	6.34	4.64	3.62	2.94	2.26	2.10	1.80	1.58	1.40	1.26	1.02	0.84	0.78	0.60	0.52	0.46	0.38	0.34	0.30

Appendix No. 3.

METAL RAILROAD TIES.

By B. E. Fernow.

The following notes on the subject of metal ties were gathered from numbers of leading technical journals (largely foreign and therefore less accessible), and represent opinions and experiences of competent railroad engineers, also what little experience and information could be gathered from American practice. If, therefore, statements on some points seem not to harmonize, it must be inferred that opinions of good authorities differ as to those points. Hardly more than the arrangement of matter is claimed to be original. The object of this compilation is to present in a ready form for reference the scattered data, and to aid the railroad managers in forming their opinion as to the advisability of employing the substitute for wooden ties on their own roads.*

In the foregoing report, to which these notes form an appendix, it has been shown that the railroads of this country consume yearly about 75,000,000 wooden ties, having an estimated actual cost value of at least $25,000,000.

This consumption forms no inconsiderable drain upon the forests of the country, and the need of economy in the use of these resources should secure a ready welcome to any substitute for wooden ties, at least in an experimental way. Mr. C. P. Sandberg, the well-known expert in railroad matters, says: "The enormous consumption of wooden ties and their rapid decay, particularly in hot countries, make the use of metal ties desirable, especially with the decreasing price of metal and the greater expense of wooden ties. The substitution of metal ties for wooden ones is of course entirely a question of locality and of price."

Although the impregnation of ties does somewhat retard the process of decay, yet the use of wood for railroad purposes cannot be considered satisfactory.

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* The journals consulted are mainly Schweizerische Bauzeitung, Organ für Fortschritte des Eisenbahnwesens, Revue Générale des Chemins de fer, Glaser's Annalen fur Gewerbe und Bauwesen, Congrès des Chemins de fer à Bruxelles, compte rendu générale, 1886.

Changing conditions of weather, by repeated soaking and drying of the tie, inevitably induce change of volume, and therefore alone make a safe fastening of the rails to a wooden tie problematic.

To this add the also problematic capacity of the fastenings, whether spikes or bolts, to secure the rail.

Further, there is to be considered the very unequal capacity of resistance which ties show, according not only to the kind of timber, but to the locality from which they come. This difference of quality depends on a number of influences, such as the conditions of the soil on which the tree has grown, the age of the tree, as well as the season of its felling, and cannot be overcome by impregnation or otherwise.

Quite different are the possibilities in this respect with iron or steel as material.

The unevenness of the track, produced by varied behavior of the ties, works detrimentally also on the rails and on all parts of the roadbed, so that for safety as well as efficiency and ultimate economy alone the metal superstructure deserves consideration.

From a railway point of view the introduction of metal ties recommends itself as affording additional revenue, if otherwise the cost of first construction and of maintenance is satisfactory, *for the manufacture of a ton of steel ties creates a traffic over the railways of two tons of raw material.*

The first introduction of metal (then iron) ties dates back probably to the year 1864, when the Brunswick railways in Germany laid test lengths of longitudinal iron stringers, so that an experience of over twenty years, valuable on some points at least, is afforded. The Dutch and Swiss companies followed soon with improvements in the system of construction, and the use of this substitute has been gradually extended, so that now all the railroad companies of Holland have introduced metal ties on their lines.

In order to make the first introduction of metal ties possible, it was necessary to make the initial cost of the longitudinal tie (Hilf system) as near that of the wooden structure as possible; consequently they were rolled unduly thin, the rail also was made weak, and thus breakages were not unfrequent, creating distrust of the system. The attempt to remedy this by increasing the weight of ties from seventy-seven to one hundred and sixty-five pounds failed on account of the increased expense. The same fate attended the attempt to strengthen the tie by riveting or bolting to it plates for the rail to rest on, because of increased cost and less secure connection between rail and tie.

Two systems of metal superstructure have been used in practice, the longitudinal and the cross-tie.

The first metal ties were constructed upon the longitudinal system (Hartwich, Hilf, Scheffler), and even to-day, after nearly a quarter of a century of trial, opinions as to the superiority of one or the other system are wide apart, though latterly preference seems to favor the cross-tie plan. The longitudinal ties, which were at first thought to be the only possible form, are abandoned gradually for cross-ties. Statistics as to the use of metal cross-ties on the Continent in 1885 were given before the Railroad Congress at Brussels as follows:

	Companies.	Miles laid with metal.	Total length of roads.
Germany	9	1, 806	14, 754
Holland	4	181	2, 053
Switzerland	4	49	1, 530
	17	*2, 036	18, 337

*11 per cent.

One of the Swiss companies—the North Eastern Railway of Switzerland—has definitely adopted metal cross-ties for all new roads and the renewal of old ones.

In England the drain which the Indian railways made in the tie market induced experiments with steel ties in 1884. Twenty steel ties (Vautherin pattern), ninety pounds per tie, with rail of ninety-five pounds, bull-headed form, lying in two half chairs, were laid. Creosoted paper was placed underneath the ties to deaden the sound. To-day millions of metal ties are used in India.

The Mexican Railway (Vera Cruz), after an experiment of two years with twenty thousand steel ties on level ground and on heavy grades, has proposed to put in yearly hereafter from forty to fifty thousand.

The change from the wooden to the steel tie is made entirely in the interest of economy, and it is calculated that in a few years the permanent section-gang on the road can be replaced by traveling gangs, who will be able to keep the road in order, the number of men employed under the new system being only 50 per cent. of those embraced in the present permanent section system.

No better testimony to the efficiency of the metal tie under proper condition could be given than the following extracts from a letter in reply to a request for information from George Foot, Esq., Superintendent of the Mexican Railway, stating his experience.

"Our experience with these ties, of which some 30,000 have been in the line since September, 1884, is so satisfactory in every respect, that we are now about to lay down 40,000 more, and our intention is to gradually relay the entire line with metallic sleepers.

"I inclose a blue print*, showing the type of tie we are about to lay down, one which is about the same as that employed on the State railways of India for both the 5.6-meter gauges, but arranged for our gauge, which is 4′ 8½″.

"The price of the new ties under contract in England is 4*s.* 4*d.* ($1.05) each, including steel keys f. o. b. in Cardiff, and their weight with keys 112 lbs. each.

"The metallic ties in use here for the last two years are almost of the same pattern as shown on the drawing, excepting the fastenings, which are much more complicated and expensive.

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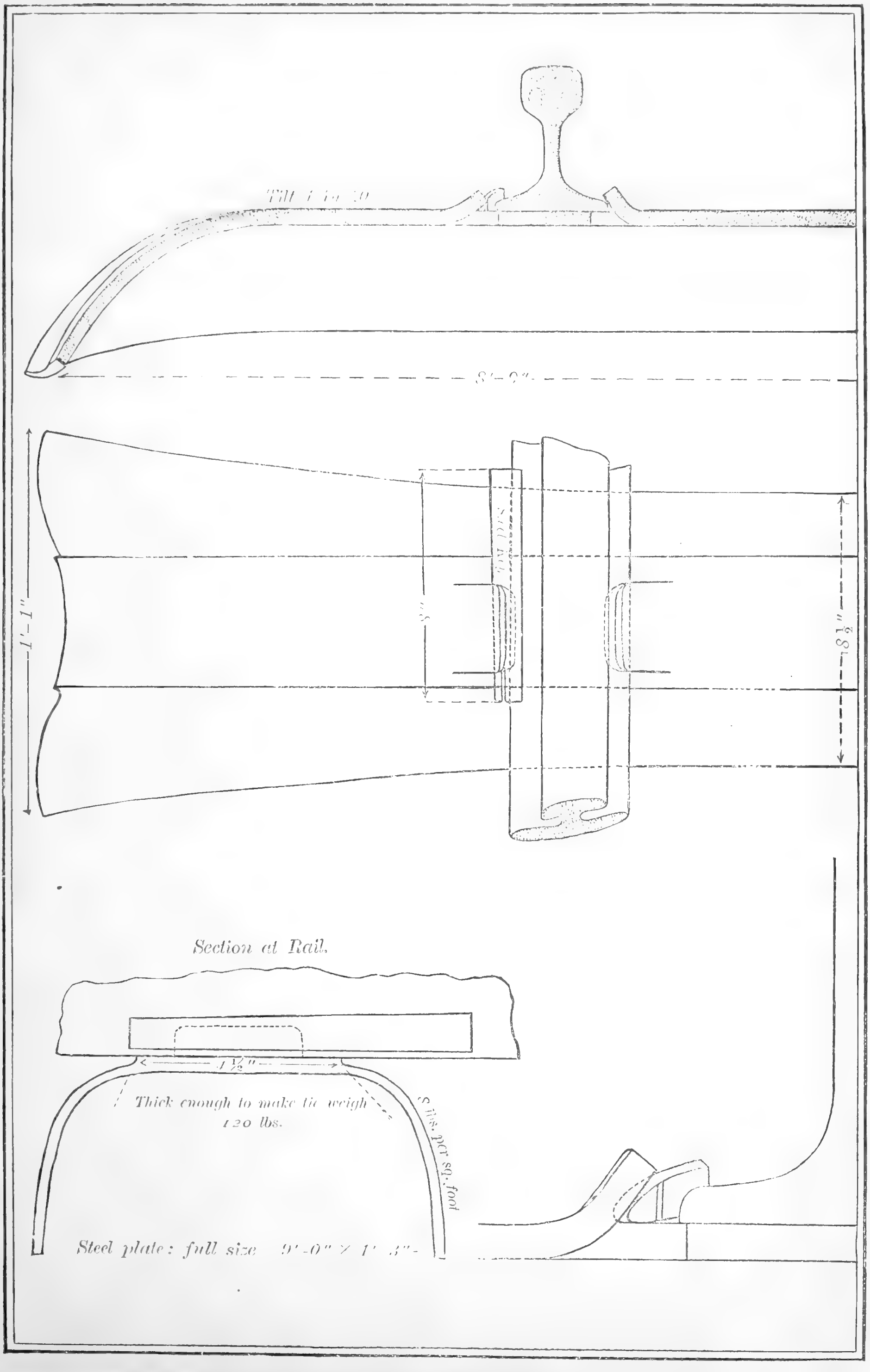
* See Plate No. I, p. III.

PLATE I.



INDIAN STATE RAILWAYS—STEEL TIE FOR 75-lb. RAIL.

"The blue print which I inclose represents the latest improvements in steel sleepers suggested by experience on railways in India, where millions of them are employed, and I think that the tie in question leaves little to be desired either in general form, simplicity of fastenings, weight, or price.

"You will observe that the metal is thickened where strength is most required, and that the rail clips are formed from the solid plate, the rail being kept in place by a simple steel key which can be driven either on the inside or outside of the rail when increased width of gauge is required on sharp curves.

"You ask me to state the advantages and disadvantages experienced by us in the use of this class of sleeper.

"So far we have no disadvantages to record, but many and very important advantages, which are as follows:

"(1) No spikes are required.

"(2) The rails are kept to gauge with almost mathematical accuracy and the result is that the oscillation of a train running at high speed over this track is reduced to a minimum, and is very marked when it runs on to a length laid with ordinary timber sleepers.

"(3) The difference in the cost of maintenance is enormous, because a track once properly laid with these steel ties and well ballasted requires no permanent road gangs and can be maintained in good order by a traveling gang going over it once or twice a year.

"This is our experience here, but it must be remembered that on this railway we have no frost or snow to contend with and very light traffic.

"In the United States these conditions would of course be altered, but I see no good reason why these ties should not bear frost well; they are extensively used in Germany and I am not aware that frost has proved an objection to their use.

"From personal experience I cannot say how metallic ties behave in cases where trains run off the line, as we very seldom on this line have such accidents, and have had none on the portions of track laid with them.

"In India the experience is that in a bad run-off a great number of ties are bent and injured, but that very few are so badly damaged as to be past repairs, and that, as a general rule, they are repaired in the shops and replaced in the line.

"I must add, however, that metallic sleepers require a very solid and perfect road-bed, and a much larger quantity of ballast than timber ties.

"The Mexican Railway is laid throughout with 62-pound steel rails, except on the Cumber 4-per-cent. incline, where we are now laying down 82-pound rails.

"Our metal ties are laid under the 62-pound rails, the number being 2,000 per mile but we find that this number is not necessary, and in future we propose to lay only 1,850 per mile.

"I may say in conclusion, that in my opinion the steel tie is the tie of the future, and that our experience here points with their use to substantial economies in repairs and maintenance and at the same time to a very perfect track."

GENERAL REQUIREMENTS.

From the experience so far accumulated it is claimed that the requirements of a good tie can be fulfilled by the steel ties now made, namely:

(1) Appropriate form.

(2) A section with sufficient moment of resistance.

(3) A material not easily fractured.

(4) Sufficient bearing area and length to resist lateral, longitudinal, and vertical strains.

To which may be added that:

(1) The average life of good steel ties is considerably longer than that of best wooden ties (estimated at 30 to 50 years).*

(2) The width of gauge is better maintained with steel ties.

(3) Cost of maintenance of permanent road with steel ties remains almost constant after the second year, while with wooden ties it increases constantly with age, making the average cost greater than with the former.

(4) Rail fastenings are possible with steel ties which are at once safer and more easily maintained than those for wooden ties.

(5) A good steel tie should not cost more than from 125 to 150 per cent. of the cost of wooden ties.

(6) The "old material" value of a steel tie is greater than that of a wooden sleeper.

"If, for comparison of the relative cost per mile of steel and wood, account is taken of the manufacture, transport, laying, maintenance, interest, and value of scrap, it is seen that there are few countries in the world where the exclusive use of wood ties is really economical.

"For countries where climate and insects destroy wood sleepers in a few years this is evident; but it speaks still better for steel sleepers that in Holland, which produces no steel and gets wood sleepers very cheaply by sea, all the railway companies have introduced metal sleepers without any pressure from the Government."

REQUIREMENTS AND COMPARISON OF DIFFERENT SYSTEMS OF SUPERSTRUCTURE.

A very elaborate investigation into the merits of different systems of superstructure, with wooden and metallic longitudinal or cross-ties, has been published in the "Organ für Fortschritte des Eisenbahnwesens" for 1886, by a high authority, W. Fuchs, replete with mathematical demonstrations and presenting a most thorough discussion on theoretical grounds, the results of which are given in the following notes:

A.—*The aggressive forces against which any system of superstructure must be prepared to stand, are,—*

(*a*) Vertical: pressure at the wheel, usually and properly taken as 7,000 kilograms (15,400 pounds).

(*b*) Lateral: shocks representing a total effect of 5.5 tons, discounted by a relief of 2 tons from the opposite wheel, the total pressure being roughly 5,000 kilograms, which may increase to the maximum 8,000 kilograms (11,000 to 17,600 pounds).

(*c*) Longitudinal: per rail not over 5,025 kilograms, adhesive weight of locomotive taken as 42,000 kilograms.

B.—*Requirements of systems.*

(*a*) Longitudinal ties.

The manner, shape, and number of cross-connections seem to be of utmost importance; blade-shaped connections are preferable to those with broad surface on account of the tendency of the latter to form humps in the road-bed; a number of cross-connections is undesirable as counteracting the advantages of the long tie and introducing the faults of the cross-tie system; the connection is best made at the rail joint, by which the favorable influence of such connection is utilized. If more connections

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* See p. 119, on Life of Metal Ties.

are required, they are best applied in the middle, at equal distances from the ends of the tie.

The main difficulty of long-tie systems lies in their deficient drainage, two "backs" forming alongside the tie in the road-bed. This objection is increased when the cross-connection has a flat surface.

Of all long-tie systems Haarmann's (employed on Berlin City Railway) appears best, exception being taken only to the form of cross-connection. Hilf's system is found in all points inferior, the former showing all the advantages required for an elegant and simply constructed superstructure; the only objection to it is that to which all long-tie systems are open—deficient drainage.

(*b*) Cross-ties.

The parts of the rail lying between the support and a point half way between supports receive less wear, and an uneven use of the rail is the consequence. Connections of rails to ties can never be made too rigid. The foot of the rail should preferably not be supported in its entire breadth, but only on its flanges to a sufficient breadth, thereby insuring more stability, permitting the use of rails not having a perfectly smooth foot, and avoiding an extra demand of resistance against tilting on the part of fastenings.

Bed-plates are most desirable for wooden as well as metal cross-ties, making the manufacture of the latter ties less expensive and less difficult.

By use of bed-plates the eating into parts most used, and the consequences resulting therefrom, on all parts of the superstructure, can be avoided. The best mode of fastening is presented by bed-plates with hook bolts.

The best length for metal cross-ties is given as 227.7 c. m. (7 feet 5½ inches); and in order to diminish the strain on the tie and counteract the tendency of every cross-tie system to change the gauge in consequence of a bending of the tie, there should be no tamping underneath for a length of 52.7 c. m. (20.7 inches). A trough, open only on the lower side, divided into three compartments by two cross-ribs placed 26.35 c. m. (10.3 inches) from the center of the tie, the outer parts filled with bed material, the central part empty, will answer to this requirement.

At 10 c. m. (3.93 inches, the height of a cross-tie), a metal cross-tie system furnishes, even in the most unfavorable bed material, at least 1.33 times greater resistance to side strains than a wood superstructure.

The distance of ties, at 1 m. (3.28 feet), used on the Prussian profile, the author considers too great, and 0.95 m. (3.12 feet), or even less on curves, just permissible. Against longitudinal forces the transmission of the shock from the rail to the tie is more imperfect with metal systems than with wooden ties; yet the resistance of a good metal system to displacement in the direction of the track is very much greater than with wooden ties. Iron ties of 10 c. m. (10.3 inches) height withstand the effects of longitudinal forces.

RESULTS IN REGARD TO METAL CROSS-TIES.

The cross-tie with short steps leaning somewhat outward is the most perfect.

The need of bed material is smaller than in any other superstructure.

Bed-plates with bolts offer very firm connections, and can be easily moved or replaced. Changes of gauge can be as easily and accurately effected as with other connections. The mode of fastening is independent of the form of tie, and can be applied to any iron tie at any later time.

The weight per running foot ought to be somewhat greater than that of ties now used, but the greater weight refers to such parts as are little subject to wear, and it does not exceed that required in the long-tie system.

C.—*Comparison of wood and metal superstructures.*

The superiority of well-devised metal superstructures over those with timber ties as usually applied, is more clear if we consider the more or less secure mode of fastenings in both systems.

If the greatest side strain of 7,350 kilograms (16,000 pounds) be exerted on the rail just over the tie, and if two spikes are used outside and one inside for fastening, then if the coefficient of friction between metal and wood be $u = \frac{1}{2}$, the two outside spikes must offer resistance $R = 7{,}350 - \frac{6000}{2} = 4{,}350$ kilograms (9,570 pounds), while under usual conditions they cannot offer more than 3,200 kilograms (7,040 pounds); one shock, therefore, is capable of loosening the rail here. Only when the three spikes are united by bed-plates does their resistance grow to 4,800 kilograms (10,560 pounds), or their total combined resistance to $4{,}800 + 3{,}000 = 7{,}800$ kilograms (17,160 pounds), against a strain of 7,350 (16,000 pounds). But this resistance is found only in absolutely sound ties. Still less secure is the usual mode of fastening against tilting; for the inside spike cannot offer more than 2,050 kilograms' (4,510 pounds) resistance, while the attacking force may reach a maximum of 4,860 kilograms (10,692 pounds).

D.—*Comparison of long- and cross-tie systems.*

The former, if perfect, like all superstructures with single supports, is superior in regard to an even uniform transmission of the force waves which form under the moving loads. The many supports of a cross-tie system exert a disturbing influence on this wave movement, in consequence of which the rail is not uniformly utilized. Therefore, in any cross-tie system, rails must wear unevenly.

It follows that on long-tie systems, smoother rolling of cars, and less wear of all parts, must result than on cross-ties; yet it is possible to get sufficient satisfaction in this respect from the latter system.

Of more importance is the greater security of long- than cross-tie systems against side strains and consequent breakage of rails.

By use of bed-plates on each tie or enlargement of rail foot this objection can be overcome.

In regard to drainage no satisfaction has as yet been obtained in the long-tie systems. The quantity of bed material needed amounts to the same in both systems. Replacement is probably cheaper with cross-ties. Metal weight is alike, yet in long ties the wearing parts are the lightest.

The author concludes that, as only two points are in favor of the long-tie system, which can partly be attained in cross-tie systems, the latter will remain the standard.

MATERIAL.

Although steel is preferable to iron for surfaces liable to wear, like those of rails and tires, yet it presents drawbacks in the case of parts subject to deflection only, as bridges and ties, and being brittle in winter, requires special precautions while cooling after leaving the rolls.

The strength of an iron tie should be much greater than a wooden one, because the former must offer sufficient resistance to deflection over its whole surface, however well it may be packed, as the reactions of the ballast during the passage of trains are distributed uniformly over the whole of the packed portion.

The faults in construction of iron ties were eliminated in those made of steel, which are not liable to split and break, as are the iron ties.

The first trials with hard-steel sleepers were not encouraging. Yet some companies have laid test lines, inspected them carefully, and have kept records as to cost of maintenance (especially in Germany and Holland), and from these trials are derived the results and experience now available in regard to this material.

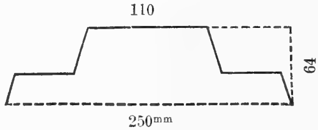
Steel ties, however, have come seriously into competition only since the increase of mild-steel production. This material is less liable to breakage than ordinary steel and less injured in punching the holes for fastening. A steel is used with a tensile strength of 25.4 to 28.6 tons per square inch, and a minimum contraction of 30 to 40 per cent.*

SHAPE.

The great number of forms of metal ties and the modes of fixing the rail to the same must be puzzling to an engineer who has to select one of them. The simpler the plan the better. If equal safety is to be obtained, the metal tie must be of equal size and cover as much surface of the ballast as the wooden tie. Yet the amount of bearing surface of the tie on the ballast, provided this be of good quality and incompressible, is of less importance than that the pressure exerted by the ballast on the underlying soil, which is often compressible, be distributed over the largest surface possible. It is not necessary that the ties have a large bearing surface on the ballast, nor that they be flat on their underside, but only that there be sufficient width between the outer edges.

To meet the requirements of a good tie, which with the smallest amount of material possesses the greatest possible strength, affords a rational distribution of the pressure on the road-bed, and lies solidly in the road-bed, the profile is of great importance.

The form adopted by the Prussian Railway seems to answer well these requirements. It is a box, with the addition of broad flanges at right angles to the sides of the box, at the end of which two short feet permit a secure hold in the bed material. A cross-section presents about this shape:



Many different patterns are in use, like the Vautherin, Elberfeld, Prussian, Rhenish, Austrian, and Webb's ties, on the London and Northwestern Railroad, with a chair for bull-head rail.

Recent improvements in rolling machinery allow the making of ties of varying thickness and having the 1-in-20 slope for the rail made in the process of rolling.

By this a saving of 12 to 21 per cent. and a distribution of material to points where most required is possible. The minimum cross-section is kept for about two-thirds of the length, while under the rail and for a short distance on each side of it, it is thickened.

The Netherlands State Railway, after many tests under various conditions, sharp curves and gradients, with iron and steel ties of various designs, and after carefully comparing cost of maintenance with that of

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* See note on jointed cross-ties, p. 125.

similar lengths of line laid on new oak ties, has decided in favor of a mild steel tie, 8 feet 6 inches long, 9.25 inches wide over the extreme edges at the bottom, 2.52 inches deep for the greater part of its length, but increased to 2.92 inches under the rail and 3.23 inches at about 4 inches outside the rail, so as to give the inclination of 1 in 20 for the cant of the flat-bottomed rail, which rests directly on the tie.

The following advantages are claimed for this tie (adopted from the St. Gotthard Railway):

(1) It is easily packed with any kind of ballast—sand, gravel, ashes, slag, stone, etc.

(2) The triangular toe which forms the bottom edge of the sloping sides of the tie prevents damage to the edge during the beating up of the ballast, and by lowering the neutral axis of the section additional stiffness is gained.

(3) It gives a broad surface for the foot of the rail to rest upon.

The weight of the tie is 104.7 pounds, saving 15 per cent. from the weight of a tie of the same strength but uniform cross-section.

The ties ordered in July, 1885, including a two years' guarantee, cost about $1.15 per tie, or "almost the same as an oak tie."

As to form, the closing of the end of the tie deserves special attention. It should have a sloping, closed end, which tends to drive the ballast in under the rail instead of out from underneath, as the early open-ended form did.

WEIGHT.

As stated before, the first iron sleepers were not successful, on account of their light weight and consequently reduced section. Those introduced in France and Germany in 1864 were only 66 pounds. The fastenings had not hold enough and breaking was frequent where the rails rested on the ties; there was also danger connected with them on account of unsteadiness and increased lateral movement. The results were due to the following causes: 1, the holes of the fastening reduced the cross-section; 2, the punching of the holes made the metal around them more or less brittle; 3, in time the foot of the rail and fastening would eat into the top of the tie; 4, with a rational beating up of the ballast the momentum of reaction of a ballast is a maximum at the cross-section, where the wheel load is applied; 5, the impulse of the moving load is transferred directly to the tie at these places.

Increase of weight gives more stability to superstructure. Metal cross-ties weighing 100 pounds have proved quite satisfactory. Those of less weight, 77 to 88 pounds, proved too light. The State Railway of Wurtemberg uses ties of 128 pounds, but the majority of German and Dutch engineers consider 112 pounds fully sufficient to maintain a perfectly steady and permanent road.

The following table, giving the weights and prices used by the different German roads, may be of interest:

Name of railway.	Weight of tie.	Average price per ton of metal.	Average price per tie.
	Pounds.		
Imperial Railway in Alsace-Lorraine	126.5	$31 68	$1 79
Bergisch-Markioch, old Vautherin pattern	126.5	30 96	1 75
Same, New Hilf pattern for main lines	98	30 96	1 35
Same, for branch lines	88	30 96	1 22
Links Rheinisch Railroad, old pattern	77	34 48	1 19
Same, new pattern	110	34 48	1 70
Rechts Rheinisch	106.5	30 70	1 46
Prussian State lines, various	114.5	34 48	1 77
Magdeburg section	120	36 77	1 97
Rechte Oder Ufer	101	42 08	1 90
Hessisch-Ludwigs	98	31 68	1 38
Altona-Kill	101	....	1 60
Wurtemberg State lines	130	37 00	2 14

FASTENINGS.

The subject of fastenings is of greater importance as regards the prevention of shocks between the rails and ties than in preserving the gauge. Whatever the method adopted for attaching the rails to the ties, it must be better than that hitherto employed for wooden ties, and keys are decidedly preferable to bolts, the threads of which rust out so that the nuts cannot be tightened. Yet there are systems of fastening steel ties which are *safer* and more easily maintained than those for wooden ties. After many years of trial, the Netherlands State Railway Company have decided to keep to bolts as the means of attachment between the rail and sleeper. In 1865 they laid 10,000 iron sleepers, fastening them by 4 bolts (0.42 inch diameter) to each tie. In 1883, for the first time, it was necessary to renew 2,000 of these 40,000 bolts, and in August, 1885, the remaining 38,000 were still in use. This shows that the bolts 0.86 inch in diameter now used will be satisfactory. The bolt holes in the ties are square, except that the corners are slightly rounded. It is proposed to retain the cast iron chair, which has rendered good service, especially with Vignoles rails, and to connect each pair of chairs by two bars of Z-section, capable of standing a deflection of nearly 4 tons per square inch, keyed to them so as to form a trough turned either upwards or downwards.

The points for consideration in fastenings are:

(1) By the insertion of a plate between the hard rail-foot and the softer tie, the latter should be saved and its natural straightness preserved, avoiding injuries in the shaping by rolls, in bending, or otherwise.

(2) A rational and direct transmission of the attacking forces from the rail to the tie should be effected.

(3) The fastenings must be such as to keep the gauge constant in the

curves as well as on the straight road, and to permit the elimination of unavoidable faults occurring in fabrication.

(4) To allow shiming up, where the action of frost makes it necessary.

The forces which work upon the fastenings are:

(1) The horizontal forces tending to press the rail-foot outward.

(2) The vertical forces tending to raise the inner edge of the rail-foot.

To counteract these forces, it is necessary, with bolt fastenings, to protect the bolt in its entire length against side forces tending to bend it or wear it away. To effect this the bolt must be placed as near the rail foot as possible, so as to reduce the leverage of the vertical force as much as possible. Small number of parts and a simple form is most desirable.

The nature and good service of the fastenings has also great bearing upon the cost of keeping the road in order.

LIFE.

The life of iron ties has been variously estimated by those in favor of the system at from thirty to fifty years; opponents place it at not more than twenty years, that of the best wood ties. This last estimate is, however, disproved by the more than twenty years' experience with longitudinal ties on the Brunswick railways. These were laid in 1864, and in 1882, on thorough inspection, were found but slightly affected by rust.

In fact, iron ties suffer less from atmospheric influences than wooden ones.

Ties on the Bergisch-Märkisch lines, after being laid for eight years in a badly-drained ballast, were found to be not more affected by rust than the rails.

Mr. Kalff, at the convention in Brussels, stated that metal sleepers laid down twenty years ago were found in perfect condition. Only, for ties kept in reserve by the side of the line or in damp tunnels and similar localities, or if transported over the sea, a coat of tar or paint might be found advisable.

With the better form and heavier sections now used, the breaking of a tie is so unusual as not sensibly to affect the annual charge.

Whatever the cause, steel rails and ties undoubtedly rust much faster than those made of iron.

Mr. P. H. Dudley, C. E., an expert on railroad matters, says: "So far as atmospheric agencies are concerned, the German experience would be a good guide here. The oxidation of rails at least shows in most localities no greater rapidity than in Germany. Failure in this country of metal ties, as far as I have seen them used, was due to their form not meeting the conditions required of a metal tie."

INFLUENCE ON ROLLING STOCK, RAILS, AND ROAD-BED.

The effect of the material of the tie on the rolling-stock is difficult to ascertain, and not much is known about the influence of metal ties.

But it may be noted that on the German railways in 1883 the number of tire breakages per 100 miles of line with wooden ties, metal cross-ties, and metal longitudinal ties, were respectively as 7.25 to 5.96 to 2.74; showing the advantage of the long-tie system, by which the shock at rail-joints especially is diminished.

The weight of the entire superstructure in itself and the good tamping of the ballast conduce to its quiet position, and serve to lessen the loss in rolling-stock and the cost of maintenance.

C. P. Sandberg, the well-known expert on rails, says:

> "It is a great mistake to diminish the rail section in consequence of the adoption of metal ties, as has been done on some railroads, for the metal in the tie can in no sense make up for the metal in the rail. The strong rail has the power of spreading the effect of the concussions from the rolling stock over several neighboring sleepers, thus dividing the effect, while the light, weak rail will concentrate the blows on one or two ties.
>
> "The heavy flange rail also is a *sine qua non* for the success of a metallic permanent way; if by 'permanency' be meant anything approaching thirty years or more."

In the Revue Générale des Chemins de fer, April, 1886, p. 260, a comparative table is given, showing the respective durability of rails on ordinary roads with wooden cross-ties, and roads on metal ties with the Vautherin and the Hohenegger system (longitudinal ties 32 feet long with one cross-tie to each length), and the Hilf system (longitudinal tie of 24½ and 29½ feet length with one cross-tie to each length).

The comparative results show: (1) That with the Vautherin system the wear is three times as much as with good wooden ties; (2) with the Hohenegger system the wear is four times as rapid; and (3) with the Hilf system it is four to five times as rapid as with wooden ties.

Metal ties do not *bend* visibly like those of wood, but descend evenly, and the leverage of the momentum of deflection at the intersection of the rails and ties is greater than in the case of wooden ties; but if the strain be limited to, say, 4 tons per square inch for iron, and about half as much again for steel, there is no fear for the resistance of metal sleepers.

If the ballast inside the rails has not been properly packed, so that only the portions outside the rails sustain the whole load, the momentum of deflection will double, but even then there will be nothing to fear; but if, on the contrary, only the central portion of the tie between the rails bear upon the ballast, the maximum momentum of deflection, which may thus be increased to five times its ordinary amount, will be transferred to the center of the tie.

Experience has shown, however, that this will not occur if care be taken not to pack the central portion of the tie.

Filling hollow sleepers with ballast having a certain amount of cohesion is not recommended, as no degree of elasticity in the filling substance can increase the resistance to deflection. The tamping of the ballast under steel ties must be so done that the middle of the tie is either empty or at least not compactly filled with ballast, while for a distance of 12 to 15 inches on each side of the rail the ballast must be well tamped.

It is also important that during the first few months after the ties are laid the road should have great and constant attention until the bed becomes consolidated. The cost of this ought to be considered as part of the cost of laying the road.

The metal tie acts best on firm ground. Thus on the Liége-Limbourg line there were 20,000 metal ties which had not been touched for twenty-two months and the road continued in a most satisfactory condition, working trains running at a maximum speed of 38 miles per hour. Lengths of ballast of medium quality in which wooden ties appeared to be dry have proved unsatisfactory with iron ties. By means of their pumping action the latter draw the wet up from below and work the ballast into mud, making a solid bed impossible. This working up into mud occurs also with wooden ties, but only after the ballast has become completely impermeable for water, and requires renewing anyhow.

The reasons for this difference may be stated as follows:

(1) The iron ties have twice the deflection of the wooden ones.

(2) On account of the accurate fastening of the rail to the iron tie, it shares the whole vertical motion of the rail, whereas with wooden ties the play of the foot of the rail in the dogs and the compressibility of the timber both tend to lessen the deflection of the tie.

(3) The hollow body of the iron tie is very favorable to the formation of an air-tight cavity, inducing the pumping action above referred to.

(4) The under surface of the wooden tie lies twice as deep as that of the iron one.

The working up of the ballast into mud by iron ties, on certain trial lengths, has interfered with their more general introduction, whereas the failure should have been put down to the inferiority of the ballast and its impermeability to water. It would be found that in similar ballast an accumulation of moisture at the bottom of wooden ties takes place.

Good ballast must fulfill the following two conditions:

(1) It must be capable of being beaten up under the tie into a firm mass so as to afford the greatest possible resistance to the deflection when the load comes upon the tie and the greatest possible resistance to being shaken loose.

(2) At the same time the material must be such that between the ties there may be in it interstices for the passage of water, but also the greatest possible cohesion and friction, to prevent slipping and to distribute equally the pressure of the load.

Broken stone fulfills these conditions best, especially as to drainage.

Water remains longer between the rails and ties with the longitudinal tie-systems than with that of cross-ties, as on account of the solid body below it is drained off more slowly; therefore in winter the gravel bed forms a frozen body. If this thaws from above, the long tie may lie entirely in a thawed bed and the cross-connection in a frozen bed. Then the cross-connections are points between which the long ties with the rails must lie free or imperfectly supported. From this occurrence danger must be apprehended, especially in changing weather.

Another objection is made on account of frost-heaving. If in a wooden structure one rail is thus lifted, the other can be accommodated. But in iron structures a greater diversity of heavings must occur, which are not so easily remedied.

The Royal Prussian Railway management, however, using Haarman's long-tie system, finds this objection not sustained even in protracted frost weather, and considers this system efficient as well as easily and cheaply maintained.

On the Braunschweig railroads the iron superstructure (long tie) upon hard subsoil is not easily maintained in wet weather.

The same experience has been made in Lorraine.

But on the Rhenish system, on well-drained ground, no difficulty is experienced.

On the road from Calbe to Blankenheim (mountainous), where more than 60 miles of Hilf long ties are laid, the cost of maintenance is double that of wooden ties, the reason among other causes being the bad condition of the bed material, a loamy and clayey sand, which becomes slippery after every rain.

A simple cross-tie system and broken-stone ballast is recommended on badly drained soils.

COST.*

The item of cost is naturally of primary importance with good financiers, but for a perpetual concern like a railroad the first cost is not always the most important factor of calculation.

In fact, the saving of labor for renewals and maintenance is now the vital question in the cost of railroad working. When this is brought to a minimum by perfection of road, safety and comfort in traveling, as well as a dividend, will be secured.

According to Sandberg, who advocates only the most solid structure, the desirable metal tie may be said to cost as much per ton and weigh as much per mile of line as the rails themselves.

Gustav Meyer says:

> "Iron cross-ties of 110 pounds weight, costing $1.73 each, must last twenty-five years in order not to involve an annual charge of more than 9.8 c. (average annual charge for wooden ties on German roads)."

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* For original cost of metal ties now in use, see table, p. 118.

To get at the annual cost for the provision and renewal of railway ties the following points must be considered:

(1) The annual interest on first cost.
(2) The annual sum laid aside for depreciation.
(3) The "old material value," lessening the amount of depreciation.
(4) Cost of labor and tools for replacing ties.
(5) Cost of the attachment to the rail.
(6) Cost of maintenance in the road-bed.
(7) Influence of tie upon the life of rolling-stock.

The first cost of fastenings for wooden ties is less than for metal ones, but the cost of renewal is greater in the former case, so that in the end the annual cost for fastenings becomes less in the case of metal ties.

The cost of maintenance of a steel-tie road three and one-half years old was found the same as that of one of the same age laid on wooden ties, but from this point on the cost of the latter increases, while the cost of the former tends to diminish, owing to the consolidation of the bed. One of the district engineers of the Netherlands Railroad states that on a test piece of 1,144 yards, on a curve of 820 yards radius and a gradient of 1 in 83, no tamping of the ballast was required for 22 months ending December 31, 1884, and that the only maintenance required was one man for 34 days inspecting and tightening up bolts.

On the Rhenish roads, which at the end of 1879 had 112 miles of track laid with longitudinal, and 197½ miles with cross metal ties, and to which, during 1880, were added 94 and 138 miles, respectively, the following results were obtained: On 100 miles of track with wooden ties 271 labor days were required yearly; with metal longitudinal system, on an average of three years, only 258, or 5 per cent. less, and the average amount of labor expended in the year 1879 was only 209 days, or 23 per cent. less; with iron cross-ties, during an average of 25½ months, 242 days, or 11 per cent. less, and for the average of the year 1879, 164½ days, or 35 per cent. less were required.

In Germany the cost of maintenance has been found to vary from $38 to $360 per mile with long-tie system, and from $47 to $107 with cross-ties, subsoil, bed material, and kind of structure causing great differences.

Taking (1) the annual interest on first cost (C) at 5 per cent. (or 0.05 C).

(2) Annual allowance (B) to be charged for renewal after *n* years, leaving out of account value of old material:

$$B = \frac{0.05}{1.05^{n+1} - 1.05} C.$$

(3) The reduction of this (B) annual allowance due to value of old material is:

$$\frac{0.05}{1.05^{n+1} - 1.05} \times \text{ value of old tie.}$$

(4). Annual amount to be allowed (x cents) for cost of changing tie after n years is:

$$\frac{0.05}{1.05^{n+1}-1.05}\times x \text{ cents.}$$

Taking the value of old wooden tie at 10 per cent. of first cost, that of old iron sleeper at 40 per cent., it would be found that a wooden tie of \$1 first cost and 12 years' life costs 10.2 cents per annum exclusive of maintenance, while an iron tie of \$2 first cost, lasting 30 years, costs 9.8 cents per annum.*

Another writer inquires how much more a metal tie will cost than a wooden one. if the former would last double the time of the latter and its value as old material be considered 40 per cent. of its first cost ($O_{,}=0.4\,N_{,}$), while that of the old wooden tie is taken as 10 per cent. of its first cost ($O_{,,}=0.1\,N_{,,}$). The cost of renewal ($R=N-O$) is, in the case of the metal tie, $R_{,}=0.6\,N_{,}$, and for the wooden tie $R_{,,}=0.9\,N_{,,}$.

The annual charge for renewal (r), if life of ties is set at $n_{,}$ and $n_{,,}$ years, and the rate of interest at p per cent., may be expressed:

$$\left(\text{setting } \frac{100\times p}{100}=e \text{ as}\right)$$

$$r_{,}=0.6\,N_{,}\,\frac{e-1}{e^{n_{,}}-1} \text{ for metal}$$

$$r_{,,}=0.9\,N_{,,}\frac{e-1}{e^{n_{,,}}-1} \text{ for wood,}$$

and these amounts capitalized (that is to say, the capital R, the interest on which at p per cent., will furnish the required amounts of yearly charge for reserve fund),

$$R=\frac{r}{e-1} \text{ would make}$$

$$R_{,}=\frac{0.6}{e^{n_{,}}-1}N_{,} \text{ for metal.}$$

$$R_{,,}=\frac{0.9}{e^{n_{,,}}-1}N_{,,} \text{ for wood.}$$

Leaving out all other advantages of iron ties, that is to say, considering only the longer life as the criterion, N' may be taken so high that the first cost of the metal tie, together with the capital necessary to renew it indefinitely, equals the sum of the same items for wooden ties, namely:

$$N_{,}+R_{,}=N_{,,}+R_{,,} \text{ or } N_{,}=N_{,,}+R_{,,}-R_{,};$$

and by substitution

$$N_{,}=\frac{(e^{n_{,,}}-0.1)\,(e^{n_{,}}-1)}{(e^{n_{,}}-0.4)\,(e^{n_{,,}}-1)}=N_{,,}$$

If, then, $n_{,}=2_{n_{,,}}$, that is to say, if the metal tie last double the time of the wooden tie, the cost of the first may be

$$N_{,}=\frac{e^{2n_{,,}}+0.9e^{n_{,,}}-0.1}{e^{2n_{,,}}-0.4}N_{,,}$$

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* See table on page 118; also bottom of page 122.

From this may be calculated at a rate of interest of 4 per cent. for a wooden tie lasting ten years, $N_{\prime}=1.9N_{\prime\prime}$, and compared with a creosoted wooden tie lasting twenty years, $N_{\prime}=1.5N_{\prime\prime}$; that is to say, if the metal tie lasts twice as long as our best oak ties, its original cost may be allowed to be nearly twice as much as the oak tie. If it lasts twice as long as a creosoted tie of twenty years' duration, it may cost one and one-half as much as this to be only equally as expensive; if duration and cost of renewal alone are considered, or, as our best oak ties do not average more than eight years' life, and a metal tie can be safely said to last three times that period, reckoning rate of interest at 5 per cent., at present prices for metal, and considering cost of renewal, it would be economy to use metal ties when oak ties cost 70 to 80 cents, and pine ties lasting five years cost 50 to 55 cents.

ADDENDA—JOINTED AND COMPOUND CROSS-TIES.

As the object of these notes is to point out where a saving in the use of wooden material for railroad construction may be effected, the following suggestion may find proper place here, describing a system of using up old wooden ties practiced on the Netherlands State Railways.

The best wooden ties fail at the point where the rail rests on the tie, while a length of from 3 to 3¼ feet between the rails remains quite solid. Laying two such lengths sawed off end to end, they are joined together by a length of inverted channel iron let into the timber, so that its web lies upon the upper surface. The rail rests on the channel iron, which thus prevents it from wearing into the tie. (By bending, the 1-in-20 cant, if required, can be given.)

The sawing, dressing, boring, and putting together of these compound wooden and iron ties can be done in wet weather by the trackmen, thus saving in the cost. The laying and batting-up are the same as with ordinary ties.

As these compound ties have four end-faces, they offer increased resistance to lateral motion.

In July, 1882, a quantity of these ties were laid in a main line through a station, and in September of the same year, a further number on a main line curve of 50 chains radius and a gradient of 1 in 62, over which ran thirty trains a day, some of them expresses. Both of these lengths have required no different treatment from the adjoining lengths laid with ordinary wood ties, while the gauge has remained exactly true.

In a similar manner may be joined together short metal waste pieces which are left in making steel ties, in order to reduce the price of the perfect steel tie, the waste pieces being riveted together. This attempt to produce a cheap steel tie, at least for secondary lines, may be considered quite successful.

The Netherlands State Railway in June, 1885, laid a number of such ties on a curve of 26 chains radius with a gradient of 1 in 62. These ties have shown no disadvantages during loading, unloading, laying, or batting-up, and have required no more tamping than ordinary ties near them.

There are six different types of these riveted ties, in all of which the rivets are 0.79 inch diameter.

The joint may be 6 inches from the center of the tie, so as to allow of short pieces being used up.

Another proposition for the use of waste material in the construction of steel ties is to cut old steel rails (Vignoles section) into lengths of 7 feet 10 inches and rivet them to cast-iron chairs (those used with Vignoles rails), two lengths to each pair of chairs, thus forming a cheap, strong, and durable tie, which will be worth as much as new ties would be after both have served their turn, while at the same time using what is now a drug in the market.

The newest proposition is, for the sake of cheapening iron ties, to employ soft cast-iron, avoiding the expense of rolling, or, rather, for the same price to give more material and more weight to the tie.

Such ties are made at Halbergerhütte, near Saarbrücken, Germany, and are capable of being deflected (slightly) without breaking, and are tough enough not to break on being dropped by the men handling them. They cost $1.60 per tie and weigh 220 pounds, instead of 110 pounds, the weight of the Haarmann tie.

To obviate the objection of danger from spreading of gauges, the writer proposes to combine with this cast-iron tie a wooden one, for the purpose simply of holding in place bolts or spikes and preventing the spreading. The wooden ties thus used are only one-third of the thickness of those now in use, allowing a saving of material. Longer bolts or spikes (by the thickness of the iron tie) are to be used.

The additional cost of this construction, taking original wooden ties at $1.20 (now $\frac{1}{3} = 40$ cents) and ten ties for 100 feet of rail, gives $\frac{10}{30} - 5280 \times 40$ cents = $7.04 increased cost ($\frac{10}{9}$ a mile).

The Webbs metal superstructure, introduced on the London and Northwestern Railroad, consists of steel ties (Vautherin profile), with six holes for chairs to be riveted to the tie. The chair consists of three parts, bottom plate bent to correspond to rail foot, and two side plates, the interior one adjusted to the rail profile below top flange, the outer allowing a space for the reception of a wooden wedge, which tightens the rail in the chair. The tie is 10 feet 7 inches (2.7 meters) and weighs with chair and bolts 175.6 pounds (78.9 kilograms).

The newest system proposed and introduced on their roads by the Bureau du Materiel fixe de la Compagnie des Chemins de fer de l'Est, in Paris, preserves as much as possible the rectangular cross-section of the wooden tie, especially the flat underside, which is important for a good underbatting; it combines wood and iron as did the earlier system of Cozyns and Debrières in 1862. It consists of a simple box with the two ends somewhat curved instead of being rectangular; upper width of tie 259 millimeters; lower, 220 millimeters; length, 2.7 meters (10.6 feet), diminished by turning down the ends to 2.5 meters; weight, 65 kilograms (143 pounds). The fastening is the important feature of the system, two clamps on either side of the rail, which may be fastened to or cut out of the tie, allowing ample space for the insertion or removal of the rail. A wooden block between the two sets of clamps driven under the rail brings this into place tight against the fastening clamps, which are adjusted to the rail profile. Two spikes driven into the block on the inside of the rail hold it in place.

The International Railway Tie Company at Boston offer a steel tie which has for a short time been in experimental use on the Boston and Maine and Maine Central Railroads. It is of simple construction, weighing 150 pounds, and can be made at $1.25 per tie. The only objection to it so far found has been a tendency to blow out the ballast, as might have been expected on account of the open ends of the tie. According to latest advice improvements in the construction of the tie remove this objection, and by simplification the price can be reduced to nearly 75 cents per tie.

The Des Moines Street Railway Company have laid 1,000 metallic ties of the Johnson Street Steel Rail Company's pattern, weighing 30 to 40 pounds and costing $1.25 per tie, the rail fastened with clamps, one riveted to the tie, the other braced against a keeper and firmly bolted. The structure lies on cedar blocks with plank flooring. Mr. Frank A. Sherman, secretary of the company, writes after six months' use of the ties: "Aside from the cost (we estimate it as 3 to 1 for oak ties) we believe the metal ties practicable. They are easily and quickly laid, can be removed readily without seriously disturbing pavements, and the rails are firmly fastened to the tie so that spreading of track is next to impossible."

Appendix 4.

CONNECTION OF RAILROADS WITH FOREST FIRES.

By N. H. EGLESTON, *Agent of the Department.*

Railroads, in addition to the great consumption of the forests involved in their construction and use, as in the production of ties, bridge, trestle and platform timber, as well as building cars and securing a supply of fuel, are very destructive to the forests by means of fires occasioned by their engines. Investigation shows the latter source of loss to be a very serious matter at present, and a more serious one prospectively.

In the census year 1880 an attempt was made, under the direction of the Government, to ascertain the extent of injury inflicted upon the forests by means of fires and the causes by which the fires were occasioned. Thirty thousand circulars making inquiry on the subject were sent out, reaching every town in the country. Replies to all of the circulars were not elicited, but it was clearly shown that during the year 1880 not less than 10,274,089 acres of woodland were burned over, involving a loss of $25,462,250.

Among the causes of forest fires, railroad locomotives were reported as among the most prominent, standing third on the list in this respect, only hunters and persons engaged in clearing land having occasioned more. One-sixth of all the fires reported were attributed to them. Another and independent investigation attributed one-eighth of the forest fires to this source.

The published reports do not undertake to give the extent of each fire, or the value of the forest or other property destroyed in each case. We cannot say with precision, therefore, what was their extent or the damage occasioned by the fires set by locomotives as compared with those originated by other means. But we have 508 fires reported as kindled by railroad engines. How many more may have originated in this way, which have not been reported, we have no means of ascertaining. If we assume that the average amount of destruction occasioned by fires started by locomotives equals that of other woodland fires, then we have 1,712,348 acres of forest consumed and property of the value of $4,244,208 destroyed by these locomotive fires. This amount, therefore, is to be added to the consumption of the forests for ties, bridge timber, &c., in making up the account of the drain upon the forests attributable to the railroads.

The following table shows the percentages of forest fires occasioned by locomotives in the several States so far as ascertainable from the reports received:

Table showing number of forest fires in 1880, acres burned, number of fires caused by locomotives, percentage of these compared with forest fires from all causes, and probable value of property destroyed by locomotives in each State from which reports have been received.

States.	Number of forest fires.	Acres burned.	Number caused by locomotives.	Per cent. of all.	Probable loss by locomotives.	Probable number of acres burned by locomotives.
Alabama	72	569, 160	4	6	$7, 273	34, 149
Delaware	14	3, 305	6	42	6. 583	1, 368
Georgia	54	705, 351	2	4	6, 704	28, 214
Indiana	99	90, 427	20	20	26, 067	18, 085
Iowa	46	11, 017	5	11	5, 001	1, 212
Kansas	10	7, 080	1	10	1, 470	708
Kentucky	106	556, 647	12	11	26, 139	61, 231
Maine	76	35, 230	14	18	22, 197	6, 341
Maryland	66	41, 076	16	24	8, 982	9, 858
Massachusetts	159	13, 899	52	33	33, 746	4, 586
Michigan	267	238, 271	43	16	157, 758	38, 123
Minnesota	84	250, 805	13	15	209, 266	37, 620
Mississippi	39	222, 800	1	3	2, 355	6, 684
Missouri	97	783, 646	16	16	47, 178	125, 383
Montana	5	88, 020	1	20	225, 600	17, 604
New Hampshire	27	5, 954	12	44	27, 988	2, 620
New Jersey	54	71, 074	28	52	131, 154	36, 948
New Mexico	47	64, 034	1	2	2, 950	1, 280
New York	102	149, 491	43	42	508, 530	62, 786
North Carolina	221	546, 102	11	5	17, 899	27, 305
Ohio	192	74, 114	27	14	111, 603	10, 375
Pennsylvania	381	685, 738	133	35	1, 065, 303	240, 008
South Carolina	67	431, 730	1	1 5	4, 368	6, 476
Tennessee	73	985, 430	6	8	420, 398	78, 834
Vermont	18	3, 941	5	28	13, 571	1, 103
Virginia	51	272, 319	13	25	81, 761	68, 080
West Virginia	54	476, 775	7	13	20, 186	61, 980
Wisconsin	108	406, 298	12	11	79, 817	44, 693
Total					3, 291, 847	1, 033, 571
Percentage					12.9 pr. ct.	10.06 pr. ct.

There are some particular considerations in connection with forest fires which make them worthy of special notice. In the first place, in the case of coniferous trees, they may not only consume the ripe timber, causing its total loss, but they destroy the young trees, which would soon replace the full-grown ones and thus continue the existence of the forest. But this is not all. The destruction of the forests by fire is often much more disastrous, attended by effects reaching beyond the simple destruction of growing wood, whether old or young. The lumberman cuts simply the standing timber, leaving the ground to be covered soon by another wood growth, possibly not so good as that removed, but having an appreciable value. In a forest of deciduous trees many of the stumps soon send up copious sprouts, and, if cattle are not allowed to intrude, a coppice will be quickly formed. But where the forest is ravaged by fire, there is involved not only the destruction of the present stand of timber, or at least its great deterioration, but the roots of the trees may also be burned and their vitality destroyed. The tree seeds also, which are in the soil ready to sprout and renew the forest growth, are consumed. The very soil itself is often burned to such a depth that many years must elapse before it will regain the ability to support any useful growth whatever.

Thus it appears that the railroads are not only great consumers of the forests, in a legitimate way, for their own construction and maintenance and by the destruction of standing timber occasioned by fires from their locomotives, but they also take away, in many cases, the reproductive power of the woodland tracts over which these fires may run.

The exposure of forests near railroad lines to destruction by fire occasioned by passing engines operates to discourage the holding or planting of woodland in such situations. In some of our States fires caused by locomotives have become so frequent and destructive that growing timber is regarded as hazardous property. In New Jersey, which abounds in pine forests, the danger from locomotives is so great that timber land near railroads has only a nominal market value. In Cumberland County, in 1880, a fire was started by sparks from a locomotive and spread 10 miles in one direction, consuming from 40,000 to 80,000 acres of forest, involving a loss of $320,000. A correspondent from that county estimates that three-fourths of all the fires in New Jersey originate from locomotives. Great destruction of the forests in Pennsylvania is attributed to the same cause, and the annual loss is estimated at millions of dollars.

The fact that these losses are so great, and that they are not necessarily incidental to any important business; that the destruction of the forests in this way does not, like cutting cord-wood to be burned in the factory, the furnace, or for domestic purposes, subserve important industries or promote human comfort, but is a loss simple and total, appeals to all, to railroad managers as well as others, to employ every practicable means for the suppression of these fires.

LAWS IN REGARD TO FIRES OCCASIONED BY LOCOMOTIVES.

The growth of railroads has given origin naturally and necessarily to a considerable body of law defining and protecting the rights and enforcing the obligations appertaining to railway corporations. This body of law, however, relating as it does to corporate organizations which have come into existence within the last fifty, and most of them within the last twenty or twenty-five years, is not as complete and definite as are the provisions of law which have been longer in the process of formation because relating to matters longer in existence and needing legal regulation. In our own country the responsibility of railroads for damages occasioned by fires kindled by sparks from their engines has been settled by statute in comparatively few cases. It is dependent mostly upon the application of the common law, and the adjudication of this differs in the various States. It is a maxim of that law that one is to use and enjoy his own property in such a manner as will not involve the injury of another. It is held that fire, being a dangerous element, whoever lights a fire, whether in a dwelling, in the field, or elsewhere, is bound to keep it so within his control that it shall not occasion damage to any one else. But he is held only to reasonable care and prudence in this respect, and there is room, in a multitude of cases, for dispute whether there was requisite care or such negligence as to render one liable for damages.

In most of our States, as has been said, the liability of railroads for damage occasioned by sparks from locomotives is determined by the common law. Most of the States, however, have made enactments on the subject. In Colorado, for example, railroad companies are required to have a strip of ground, not less than 6 feet wide, plowed every year between July and October on each side of the line of road, sufficient to prevent the spread of fire. This is not required within the limits of towns or cities, or on roads running through mountains where plowing would be impracticable.

In Connecticut the statute declares the fact that a fire was occasioned by a locomotive shall be *prima facie* evidence to charge with negligence those owning or operating the railroad on which the locomotive was in use. In Massachusetts whoever willfully or without proper care sets fire to the property of another is liable to a fine of $250, and fire wardens are directed to prosecute such offenders.

In Illinois the fact that a fire has been started by sparks from a locomotive is made, as in Connecticut, presumptive evidence of criminal negligence.

The law of Maine enacts that when property is injured by fire communicated by a locomotive, the corporation using it is responsible for such injury, and it has an insurable interest in the property along the route for which it is responsible and may procure insurance thereon.

In Maryland, railroad companies are responsible for injuries occasioned by fire, unless they can prove to the satisfaction of the court that there was no negligence.

In Michigan railroad companies are made liable for all loss or damage occasioned by the engines or employés of such companies. It is provided, however, that they shall not be liable if the engines are in good order and properly managed, all proper precautions are taken to prevent the origin of fires, and proper efforts are made to extinguish fires, in case of their extending beyond the limits of the road, when the existence of such fires is communicated to any of the officers of the road.

In New Hampshire railroads are made liable for all damages. They are also declared to have an insurable interest in all property on the line of the road exposed to damage.

The law of Vermont is similar to that of New Hampshire.

In New Jersey it is provided that engines must have screens, and the fact of fire is made *prima facie* evidence of the violation of the law.

The exposure of the railroad companies to complaints on account of fires originated by their locomotives, and to suits at law for damages, as well as other reasons appealing to their self-interest, have led to many and protracted experiments for the purpose of preventing damage to property arising from this source and inconvenience to passengers. Many contrivances for this purpose have been tried. Some have been, in a degree, successful, but most of them have proved failures in practice. Within a few years, however, spark-arresters have been devised which railroad engineers and managers declare to be so efficient in securing the end desired that it would seem to be imposing no hardship on the railroad companies to compel them by law to furnish all their locomotives, as a condition of their use, with one or another of these safeguards. An eminent expounder of the English common law says that though railway companies may be expressly authorized by statute to use locomotive furnaces of a dangerous character, "no statute can exempt them from the consequences of negligence in the management of their railways, or the construction of their fire-boxes, chimneys, or furnaces whereby coals of fire are thrown on the adjoining property. If they neglect to avail themselves of all such contrivances as are in known practical use to prevent the emission of sparks from their engines, they will be responsible for such neglect, and if they run locomotives without statutable authority, in that case they are responsible for any damage caused by such engines in setting fire to adjoining property or otherwise, although they have not been guilty of negligence."

It would seem that our interpretation of the common law should be as effective as that of England in protecting property from destruction by fires originating from passing locomotives, or that our statute laws should be made to accomplish the same end.

SMOKE-CONSUMING DEVICE FOR LOCOMOTIVES.*

By J. N. Lauder,
Superintendent of Motive Power, Old Colony Railroad.

In presenting this paper on smoke-consuming devices for locomotives, it is not my purpose to enter into the details of the mechanical construction of the various devices that have been experimented with in a practical way during the last thirty years, or, to speak more accurately, ever since the locomotive was brought into existence, but to give, in a general way, what has been done in the past and what is being done at the present time to mitigate the evils of the discharge of unconsumed products of combustion from the chimney of the locomotive.

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* Reprinted from the Proceedings of the American Forestry Congress at Boston, Mass., 1885.

The smoke and sparks that are discharged from the locomotive are so annoying to passengers that on some of our lines a trip by rail on a hot day is something to be dreaded, and the danger to forests and other property from fires set by these sparks is, in the aggregate, enormous.

To the novice the remedy for all this would seem to be to so arrange the furnace that perfect combustion would take place. This may be done on stationary or marine engines, where heating surface enough can be provided to allow of slow and perfect combustion, but in the locomotive the weight and size of boiler is limited and artificial means must be used to provide for such rapid combustion as is required when the engine is developing its full power.

The attention of locomotive mechanics has been drawn to this question of fuel-combustion ever since the birth of the locomotive, but their efforts to make it perfect have been only partially successful, and while the heating surface of our boilers is so small in comparison with the requirements of the engines a forced draft will have to be resorted to. This fact being recognized, it necessarily follows that when the engine is developing its full power the artificial draft is so strong that small particles of coal will be lifted from the fire and drawn through the flues unconsumed and discharged out of the chimney in the form of what is called sparks. The fact that some solid matter will be drawn through the flues from the fire being established, I will now briefly consider the various mechanical contrivances that have from time to time been brought forward to arrest and dispose of these solids.

Among the earliest contrivances (when wood was the universal fuel used in this country) was a chimney shaped like a funnel placed with the broad mouth upward. This broad end was covered with a wire screen, and inside of this chimney was placed a straight pipe somewhat smaller than the smallest diameter of the chimney, its height being about two-thirds that of the chimney. Over this, and near the wire screen, was mounted a deflecting plate with edges curving downward. A spark-reservoir was placed in some suitable position near the smoke-box, and pipes were made to lead from the annular space between the chimney and the inside pipe to this reservoir. The operation of this arrangement was as follows:

The unconsumed products of combustion that were drawn through the flues were driven by the exhaust steam upwards against the curved deflector at the top of the chimney, and the larger and heavier particles were forced down and into the spark-reservoir. The lighter particles would pass to the atmosphere through the wire screen, but would rarely have life enough to set anything on fire. The reservoir, however, was soon abandoned, as it was found in practice that with wood for fuel the sparks were so reduced in size by friction in their passage through the flues and chimney that they could all pass through the screen to the atmosphere with little danger of setting fires.

When coal came to be used as fuel the old arrangement of chimney was found to be unsuitable, and new appliances had to be devised. A new and annoying element had to be met—that of gas and smoke, caused by imperfect combustion in the furnace. When fresh coal is added to the fire a vast quantity of gas is evolved and unless a sufficient quantity of atmospheric air is brought into immediate contact with it, it will pass off in the form of smoke.

Various plans to furnish the requisite amount of air, and at the proper time, have been tried, but the varying conditions under which the engine is working have so far made it practically a failure.

Letting air into the furnace over the fire, while it will prevent the formation of smoke if let in in sufficient quantity, will also lower the steam-producing qualities of the boiler. Air mixed with a jet of steam driven into the furnace over the fire has been tried at various times and in various ways, but it has always ended in failure. D. K. Clark, the eminent English engineer and author, in his work on the locomotive, describes a method of injecting air and steam mixed into the furnace of a locomotive boiler to promote the combustion of the gases.

Recent so-called inventions brought out in this country are almost exact duplicates of appliances described by Clark long ago.

Rotary blowers have been used to drive the products of combustion from the smoke-box back to and into the furnace to be subjected to a reburning process, but such methods never got beyond the experimental stage. Double or twin furnaces have been tried, but while producing good combustion the mechanical difficulties to be overcome have thus far interfered with their success. Several years ago mechanical devices of various forms were quite largely used for driving the solid, unconsumed products of combustion from the smoke-box back through suitable tubes to the furnace, but they have nearly all given way to more modern and better methods.

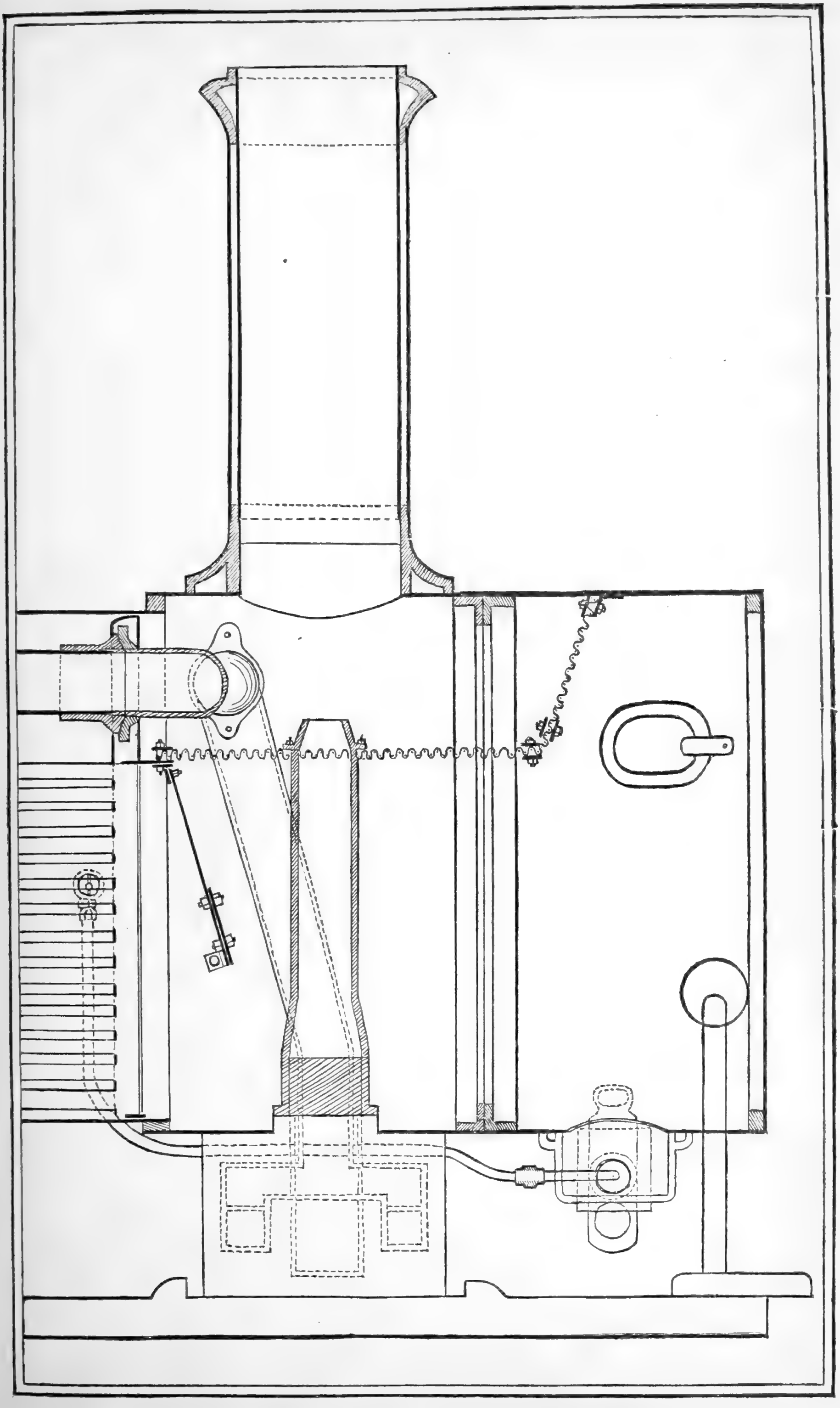
I will now proceed to discuss the most approved methods of promoting combustion, and also the mechanical means employed to prevent the escape of sparks from the chimney. And here let me say, curious as it may seem, the wonderful discoveries made in the last twenty years in the production of steel have a direct bearing on the question under discussion.

The substitution of steel for iron in rails and tires has made it possible to so increase the weight of the locomotive that larger boilers can be used, and therefore a very much greater heating surface in proportion to the cylinder area. This fact makes it possible to do what could not be done were soft-iron rails and tires still in use.

The modern locomotive boiler has little to distinguish it from its prototype of thirty years ago. All combustion chambers, water tables, and complications of all kinds have been discarded, and we have the plain rectangular furnace, with plenty of tubes to freely carry off the products of combustion. Its leading feature is its size and large heating surface. Its enormous evaporative power will be recognized when I say that this boiler, when pushed to its full capacity, will convert 3,000 gallons of water per hour into steam. To accomplish this amount of work on a grate surface of only 18 square feet, very rapid combustion must be maintained, and this can be done only by a forced draft. A forced draft means imperfect combustion, and imperfect combustion means particles of unconsumed coal drawn through the tubes. These unconsumed solids must be arrested in their course to the atmosphere and deposited in receptacles where their presence will not be harmful. This is measurably accomplished by the use of the appliances shown in the drawings. The smoke-box is made twice the usual length; a coarse wire-screen is drawn across high enough to be above all the boiler flues; the chimney is a plain, open pipe, smooth and free from obstructions; the exhaust pipes are carried up through the screen, terminating in a single nozzle. In front of the flues a deflecting plate is placed at a suitable distance from the ends of the flues, and is set at an angle of about twenty degrees. The functions of this plate are twofold—first, it equalizes the draft through the flues; and, second, it deflects the sparks downward, and instead of their being shot upward through the chimney they are banked up in the forward end of the smoke-box, there to remain until they are removed at the end of the trip. In the furnace is placed a fire-brick arch, extending entirely across the furnace and from the flue-sheet under the flues back about two-thirds of the length of the furnace. The gases, as they arise from the coal, are forced to travel back and over this arch on their passage to the flues, and by the delay thus caused, and also by their contact with the intensely hot fire-brick composing the arch, are very thoroughly consumed. The unburned solids lifted from the fire are also prevented from being drawn directly into the flues, the force of the draft caused by the exhaust steam in the chimney causing them to impinge against the hot brick, where the heat is so intense that a large percentage of them are consumed that would otherwise be drawn through the flues in a solid state. The brick arch is supported on four iron tubes, placed diagonally in the furnace, connecting the water-space under the flues with the water over the furnace crown. These tubes not only make a reliable support for the brick, but best promote the circulation of the water in the boiler.

The arrangement of smoke-arch described is not of recent design, but was patented

PLATE II.



OLD COLONY RAILROAD SPARK ARRESTER.

in substantially its present form about twenty years ago by Mr. John Thompson, of East Boston, who was then connected with the Eastern Railroad in the capacity of master mechanic. It was tried thoroughly by him at that time, but was abandoned for the reason that a comparatively few miles run would fill up the smoke-arch with sparks and so interfere with the draft that the capacity of the boiler to generate steam in sufficient quantities to supply the wants of the engine was destroyed. The small furnaces used at that time and the powerful artificial draft made necessary thereby produced this result.

As I stated in a former paragraph, the introduction of steel for rails and tires made the use of larger boilers possible, and with their introduction came the successful use of the spark-consuming and arresting devices described. The railroad with which I am connected has had these appliances in use on a limited number of engines for the past two years, and in no case has a forest or other fire been set by them, and if kept in proper order I believe they are absolutely safe.

In conclusion, I wish to say that careful and intelligent manipulation of the fire by the fireman is imperative, and will do more to prevent the formation of smoke than any mechanical contrivances.

Upon solicitation the following letter on the same subject was received by the Department:

IMPORTANCE OF SPARK-ARRESTERS.

CHICAGO AND NORTHWESTERN RAILWAY COMPANY,
DEPARTMENT OF MOTIVE POWER AND MACHINERY,
Chicago, October 27, 1886.

Hon. NORMAN J. COLMAN,
Commissioner of Agriculture.

DEAR SIR: I herewith beg leave to submit the following in answer to your request in regard to the best appliances in use on locomotives on the railways of this country for the prevention of fires on the lines of such railways, the preservation of forests, and all vegetation contiguous to them. It is a subject that has engaged and is, I believe, engaging the attention of many of the practical and scientific men of the day. Perhaps the subject has not yet received the attention it deserves, but I believe there is a growing tendency, both by railway officials and those not connected with railways, to solve this question; and while I do not think we have attained perfection, and never may attain it, I do think great improvements have been made in this direction within the last few years. For many years the almost universal practice was to use what is called the "Diamond Stack," which is too generally known to need a description here. While this and its appliances may have been faulty in principle, or in some particulars, it has been considered the standard until within a few years, when to some extent it has been superseded by other appliances for arresting sparks, among which (and one that is meeting with the most favor) is what is known as the "Extended Front-end and Straight Stack." This device differs materially from the appliances used with the "Diamond Stack," both in construction and principle. With the "Diamond Stack" the practice usually has been to place the netting in the stack over a cast-iron cone or deflector, the point of discharge of the exhaust pipes from 8 to 12 inches above the lower row of tubes in the boiler, and between the top of the exhaust pipes and the bottom of the stack, an intermediate pipe made of a size to give the best results according to the varying conditions, and designated as an "extension pipe," "petticoat pipe," and by various other names, but all for the same purpose, although varying in construction, to equalize the draft and carry the cinders that would be drawn through the flues in a straight line to the point or center of the cone or deflector; here they would be turned downward again and broken up by contact with the cone or deflector, and either be burned in the bottom of the smoke-box or pass out through the netting above. This is but one of the many devices in use, varying in construction, but yet embodying the same general principles. With the "Extended Front-end" the principle is different in many particulars; the exhaust pipes are carried higher, the point of discharge being above the netting, creating what may be perhaps fitly called a vacuum draft, instead of a direct or more forced draft (as in the other devices named), thus admitting of a larger area of netting and equalizing the draft more perfectly than with the other arrangements, in which the point of discharge is below the netting and nearer the bottom of the boiler or flues. My experience has been that more complete combustion of smoke and gases is obtained by this device than by the "Diamond Stack" and the appliances used in connection with it. The question of brick arches, or deflectors as an aid to combustion, has also received a good deal of attention and discussion from many who have made careful experiments with them, but I believe there is a great difference of opinion in regard to their utility for that purpose. My own experience is, that I have got better results from their use as an aid to combustion, and also as a preventive of fire being thrown from the stacks of locomotives than without them. While no doubt a large percentage of the destruction of forests along the lines of railways may be attributable to fires originating from sparks from stacks and ash-pans of locomotives, yet it is also a question whether, owing to the imperfect combustion, a large percentage is due also to the escape of noxious vapors and gases from locomotives. At the time this may be an unseen factor, yet I believe it is a very potent one, and one, too, that can be overcome only by more perfect appliances for effecting that result. The practice now is, largely, to increase the dimensions of the cylinders of locomotives to the maximum which boilers with our present standard gauge of road can be made to supply. This forcing process I presume will prevail as long as coal can be furnished for fuel to locomotives as cheaply as it is at present on many of the large railroads of the country, and in view of the increased tonnage locomotives can haul under this system; for it is a process quite necessary in generating steam enough to supply cylinders, which are perhaps not always in proportion to the boiler-capacity, nor with the end in view of a more perfect combustion.

In regard to the best appliances to prevent the evils complained of, I have endeavored as far as possible to confine myself to my own experience in the matter. I do not think it is my province to commend any one or particular device for this purpose, nor do I think that any one can, in view of the fact that the service on the railways of this country and its conditions are so varied. The great difference in the quality of the coal used on the different roads, and many other factors, all combine to make it difficult to recommend any one device that would be applicable to all; while the same general principles might apply if modified to meet the requirements of different kinds of service and conditions. But from my own experience I believe that we are obtaining, and shall obtain, better results from the use of the "Extended Front-end," and its appliance, in the way of combustion and less liability to fire, than from the use of the "Diamond Stack" and its appliances. I believe also, if the importance of the matter should be properly presented to the managers of railways of this country, and a reasonable amount of discretion is allowed to officials in charge of the motive power of our railways to make a system of careful and intelligent experiments, the best results will be obtained.

Very truly yours,

G. W. TILTON,

Superintendent Motive Power and Machinery.

INDEX.