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HOLDING POWER OF RAILROAD SPIKES

By Roy I. Webber, C. E., Instructor in Civil Engineering

The determination of a proper fastening between the rail and the tie has become a matter of considerable importance. During the period when the supply of suitable hard wood timber was sufficient, the ordinary spike satisfactorily fulfilled the requirements of traffic; but with the increase in the amount of traffic handled, and the heavier weights of cars and locomotives, and also with the use of soft deciduous and coniferous woods for ties, the common spike has proved deficient. Variations in the form of the ordinary spike have been developed, and new forms of spikes have been devised in an attempt to overcome the loss of efficiency attendant upon the use of inferior timbers.

In view of these conditions, and the meager supply of published data on the holding power of spikes in ties, the writer has carried out a series of experiments to determine the resistance to withdrawal offered by the same type of spike in different timbers and by different forms of spikes in the same timber, and also to determine whether or not the preservative has any influence upon this resistance.

The writer wishes to express his thanks for the hearty cooperation received from the various persons, firms and corporations mentioned in the text. He wishes also to express his indebtedness for personal aid, to Mr. Robert Trimble, Chief Engineer Maintenance of Way, Pennsylvania Lines; Mr. George E.
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| 20        | Loblolly Pine  | Zinc-Tannin       | 1905         | Treated Decem-
ber, 1905; sound |
| 21        | Loblolly Pine  | Zinc-Tannin       | 1905         | Treated Dec; '05; sound |
| 22        | Red Oak        | Zinc-Tannin       | 1905         | Treated Dec; '05; split |
| 23        | Black Oak      | Zinc-Tannin       | 1905         | Treated Dec; '05 |
| 24        | Black Oak      | Zinc-Tannin       | 1905         | Treated Dec; '05 |
| 25        | Water Oak      | Zinc-Tannin       | 1905         | Treated Dec; '05 |
| 26        | Water Oak      | Zinc-Tannin       | 1905         | Treated Dec; '05 |
| 27        | Black Oak      | Zinc-Tannin       | 1905         | Treated Dec; '05 |
| 28        | Red Oak        | Zinc-Tannin       | 1905         | Treated Dec; '05 |
| 29        | Water Oak      | Zinc-Tannin       | 1905         | Treated Dec; '05 |
| 30        | Red Oak        | Zinc-Tannin       | 1905         | Treated Dec; '05 |
| 31        | White Oak      | Zinc-Tannin       | 1905         | Treated Dec; '05 |
| 32        | White Oak      | Zinc-Tannin       | 1905         | Treated Dec; '05 |
| 33        | White Oak      |                    | 1905         | Seasoned; in track two years |
| 34        | Water Oak      | Creosote          | 1904         | Indiana Oak; sap wood showed slight decay |
| 35        | Burr Oak       | Creosote          | 1904         | Georgia Oak; seasoned; sound |
| 36        | Beech          | Creosote          | 1904         | Sound |
| 37        | Elm            | Creosote          | 1904         | Sound |
| 38        | Beech          |                    | 1904         | Sound |
| 39        | Loblolly Pine  |                    | 1904         | Seasoned; sound |
| 40        | Chestnut       |                    | 1904         | Seasoned; sound |
| 41        | Red Oak        | Creosote          | 1904         | Showed tendency to split |
| 42        | Beech          |                    | 1904         | Sound |
| 43        | Beech          |                    | 1904         | Sound |
| 44        | Beech          |                    | 1904         | Sound |
PLATE I

Testing Machine with Tie in Position for Test
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Boyd, Roadmaster of the Illinois Central Railroad; Mr. A. L. Kuehn, Superintendent of Maintenance of Way, of the Cleveland, Cincinnati, Chicago and St. Louis Railway; Dr. Octave Chanute, President of the Chicago Tie Preserving Company, Chicago, Illinois; and to Professor Ira O. Baker and Professor C. H. Hurd of the University of Illinois.

THE TIES

The ties used in these experiments were furnished gratuitously as follows: Nos. 1 to 11, and 16 to 30 by the Chicago Tie Preserving Company, Chicago, Illinois; Nos. 12 to 15 by the Illinois Central Railroad Company; Nos. 31 to 41 by the Cleveland, Cincinnati, Chicago and St. Louis Railroad Company. Table I gives a description of the several ties used. The ties were taken either from the stock pile of the railroad companies or from those of the treating plant. No attempt has been made to trace their history farther back than the place of growth and the date of treatment. Treated ties were used in a majority of the experiments, since in the future, as the inferior grades are pressed into service, the tendency will doubtless be toward the use of preserved timber.

EXPERIMENTS

Two distinct lines of experiments were undertaken: (1) The determination of the resistance to direct pull of several forms of spikes; and (2) An investigation of the resistance to lateral thrust. Therefore the paper naturally divides itself into two parts: Part I, Resistance to Direct Pull; Part II, Resistance to Lateral Displacement.

All of the experiments were made in the Laboratory of Applied Mechanics, University of Illinois.

PART I RESISTANCE TO DIRECT PULL

The experiments were made with a Riehle 100,000-pound testing machine. Plate I shows the machine with a tie in position for a test. The pulling device for ordinary spikes, also shown in Plate I, was a Verona spike-puller threaded into a piece of steel gripped between the lower jaws of the machine; the pulling device for the screw spikes was of the same general pattern and was designed especially for these tests. A scale graduated to 1-16 of an inch was so set that the distance moved through the lower head of the machine could be measured directly. A load of 500
pounds was applied to insure the tie's having a good bearing before any records were taken. The machine was geared to move at the rate of 5-8 of an inch per minute, which allowed time for carefully balancing the machine and for taking the readings of the scales. Five observations were usually taken; viz., when the lower head of the machine had moved through 1-8, 1-4, 1-2 and 3-4 of an inch, and also at the point at which the maximum fiber resistance was developed. No observations were made after the spike had been pulled 3-4 of an inch, as it would have lost its usefulness long before that point had been reached.

Further consideration of this part of the paper will be continued under the following heads: Art. 1, Holding Power of Ordinary Spikes; Art. 2, Holding Power of Screw Spikes without Linings; and Art. 3, Holding Power of Screw Spikes with Helical Linings.

**ART. 1 HOLDING POWER OF ORDINARY SPIKES**

The ordinary spikes were received from the following companies, the numbers in this list being the designations in the subsequent tables: Nos. 1 and 2 from the Pennsylvania Railroad Company; Nos. 3 and 4 from the American Iron and Steel Manufacturing Company, Scranton, Pennsylvania; Nos. 5 to 10 from Dillworth, Porter and Company, Pittsburg, Pennsylvania; No. 11 from the W. A. Zelnicker Supply Company, St. Louis, Missouri, and Nos. 12 to 14 from the Illinois Steel Company, Chicago, Illinois.

The nominal dimensions of the four sizes of spikes are shown in Table II. The actual lengths varied considerably from the nominal lengths, usually being less. This was particularly true concerning the 6-inch spike. The actual cross sections were nearly the same as the nominal, the variation in thickness rarely being over 1-64 of an inch. As the range in thickness of the spikes was only 1-16 of an inch, some experiments were made with plain, square and chisel-pointed bars 1-2, 3-4, and 7-8 of an inch thick to determine the relation between the holding power and the cross section. The spikes had differently shaped points, as shown in Table II. Three spikes were used for each experiment, and these three were always of the same size and lot number.

The spikes were driven by Mr. M. Flood, an experienced track foreman detailed for this purpose by the division engineer of the Cleveland, Cincinnati, Chicago and St. Louis Railway.
WEBBER—HOLDING POWER OF RAILROAD SPIKES

TABLE II

DESCRIPTION OF THE ORDINARY SPIKES

<table>
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<tr>
<th>Record Number</th>
<th>Nominal Length, inches</th>
<th>Section, square inches</th>
<th>Area, square inches</th>
<th>Type of Point</th>
<th>Depth Inserted, inches</th>
<th>Condition of Surface of Spike</th>
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<td>5</td>
<td>Smooth</td>
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<td>5-8</td>
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<td>0.372</td>
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<td>Smooth</td>
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<td>5 1-2</td>
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<td>0.372</td>
<td>Chisel</td>
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<td>Smooth</td>
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Whole ties were used to insure freedom from splitting in driving the spikes, and care was exercised to avoid driving the spike into knots or cracks. The spikes were driven into the tie to a depth of 5 inches. In some instances, as shown in the record, holes were bored for the ordinary spikes, the hole being 1-16 or 1-8 of an inch less in diameter than the cross sectional dimensions of the spike. The depth of boring was not quite as great as the depth of insertion, so that the pointed end of the spike was forced into the undisturbed wood. Table III gives the detailed numerical results of the tests and Plates II and III show graphically the curves of average resistances of the different ties.
PLATE II

Distance — Spike was Withdrawn in Inches

Curves Showing Resistance to Withdrawal of the Spike from the Tie.
PLATE III

Curves Showing Resistance to Withdrawal of the Spike from the Tie.
### TABLE III
DETAILED RECORD OF TESTS OF DIRECT PULL OF ORDINARY SPIKES

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<th>Kind of Tie</th>
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### TABLE III—Continued

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<th>1⅞ inch</th>
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<th>Pounds</th>
<th>Distance Withdrawn, inches</th>
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*This was the first tie tested, and gave unusually high results.
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<td>Av.</td>
<td>2530</td>
<td>5040</td>
<td>3280</td>
<td>3170</td>
<td>5210</td>
<td>5-16</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>12</td>
<td>1</td>
<td>2610</td>
<td>5670</td>
<td>4400</td>
<td>4170</td>
<td>6250</td>
<td>5-16</td>
</tr>
<tr>
<td></td>
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<td>2</td>
<td>2460</td>
<td>6220</td>
<td>4400</td>
<td>4170</td>
<td>7040</td>
<td>5-16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Av.</td>
<td>2590</td>
<td>5900</td>
<td>4400</td>
<td>4170</td>
<td>6650</td>
<td>5-16</td>
</tr>
<tr>
<td>Chestnut</td>
<td>40</td>
<td>5</td>
<td>1</td>
<td>2300</td>
<td>3100</td>
<td>2410</td>
<td>2260</td>
<td>4300</td>
<td>3-16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>2750</td>
<td>4940</td>
<td>2840</td>
<td>2610</td>
<td>4920</td>
<td>3-16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>2800</td>
<td>5730</td>
<td>3950</td>
<td>3650</td>
<td>6650</td>
<td>5-16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Av.</td>
<td>2490</td>
<td>3060</td>
<td>2540</td>
<td>2270</td>
<td>4470</td>
<td>3-16</td>
</tr>
<tr>
<td>Chestnut</td>
<td>40</td>
<td>12</td>
<td>1</td>
<td>3320</td>
<td>4670</td>
<td>3100</td>
<td>2940</td>
<td>5420</td>
<td>1-4</td>
</tr>
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<td></td>
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<td>2</td>
<td>4900</td>
<td>6230</td>
<td>2800</td>
<td>2670</td>
<td>5940</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>5110</td>
<td>6230</td>
<td>2800</td>
<td>2670</td>
<td>5940</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Av.</td>
<td>3480</td>
<td>5110</td>
<td>2770</td>
<td>2350</td>
<td>5110</td>
<td>1-4</td>
</tr>
<tr>
<td>Chestnut</td>
<td>40</td>
<td>4</td>
<td>1</td>
<td>1300</td>
<td>3780</td>
<td>3170</td>
<td>2940</td>
<td>5110</td>
<td>3-16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>2300</td>
<td>5420</td>
<td>3360</td>
<td>2780</td>
<td>5110</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>2440</td>
<td>5640</td>
<td>3190</td>
<td>2590</td>
<td>6220</td>
<td>5-16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Av.</td>
<td>2850</td>
<td>4950</td>
<td>3240</td>
<td>2770</td>
<td>5690</td>
<td>1-4</td>
</tr>
</tbody>
</table>
A study of the results of Table III has been made to determine: (A) Comparative holding power in untreated ties; (B) Comparative holding power in treated ties; (C) Comparative holding power of the same timber, treated and untreated; (D) Effect of preservative on the holding power; (E) Relation between the cross section of the spike and holding power; (F) Relation between the depth of pene-
raction and the holding power; (G) Effect of the point of the spike on the holding power; (H) Effect of bored holes on the holding power; (I) Effect upon the holding power of re-driving the spike.

A Comparative Holding Power in Untreated Ties

Table IV is compiled from Table III to show the average holding power for different untreated ties. Each result in Table IV is the average of the corresponding results in Table III.

**TABLE IV**

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>No. of Tests</th>
<th>No. of Spikes</th>
<th>Resistance in Pounds for a Pull of 1-8 inch</th>
<th>Resistance in Pounds for a Pull of 1-4 inch</th>
<th>Maximum Resistance</th>
<th>Resistance in per cent of that in White Oak</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Oak</td>
<td>10</td>
<td>30</td>
<td>3510</td>
<td>3950</td>
<td>7870</td>
<td>100</td>
</tr>
<tr>
<td>Elm</td>
<td>11</td>
<td>33</td>
<td>2310</td>
<td>5390</td>
<td>7200</td>
<td>100</td>
</tr>
<tr>
<td>Beech</td>
<td>3</td>
<td>9</td>
<td>2240</td>
<td>3790</td>
<td>8180</td>
<td>100</td>
</tr>
<tr>
<td>Chestnut</td>
<td>4</td>
<td>12</td>
<td>2970</td>
<td>4070</td>
<td>5190</td>
<td>100</td>
</tr>
<tr>
<td>Loblolly Pine</td>
<td>2</td>
<td>6</td>
<td>2920</td>
<td>3190</td>
<td>3630</td>
<td>85</td>
</tr>
</tbody>
</table>

Table IV shows the comparative holding power of five kinds of timber. The last three columns show the holding power in terms of that of white oak. It is thought that a pull of 1-4 of an inch gives results which are of more value in comparing the holding power of the different kinds of ties than the results for either greater or less distances, since the results for the 1-4-inch pull represent the resistances of the various timbers to the withdrawal of the spike for a distance which should not be exceeded in practice, and since the maximum resistance and the results for a pull of 1-8 of an inch represent the resistances for distances which are therefore not of so much consequence as the 1-4-inch pull. Notice that with chestnut and loblolly pine the maximum resistance occurs at 3-16 of an inch, which is a reason for comparing their maximum resistance with that of white oak at 1-4 of an inch instead of with its maximum resistance, as in Table IV. If this is done, the efficiencies of chestnut and loblolly pine for a 1-4-inch pull or less are 131 and 85 per cent respectively.
The fact that the maximum resistance did not occur until the spike had been pulled from 3-16 to 3-8 of an inch is interesting. While the spike is being driven the fibers of the wood are bent downward and are pressed outward, and as the spike is withdrawn the friction between the spike and the wood tends to draw the fibers into their original position, which causes them to crowd laterally against the spike and also toward the surface of the tie, until finally the external pull exceeds the internal resistance and the spike slips. When the fiber structure is open, there is considerable cellular space for the displaced fibers to occupy, and therefore the maximum resistance is low, and is quickly attained; but when the fiber structure is compact, the reverse is true.

As the loblolly pine ties should always be preserved, the results in Table IV for this timber are of doubtful value. For the best results elm ties also should be treated; but as some species of elm do not absolutely require treatment, elm is properly included in Table IV. Arranging these timbers in the descending order of their resistances for a 1-4-inch pull, we have elm, chestnut, white oak, beech and loblolly pine.

The maximum holding power for the first three timbers in Table IV is satisfactory, but that for the last two is quite low. The last fact indicates that when timber of the softer varieties or timber having loose fiber structure is used for ties, some more efficient form of fastening should be devised.

**B Comparative Holding Power in Treated Ties**

Table V is compiled from Table III to show the average holding power obtained with various treated ties, each result in this table being the mean of the corresponding values in Table III. The average results obtained with untreated white oak are also included so that comparisons can be made.

The average for the resistances for all of the treated timbers is shown at the foot of the table. Excluding the last two timbers, the average resistance for the 1-4-inch pull is 5690 pounds. The maximum resistance of the last two timbers should be averaged with the resistances of the others for the 1-4-inch pull, in which case the average resistance for all of the timbers for a 1-4-inch pull or less is 5400 pounds.

Table V shows that the resistances of the several timbers do not differ widely, and that the soft timbers give results which
### TABLE V

**AVERAGE HOLDING POWER IN TREATED TIES**

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>No. of Tests</th>
<th>No. of Spikes</th>
<th>Resistance in Pounds for a Pull of</th>
<th>Maximum Resistance</th>
<th>Resistance in per cent of that of White Oak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1-8 inch</td>
<td>1-4 inch</td>
<td>Pounds</td>
</tr>
<tr>
<td>White Oak (Untreated)</td>
<td>10</td>
<td>30</td>
<td>3510</td>
<td>3950</td>
<td>7870</td>
</tr>
<tr>
<td>Water Oak</td>
<td>16</td>
<td>48</td>
<td>2870</td>
<td>5730</td>
<td>6780</td>
</tr>
<tr>
<td>Black Oak</td>
<td>13</td>
<td>39</td>
<td>2910</td>
<td>5890</td>
<td>7230</td>
</tr>
<tr>
<td>Red Oak</td>
<td>20</td>
<td>60</td>
<td>2950</td>
<td>5350</td>
<td>7330</td>
</tr>
<tr>
<td>Burr Oak</td>
<td>3</td>
<td>9</td>
<td>2670</td>
<td>5750</td>
<td>9210</td>
</tr>
<tr>
<td>Ash</td>
<td>6</td>
<td>15</td>
<td>3370</td>
<td>5200</td>
<td>7730</td>
</tr>
<tr>
<td>Elm</td>
<td></td>
<td></td>
<td>2500</td>
<td>5940</td>
<td>7500</td>
</tr>
<tr>
<td>Beech</td>
<td>3</td>
<td>9</td>
<td>2650</td>
<td>6190</td>
<td>8900</td>
</tr>
<tr>
<td>Poplar</td>
<td>4</td>
<td>12</td>
<td>2890</td>
<td>5290</td>
<td>8770</td>
</tr>
<tr>
<td>Loblolly Pine</td>
<td>4</td>
<td>12</td>
<td>2020</td>
<td>3780</td>
<td>4310</td>
</tr>
<tr>
<td>Sweet Gum</td>
<td>5</td>
<td>15</td>
<td>3230</td>
<td>5320</td>
<td>5300</td>
</tr>
<tr>
<td>Av.</td>
<td></td>
<td></td>
<td>2950</td>
<td>5320</td>
<td>7040</td>
</tr>
</tbody>
</table>

The table shows that the range for the maximum resistances is much greater than for either the 1-8-or the 1-4-inch pull. The resistances for the different species of oak are very nearly the same, the mean for a 1-8 inch pull being 2850 pounds, for a 1-4-inch pull 5680 pounds and for the maximum 7740 pounds. Notice that with nearly all of the timbers the maximum resistance was obtained after the spike was pulled more than 1-4 of an inch, but there is no apparent relation between the amount of the holding power and the distance through which the spike has been pulled.

Comparing the resistances of treated timbers with that of untreated white oak, we see that the initial resistance of the white oak is higher than any of the other woods except one; while on the other hand, the resistance at 1-4 of an inch in white oak is less than in any of the other woods save one. The maximum resistances of all but the last three timbers are practically the same.

Considering the uniformity of the results obtained with a pull of 1-4 of an inch in the few timbers which were available, there appears to be no strong reason for much discrimination between the different treated timbers.
C Comparative Holding Power of the Same Timber, Treated and Untreated

Table VI has been compiled from Table III for the purpose of studying the effect of the treatment upon the holding power of a timber.

### TABLE VI

**Relative Holding Power in Treated and Untreated Ties**

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>No. of Ties</th>
<th>No. of Spikes</th>
<th>Condition of Tie</th>
<th>Resistance and Gain in Pounds Due to Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1-8 in. Pull</td>
</tr>
<tr>
<td>Elm</td>
<td>3</td>
<td>27</td>
<td>Untreated</td>
<td>2310</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>15</td>
<td>Treated</td>
<td>2590</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5390</td>
</tr>
<tr>
<td>Beech</td>
<td>1</td>
<td>9</td>
<td>Untreated</td>
<td>2240</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>9</td>
<td>Treated</td>
<td>2950</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2950</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5390</td>
</tr>
<tr>
<td>Loblolly</td>
<td>1</td>
<td>6</td>
<td>Untreated</td>
<td>2920</td>
</tr>
<tr>
<td>Pine</td>
<td>2</td>
<td>12</td>
<td>Treated</td>
<td>2920</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3190</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>640</td>
</tr>
<tr>
<td>Red Oak</td>
<td>3</td>
<td>15</td>
<td>Untreated</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>21</td>
<td>Treated</td>
<td>...</td>
</tr>
</tbody>
</table>

Table VI shows that higher resistances are developed in treated than in untreated ties. The average increase due to treatment for a 1-8 inch pull was 330 pounds; for a 1-4 inch pull, excluding the seemingly unreasonable increase in beech, 685 pounds; and for the maximum resistance 747 pounds.

Considerable reliance is placed upon the conclusions drawn from Table VI, inasmuch as the methods of making the tests were exactly the same for the treated and untreated ties, and since the same number of spikes, fifty-seven, was used in both cases, and also since the preserved ties were treated by different processes and at different plants.

The increased resistance due to treatment has two causes: (1) The presence of the preservative in the cells, thus reducing the space into which the fibers can crowd as the spike is withdrawn; and (2) The hardening of the fibers by the steaming, preparatory to treatment, which renders them less pliable.
The movement which took place among the fibers near the surface of the tie is interesting. In the untreated ties there was a crumpling of the fibers close to the spike, while the fibers in the treated ties were torn out in deep slivers extending from the spike to the blocks which supported the tie.

**D Effect of the Preservatives on the Holding Power**

Three distinct kinds of preserving solutions were used in the ties tested,—creosote, zinc-creosote and zinc-tannin.

Table VII has been compiled from Table III to study the effect produced by the treating solution upon the holding power of the tie.

Table VII does not show any marked difference between the resistances in ties treated with the different preservative solutions. For example, the maximum resistance of the red oak is lower when treated with zinc-tannin than when treated with zinc-creosote, but the reverse is true of the initial resistance of the red oak and also of the maximum resistance of black oak. With elm the initial resistance is higher in creosoted ties than in those treated with zinc-creosote, but the maximum resistance is lower. If any rating were made in order of efficiency, it would appear about as follows: (1) creosote, (2) zinc-creosote, and (3) zinc-tannin. However, there are too many uncertain quantities involved to make such a rating reliable; and moreover, the effect of the treating solution upon the holding power is only one of the many elements which must be considered when choosing between the different treating solutions.

**E Relation between the Cross Section of the Spike and the Holding Power**

The question to be answered here is, which size of spike will develop the highest holding power. To answer this question, Table VIII showing the relation between the cross section and the holding power has been compiled from Table III.

From a study of the results of Table VIII it will be noticed that no general rating can be made for the various sized spikes in order of the resistances developed, since the spike which develops the lowest holding power for the 1-8 inch or the 1-4 inch pull seldom develops the highest maximum resistance. For example, in white oak, the 19-32 inch spike developed the highest resistance for the
### TABLE VII

**Effect of Different Preservatives on the Holding Power**

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>Tie No.</th>
<th>Preservative</th>
<th>Resistance in Pounds for a Pull of</th>
<th>Maximum Resistance, Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1-8 inch</td>
<td>1-4 inch</td>
</tr>
<tr>
<td>Water Oak</td>
<td>4, 5, 25, 26, 29</td>
<td>Zinc-Tannin</td>
<td>2380</td>
<td>5010</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>Creosote</td>
<td>3020</td>
<td>6270</td>
</tr>
<tr>
<td>Red Oak</td>
<td>6, 9, 22, 28, 30</td>
<td>Zinc-Tannin</td>
<td>3170</td>
<td>5470</td>
</tr>
<tr>
<td></td>
<td>41</td>
<td>Creosote</td>
<td>3120</td>
<td>5800</td>
</tr>
<tr>
<td>Red Oak</td>
<td>7, 8</td>
<td>Zinc-Creosote</td>
<td>2350</td>
<td>4940</td>
</tr>
<tr>
<td></td>
<td>41</td>
<td>Creosote</td>
<td>3120</td>
<td>5800</td>
</tr>
<tr>
<td>Elm</td>
<td>10</td>
<td>Zinc-Creosote</td>
<td>2520</td>
<td>5870</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>Creosote</td>
<td>2600</td>
<td>6350</td>
</tr>
<tr>
<td>Red Oak</td>
<td>6, 7, 8, 9, 22</td>
<td>Zinc-Creosote</td>
<td>2350</td>
<td>4940</td>
</tr>
<tr>
<td></td>
<td>28, 30</td>
<td>Zinc-Tannin</td>
<td>3170</td>
<td>5470</td>
</tr>
<tr>
<td>Black Oak</td>
<td>16, 18</td>
<td>Zinc-Creosote</td>
<td>2850</td>
<td>5620</td>
</tr>
<tr>
<td></td>
<td>23, 24, 27</td>
<td>Zinc-Tannin</td>
<td>2830</td>
<td>5620</td>
</tr>
</tbody>
</table>

1-8-inch pull, but the 9-16-inch spike developed the highest resistance for the 1-4-inch pull, and also the highest maximum resistance. In black oak the highest resistance for the 1-8-inch pull was developed by the 9-16 spike, but that for the 1-4-inch pull was developed by the 19-32-inch size and the maximum resistance by the 5-8-inch spike. Averaging all of the resistances for the 1-8-inch pull, the 1-4-inch pull and the maximum resistance collectively, we see that the average holding power of the 9-16-inch spike is 4990 pounds, for the 19-32-inch spike 5420 pounds and for the 5-8-inch spike 5290 pounds. Because of the large number of spikes tested, seventy-two 9-16-inch, thirty-six 19-32-inch, and one hundred and two 5-8-inch, and the irregularity of the results, it was decided that no conclusions could be drawn from Table VIII as to the relative holding power of the different sizes of spikes. However, the thick-
TABLE VIII

RELATION BETWEEN THE CROSS SECTION OF THE SPIKE AND ITS HOLDING POWER

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>No. of Ties</th>
<th>No. of Spikes</th>
<th>Condition of Tie</th>
<th>Size of Spike, inches</th>
<th>1(\frac{3}{4}) in. Pull</th>
<th>3(\frac{1}{2}) in. Pull</th>
<th>Maximum Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Oak</td>
<td>2</td>
<td>9</td>
<td>Seasoned</td>
<td>9-16</td>
<td>3110</td>
<td>6280</td>
<td>8760</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6</td>
<td></td>
<td>19-32</td>
<td>3750</td>
<td>5830</td>
<td>7620</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>15</td>
<td></td>
<td>5-8</td>
<td>3660</td>
<td>6030</td>
<td>7620</td>
</tr>
<tr>
<td>Black Oak</td>
<td>4</td>
<td>15</td>
<td>Treated</td>
<td>9-16</td>
<td>2910</td>
<td>5340</td>
<td>6530</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6</td>
<td></td>
<td>19-32</td>
<td>2650</td>
<td>6130</td>
<td>7130</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>18</td>
<td></td>
<td>5-8</td>
<td>2550</td>
<td>5710</td>
<td>7240</td>
</tr>
<tr>
<td>Water Oak</td>
<td>5</td>
<td>15</td>
<td>Treated</td>
<td>9-16</td>
<td>2960</td>
<td>5560</td>
<td>6670</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>18</td>
<td></td>
<td>19-32</td>
<td>2970</td>
<td>5310</td>
<td>6010</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>15</td>
<td></td>
<td>5-8</td>
<td>2650</td>
<td>5330</td>
<td>6730</td>
</tr>
<tr>
<td>Red Oak</td>
<td>7</td>
<td>21</td>
<td>Treated</td>
<td>9-16</td>
<td>2300</td>
<td>4760</td>
<td>7650</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>36</td>
<td></td>
<td>5-8</td>
<td>3260</td>
<td>5990</td>
<td>6780</td>
</tr>
<tr>
<td>Beech</td>
<td>1</td>
<td>3</td>
<td>Seasoned</td>
<td>9-16</td>
<td>1880</td>
<td>3900</td>
<td>9410</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td></td>
<td>19-32</td>
<td>2550</td>
<td>5400</td>
<td>7660</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td></td>
<td>5-8</td>
<td>2290</td>
<td>5070</td>
<td>7900</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td>Treated</td>
<td>9-16</td>
<td>2480</td>
<td>5400</td>
<td>9410</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td></td>
<td>19-32</td>
<td>3530</td>
<td>6900</td>
<td>8250</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td></td>
<td>5-8</td>
<td>2550</td>
<td>6090</td>
<td>9040</td>
</tr>
<tr>
<td>Sweet Gum</td>
<td>1</td>
<td>6</td>
<td>Treated</td>
<td>9-16</td>
<td>2190</td>
<td>3770</td>
<td>4610</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>12</td>
<td></td>
<td>5-8</td>
<td>3490</td>
<td>4450</td>
<td>5460</td>
</tr>
</tbody>
</table>

ness of the spikes varied by only 1-16 of an inch or about 10 per cent, and their areas by only 0.075 of a square inch or about 20 per cent.

To test still further the relationship between the size of the spike and the holding power, a series of experiments was made with plain square rods with the results shown in Table IX. Each result is the mean of fifteen tests in a single kind of timber.
WEBBER—HOLDING POWER OF RAILROAD SPIKES

TABLE IX

EXPERIMENTS WITH PLAIN SQUARE RODS IN BEECH TIMBER

<table>
<thead>
<tr>
<th>Size of Rod</th>
<th>Area, sq. in.</th>
<th>Average Maximum Results, pounds</th>
<th>Increase for each Increment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Area</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>square inches</td>
</tr>
<tr>
<td>Successive increments in the size of the rod = 1-8 inch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2 inch square</td>
<td>0.250</td>
<td>6280</td>
<td>. . . . . .</td>
</tr>
<tr>
<td>5-8 inch square</td>
<td>0.301</td>
<td>6970</td>
<td>0.111</td>
</tr>
<tr>
<td>3-4 inch square</td>
<td>0.562</td>
<td>9070</td>
<td>0.171</td>
</tr>
<tr>
<td>7-8 inch square</td>
<td>0.765</td>
<td>9580</td>
<td>0.203</td>
</tr>
<tr>
<td>Successive increments in the size of the rod = 1-16 inch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-16 inch square</td>
<td>0.250</td>
<td>6280</td>
<td>. . . . . .</td>
</tr>
<tr>
<td>9-16 inch square</td>
<td>0.316</td>
<td>6450</td>
<td>0.006</td>
</tr>
<tr>
<td>10-16 inch square</td>
<td>0.391</td>
<td>6970</td>
<td>0.075</td>
</tr>
</tbody>
</table>

It will be seen from the results in Table IX that there is an irregular increase in the holding power as the size of the rod is increased. Notice that with increments of 1-8-inch, the successive increments in the resistance are at first large, but with the last rod this increment suddenly falls to practically nothing. This drop in the increment is principally due to the tendency of the large rod to split the tie. The results with 1-16-inch increments do not differ materially from those in the first part of the table.

The deduction for Table IX is that the holding power will be increased as the size of the rod is increased, but that it is not expedient to use rods (or spikes) larger than 3-4 of an inch unless holes are bored for them.

F. Relation between the Depth of Penetration and Holding Power

A series of experiments was made to determine the relation between the depth of penetration and the holding power. The results are given in Table X.
## TABLE X

**HOLDING POWER IN A WHITE OAK TIE WITH VARYING DEPTHS OF PENETRATION**

<table>
<thead>
<tr>
<th>Depth of Penetration</th>
<th>Resistance, Pounds</th>
<th>Test Number</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1-2 in.</td>
<td>150</td>
<td>150</td>
<td>140</td>
</tr>
<tr>
<td>1 in.</td>
<td>480</td>
<td>...</td>
<td>500</td>
</tr>
<tr>
<td>1 1/2 in.</td>
<td>1440</td>
<td>1000</td>
<td>1780</td>
</tr>
<tr>
<td>2 in.</td>
<td>2250</td>
<td>2250</td>
<td>2050</td>
</tr>
<tr>
<td>2 1/2 in.</td>
<td>3430</td>
<td>3840</td>
<td>3050</td>
</tr>
<tr>
<td>3 in.</td>
<td>3710</td>
<td>3800</td>
<td>4220</td>
</tr>
<tr>
<td>3 1/2 in.</td>
<td>4760</td>
<td>5980</td>
<td>4210</td>
</tr>
<tr>
<td>4 in.</td>
<td>5950</td>
<td>7190</td>
<td>6310</td>
</tr>
<tr>
<td>4 1/2 in.</td>
<td>7510</td>
<td>7510</td>
<td>7720</td>
</tr>
<tr>
<td>5 in.</td>
<td>8380</td>
<td>9070</td>
<td>8540</td>
</tr>
</tbody>
</table>

The spikes had a taper point approximately 1 inch long. Plate IV shows that the holding power varies directly with the penetration, not counting the taper point. It is impracticable to use a spike longer than 5 1/2 inches in a 6-inch tie, since a longer spike would either pass entirely through the tie or sliver it on the under side. In either case the fiber adjacent to the spike would quickly decay owing to the access of water. In a thicker tie, however, a longer spike could be used advantageously. The main precaution is to keep the spike from damaging the under surface of the tie, otherwise the longer the spike the greater the holding power.
PLATE IV

Depth of Penetration, Inches.

Curve Illustrating Resistance to Withdrawal for Various Depths of Penetration.
Effect of the Point of the Spike on the Holding Power

There were three distinct types of points on the spikes,—blunt-point, chisel-point and bevel-point.

![Forms of Points of Spikes](image)

The average results obtained with spikes having these types of points have been compiled from Table III, and are shown in Table XI. The average and relative resistances of each type of spike for all timbers are shown at the foot of the table. These averages show that both the blunt-pointed and the bevel-pointed spike are higher in holding power than the chisel-pointed spike. Since the average resistances of the blunt and the bevel-pointed spikes are practically the same, and since the blunt-pointed spike develops the highest resistance for the 1-8-inch and the 1-4-inch pull the greatest number of times, the blunt-pointed spike is first in point of efficiency, although the bevel-pointed spike is a close competitor under all conditions. The chisel-pointed spike is last.

The two upper figures of Plate V are the two halves of a red-oak tie showing the position of the fibers adjacent to the spike; and the lower figure is a portion of the other end of the same tie split after the spikes had been pulled out. The photograph was taken immediately after the tie had been split. The figures are too small to show details clearly, but an examination of the tie showed that the blunt-pointed spike disturbed more fiber than either the chisel or the bevel-pointed spikes, the last two disturbing about the same amount. The examination also showed that the blunt-pointed spike tore rather than cut the fibers, and deposited them in unequal bundles along its faces, while the chisel-pointed spike cut the fibers and deposited them quite uniformly both across and
Effect of Spikes in Displacing the Fibers of the Tie
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### Table XI

**EFFECT OF THE FORM OF THE POINT OF THE SPIKE ON THE HOLDING POWER**

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>No. of Spikes</th>
<th>Type of Point</th>
<th>Resistance in Pounds for 1-8 in. Pull</th>
<th>Maximum Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pounds</td>
<td>Pounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Relative</td>
<td>Relative</td>
</tr>
<tr>
<td>Water Oak</td>
<td>33</td>
<td>Chisel</td>
<td>2780</td>
<td>6540</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Bevel</td>
<td>3050</td>
<td>6330</td>
</tr>
<tr>
<td>Black Oak</td>
<td>9</td>
<td>Blunt</td>
<td>3020</td>
<td>8280</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Chisel</td>
<td>2850</td>
<td>6930</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Bevel</td>
<td>2680</td>
<td>6800</td>
</tr>
<tr>
<td>Red Oak</td>
<td>18</td>
<td>Blunt</td>
<td>2220</td>
<td>5760</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>Chisel</td>
<td>2880</td>
<td>7630</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>Bevel</td>
<td>3100</td>
<td>7370</td>
</tr>
<tr>
<td>White Oak</td>
<td>10</td>
<td>Blunt</td>
<td>4080</td>
<td>8760</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Chisel</td>
<td>3490</td>
<td>7690</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Bevel</td>
<td>2990</td>
<td>8010</td>
</tr>
<tr>
<td>Elm</td>
<td>21</td>
<td>Chisel</td>
<td>2150</td>
<td>7710</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>Bevel</td>
<td>2500</td>
<td>7050</td>
</tr>
<tr>
<td>Beech</td>
<td>6</td>
<td>Blunt</td>
<td>2180</td>
<td>9250</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Chisel</td>
<td>2570</td>
<td>8470</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Bevel</td>
<td>3040</td>
<td>7900</td>
</tr>
<tr>
<td>Chestnut</td>
<td>3</td>
<td>Blunt</td>
<td>2850</td>
<td>5690</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Chisel</td>
<td>2490</td>
<td>4470</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Bevel</td>
<td>3320</td>
<td>5310</td>
</tr>
<tr>
<td>Loblolly</td>
<td>3</td>
<td>Blunt</td>
<td>2860</td>
<td>4020</td>
</tr>
<tr>
<td>Pine</td>
<td>6</td>
<td>Chisel</td>
<td>3420</td>
<td>4120</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Bevel</td>
<td>2800</td>
<td>5520</td>
</tr>
<tr>
<td>Average for all</td>
<td></td>
<td>Blunt</td>
<td>2870</td>
<td>6860</td>
</tr>
<tr>
<td></td>
<td>Chisel</td>
<td>2840</td>
<td>6610</td>
<td></td>
</tr>
<tr>
<td>Timbers</td>
<td>Bevel</td>
<td>2930</td>
<td>6800</td>
<td></td>
</tr>
</tbody>
</table>

in front of each face. The bevel-pointed spike forced a majority of the fibers to the front face and toward the corners. The relatively high holding power of both the blunt and the bevel-pointed spikes is due to this unequal concentration of the fibers.
H Effect of Bored Holes on the Holding Power

A series of tests was made to study the effect of boring holes for the spike. The first step was to determine the proper size of the hole. Table XII shows the summary of a series of tests made at the University of Illinois in 1891* to determine the relationship between the holding power and the “drift”.

**TABLE XII**

**RESULTS OF EXPERIMENTS WITH SQUARE DRIFT-BOLTS IN PINE TIMBER**

<table>
<thead>
<tr>
<th>Size of Drift-Bolt</th>
<th>Size of Hole, inches</th>
<th>Drift, inches</th>
<th>Holding Power, Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>6-inch depth</td>
<td>Per inch depth</td>
</tr>
<tr>
<td>1 inch square</td>
<td>16-16</td>
<td>....</td>
<td>3972</td>
</tr>
<tr>
<td>1 inch square</td>
<td>15-16</td>
<td>1-16</td>
<td>4260</td>
</tr>
<tr>
<td>1 inch square</td>
<td>14-16</td>
<td>1-8</td>
<td>4660</td>
</tr>
<tr>
<td>1 inch square</td>
<td>13-16</td>
<td>3-16</td>
<td>4050</td>
</tr>
</tbody>
</table>

This table shows that with 1-inch square drift-bolts a drift of 1-8 of an inch gives a maximum holding power, but that a drift of 1-16 of an inch gives nearly as much resistance. It is not known that this relation holds with bolts less than 1-inch square, but the author assumed that this was sufficient reason for using a drift of 1-16 and 1-8 of an inch in this investigation, which conclusion is in accord with the usual railroad practice.

The second step was to determine the resistance to the different sized spikes in different kinds of ties. The detailed results for these experiments are given in Table XIII. Notice that the results are arranged according to the drift. The average results from Table XIII are shown in Table XIV along with the results from Table III for the same spike driven in the ordinary way.

The average resistances for all timbers, recorded at the foot of Table XIV, show that for a pull of 1-4 of an inch or less the spike driven into a bored hole develops higher holding power than one driven in the ordinary way. For a 1-4-inch pull or less the relative resistances show a marked increase in a majority of cases, but the maximum resistance for spikes driven into bored holes is usually the lowest.

* Technograph No. 5, 1891, University of Illinois
## TABLE XIII

### HOLDING POWER OF ORDINARY SPIKES IN BORED HOLES

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>Size of Spike, in. sq.</th>
<th>Diameter of Hole, inches</th>
<th>Resistance in Pounds for Pull of Hole 1-16 in. Smaller than Spike</th>
<th>Maximum Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1/8 inch</td>
<td>1/4 inch</td>
</tr>
<tr>
<td>Water Oak</td>
<td>9-16</td>
<td>1-2</td>
<td>2330</td>
<td>3860</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2050</td>
<td>3890</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2120</td>
<td>4770</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>1660</td>
<td>4450</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2500</td>
<td>4400</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3250</td>
<td>3750</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2990</td>
<td>4890</td>
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<td>Black Oak</td>
<td>9-16</td>
<td>1-2</td>
<td>3460</td>
<td>6770</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>3000</td>
<td>7120</td>
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<td></td>
<td></td>
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<td>4550</td>
<td>6810</td>
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<td>2970</td>
<td>6350</td>
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<td></td>
<td></td>
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<td>2910</td>
<td>6710</td>
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<td></td>
<td></td>
<td></td>
<td>2260</td>
<td>6720</td>
</tr>
<tr>
<td>Red Oak</td>
<td>9-16</td>
<td>1-2</td>
<td>3070</td>
<td>6550</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3950</td>
<td>6930</td>
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<td></td>
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<td>2120</td>
<td>5920</td>
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<td></td>
<td></td>
<td></td>
<td>2830</td>
<td>6900</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2660</td>
<td>4310</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2870</td>
<td>5710</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2990</td>
<td>6100</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>3950</td>
<td>6580</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2700</td>
<td>7430</td>
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<td></td>
<td></td>
<td></td>
<td>2080</td>
<td>7410</td>
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<td>6390</td>
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<td></td>
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<td>3000</td>
<td>5380</td>
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<td>6240</td>
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<td>2710</td>
<td>6530</td>
</tr>
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<td></td>
<td></td>
<td>2600</td>
<td>5460</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2850</td>
<td>5580</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3130</td>
<td>6800</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2950</td>
<td>5890</td>
</tr>
</tbody>
</table>
## TABLE XIII—Continued

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>Size of Spike, in. sq.</th>
<th>Diameter of Hole, inches</th>
<th>Resistance in Pounds for Pull of</th>
<th>Maximum Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-2</td>
<td>1-1 inch</td>
<td>1-2 inch</td>
<td>3-4 inch</td>
</tr>
<tr>
<td>Ash</td>
<td>5-16</td>
<td>4080</td>
<td>7210</td>
<td>4720</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2510</td>
<td>6540</td>
<td>3360</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1980</td>
<td>4850</td>
<td>4380</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2850</td>
<td>5840</td>
<td>3220</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2530</td>
<td>5760</td>
<td>3510</td>
</tr>
<tr>
<td></td>
<td>9-16</td>
<td>Av.</td>
<td>2790</td>
<td>6040</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-8</td>
<td>3920</td>
<td>4700</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2840</td>
<td>6300</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1660</td>
<td>5100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2100</td>
<td>6340</td>
</tr>
<tr>
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### TABLE XIII—Concluded

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<tr>
<th>Kind of Tie</th>
<th>Size of Spike, in. sq.</th>
<th>Diameter of Hole, inches</th>
<th>Resistance in Pounds for Pull of</th>
<th>Maximum Resistance</th>
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<td>3430</td>
<td>2980</td>
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## TABLE XIV

**AVERAGE RESISTANCE OF SPIKES WITH AND WITHOUT BORED HOLES**

<table>
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<tr>
<th>Kind of Tie</th>
<th>Size of Spike, in.-sq.</th>
<th>No. of Spikes</th>
<th>How Driven</th>
<th>Resistance in Pounds for</th>
<th>Relative Resistance</th>
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<td>Water Oak</td>
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<td>Hole</td>
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<td>6110</td>
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<td></td>
<td>15</td>
<td>No Hole</td>
<td>2960 5660</td>
<td>6670</td>
</tr>
<tr>
<td>Black Oak</td>
<td>9-16</td>
<td>6</td>
<td>Hole</td>
<td>3300 6750</td>
<td>7310</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>No Hole</td>
<td>2970 5320</td>
<td>6490</td>
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<td>Red-Oak</td>
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<td>Hole</td>
<td>3070 6390</td>
<td>6640</td>
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<td>3260 5430</td>
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<td>5-8</td>
<td>7</td>
<td>Hole</td>
<td>2950 5890</td>
<td>6960</td>
</tr>
<tr>
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<td></td>
<td>21</td>
<td>No Hole</td>
<td>2310 4760</td>
<td>7660</td>
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<tr>
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<td>9-16</td>
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<td>Hole</td>
<td>3150 5770</td>
<td>6760</td>
</tr>
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<td>No Hole</td>
<td>2180 4700</td>
<td>9410</td>
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<td>Ash</td>
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<td>5</td>
<td>Hole</td>
<td>2790 6040</td>
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</tr>
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<td>No Hole</td>
<td>4150 4630</td>
<td>6810</td>
</tr>
<tr>
<td>Sweet Gum</td>
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<td>6</td>
<td>Hole</td>
<td>2610 5550</td>
<td>6060</td>
</tr>
<tr>
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<td></td>
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<td>No Hole</td>
<td>2190 3730</td>
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<td>4</td>
<td>Hole</td>
<td>2830 4250</td>
<td>5210</td>
</tr>
<tr>
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<td></td>
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<td>No Hole</td>
<td>3460 4450</td>
<td>5460</td>
</tr>
<tr>
<td>Av. for all Timbers</td>
<td>......</td>
<td>Hole</td>
<td>2930 5680</td>
<td>6570</td>
<td>102 117</td>
</tr>
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<td></td>
<td></td>
<td>No Hole</td>
<td>2880 4840</td>
<td>6740</td>
<td>100 100</td>
</tr>
</tbody>
</table>

**Drift 1-16 of an inch**

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>Size of Spike, in.-sq.</th>
<th>No. of Spikes</th>
<th>How Driven</th>
<th>Resistance in Pounds for</th>
<th>Relative Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Oak</td>
<td>5-8</td>
<td>6</td>
<td>Hole</td>
<td>3270 5010</td>
<td>5800</td>
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<tr>
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<td></td>
<td>21</td>
<td>No Hole</td>
<td>2310 4760</td>
<td>7660</td>
</tr>
<tr>
<td>Beech</td>
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<td>10</td>
<td>Hole</td>
<td>2780 5550</td>
<td>7200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>No Hole</td>
<td>2180 4700</td>
<td>9410</td>
</tr>
<tr>
<td>Sweet Gum</td>
<td>5-8</td>
<td>3</td>
<td>Hole</td>
<td>2730 34 30</td>
<td>4640</td>
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<tr>
<td></td>
<td></td>
<td>9</td>
<td>No Hole</td>
<td>3460 4450</td>
<td>5460</td>
</tr>
<tr>
<td>Av. for all Timbers</td>
<td>......</td>
<td>Hole</td>
<td>2930 4660</td>
<td>6550</td>
<td>111 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Hole</td>
<td>2650 4640</td>
<td>7510</td>
<td>100 100</td>
</tr>
</tbody>
</table>
As far as conclusions can be drawn from these experiments, the spike driven into a bored hole is superior to one driven in the ordinary way.

I Effect upon the Holding Power of Re-driving the Spike

In practice, when the spike is pulled out of the tie a moderate distance, it is driven back, provided the hole is not greatly enlarged. If the hole is much enlarged the spike is driven at another point. This constant re-spiking rapidly ruins the tie. A series of tests was made to determine the effect upon the holding power of re-driving the spike. The average maximum holding power of the re-driven spikes is shown in Table XV along with the original maximum holding power of the same spike.

It will be seen that the holding power of the re-driven spike is very much less than that of the newly-driven spike. The resistance is affected so much in some woods as to make the practice of re-driving the spike a questionable procedure if the holding power alone is considered; but as the practice of re-driving the spike helps to lengthen the life of the tie, the practice can not be justly condemned so long as the holding power is not excessively reduced.

### TABLE XV

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>No. of Spikes</th>
<th>Average Maximum Resistance, Pounds</th>
<th>Percent of Original</th>
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<tr>
<td>Ash</td>
<td>6</td>
<td>Original: 8640</td>
<td>After Re-driving: 6490</td>
</tr>
<tr>
<td>Water Oak</td>
<td>6</td>
<td>Original: 8020</td>
<td>After Re-driving: 5760</td>
</tr>
<tr>
<td>Red Oak</td>
<td>6</td>
<td>Original: 8030</td>
<td>After Re-driving: 5230</td>
</tr>
<tr>
<td>Elm</td>
<td>6</td>
<td>Original: 7910</td>
<td>After Re-driving: 4840</td>
</tr>
<tr>
<td>Poplar</td>
<td>6</td>
<td>Original: 4920</td>
<td>After Re-driving: 3980</td>
</tr>
<tr>
<td>Sweet Gum</td>
<td>6</td>
<td>Original: 5040</td>
<td>After Re-driving: 4150</td>
</tr>
</tbody>
</table>

A series of tests was made to determine the holding power of screw spikes. The tests were conducted in the same manner as those with the ordinary spikes.
The screw spikes were received from the following companies: No. 1 from the Illinois Central Railroad Company; No. 2 from the American Iron and Steel Manufacturing Company, Scranton, Pennsylvania; No. 3 from the South Side Elevated Railroad Company, Chicago, Illinois; No. 4 from the Oliver Steel and Iron Company, Pittsburg, Pennsylvania; and No. 5 from the Pennsylvania Railroad Company.

A description of the different spikes is given in Table XVI.

**TABLE XVI**

**DESCRIPTION OF SCREW SPIKES**

<table>
<thead>
<tr>
<th>Spike No.</th>
<th>Length, inches</th>
<th>Diameter of Core, inches</th>
<th>Projection of Thread, inches</th>
<th>Pitch, inches</th>
<th>Depth of Insertion, inches</th>
<th>Diameter of Bored Hole, inches</th>
</tr>
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<tr>
<td>1</td>
<td>5</td>
<td>21-32</td>
<td>3-16</td>
<td>1-2</td>
<td>4 1-2</td>
<td>11-16</td>
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<tr>
<td>2</td>
<td>5</td>
<td>11-16</td>
<td>1-8</td>
<td>1-2</td>
<td>4 1-2</td>
<td>11-16</td>
</tr>
<tr>
<td>3</td>
<td>5 1-4</td>
<td>11-16</td>
<td>1-8</td>
<td>1-2</td>
<td>4 3-4</td>
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<td>21-32</td>
<td>3-16</td>
<td>1-2</td>
<td>4 1-2</td>
<td>11-16</td>
</tr>
</tbody>
</table>

The shank or threaded portion of the spike was usually 7-8 of an inch in diameter, and approximately one inch of the upper portion of the core tapered from the diameter of the core to that of the shank. The hole bored for the spike was not reamed, and the result was a tight fit between the wood and the spike. This tight contact is gained in practice by the head of the spike bearing against the base of the rail. The spike was driven by means of a wrench, the thread cutting its own path. The number of screw spikes obtainable was not sufficient to make as long a series of tests as with the ordinary spikes.

A study of the results with this spike has been made to determine: (A) Relation between the depth of penetration and the holding power; (B) Relation between the holding power of the screw and of the ordinary spikes; and (C) Influence of certain details of the screw spike upon its holding power.

The detailed results of the tests with screw spikes are given in Table XVII, and the average results are shown in Plates II and III.
## TABLE XVII
### DETAILED RECORD OF TESTS WITH SCREW SPIKES

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<th>Kind of Tie</th>
<th>No. of Tie</th>
<th>No. of Spike</th>
<th>No. of Test</th>
<th>Resistance in Pounds for a Pull of</th>
<th>Maximum Resistance</th>
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<td>7480</td>
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<td>Av.</td>
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<td>No. of Spike</td>
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<td>2 3840</td>
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<td>3 8200</td>
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<td></td>
<td></td>
<td>Av. 5820</td>
<td>9240</td>
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</table>
A Relation between Depth of Penetration and the Holding Power

A series of tests was made to determine the relation between the depth of penetration and the holding power of the screw spikes. The experiments consisted of pulling spikes driven to depths of 1, 2, 3, 4 and 5 inches into a beech tie, three spikes being used for each depth. The numerical results are shown in Table XVIII, and their averages are shown graphically in Plate VI together with some additional matter which is shown for the sake of comparison.

TABLE XVIII

<table>
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<th>Test Number</th>
<th>Resistance in Pounds for a Penetration of</th>
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<td>1</td>
<td>2770</td>
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<td>3</td>
<td>2790</td>
</tr>
<tr>
<td>Av.</td>
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</table>

The results in Plate VI can be quite closely represented by two intersecting straight lines. The probabilities are that the actual resistances would be more nearly represented if the two straight lines were joined by a short curve near their intersection. Only the upper portion of the diagram is of interest, since penetrations of less than four inches should never be used, at least on heavy traffic railroads, the only roads likely to use screw spikes.

The diagram shows that the resistance varies directly with the depth of penetration.

B Relative Holding Power of Screw Spikes and Ordinary Spikes

Table XIX has been prepared from Table XVII and from Table III, to determine the relation between the holding power of the screw spike and that of the ordinary spike. As previously stated, the ordinary spikes were driven into the tie to a uniform depth of 5 inches, while the screw spikes, being of different lengths, necessarily were inserted to unequal depths. On account of the relation existing between the depth of penetration and the holding power, the resistance for the screw spikes, shown in Table XIX, is based upon a penetration of 5 inches.
PLATE VI

Depth of Penetration, Inches.

Curves Illustrating Resistance to Withdrawal of the Screw and Ordinary Spikes for Various Depths of Penetration.
From Table XIX it will be seen that the holding power of the screw spike is always greater than that of the ordinary spike, and that the relation between the two varies in the several timbers. For a pull of 1-4 of an inch in the hard woods the holding power of the screw spike is from 167 to 221 per cent of that of the ordinary spike, and in the soft woods the range is from 117 to 258 per cent; or the average gain in the hard woods is 76 per cent, and in the soft woods 98 per cent. It is interesting to note that the resistances in the several timbers for the 1-8-inch pull with the screw spike are in eight out of eleven instances nearly the same as, or greater than, the resistances for the 1-4-inch pull with the ordinary spike. This signifies that the screw spike is about twice as efficient as the ordinary spike for a pull of 1-4 of an inch or less. The curve in Plates II and III show graphically the relative efficiency of the two forms of spikes with some information to be referred to later.

C Effect of Certain Details of the Screw Spike upon Its Holding Power

In countries where the screw spike is extensively used it has been perfected in detail until it nearly fulfills the requirements of practice. In North America the screw spike will probably be the successor to the ordinary spike, and it may again be necessary to adjust the details to suit local conditions. Therefore a few observations on the relation of some of the details of this spike to its holding power come within the scope of this paper. The details to be discussed are the diameter of the core, the projection and pitch of the thread and the length of the thread. These details being interdependent will be discussed collectively.

The soft steel from which the screw spike is made has an ultimate strength of about 66,000 pounds per square inch, so that the tensile strength of a spike 11-16 of an inch in diameter is approximately 24,000 pounds. The ultimate compressive resistance across the grain of well-seasoned white oak is about 4,000 pounds per square inch, and experiments demonstrate that the thread of the spike in compacting the wood fibers increases the resistance about 40 per cent.* Therefore, taking 5,600 pounds as the ultimate compressive strength of compacted white oak, and taking 17 3-4 inches and 1-8 of an inch respectively as the length and projection of the

*Bulletin No. 50, U. S. Dept. of Agriculture.
### Table XIX

**Relative Holding Power of the Screw Spike and of the Ordinary Spike in Several Timbers**

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>Kind of Spike</th>
<th>Resistance in Pounds for</th>
<th>Relative Resistances</th>
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<td>5730</td>
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<td>Screw</td>
<td>4888</td>
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<tr>
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<td>Ordinary</td>
<td>2910</td>
<td>5890</td>
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<tr>
<td></td>
<td>Screw</td>
<td>4760</td>
<td>10420</td>
</tr>
<tr>
<td>Red Oak</td>
<td>Ordinary</td>
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<td>5350</td>
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<td>4000</td>
<td>10400</td>
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<td></td>
<td>Screw</td>
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<td>13140</td>
</tr>
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<td>4070</td>
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<tr>
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<td>6340</td>
</tr>
<tr>
<td>Sweet Gum</td>
<td>Ordinary</td>
<td>3230</td>
<td>4120</td>
</tr>
<tr>
<td></td>
<td>Screw</td>
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<td>7710</td>
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<tr>
<td>Loblolly Pine</td>
<td>Ordinary</td>
<td>2920</td>
<td>3500</td>
</tr>
<tr>
<td></td>
<td>Screw</td>
<td>5750</td>
<td>9050</td>
</tr>
</tbody>
</table>

Thread on the 5-inch spike, and making no allowance for frictional resistance between the core of the spike and the wood, the theoretical resistance would be

\[ 5,600 \times 17.34 \text{ inches} \times 1.8 \text{ inches} = 12,430 \text{ pounds.} \]

The average actual resistance obtained in white oak ties as shown in Table XIX is 12,630 pounds which agrees closely with the theoretical resistance. The tensile strength of the screw spike is
about 12,000 pounds greater than the maximum resistance of white oak, which difference is greater than necessary and indicates an uneconomical use of metal in the spike. Since the ties tested are representative of American practice, there is no apparent reason for not having the ultimate strength of the two materials in contact more nearly equal than at present, and by some slight change in the detail of the spike this could readily be accomplished. Three ways in which the ultimate strength of the materials may be made more nearly equal are: (1) increase in length of threaded portion; (2) increase in projection of thread, the length and the diameter of the core remaining the same; (3) increase in projection of thread at the expense of the core, the length remaining the same. The pitch is assumed to be 1-2 inch in all cases, since it has been found in practice that this pitch gives better results than either a greater or smaller pitch.*

(1) The length of the thread on the 5-inch spike is 17 3-4 inches and the width is 1-8 of an inch; therefore, the bearing area is 2.22 square inches. If the spike is made 6 inches long two convolutions of the thread will be added, the bearing area will become 2.71 square inches, and the holding power will be increased from 12,630 pounds to 15,180 pounds. This leaves a difference of only 8,900 pounds between the ultimate strength of the wood and that of the spike.

(2) If the length of the spike and the diameter of the core are not changed, and if the projection of the thread is increased 1-32 of an inch, the total resistance would amount to 15,510 pounds, leaving the ultimate strength of the spike only 8,500 pounds greater than that of the wood.

(3) If the length of the threaded portion of the spike remains unchanged and if the projection of the thread is increased 1-32 of an inch at the expense of the core, the maximum resistance would amount to 15,510 pounds, while the ultimate strength of the spike would be reduced to 20,200 pounds.

The diameter of the shank of the spike would have to be increased with some of the changes in the detail of the lower portion, and when the resistance to lateral displacement is taken into account, we see that this change also would be beneficial.

The conclusion is that the screw spike in its present form is

*Bulletin No. 50, U. S. Dept. of Agriculture.
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PLATE VII

SCREW SPIKES AND TOOLS FOR INSERTING THEM

"1/16 inch Bit."

Screw Tap.

Driver.

Metal Lining

Screw Spike

SCREW SPIKES AND TOOLS FOR INSERTING THEM
about twice as efficient as the ordinary spike; and that this efficiency could be increased by some slight change in the detail of the screw spike.

**ART. 3 HOLDING POWER OF SCREW SPIKES WITH HELICAL LININGS**

A few experiments were made with screw spikes having helical linings. On account of the small number of linings obtainable the tests were limited; as this lining, being a foreign invention, is not yet used by the railroads of this country except for experimental purposes. The tests were still further limited since the linings could not be used a second time; and further since all of the linings could not be driven successfully, as the friction between the metal and the wood sometimes caused the driver to loosen its hold, which could not be regained even after carefully following printed instructions. This accounts for the use of only two linings in some of the timber. The linings together with a set of special tools for inserting them in the tie were furnished by Mr. Robert Trimble, Chief Engineer Maintenance of Way, Pennsylvania Lines, (see Plate VII).

The linings were made by Mr. J. Thiollier of Paris, France, and are described by him as being 0.33 inch by 0.17 inch in section, and also as being of the class which he calls P. M. or small sized linings. They were 4 inches long with a 1-2-inch pitch. The total diameter was 1 5-16 inches, the diameter inside of the spiral band slightly over 11-16 of an inch, and the thickness and width of the metal band 1-8 and 1-4 of an inch, respectively. The linings were evidently designed to be used with the screw spike of the French Eastern Railway, No. 1, Table XVI, and hence they were tested with this spike only.

The method of fixing the lining in place was as follows: A hole having the same diameter as the core of the spike was bored in the tie; the hole was tapped, and the lining inserted by means of special tools designed for the purpose; the spike was inserted in the usual manner.

The detailed results of these tests are shown in Table XX, and the average results are shown graphically in Plates II and III. The relative holding power of the several kinds of spikes in different timbers is shown in Table XXI. The results of this table and the diagrams in Plates II and III show that in hard woods
the resistances for a 1-8-inch pull are usually greater for the spike and lining than for the naked screw spike, but for pulls greater than 1-8 of an inch the reverse is true. In soft woods the spike and lining gave greater resistances than the naked screw spike except in sweet gum. The lower resistance in the hard woods is accounted for by the fact that the spike begins to move before the lining, and the fibers, being hard, are bent slightly upward so that the bearing surfaces of the wood and the spike are only partially in contact. Moreover, the fibers probably slip over the rounded edge of the lining, which tends to lower the resistance. In the soft woods more than in the hard woods, the fibers mash together as the spike is pulled out, consequently the bearing surfaces of the wood and the spike have full contact and the resistance is greater than with the naked screw spike.

In justice to Mr. Thiollier it is only right to say that he claims no more for the P. M. lining than is set forth in these experiments. He says that the P. M. lining will offer no more resistance than a naked screw spike. The principal claims for the P. M. lining are that it can be placed on the track without removing either the rail or the tie, and that it forms an advantageous substitute for the square wooden dowel used on some railways.

As a repair measure this lining is of doubtful value, for it extends only about 1-8 of an inch beyond the thread of the spike; and when the spike has been pulled even a small distance the adjacent wood is badly damaged, so that the wood which remains after the hole is tapped for the lining can offer but slight resistance. Moreover, it is not certain that the extreme fibers reached by the lining are not somewhat affected, hence it would be better to ream the hole, cutting out all damaged wood and to introduce a threaded hard wood dowel, or to use a lining of larger size.

The writer claims that the use of the small lining is impracticable for the following reasons: (1) It is designed to be put in place with the tie in the track; (2) The lining cannot always be inserted into the wood to its full length by means of hand tools, even with utmost precaution; (3) At best the holding power is not increased to any marked degree over that of the naked screw spike; and (4) The labor involved is more than double that required to drive the naked screw spike, and the cost is increased.
**WEBBER—HOLDING POWER OF RAILROAD SPIKES**

**TABLE XX**

**RESISTANCE OF SCREW SPIKES WITH HELICAL LININGS**

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<th>Kind of Tie</th>
<th>No. of Tests</th>
<th>Resistance in Pounds for Pull of</th>
<th>Maximum Resistance</th>
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<td>1-4 in.</td>
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<td>8070</td>
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<td>8070</td>
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* Screw spike with helical lining.

The * belongs after "Lining."
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PLATE VIII

IMPACT APPARATUS
PART II RESISTANCE TO LATERAL DISPLACEMENT

The railroad spike is subjected not only to a direct pull by the undulation of the rail, but also to a horizontal thrust due to the lateral movement of the rail. On roads having a large amount of curvature the lateral resistance is of more importance than that of direct pull.

To determine the amount of the resistance to lateral displacement which is developed by various forms of spikes the writer made a series of tests in which the lateral thrust was produced by the blows of a heavy hammer. The hammer consisted of a cast-iron weight suspended by a wooden rod from the joists of the floor above.

The place in which the apparatus was used was such that a good photograph could not be taken. Plate VIII is a view of the apparatus set up in a light suitable for photographing. All essential features are correctly represented. Fastened to the joists were metal strips upon which the knife edges of the rocking arm rested. These strips were 6 feet long, and were notched along the entire upper edge to permit the placing of the rocking arm in different positions. The length of the suspending rod was 9 feet.

The weight of the hammer was 100 lb. and the distance through which it was allowed to fall was 1 1/2 feet, so that the amount of the impact for each blow was 150 ft.-lb. The hammer delivered its blow on the end of a tool-steel bar which projected beyond the end of the tie, the other end of the bar being shaped to fit under the head of the spike.

The spikes used in this series of tests were 9-16 inch and 5-8 inch ordinary spikes and screw spikes. Each spike was subjected to five blows and the displacement produced by each blow was carefully measured. Usually four or five spikes of each kind were tested, but when there was much lack of uniformity in the results a larger number were tested.

All of the spikes were bent to a curve, the central point of which was about 1 1-2 inches below the surface of the tie. The ordinary spikes were pulled from the tie a short distance, but the thread of the screw spikes gripped the wood so as to prevent the spike from being pulled out even a perceptible amount.
ART. 3 LATERAL RESISTANCE OF ORDINARY SPIKES

The detailed results of the experiments with ordinary spikes are given in Table XXII and the average movement of the spike for each of the several blows is shown in Table XXIII. The average total movement of the 5-8 inch spikes in the first seven timbers was 0.65 inch, and that of the 9-16 inch spikes was 0.75 inch. In the last four timbers the average total movement of the 5-8 inch spikes was 0.74 inch, and that of the 9-16 inch spikes was 0.94 inch.

The total deflection of the 9-16 inch spikes was usually sufficient to allow a rail to clear the head of the spike if it were overturned. The corresponding movement of the 5-8 inch spikes was not usually sufficient to allow a like clearance, although it was considerably more than would be allowed in practice.

The first blow is of more importance than the succeeding blows in testing the efficiency of a spike. While the distances through which the different sized spikes were deflected by the first blow differ but a small amount, this difference is sufficient to show that the deflection is less for the 5-8 inch spikes than for the 9-16 inch.

These results, together with the fact that the 5-8 inch spikes were bent less by the impact than the 9-16 inch spikes, indicate that the 5-8 inch spike is more efficient in resisting lateral displacement than the 9-16 inch spike.

ART. 4 LATERAL RESISTANCE OF SCREW SPIKES

The method of determining the lateral resistance of screw spikes was the same as that used for ordinary spikes. The results for this set of tests are given in Table XXIV. The screw spikes used were all practically alike except that they were of various lengths. In making the tests the spikes were used indiscriminately, but since they were not all of the same length some tests were made to determine the effect of impact upon spikes which were driven into the tie to different depths. The spikes used for the latter tests were all of the same make, and were cut to lengths of 3, 3 1-2, 4, 4 1-2 and 5 inches, and were all driven into a single kind of timber. The results of these tests are shown in Table XXV. While the results for the 4- and 4 1-2-inch spikes are the same, the
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Averages in the last column of the table show that the amount of the lateral movement decreases as the depth of penetration increases. Also, the difference between the deflections of the 4-, 4 1/2-, and 5-inch spikes is practically negligible, but for shorter lengths the difference in the deflections becomes greater.

Table XXVI gives the lateral movement of the screw spikes for each of the several blows for which the total movements were given in Table XXIV. The number of spikes used in each kind of timber was usually three; but in case there was considerable variation in the results, more spikes were tested. By a study of this table the effect of impact upon screw spikes in different kinds of timber may be determined.
### TABLE XXIII
LATERAL MOVEMENT OF ORDINARY SPIKES FOR EACH BLOW

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<th>Average Movement, inches</th>
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</tr>
<tr>
<td></td>
<td>5-8</td>
<td>0.17</td>
<td>0.16</td>
</tr>
<tr>
<td>Red Oak</td>
<td>9-16</td>
<td>0.21</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>5-8</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Ash</td>
<td>9-16</td>
<td>0.23</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>5-8</td>
<td>0.18</td>
<td>0.15</td>
</tr>
<tr>
<td>Elm</td>
<td>9-16</td>
<td>0.22</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>5-8</td>
<td>0.21</td>
<td>0.14</td>
</tr>
<tr>
<td>Beech</td>
<td>9-16</td>
<td>0.25</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>5-8</td>
<td>0.14</td>
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</tr>
<tr>
<td>Poplar</td>
<td>9-16</td>
<td>0.27</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>5-8</td>
<td>0.16</td>
<td>0.18</td>
</tr>
<tr>
<td>Chestnut</td>
<td>9-16</td>
<td>0.32</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>5-8</td>
<td>0.22</td>
<td>0.19</td>
</tr>
<tr>
<td>Sweet Gum</td>
<td>9-16</td>
<td>0.28</td>
<td>0.21</td>
</tr>
<tr>
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<td>5-8</td>
<td>0.16</td>
<td>0.18</td>
</tr>
<tr>
<td>Loblolly Pine</td>
<td>9-16</td>
<td>0.22</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>5-8</td>
<td>0.18</td>
<td>0.12</td>
</tr>
</tbody>
</table>
# TABLE XXIV
## Detailed Results of Impact Tests of Screw Spikes

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>Total Lateral Movement of Spike, in Inches</th>
<th>Number of Blows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>White Oak</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.07</td>
</tr>
<tr>
<td></td>
<td>Av.</td>
<td>.09</td>
</tr>
<tr>
<td>Black Oak</td>
<td></td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td>Av.</td>
<td>.11</td>
</tr>
<tr>
<td>Water Oak</td>
<td></td>
<td>.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.08</td>
</tr>
<tr>
<td></td>
<td>Av.</td>
<td>.09</td>
</tr>
<tr>
<td>Red Oak</td>
<td></td>
<td>.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.17</td>
</tr>
<tr>
<td></td>
<td>Av.</td>
<td>.13</td>
</tr>
<tr>
<td>Ash</td>
<td></td>
<td>.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.12</td>
</tr>
<tr>
<td></td>
<td>Av.</td>
<td>.16</td>
</tr>
<tr>
<td>Elm</td>
<td></td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.12</td>
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<tr>
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<td>.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.25</td>
</tr>
<tr>
<td></td>
<td>Av.</td>
<td>.17</td>
</tr>
<tr>
<td>Beech</td>
<td></td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.11</td>
</tr>
<tr>
<td></td>
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<td>.12</td>
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<tr>
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<td></td>
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<td>.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.20</td>
</tr>
<tr>
<td></td>
<td>Av.</td>
<td>.14</td>
</tr>
<tr>
<td>Kind of Tie</td>
<td>Number of Blows</td>
<td>1</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------</td>
<td>----</td>
</tr>
<tr>
<td>Poplar</td>
<td></td>
<td>.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.19</td>
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<tr>
<td></td>
<td></td>
<td>.18</td>
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<tr>
<td></td>
<td></td>
<td>.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.16</td>
</tr>
<tr>
<td>Av.</td>
<td></td>
<td>.17</td>
</tr>
<tr>
<td>Chestnut</td>
<td></td>
<td>.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.19</td>
</tr>
<tr>
<td>Av.</td>
<td></td>
<td>.16</td>
</tr>
<tr>
<td>Sweet Gum</td>
<td></td>
<td>.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.26</td>
</tr>
<tr>
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<td></td>
<td>.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.25</td>
</tr>
<tr>
<td>Av.</td>
<td></td>
<td>.24</td>
</tr>
<tr>
<td>Loblolly Pine</td>
<td></td>
<td>.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.21</td>
</tr>
<tr>
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<td></td>
<td>.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.23</td>
</tr>
<tr>
<td>Av.</td>
<td></td>
<td>.21</td>
</tr>
</tbody>
</table>

Table XXVII is given to facilitate the comparison of the relative lateral resistance of ordinary and screw spikes. The data were collected from Tables XXIII and XXVI. The average total deflection of the screw spike in the first seven timbers is 0.50 inch which is 0.15 inch less than that of the 5-8-inch ordinary spike and 0.25 inch less than that of the 9-16-inch ordinary spike. In the
TABLE XXV
RELATION BETWEEN THE DEPTH OF PENETRATION AND THE RESISTANCE TO LATERAL DISPLACEMENT

<table>
<thead>
<tr>
<th>Depth of Insertion</th>
<th>Deflection in Inches</th>
<th>Number of Blows</th>
<th>Average for Five Blows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3 in.</td>
<td></td>
<td>0.24</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.22</td>
<td>.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.24</td>
<td>.43</td>
</tr>
<tr>
<td>Av.</td>
<td></td>
<td>0.23</td>
<td>0.43</td>
</tr>
<tr>
<td>3 1-2 in.</td>
<td></td>
<td>0.24</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.24</td>
<td>.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.19</td>
<td>.34</td>
</tr>
<tr>
<td>Av.</td>
<td></td>
<td>0.22</td>
<td>0.40</td>
</tr>
<tr>
<td>4 in.</td>
<td></td>
<td>0.20</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.21</td>
<td>.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.23</td>
<td>.33</td>
</tr>
<tr>
<td>Av.</td>
<td></td>
<td>0.21</td>
<td>0.37</td>
</tr>
<tr>
<td>4 1-2 in.</td>
<td></td>
<td>0.24</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.20</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>.22</td>
<td>.36</td>
</tr>
<tr>
<td>Av.</td>
<td></td>
<td>0.22</td>
<td>0.33</td>
</tr>
<tr>
<td>5 in.</td>
<td></td>
<td>0.22</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.23</td>
<td>.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.15</td>
<td>.34</td>
</tr>
<tr>
<td>Av.</td>
<td></td>
<td>0.20</td>
<td>0.34</td>
</tr>
</tbody>
</table>

last four kinds of timber the average total deflection of the screw spike was 0.70 inch, which is practically the same as that of the 5-8-inch ordinary spike, but which is 0.24 inch less than that of 9-16-inch common spike. The results in the last two columns of Table XXVII show that the screw spike is superior to the 9-16-inch ordinary spike in all but two kinds of timber, and that the screw spike has a higher efficiency than the 5-8-inch ordinary spike in all but three kinds of timber.
TABLE XXVI
LATERAL MOVEMENT OF THE SCREW SPIKE FOR EACH BLOW

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>Movement for Each of the Several Blows</th>
<th>Average Movement, Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>White Oak</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>Black Oak</td>
<td>0.11</td>
<td>0.08</td>
</tr>
<tr>
<td>Water Oak</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>Red Oak</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>Ash</td>
<td>0.16</td>
<td>0.09</td>
</tr>
<tr>
<td>Elm</td>
<td>0.17</td>
<td>0.16</td>
</tr>
<tr>
<td>Beech</td>
<td>0.14</td>
<td>0.12</td>
</tr>
<tr>
<td>Poplar</td>
<td>0.17</td>
<td>0.07</td>
</tr>
<tr>
<td>Chestnut</td>
<td>0.16</td>
<td>0.10</td>
</tr>
<tr>
<td>Sweet Gum</td>
<td>0.24</td>
<td>0.16</td>
</tr>
<tr>
<td>Loblolly Pine</td>
<td>0.21</td>
<td>0.13</td>
</tr>
</tbody>
</table>

The last two columns in Table XXVII show that the ordinary spike was usually displaced more than the screw spike by each blow. This should be expected since the common spike was smaller in cross section than the screw spike, and also since the latter had better bond with the wood. While the use of the screw spike is recommended to the American railroads, it is thought that the practice of Bavarian railroads could be followed to advantage. These roads have adopted the use of the screw spike on the gage side of the rail to resist overturning, but use two square spikes on the outside to resist lateral movement. This practice has been found to give very beneficial results. The figures in the last two columns of Table XXVII show that the lateral resistance of two ordinary spikes is considerably more than that of one screw spike, and therefore if two spikes are considered as resisting the impact instead of one, the results will be in favor of the ordinary spikes. Not only is this true, but the first cost for spikes would be reduced, since the screw spike costs about four cents at
TABLE XXVII
RELATIVE LATERAL DISPLACEMENT OF ORDINARY AND SCREW SPIKES

<table>
<thead>
<tr>
<th>Kind of Tie</th>
<th>Movement of Ordinary Spikes</th>
<th>Average Movement of Screw Spike, inches</th>
<th>Average Movement of Ordinary Spikes in Terms of per cent of Movement of Screw Spike</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9-16 in.</td>
<td>5-8 in.</td>
<td></td>
</tr>
<tr>
<td>White Oak</td>
<td>0.136</td>
<td>0.118</td>
<td>0.078</td>
</tr>
<tr>
<td>Black Oak</td>
<td>0.152</td>
<td>0.122</td>
<td>0.082</td>
</tr>
<tr>
<td>Water Oak</td>
<td>0.142</td>
<td>0.124</td>
<td>0.086</td>
</tr>
<tr>
<td>Red Oak</td>
<td>0.148</td>
<td>0.122</td>
<td>0.108</td>
</tr>
<tr>
<td>Ash</td>
<td>0.156</td>
<td>0.146</td>
<td>0.108</td>
</tr>
<tr>
<td>Elm</td>
<td>0.138</td>
<td>0.140</td>
<td>0.140</td>
</tr>
<tr>
<td>Beech</td>
<td>0.168</td>
<td>0.110</td>
<td>0.102</td>
</tr>
<tr>
<td>Poplar</td>
<td>0.164</td>
<td>0.128</td>
<td>0.130</td>
</tr>
<tr>
<td>Chestnut</td>
<td>0.246</td>
<td>0.186</td>
<td>0.132</td>
</tr>
<tr>
<td>Sweet Gum</td>
<td>0.192</td>
<td>0.142</td>
<td>0.148</td>
</tr>
<tr>
<td>Loblolly Pine</td>
<td>0.148</td>
<td>0.128</td>
<td>0.154</td>
</tr>
</tbody>
</table>

the present time, whereas the ordinary spike costs much less. The maintenance cost of either form of spike is almost negligible.

An item of interest which is properly beyond the limits of this article is that of the ninety screw spikes used in making these tests only two were broken. One was broken under a tension of 14,000 pounds, the break being caused by an incipient crack just under the head of the spike. The other spike broke under the fourth blow of the hammer, this break being due to uncombined graphite in the metal. As the spikes were obtained from different sources, and were of different manufacture, it is thought that the test was sufficiently severe to show that the screw spike, as manufactured at present, will successfully withstand the shocks of passing trains. As the spikes were used several times during the tests, the percentage of spikes broken is very low.
SUMMARY OF RESULTS

(1) The maximum resistance to direct pull varies from 6,000 to 14,000 pounds for screw spikes, from 3,000 to 8,000 pounds for ordinary spikes when driven into untreated timbers, and from 4,000 to 9,000 pounds for ordinary spikes when driven into treated timbers.

(2) The direct pull required to withdraw ordinary spikes 1-8-inch varies from 2,000 to 3,500 pounds for untreated timbers, and from 2,500 to 3,500 pounds for treated timbers.

(3) The direct pull required to withdraw ordinary spikes 1-4-inch varies from 3,000 to 5,400 pounds for untreated timbers and from 3,800 to 5,900 pounds for treated timbers.

(4) Timbers having loose fiber structures have lower resistances to direct pull than timbers having compact fiber structures.

(5) The amount of withdrawal which must occur for ordinary spikes to develop the maximum resistance is less for soft woods than for hard woods.

(6) Spikes driven into treated timber offer a greater resistance to direct pull than spikes in untreated timbers, and the difference between this resistance for treated and untreated timbers is greater for soft woods than for hard woods.

(7) The difference in the resistance to direct pull for the different sized spikes in use (9-16 inch, 19-32 inch, and 5-8-inch) is very small.

(8) The resistance of ordinary spikes to direct pull varies directly as the depth of penetration, neglecting the tapering point.

(9) Blunt-pointed and bevel-pointed spikes have a slightly greater resistance to direct pull than chisel-pointed spikes.

(10) For withdrawals less than 1-4 inch, ordinary spikes which are driven into bored holes have a little greater resistance to direct pull than spikes driven in the ordinary way.

(11) The resistance to direct pull for re-driven spikes is from 60 to 80 per cent of the resistance of newly driven spikes.

(12) The efficiency of screw spikes to resist withdrawal is nearly twice as great as that of common spikes.

(13) The resistance of 5-8-inch spikes to lateral displacement is slightly greater than that of 9-16-inch spikes.

(14) The resistance to lateral displacement increases with
the depth of penetration, but the increase is negligible for depths of penetration greater than 4 inches.

(15) Screw spikes are more efficient than ordinary spikes in resisting lateral displacement.

Publications of The Engineering Experiment Station

*Bulletin No. 1.* Tests of Reinforced Concrete Beams, by A. N. Talbot. 1904.

*Circular No. 1.* High-Speed Tool Steels, by L. P. Breckenridge. 1905.


*Circular No. 2.* Drainage of Earth Roads, by Ira O. Baker. 1906.

*Bulletin No. 3.* The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906.

*Bulletin No. 4.* Tests of Reinforced Concrete Beams, series of 1905, by A. N. Talbot. 1906.

*Bulletin No. 5.* Resistance of Tubes to Collapse, by A. P. Carman. 1906.

*Bulletin No. 6.* Holding Power of Railroad Spikes, by R. I. Webber. 1906.