WEBBER

Holding Power
of
Railroad Spikes

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HOLDING POWER OF RAILROAD SPIKES

BY

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This is to certify that the following thesis, prepared by

ROY I. WEBBER

entitled,

THE HODING POWER OF RAILROAD SPIKES,

is accepted by me as fulfilling this particular of the requirements for the Degree of CIVIL ENGINEER.

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HOLDING POWER OF RAILROAD SPIKES

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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.

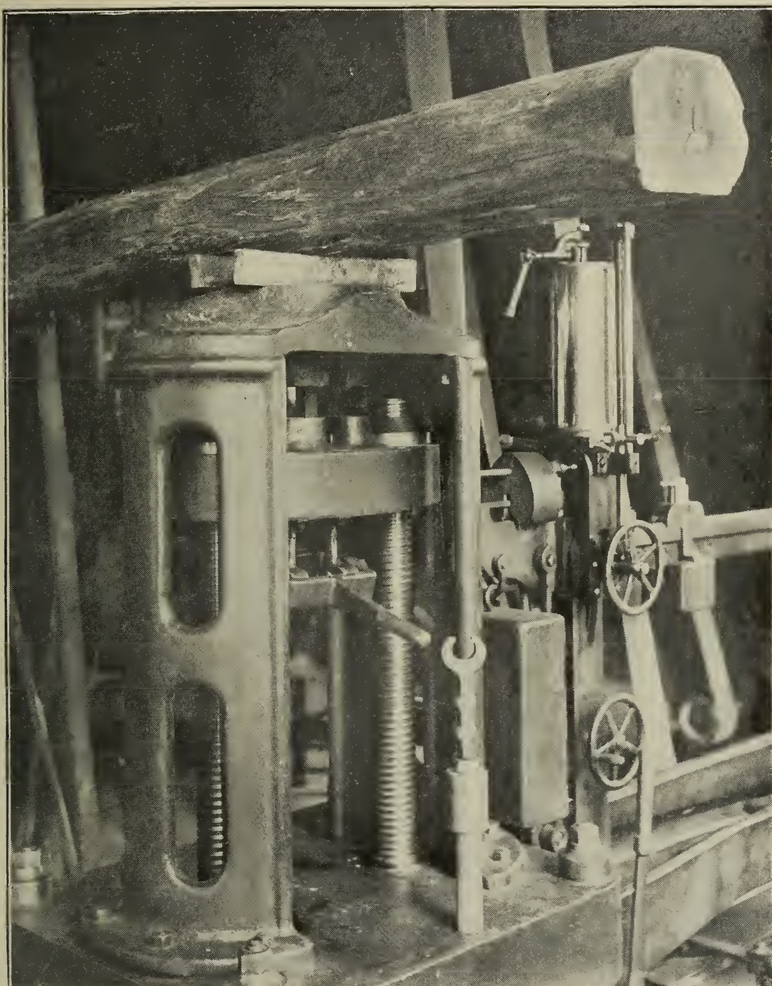
The writer wishes to express his thanks for the hearty co-operation received from the various persons, firms and corporations mentioned in the text. He wishes also to express his indebtedness for personal aid, to Mr. Robert Trimble, Chief Engineer Maintenance of Way, Pennsylvania Lines; Mr. George E.

TABLE I

DESCRIPTION OF THE TIES

No. of Tie	Kind of Timber	Kind of Treatment	Date Treated	Remarks
1	Blue Ash	Zinc-Creosote	1905	Seasoned; sound
2	Blue Ash	Zinc-Creosote	1905	Seasoned; sound
3	Sweet Gum	Zinc-Creosote	1904	Seasoned; sound
4	Water Oak	Zinc-Tannin	1904	Seasoned; sound
5	Water Oak	Zinc-Tannin	1904	Seasoned; sound
6	Red Oak	Zinc-Tannin	1904	Seasoned; sound
7	Red Oak	Zinc-Creosote	1905	Seasoned; sound
8	Red Oak	Zinc-Creosote	1905	Seasoned; sound
9	Red Oak	Zinc-Tannin	1904	Seasoned; sound
10	Rock Elm	Zinc-Creosote	1905	Seasoned; sound
11	Poplar	Zinc-Creosote	1905	Seasoned; sound
12	Elm	....	....	Seasoned; sound
13	Elm	....	....	Seasoned; sound
14	Beech	....	....	Seasoned; sound
15	Elm	....	....	Seasoned; sound
16	Black Oak	Zinc-Creosote	1902	Seasoned
17	Red Oak	Zinc-Creosote	1902	Seasoned
18	Black Oak	Zinc-Creosote	1902	Seasoned
19	Poplar	Zinc-Creosote	1902	Seasoned
20	Loblolly Pine	Zinc-Tannin	1905	Treated December, 1905; sound
21	Lob'y 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	....	....	Seasoned; in track two years; Indiana Oak; sap wood showed slight decay
32	White Oak	....	....	(see 31)
33	White Oak	....	....	Georgia Oak; seasoned; sound
34	Water Oak	Creosote	1904	Sound
35	Burr Oak	Creosote	1904	Sound
36	Beech	Creosote	1904	Sound
37	Elm	Creosote	1904	Sound
38	Beech	....	....	Sound
39	Lob'y Pine	....	....	Seasoned; sound
40	Chestnut	....	....	Seasoned; sound
41	Red Oak	Creosote	1904	Showed tendency to split
42	Beech	....	....	Sound
43	Beech	....	....	Sound
44	Beech	....	....	Sound

PLATE I



Testing Machine with Tie in Position for Test

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.

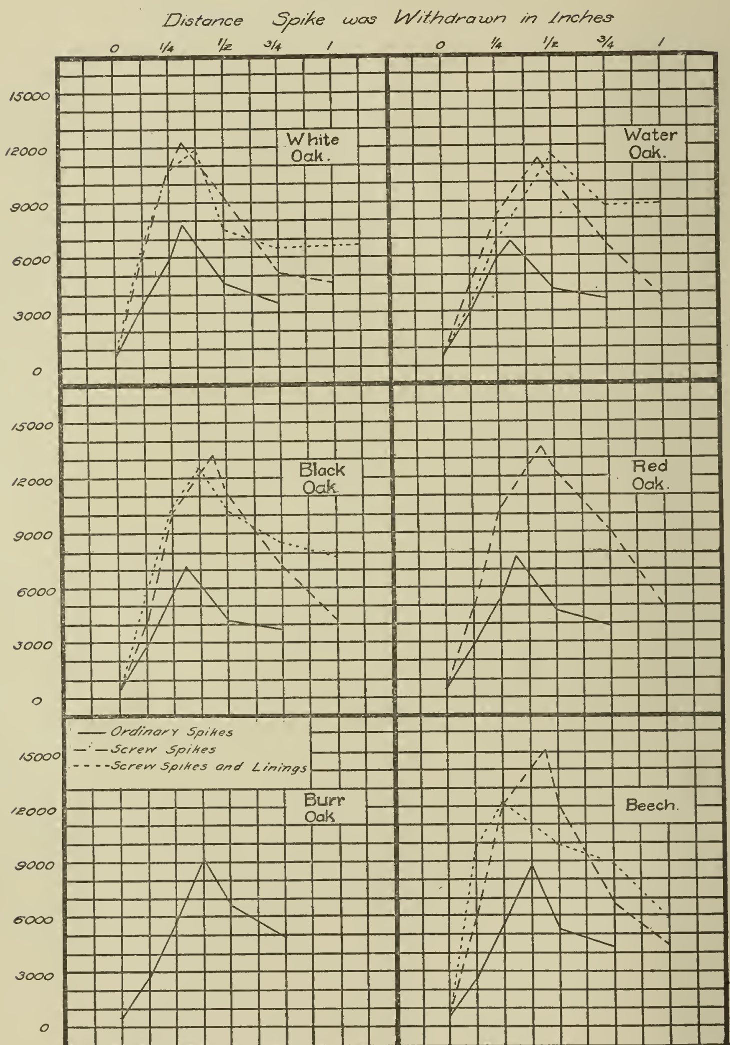
TABLE II

DESCRIPTION OF THE ORDINARY SPIKES

Record Number	Nominal Length, inches	Section, inches square	Area, square inches	Type of Point	Depth Inserted, inches	Condition of Surface of Spike
1	6	5-8	0.372	Chisel	5	Smooth
2	5 1-2	5-8	0.372	Chisel	5	Smooth
3	5 1-2	5-8	0.372	Blunt	5	Smooth
4	5 1-2	5-8	0.372	Blunt	5	Smooth
5	6	5-8	0.372	Sharp	5	Smooth
6	5 1-2	19-32	0.352	Sharp	5	Smooth
7	5 1-2	19-32	0.352	Chisel	5	Smooth
8	6	5-8	0.372	Blunt	5	Smooth
9	5 1-2	9-16	0.316	Blunt	5	Smooth
10	5 1-2	9-16	0.316	Sharp	5	Smooth
11	5 1-2	9-16	0.316	Chisel	5	Smooth
12	5 1-2	9-16	0.316	Sharp	5	Smooth
13	5 1-2	9-16	0.316	Chisel	5	Smooth
14	6	5-8	0.372	Chisel	5	Smooth

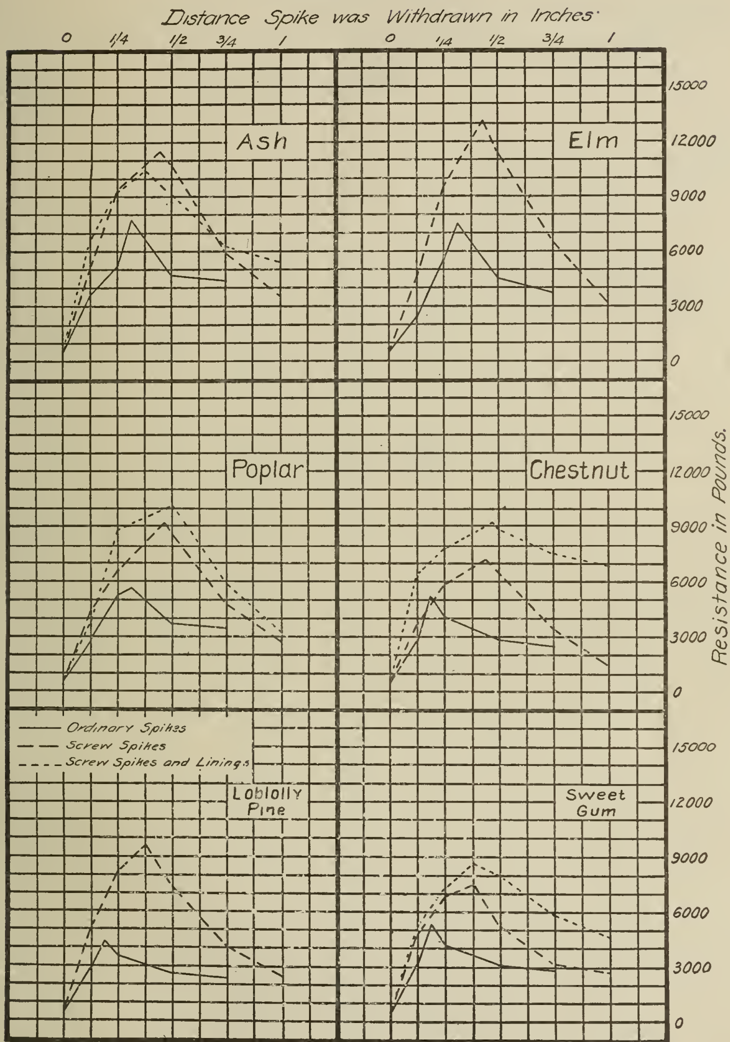
Whole ties were used to insure freedom from splitting in driving the spikes, and care was exercised to avoid driving the spike into knots or cracks. The spikes were driven into the tie to a depth of 5 inches. In some instances, as shown in the record, holes were bored for the ordinary spikes, the hole 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



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

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of				Maximum Resistance	
				1-8 inch	1-4 inch	1-2 inch	3-4 inch	Pounds	Distance Withdrawn, inches
Blue Ash	1	12	1	1800	4460	5220	4450	6840	3-8
			2	4040	5060	4510	3990	7260	3-16
			3	4270	4340	3860	3370	6330	3-16
			Av.	4150	4630	4530	3970	6810	3-16
	2	6	1	2220	4700	5250	5230	8740	3-8
			2	3390	6940	4710	4710	8020	5-16
			3	2860	5670	4890	4830	8540	3-8
			Av.	3000	5770	4890	4830	8640	3-8
Sweet Gum	3	5	1	2630	1930	2010	2220	4300	3-16
			2	3940	4010	3000	2550	5640	3-16
			3	5180	3920	4620	4560	5180	1-8
			Av.	3920	3960	2690	2470	5040	3-16
	3	14	1	2900	4030	3260	2720	5610	3-16
			2	3470	4100	2750	2780	5370	3-16
			3	3540	3580	3030	2500	4900	3-16
			Av.	3300	3900	3010	2640	5330	3-16
	3	5	1	3030	5100	2930	2930	5100	1-4
			2	2690	5570	4040	3100	5570	1-4
			3	5030	3400	....	....	5700	3-16
			Av.	3580	4370	3440	3420	5440	1-4
	3	11	1	2110	4030	2340	1680	4030	1-4
			2	2780	3190	2320	....	4810	3-16
			3	1680	4100	3730	3340	4980	5-16
			Av.	2190	3770	2790	2510	4610	1-4
	3	3	1	2650	6500	4410	4030	6500	1-4
			2	3890	4100	3590	3340	5460	3-16
			3	2910	6180	4800	4070	6180	1-4
			Av.	3150	5590	4190	3810	6050	1-4

TABLE III—*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds For Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Distance Withdrawn, inches
Water Oak	4	14	1	2790	6580	4190	3930	7560	5-16
			2	3300	7060	2970	2940	7060	1-4
			3	2220	5330	3920	3200	7740	5-16
			Av.	2770	6320	3660	3360	7450	5-16
	5	14	1	2870	6040	4270	3400	7720	5-16
			2	1610	4460	5060	4240	7780	3-8
			3	....	....	....	....	....	....
			Av.	2240	5250	4660	3820	7750	3-8
	26	14	1	2560	5430	3610	3530	6150	1-4
			2	3440	3340	3050	2590	4960	3-16
			3	3160	....	3200	3210	5810	3-16
			Av.	3050	4380	3290	3110	5640	3-16
	29	14	1	1580	3900	3970	3160	6000	5-16
			2	1470	3550	3450	3090	5110	5-16
			3	2190	4070	2990	. .	4070	1-4
			Av.	1740	3840	3470	3130	5060	5-16
	4	6	1	1960	6030	5420	4530	8690	5-16
			2	2390	5320	....	....	8040	3-8
			3	3200	6380	4380	4100	7320	5-16
			Av.	2520	5920	4900	4320	8020	5-16
	5	6	1	2750	6070	5260	4560	8580	3-8
			2	4330	4890	3430	3040	5270	3-16
			3	1610	4360	3190	3020	4760	1-4
			Av.	2930	5240	3960	3870	6200	1-4
	25	7	1	3370	3860	3380	3180	4910	3-16
			2	1800	5440	3370	3130	5440	1-4
			3	2550	4490	3680	3230	4490	1-4
			Av.	2570	4600	3380	3180	4940	1-4
	26	6	1	3200	5300	4020	3820	5300	1-4
			2	2130	5710	4200	3700	5710	1-4
			3	3500	5820	4620	4340	5820	1-4
			Av.	2940	5610	4280	3950	5610	1-4

TABLE III—*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Distance Withdrawn, inches
Water Oak	29	6	1	2810	4480	3750	3160	4480	1-4
			2	4620	....	4070	3720	4760	3-16
			3	3720	3450	2910	....	3720	1-8
			Av.	3720	3970	3240	3440	4320	3-16
	4	13	1	2820	5920	4360	4360	9000	3-8
			2	3130	5600	4170	3460	7450	5-16
			3	3430	6330	4440	4060	9000	3-8
			Av.	3160	5980	3320	4260	8380	3-8
	5	11	1	3000	6020	3340	2750	6240	5-16
			2	3200	8010	4720	5300	9180	5-16
			3	3230	5800	3900	3890	6490	5-16
			Av.	3140	6610	3950	3980	7300	5-16
	26	11	1	3080	....	2650	2270	4240	3-16
			2	2270	5090	3360	2940	5090	1-4
			3	1990	5420	3610	3000	5420	1-4
			Av.	2450	5260	5210	2770	4920	1-4
	25	13	1	2440	5100	4230	3640	6450	5-16
			2	3440	6680	4000	3980	6680	1-4
			3	1840	3710	2830	2540	4550	5-16
			Av.	3570	5160	3680	3380	5860	5-16
	34	13	1	2340	5620	5770	5080	9070	3-8
			2	1700	3730	2830	2260	4970	5-16
			3	3360	6560	3600	3010	6560	1-4
			Av.	2470	5300	4070	3950	6870	5-16
	34	14	1	4090	7000	4070	4020	8430	5-16
			2	3090	6780	3550	2900	6780	1-4
			3	3180	7280	4660	2870	8040	5-16
			Av.	3450	7020	4090	3260	7750	5-16
	34	6	1	2370	4720	4940	4730	6400	5-16
			2	3010	6670	5210	4930	7360	5-16
			3	3900	8130	5060	4540	8130	1-4
			Av.	3130	6510	5070	4740	7290	5-16

TABLE III—*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Distance Withdrawn, inches
Black Oak	16	8	1	3010	6880	5950	4930	9000	3-8
			2	....	7220	....	4380	9100	3-8
			3	3880	8500	4620	3180	8700	5-16
			Av.	3450	7530	5300	4160	8940	3-8
	16	14	1	3230	6110	3270	2890	6110	1-4
			2	....	6280	4120	3760	6540	5-16
			3	2090	4390	3980	3540	7760	3-8
			Av.	2660	5590	3790	3390	6810	5-16
	23	1	1	2980	6740	3460	3290	8210	5-16
			2	3380	7940	4290	3850	7940	1-4
			3	1220	2920	....	4050	9060	1-2
			Av.	2200	5130	3870	3730	8070	3-8
	27	5	1	3430	8070	5300	4740	10000	5-16
			2	....	5910	4500	4170	8970	5-16
			3	2870	7570	4200	3850	7070	1-4
			Av.	3150	7020	4670	4250	8680	5-16
	27	8	1	3510	8470	3370	3370	8470	1-4
			2	2750	7130	2900	2930	8780	5-16
			3	2940	6690	4480	2940	....	1-4
			Av.	3070	7430	4600	3080	8620	1-4
	18	11	1	2650	5240	3340	2670	7130	5-16
			2	....	....	....	....	....	....
			3	2660	6190	5040	4440	8250	9-16
			Av.	2660	5720	4190	3550	7690	5-16
	18	10	1	1700	3410	3330	2570	5860	3-8
			2	2120	3900	3170	2900	5660	3-8
			3	2250	4000	2830	3090	4000	1-4
			Av.	2020	3770	3110	2850	4880	3-8
	16	11	1	3650	5890	4010	3410	5890	1-4
			2	4370	4430	3790	3550	6170	3-16
			3	2400	6230	5320	4380	8620	5-16
			Av.	3470	5520	4370	3780	6890	1-4

TABLE III--*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Distance Withdrawn, inches
Black Oak	27	11	1	4900	7070	3890	3140	7070	1-4
			2	3780	5740	3670	3260	5740	1-4
			3	2730	6550	....	3440	6550	1-4
			Av.	3800	6450	3780	3280	6450	1-4
	24	10	1	3950	6580	4150	3650	6880	1-4
			2	1810	4050	3460	2780	6510	5-16
			3	2960	5390	3600	3410	6500	5-16
			Av.	2910	5340	3740	3280	6530	5-16
	24	4	1	2330	5070	5820	5710	7740	3-8
			2	1880	5570	4320	3740	7010	5-16
			3	3450	6500	4300	3800	7360	5-16
			Av.	2550	5710	4810	4740	7240	5-16
	23	7	1	1820	4690	2800	2880	...	5-16
			2	2250	4110	5520	3880	8790	7-16
			3	2960	7120	4590	3620	7120	1-4
			Av.	2340	5760	3930	3120	7700	3-8
	24	6	1	2520	6110	4040	3490	7070	5-16
			2	1810	5710	4160	3490	7070	5-16
			3	3020	6480	3980	3710	7360	5-16
			Av.	2650	6130	4030	3560	7130	5-16
Red Oak	6	8	1	....	....	....	....	....	....
			2	1870	4750	4410	4190	7190	3-8
			3	2320	6750	4150	3760	8300	5-16
			Av.	2050	5750	4280	3980	7750	3-8
	9	8	1	2210	5460	4310	4100	7300	5-16
			2	2940	6840	3730	3370	7200	5-16
			3	3170	6570	3410	3360	6570	1-4
			Av.	2640	6290	3820	3610	6790	5-16

TABLE III—*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Distance Withdrawn, inches
Red Oak	7	1	1	1450	3300	8700	4920	9210	5-8
			2	2030	4200	7780	4220	8800	7-16
			3	....	....	....	...	....	...
			Av.	1740	3750	8240	4570	9000	1-2
	8	8	1	1570	3100	2910	2600	7330	7-16
			2	1730	3750	3220	2990	7230	7-16
			3	1950	4890	4200	3220	8970	7-16
			Av.	1680	3910	3440	2920	7840	7-16
	22	8	1	2500	3940	2760	2770	5120	3-16
			2	2970	2890	2510	2370	4990	3-16
			3	3490	3490	2460	2370	5270	3-16
			4	2210	4670	2570	2550	4670	1-4
			5	3770	3250	2620	2440	5150	3-16
			6	2620	5490	3780	3400	5490	1-4
			Av.	2930	3950	2800	2650	5120	3-16
	41	1	1	2170	4400	4540	3630	7040	5-16
			2	3900	3650	2230	2420	6040	3-16
			3	1930	4300	2690	2530	5650	5-16
			Av.	2660	4110	3150	2860	6240	1-4
	17	1	1	1710	5030	5420	6260	9720	3-8
			2	2240	5240	9900	6710	11900	1-2
			3	3280	6400	7550	7020	10940	7-16
			Av.	2410	5560	7620	6660	10850	3-8
	6	12	1	3520	4480	3300	2910	5950	3-16
			2	3700	....	3500	3640	6930	1-4
			3	3690	....	3710	3080	4460	3-16
			4	3320	4350	3550	2990	6240	3-16
			Av.	3550	4410	3520	3150	5900	3-16
	6	11	1	2150	5330	4640	3420	7580	5-16
			2	2990	7830	4570	3200	7830	1-4
			3	3240	7000	4710	3670	8280	5-16
			Av.	2760	6740	4640	3430	7890	5-16

TABLE III—*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Distance Withdrawn, inches
Red Oak	7	12	1	2430	5010	7120	5630	9080	3-8
			2	3430	6110	4930	4300	7020	5-16
			3	....	....	....	....	....	....
			Av.	2930	5560	6030	4960	8030	3-8
	9	12	1	3530	5410	3790	3680	5410	1-4
			2	3000	6280	3950	3510	6280	1-4
			3	3720	7140	4350	4300	7140	1-4
			Av.	3420	6280	4030	3830	6280	1-4
	9	13	1	3270	....	3790	3630	7030	1-4
			2	3740	4600	3730	3110	6660	3-16
			3	3690	4610	3540	3180	6130	3-16
			Av.	3560	4600	3680	3320	6610	3-16
	17	12	1	....	....	11620*	....	....	....
			2	....	....	11230	...	....	....
			3	....	....	10630	....	....	....
			Av.	....	....	11490	....	....	....
	28	12	1	....	....	3430	3130	6390	1-4
			2	3910	7150	4410	3480	7150	1-4
			3	3810	5000	4270	3670	6760	3-16
			Av.	3860	6080	4040	3530	6770	1-4
	28	11	1	....	....	5200	3710	8200	5-16
			2	6250	4000	3280	2600	6250	1-8
			3	2880	6870	3740	3280	6870	1-4
			Av.	4570	5440	4070	3200	7100	1-4
	8	12	1	3030	6800	6080	4950	9420	5-16
			2	2680	....	....	....	...	....
			3	3580	6250	6680	4640	9240	3-8
			Av.	3060	6530	6380	4790	9330	5-16

*This was the first tie tested, and gave unusually high results.

TABLE III—*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Distance Withdrawn, inches
Red Oak	22	13	1	2440	5810	3270	3340	5810	1-4
			2	2850	5040	2770	2170	5040	1-4
			3	1880	4530	3700	3450	6280	3-8
			Av.	2390	5130	3250	2990	5710	1-4
	30	12	1	3700	3960	2950	2460	5500	3-16
			2	1700	3560	2920	3150	4720	3-8
			Av.	2700	3760	2940	3010	5110	1-4
	30	10	1	1680	3580	3070	3030	5570	3-8
			2	2020	4070	2490	2480	5220	5-16
			3	2540	4590	3070	2890	6080	3-8
			Av.	2040	4070	2870	2760	5620	3-8
	41	12	1	4500	7690	3530	3340	7690	1-4
			2	4750	....	3200	3300	7210	3-16
			3	1930	5840	3370	3750	7430	5-16
			Av.	3730	6760	3360	3460	7440	1-4
	41	9	1	3670	7950	3100	2420	7950	1-4
			2	3760	7110	3450	3300	7110	1-4
			3	4620	4500	4450	3960	6230	3-16
			Av.	4010	6520	3660	3220	7090	1-4
	28	3	1	....	....	5290	4000	8290	5-16
			2	....	....	4940	4420	7840	5-16
			3	....	....	4190	3510	4940	1-8
			Av.	....	....	4810	3970	7020	5-16
Burr Oak	35	1	1	2960	4960	8240	5560	8240	1-2
			2	1410	3570	9450	6220	9450	1-2
			3	3090	6850	5930	5600	9440	3-8
			Av.	2490	5130	7540	5780	9040	1-2
	35	11	1	4020	8640	6210	5770	10560	3-16
			2	2200	3390	9240	4500	9240	1-2
			3	2230	5020	6290	5250	9000	3-8
			Av.	2820	5680	7250	5170	9600	3-8

TABLE III—*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Distance Withdrawn, inches
Burr Oak	35	8	1	2690	7040	4820	4110	10090	3-8
			2	2740	5840	4060	3700	7920	3-16
			Av.	2710	6440	4440	3950	9000	1-4
White Oak	31	1	1	3240	7030	3400	3140	7030	1-4
			2	2430	5870	4390	3850	7580	3-8
			3	3700	7500	4180	3330	7500	1-4
			Av.	3150	6800	3990	3440	7370	3-16
	31	14	1	....	4020	3600	3280	7830	3-16
			2	3960	7100	4000	3750	7100	1-4
			3	2250	5580	3650	3200	8980	3-8
			Av.	3110	5560	3750	3410	7940	3-16
	33	1	1	4220	3570	3810	3040	7520	3-16
			2	1950	3670	4640	3340	6940	3-8
			3	3190	5260	3810	3500	6410	5-16
			Av.	3120	4160	4090	3290	6990	5-16
	32	7	1	3860	9440	5930	4650	9440	1-4
			2	3460	6400	3710	3680	8650	5-16
			3	1610	3740	4670	5570	9360	1-2
			Av.	2980	6530	4770	4300	9150	3-8
	33	7	1	4790	3910	2860	2530	5750	3-16
			2	4150	4930	3510	3270	6500	3-16
			3	4630	3840	3070	2450	6030	3-16
			Av.	4520	4230	3150	2750	6090	3-16
	32	10	1	2400	3490	8280	3820	8280	1-2
			2	3100	4840	5410	3880	10190	3-8
			3	2570	6410	10670	4400	10670	1-2
			Av.	2690	4910	8120	4030	9710	1-2
	33	10	1	2930	5490	2390	2330	5490	1-4
			2	3080	6360	2860	2460	6360	1-4
			3	3890	6810	3540	3360	6810	1-4
			Av.	3300	6220	2930	2720	6220	1-4

TABLE III—*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Distance Withdrawn, inches
White Oak	32	9	1	3630	7500	5340	4650	9640	3-8
			2	2960	6760	4250	4500	10650	3-8
			3	3490	8270	4810	4590	10750	5-16
			Av.	3360	7510	4800	4430	10350	3-8
	31	3	1	....	....	5200	4330	8380	3-8
			2	4000	7490	3980	3770	7490	1-4
			3	4100	8450	5010	4240	8450	1-4
			Av.	4050	7920	4730	4080	8770	3-16
	33	4	1	4200	....	4330	3790	7330	3-16
			2	4200	7530	4390	3630	7530	1-4
			3	5900	3850	3100	2790	6590	3-16
			Av.	4830	5690	3940	3410	7150	3-16
Rock Elm	10	5	1	2250	6530	4460	4420	8280	5-16
			2	3260	7160	4620	3850	7160	1-4
			3	2910	5880	4650	4340	7300	3-8
			Av.	2810	6520	4580	3210	7910	5-16
	10	2	1	1920	3770	6060	5310	7410	7-16
			2	....	....	....	....	....	....
			3	1960	4510	4420	4160	7730	3-8
			Av.	1940	4140	5240	4730	7570	3-8
	10	11	1	3730	7760	4310	3930	7760	1-4
			2	2800	5820	4460	3580	6800	5-16
			3	3300	6270	4120	3550	7840	5-16
			4	1600	6070	5030	4140	7700	5-16
			5	....	7810	5210	4490	7810	1-4
			Av.	2800	6950	4620	3340	7600	5-16
Red Elm	13	14	1	1240	....	6430	4380	9230	7-16
			2	3000	6500	5080	4960	10040	7-16
			3	1760	5970	....	4040	8810	3-8
			Av.	2000	6235	5750	4460	9350	5-16

TABLE III—*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Distance Withdrawn, inches
Red Elm	13	2	1	1930	3990	4540	3760	7730	5-16
			2	2240	3860	5250	3970	8100	7-16
			3	1960	4200	4540	3850	7120	3-8
			Av.	2040	4020	4770	3890	7650	7-16
	13	10	1	2810	4930	4850	3510	7550	3-8
			2	2450	4800	4930	3740	7430	3-8
			3	2140	5030	3790	3210	8690	7-16
			Av.	2460	4920	4520	3490	7890	3-8
White Elm	12	14	1	1750	4500	3270	2720	5330	3-8
			2	2810	5500	3530	3010	5590	5-16
			3	1890	5610	3620	2770	5610	1-4
			Av.	2150	5200	3470	2830	5510	5-16
	12	5	1	2460	5790	3590	2980	6280	5-16
			2	2140	5410	2830	2770	5410	1-4
			3	1770	5270	2520	2430	5270	1-4
			Av.	2120	5490	2980	2720	5650	1-4
	15	5	1	2630	6330	5580	....	9500	3-8
			2	3810	7260	4680	4310	9560	3-8
			3	2810	6100	4160	3620	8050	5-16
			Av.	3080	6560	4770	4000	9030	3-8
	37	5	1	2490	8130	3900	3660	8130	1-4
			2	....	5760	4040	3330	6650	5-16
			3	2790	6540	3770	3420	7460	5-16
			Av.	2640	6810	3910	3470	7410	5-16
	15	13	1	1600	4600	...	5900	9670	7-16
			2	2230	5770	5530	4820	8760	3-8
			3	1450	4200	9310	6190	9310	1-2
			Av.	1760	4860	7420	5630	9250	7-16
	12	10	1	1990	3560	3350	2700	5370	3-8
			2	1920	4320	3540	2690	5450	3-8
			3	1830	3930	2360	1650	4100	1-4
			Av.	1910	3970	3080	2010	4970	3-8

TABLE III—*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of				Maximum Resistance	
				1-8 inch	1-4 inch	1-2 inch	3-4 inch	Pounds	Distance Withdrawn, inches
White Elm	15	12	1	....	5590	4670	3810	7860	3-8
			2	2430	5630	3870	3350	6140	5-16
			3	2600	5550	3140	....	5550	1-4
			Av.	2510	5920	3890	3580	6520	5-16
	37	2	1	2100	4710	3390	3330	7170	3-8
			2	2920	5160	4070	3840	6310	5-16
			3	3150	5900	4300	3860	7570	3-8
			Av.	2390	5290	3920	3680	7020	3-8
Beech	14	6	1	....	....	5390	4670	7680	1-4
			2	2870	5150	4870	4320	7190	3-8
			3	2230	5660	5310	4940	7820	5-16
			Av.	2550	5400	5190	4470	7560	5-16
	36	6	1	4330	4740	4400	4510	7120	3-8
			2	3610	8100	6230	5320	8560	1-4
			3	2640	8120	5470	4640	9080	5-16
			Av.	3530	6990	5030	4820	8250	5-16
	14	2	1	2550	4740	4570	4100	7670	5-16
			2	2200	5570	5690	4190	8170	3-8
			3	2120	4910	4800	3970	7860	3-8
			Av.	2290	5070	4700	4090	7900	3-8
	36	2	1	3210	5940	4010	3840	8460	3-8
			2	3110	6900	4170	3900	10400	3-8
			3	2120	5440	5240	4130	8270	5-16
			Av.	2850	6090	4470	3960	9040	3-8
	14	9	1	2660	5070	....	3560	8130	3-8
			2	1500	2820	9910	5060	9910	1-2
			3	1490	3810	8900	5280	9220	7-16
			Av.	1880	3900	8960	4630	9090	7-16
	36	9	1	2130	4900	4240	4210	9890	3-8
			2	2940	6640	3860	3650	9430	5-16
			3	2370	4920	3830	3600	8900	3-8
			Av.	2480	5490	3980	3820	9410	3-8

TABLE III—*Continued*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Distance Withdrawn, inches
Poplar	11	2	1	2700	4690	3980	3520	4690	1-4
			2	4690	....	3240	2890	4980	3-16
			3	3000	5100	3240	2900	5100	1-4
			Av.	3460	4890	3490	3100	4920	1-4
	19	2	1	2750	4510	4400	3980	6990	3-8
			2	2710	5270	2840	2610	5270	1-4
			3	3100	6050	4080	3650	6050	1-4
			Av.	2850	5240	3760	3410	5900	1-4
	11	12	1	2220	5130	2960	2750	5350	5-16
			2	2750	4940	3800	3590	5070	5-16
			Av.	2480	5040	3280	3170	5210	5-16
	19	12	1	2610	5670	....	....	6250	5-16
			2	2460	6220	4400	4170	7040	5-16
			Av.	2530	5990	4400	4170	6650	5-16
Chestnut	40	14	1	2300	3100	2410	2260	4300	3-16
			2	2330	2600	2860	2460	4060	3-16
			3	3730	3370	2370	2100	5050	3-16
			Av.	2490	3060	2540	2270	4470	3-16
	40	5	1	....	....	....	....	5830	3-16
			2	3010	2720	2650	2650	5180	3-16
			3	3300	3570	2950	2400	5500	3-16
			Av.	3150	3150	2800	2520	5510	3-16
	40	12	1	3320	6230	3050	2270	6230	1-4
			2	5110	....	....	....	5110	1-8
			3	2000	4000	2490	2430	4000	1-4
			Av.	3480	5110	2770	2350	5110	1-4
	40	4	1	1300	3780	3170	2940	5420	3-16
			2	2300	5420	3360	2780	5420	1-4
			3	2440	5640	3190	2590	6220	5-16
			Av.	2850	4950	3240	2770	5690	1-4

TABLE III—*Concluded*

Kind of Tie	Tie No.	Spike No.	Test No.	Resistance in Pounds for Pull of				Maximum Resistance	
				1-8 inch	1-4 inch	1-2 inch	3-4 inch	Pounds	Distance Withdrawn, inches
Loblolly Pine	39	14	1	3390	2970	2620	2590	3390	1-8
			2	3760	3980	2790	2420	3980	1-4
			3	4050	2860	2020	1850	4050	1-8
			Av.	3730	3270	2480	2290	3810	1-8
	21	14	1	2880	4550	2370	1870	4550	1-4
			2	1980	2110	1890	1570	3520	3-16
			3	4510	3910	3340	2880	5200	3-16
			Av.	3120	3520	2560	2110	4420	3-16
	20	5	1	2250	4550	2930	2540	4550	1-4
			2	2810	2670	2720	2640	4570	3-16
			3	3610	....	....	....	3610	1-8
			4	1890	2690	2290	2030	3710	3-16
			Av.	2640	3270	2650	2410	4110	3-16
	21	10	1	3570	4450	2500	2230	4450	1-4
			2	2550	4890	3400	3020	4890	1-4
			Av.	3060	4670	2950	2630	4670	1-4
	20	3	1	3090	4800	2730	2320	4800	1-4
			2	2610	2330	2300	2030	3440	3-16
			3	1870	3810	2510	2280	3810	1-4
			Av.	2860	3650	2510	2210	4020	1-4
	39	6	1	3110	2120	2170	1710	3110	1-8
			2	1560	3880	3060	2380	3880	1-4
			3	1630	3330	2640	2650	3330	1-4
			Av.	2100	3110	2960	2250	3440	1-4

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 penetration 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

AVERAGE HOLDING POWER IN UNTREATED TIES

Kind of Tie	No. of Tests	No. of Spikes	Resistance in Pounds for a Pull of		Maximum Resistance		Resistance in per cent of that in White Oak		
			1-8 inch	1-4 inch	Pounds	Distance Pulled, inches	1-8 inch	1-4 inch	Maximum
White Oak	10	30	3510	3950	7870	5-16	100	100	100
Elm	11	33	2310	5390	7290	3-8	66	136	93
Beech	3	9	2240	3790	8180	3-8	64	96	104
Chestnut	4	12	2990	4070	5190	3-16	86	103	66
Loblolly Pine	2	6	2920	3190	3630	3-16	85	81	46

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

Kind of Tie	No. of Tests	No. of Spikes	Resistance in Pounds for a Pull of		Maximum Resistance		Resistance in per cent of that of White Oak		
			1-8 inch	1-4 inch	Pounds	Distance Pulled, inches	1-8 inch	1-4 inch	Maxi-mum
White Oak (Untreated)	10	30	3510	3950	7870	5-16	100	100	100
Water Oak	16	48	2870	5730	6780	5-16	82	145	86
Black Oak	13	39	2910	5890	7230	5-16	83	149	92
Red Oak	20	60	2950	5350	7730	5-16	84	135	98
Burr Oak	3	9	2670	5750	9210	3-8	76	145	117
Ash	2	6	3570	5200	7730	5-16	101	131	98
Elm	5	15	2590	5940	7500	5-16	74	150	96
Beech	3	9	2950	6190	8900	3-8	84	157	113
Poplar	4	12	2830	5290	5670	5-16	81	134	72
Loblolly Pine	4	12	2920	3780	4310	1-4	83	109	55
Sweet Gum	5	15	3230	5320	5300	3-16	92	96	67
Av.	....	....	2950	5320	7040	....	84	135	89

compare favorably with those obtained for the hard woods. This table also shows that the range for the maximum resistances is much greater than that 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

Kind of Tie	No. of Ties	No. of Spikes	Condition of Tie	Resistance and Gain in Pounds Due to Treatment					
				1-8 in. Pull	Gain	1-4 in. Pull	Gain	Maximum Resistance	Gain
Elm	3	27	Untreated	2310		5390		7290	
	2	15	Treated	2590	280	5940	550	7500	210
Beech	1	9	Untreated	2240		3790		8180	
	1	9	Treated	2950	710	6190	2400	8900	820
Loblolly Pine	1	6	Untreated	2920		3190		3630	
	2	12	Treated	2920	000	3730	640	4310	680
Red Oak	3	15	Untreated	......		......		6460	
	4	21	Treated	......		.....		7730	1270

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 morever, 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

Kind of Tie	Tie No.	Preservative	Resistance in Pounds for a Pull of 1-8 inch	Resistance in Pounds for a Pull of 1-4 inch	Maximum Resistance, Pounds
	Comparison of Zinc-Tannin and Creosote				
Water Oak	4, 5, 25, 26, 29	Zinc-Tannin	2380	5010	6260
	34	Creosote	3020	6270	7310
Red Oak	6, 9, 22, 28, 30	Zinc-Tannin	3170	5470	6580
	41	Creosote	3120	5800	6920
	Comparison of Zinc-Creosote and Creosote				
Red Oak	7, 8	Zinc-Creosote	2350	4940	8500
	41	Creosote	3120	5800	6920
Elm	10	Zinc-Creosote	2520	5870	7690
	37	Creosote	2600	6350	7210
	Comparison of Zinc-Tannin and Zinc-Creosote				
Red Oak	6, 7, 8, 9, 22	Zinc-Creosote	2350	4940	8500
	28, 30	Zinc-Tannin	3170	5470	6580
Black Oak	16, 18	Zinc-Creosote	2850	5620	7040
	23, 24, 27	Zinc-Tannin	2830	5620	7550

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

Kind of Tie	No. of Ties	No. of Spikes	Condition of Tie	Size of Spike, inches	Resistance to Withdrawal, Pounds		
					1-8 in. Pull	1-4 in. Pull	Maximum Resistance
White Oak	2	9	Seasoned	9-16	3110	6280	8760
	2	6		19-32	3750	5380	7620
	3	15		5-8	3650	6030	7620
Black Oak	4	15	Treated	9-16	2910	5340	6530
	2	6		19-32	2650	6130	7130
	4	18		5-8	2550	5710	7240
Water Oak	5	15	Treated	9-16	2960	5560	6670
	6	18		19-32	2970	5310	6010
	5	15		5-8	2650	5360	6730
Red Oak	7	21	Treated	9-16	2300	4760	7650
	9	36		5-8	3260	5990	6780
Beech	1	3	Seasoned	9-16	1880	3900	9410
	1	3		19-32	2550	5400	7660
	1	3		5-8	2290	5070	7900
	1	3	Treated	9-16	2480	5490	9410
	1	3		19-32	3530	6990	8250
	1	3		5-8	2850	6090	9040
Sweet Gum	1	6	Treated	9-16	2190	3770	4610
	1	12		5-8	3490	4450	5460

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.

TABLE IX

EXPERIMENTS WITH PLAIN SQUARE RODS IN BEECH TIMBER

Size of Rod	Area, sq. in.	Average Maximum Results, pounds	Increase for each Increment			
			Area		Resistance	
			square inches	per cent	pounds	per cent
Successive increments in the size of the rod = 1-8 inch						
1-2 inch square	0.250	6280	.....	..	....	..
5-8 inch square	0.391	6970	0.141	53	690	11
3-4 inch square	0.562	9070	0.171	44	2600	37
7-8 inch square	0.765	9380	0.203	35	310	3
Successive increments in the size of the rod = 1-16 inch						
8-16 inch square	0.250	6280	.....	..	....	..
9-16 inch square	0.316	6450	0.066	25	170	3
10-16 inch square	0.391	6970	0.075	23	520	8

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.

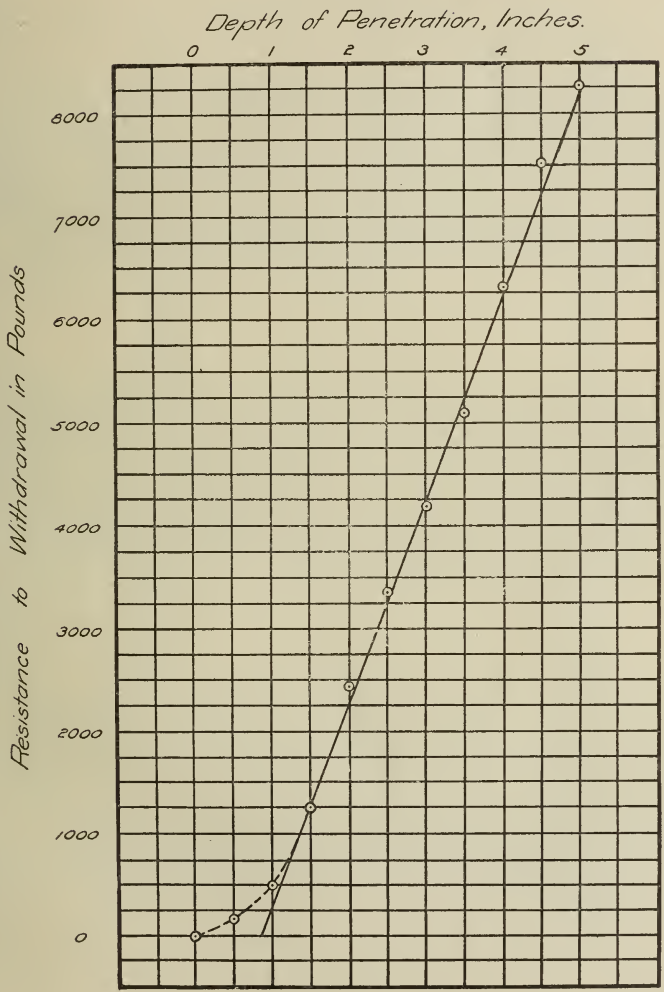
TABLE X

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

Depth of Penetration	Resistance, Pounds					
	Test Number					Average
	1	2	3	4	5	
1-2 in.	150	150	140	160	170	150
1 in.	480	....	500	510	490	500
1 1-2 in.	1440	1000	1760	1320	950	1290
2 in.	2250	2250	2050	2900	2760	2450
2 1-2 in.	3430	3840	3050	2940	3570	3360
3 in.	3710	3800	4200	4220	4810	4210
3 1-2 in.	4760	5980	4210	4500	5860	5060
4 in.	5950	7190	6310	5850	6080	6270
4 1-2 in.	7510	7510	7720	7340	....	7520
5 in.	8380	9070	8540	7790	7900	8340

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



Ordinary Spikes.

Curve Illustrating Resistance to Withdrawal for Various Depths of Penetration.

G 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.

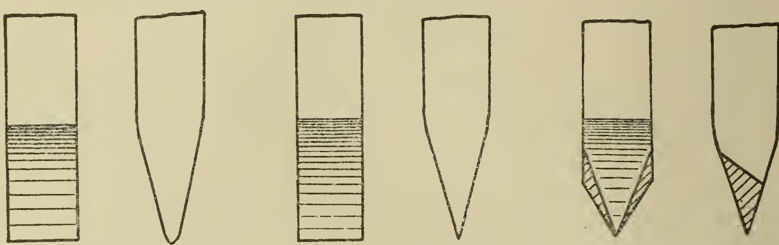
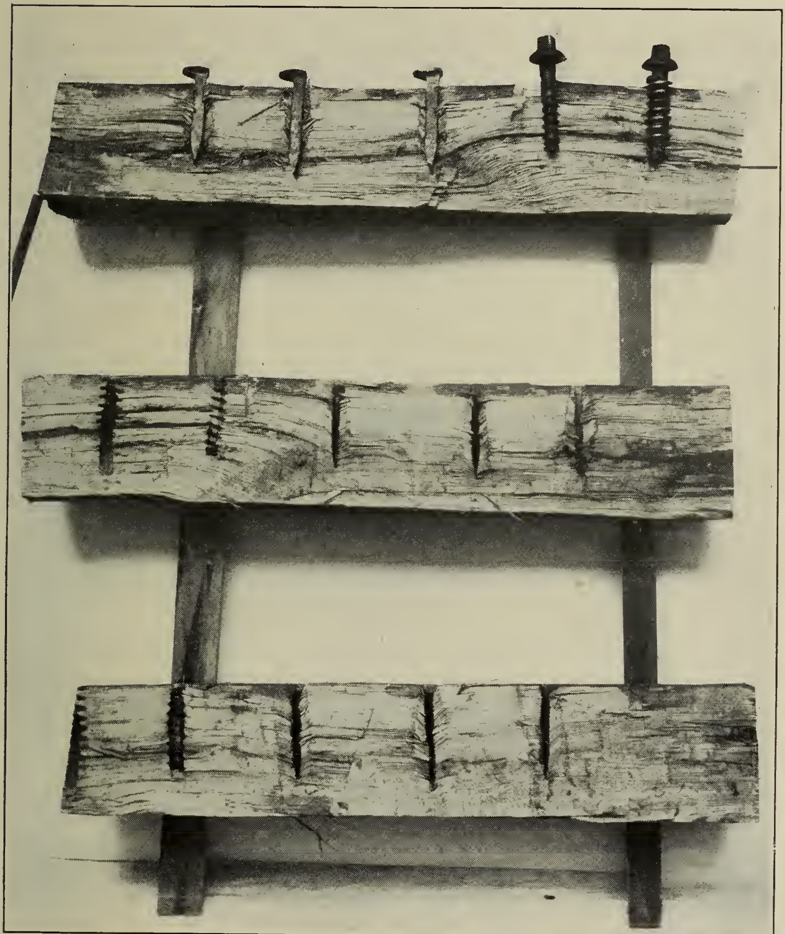


FIG. 1 FORMS OF POINTS OF SPIKES

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

PLATE V



Effect of Spikes in Displacing the Fibers of the Tie

TABLE XI

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

Kind of Tie	No. of Spikes	Type of Point	Resistance in Pounds for 1-8 in. Pull		Resistance in Pounds for 1-4 in. Pull		Maximum Resistance	
			Pounds	Relative	Pounds	Relative	Pounds	Relative
Water Oak	33	Chisel	2780	100	5520	100	6540	100
	15	Bevel	3050	110	5440	98	6330	97
Black Oak	9	Blunt	3020	106	6890	121	8280	119
	18	Chisel	2850	100	5690	100	6930	100
	12	Bevel	2680	91	5560	98	6800	98
Red Oak	18	Blunt	2220	77	4400	82	5760	76
	21	Chisel	2880	100	5350	100	7630	100
	21	Bevel	3100	107	5580	104	7370	97
White Oak	10	Blunt	4080	117	7040	135	8760	123
	12	Chisel	3490	100	5190	100	7090	100
	6	Bevel	2990	86	5610	108	8010	113
Elm	21	Chisel	2150	100	5240	100	7710	100
	21	Bevel	2500	116	5740	109	7050	92
Beech	6	Blunt	2180	85	4670	84	9250	109
	6	Chisel	2570	100	5580	100	8470	100
	6	Bevel	3040	118	6190	111	7900	93
Chestnut	3	Blunt	2850	114	4950	162	5690	127
	3	Chisel	2490	100	3060	100	4470	100
	6	Bevel	3320	133	4130	135	5310	119
Loblolly Pine	3	Blunt	2860	84	3650	118	4020	97
	6	Chisel	3420	100	3390	100	4120	100
	9	Bevel	2800	82	5010	148	5520	134
Average for all		Blunt	2870	101	5340	112	6960	105
		Chisel	2840	100	4810	100	6610	100
Timbers		Bevel	2930	103	5490	114	6800	103

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

Size of Drift-Bolt	Size of Hole, inches	Drift, inches	Holding Power, Pounds	
			6-inch depth	Per inch depth
1 inch square	16-16	....	3972	662
1 inch square	15-16	1-16	4260	710
1 inch square	14-16	1-8	4660	777
1 inch square	13-16	3-16	4050	675

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

Kind of Tie	Size of Spike, in. sq.	Diameter of Hole, inches	Resistance in Pounds for Pull of				Maximum Resistance	
			1-8 inch	1-4 inch	1-2 inch	3-4 inch	Pounds	Pull, inches
			Hole 1-16 in. Smaller than Spike					
Water Oak	9-16	1-2	2330	3860	3660	3180	5740	5-16
			2050	3860	3970	3320	5730	3-8
			2020	6470	4740	4010	6750	5-16
			1660	4450	4090	3890	6460	5-16
			2500	6400	4120	3600	6400	1-4
			3250	3750	3440	3120	4940	3-16
			2390	4890	3930	3080	6740	5-16
		Av.	2310	4810	3990	3410	6110	
Black Oak	9-16	1-2	3460	6770	3570	2850	7190	5-16
			3000	7120	3810	3360	8190	5-16
			4590	6810	3550	3350	6810	1-4
			2670	6350	3850	3560	6350	1-4
			2910	6710	3390	2970	6710	1-4
			2260	6720	3810	3270	8630	1-2
		Av.	3150	6750	7310	3660	3230	
Red Oak	9-16	1-2	3970	6550	3500	3140	6830	5-16
			3920	6930	3250	3720	6930	1-4
			2180	5920	4590	3900	6990	5-16
			2830	6900	3770	3320	6900	1-4
			2660	4310	3440	2720	5320	5-16
			2870	5710	4090	3410	5710	1-4
			2900	6100	3380	3100	6100	1-4
			3950	6680	4690	4040	6680	1-4
			2700	7430	3410	3420	7480	1-4
			2680	7410	3950	3420	7410	1-4
		Av.	3070	6390	3810	3420	6640	
	5-8	9-16	3000	5380	3610	....	5380	1-4
			3300	5010	3360	....	5010	1-4
			3130	6240	3540	3510	6240	1-4
			2710	6530	4070	3600	7040	5-16
			2600	5460	5160	4170	6990	5-16
			2850	5810	4860	4400	8800	....
			3130	6800	6980	4950	9420	5-16
		Av.	2950	5890	4390	4140	6960	

TABLE XIII—*Continued*

Kind of Tie	Size of Spike, in. sq.	Diameter of Hole, inches	Resistance in Pounds for Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	Maximum Resistance Pounds	Pull, inches
Ash	9-16	1-2	4080	7210	4720	3300	8180	5-16
			2510	6540	3360	3180	8380	5-16
			1980	4850	4380	4050	8830	7-16
			2850	5840	3220	2290	6180	5-16
			2530	5760	3510	2730	5760	1-4
		Av.	2790	6040	3840	3090	7460	
	5-8	9-16	3920	4700	3860	3280	6460	3-16
			2840	6300	4070	3600	6480	5-16
			1660	5100	5300	4370	8510	5-16
			2100	6340	5150	4540	8760	5-16
		Av.	2630	5610	4590	3950	7550	
Beech	9-16	1-2	2960	6820	3820	3790	7100	3-16
			2910	5710	4010	3550	7270	5-16
			2890	5610	3240	2850	5610	1-4
			2830	2900	2800	2690	6000	3-16
			3360	5450	2940	2620	5450	1-4
			3360	6610	3680	3210	6610	1-4
			3770	6780	3470	2890	8200	3-8
			2870	6930	4740	4360	6930	1-4
			3540	5110	5060	4010	7640	3-8
		Av.	3150	5770	3750	3330	6750	
Sweet Gum	9-16	1-2	2850	5840	3220	2290	6180	5-16
			2530	5760	3510	2730	5760	1-4
			2250	6210	4640	3570	7170	5-16
			2630	3940	3350	2870	4940	3-16
			2790	5220	4220	3680	6010	3-16
			2610	6300	3900	3370	6300	1-4
		Av.	2610	5550	3810	3080	6060	
	5-8	9-16	3030	3080	2740	2320	4370	3-16
			2620	5760	3560	2940	5760	1-4
			2850	3840	3290	2730	5500	3-16
		Av.	2830	4230	3200	2660	5210	

TABLE XIII—*Concluded*

Kind of Tie	Size of Spike, in. sq.	Diameter of Hole, inches	Resistance in Pounds for Pull of				Maximum Resistance	
			1-8 inch	1-4 inch	1-2 inch	3-4 inch	Pounds	Pull, inches
			Hole 1-8 in. Smaller than Spike					
Red Oak	5-8	1-2	1800	5710	5000	4190	7270	5-16
			2340	6860	4490	3950	6860	1-4
			2630	5850	4010	3440	5850	1-4
			3170	4410	2570	2100	4410	1-4
			4070	3000	2600	2190	4410	3-16
			4720	4220	2550	2500	6030	3-16
		Av.	3270	5010	3540	3060	5800	
Beech	9-16	7-16	1340	4560	3530	3620	7080	3-8
			2540	5620	4720	4100	6920	5-16
			4000	4720	3000	2640	6000	3-16
			3560	7280	3800	3360	7280	1-4
			3580	5270	3800	3250	6940	3-16
			3240	6900	4020	3810	7830	5-16
			2510	6150	3710	3630	6150	1-4
			2290	4620	5410	4150	7950	7-16
			2790	6380	4630	3420	8230	5-16
			1900	3790	5010	4360	7660	7-16
		Av.	2180	5530	4160	3630	7200	
Sweet Gum	5-8	1-2	2400	...	2710	2320	3980	3-16
			2850	3180	2920	2540	4750	3-16
			2950	3700	3300	2240	5200	3-16
		Av.	2730	3430	2980	2370	4640	

TABLE XIV

Average Resistance of Spikes with and without Bored Holes

Kind of Tie	Size of Spike, in. sq.	No. of Spikes	How Driven	Resistance in Pounds for			Relative Resistance		
				1-8 in. Pull	1-4 in. Pull	Maximum Resistance	1-8 in. Pull	1-4 in. Pull	Maximum Resistance
			Drift 1-16 of an inch						
Water Oak	9-16	7	Hole	2310	4810	6110	78	85	92
		15	No Hole	2960	5660	6670	100	100	100
Black Oak	9-16	6	Hole	3300	6750	7310	110	122	113
		15	No Hole	2970	5320	6490	100	100	100
Red Oak	9-16	10	Hole	3070	6390	6640	111	112	97
		36	No Hole	3260	5450	6820	100	100	100
	5-8	7	Hole	2950	5890	6960	127	123	91
		21	No Hole	2310	4760	7660	100	100	100
Beech	9-16	9	Hole	3150	5770	6760	145	123	72
		9	No Hole	2180	4700	9410	100	100	100
Ash	9-16	5	Hole	2790	6040	7460	67	130	110
		6	No Hole	4150	4630	6810	100	100	100
Sweet Gum	9-16	6	Hole	2610	5550	6060	119	149	131
		6	No Hole	2190	3730	4610	100	100	100
	5-8	4	Hole	2830	4230	5210	82	95	96
		9	No Hole	3460	4450	5460	100	100	100
Av. for all Timbers	....	....	Hole	2930	5680	6570	102	117	98
	.....	....	No Hole	2880	4840	6740	100	100	100
			Drift 1-8 of an inch						
Red Oak	5-8	6	Hole	3270	5010	5800	141	105	75
		21	No Hole	2310	4760	7660	100	100	100
Beech	9-16	10	Hole	2780	5530	7200	122	118	77
		9	No Hole	2180	4700	9410	100	100	100
Sweet Gum	5-8	3	Hole	2730	3430	4640	79	77	85
		9	No Hole	3460	4450	5460	100	100	100
Av. for all Timbers	....	....	Hole	2930	4660	6550	111	100	87
	.....	....	No Hole	2650	4640	7510	100	100	100

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

TABLE XV

RELATIVE HOLDING POWER OF NEWLY-DRIVEN AND RE-DRIVEN SPIKES

Kind of Tie	No. of Spikes	Average Maximum Resistance, Pounds		Per cent of Original
		Original	After Re-driving	
Ash	6	8640	6490	75
Water Oak	6	8020	5760	72
Red Oak	6	8030	5230	65
Elm	6	7910	4840	61
Poplar	6	4920	3980	81
Sweet Gum	6	5040	4150	82

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.

ART. 2 HOLDING POWER OF SCREW SPIKES WITHOUT LININGS

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

Spike No.	Length, inches	Diameter of Core, inches	Projection of Thread, inches	Pitch, inches	Depth of Insertion, inches	Diameter of Bored Hole, inches
1	5	21-32	3-16	1-2	4 1-2	11-16
2	5	11-16	1-8	1-2	4 1-2	11-16
3	5 1-4	11-16	1-8	1-2	4 3-4	11-16
4	5 1-2	11-16	1-8	1-2	5	11-16
5	5	21-32	3-16	1-2	4 1-2	11-16

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

Kind of Tie	No. of Tie	No. of Spike	No. of Test	Resistance in Pounds for a Pull of					Maximum Resistance	
				1-8 inch	1-4 inch	1-2 inch	3-4 inch	1 inch	Pounds	Distance Pulled, inches
Blue Ash	2	2	1	7350	10900	11650	6270	3370	13360	7-16
			2	5080	9930	13470	6010	3190	13470	1-2
			3	7520	11650	12300	6220	3030	12300	1-2
			Av.	6650	10830	12470	6160	3190	13040	1-2
	1	4	1	3320	7480	10840	6520	5000	10840	1-2
			2	3740	7570	9410	5940	4560	9410	1-2
			3	4350	9200	6800	4870	3260	9700	3-8
			Av.	3800	8080	9010	5780	3940	9980	1-2
Sweet Gum	3	2	1	3810	4940	4870	2420	1900	5980	7-16
			2	5790	7100	4900	3280	3770	7100	1-4
			3	4270	6030	4620	2820	3450	6590	3-8
			Av.	4620	6060	4790	2840	3040	6560	3-8
	3	4	1	5920	9000	6000	4000	2900	9720	7-16
			2	4550	7400	5600	3410	2300	8100	3-8
			3	4780	7120	5090	3290	1800	7870	3-8
			Av.	5080	7840	5560	3560	2330	8560	3-8
Water Oak	34	3	1	4820	10230	14530	9630	4600	14530	1-2
			2	4670	9170	12140	10000	6260	12640	5-8
			3	4680	7030	14360	9660	4490	14360	1-2
			Av.	4720	8810	13680	9800	5100	13840	7-16
	26	2	1	4110	8010	7190	3490	2150	9620	7-16
			2	3670	7420	7850	3970	2790	8900	3-8
			3	5270	7790	5190	3540	2600	8060	7-16
			Av.	4350	8290	6740	3660	2510	8860	7-16
Black Oak	16	3	1	5520	12370	16930	10720	6200	16930	1-2
			2	4860	11410	13100	7390	4050	14350	7-16
			3	4260	9870	9760	7690	3970	12160	3-8
			Av.	4880	11220	13260	8600	4740	14480	7-16
	23	2	1	5850	10290	9460	6600	4200	12500	3-8
			2	4910	10780	8590	6000	2500	12570	5-8
			3	1090	6370	10400	7100	6000	10400	1-2
			Av.	3950	9150	9380	6560	4230	11820	5-8

TABLE XVII—*Continued*

Kind of Tie	No. of Tie	No. of Spike	No. of Test	Resistance in Pounds for a Pull of					Maximum Resistance	
				1-8 inch	1-4 inch	1-2 inch	3-4 inch	1 inch	Pounds	Distance Pulled, inches
Red Oak	9	4	1	2720	7810	12720	7970	3710	12720	1-2
			2	6390	11440	11590	7050	3600	12770	3-8
			3	4240	9770	11130	9160	4970	11790	3-8
			Av.	4450	9670	11810	8060	4130	12430	3-8
	7	4	1	3940	9780	12780	9560	4880	13590	7-16
			2	7890	13860	14430	7990	4530	15200	3-8
			3	4220	9780	14800	12350	6500	14800	1-2
			Av.	5350	11140	12670	9960	6300	14860	7-16
Beech	36	2	1	2610	8400	8320	4170	....	14560	5-16
			2	8320	12370	10820	6130	....	13180	3-8
			3	5190	11880	11270	6880	....	14310	3-8
			Av.	5040	10850	10140	5730	....	14020	3-8
	14	3	1	6330	11980	10240	4480	3230	14550	7-16
			2	6130	12980	17360	9930	3900	17360	1-2
			3	8240	15620	14700	8900	5890	16450	7-16
			Av.	6900	13530	14000	7770	4340	16120	7-16
White Oak	31	4	1	3010	9340	8180	6390	4530	11630	7-16
			2	7950	12490	9390	5350	2880	13200	5-16
			3	8210	12080	7560	4950	3290	12740	5-16
			Av.	6390	11300	8380	5230	3570	12520	5-16
	31	3	1	5000	8290	5450	2960	....	8290	1-4
			2	4600	8030	6600	3340	....	8700	5-16
			3	5880	9370	....	....	....	10530	3-8
			Av.	5160	8560	5530	3150	....	9150	5-16
	32	3	1	6420	11300	16450	9590	4360	16450	1-2
			2	8590	14190	11370	5490	3190	15580	5-16
			3	4420	13000	Broke	....	....	13000	1-4
			Av.	6480	12830	13910	7040	3780	15010	3-8
Elm	10	3	1	4310	8290	14190	6340	2780	14190	1-2
			2	5040	10920	13200	7950	3100	14400	7-16
			3	4200	9130	13230	7350	3460	13230	1-2
			Av.	4520	9450	13540	7210	3110	13940	1-2

TABLE XVII—*Concluded*

Kind of Tie	No. of Tie	No. of Spike	No. of Test	Resistance in Pounds for a Pull of 1-8 inch	1-4 inch	1-2 inch	3-4 inch	1 inch	Maximum Resistance Pounds	Distance Pulled, inches
	13	1	1	6090	11560	9920	4400	2420	11560	1-4
			2	5220	10400	11440	6450	3200	12740	7-16
			3	4570	9890	12400	7990	4000	14390	7-16
			Av.	5290	10280	11250	6260	3200	12890	7-16
	12	4	1	6830	11280	10080	5280	2340	12840	3-8
			2	3270	8650	9570	6350	3450	11610	7-16
			3	3700	7840	12480	7110	3360	12480	1-2
			Av.	4570	9260	10680	6250	3050	12310	7-16
Poplar	11	4	1	4130	7980	8000	4790	3300	10120	7-16
			2	2960	6200	8910	4820	2130	9610	7-16
			3	4760	7970	10130	7210	4480	10130	1-2
			Av.	3950	7380	9010	5610	3270	9960	7-16
	11	1	1	3450	6300	9340	5250	2940	9340	1-2
			2	3300	6550	8490	3860	1620	8490	1-2
			3	2640	5260	8060	2710	1520	8060	1-2
			Av.	3130	6040	8290	3940	2030	8290	1-2
Chestnut	40	4	1	5200	6950	6400	3340	....	7610	3-8
			2	2750	6210	8250	3800	....	8250	1-2
			3	3240	6260	6160	4580	....	7290	5-16
			Av.	3730	6480	6940	3910	....	7720	3-8
	40	1	1	3070	5460	5680	3570	1930	7010	7-16
			2	3960	3270	5310	2820	1140	6470	7-16
			3	3940	5630	5580	2510	1400	6300	7-16
			Av.	3660	5450	5520	2960	1490	6590	7-16
Loblolly Pine	20	1	1	5260	7610	5510	2670	1460	9340	3-8
			2	3840	6270	6210	3630	2120	7550	7-16
			3	4830	7780	7360	3060	2390	8190	3-8
			Av.	4640	7270	6390	3120	2320	8690	3-8
	39	1	1	6180	10220	7590	4070	1720	11840	3-8
			2	5350	8260	9060	5060	2460	11190	3-8
			3	....	...	8200	5520	3400	9850	7-16
			Av.	5820	9240	8280	4880	2530	10630	3-8

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

RESULTS OBTAINED FROM EXPERIMENTS ON DEPTH OF PENETRATION

Test Number	Resistance in Pounds for a Penetration of				
	1 inch	2 inches	3 inches	4 inches	5 inches
1	2770	4560	9610	13100	17360
2	2760	6000	10000	14330	17500
3	2790	4940	8490	13330	16840
Av.	2770	5170	9360	13590	17230

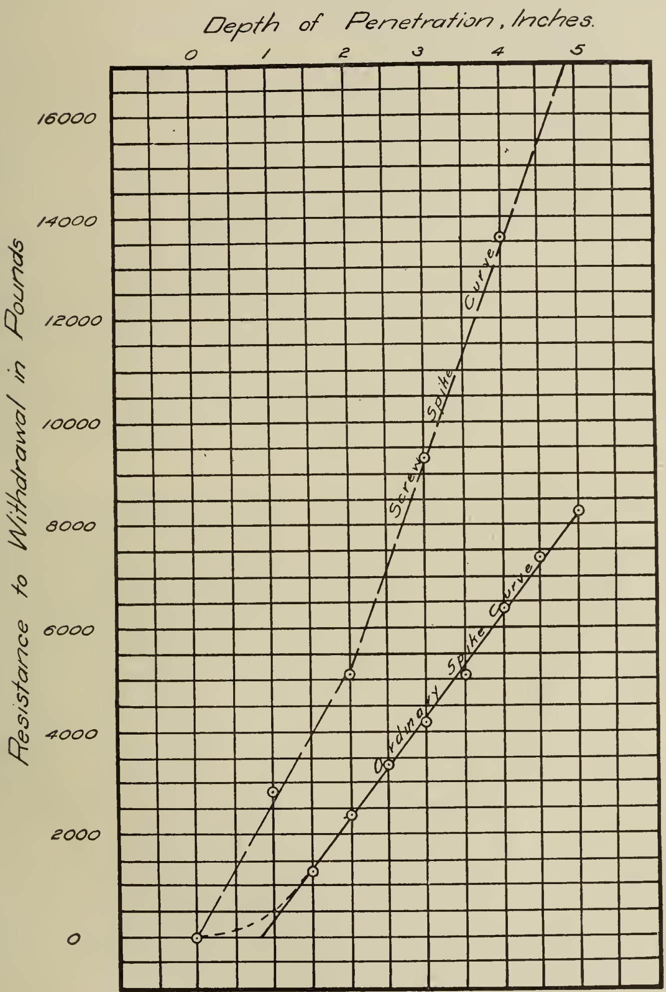
The results in Plate VI can be quite closely represented by two intersecting straight lines. The probabilities are that the actual resistances would be more nearly represented if the two straight lines were joined by a short curve near their intersection. Only the upper portion of the diagram is of interest, 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



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

Kind of Tie	Kind of Spike	Resistance in Pounds for			Relative Resistances		
		1-8-in. Pull	1-4-in. Pull	Max. Resist.	1-8-in. Pull	1-4-in. Pull	Max. Resist.
Water Oak	Ordinary Screw	2870 4888	5730 9180	6780 12190	100 170	100 160	100 179
Black Oak	Ordinary Screw	2910 4760	5890 10420	7230 14110	100 164	100 177	100 203
Red Oak	Ordinary Screw	2950 4900	5350 10400	7730 13560	100 166	100 194	100 176
White Oak	Ordinary Screw	3510 6250	5950 11900	7870 12630	100 178	100 200	100 188
Ash	Ordinary Screw	3570 5700	5200 10470	7730 12760	100 162	100 200	100 165
Beech	Ordinary Screw	2600 6450	5490 13140	8840 16230	100 248	100 221	100 238
Elm	Ordinary Screw	2380 5120	5580 10090	7500 13690	100 215	100 181	100 183
Poplar	Ordinary Screw	2830 3880	5290 6210	5670 7490	100 137	100 117	100 132
Chestnut	Ordinary Screw	2850 3690	4070 6340	5200 8700	100 129	100 155	100 167
Sweet Gum	Ordinary Screw	3230 5430	4120 7710	5300 8280	100 167	100 162	100 156
Loblolly Pine	Ordinary Screw	2920 5750	3500 9050	4300 10620	100 197	100 258	100 247

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 x 17 3-4 inches x 1-8 inches=12,430 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.

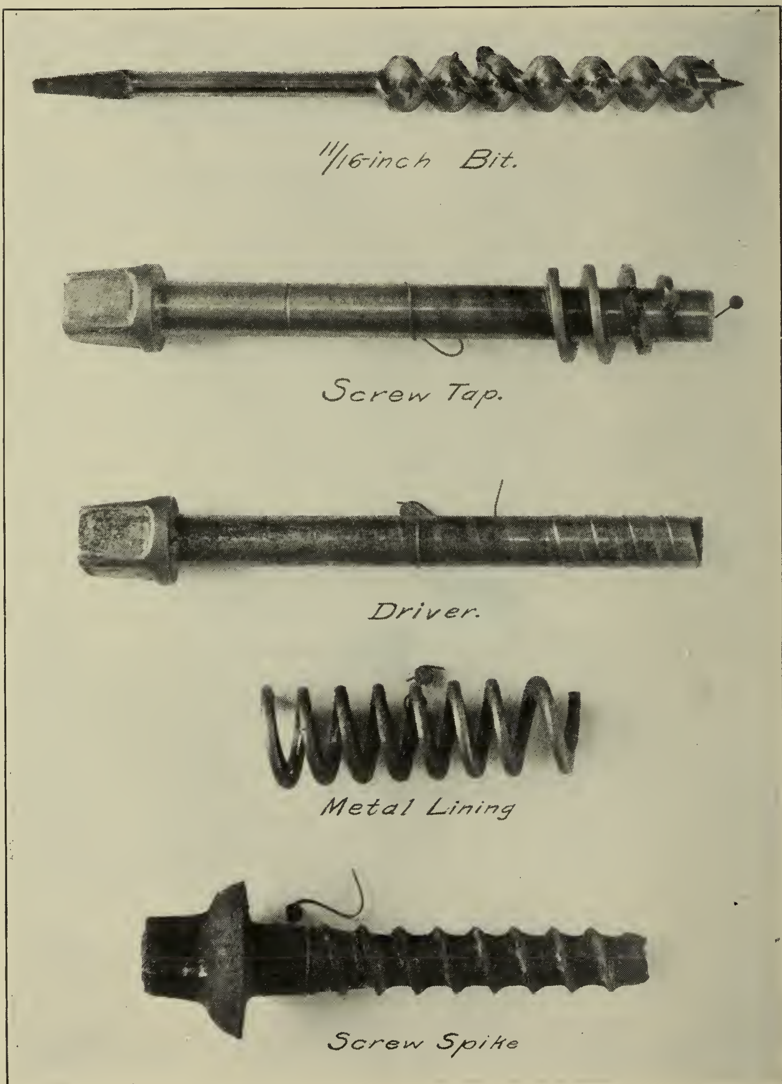
(3) If the length of the threaded portion of the spike remains unchanged and if the projection of the thread is increased 1-32 of an inch at the expense of the core, the maximum resistance would amount to 15,510 pounds, while the ultimate strength of the spike would be reduced to 20,200 pounds.

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.

PLATE VII



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.

TABLE XX

RESISTANCE OF SCREW SPIKES WITH HELICAL LININGS

Kind of Tie	Tie No.	No. of Tests	Resistance in Pounds for Pull of					Maximum Resistance	
			1-8 in.	1-4 in.	1-2 in.	3-4 in.	1 in.	Pounds	Pull, in.
Ash	1	1	8410	11380	10150	7570	6480	12160	1-4
		2	5830	8670	9410	6590	5630	10500	3-8
		3	5670	8070	7930	4690	4200	8750	3-8
		Av.	6640	9370	9160	6280	5440	10470	3-8
Sweet Gum	3	1	6010	9100	7750	5380	5150	9510	1-4
		2	4830	6440	7650	6270	4380	7970	3-8
		3	4270	6250	8600	6130	4410	8600	1-2
		Av.	5030	7260	8000	5930	4650	8690	3-8
Water Oak	26	1	3420	7100	11080	8290	8740	11080	1-2
		2	2970	6460	12080	9250	9170	12080	1-2
		Av.	3190	6780	11580	8780	8960	11580	1-2
White Oak	32	1	5810	10740	8420	6890	7120	12900	3-8
		2	7070	11020	6650	6170	6340	11020	1-4
		Av.	6440	10880	7530.	6530	6750	11960	3-8
Black Oak	23	1	5960	11130	9810	8560	7520	12550	3-8
		2	5420	9710	10770	8470	7960	12460	3-8
		Av.	5690	10420	10290	8510	7740	12500	3-8
Beech		1	10830	10120	8070	7320	5390	10830	1-8
		2	8610	11600	11850	10350	6280	13480	3-8
		Av.	9720	10860	9960	8830	5830	12150	1-4
Poplar	11	1	3970	8860	9900	5880	5300	9920	3-8
		2	4080	9470	10550	5940	5110	11140	3-8
		3	3670	8260	9910	6030	5250	9910	1-2
		Av.	3910	8860	10120	5950	3220	10320	3-8
Chestnut		1	7020	9600	8230	6920	6120	9770	3-8
		2	5750	7010	8890	8180	6730	8890	1-2
		3	6300	7240	9280	7660	6860	9280	1-2
		Av.	6390	7950	8810	7590	6900	9150	1-2

TABLE XXI

Relative Holding Power of the Ordinary Spike, the Screw Spike, and the Screw Spike with Helical Lining in Several Timbers

Kind of Tie	Kind of Spike	Resistance in Pounds for			Relative Resistance		
		1-8-in. Pull	1-4-in. Pull	Max. Resist.	1-8-in. Pull	1-4-in. Pull	Max. Resist.
White Oak	Ordinary	3510	5950	7870	100	100	100
	Screw*	6250	11900	12630	178	200	188
	Lining	6440	10880	11960	183	183	152
Water Oak	Ordinary	2870	5730	6780	100	100	100
	Screw*	4880	9180	12190	170	160	179
	Lining	3190	6780	11580	111	118	171
Black Oak	Ordinary	2910	5890	7230	100	100	100
	Screw*	4760	10420	14110	164	177	203
	Lining	5690	10420	12500	195	177	173
Ash	Ordinary	3570	5200	7730	100	100	100
	Screw*	5700	10470	12760	162	200	165
	Lining	6640	9370	10470	186	180	135
Beech	Ordinary	2600	5490	8840	100	100	100
	Screw*	6450	13140	16230	248	221	238
	Lining	9720	10860	12150	373	198	138
Poplar	Ordinary	2830	5290	5670	100	100	100
	Screw*	3850	6210	7490	137	117	132
	Lining	3910	8860	10320	138	162	182
Chestnut	Ordinary	2850	4070	5200	100	100	100
	Screw*	3690	6340	8700	129	155	167
	Lining	6390	7950	9150	224	195	176
Sweet Gum	Ordinary	3230	4120	5300	100	100	100
	Screw*	5430	7710	8280	167	162	156
	Lining	5030	7260	8690	136	176	164

* Screw spike with helical lining.

The * belongs after "Lining."

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

TABLE XXII

DETAILED RESULTS OF IMPACT TESTS OF ORDINARY SPIKES

Kind of Tie	Size of Spike, in. sq.	Total Lateral Movement of Spikes in Inches				
		Number of Blows				
		1	2	3	4	5
White Oak	9-16	0.27	0.35	0.48	0.65	0.81
		.18	.35	.56	.67	.73
		.10	.22	.33	.45	.54
		.30	.35	.50	.52	.60
		.21	.35	.60	.74	.93
	Av.	0.21	0.32	0.49	0.61	0.70
	5-8	0.11	0.20	0.26	0.30	0.39
		.15	.30	.41	.50	.57
		.19	.36	.50	.60	.68
		.21	.36	.49	.65	.74
		.20	.34	.42	.50	.57
	Av.	0.17	0.31	0.42	0.51	0.59
Water Oak	9-16	0.23	0.34	0.52	0.60	0.75
		.20	.33	.56	.73	.88
		.14	.42	.53	.68	.75
		.20	.35	.48	.54	.65
		.19	.39	.63	.72	.78
	Av.	0.19	0.37	0.54	0.65	0.76
	5-8	0.12	0.25	0.36	0.48	0.55
		.20	.37	.54	.63	.69
		.15	.25	.31	.39	.50
		.19	.28	.43	.51	.65
		.20	.37	.53	.65	.69
	Av.	0.17	.30	0.43	0.53	0.61
Black Oak	9-16	0.25	0.40	0.56	0.70	0.75
		.13	.30	.41	.58	.72
		.16	.32	.49	.58	.70
		.24	.44	.62	.71	.80
		.23	.35	.56	.65	.69
		.26	.39	.59	.67	.78
	Av.	0.21	0.37	0.54	0.65	0.71
Black Oak	5–8	0.23	0.38	0.50	0.58	0.65
		.17	.30	.42	.53	.64
		.17	.35	.50	.61	.77
		.15	.32	.40	.49	.55
		.11	.26	.37	.41	.45
		.22	.35	.50	.59	.65
	Av.	0.17	0.33	0.45	0.53	0.62

TABLE XXII—*Continued*

Kind of Tie	Size of Spike, in. sq.	Total Lateral Movement of Spikes in Inches				
		Number of Blows				
		1	2	3	4	5
Red Oak	9-16	0.21	0.35	0.51	0.61	0.73
		.19	.30	.46	.57	.75
		.20	.37	.55	.64	.77
		.22	.41	.49	.61	.72
	Av.	0.21	0.36	0.50	0.61	0.74
	5-8	0.12	0.21	0.32	0.42	0.49
		.15	.24	.34	.43	.50
		.12	.25	.35	.49	.53
		.18	.42	.55	.72	.85
	Av.	0.14	0.28	0.39	0.52	0.60
Ash	9-16	0.24	0.45	.057	0.68	0.80
		.24	.43	.53	.65	.74
		.20	.33	.52	.65	.75
		.25	.41	.60	.72	.83
	Av.	0.23	0.41	0.56	0.68	0.78
	5-8	0.19	0.37	0.55	0.73	0.84
		.19	.33	.48	.64	.75
		.18	.31	.44	.60	.69
		.15	.30	.39	.54	.63
	Av.	0.18	0.33	0.47	0.63	0.73
Elm	9-16	0.22	0.33	0.50	0.67	0.78
		.21	.30	.39	.56	.70
		.25	.37	.49	.58	.66
		.18	.30	.43	.54	.67
	Av.	0.22	0.33	0.45	0.59	0.70
	5-8	0.20	0.38	0.50	0.61	0.71
		.21	.35	.48	.60	.72
		.20	.35	.49	.61	.70
		.21	.32	.44	.55	.66
	Av.	0.21	0.35	0.48	0.59	0.70
Beech	9-16	0.28	0.30	0.58	0.72	0.87
		.26	.46	.57	.75	.86
		.21	.32	.53	.65	.75
		.30	.54	.63	.71	.89
		.19	.37	.55	.70	.80
		.27	.46	.61	.72	.86
	Av.	0.25	0.41	0.58	0.71	0.84

TABLE XXII—*Continued*

Kind of Tie	Size of Spike, in. sq.	Total Lateral Movement of Spikes in Inches				
		Number of Blows				
		1	2	3	4	5
Poplar	5–8	0.15	0.23	0.33	0.46	0.53
		.13	.20	.29	.41	.49
		.16	.27	.36	.49	.58
		.12	.26	.43	.50	.57
		.12	.30	.37	.46	.62
		.14	.25	.31	.39	.50
	Av.	0.14	0.25	0.35	0.45	0.55
	9-16	0.27	0.41	0.59	0.75	0.88
		.22	.40	.54	.67	.74
		.30	.45	.60	.68	....
		.27	.41	.54	.75	.84
		.27	.40	.52	.61	.76
	Av.	0.27	0.41	0.56	0.69	0.81
Chestnut	5–8	0.10	0.29	0.41	0.50	0.63
		.16	.28	.41	.51	.60
		.20	.39	.50	.66	.75
		.17	.39	.39	.46	.57
	Av.	0.16	0.34	0.43	0.53	0.64
	9–16	0.35	0.65	0.90	1.06	1.40
		.35	.60	.80	.97	1.10
		.35	.60	.90	1.12	1.35
		.31	.62	.91	1.01	1.19
		.29	.52	.75	.93	1.18
		.30	.50	.73	.93	1.19
	Av.	0.32	0.58	0.83	1.00	1.23
Sweet Gum	5–8	0.17	0.40	0.60	0.78	0.85
		.10	.30	.67	.88	1.05
		.27	.45	.63	.80	.92
		.25	.48	.70	.91	1.03
		.24	.40	.57	.75	.90
		.28	.42	.53	.65	.84
	Av.	0.22	0.41	0.61	0.79	.93
	9–16	0.29	0.51	0.60	0.78	0.95
		.23	.40	.66	.75	.88
		.30	.51	.67	.75	.92
		.31	.54	.72	.97	1.10
	Av.	0.28	0.49	0.66	0.81	0.96

TABLE XXII—*Concluded*

Kind of Tie	Size of Spike, in. sq.	Total Lateral Movement of Spikes in Inches				
		Number of Blows				
		1	2	3	4	5
Sweet Gum	5-8	0.14	0.28	0.45	0.62	0.78
		.18	.35	.54	.62	.75
		.16	.33	.46	.62	.70
		.14	.38	.42	.50	.61
	Av.	0.16	0.34	0.47	0.59	0.17
Loblolly Pine	9-16	0.22	0.33	0.50	0.61	0.70
		.23	.38	.65	.76	.81
		.12	.23	.35	.42	.50
		.24	.37	.58	.71	.88
		.26	.42	.53	.70	.75
		.23	.45	.64	.72	.77
	Av.	0.22	0.36	0.54	0.65	0.74
	5-8	0.16	0.30	0.40	0.50	0.65
		.17	.42	.63	.72	.85
		.17	.22	.30	.51	.55
		.15	.23	.40	.52	.59
		.23	.38	.46	.61	.71
		.12	.19	.29	.36	.41
		.23	.39	.53	.68	.78
	Av.	0.18	0.30	0.43	0.56	0.65

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

Kind of Tie	Size of Spike, in. sq.	Movement for Each of the Several Blows, inches					Average Movement, inches
		1	2	3	4	5	
White Oak	9-16 5-8	0.21 0.17	0.11 0.14	0.17 0.11	0.12 0.09	0.09 0.08	0.136 0.118
Water Oak	9-16 5-8	0.19 0.17	0.18 0.13	0.17 0.13	0.11 0.10	0.11 0.08	0.152 0.122
Black Oak	9-16 5-8	0.21 0.17	0.16 0.16	0.17 0.12	0.11 0.08	0.06 0.09	0.142 0.124
Red Oak	9-16 5-8	0.21 0.14	0.15 0.14	0.14 0.11	0.11 0.14	0.13 0.08	0.148 0.122
Ash	9-16 5-8	0.23 0.18	0.18 0.15	0.15 0.14	0.12 0.16	0.10 0.10	0.156 0.146
Elm	9-16 5-8	0.22 0.21	0.11 0.14	0.12 0.13	0.13 0.11	0.11 0.11	0.138 0.140
Beech	9-16 5-8	0.25 0.14	0.16 0.11	0.17 0.10	0.13 0.10	0.13 0.10	0.168 0.110
Poplar	9-16 5-8	0.27 0.16	0.14 0.18	0.15 0.09	0.14 0.10	0.12 0.11	0.164 0.128
Chestnut	9-16 5-8	0.32 0.22	0.26 0.19	0.25 0.20	0.17 0.18	0.23 0.14	0.246 0.186
Sweet Gum	9-16 5-8	0.28 0.16	0.21 0.18	0.17 0.13	0.15 0.12	0.15 0.12	0.192 0.142
Loblolly Pine	9-16 5-8	0.22 0.18	0.14 0.12	0.18 0.13	0.11 0.13	0.04 0.09	0.148 0.128

TABLE XXIV

DETAILED RESULTS OF IMPACT TESTS OF SCREW SPIKES

Kind of Tie		Total Lateral Movement of Spike, in Inches — Number of Blows 1	2	3	4	5
White Oak		0.09 .10 .07	0.16 .20 .14	0.23 .24 .21	0.30 .32 .28	0.38 .41 .40
	Av.	0.09	0.17	0.23	0.30	0.40
Black Oak		0.11 .10 .11	0.21 .19 .18	0.26 .25 .24	0.36 .33 .31	0.40 .44 .42
	Av.	0.11	0.19	0.25	0.33	0.42
Water Oak		0.09 .11 .08	0.13 .17 .18	0.22 .23 .26	0.33 .34 .35	0.42 .45 .41
	Av.	0.09	0.16	0.24	0.34	0.43
Red Oak		0.12 .11 .17	0.21 .20 .23	0.35 .34 .33	0.45 .44 .46	0.54 .52 .52
	Av.	0.13	0.21	0.34	0.45	0.53
Ash		0.17 .18 .12	0.23 .27 .25	0.34 .35 .33	0.47 .46 .45	0.54 .55 .53
	Av.	0.16	0.25	0.34	0.46	0.54
Elm		0.11 .12 .21 .25	0.30 .22 .40 .40	0.38 .37 .58 .52	0.48 .49 .85 .63	0.56 .53 .96 .75
	Av.	0.17	0.33	0.46	0.61	0.70
Beech		0.10 .11 .12 .16 .17 .20	0.18 .18 .19 .28 .31 .40	0.23 .26 .25 .38 .52 .52	0.28 .31 .32 .49 .58 .60	0.36 .37 .42 .58 .65 .68
	Av.	0.14	0.26	0.36	0.43	0.51

TABLE XXIV—*Concluded*

Kind of Tie		Total Lateral Movement of Spike, in Inches				
		Number of Blows				
		1	2	3	4	5
Poplar		0.09	0.16	0.32	0.60	0.78
		.10	.16	.27	.40	.61
		.09	.15	.34	.39	.49
		.19	.35	.44	.61	.78
		.18	.40	.53	.62	.75
		.17	.27	.40	.63	.71
		.16	.30	.39	.51	.62
	Av.	0.17	0.24	0.38	0.54	0.67
Chestnut		0.16	0.23	0.38	0.43	0.50
		.13	.22	.37	.52	.56
		.12	.24	.33	.42	.51
		.20	.31	.39	.51	.59
		.19	.28	.39	.48	.65
	Av.	0.16	0.26	0.37	0.47	0.56
Sweet Gum		0.20	0.38	0.52	0.68	0.78
		.26	.46	.60	.71	.79
		.30	.48	.51	.74	.88
		.18	.32	.40	.49	.61
		.25	.38	.47	.59	.68
	Av.	0.24	0.40	0.50	0.64	0.74
Loblolly Pine		0.20	0.41	0.62	0.72	0.88
		.21	.39	.58	.69	.78
		.21	.32	.48	.64	.81
		.23	.37	.56	.66	.80
	Av.	0.21	0.37	0.56	0.68	0.82

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

Depth of Insertion	Deflection in Inches					Average for Five Blows
	Number of Blows					
	1	2	3	4	5	
3 in.	0.24	0.46	0.64	0.78	0.87	
	.22	.41	.55	.69	.84	
	.24	.43	.67	.76	.98	
Av.	0.23	0.43	0.62	0.73	0.90	0.582
3 1-2 in.	0.24	0.46	0.62	0.77	0.80	
	.24	.39	.53	.69	.80	
	.19	.34	.49	.63	.74	
Av.	0.22	0.40	0.55	0.70	0.78	0.530
4 in.	.20	0.39	0.49	0.60	0.71	
	.21	.40	.57	.63	.77	
	.23	.33	.57	.62	.72	
Av.	0.21	0.37	0.54	0.62	0.73	0.494
4 1-2 in.	0.24	0.30	0.50	0.65	0.74	
	.20	.34	.53	.68	.73	
	.22	.36	.54	.62	.79	
Av.	0.22	0.33	0.52	0.65	0.75	0.494
5 in.	0.22	0.38	0.49	0.61	0.71	
	.23	.40	.55	.67	.75	
	.15	.34	.48	.57	.69	
Av.	0.20	0.34	0.51	0.62	0.72	0.478

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

Kind of Tie	Movement for Each of the Several Blows					Average Movement, inches
	1	2	3	4	5	
White Oak	0.09	0.08	0.05	0.07	0.10	0.078
Black Oak	0.11	0.08	0.06	0.07	0.09	0.082
Water Oak	0.09	0.07	0.08	0.10	0.09	0.086
Red Oak	0.13	0.08	0.13	0.12	0.08	0.108
Ash	0.16	0.09	0.09	0.12	0.08	0.108
Elm	0.17	0.16	0.13	0.15	0.09	0.140
Beech	0.14	0.12	0.10	0.07	0.08	0.102
Poplar	0.17	0.07	0.12	0.16	0.13	0.130
Chestnut	0.16	0.10	0.11	0.10	0.09	0.132
Sweet Gum	0.24	0.16	0.10	0.14	0.10	0.148
Loblolly Pine	0.21	0.13	0.19	0.12	0.14	0.154

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

Kind of Tie	Movement of Ordinary Spikes		Average Movement of Screw Spike, inches	Average Movement of Ordinary Spikes in Terms of per cent of Movement of Screw Spike	
	9-16 in.	5-8 in.		9-16 in.	5-8 in.
White Oak	0.136	0.118	0.078	175	152
Black Oak	0.152	0.122	0.082	186	149
Water Oak	0.142	0.124	0.086	165	145
Red Oak	0.148	0.122	0.108	137	115
Ash	0.156	0.146	0.108	144	135
Elm	0.138	0.140	0.140	99	100
Beech	0.168	0.110	0.102	165	108
Poplar	0.164	0.128	0.130	126	99
Chestnut	0.246	0.186	0.132	186	141
Sweet Gum	0.192	0.142	0.148	129	96
Loblolly Pine	0.148	0.128	0.154	96	83

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.

Bulletin No. 2. Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 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.