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HOLDING POWER OF WOOD SCREWS

BY

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Bureau of Standards

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By I. J. Fairchild

ABSTRACT

The results of tests of the holding power of over 10,000 wood screws inserted in the side and end grain of seven kinds of wood, viz, yellow poplar, cypress, sycamore, North Carolina pine, Georgia pine, hard maple, and white oak, are tabulated and discussed.

The effect of various sizes of lead holes, of screw lubrication, of cracks in the wood, and of the dimensions and finish of the screws is described.

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I. INTRODUCTION

1. SCOPE OF THE TESTS

This investigation was undertaken in response to specific requests for data on the holding power of wood screws in the application of builders' hardware, and for the benefit of manufacturers of furniture, fixtures, vehicles, freight cars, ships, pianos, woodenware, boxes and crates, and other users of wood screws.

"Holding power" is here defined as the maximum load in tension which a given screw can withstand when the load is applied to the head of the screw along its axis. The load may reach its maximum limit either (*a*) through the withdrawal of the screw from the wood, or (*b*) in the denser woods through the breaking of the screw by fracture at the root of a thread near the shank, or (*c*) by collapse of the head of the screw.

Since over 80 per cent of the wood screws manufactured are of steel with flat head, the tests were confined to this type. Ninety-five sizes were used, including every standard diameter from the smallest to the largest, in one-half of all the standard lengths. Seven different kinds of wood were employed, covering the full range of densities from the softest to the hardest woods in common use, in order to obtain the complete range of maximum direct tensional loads which wood screws are capable of supporting.

2. PREVIOUS INVESTIGATIONS

In 1884 the Watertown Arsenal (1)[1] tested a total of 124 wood screws drawn from pine and California laurel wood, and formulated a statement of average adhesive resistance per square inch of surface in wood based upon the area of the cylindrical surface at the top of the threads.

Norris M. Works (3), after testing 557 wood screws pulled from white pine, developed a formula for holding strength as a function of the area in contact with wood. He states that the holding strength of screws per unit area in contact with wood is a constant for all screws in a given wood.

P. J. Haler and H. T. Wright (6) examined a total of seven wood screws pulled from oak, white pine, and white deal wood, and set up a table of holding power per inch of length for a single diameter of screw.

3. ACKNOWLEDGMENTS

The author wishes to express his indebtedness to the following wood-screw manufacturers of the United States for donating the screws used in the tests: American Screw Co., Bridgeport Screw Co., Champion Manufacturing Co., Continental Wood Screw Co., Corbin Screw Corporation, Eagle Lock Co., Keeler Brass Co., National Lock Co., National Screw & Manufacturing Co., Charles Parker Co., Reed & Prince Manufacturing Co., and Southington Hardware Co.

Acknowledgment is also gratefully made to the Forest Service of the Department of Agriculture for identifying the woods used, to George W. Thurston for helpful information and suggestions, and to Daniel Aronowsky for his assistance in carrying out the tests.

[1] The figures given in parentheses here and throughout the text relate to the reference numbers in the bibliography at the end of this paper.

II. DESCRIPTION OF MATERIALS USED

1. WOOD SCREWS

The following sizes of flat-head steel wood screws were used, comprising all of the diameters in one-half the lengths now manufactured:

Length in inches	Numbers
¼	0, 1, 2, 3, 4.
½	1, 2, 3, 4, 5, 6, 7, 8, 9, 10.
¾	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14.
1	3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 16.
1½	4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20.
2	6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20.
2½	6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20.
3	8, 9, 10, 11, 12, 14, 16, 18, 20, 24.
4	12, 14, 16, 18, 20, 24.
5	14, 16, 18, 20, 24.

The above screws, totaling 100 gross, were supplied by 12 different manufacturers, so that the screws are representative of the product of the industry.

The screws were found to conform with United States Government Master Specification No. 52 for wood screws, except that in a few instances the body diameter slightly exceeded the maximum plus tolerance. A wide variety of thread shapes was found, ranging from thin and sharp, as at *A*, Figure 1, to thick and dull, as at *B*, Figure 1, with the shape at the root of thread varying from conical, as at *A*, Figure 2, to cylindrical, as at *B*, Figure 2. The finish or texture of the metal at the surface of the body and threads also varied from a high polish to a coarse, rough texture.

2. TIMBERS

Seven kinds of wood were used, as listed in Table 1. The timbers were 3¾ by 3¾ inches in cross section and 6 feet long. These dimensions were convenient for easy handling and permitted the insertion of small screws in each of the four sides, thus conserving lumber and obviating the need for more than one set of holding lugs.

Immediately following the tests on each variety of wood a sample was submitted to the chemistry division for determination of moisture content and density. The data for each variety of timber are given in Table 1.

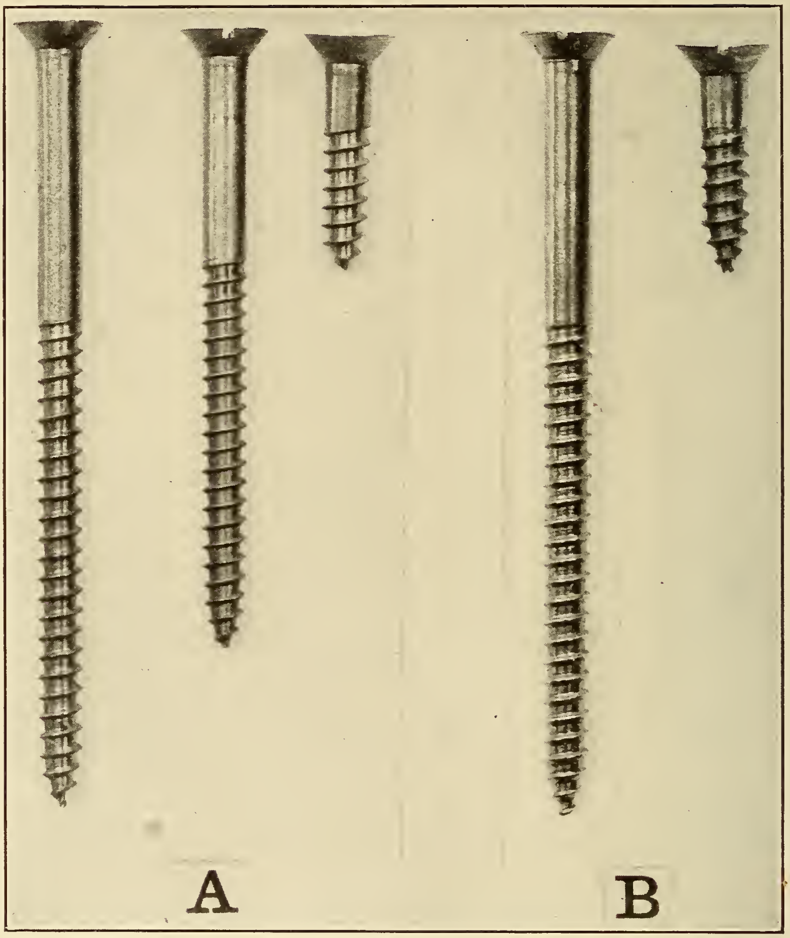

Fig. 1

Table 1

Lumber-yard designation	Forest Service identification	Timber numbers	Moisture content	Weight per cubic foot	Rate of growth (number of rings per inch)
			Per cent	Pounds	
Yellow poplar	Yellow poplar (Leriodendron tulipifera).	1-8	7.7	25	Indistinct.
Cypress	Cypress (Taxodium sp.)	9-16	12.9	26	Do.
Georgia pine	Yellow or hard pine (Pinus sp.)	17-24	7.6	39	9 to 19.
North Carolina pine.	do	25-32	8.9	38	7 to 16.
Sycamore	Sycamore (Platanus sp.)	33-40	10.3	35	Indistinct.
Hard maple	Sugar maple (Acer saccharum)	41-48	8.2	46	7 to 11.
White oak	White oak (Quercus sp.)	49-56	7.7	44	16 to 25.

The investigation of qualities of various woods which control holding power is outside the scope of this paper. Density and moisture content are undoubtedly two important factors, and these can be easily measured.

The resistance of a wood to splitting ("fissibility") is also considered by Stone [2] to be one of the most important characteristics, but no standard method of measuring this property has been developed.

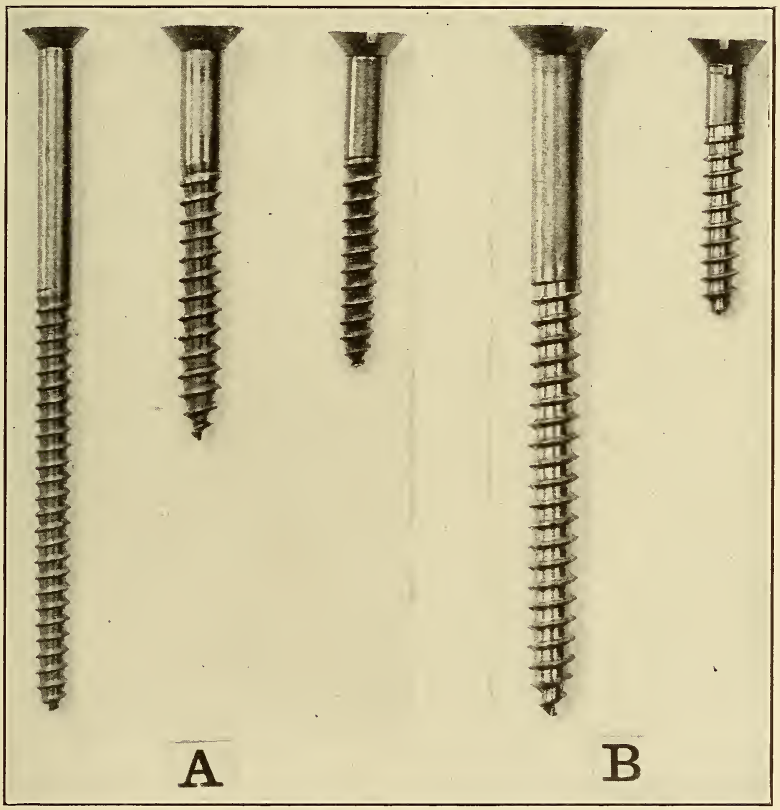

FIG. 2

3. PRESENTATION OF SCREW TO GRAIN OF WOOD

When a screw is inserted into the side of a timber normal to its surface, the axis of the screw may be (*a*) perpendicular, (*b*) tangent, or (*c*) inclined to the annular rings, depending on the way the timber was sawed from the log (see fig. 3). When inserted into the end grain, however, the axis of the screw is usually nearly parallel to the longitudinal fibers of the wood. In measuring holding power we have,

[2] Herbert Stone, A Text Book of Wood. W. Rider & Son, London; 1921.

then, to consider three presentations of the screw with respect to the side grain and one with respect to the end grain of the wood.

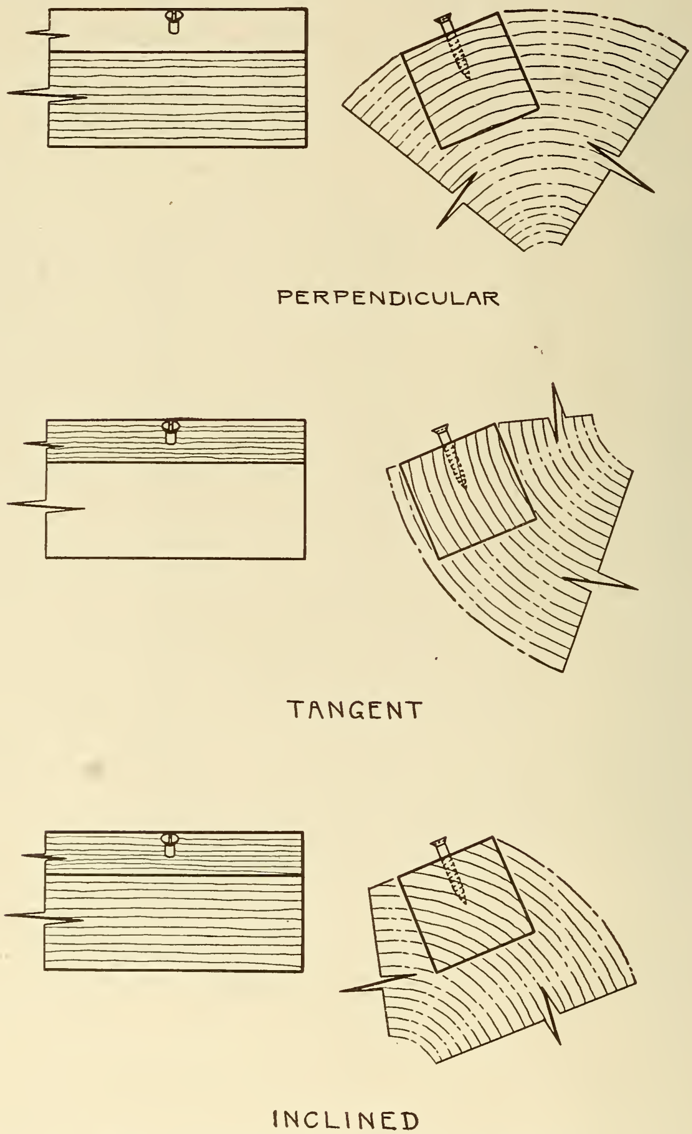

Fig. 3.—*Presentation of screw to grain of wood*

III. APPARATUS FOR TESTS

1. TESTING MACHINE

All tests were run on a 20,000-pound Olsen testing machine (Bureau of Standards No. 19918), which is provided with a second rider and counterpoise for converting the readings to a 2,000-pound maximum.

The machine with its two sets of riders was considered throughout as two separate and distinct testing machines, which are herein referred

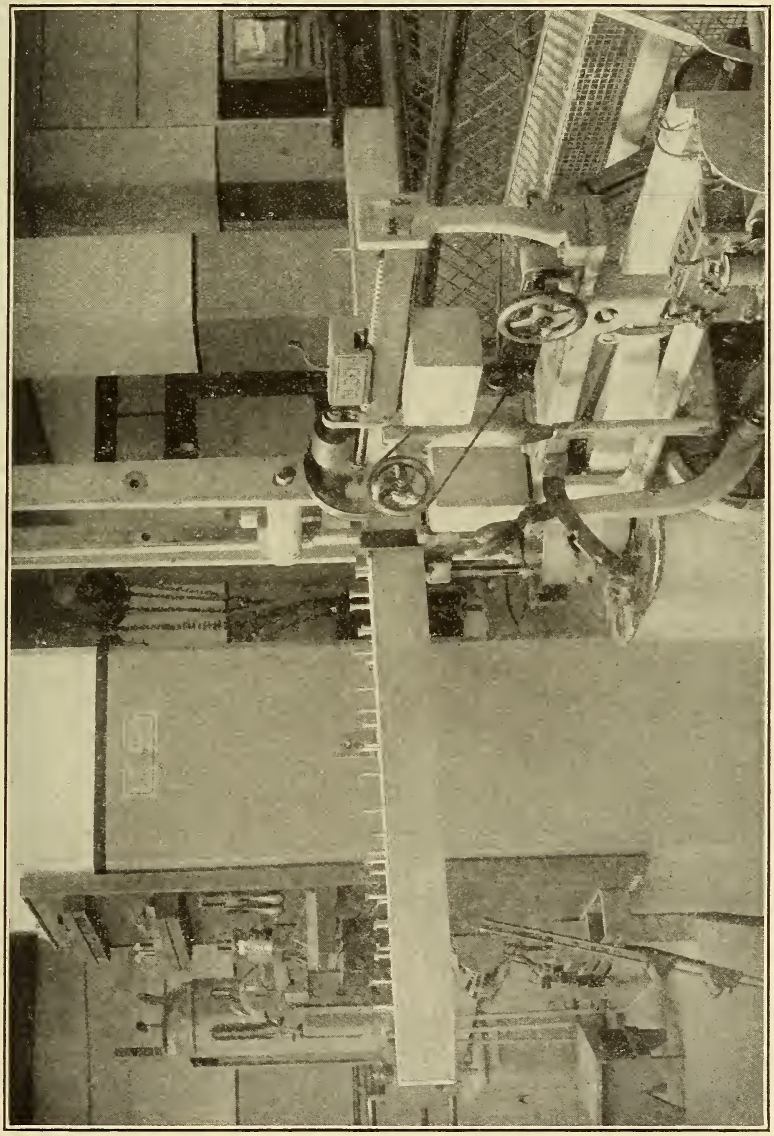

Fig. 4

to as the 2,000-pound and the 20,000-pound machines. Each machine was calibrated before beginning the tests.

2. SPECIAL EQUIPMENT

Special lugs were employed to hold the timbers and to permit the extraction of successive screws with a minimum loss of time. Figure 4 illustrates the 20,000-pound machine with a timber containing large-size screws in place for testing. Figure 5 presents a close-up of the same timber, with the upper ends of the lugs and the method

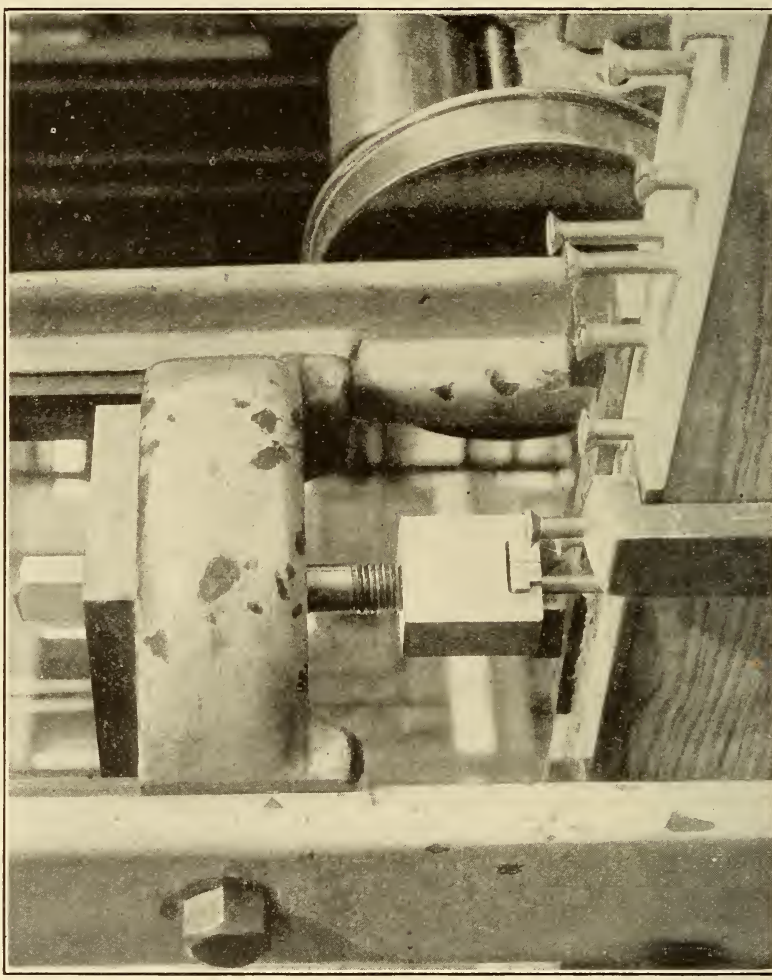

Fig. 5

of gripping the screws plainly evident. Figure 6 shows the lugs, grips, and holder with the timber removed. The grips are made in pairs to fit the T slot in the holder and to grip snugly the head of one or more sizes of wood screws. The holder with its supporting screw and block may be freely moved in a transverse horizontal direction to accommodate (within limits) the position of the screw in the timber. The timbers are also free to slide lengthwise in the lugs to bring each individual screw within the range of motion of the holder.

For the softer woods it was also necessary to use bearing plates to prevent the lugs from sinking into the wood, and thus destroy the alignment of the timber with respect to the direction of the applied force. These bearing plates may be seen in Figure 5.

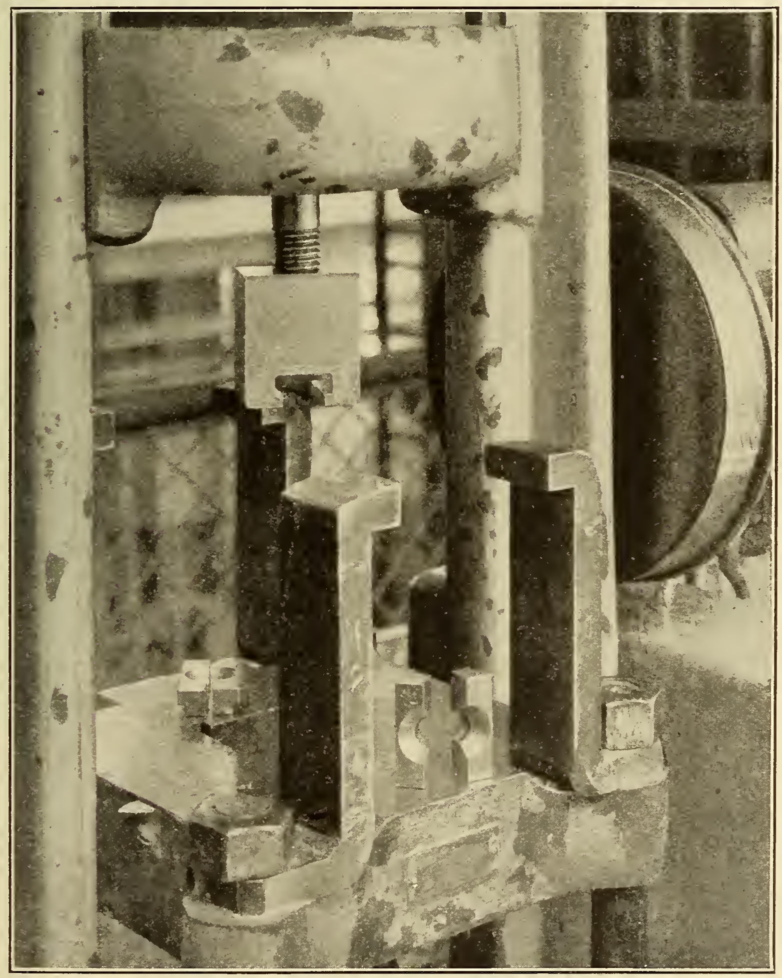

Fig. 6

IV. METHOD, RESULTS, AND DISCUSSION OF TESTS

1. LEAD-HOLE SIZE

It was first necessary to determine the most efficient size of lead hole for a given size of screw. For these preliminary tests certain popular sizes of wood screws were selected, including 1½-inch No.

10, 2-inch No. 12, 2-inch No. 14, and 2-inch No. 18. The drill sizes varied from 40 to 100 per cent of the core diameter of the screw. Readings were also taken for each size with no lead hole, the screws being forced in the required depth with a power screw driver. Ten screws were inserted for each condition of test, and the values given represent in each instance the average of 10 determinations.

All lead holes were made on a drill press to prevent the possibility of screws entering the wood in any direction other than perpendicular to the surface. It is clear that a screw inserted at an angle other

Fig. 7.—*Determination of lead-hole size in poplar*

than 90° to the surface of the wood and withdrawn by a force acting perpendicular to the surface would support a greater load than where the load is applied axially.

All screws, except the very small sizes, were inserted with special screw drivers in a drill press. This was done to expedite the work and presumably gives results comparable with insertion by a manually operated screw driver. This method makes it possible to insert screws which could not be driven by hand, such as a heavy screw in oak without a lead hole or with a small lead hole. There is, however, an inherent limit of torsional stress which the screw heads will withstand which serves to prevent the adoption of too small a lead hole. All screws were inserted to a depth of three-fourths the nominal length.

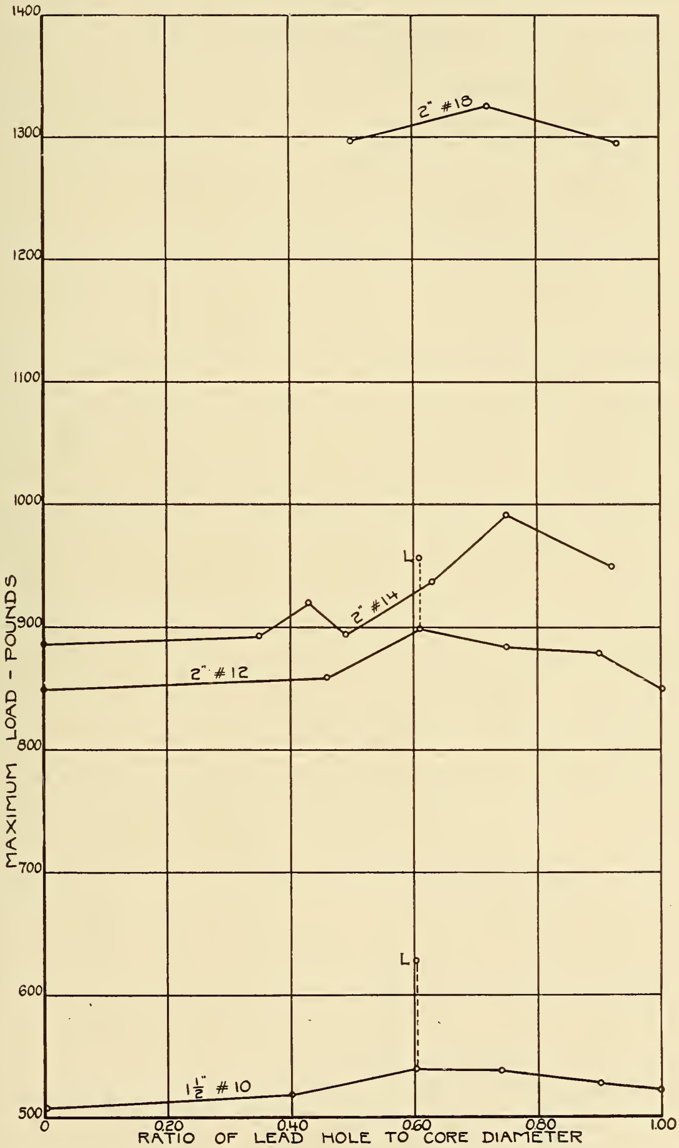

FIG. 8.—*Determination of lead-hole size in sycamore*

The effect of various lead-hole diameters on the holding power is illustrated in Figures 7, 8, and 9. In softwoods, such as poplar (see fig. 7), the maximum loads occur when the lead hole is about 50 per cent of the core diameter of the screw. A marked decrease in load occurs when the lead-hole diameter approaches the core diameter of the screw, or when no lead hole is used.

In woods of intermediate density, such as sycamore, maximum loads are obtained with a lead hole about 70 per cent of the core diameter (see fig. 8). The reduction in load due to the absence of a

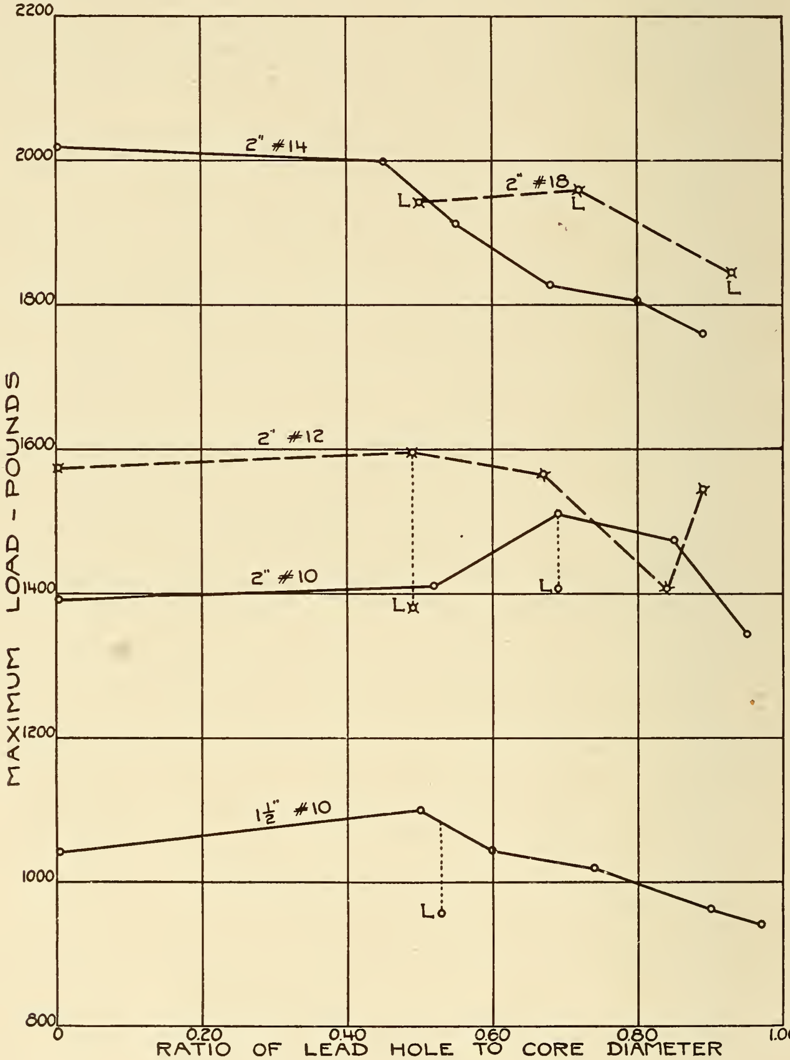

Fig. 9.—*Determination of lead-hole size in oak*

lead hole or to a lead-hole diameter equal to the core diameter of the screw is not so marked as in the case of softwoods, although a distinct difference is apparent. In the case of a hardwood, such as oak (see fig. 9), the results are somewhat erratic, due in part to occasional splitting of the wood and to the extra force required to insert screws in this material with a small lead hole. These curves are comparatively flat, however, indicating that the size of lead hole employed is not so important in the hardwoods. It is clear that a lead hole equal to the core diameter of the screw is less efficient than one equal to 80 or 90 per cent of the core diameter.

A frequent practice among carpenters and cabinetmakers is to select a lead-hole drill diameter equal to the core or root diameter of the screw. The results of the above test all indicate that this practice should be discontinued whenever anything approaching the maximum efficiency of the screw is desired. It is recognized that in certain hardwoods it is almost impossible to insert a screw with a small lead hole, say 50 to 70 per cent of the core diameter. In such cases it is recommended that a lead hole of approximately 90 per cent of the core diameter be employed, using soap or other lubricant if necessary to permit insertion of the screw.

A study of the above results and of the conditions relating to the insertion of screws led to the adoption of a lead hole of 70 per cent of the core diameter throughout the remainder of the tests, except in the case of the very hard woods, where a 90 per cent lead hole was employed for the larger sizes of screws.

Since the average factory or shop is not equipped with all available drill sizes, the standard drill size nearest to the desired diameter was used in each case.

2. LUBRICATION

A few of the tests for determination of lead-hole size were repeated under the same conditions, except that white soap was used as a lubricant. A comparison of the values thus obtained indicates the results which may be expected from the use of lubricant on screws.

In Figures 7, 8, and 9 those points marked with *L* indicate loads obtained from screws lubricated with white soap. The lead holes were drilled in the usual manner and soap applied to the screw threads by wiping the screw across the soap. In the case of 2-inch No. 12 and 2-inch No. 14 screws in poplar, the reduction in load due to lubrication was almost negligible. In the case of 1½-inch No. 10 and 2-inch No. 12 screws in sycamore, the load was appreciably increased by the use of lubricant. It is believed, however, that this increase is very largely due to further drying of the wood which occurred between the two tests, as the sycamore samples when first received were not thoroughly seasoned.

In the case of 1½-inch No. 10, 2-inch No. 10, and 2-inch No. 12 screws in oak, the reduction in load due to lubrication was more appreciable than in poplar, but was usually less than 10 per cent of the maximum load reported.

It is believed that users of wood screws need have no hesitancy in applying a lubricant to screws when necessary to facilitate insertion.

No attempt was made to determine the weakening effect, if any, of the lubricant upon the holding power of screws when withdrawal is delayed for months or years. All screws were withdrawn within one or two days after insertion.

3. SIDE GRAIN

Following the determination of the proper lead-hole size and the effect of lubrication, about 6,650 screws were inserted and withdrawn from the side grain of the seven varieties of wood mentioned above. Ten screws of each diameter and length were used in each wood in order to obtain reliable average values of holding power. Results for individual screws seldom ranged more than 5 to 10 per cent from the average values. Lead holes equal to either 70 or 90 per cent of the core diameter were drilled in each case according to the kind of wood and diameter of screw.

With the exception of the very small sizes, all screws were inserted on the drill press to a depth equal to three-fourths of the nominal length. This depth is sufficient to cover the threaded length of all screws, allows space for gripping the heads, and permits direct comparison of the results of the tests.

The average loads sustained by wood screws in the various woods are set forth in Table 2. Each figure represents the average of 10 determinations. For each length of screw the average load obtained from all diameters is computed for each wood. These general averages indicate the comparative holding power of the various woods; the lowest figure in each case is taken as the denominator of a fraction to determine the relative holding power of the woods.

The results are consistent, except in the case of sycamore. It is believed the results here given are more or less unfavorable to sycamore, since the samples used were not seasoned as thoroughly as the other woods.

In a great many instances the screws themselves failed instead of withdrawing from the wood. The failures occurred either immediately below the head or at the upper full-depth thread. Each failure was accompanied by a loud report common to the failure of tensile specimens. A summary of the failures (Table 3) indicates that the screws are well balanced for strength, 59 per cent of failures occurring under the head and 41 per cent in the thread.

TABLE 2.—*Wood screws withdrawn from the side grain of designated wood*

[Average loads (pounds)]

No. of screw	Cypress	Poplar	Sycamore	North Carolina pine	Georgia pine	Oak	Maple	Cypress	Poplar	Sycamore	North Carolina pine	Georgia pine	Oak	Maple
	Length, ¼ inch							Length, ½ inch						
0	17	------	------	------	------	------	------	------	------	------	------	------	------	------
1	19	16	24	20	67	74	88	53	75	121	99	158	133	182
2	17	15	21	13	56	30	65	59	80	120	104	170	155	193
3	18	20	43	19	62	78	89	70	94	149	116	198	177	239
4	12	------	34	19	57	36	76	76	93	154	128	198	189	280
5	------	------	------	------	------	------	------	79	100	169	133	204	220	324
6	------	------	------	------	------	------	------	84	133	211	138	245	239	360
7	------	------	------	------	------	------	------	73	112	184	148	223	192	310
8	------	------	------	------	------	------	------	76	104	166	124	194	187	285
9	------	------	------	------	------	------	------	77	114	167	153	172	227	328
10	------	------	------	------	------	------	------	92	130	189	132	233	233	275
	Length, ¾ inch							Length, 1 inch						
2	110	146	205	193	291	258	311	------	------	------	------	------	------	------
3	107	141	207	182	321	244	378	150	214	279	276	421	356	530
4	130	168	243	201	372	350	501	154	228	324	293	456	422	595
5	136	205	284	240	360	401	593	183	277	362	345	527	535	665
6	153	214	310	247	398	446	652	198	305	415	363	562	602	877
7	141	215	308	271	429	448	639	207	321	480	430	607	731	959
8	149	228	332	263	422	434	631	203	305	467	405	621	702	958
9	147	257	332	275	416	422	646	214	389	436	396	583	681	1, 025
10	179	243	336	264	417	431	674	266	426	502	405	654	713	1, 104
11	213	282	375	364	453	463	632	309	402	553	541	696	696	935
12	201	218	350	337	408	523	559	316	352	594	579	651	999	971
14	210	262	381	359	452	590	612	302	342	577	537	614	959	950
16	------	------	------	------	------	------	------	342	302	513	550	678	932	824
Average of all sizes	156	215	305	266	395	418	569	237	322	461	427	588	702	875
Ratio	1	1. 38	1. 96	1. 71	2. 53	2. 68	3. 65	1	1. 36	1. 95	1. 83	2. 49	2. 96	3. 69
	Length, 1½ inches							Length, 2 inches						
4	233	384	463	489	627	657	562	------	------	------	------	------	------	------
5	262	408	533	529	838	740	987	------	------	------	------	------	------	------
6	277	458	595	524	691	736	993	342	642	682	698	855	804	973
7	257	461	584	629	799	870	973	335	592	753	766	1, 014	1, 009	984
8	313	541	719	652	959	1, 062	1, 464	386	640	834	916	1, 205	1, 255	1, 384
9	317	628	710	688	977	944	1, 466	404	780	913	935	1, 230	1, 375	1, 733
10	398	624	783	641	1, 131	1, 102	1, 648	562	970	1, 083	1, 026	1, 613	1, 539	1, 630
11	476	653	824	863	1, 215	1, 179	1, 534	640	890	1, 032	1, 302	1, 707	1, 555	2, 161
12	483	504	877	906	1, 069	1, 540	1, 544	676	742	1, 017	1, 231	1, 775	2, 164	2, 243
14	542	650	941	1, 069	1, 277	1, 662	1, 772	677	779	1, 088	1, 256	1, 749	1, 982	2, 205
16	573	520	870	988	1, 220	1, 586	1, 395	863	775	1, 305	1, 504	1, 934	2, 512	2, 370
18	621	767	1, 049	1, 005	1, 032	1, 933	1, 721	908	1, 214	1, 388	1, 437	1, 332	2, 745	2, 549
20	567	797	942	836	813	1, 610	1, 486	913	1, 175	1, 394	1, 365	1, 492	2, 470	2, 534
Average of all sizes	409	569	761	755	973	1, 202	1, 350	610	836	1, 045	1, 131	1, 445	1, 765	1, 888
Ratio	1	1. 39	1. 86	1. 85	2. 38	2. 94	3. 3	1	1. 37	1. 71	1. 85	2. 37	2. 89	3. 1

TABLE 2.—*Wood screws withdrawn from the side grain of designated wood*—Con.

No. of screw	Cypress	Poplar	Sycamore	North Carolina pine	Georgia pine	Oak	Maple	Cypress	Poplar	Sycamore	North Carolina pine	Georgia pine	Oak	Maple
	Length, 2½ inches							Length, 3 inches						
6	433	783	678	674	772	718	939	------	------	------	------	------	------	------
7	444	821	925	1, 046	1, 147	1, 069	996	------	------	------	------	------	------	------
8	475	825	967	1, 077	1, 307	1, 523	1, 478	685	1, 078	1, 093	1, 066	1, 119	1, 060	918
9	537	1, 050	1, 076	1, 252	1, 541	1, 699	1, 891	630	1, 193	1, 241	1, 405	1, 691	1, 800	1, 756
10	659	1, 214	1, 227	1, 509	1, 972	1, 780	2, 056	841	1, 550	1, 497	1, 829	1, 849	1, 981	2, 022
11	817	1, 147	1, 198	1, 604	2, 088	1, 895	2, 335	982	1, 375	1, 351	1, 745	1, 929	1, 787	1, 835
12	753	839	1, 267	1, 774	2, 007	2, 389	2, 618	947	1, 115	1, 549	1, 942	2, 476	2, 825	2, 601
14	784	966	1, 396	1, 606	2, 193	2, 501	2, 681	999	1, 258	1, 725	2, 032	2, 806	3, 000	2, 949
16	915	943	1, 512	1, 673	2, 154	2, 541	2, 877	1, 060	1, 202	1, 795	2, 004	2, 553	3, 049	3, 319
18	969	1, 356	1, 523	1, 633	1, 710	3, 184	2, 756	1, 134	1, 405	2, 003	2, 285	2, 658	3, 285	4, 223
20	1, 079	1, 481	1, 625	1, 645	1, 899	3, 113	3, 263	1, 183	1, 563	2, 000	3, 182	2, 989	3, 723	4, 175
24	------	------	------	------	------	------	------	1, 053	1, 570	2, 085	2, 630	2, 690	2, 950	4, 866
Average of all sizes	715	1, 039	1, 218	1, 408	1, 712	2, 037	2, 172	950	1, 331	1, 634	2, 012	2, 276	2, 546	2, 866
Ratio	1	1. 45	1. 7	1. 97	2. 39	2. 85	3. 04	1	1. 4	1. 72	2. 22	2. 40	2. 68	3. 02
	Length, 4 inches							Length, 5 inches						
12	1, 306	1, 384	2, 053	2, 410	2, 617	2, 727	2, 501	------	------	------	------	------	------	------
14	1, 306	1, 512	2, 143	2, 481	2, 693	2, 843	2, 769	1, 758	2, 128	2, 508	2, 522	2, 640	2, 537	2, 632
16	1, 398	1, 633	2, 257	2, 815	3, 034	3, 338	3, 194	1, 690	2, 086	2, 636	2, 711	2, 827	2, 771	3, 104
18	1, 558	1, 968	2, 597	3, 235	3, 610	3, 855	3, 965	1, 915	2, 379	2, 811	3, 421	3, 854	4, 019	3, 948
20	1, 556	2, 116	2, 497	4, 201	3, 860	4, 523	4, 588	1, 829	2, 400	2, 569	3, 964	4, 037	4, 134	4, 219
24	1, 428	2, 007	2, 845	3, 972	3, 584	3, 818	6, 466	2, 172	2, 922	3, 975	4, 563	4, 992	5, 539	5, 506
Average of all sizes	1, 425	1, 770	2, 399	3, 185	3. 233	3, 517	3, 914	1, 873	2, 383	2, 900	3, 436	3, 670	3, 800	3, 882
Ratio	1	1. 24	1. 68	2. 24	2. 27	2. 47	2. 75	1	1. 27	1. 55	1. 83	1. 96	2. 03	2. 07

TABLE 3.—*Screw failures*

Kind of wood	Number of screw failures			Percentage of total failures (all woods)	Order of strength
	At head	At thread	Total		
Poplar	16	1	17	1. 5	2
Cypress	2	0	2	. 2	1
Georgia pine	135	75	210	19. 0	5
North Carolina pine	69	47	116	10. 5	4
Sycamore	44	11	55	5. 0	3
Hard maple	227	205	432	39. 1	7
White oak	160	112	272	24. 6	6
Total failures	653	451	1, 104	----------	----------
Per cent	59	41	100	----------	----------

The failures in the head were frequently due to an excessive depth of slot or to undercutting beneath the head. The table of screw failures may also be used as a guide to the holding strength of the various woods by comparing the total number of failures in each. This comparison gives the same relative order of strength as is shown by Table 2, and would, therefore, seem to offer a certain amount of corroboration.

The average results are also shown graphically in Figures 10, 11, 12, 13, 14, 15, and 16. The ordinates are screw diameters with an additional scale to show screw numbers, while the loads are taken as abscissas. Points indicating screws of the same length are connected to form curves.

Fig. 10.—*Cypress, side grain*

These curves have a peculiar shape, which at first thought is somewhat puzzling, since they show that a screw of a given diameter may have a holding power equal to or even greater than one of the same length but of larger diameter. This peculiarity may be attributed to at least two causes—first, the larger-diameter screw has coarser threads, and second, it has a longer point, both of which tend to reduce materially the number of effective threads as well as the number of perfect threads.

The results of this analysis may be stated briefly as follows: For a given length of screw, axially loaded, the holding power increases with the diameter up to a certain limit, beyond which an increase in diameter results in a decrease in holding power. Many standard-size screws lie beyond this dividing line.

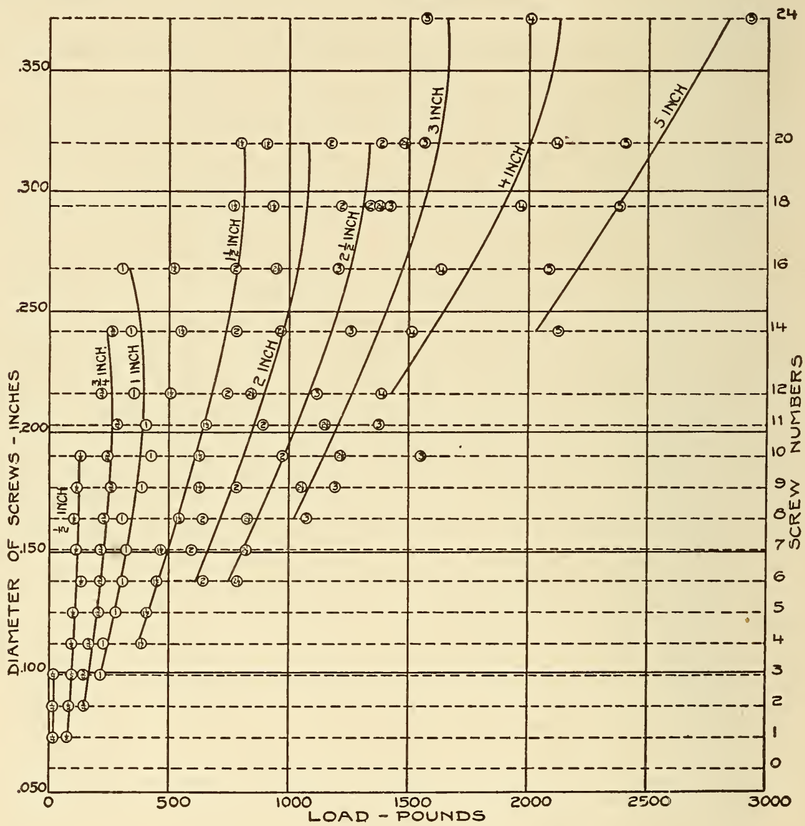

FIG. 11.—*Yellow poplar, side grain*

The phenomenon is apparently confined to screws 3 inches and under in length, but no doubt would also be found in longer lengths if the range of diameters were extended sufficiently. It would, therefore, appear that for a service requiring a given length of screw, 3 inches or less, the largest standard diameters should be avoided except where the screws are in shear or where the size of the head governs the selection.

Another peculiarity indicated by the data is confined to the denser woods. In Figure 14 it will be noted that several points near the lower end of the curves, particularly for 3 and 4 inch screws, have been disregarded in determining the location or direction of the curves. The curve for 5-inch lengths has been omitted in Figures 13, 14, 15, and 16, since lengths shorter than this seem to develop the maximum holding power in these woods. The data indicate that for a given diameter of screw the maximum holding power is obtained

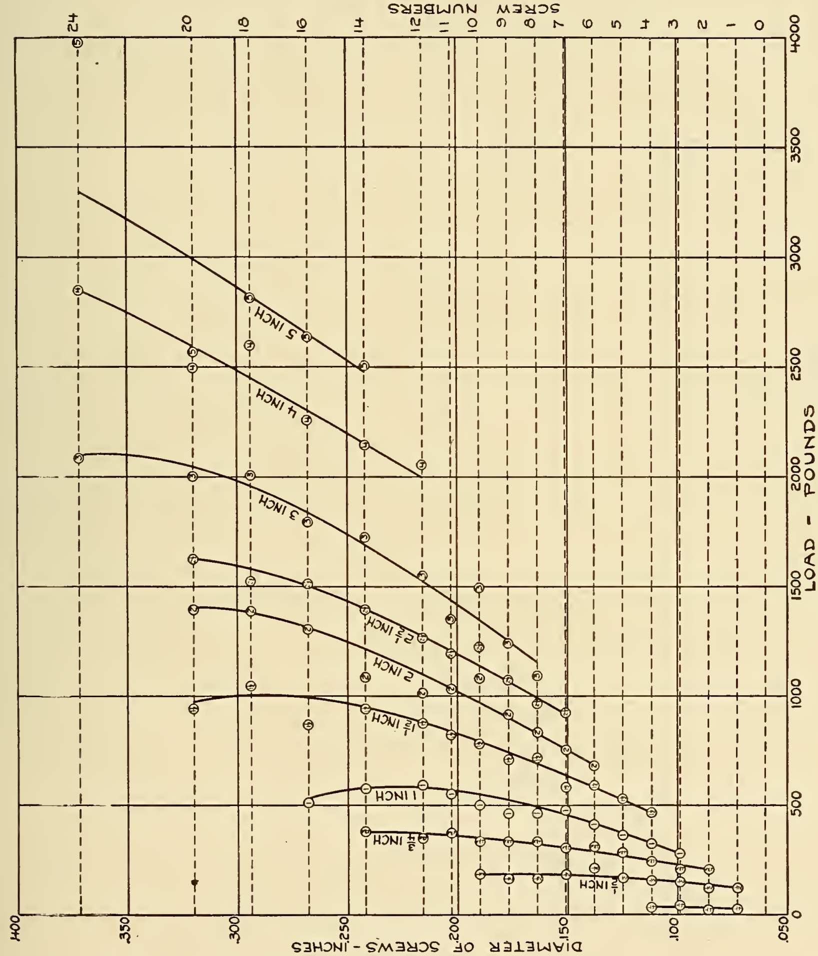

Fig. 12.—*Sycamore, side grain*

with a certain length, and that beyond this point additional length does not result in increased holding power. It does not follow, however, that this additional length has no value, since it is frequently required in securing thick members where only a portion of the threaded length is effective.

There are a number of standard screws whose length exceeds that corresponding to maximum efficiency for axial loading in the denser woods, and therefore care should be exercised in the selection of long screws to avoid a waste of material.

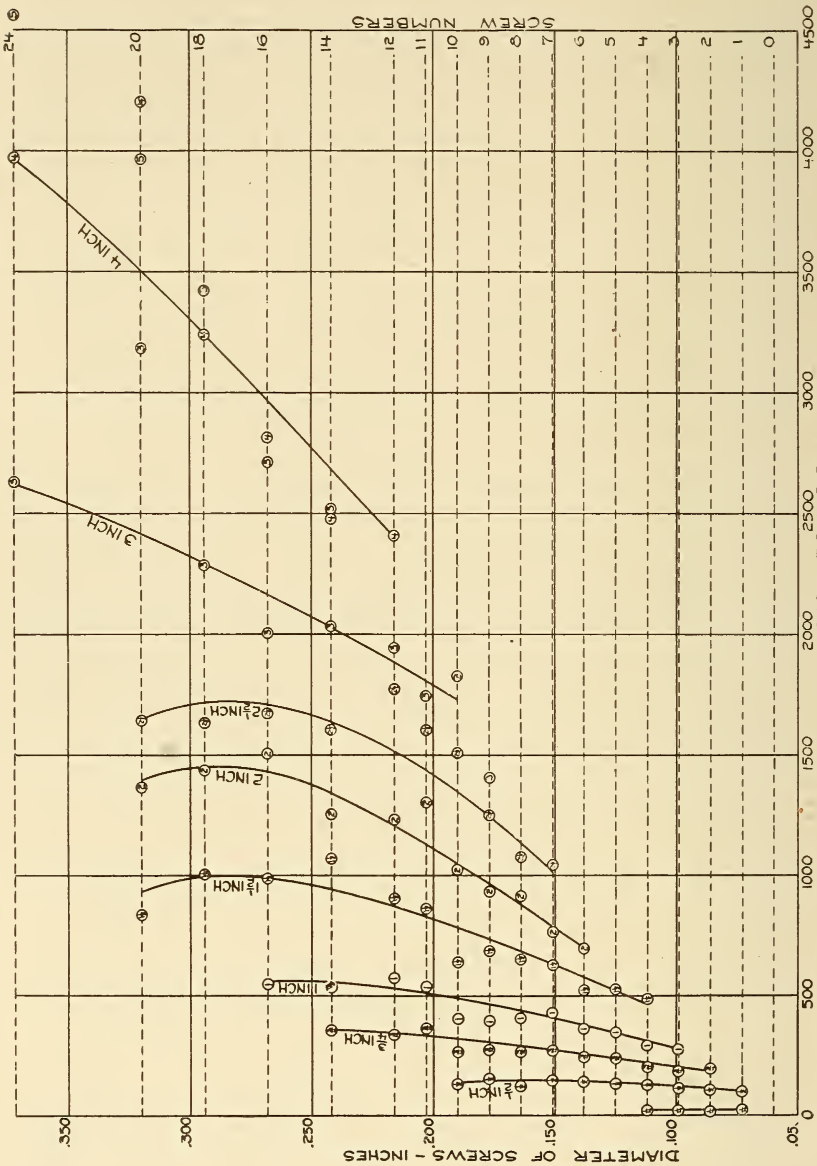

Fig. 13.—*North Carolina pine, side grain*

The effect of the various presentations of the screw to the grain (fig. 3) could not be separated sufficiently from other variables to warrant any definite conclusions. The tests seem to indicate that when the screw axis is perpendicular to the annular rings the holding strength is somewhat greater than when the screw is tangent to the annular rings, and that an inclined presentation gives an intermediate value.

The effect of cracks already present or started by the screw is not quantitatively shown by the tests, but results indicate that even a

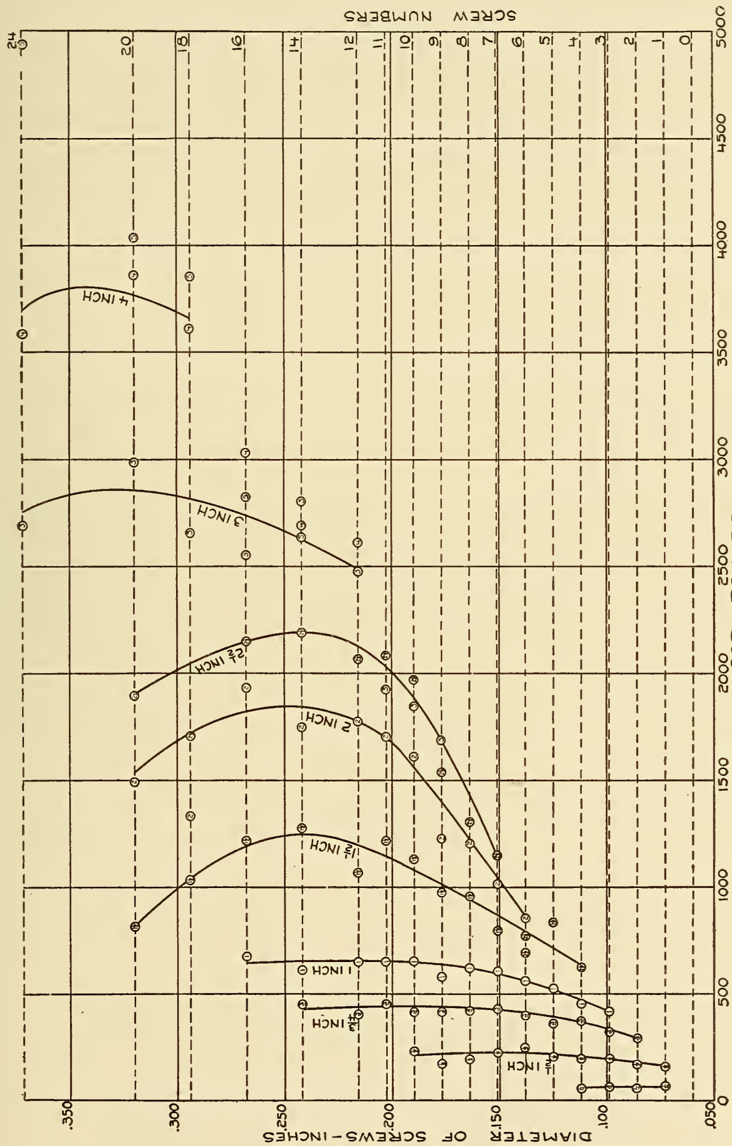

Fig. 14.—*Georgia pine, side grain*

slight crack reduces the holding power to a marked extent, usually from 10 to 25 per cent.

In general, according to our observation, most furniture, boxes, and other articles manufactured from wood fail, if at all, at the

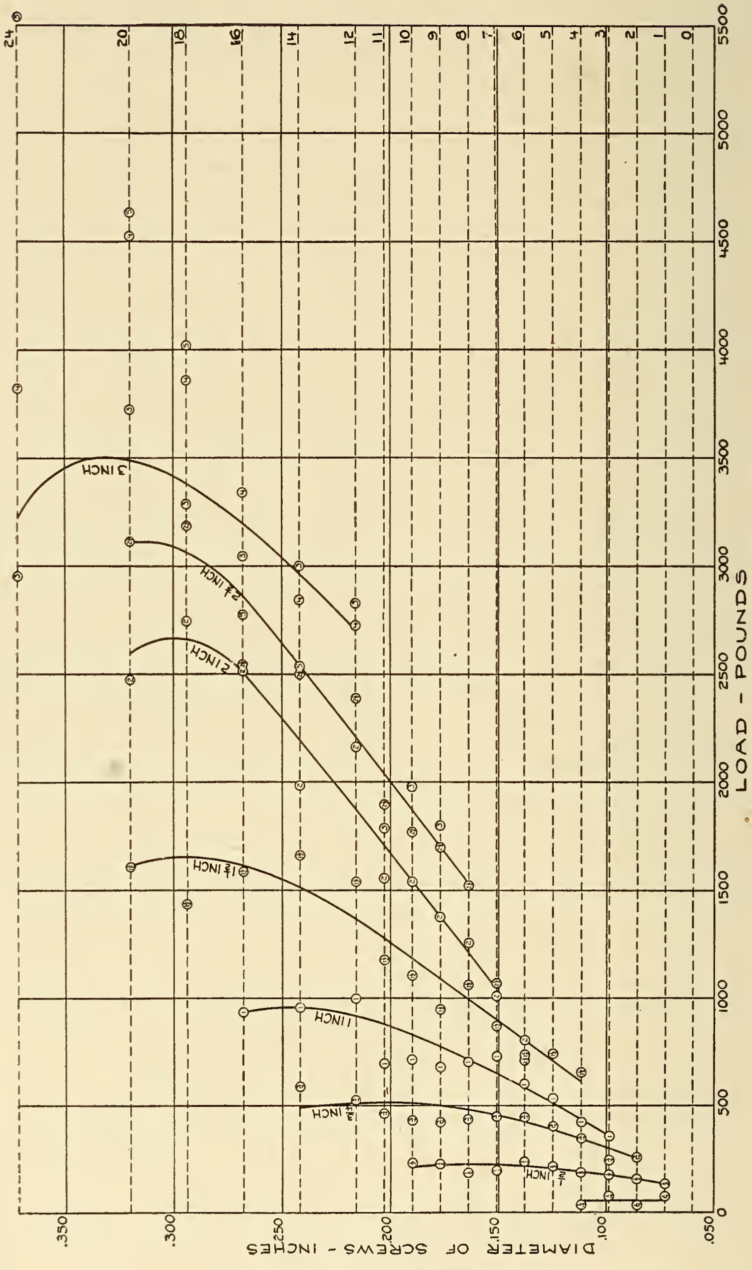

Fig. 15.—*White oak, side grain*

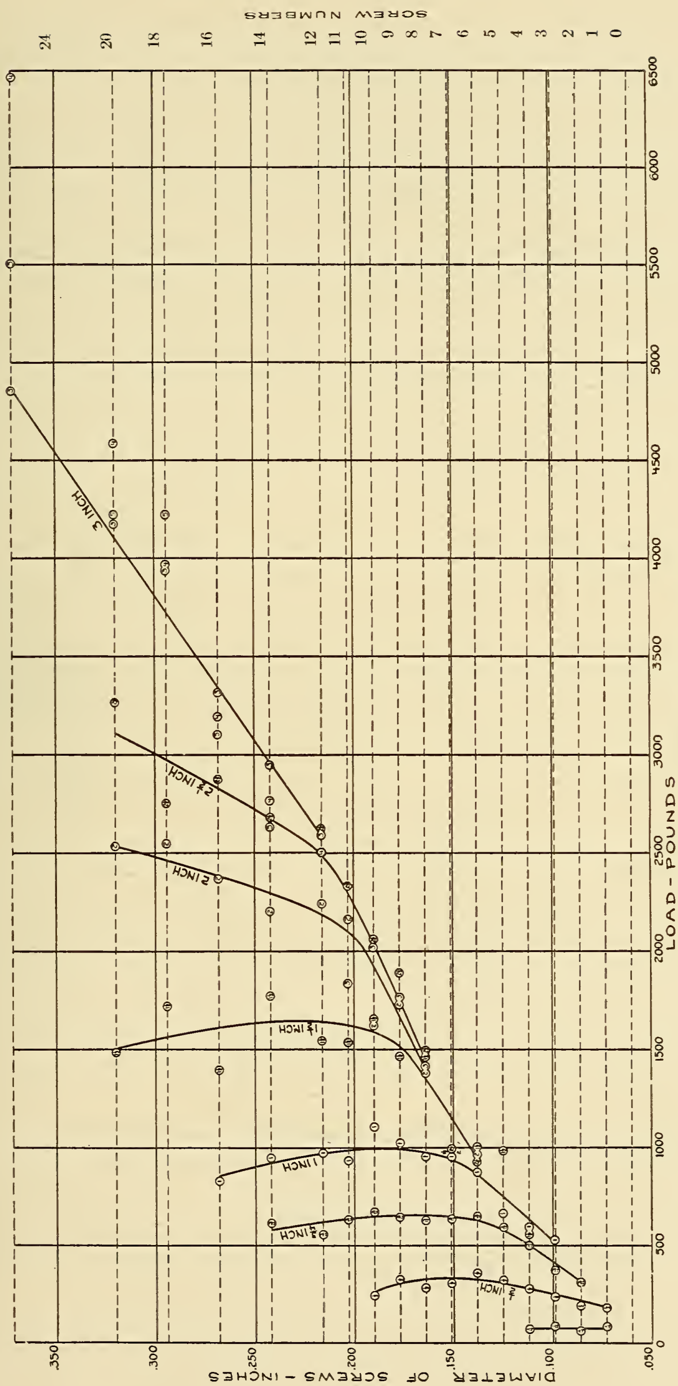

Fig. 16.—*Hard maple, side grain*

joints. With the aid of the data here presented it would seem entirely practicable under certain conditions to select a size and quantity of wood screws to produce a joint of equal or greater strength than the adjacent wood. If the ultimate strength of the steel used in screws is assumed to be 50,000 lbs. per sq. in. and the wood is assumed in shear with the grain with a corresponding ultimate strength when green of from 561 to 1,990 lbs. per sq. in (strength when dry 50 per cent. greater),[3] it can easily be shown that the total cross-sectional area of screws should be from 1/89 to 1/25 of the cross-sectional area of the wood supported, provided that conditions permit the use of screws of such length as to develop the full strength of the metal.

For example, a Georgia pine board 3/4 inch thick and 5 feet long, with corresponding sectional area of 45 square inches in shear with the grain, would require eighteen 3-inch No. 12 screws (see fig. 17).

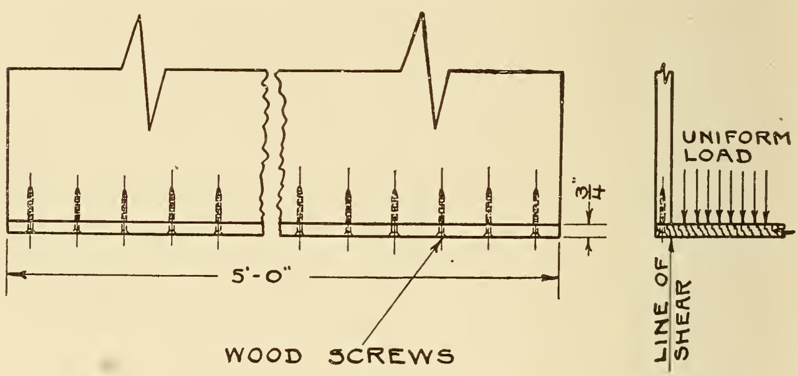

Fig. 17

If conditions prohibit a 3-inch length, then thirty two 2-inch No. 12 or sixty-nine 1½-inch No. 12 may be substituted, provided splitting of the wood can be avoided. It should be noted that since the board is 3/4 inch thick the holding power of a 1½-inch screw is reduced to the equivalent of a 1-inch screw, and that of a 2 inch screw should be interpolated between a 1½-inch and 2-inch screw (fig. 14) to allow for the reduced length of thread in the wood.

The above example would require a spacing between screws of 3.33 inches, 1.875 inches, or 0.87 inch, respectively, according to the size of screws used, for an admittedly weak condition of the wood. For other conditions of stress in the wood the number of screws should be increased according to the ratios of ultimate strength of the wood, provided that splitting can be avoided.

In view of the rapidly increasing value of wood and the attendant necessity for greater conservation in contrast to the low cost of wood screws, it is believed that the use of a much greater number of wood

[3] H. S. Betts, Timber, McGraw Hill, New York; 1919.

screws for a given joint than is now common practice is both warranted and advisable.

4. END GRAIN

After completing the side-grain tests additional timbers were cut into 3¾-inch lengths with a machine saw to insure proper alignment of the surfaces. Five screws of each size were used for each end-grain condition, but not necessarily in the same block, as in many instances not more than two screws could be inserted in a given block without having a tendency to split the wood. No effort was made to determine the limiting conditions for splitting the wood, although record was kept of all instances where splitting occurred.

The average loads sustained by screws in the end grain are given in Table 4. The end-grain condition seems to produce more erratic results than any of the side-grain conditions. It is believed this is due largely to the tendency of the screw to split the wood. Owing to the rather irregular results obtained from the end grain, no curves are given for this condition.

TABLE 4.—*Wood screws withdrawn from the end grain of designated wood*

[Average loads (pounds)]

Number of screw	Cypress	Georgia pine	Oak	Maple	Cypress	Georgia pine	Oak	Maple	Cypress	Cypress	Georgia pine	Oak	Maple
	Length, 1½ inches				Length, 2 inches				Length, 2½ inches	Length, 3 inches			
8					348	845	851	1,089		699	1,114	949	890
10	343	823	816	1,165						700	1,724	1,777	1,937
12					501	1,469	1,257	1,881					
16						1,554	1,744	2,480					
20						1,611	1,675	2,444	1,006				
	Length, 4 inches				Length, 5 inches								
12	861	2,112	2,095	2,376									
16					1,425	2,724	2,538	2,697					
18					987								
20					1,336	3,520	2,439	3,866					
24					1,523								

A rather interesting feature of the tests is illustrated in Figure 18. It shows two typical screws after withdrawal from the end grain of cypress, with the wood fibers adhering tenaciously to the threads. These fibers appear to have been severed by the threads during insertion of the screw and then torn from the adjacent uncut fibers upon withdrawal.

The ratios of holding power in the end grain to that in the side grain are given in Table 5. The tests indicate that these ratios vary from 52 to 108 per cent, and that it is not too much to expect the end-grain condition to sustain on the average about 75 per cent of the safe-load value for the side grain. This ratio agrees with that given by Works (3) for white pine.

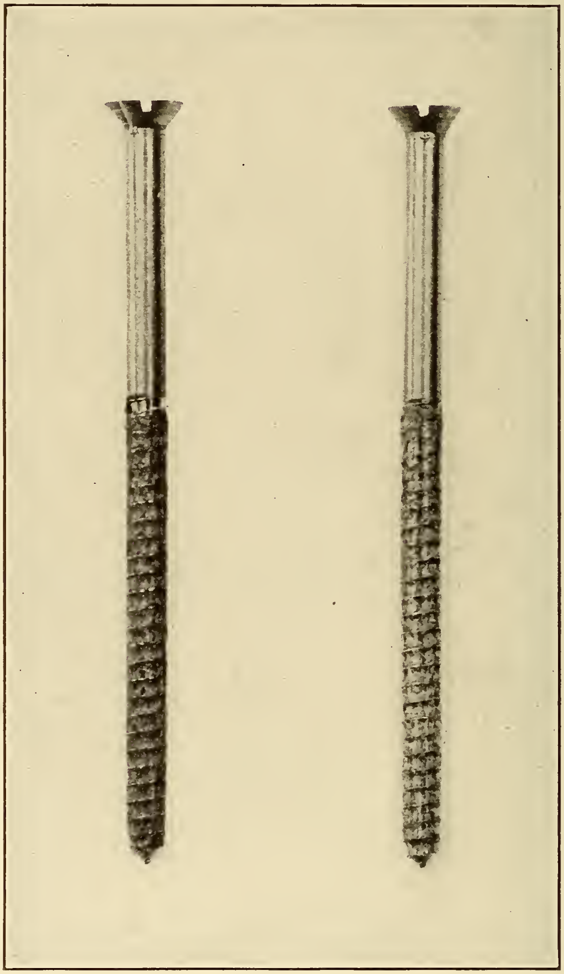

Fig. 18.

5. SCREW DESIGN

No screws failed by shearing or other deformation of the threads. This indicates that manufacturers need have no fear of making the threads thin and sharp, particularly as this seems to increase the holding power.

Screws having a thread surface of rough texture appear to have a greater holding power than those which are highly polished. It follows, therefore, that a high polish is unnecessary and is a source of avoidable waste, if not altogether inadvisable.

TABLE 5.—*Ratio of holding power of wood screws, end grain over side grain*

Kind of wood	Ratio, $\frac{\text{end grain}}{\text{side grain}}$ (all sizes)		
	Maximum	Minimum	Average
	Per cent	*Per cent*	*Per cent*
Cypress	102	52	79
Georgia pine	108	70	87
Hard maple	105	71	90
White oak	92	58	75

Many screws failed by the two halves of the head breaking into the slot. In each case this seemed to be caused by an excessive depth of slot. It is suggested that the depth of slot be controlled within rather narrow limits, preferably with no depth of slot greater than half the height of the head.

In general, the screws seem to be very well designed, and it is quite remarkable that the weak sections were so evenly divided between the upper end of the thread and the bottom of the head, particularly in consideration of the number of manufacturers represented.

V. GENERAL SUMMARY

Tensional tests on over 10,000 wood screws in seven kinds of wood indicate the following general summary of conditions conclusively contributing toward maximum holding power:

1. LEAD HOLE

(*a*) In softwoods the size of the lead hole is important and should be about 70 per cent of the core or root diameter of the screw.

(*b*) In hardwoods the lead hole should be about 90 per cent of the core diameter of the screw.

2. LUBRICATION

A lubricant, such as soap, may be used where necessary for easy insertion without any great loss in holding power.

3. HOLDING POWER

(*a*) For the ultimate holding power of a given size of screw in a given wood refer to Tables 2 and 4 or Figures 10 to 16, inclusive. In choosing between two adequate screws, use the smaller diameter and longer length when practicable.

(*b*) For a given length of screw, axially loaded, the holding power increases with the diameter to a certain limit, beyond which an increase in diameter decreases the holding power.

(*c*) For a given diameter of screw, axially loaded, the holding power increases with the length to the limit in hardwoods, where the metal of the screw fails in tension.

4. QUANTITY OF SCREWS

In the design of wood joints a sufficient number of screws should be used to make the fastening as strong as the wood where splitting of the wood does not prevent.

5. END GRAIN

Where splitting can be avoided, the end grain should support about 75 per cent of the safe load computed for the side grain under similar conditions.

6. SCREW DETAILS

Where holding power is unusually important, select wood screws with thin, sharp threads; rough unpolished surface; full diameter under head, and with shallow slots.

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WASHINGTON, December 31, 1925.