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Canadian Society of Civil Engineers.

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ADVANCE PROOF—(*Subject to revision*).

HOLDING POWER OF WOOD SCREWS,

BY

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(To be read Thursday, April 27th, 1899.)

Engineering records, as far as the authors can ascertain, contain only two accounts of experiments having any reference to this subject. In 1874-77 the U. S. military engineers made experiments on drift bolts, and incidentally compared them with wood screws (*Eng. News.*, Feb., 1891), and in 1897 Prof. Martens, of Germany, experimented on the variation of the strength of wood screws in order to find out the most efficient shape of thread and depth of cutting. No effort in either case was made to establish any relation between the strength developed and the size of screw when driven in different sized holes in different woods, both parallel to and across the grain of the wood. This, it is the object of these tests to determine in some small degree.

SCREWS.—317 tests were made. The screws tested were $\frac{3}{8}''$, $\frac{1}{2}''$, $\frac{5}{8}''$ and $\frac{3}{4}''$, and may be taken as representative types of each size ordinarily used in practice.

WOODS.—The woods on which the experiments were made were Red Pine and White Oak, representative respectively of the soft and hard woods. Both were carefully selected, well-seasoned, free from knots and shakes, and of as homogeneous a structure as could be obtained. In order to obtain results that could be legitimately compared, the pieces used were in each case cut out of one large stick and were about 6″ x 6″ by 8′ long. They were so dressed that the grain of the wood was parallel and at right angles to the faces.

BORING.—The boring was accomplished by means of a feed drill driven by an electric motor. The holes were bored first on one face parallel to the grain, the screws driven and immediately drawn. Then intermediate to these holes on one of the contiguous faces the same screws were driven, that is at right angles to the grain of the wood. The holes were spaced $3\frac{1}{2}''$ centres for the small $\frac{3}{8}''$ screws, and as much as $7''$ centres for the $\frac{3}{4}''$ screws and staggered $2''$ in all cases. In case the drawing of one screw would develop cracks along the wood, this arrangement of the holes would eliminate any danger of injury to the next screw drawn, as it gave a distance of $7''$ in the one case and $14''$ in the other along the line of least resistance between the consecutive screws. This gave ample space between, as only in a few cases did any indication of splitting occur. When driven across the grain the layers of wood at the surface were lifted up slightly, but only after the maximum load had been reached, and consequently did not affect the final result and the conclusions deduced therefrom.

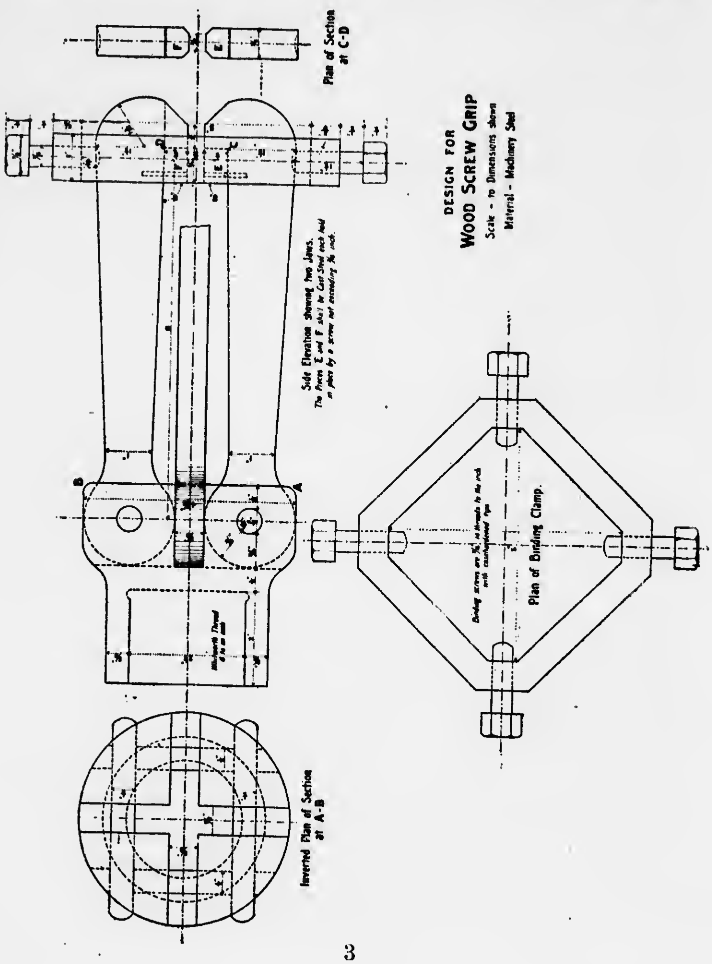
The size of holes into which the screws were driven was as given in the following table :—

Size of Screw in inches.	Min. Diam. in inches.	Size of Hole in inches.	No. Threads per in.
$\frac{3}{8}$	$\frac{13}{48}$	$\frac{1}{4}$ and $\frac{5}{16}$	8
$\frac{1}{2}$	$\frac{25}{64}$	$\frac{3}{8}$ and $\frac{7}{16}$	6
$\frac{5}{8}$	$\frac{31}{64}$	$\frac{1}{2}$ and $\frac{9}{16}$	6
$\frac{3}{4}$	$\frac{35}{64}$	$\frac{9}{16}$ and $\frac{5}{8}$	4

The smallest holes were of the same diameter as the minimum diameter of the screw, and the others were 1-16″ larger or 1-16″ smaller than the stem of the screw. These were the only sizes of holes used. It yet remains to determine what is the best size of hole to use to give the greatest strength with the least amount of work done in driving the screw.

Driving.—At first a few of the screws were driven by hand, but it was difficult to apply just enough pressure to prevent the fibres of the wood from lifting caused by the resistance to entrance of the screw. This method therefore was abandoned, and all the rest were machine driven, applying just sufficient pressure to maintain on entrance a uniform feed as determined by the pitch of the thread of the screw. For the smaller sizes, viz.: $\frac{3}{8}''$ and $\frac{1}{2}''$ screws, the same feed drill was used for driving as for boring the holes, a special clutch having been designed and constructed to receive and hold the heads; but the larger sizes, $\frac{5}{8}''$ and $\frac{3}{4}''$, offered too great a resistance to entrance to be driven in this way. A torsion machine was therefore fitted up with higher speed pulleys, and though somewhat slower served the purpose very well.

Drawing the Screws.—The Emery Hydraulic Testing machine was used to draw the screws. It was found necessary to design a



special grip for the purpose. The design was based on the strength required to withstand a tensile stress equal to that necessary to break the largest size of screw tested, viz.: $\frac{3}{4}''$, and the bending moments set up in the jaws due to this strain, and also to be easily adjustable to the different sizes tested.

Allowing 50,000 lbs. as the tensile strength of wrought iron, there would be required in the jaws a strength sufficient to withstand a strain of 22,000 lbs. absolute, the minimum diameter of the $\frac{3}{4}''$ screw being 9-16''.

The jaws were designed to have a factor of safety of 5' and consisted of a hollow cylindrical head of machinery steel cut internally with Whitworth thread (6 to the inch) and 3'' deep, with a solid base slotted at right angles to receive the heads of the four jaws. The jaws were tight fitting, and hung on $\frac{1}{2}''$ turned pins, 10'' in length and $\frac{5}{8}$ sq. in. smallest sectional area, and had case hardened blocks, fastened by a screw, to resist abrasion. The clamp that held the jaws firmly in the head of the screw was of the same material, machine steel. They, with 4 set screws, with case hardened tips resting in cup-shaped depressions in the jaws, as near as may be in the plane of the point of application of the force exerted on the screw head. This was to eliminate as far as possible the effect of bending in the jaws that would otherwise be great.

In applying the force necessary to draw the screw, care was taken to observe a uniform rate of loading so that each screw would be drawn in as nearly as possible the same length of time. This was done by attaching to the valve of the machine a pointer so that the fluid was allowed to flow uniformly in all cases. But, owing to the want of perfect uniformity in the structure of the wood, it was impossible to so regulate the feed that each screw would be drawn in the same time. To determine what effect, if any, this difference of time had upon the maximum load, experiments were made, the results of which are given in Table II.

Table I.—Summary and remarks.

1. When driven across the grain the *strength developed varied as the depth driven, i.e.*, depth of thread in wood. In no case were the screws driven deeper than the length of thread. Otherwise the friction between the stem of the screw and the wood would affect the maximum load, and the effect of a drift bolt would be added to the effect of the thread of the screw.

Thus taking 960 as the unit theoretical load :—

Ratio	=	1	2	3
Theoretical load	=	960	1920	2880
Actual load	=	960	1970	2940
Difference	=	0	50	60
Per cent of difference	=	0%	2.5%	2%

The first two results given - 600 and 740—are the results of hand-driven screws where insufficient pressure had been applied to prevent the wood from lifting, thus reducing the strength from a theoretical maximum of 930 lbs. to an actual load of 740 lbs., a difference of 190 lbs., or a loss of 24%.

Thus taking 930 as the unit theoretical load :

Ratio	=	1	2	3
Theoretical load	=	930	1860	2790
Actual load	=	740	1870	2744
Difference	=	190	10	46
% of difference	=	24 % loss	.6 % gain	1.7 % loss

This serves to show the extreme importance of the exercise of care in driving the screws, especially where the depth is not great.

Table II.—In the first division of the table the rate of loading varied between 21 seconds and 130 seconds, and the greatest deviations from the mean load were :

— 350 and + 200

and the least were : — 20 and + 10.

In the second division of the Table with a practically uniform rate of loading varying between 15 seconds and 18 seconds the greatest deviations from the mean load were :

— 246 and + 354

and the least were : — 16 and + 54.

Throughout the tests the rate of loading did not vary more than from 10 to 25 seconds, and the above shows that a variation of as great as 109 seconds did not appreciably affect the maximum loads. So that within the limits possible, which are small, the time does not at all affect the results given.

Table III.—1. In Pine, screws in the *smaller hole* gave from 2% to 14% greater maximum strength than the same screws in the *larger* sized hole.

2. In Oak, screws in the *larger hole* gave from 4% to 15% greater maximum strength than the same screws in the *smaller* sized holes.

3. In Pine, screws driven *parallel* to the grain developed 3% to 28% greater strength than those driven *across* the grain.

4. In Oak, screws driven *across* the grain developed 3% to 16% greater strength than when driven *parallel* to the grain.

5. *The strength developed varies as the circumferences of the screws and hence as the diameters*, the length of thread being the same. Thus taking 2688 as the unit theoretical load:

Size of screw..............	=	$\frac{3}{8}''$	$\frac{1}{2}''$	$\frac{5}{8}''$	$\frac{3}{4}''$
Ratio of diameters........	=	3	4	5	6
Loads	=	2688	3890	4520	5430
Theoretical loads..........	=	2688	3584	4480	5376
Error..............................		00	306	40	54
Per cent. of error		0%	8%	.9	.9%

This ratio is a simple one, and agrees well with the results of our tests. The strength developed appears to be independent of the number of threads per inch. The finer the pitch of the thread of the screw the more bearing area will it have, but there is then the danger of injuring the fibres of the wood to such an extent as to vitiate the benefits of the larger bearing area.

6. All but two of the $\frac{3}{8}''$ screws driven in oak failed in tension at an average load of 55,000 lbs. per sq. in.

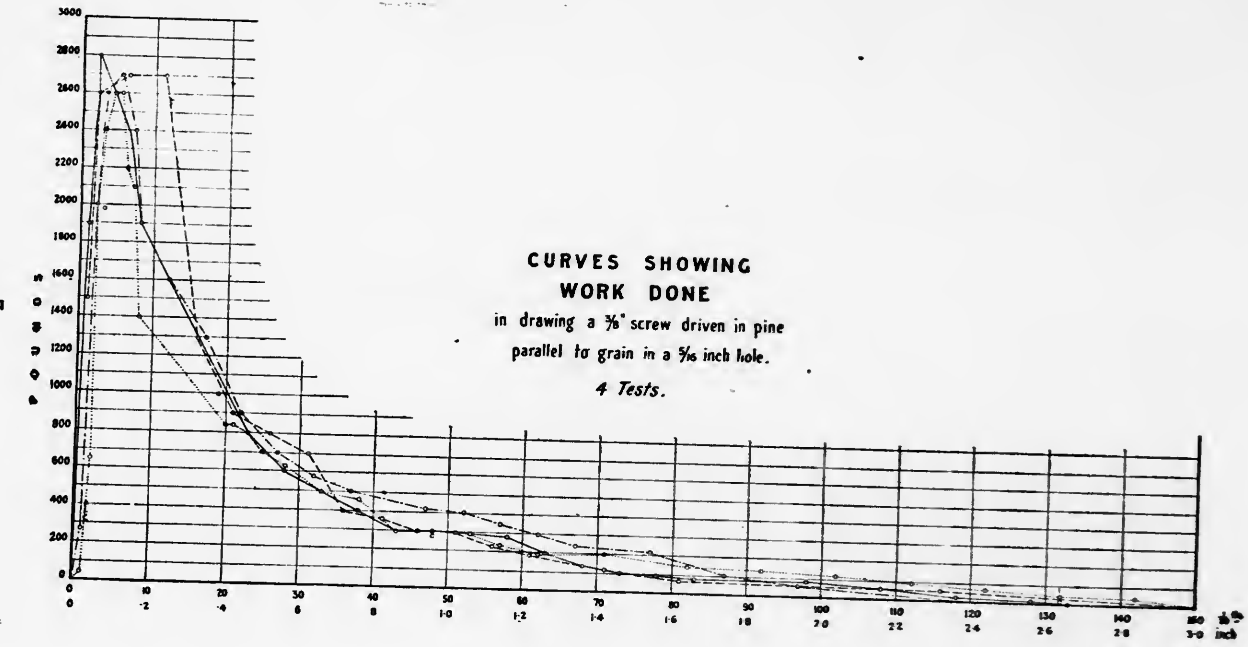
Table IV. gives in compact form the absolute maximum loads borne by each size of screw: (*a*) driven in oak, (*b*) driven in pine, both parallel and across the grain.

The last column gives the absolute load per inch of thread.

Curves.—A sheet of curves is also given showing the work done on a $\frac{3}{8}''$ screw driven 3″ parallel to the grain in Red Pine. The area of the average curve computed by the method of average ordinates gives:

Work done.................................... = 1400 ft. lbs.

When driven across the grain the work done would be much greater, because the maximum load was, in almost all cases, maintained for quite an appreciable distance of travel of the screw, although, as was the case with Pine, the maximum load was not as great as when driven parallel to the grain. This is doubtless due to the greater elasticity and lesser rigidity of the fibres transversely than when edgewise to the action of the load. The curve would then at the maximum load show an almost horizontal line somewhat similar to that shown in dotted *black*, only more marked, and would, moreover, fall away less abruptly than those shown on the sheet, thus enclosing a much greater area and hence a greater amount of work done.



CURVES SHOWING WORK DONE

in drawing a 3/8" screw driven in pine parallel to grain in a 5/16 inch hole.

4 Tests.

COMPARISON OF STRENGTH DEVELOPED BY A ⅜" SCREW DRIVEN TO DIFFERENT DEPTHS, VIZ., 1", 2" and 3".

Mean of x Tests.	Size of Hole.	Depth Driven.	Kind of Wood.	Direction of Grain.	Maximum Load.	Remarks.
5	¼"	1"	Red Pine	Parallel	600	
5	5/16"	1"	do	do	740	
6	5/16"	1"	do	Across	940	
6	¼"	1"	do	do	960	
5	5/16"	2"	do	Parallel	1870	
5	¼"	2"	do	do	2010	
8	¼"	2"	do	Across	1970	
8	5/16"	2"	do	do	1760	
8	¼"	3"	do	Parallel	2870	
8	5/16"	3"	do	do	2744	
8	¼"	3"	do	Across	2940	
8	5/16"	3"	do	do	2845	

TABLE II—COMPARISON OF STRENGTH DEVELOPED WITH RATE OF LOADING.

Size of Screw.	Size of Hole.	Time to Max. Load.	Depth Driven.	Mean of 12 Tests.	Maximum Load.	Deviation from Mean.	Remarks.
½"	7/16	0′ 21"	3"	3850	3810	− 40	
		28"			3860	+ 10	
		28"			3500	− 350	
		31"			3700	− 150	
		40"			4000	+ 150	
		55"			3900	+ 50	
		1′ 05"			4050	+ 200	
		1′ 14"			3980	+ 130	
		1′ 17"			3760	− 90	
		1′ 37"			3960	+ 110	
		2′ 00"			3830	− 20	
		2′ 10"			3900	+ 50	
⅝	9/16	15^{s}	3"	4546	4600	+ 54	
		17^{s}			4600	+ 54	
		15"			4530	− 16	
		17"			4600	+ 54	
		15"			4490	− 56	
		16"			4900	+ 354	
		14"			4300	− 246	
		18"			4820	+ 274	
		15"			4420	− 126	
		17"			4200	− 346	

TABLE III.—GENERAL COMPARISON OF STRENGTH DEVELOPED BY SCREWS 3/8", 1/2", 5/8" AND 3/4" DIAMETER IN DIFFERENT SIZED HOLES DRIVEN 3".

Mean of x tests.	Size of Hole.	Kind of Wood.	Direction of Grain.	Size of Screw.	Max. Load.	
4	1/4"	Red Pine	parallel	3/8"	2820	
13	3/8"	do	do	1/2"	4500	
12	1/2"	do	do	5/8"	5150	
6	5/8"	do	do	3/4"	5520	
5	1/4"	do	across	3/8"	2865	
12	3/8"	do	do	1/2"	3890	
7	1/2"	do	do	5/8"	3720	
8	5/8"	do	do	3/4"	5330	
5	5/16"	do	parallel	3/8"	2688	
12	7/16"	do	do	1/2"	3890	
12	9/16"	do	do	5/8"	4520	
4	9/16"	do	do	3/4"	5430	
6	5/16"	do	across	3/8"	2678	
12	7/16"	do	do	1/2"	3530	
12	9/16"	do	do	5/8"	3580	
4	9/16"	do	do	3/4"	4700	
4	1/4"	Wh.Oak	diagonal	3/8"	4800	Screw failed.
4	3/8"	do	do	1/2"	7180	do do
4	1/2"	do	do	5/8"	9035	
4	9/16"	do	parallel	3/4"	7715	
6	9/16"	do	across	5/8"	7700	
4	9/16"	do	do	3/4"	8150	
5	1/2"	do	do	5/8"	6520	
3	5/8"	do	do	3/4"	8800	
4	9/16"	do	parallel	3/4"	7715	
4	5/8"	do	do	3/4"	7425	
4	9/16"	do	do	5/8"	7350	
4	1/2"	do	do	5/8"	6300	

TABLE IV.—ABSOLUTE MAXIMUM STRENGTH DEVELOPED.

Size of Hole.	Mean of x tests.	Size of Screw.	Minimum Diameter.	Max. Diameter	No. of Threads per inch.	Length of thread = depth driven.	Kind of Wood.	Direction of Grain.	Max. Load in pounds.	Strength per inch of Thread.	REMARKS.
1/4"	4	[illegible]	....	....	......	3"	Wh. Oak.	parallel	4800	....	Screws
5/16"	4	[illegible]	....	....	......	do	do	do	4750	....	all failed
5/16"	1	[illegible]	....	....	......	do	do	do	4960	1653	Scr'w drew
3/8"	4	[illegible]	....	....	......	do	do	do	7180	....	All fail-
7/16"	4	[illegible]	....	....	......	do	do	do	7263	....	ed
7/16"	1	[illegible]	....	....	......	do	do	do	7460	2480	Scr'w drew
1/2"	4	[illegible]	....	....	......	4½"	do	parallel	9320	2070	
9/16"	4	[illegible]	....	....	......	do	do	do	9845	2180	
1/2"	4	[illegible]	...	....	......	do	do	across	9505	2110	
9/16"	4	[illegible]	....	....	......	do	do	do	9815	....	
9/16"	4	[illegible]	....	....	......	4"	do	parallel	9870	2460	
5/8"	4	[illegible]	....	....	......	do	do	do	9720	2430	
9/16"	4	[illegible]	....	....	......	do	do	across	9820	2455	
5/8"	4	[illegible]	....	....	......	do	do	do	10736	2684	
1/4"	10	[illegible]	....	....	......	3"	Red Pine.	parallel	2820	940	Hand
5/16"	9	[illegible]	....	....	......	do	do	do	2688	896	driven
1/4"	8	[illegible]	....	....	......	do	do	across	2865	955	do
5/16"	4	[illegible]	....	....	......	do	do	do	2678	893	
3/8"	12	[illegible]	....	....	......	......	do	parallel	4500	1500	Hand
7/16"	12	[illegible]	....	....	......	......	do	do	3850	1283	driven
3/8"	18	[illegible]	....	....	......	......	do	across	3890	1296	
7/16"	12	[illegible]	....	....	......	......	do	do	3530	1176	
1/2"	4	[illegible]	....	....	......	4½"	do	parallel	7387	1640	
9/16"	4	[illegible]	....	....	......	do	do	do	6710	1490	
1/2"	4	[illegible]	....	....	......	do	do	across	7037	1564	
9/16"	4	[illegible]	....	....	......	do	do	do	6222	1382	
9/16"	4		....	....	......	4"	....	parallel	7250	1810	
5/8"	4		....	....	......	do	....	do	7360	1840	
9/16"	4		....	....	......	do	....	across	6237	1559	
5/8"	4		....	....	......	do	....	do	7117	1779