SLANT DRIVING OF NAILS! DOES IT PAY?

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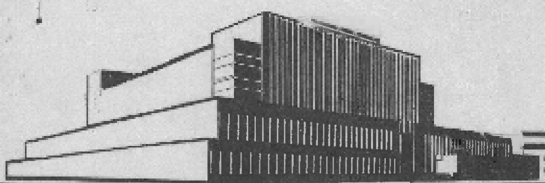

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

SLANT DRIVING OF NAILS! DOES IT PAY?[1]

Forest Products Laboratory,[2] Forest Service
U. S. Department of Agriculture

Ever since thongs, wooden pins, and other early mediums for fastening wood have been replaced by nails and bolts, man has been striving to still further improve the strength of joints and fastenings. One of the means of improvement which has been advocated is the driving of nails on a slant rather than perpendicular to a surface. The merits of slant driving are still open to question, and perhaps it is not too much to assume that the arguments concerning this method of nailing are as old as nails themselves. Speculating on this subject, the authors asked a prominent engineer, who during most of his life has been intimately in touch with wood construction problems, when he first heard of slant nailing. "It was a moot question when I was a boy," came the quick response.

This question of slant driving of nails is one which has also arisen at the Forest Products Laboratory from time to time in connection with studies of joints and fastenings, both from the standpoint of shipping containers and construction uses of lumber. Considering the subject broadly, one might ask: What difference, if any, exists in the resistance to direct withdrawal of single nails driven straight or on a slant? What is the advantage of slant driving with respect to direct withdrawal when groups of nails are considered? How does slant driving affect the strength and serviceability of nailed wooden boxes? How do time and moisture changes in the wood after driving affect the relative efficiency of either type of nailing? With such questions in mind, the results of tests made at the Forest Products Laboratory are of interest.

It is assumed that when a nail is driven there is a rather complete and firm contact between its surface and the surrounding wood fibers, which gives to straight-driven nails their great holding power. If this firm contact is broken because of shrinkage of the wood or as a result of variations in moisture content with time, a straight-driven nail may lose a part or all of its holding

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[1] Original report by L. J. Markwardt and J. M. Gahagan published in Packing & Shipping, January 1930.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

power. It is evident that when a slant-driven nail is pulled in a direction at right angles to the surface of a board (1) the intimate pressure of contact with the wood fibers is reduced on one side while the fibers are mashed or split out on the opposite side; (2) a progressive bending of the nail occurs as it is withdrawn, provided the nail is prevented from "working" out; (3) or there is a combination of reduction of intimate contact and nail bending. One might, therefore, expect that the reduction in holding of a slant-driven nail, because of the crushing of the fibers and decrease in surface contact, would tend to offset any increase resulting from the work done in progressively bending the nail and that a considerable variation in these factors would occur. Taking an extreme case, a nail inserted in a vertically bored hole of the same diameter would offer little or no resistance to direct withdrawal, whereas a nail in a slant hole would show at least some resistance to withdrawal in a direction perpendicular to the surface. One would expect, therefore, the least difference in holding between slant and straight-driven nails just after they are driven or when the contact is most complete; the greatest difference, and in favor of the slant nail, from driving into end surfaces or under conditions where the wood dries or changes moisture content after the nails are driven, approaching in this case the example referred to where the nail is placed in a bored hole with little friction.

Holding Power of Individual Nails

In order to compare the relative resistance to direct withdrawal tests were made of nails driven into specimens of various species and pulled according to the standard laboratory method (fig. 1) immediately after driving or after the wood had undergone changes in moisture content. The results of these tests are shown in table 1. In studying the data it should be noted that the slant nails were driven at the extreme angle of 45 degrees in order to bring out any differences. Considering end-grain holding, it may be seen that slant nailing gave decidedly higher results than straight nailing. For side grain, however, neither type of nailing gave consistently higher results than the other, the advantage varying among species, and with the moisture condition of the lumber. When driven into green specimens and pulled after drying had occurred, the slant-driven nails apparently lost but little or none of their holding for both side and end grain conditions, whereas straight-driven nails lost by far the greater part of their holding power. In this connection, however, the practice of using green or partially-seasoned lumber, which will dry out in use, is not recommended.

It should be noted here that these comparisons are made on the basis of equal depth of penetration. When straight driving is used in practice, however, less of the nail length is used in penetrating the member receiving the head, and, consequently, more of the length is in the member receiving the point to contribute to holding power than is the case with slant driving. Assuming a nail passes through a 25/32-inch member at a 45-degree slant, about 5/16 inch of the effective length is lost. If this factor is taken into account, the advantage of slant driving would be much less than is shown by the figures given, which are based on equal depth of penetration.

Tests of Nails in Groups

The load and the work required to pull groups of nails representing different methods of driving were determined by tests on carefully matched specimens of air-dry material. Three types of nailing, straight, parallel-slant, and cross-slant, as illustrated in Figure 2 were used. A part of the specimens were tested for load and work of slow withdrawal by means of a special device used in conjunction with a universal testing machine (fig. 3). The remainder were tested for work of rapid withdrawal by means of a pendulum type of testing machine (fig. 4).

The results of both sets of tests are shown in table 2. It may be seen that for groups of four nails in end grain, slant nailing gave consistently higher results throughout than straight nailing. When driven and pulled immediately from side grain there was very little difference for the two kinds of nailing, but where the specimens were nailed and then subjected to further seasoning before testing, slant driving gave decidedly higher results. It may be observed that the results based on angles of 10 and 15 degrees are in general conformity with those on single nails having the more extreme slant.

It may be further noted from table 2, particularly in the case of material which underwent moisture changes after driving, that cross-slant driving (see column 2 of table 2) in general resulted in higher loads than the parallel-slant condition; and that the 15-degree slant gave more efficient results than the 10 degrees.

Tests of Boxes

In the third phase of the study, wooden canned food boxes were chosen for the purpose of making further comparisons of straight and slant nailing because they are so dependent on nailing for their serviceability and because standard methods of test for this type of container have long been in use.

The boxes used were what are known as Style 2 and Style 5 types.[3] Two kinds of nailing, straight and cross-slant (fig. 2), were used, except that six nails at a nailing edge instead of four constituted a group. The boxes were made from lumber that was carefully matched for the two types of nailing in order that the results might be comparable.

The tests of the boxes were made in a revolving drum machine, Figure 5, and the number of drops a box withstood was taken as a criterion of the amount of rough handling it would withstand in service. The results of the test are shown in table 3, together with other pertinent information regarding details of construction of the different types of boxes.

In general, the results of the box tests conform to those on individual and group nails. For boxes which are dependent for their strength largely on end-grain holding of nails fastening the sides, the resistance to rough handling is noticeably increased by cross-slant driving at 15 degrees when dry material is used and the boxes are nailed and tested at once. When green or partially-seasoned lumber was used, however, and large reductions in moisture content encountered after nailing, the slant-nailed boxes, although averaging slightly better than those that were straight nailed, were far below any acceptable standard of serviceability. The addition of a single nail per nailing edge in any case could usually be relied upon as more advantageous than slant driving.

For boxes dependent for their strength largely on side-grain holding of nails at the top and bottom, the results are similar to those dependent on end-grain holding, except that there is in general less difference between straight and slant driving.

The advantage of slant driving is noticeably less in the boxes with two-piece sides and three-piece tops and bottoms, as against one and two-piece construction, respectively, apparently on account of the reduced effectiveness of cross-slant nailing when narrow pieces are used.

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[3] A Style 2 box has two vertical and two horizontal cleats nailed to each end, the cleats usually being about the same thickness as the end to permit nailing from sides, top, and bottom. A Style 5 box has two vertical cleats nailed to each end, the direction of the grain in the cleat being perpendicular to the grain of the ends. These cleats are usually only about half the thickness of the ends, are placed on the inside, and serve only to reinforce the end against splitting.

Discussion and Conclusions

It is not presumed that the results of these studies furnish a definite, numerical appraisal of the serviceability of slant nailing nor warrant any general recommendation regarding its use. They will, however, be of value in deciding whether straight or slant driving should be used in any particular case.

Taken broadly, the studies show both advantages and limitations of slant driving. From the standpoint of holding, the most significant advantage of slant driving appears to be with nails driven into the end grain of the wood, and with nails driven into green wood that is subsequently allowed to dry.

Although the results of tests thus show an advantage for slant driving when the wood undergoes serious moisture changes, it may be observed that slant driving will not compensate for the serious loss in nail-holding power resulting from the use of green lumber. The difficulties involved in starting and driving nails, particularly at the greater slants, the loss in depth of penetration, the destruction and mutiliation of the wood fibers at the surface in starting the nail, and the breaking down of the wood under the hammer, to a considerable extent offset the advantages of slant nailing.

Table 1.--Effect of 45-degree slant driving on holding power of single nails.
[Average force required to pull one 7d cement-coated nail[1]]

Species	How driven[2]	Driven into green material and pulled at once					Driven into green material and pulled after drying						Driven into dry material and pulled at once				
			Side grain						Side grain					Side grain			
		Moisture content	Radial	Tangential	Average radial and tangential	End grain	Drying period	Moisture content	Radial	Tangential	Average radial and tangential	End grain	Moisture content	Radial	Tangential	Average radial and tangential	End grain
		Per cent	Pounds	Pounds	Pounds	Pounds	Days	Per cent	Pounds	Pounds	Pounds	Pounds	Per cent	Pounds	Pounds	Pounds	Pounds
Aspen	Straight	---	---	---	---	---	68	4.7	11	12	11	13	7.9	96	100	98	56
	Slant	---	---	---	---	---	68	4.9	116	110	113	97	7.8	144	150	146	159
Fir, red	Straight	---	---	---	---	---	78	5.8	20	20	20	19	8.3	125	133	129	79
	Slant	---	---	---	---	---	71	5.7	143	148	145	136	8.8	157	165	161	189
Fir, silver	Straight	---	---	---	---	---	89	5.6	18	25	22	28	9.1	149	145	146	89
	Slant	---	---	---	---	---	90	5.7	121	123	122	132	8.7	172	176	175	183
Fir, lowland white	Straight	---	---	---	---	---	106	6.9	28	36	32	30	8.4	141	156	149	80
	Slant	---	---	---	---	---	106	5.9	138	138	138	132	8.2	146	167	157	169
Fir, white	Straight	74.6	126	139	133	67	---	---	---	---	---	---	8.2	125	135	130	72
	Slant	74.6	103	109	106	104	---	---	---	---	---	---	9.3	165	170	168	180
Hemlock, western	Straight	---	---	---	---	---	105	5.5	26	29	27	44	8.6	251	255	253	140
	Slant	---	---	---	---	---	105	5.5	138	137	138	155	8.8	215	238	227	226
Larch, western	Straight	---	---	---	---	---	102	7.6	68	84	76	70	---	---	---	---	---
	Slant	---	---	---	---	---	108	6.5	154	143	148	160	---	---	---	---	---
Pine, lodgepole	Straight	---	---	---	---	---	105	7.2	25	34	30	26	7.5	214	218	216	130
	Slant	---	---	---	---	---	110	6.1	136	137	137	143	8.7	183	180	182	197
Pine, lodgepole	Straight	40.4	150	146	148	75	76	5.8	22	26	24	21	7.7	171	163	167	119
	Slant	40.4	104	107	105	100	80	6.1	159	155	157	143	8.9	171	168	170	182

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[1] The averages are based on approximately 90 nails for each type of driving and for each condition of seasoning.

[2] The nails were driven in pairs into the sides and ends of matched specimens. One of each pair was driven normal to the surface and the other at an angle of 45 degrees. After driving, the projecting portions of the slant nails were bent normal to the surface of the specimen to facilitate pulling.

Table 2.--Effect of 10 and 15-degree slant driving on both resistance and work of withdrawal of nails in groups of four.
([illegible])[1]

Rate of withdrawal	How driven	Number of nails tested for each condition	Driven into material at about 14 percent moisture content and pulled at once										Driven into material at about 14 percent moisture content and pulled after further drying of one month										Driven into material at about 5 percent moisture content and pulled at once									
			Nails pulled from side grain					Nails pulled from end grain					Nails pulled from side grain					Nails pulled from end grain					Nails pulled from side grain					Nails pulled from end grain				
			Moisture content	Maximum load per nail	Ratio of slant to straight driving	Total work per nail	Ratio of slant to straight driving	Moisture content	Maximum load per nail	Ratio of slant to straight driving	Total work per nail	Ratio of slant to straight driving	Moisture content	Maximum load per nail	Ratio of slant to straight driving	Total work per nail	Ratio of slant to straight driving	Moisture content	Maximum load per nail	Ratio of slant to straight driving	Total work per nail	Ratio of slant to straight driving	Moisture content	Maximum load per nail	Ratio of slant to straight driving	Total work per nail	Ratio of slant to straight driving	Moisture content	Maximum load per nail	Ratio of slant to straight driving	Total work per nail	Ratio of slant to straight driving
			Percent	Lbs.	Percent	In.-lbs.	Percent	Percent	Lbs.	Percent	In.-lbs.	Percent	Percent	Lbs.	Percent	In.-lbs.	Percent	Percent	Lbs.	Percent	In.-lbs.	Percent	Percent	Lbs.	Percent	In.-lbs.	Percent	Percent	Lbs.	Percent	In.-lbs.	Percent
Slow	Straight	24	--	252	100	153	100	--	152	100	104	100	5.7	82	100	61	100	6.0	91	100	45	100	6.8	257	100	185	100	4.7	165	100	95	100
Slow	Parallel slant 15 degree	24	--	255	101	161	105	--	166	109	119	114	5.9	117	143	89	146	6.2	83	91	55	122	6.6	295	115	194	105	--	180	109	107	113
Slow	Cross slant 15 degree	24	--	233	92	149	97	--	168	110	115	110	5.9	144	176	121	199	6.3	110	121	87	193	7.2	265	103	207	112	4.6	192	116	155	163
Rapid	Straight	40	13.7	--	--	131	100	13.6	--	--	88	100	5.3	--	--	70	100	5.2	--	--	59	100	6.1	--	--	176	100	6.1	--	--	123	100
Rapid	Parallel slant 10 degrees	40	13.7	--	--	128	98	13.6	--	--	89	101	5.3	--	--	84	120	5.2	--	--	75	127	6.1	--	--	--	--	--	--	--	--	--
Rapid	Parallel slant 15 degrees	40	13.7	--	--	136	104	13.6	--	--	103	117	5.3	--	--	95	135	5.2	--	--	93	157	6.1	--	--	181	103	6.1	--	--	143	116
Rapid	Cross slant 10 degrees	40	13.7	--	--	139	106	13.6	--	--	105	119	5.3	--	--	118	168	5.2	--	--	83	140	6.1	--	--	--	--	--	--	--	--	--
Rapid	Cross slant 15 degrees	40	13.7	--	--	141	108	13.6	--	--	113	128	5.3	--	--	128	183	5.2	--	--	101	171	6.1	--	--	183	104	6.1	--	--	147	119

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[1] The specimens used in these tests were made from clear material, carefully matched, to eliminate variations as far as possible.

Table 3.--Detailed results of drum tests to determine the effect of 15-degree slant nailing on the strength of wooden boxes.[1]

Test series	Number of pieces		Size and arrangement of nails		Results of tests						Average ratio of slant to straight	Type of failure	
	In sides	In top and bottom	In sides	In top and bottom	Straight nailing			Slant nailing				Straight nailing	Slant nailing
					Reference number	Moisture content	Number of drops	Reference number	Moisture content	Number of drops			
						Per cent			Per cent		Per cent		
Series No. 1 - Style 5[2] boxes made of air-dry western yellow pine and tested immediately.	One	Two	5d with point in end grain	7d with point in side grain	1	13.4	8	2	13.9	25		Nail pull at side	Nail pull at side
					3	13.6	58	4	13.6	115		Do	Do
					5	13.3	28	6	13.1	77		Do	Do
							Av. 31			Av. 72	232		
	One	Two	7d with point in end grain	5d with point in side grain	7[3]	12.1	17	8[3]	13.2	25		Splitting	Splitting
					9	12.8	41	10	12.9	58		Nail pull at bottom	Nail pull at top
					11[3]	12.6	36	12[3]	13.0	12		Splitting	Splitting
							Av. 41			Av. 58	141		
	Two	Three	5d with point in end grain	7d with point in side grain	13	12.4	8	14	12.3	23		Nail pull at side	Nail pull at side
					15	12.6	31	16	12.6	30		Do	Do
					17	12.5	45	18	13.0	40		Splitting	Do
					19	13.4	24	20	13.0	19		Nail pull at side	Do
					21	13.5	28	22	13.3	36		Do	Do
					23	---	42	24	13.2	43		Do	Do
							Av. 30			Av. 32	107		
	Two	Three	7d with point in end grain	5d with point in side grain	25[3]	11.0	12	26	7.3	62		Splitting	Nail pull at top
					27[3]	11.4	8	28	11.6	36		Do	Do
					29[3]	10.9	16	30	10.8	96		Do	Do
							Av. --			Av. 64	---		
Series No. 2 - Style 5[2] boxes made of green western yellow pine and tested after drying 46 days.	One	Two	5d with point in end grain	7d with point in side grain	31	4.6	10	32	4.6	17		Nail pull at side	Nail pull at bottom
					33	5.2	5	34	5.1	13		Do	Nail pull at side
					35	4.6	18	36	4.5	5		Do	Nail pull at bottom
							Av. 11			Av. 11.7	106		
	One	Two	7d with point in end grain	5d with point in side grain	37	4.6	4	38	4.7	5		Nail pull at bottom	Nail pull at top
					39	4.6	3	40	4.7	5		Do	End split
					41	4.1	3	42	4.8	2		Do	Nail pull at top
							Av. 3.3			Av. 4	121		
	Two	Three	5d with point in end grain	7d with point in side grain	43	4.6	6	44	4.9	6		Nail pull at side	Nail pull at bottom
					45	4.8	5	46	5.0	6		Do	Nail pull at side
					47	4.3	4	48	4.4	4		Do	Do
							Av. 5			Av. 5.3	106		
	Two	Three	7d with point in end grain	5d with point in side grain	49	4.7	4	50	4.9	4		Nail pull at bottom	Nail pull at bottom
					51	5.0	3	52	5.8	3		Nail pull at top	Do
					53	4.8	1	54	5.0	3		Do	Splitting
							Av. 2.7			Av. 3.3	122		
Series No. 3 - Style 2[2] boxes made of air-dry western yellow pine and tested immediately.	Two	Three	5d with point in end grain	7d with point in side grain	55	11.2	48	56	16.0	58		Nail pull and splitting at side	Nail pull at side
					57	15.7	40	58	16.7	113		Nail pull at side	Do
					59	15.0	41	60	16.6	60		Do	Do
							Av. 43			Av. 77	179		
	Two	Three	7d with point in end grain	5d with point in side grain	61	15.7	130	62	---	139		Nail pull at bottom	Nail pull at top
					63	16.2	142	64	15.5	84		Nail pull at top	Do
					65	17.6	107	66	15.4	214		Nail pull at bottom	Splitting
							Av. 126			Av. 146	116		
Series No. 4 - Style 2[2] boxes made of western yellow pine at 15.8 per cent moisture and tested after drying 30 days.	Two	Three	5d with point in end grain	7d with point in side grain	67	4.9	10	68	5.1	10		Nail pull at side	Nail pull at side
					69	5.2	14	70	5.5	13		Do	Do
					71	5.6	12	72	5.1	6		Do	Do
							Av. 12			Av. 9.7	81		
	Two	Three	7d with point in side and end grain	5d with point in side grain	73	4.7	7	74	5.0	20		Nail pull at top	Nail pull at top
					75	5.6	16	76	5.4	25		Do	Nail pull at side; one broken nail
					77	5.7	8	78	5.4	12		Do	Nail pull at side; also broken nails
							Av. 10.3			Av. 19	184		

[1] The boxes for each series of tests were made from carefully matched material and loaded with two dozen No. 3 cans, weighing approximately 60 pounds. Six cement-coated nails per nailing edge were used throughout.

[2] A Style 2 box is one having each end reinforced with two vertical and two horizontal cleats on the outside. A Style 5 box is one having each end reinforced with two thin vertical cleats on the inside corners, the cleats serving as reinforcement for the ends and not as a nailing edge for the sides.

[3] Boxes numbered 7, 8, 11, 12, 25, 27, and 29, which failed by splitting, obviously did not develop the strength of nailing and the results were therefore omitted from the averages.

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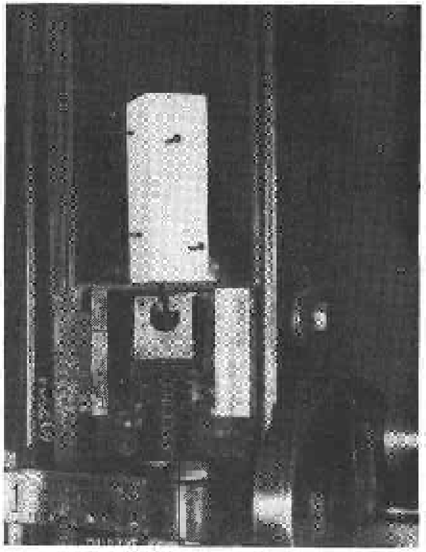

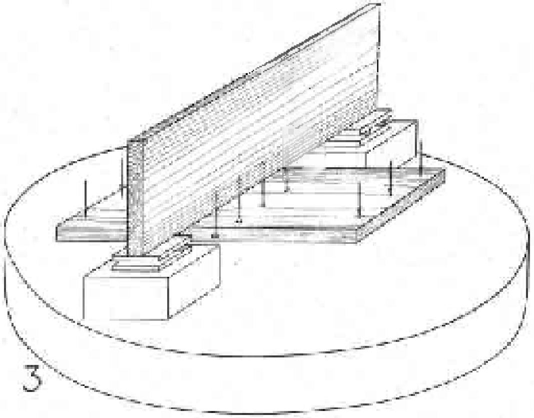

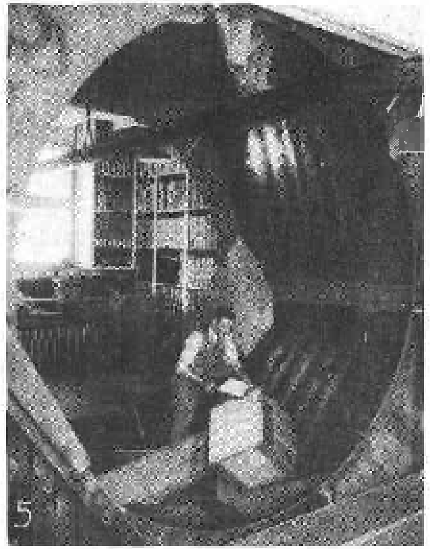

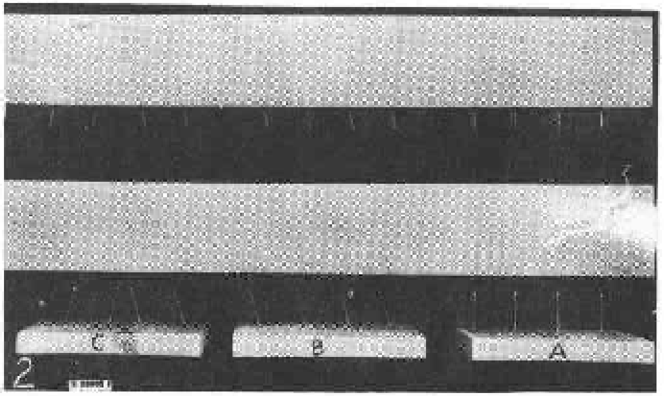

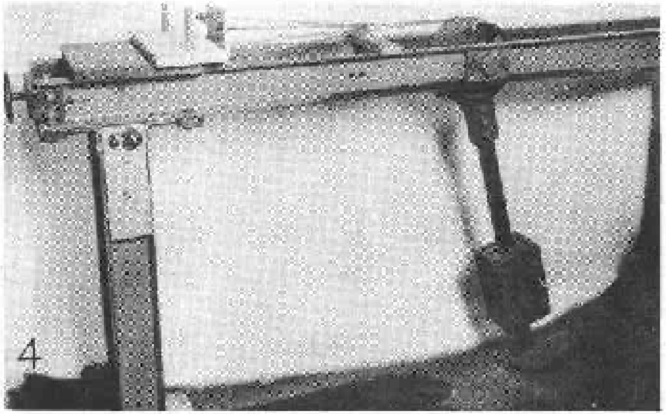

Fig. 1.--Method of determining nail-holding power

Fig. 2.--Arrangement of nails for testing in groups.
A--Straight; B--Parallel slant; C--Cross slant

Fig. 3.--Method of making static tests of nails in groups

Fig. 4.--Method of making dynamic tests of nails in groups

Fig. 5.--Method of testing boxes in large 14-foot revolving hexagonal drum

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The following are obtainable free on request from the Director, Forest Products Laboratory, Madison 5, Wisconsin:

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List of publications on Growth, Structure, and Identification of Wood

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