WITHDRAWAL AND LATERAL STRENGTH OF THREADED NAILS

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An experimental study on the performance of threaded nails was conducted to understand and characterize the withdrawal and lateral strength of threaded nails for efficient application in wood construction. Both lateral and withdrawal joints were tested using annularly and helically threaded nails. In total, 1,210 withdrawal and 620 lateral joints were tested. In addition, dowel bearing and nail bending tests were conducted to determine input parameters for the yield model. Withdrawal test results show that U.S. design provisions for threaded nails are conservative. Preliminary results of lateral tests compared to the yield models with joint strength defined by the 5% diameter offset method indicate that this classification of failure needs refinement.

1. INTRODUCTION

Stern [1] advocated the use of threaded nails in wood construction because of their increased withdrawal strength and has extensively researched the use of threaded nails in pallets. Based on post-frame construction experience, Geisthardt and others [2] stated that published withdrawal design values for large threaded nails are conservative. Also, past studies on threaded nails in the United States were limited in scope and focused on fundamental mechanics and moisture effects.

The goal of this study was to gain understanding of threaded nails in withdrawal and lateral loading. Primary objectives were to (1) determine the withdrawal strength for threaded nails, (2) determine the lateral performance of threaded nail joints, (3) find dowel bearing strength for threaded nails, (4) establish nail bending yield strength values of high carbon threaded nails, and (5) compare withdrawal and lateral strength predictions with actual data.

2. BACKGROUND

2.1 Withdrawal Design

Current withdrawal design values, published in the National Design Specifications for Wood Construction (NDS) [3] and the Standard for Load and Resistance Design LRFD) for Engineered Wood Construction [4], for threaded nails are based on research conducted on smooth shank nails in the late 1930s. The withdrawal capacity for both the NDS and LRFD design specifications with the safety and duration of load factors removed is based on the expression

$$W = 47.58G^{5/2}DL \qquad (1)$$

where *G* is specific gravity based on dry weight and volume, *D* is nail diameter (mm), and *L* is nail penetration (mm). This expression should therefore predict mean experimental values A threaded nail diameter for input into equation (1) may be defined as by a shank or thread diameter; the NDS chose to define threaded nail diameter based on the diameter of an equivalent pennyweight common nail. Unlike the NDS, the LRFD specifications state that withdrawal values for threaded nails can be determined by tests or equation (1) by inputting the least shank diameter.

The American Society of Mechanical Engineers (ASME) [5] publishes a design specification to assign withdrawal capacity for pallet-threaded nails. This specification calculates 5th-percentile withdrawal strength values for helically threaded nails, considering nail geometry and wood material characteristics:

European researchers have published expressions for several types of threaded nails [6,7]. Moat recently, Werner and Siebert [7] tested annularly threaded nails and developed the following expressions to predict withdrawal strength

$$W = 95G^2DL \qquad (2)$$

were *G, D,* and *L* are defined as in equation (1). They also stated a need for small manufacturing tolerances because of the strong influence of nail geometry on withdrawal resistance.

To our knowledge, no design expression specifically addressing the withdrawal strength of threaded nails has been published [8] or proposed for the Eurocode [9]. The proposed Eurocode [9] does allow the testing of threaded nails for design withdrawal values.

2.2 Lateral Design

Both the NDS and LRFD wood design codes have adopted a connection design philosophy known as the yield theory. This theory was proposed for timber connections by Johansen [10] and has worldwide acceptance as a valid design criteria. This approach considers the interaction of wood bearing and nail bending at maximum load or yielding condition. The wood is assumed to be at a uniform stress equal to its bearing strength, the nail is assumed to be fully plastic with internal stress equal to the yield stress. This theory does not consider the effects of axial nail tension, interface friction, and head fixity on the strength of the connection.

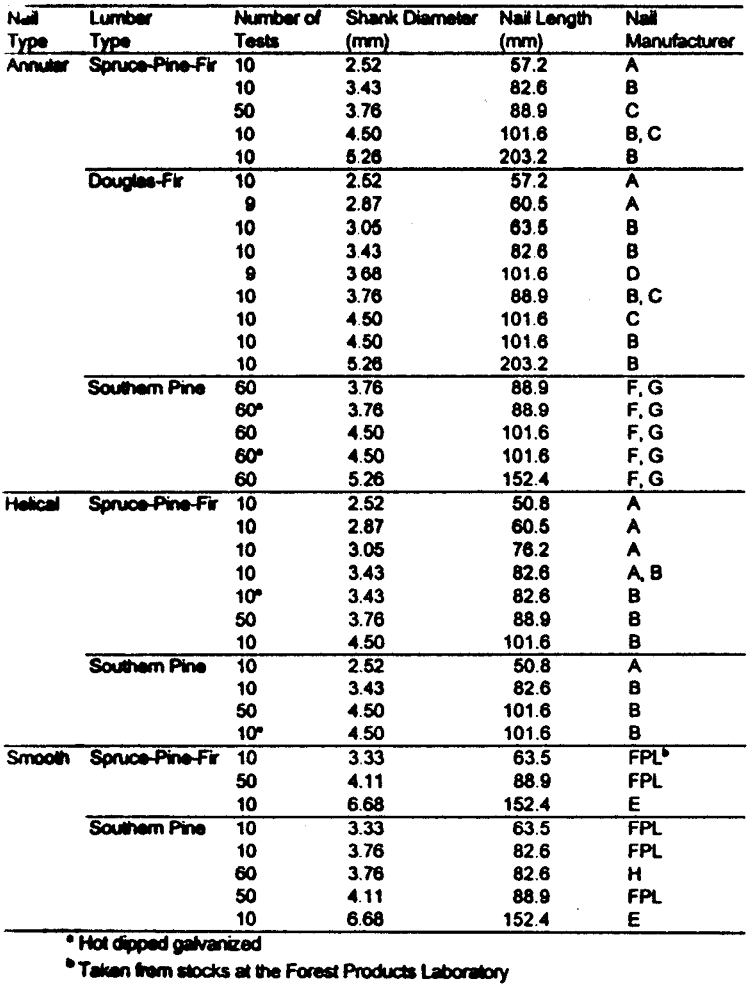
ASME also publishes a design specification to assign lateral strength values for pallet nails. This specification determines the load capacity at a 0.038-mm joint deformation for threaded nails considering the anticipated fastener quality, MIBANT angle of fastener (deg), and minimum thickness of wood member,

3. TEST PROGRAM

This research was conducted cooperatively between the USDA Forest Products Laboratory and Texas A&M University. Specific details of the research can be found In reports by Skulteti and others [11], Theilen and others [12], and a USDA Forest Service Research Paper being prepared for publication.

3.1 Withdrawal Tests

Three classes of nails – annularly threaded, helically threaded, and smooth shank (common) – were tested for withdrawal strength in Douglas-fir, Southern Pine (So. Pine), and Spruce–Pine–Fir (SPF) lumber (table 1). Nails were obtained from nine sources and several nail types ware galvanized to evaluate the effects of galvanizing on withdrawal. In total, 1,210 nails were tested according to ASTM D1761 [13] procedures.



Nail Type	Lumber Type	Number of Tests	Shank Diameter (mm)	Nail Length (mm)	Nail Manufacturer
Annular	Spruce-Pine-Fir	10	2.52	57.2	A
		10	3.43	82.6	B
		50	3.76	88.9	C
		10	4.50	101.6	B, C
		10	5.26	203.2	B
	Douglas-Fir	10	2.52	57.2	A
		9	2.87	60.5	A
		10	3.05	63.5	B
		10	3.43	82.6	B
		9	3.68	101.6	D
		10	3.76	88.9	B, C
		10	4.50	101.6	C
		10	4.50	101.6	B
		10	5.26	203.2	B
	Southern Pine	60	3.76	88.9	F, G
		60[a]	3.76	88.9	F, G
		60	4.50	101.6	F, G
		60[a]	4.50	101.6	F, G
		60	5.26	152.4	F, G
Helical	Spruce-Pine-Fir	10	2.52	50.8	A
		10	2.87	60.5	A
		10	3.05	76.2	A
		10	3.43	82.6	A, B
		10[a]	3.43	82.6	B
		50	3.76	88.9	B
		10	4.50	101.6	B
	Southern Pine	10	2.52	50.8	A
		10	3.43	82.6	B
		50	4.50	101.6	B
		10[a]	4.50	101.6	B
Smooth	Spruce-Pine-Fir	10	3.33	63.5	FPL[b]
		50	4.11	88.9	FPL
		10	6.68	152.4	E
	Southern Pine	10	3.33	63.5	FPL
		10	3.76	82.6	FPL
		60	3.76	82.6	H
		50	4.11	88.9	FPL
		10	6.68	152.4	E

[a] Hot dipped galvanized

[b] Taken from stocks at the Forest Products Laboratory

Table 1 Withdrawal test matrix

3.2 Lateral Tests

Several lateral joint configurations were tested with helically and annularly threaded nails. Shank diameter, nail coating, main and ride member thickness, joint configuration, and member species (table 2) were parameters varied in this test program. Joints were tested based on the provisions of ASTM D1761, but an improved test fixture (fig. 1) that reduces the eccentricity present in the standard ASTM setup was substituted [14]. In addition, nail bending yield strength and dowel bearing tests were conducted to establish input parameters to the yield theory and for comparisons with material properties assumed in U.S. design standards.

		Nail		Main member		Side member	
Nail Type	No. of Tests	Diameter (mm)	Nail Manufacturer	Thickness (mm)	Wood Species	Thickness (mm)	Wood Species
Helical	10	3.43	B	41	So. Pine	41	So. Pine
	50	3.76	B	44	So. Pine	44	So. Pine
	10	4.50	B	51	So. Pine	51	So. Pine
	10	3.43	B	41	SPF	41	SPF
	10	3.76	B	44	SPF	44	SPF
	10	4.50	B	51	SPF	51	SPF
Annular	10	3.05	B	32	So. Pine	32	So. Pine
	50	3.76	B	59	So. Pine	30	So. Pine
	20	3.76	F	89	So. Pine	38	So. Pine
	40	3.76	G	89	So. Pine	38	So. Pine
	20[a]	3.76	F	89	So. Pine	38	So. Pine
	20[a]	3.76	G	89	So. Pine	38	So. Pine
	10	4.50	B	76	So. Pine	76	So. Pine
	10	4.50	B	102	So. Pine	51	So. Pine
	20	4.50	F	89	So. Pine	38	So. Pine
	20	4.50	G	89	So. Pine	38	So. Pine
	40[a]	4.50	F	89	So. Pine	38	So. Pine
	20[a]	4.50	G	89	So. Pine	38	So. Pine
	9	3.05	B	32	SPF	32	SPF
	50	3.43	B	41	SPF	41	SPF
	10	3.76	B	44	SPF	44	SPF
	10	3.76	B	59	SPF	30	SPF
	50	4.50	B	51	SPF	51	SPF
	10	4.50	B	76	SPF	76	SPF
	10	4.50	B	102	SPF	51	SPF
	10	3.76	B	44	So. Pine	44	SPF
	10	3.76	B	59	So. Pine	30	SPF
	10	4.50	B	76	So. Pine	76	SPF
	10	4.50	B	102	So. Pine	51	SPF
	50[b]	3.76	B	30	So. Pine	30	So. Pine
	10[b]	4.50	B	51	So. Pine	51	So. Pine

[a] Galvanized nails

Table 2 Lateral joint test matrix

4. RESULTS AND DISCUSSION

Although two threaded nail design procedures exist for deriving design **values In** the United States, only the procedures given in the NDS and LRFD codes for building construction are discussed in the following section.

Figure 1 Lateral joint test fixture

4.1 Withdrawal Tests

Maximum withdrawal loads were divided by the length of nail penetration to determine a withdrawal strength. Mean withdrawal strength values divided by shank diameter and one standard deviation error bars are plotted versus specific gravity for comparison with the current U.S. design expression for threaded nails (fig. 2). For annularly threaded nails (fig. 2a), current U.S. expression (eq. (1)). fails to predict the mean withdrawal strength, but the expression developed by Werner and Siebert [7] overpredicts results. For helically threaded nails, the current U.S. expression did not adequately predict the mean experimental results for the lower specific gravity wood. The ratio of mean results to equation (1) divided by shank diameter ranged between 1.5 and 2.9 with an average of 2.1 for annularly threaded nails. For helically threaded nails, he same ratio ranged from 1.2 in southern pine wood and 1.7 in the spruce-pine-fir. For annularly threaded nails, the ratios increased with a specific gravity increase; but for helically threaded nails, the ratios decreased with a specific gravity increase.

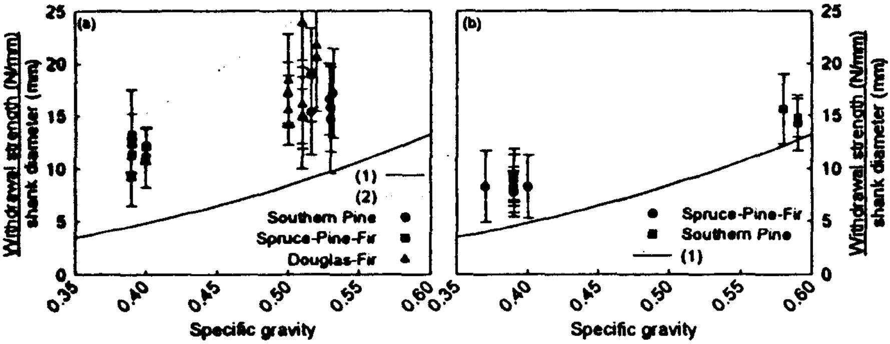


Figure 2 Comparison of threaded nail withdrawal strength and design expressions: (a) annularly threaded nails compared to (1) and (2) (b) helically threaded nails compared to (1).

An analysis of variance with a 0.05 level of confidence was conducted to investigate if nail source and galvanizing have an effect on withdrawal strength. Based on a comparison of similar sized nails in similar wood, nail source has no statistical effect on withdrawal strength. Comparison of galvanized and bright threaded nails indicates no effect on withdrawal strength, but researchers did observe an 8% decrease in mean withdrawal strength in annularly threaded nails and an 18% decrease in mean withdrawal strength in helically threaded nails [12]. It is still believed that the galvanizing fills the root of the thread, thereby slightly reducing the withdrawal strength of galvanized nails.

4.2 Lateral Tests

In total, 220 nail bending and 140 dowel bearing tests were conducted to determine relevant input properties for the yield model and for comparison with the current design property assumptions. For smooth shank nails, current nail bending yield strength and dowel bearing stress predict mean property response. Figure 3 plots the mean threaded nail bending yield strength and dowel bearing results with one standard deviation error bars and the current NDS assumed nail bending yield strength and bearing strength. Results indicate that the current assumed nail bending yield strengths greatly under-predict mean results for high-carbon-content heat-treated and tempered nails. At a minimum, published nail bending yield strengths could be increased by 34% for annularly threaded nails and 56% for helically threaded nails. These increases could be adopted only if standardization and quality control of threaded nail material and geometric properties is also implemented. Dowel bearing strength in the tower specific gravity wood was greater than the NDS value by a minimum of 25%, but as the specific gravity increases the results and the dowel bearing expression coincided. The effect of threads on dowel bearing strength will be addressed in the future.

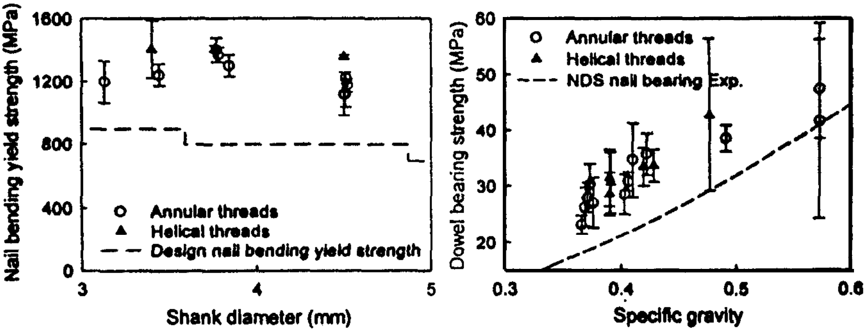


Figure 5 Comparison of nail bending and dowel bearing results with US design values: (a) nail bending yield strength (b) dowel bearing strength

Yield theory predictions were made using results from the material tests and nail shank diameter. These predictions were compared with the average experimental 5% diameter offset results. Figure 4 shows typical load versus joint displacement curves for a 3.76-mm annularly threaded nail and a 3.76-mm helically threaded nail along with the 5% diameter offset and yield prediction values, Except for one geometry, all yield model predictions overpredicted the 5% diameter offset load by 37% to 67% and underpredicted the maximum load by 20% to 228%. In most joints, the nail head was pulled in the side member. Underpredictions of the maximum load seemed reasonable because the yield theory does not consider the effects of axial tension and head fixity or pull through on connection strength. These effects increase the joint response at maximum load. It is specutated that the nail has not yet formed a plastic hinge at the currently defined 5% diameter offset level; therefore, the underlying nail yielding assumption of the yield theory is not satisfied.

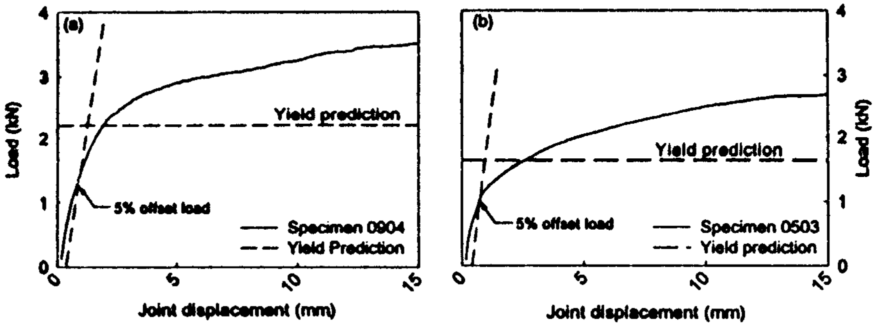


Figure 4 Typical load-displacement for 3.76-mm diameter threaded nails with 5%-diameter offset loads and yield prediction: (a) annularly threaded nails in southern pine and (b) helically threaded nails in spruce-pine-fir

5. CONCLUSIONS

Current NDS and LRFD design procedures for withdrawal strength underestimate the performance of specific threaded nails tested herein. Based on this study, design withdrawal strength values for annularly threaded nails could safety be increased by 50% for the full range of specific gravity values examined. Similarly for helically threaded nails, design withdrawal strength values could be increased for low-specific-gravity material like Spruce-Pine-Fir.

Neither the nail source nor the galvanized coating had a statistically significant effect on the withdrawal strength of annularly and helically threaded nails. However, results tended to show tower mean withdrawal strength values for galvanized nails as compared to bright nails because galvanizing fills the roots of threaded nails.

Current NDS and LRFD assume nail bending yield strengths and dowel bearing poperties that underestimate the mean performance of threaded nails. Nail bending yield strengths could safety be increased by 30% to better reflect experimental mean values. Dowel bearing properties could be increased for Spruce-Pine-Fir but further analysis and research is needed to determine the dowel bearing strengths for common nails and threaded nails.

In all but one case, lateral joint 5% diameter offset values were over predicted and the maximum joint values were under predicted by the yield theory. Additional research is needed on the definition of nail joint failure in current U.S. specifications. Maximum lateral joint loads with threaded nails should always be under predicted by the yield equations because they do not consider the presence of axial loads in the nails and head fixity effects.

Although this study indicates increases in withdrawal and lateral strength for threaded nails, increases should only be allowed after standard thread characteristics are established and an inspection to assure quality control is maintained. Current general nail classifications are not sufficient in defining the critical thread characteristics like thread length or thread-crest and root diameter that influence withdrawal strength.

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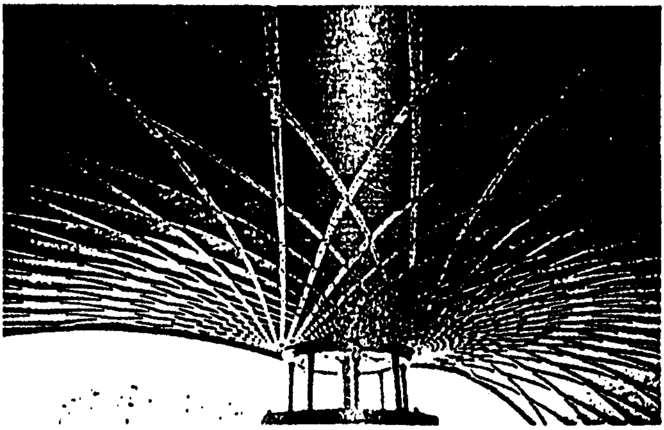

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