Withdrawal Capacity of Plain, Annular Shank, and Helical Shank Nail Fasteners in Spruce-Pine-Fir Lumber

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Abstract

This study examines the withdrawal load and energy capacity of three types of nail fasteners that are commonly used to attach sheathing to framing members: 8d common, annular ring shank, and helical shank. A baseline set of data was collected for single nails in accordance with test methods defined in ASTM D1761. Tests were performed until complete withdrawal occurred in order to quantify the total withdrawal energy. The average peak loads from testing were within 7 to 8 percent of predicted values. The annular and helical nails had much higher peak load capacity as expected, and the withdrawal energy was also greater. A new device was developed in order to subject multiple nails to withdrawal loading simultaneously. Reinforced sheathing was used to transfer load from the hydraulic actuator to the nails, which is more representative of actual structural response where there is load sharing among the nails. This device allowed direct comparison with the single nail results. Further, it also allowed the examination of a ''stitched'' nailing pattern, where fasteners are driven at alternating angles of ±60° measured from the framing member face. It was found that the stitched pattern resulted in 42 percent higher peak load capacity per fastener for 8d common nails, but for the helical and annular nails, peak load was similar to that achieved with a normal 90° drive angle. Withdrawal energy was 24 to 48 percent higher for all nail types using the stitched pattern.

In roof and wall building systems, a sheathing panel's ability to support negative pressures is mainly provided by the fastener resistance to withdrawal and pull-through (Sutt et al. 2008). In withdrawal and pull-through failures, withdrawal refers to the fastener withdrawing from the framing members, and pull-through refers to the head of the fastener pulling through the sheathing. The resistance of a nail to withdrawal from wood-based materials is characterized by several factors, including framing member material density and moisture content/conditioning, nail shank diameter, and the depth of penetration (US Department of Agriculture [USDA] 2010). The resistance to nailhead pull-through in sheathing is influenced by similar factors, including material density and conditioning, as well as other factors, such as nailhead diameter and the sheathing thickness (Herzog and Yeh 2006).

Several nail types designed to increase nail withdrawal capacity—including ring shank and helically threaded shank—have been developed. When comparing annular and helically threaded nails in spruce-pine-fir (SPF) at 12 percent moisture content, Rammer et al. (2001) found no significant difference in mean withdrawal strength. The *Wood Handbook,* Chapter 8, Fastenings (USDA 2010) provides peak withdrawal values for annular, helical, and common nails but indicates the peak withdrawal load can vary significantly from nail to nail depending on the shank's surface coating or even the type of chemical residue present after production. Based on these observations, the *Wood Handbook* only presents nail performance up to and for a limited displacement postpeak. Previous testing and development of reference design values are based on single

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Forest Prod. J. 63(5/6):213–220.
doi:10.13073/FPJ-D-13-00055

fastener withdrawal standard test methods per ASTM D1761 (ASTM International 2006) and do not consider the simultaneous loading of multiple fasteners. The current reference design value for multinail connections is the sum of the individual fastener design values (American Forest & Paper Association [AF&PA] 2005), which may produce a nonconservative design value for panels under negative pressure (Sutt et al. 2008). In most cases the connection designer must make judgment decisions regarding pull-through resistance, potential load sharing between fasteners, and the actual capacity of annular and helical shank nails (Sutt et al. 2008).

The objective of this study was to assess the relative withdrawal capacity of annular, helical, and smooth shank nails in single nail and multinail connections under nominally identical laboratory conditions. Single nail withdrawal tests were performed in accordance with ASTM D1761 (ASTM International 2006). Multinail connection tests used a modified apparatus to pull a line of six fasteners by loading a tributary area of sheathing, which distributed the load to the fasteners in a manner more consistent with actual sheathing loading scenarios. To allow direct comparison with the single nail withdrawal tests, testing with the modified apparatus isolated the failure mode of the nails to direct withdrawal through the use of reinforced sheathing that prevented nailhead pull-through. In all tests, the fasteners were pulled to complete withdrawal to allow calculation of work (energy) required during complete withdrawal. While not used directly in conventional design, withdrawal energy is a measure of a connection's ability to absorb energy during extreme loading due to blasts or ground motion/seismic events.

The effect of nail drive angle on withdrawal strength and energy absorption was also investigated using the modified testing apparatus, where the nails were driven at alternating angles along the length of the stud in a stitched fastener pattern. An angle of 30° from vertical (60° from the stud face) was selected to coincide with the National Design Specification for Wood Construction's drive angle for toe nailing (AF&PA 2005).

Materials and Methods

Specimen fabrication

All 2 by 4 framing member specimens used in the testing consisted of locally purchased No. 2 SPF south (SPF-s) 2 by 4 lumber. All wood specimens were conditioned to 12 percent moisture content prior to testing. All tests were conducted within 1 hour of removing the wood from the conditioning chamber, and nails were driven immediately prior to testing. The reinforced sheathing used in the testing consisted of 3/8-inch (9.5-mm)-thick CDX plywood (i.e., plywood with a ''C'' grade veneer on the front, ''D'' grade veneer on the back, and rated for limited exposure) with thermoplastic E-glass composite layers bonded to both faces to prevent nailhead pull-through. Single nail withdrawal tests used nails driven into the SPF-s lumber with a 0.40-inch (10.2-mm) spacing between the nailhead and specimen to account for the thickness of the reinforced sheathing. This testing used three commercially available Bostitch nail types that were all plastic collated for use in a pneumatic framing nailer (Fig. 1): 8d common, 8d Hurriquake (annular ring shank), and 8d helical. Nail dimensions are provided in Table 1. The Hurriquake nail is made of a carbon steel alloy and includes annular rings, a larger head diameter, and a helical twist located directly below the nail's head (Curry 2007). The helical region extends to approximately 0.5 inch (12.7 mm) below the bottom of the nailhead. Using the reinforced sheathing to prevent nailhead pull-through for all nail types and a 2.1-inch (53.3-mm) embedment length, the Hurriquake nail is effectively reduced to an annular shank nail with respect to withdrawal from the framing member.

Figure 1.—Photo of nails tested (from left) 8d common, 8d annular, and 8d helical.

All withdrawal tests in this study were conducted in accordance with ASTM D1761 (ASTM International 2006) with limited modifications. ASTM D1761 indicates a recommended displacement rate of 0.1 inch/min (2.54 mm/min) for all fastener withdrawal testing. This load rate corresponds to a test duration of up to 21 minutes in order to achieve complete withdrawal. To expedite testing, the displacement rate was increased to 1 inch/min (25.4 mm/min) and all testing was performed using an Instron servo-hydraulic actuator. Prior studies have shown that load rate had only a minor effect on 8d common nail peak withdrawal loads (Kallem 1997, Rosowsky and Reinhold 1999). Nails tested at 0.1 inch/min (2.54 mm/min), 1.0 inch/min (25.4 mm/min), and instantaneous withdrawal rates gave peak withdrawal loads of 153 pounds (0.681 kN), 146 pounds (0.649 kN), and 145 pounds (0.645 kN), respectively (Kallem 1997). The intent of this study was not to investigate loading rate effects, but rather to compare fastener types, the effect of testing one fastener versus multiple fasteners, and to investigate the effect of an angled drive pattern. To ensure a consistent starting point for each test, the nails were preloaded to 15 pounds (66.7 N) before the start of each test. Though the nails were packaged for nail gun use, all nails were hand driven to comply with ASTM D1761, and the plastic collation material was removed prior to the nail being driven. Steel jigs were used to ensure consistent and accurate drive angles.

Single nail withdrawal tests were initially performed per ASTM D1761 (ASTM International 2006) in order to develop a baseline comparison between nails in terms of average peak withdrawal capacity and average energy. In order to calculate the withdrawal energy, the fasteners used in this testing were loaded until complete withdrawal from the stud occurred. To date, limited research has been performed where nails have been loaded to complete

Table 1.—Average measured nail properties.

Nail type	Shank diameter, in. (mm)	Total length, in. (mm)	Head diameter, in. (mm)	Weight, oz (g)
8d common	0.130 (3.30)	2.46 (62.5)	0.279 (7.08)	0.153 (4.34)
8d annular	0.131 (3.34)	2.46 (62.6)	0.315 (7.99)	0.153 (4.33)
8d helical	0.146 (3.71)	2.37 (60.1)	0.284 (7.21)	0.181 (5.14)

withdrawal. However, this information may be useful in design situations where energy absorption is important and large withdrawal distances of some fasteners can be tolerated. Given the variability in wood, a sample size of 10 was selected for each test configuration.

Single nail withdrawal specimens

To fabricate the single nail withdrawal test specimens, five full-length (8 ft [2.44 m]) 2 by 4 specimens were selected and cut into test blocks measuring approximately 1.5 by 3.5 by 7 inches (38 by 89 by 178 mm). The five 2 by 4s were selected based on visual inspection of a single lift of 2 by 4s to represent the range of grain patterns typical of the No. 2 SPF lumber with consideration to the angle of the grain (tangential or radial to nail) and distance between growth rings (ring density; Fig. 2).

One test block from each of the five 2 by 4s was used for each type of nail in an attempt to pair each nail type with blocks of similar grain angles and ring densities. For each test block two nails were spaced 3 inches (76 mm) apart and 2 inches (51 mm) from the end of the block. The two nails were set into each test block, leaving a 0.40-inch (10-mm) gap between the bottom of the nailhead and the stud to account for the thickness of the sheathing that would normally occupy this space. The testing apparatus was designed according to ASTM D1761 (ASTM International 2006), as seen in Figure 3. The test matrix for the single nail withdrawal testing is provided in Table 2.

When considering the typical cross-sectional properties of the lumber used in the testing (see Fig. 2) it was assumed that density would affect each nail type's withdrawal capacity. It is practically impossible to quantify the density of the wood in immediate contact with the nails. Thus, to estimate density's role in nail withdrawal capacity, the local density of the wood around the nail was measured. Sections measuring 1.5 by 1.5 by 3.5 inches (38 by 38 by 76 mm) were cut from the 7-inch (178-mm) blocks centered around each nail hole following withdrawal testing. The specimen densities for the single nail withdrawal tests were determined per ASTM D2395 (ASTM International 2007) method A. As detailed later, an analysis of covariance (ANCOVA) was conducted to assess the significance of density for the nail withdrawal capacity.

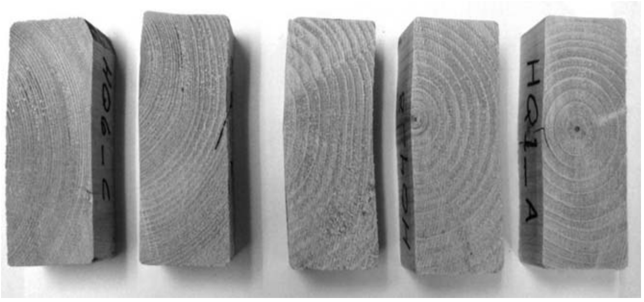

Figure 2.—Typical representative cross sections from five spruce-pine-fir south (SPF-s) 2 by 4s.

Multinail withdrawal specimens

For each modified specimen, an 18 by 16-inch (457 by 406-mm) section of reinforced sheathing was attached to a 23.3-inch (591-mm)-long section of No. 2 SPF-s 2 by 4 with six nails along the centerline of the sheathing, a 3-inch (76-mm) inner nail spacing, and a 1.5-inch (38-mm) outer nail spacing from the edge of the sheathing (see Fig. 4). The 60° (measured off the narrow face of the stud) angled nails were driven with a guide dado cut into a wood block to ensure a relatively consistent angle. The nails used a stitched pattern with consecutive nails alternating first away from and then toward one end of the 2 by 4 along the length of the stud (see Fig. 4).

The modified apparatus shown in Figure 5 was intended to mimic how fasteners are loaded in wall panels under negative pressure, where the load on the sheathing is transferred through the fasteners to the framing members. The apparatus was made of steel to maximize its stiffness and consisted of an upper section attached to the outer edge of the sheathing panel and a lower section restraining the 2 by 4 section at the boundaries of the specimen. The upper section of the apparatus was fabricated from a 4 by 6 by 3/8-inch (102 by 152 by 10-mm) steel rectangular tube and two 4 by 6 by 3/8-inch (102 by 152 by 10-mm) steel angles connected with eight total (four each) 0.5-inch (12.7-mm)-diameter bolts through the 4-inch (102-mm) flanges on each side of the steel tube. Holes of 0.625-inch (15.9-mm) diameter were drilled into the 6-inch (152-mm) flanges to fasten the sheathing, and 0.25-inch (6.4-mm)-thick backer bars were placed on the bottom of the sheathing to ensure a uniform clamping force along the edge of the sheathing and to simulate a fixed-type connection representing an interior framing member. The sheathing connection was made with

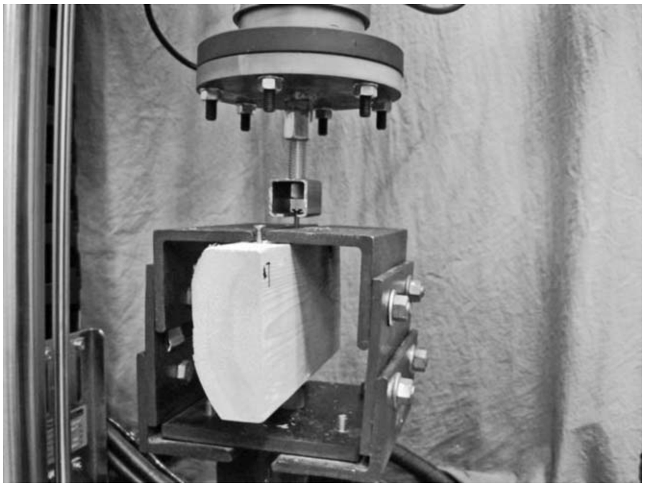

Figure 3.—ASTM D1761 test apparatus.

Table 2.—ASTM D1761 single nail withdrawal test matrix.

Quantity	Stud type[a]	Nail type
10	No. 2 SPF-s	Common
10	No. 2 SPF-s	Annular
10	No. 2 SPF-s	Helical

[a] SPF-s = spruce-pine-fir south.

four 0.5-inch (12.7-mm)-diameter bolts on each side of the apparatus. The bottom of the apparatus was a 2 by 4 by 3/16-inch (50.8 by 102 by 4.8-mm) steel box tube, routed along its length to within 1 inch (25 mm) of each end to accommodate the 23.3-inch (591-mm)-long stud for each specimen. The modified withdrawal test matrix summarizing the specimen configurations can be found in Table 3.

Because the sheathing bends during loading, the nail displacement during withdrawal is not equal to the cylinder displacement of the load actuator. Also, owing to the test setup, there was no direct method of measuring each of the six nail's exact withdrawal displacement. Instead two linear variable differential transformers (LVDTs) located at each end of the sheathing were used to measure the displacement of the sheathing during withdrawal. The LVDTs were placed at opposite ends of the sheathing to capture any uneven withdrawal of the nails, and the deflection rods ran through small holes cut in the rectangular steel tube section to directly contact the sheathing. The displacements of the two LVDTs were averaged to determine the sheathing displacement. The average nail displacement during the withdrawal was then taken as the difference between the total cylinder displacement of the Instron and the average displacement of the LVDTs.

In preliminary tests with the modified apparatus, the bottom section was allowed to rotate freely, and slight eccentricities in the system magnified as load increased. This often resulted in a zippering effect, where the apparatus rotated and the nails withdrew unevenly. This unrealistic loading scenario was prevented by restraining rotation with wood blocking placed under the ends of the fixture to keep the sheathing and the stud parallel (see Fig. 6).

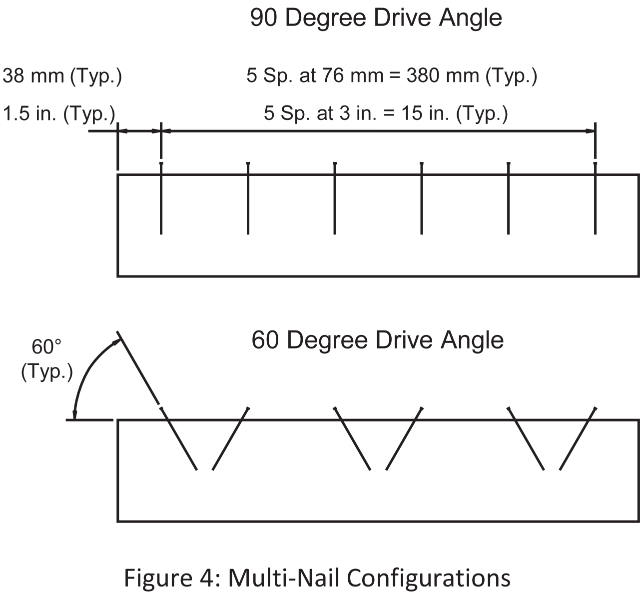

Figure 4.—Multinail configurations.

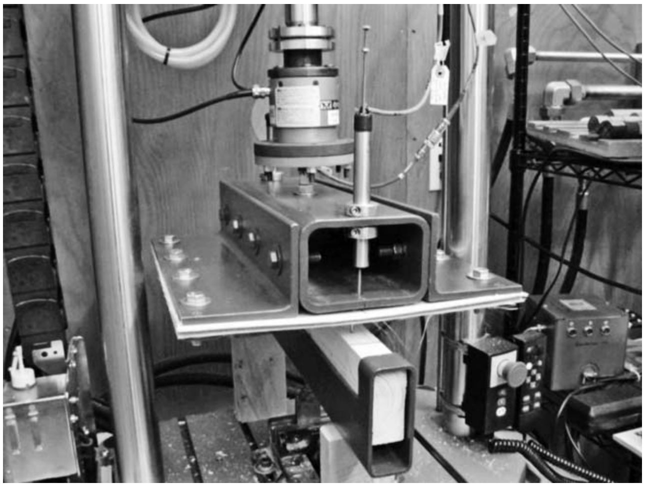

Figure 5.—Modified nail withdrawal apparatus setup.

Owing to the size of the stud sections and the number of nails in each specimen for the modified test setup, local density of the wood around each nail was not quantified. It was assumed that the sheathing, reinforced to prevent nailhead pull-through, was stiff enough to ensure relatively uniform displacements among the six fasteners.

Results

Single nail withdrawal results

Figure 7 shows the individual load-displacement response for each fastener tested grouped by nail type, and Figure 8 shows the average load-displacement history of each nail type in single nail withdrawal. The common nail data appear noisy, which is believed to be the result of stick-slip motion, indicating nail withdrawal was still controlled by static friction despite the higher displacement rate compared with that specified in ASTM D1761 (ASTM International 2006). The common nail shows a nearly linear decay postpeak. The annular nail has a high initial peak; however, the load generally decays quickly due to the annular rings ''coring'' the wood. The gaps caused by this coring become filled with wood during withdrawal, and the response is then very similar to a common nail with postpeak response predominantly controlled by friction. The helical nail showed the highest average withdrawal load and generally showed higher capacity postpeak. When driving the helical nails they consistently rotated (or threaded) 1.25 turns but did not spin or unthread during withdrawal. This effect combined with the loose pitch of the helical threads likely contributed

Table 3.—Modified withdrawal test matrix.

Quantity	Stud type[a]	Nail type	Drive angle (°)
10	No. 2 SPF-s	Common	90
10	No. 2 SPF-s	Common	60
10	No. 2 SPF-s	Annular	90
10	No. 2 SPF-s	Annular	60
10	No. 2 SPF-s	Helical	90
10	No. 2 SPF-s	Helical	60

[a] SPF-s = spruce-pine-fir south.

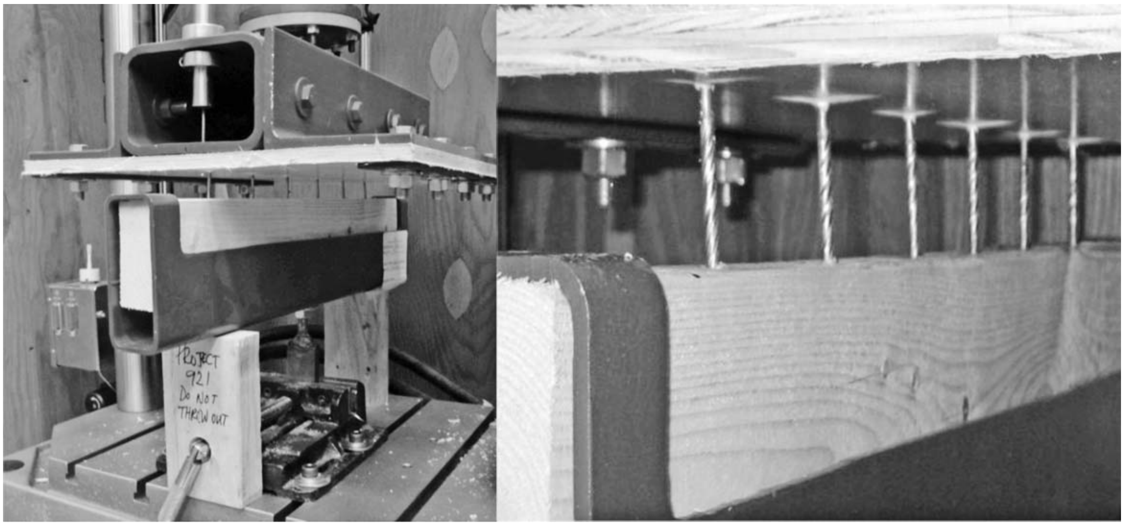

Figure 6.—Modified apparatus blocking setup.

to the longer sustained load, giving the shank more bearing length in the wood. The peak withdrawal load and withdrawal energy for each nail type are listed in Table 4.

Once each nail's block density was obtained per ASTM D2395 (ASTM International 2007), the density was plotted against the peak load and total withdrawal energy. A linear least-squares fit was used to relate density to both peak load and withdrawal energy. The linear least-squares fit and correlation coefficient (R^2) values for each nail type in the control studs can be found in Figures 9 and 10. It is generally accepted that fastener withdrawal capacity is dependent on wood density (AF&PA 2005); however, the testing performed here on 8d common nails in SPF-s did not show this. In contrast, the annular and helical nails were all found to have a reasonable linear correlation to density, with R^2 values between 0.36 and 0.82. Average peak load was more affected by density than the withdrawal energy. The stronger correlation between density and withdrawal capacity for the annular and helical nails compared with 8d common nails could be due to the capacity of the 8d common nail relying primarily on friction, whereas the withdrawal capacity of the annular and helical nails also depends on the bearing strength of the wood in contact with the nail shank deformations.

The measured average peak (maximum) loads are compared with the values predicted by the USDA (2010) in Table 4. The predicted peak withdrawal values p (in units of pound-force [lbf]) were computed using Equations 8-1

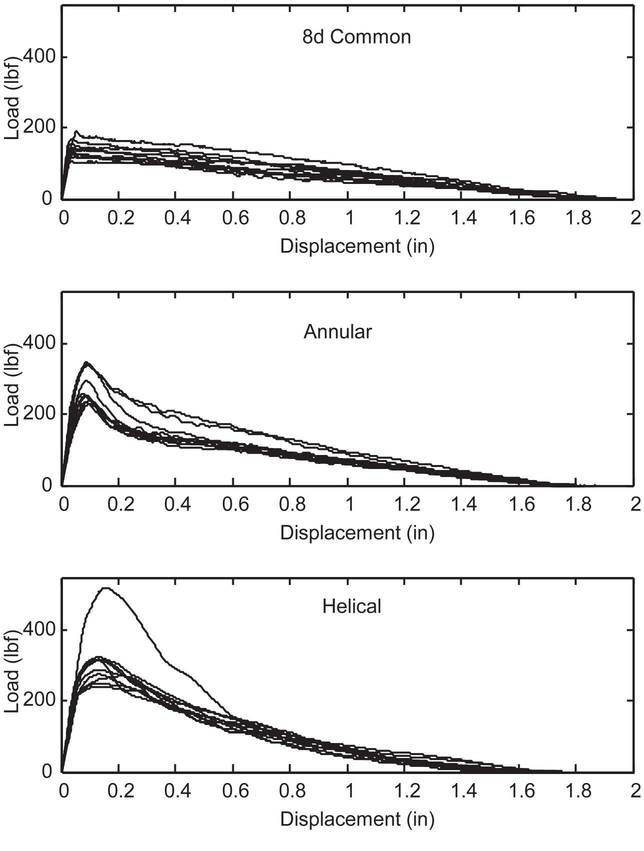

Figure 7.—Single nail withdrawal testing load displacement.

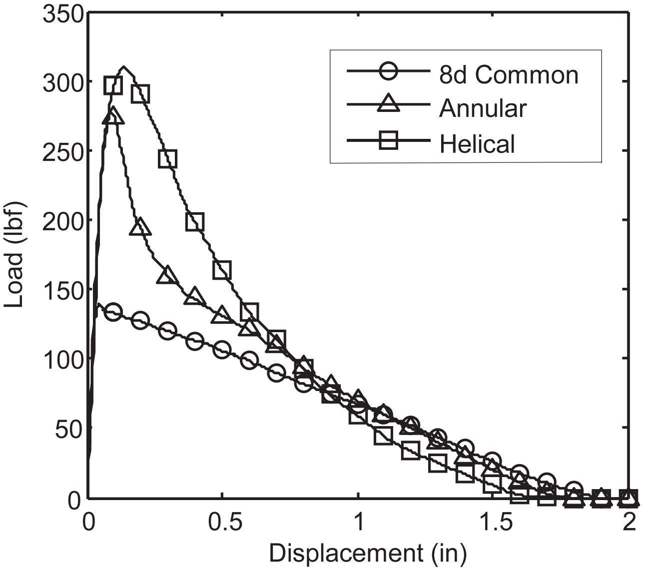

Figure 8.—Single nail withdrawal testing average load displacement.

Table 4.—Single nail withdrawal results.[a]

Nail type	Predicted withdrawal load, lbf [N][b]	Withdrawal load, lbf [N] (%)	Withdrawal energy, in.-lbf [N-m] (%)	Specific gravity (%)[a]
Common	153 [680]	164 [730] (16)	131 [14.8] (17)	0.351 (9)
Annular	306 [1,360]	283 [1,260] (17)	164 [18.5] (18)	0.327 (10)
Helical	340 [1,510]	313 [1,390] (25)	185 [20.9] (14)	0.334 (8)

[a] Coefficients of variation are shown in parentheses.

[b] According to US Department of Agriculture (2010).

and 8-2 from the *Wood Handbook* (see Eq. 1 and Eq. 2, respectively), which account for the depth of penetration of the nail in the member L (in.), the measured shank diameter D (in.), and average wood specific gravity G for the set of specimens. Equation 1 is used for smooth shank nails, while Equation 2 is used for shape-modified nails (i.e., annular and helical). The penetration depth was taken as the measured overall nail length minus 0.4 inch (10 mm). The measured values are consistently within 7 to 8 percent of the predicted withdrawal loads based on USDA (2010) empirical equations for all nail types.

$$p = 7,850 \times G^{5/2} \times D \times L\,(\text{in.} - \text{lbf}) \tag{1}$$

$$p = 10,000 \times G^{2} \times D \times L\,(\text{in.} - \text{lbf}) \tag{2}$$

Analysis of covariance

An ANCOVA was performed to determine whether or not density could be removed as a variable. The ANCOVA tests whether uncontrolled variables, such as density, have an effect on an outcome variable (peak load and energy in this case). Assuming a linear relationship, an ANCOVA can quantify and remove the effect of certain variables (covariates), which are predictive of the outcome of a test. If a statistically significant effect is determined, the ANCOVA analysis can be used to predict what the result would have been if the density of both sample sets had been equal. The ANCOVA uses linear correlation and regression to remove the effects of a certain variable among specimens by comparing between two sets of test data (Lowry 2002). The significance of the relationship is qualified in terms of a 0.05 or 0.01 level of significance, i.e., a 95 or 99 percent confidence interval.

In the ANCOVA, the 8d common nail data were not used because the common nails showed no correlation to density over the smaller density range observed within the SPF-s species. The standard F test values for the 95 percent confidence and 99 percent confidence were found to be 4.45 and 8.40 using 1 numerator degree of freedom and 17 denominator degrees of freedom, respectively (Lowry 2002). If the calculated F test value is greater than these respective numbers, the applicable level of confidence has been satisfied. The annular and helical nail analyses did not show a significant relationship between specimen density and peak load or total energy, with F values of 0.96 and 2.9, respectively. In other words, the ANCOVA analysis indicates that peak load and total energy values cannot be adjusted due to one sample set being denser than the other. The average density of the helical specimens was greater than the density of the annular specimens by only 2.2 percent.

Multinail withdrawal results

Figure 11 shows the individual load-displacement response for each multinail specimen grouped by nail type and drive angle, and Figure 12 shows the average load-displacement history of each nail type and drive angle. For direct comparison with the single fastener tests, the multinail withdrawal and energy values were divided by the number of fasteners in the connection (six). These results are summarized in Table 5.

One of the most apparent differences in the multinail results compared with the single nail results is the

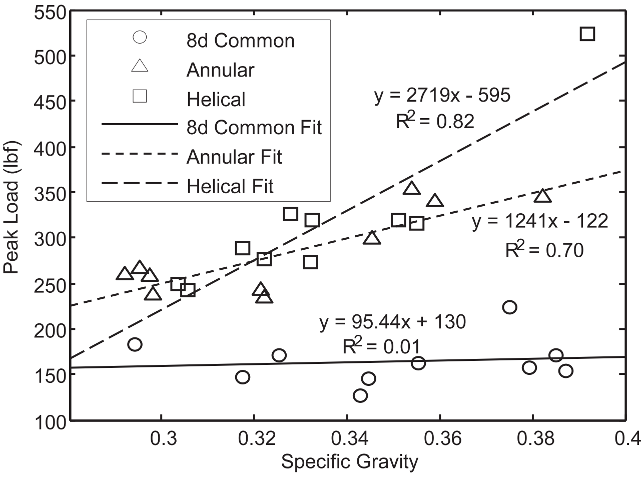

Figure 9.—Peak withdrawal load versus density linear least-squares fit.

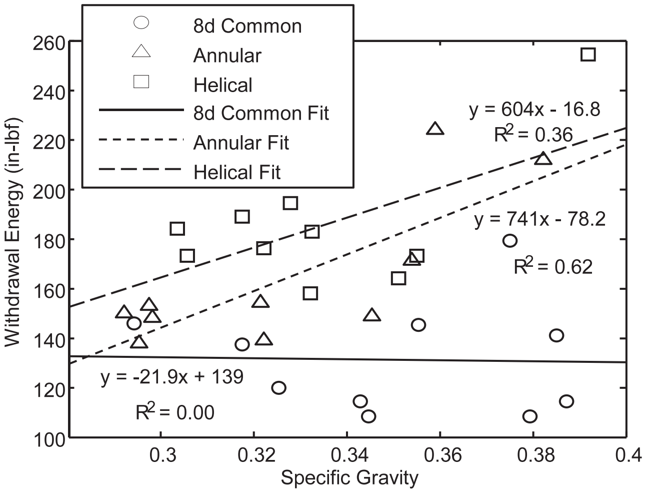

Figure 10.—Total withdrawal energy versus density linear least-squares fit.

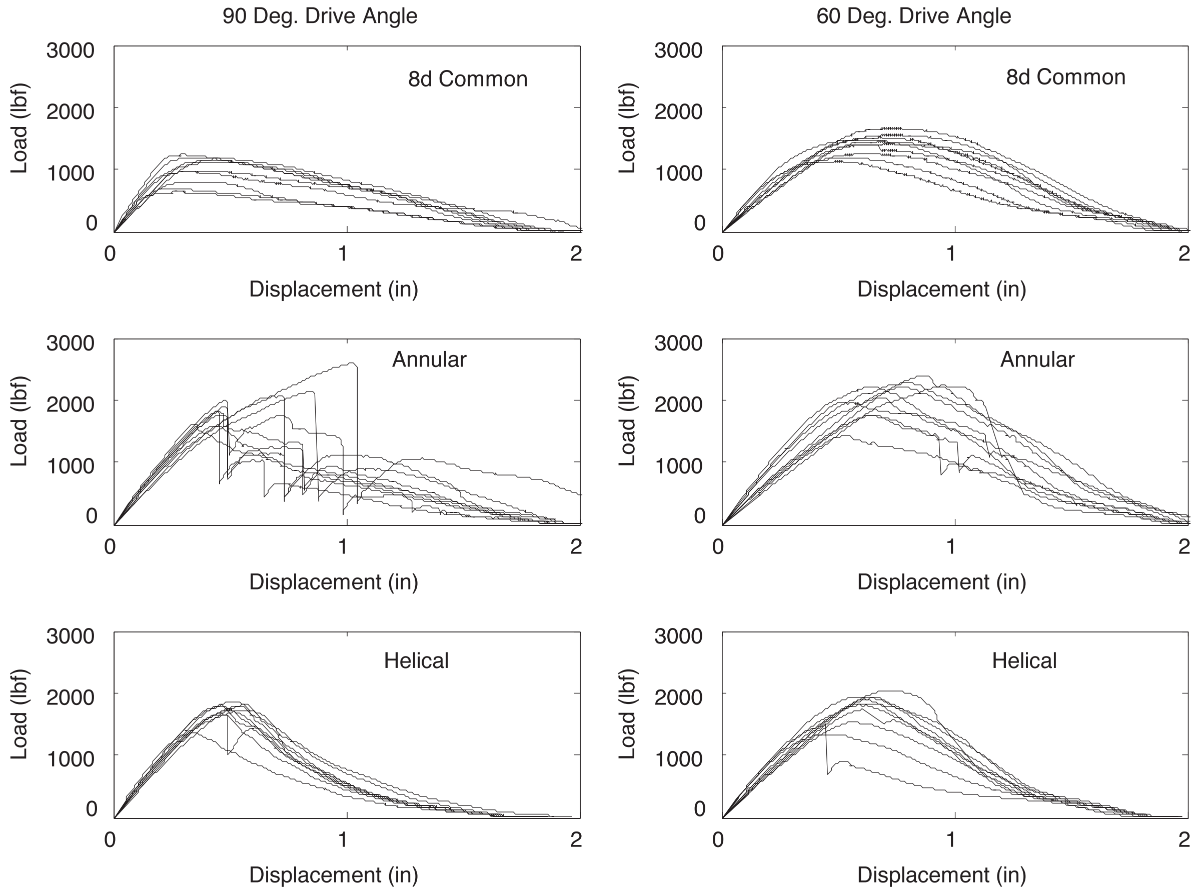

Figure 11.—Multinail withdrawal testing average load displacement.

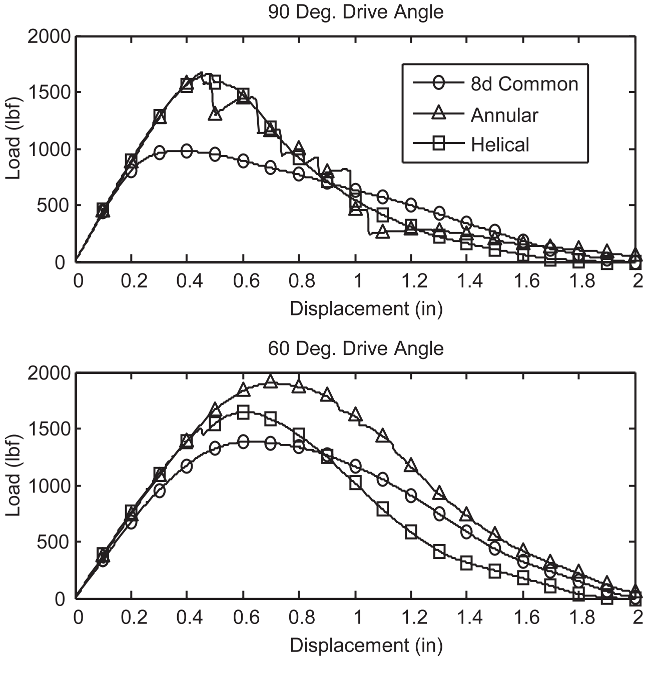

Figure 12.—Multinail withdrawal testing average load displacement.

decreased stiffness and greater displacements to the point at which the peak load is reached. One reason for this is the fact that the measured deformations include the compression of the sheathing that occurs locally at the bearing surfaces in the fixture. The other reason is load sharing among the six fasteners. The deflection at which peak load is developed in a single fastener is different for all nails. At a 90° drive angle, the response of the 8d common nails and helical nails was similar to that observed during single nail testing. However, the annular nails behaved differently in that there was generally a sudden decrease in a load just after the peak load was reached and an audible popping sound was noted.

Generally the average peak load per nail was similar to the single nail results at a 90° angle. The average peak load was slightly higher, nearly the same, and slightly less for the annular, 8d common, and helical nails, respectively. The coefficient of variation increased for the 8d common nails, but decreased for the other two. The withdrawal energy increased for all nail types, with significant gains noted for the 8d common and annular nails. The fact that the load is shared among nails seems to help improve average energy absorption. Mixed results were noted for the coefficient of variation for withdrawal energy.

The multinail testing apparatus allowed the effect of nail drive angle to be examined. The resistance of nails to withdrawal is generally greatest when they are driven perpendicular to the grain of the wood (USDA 2010), but this does not necessarily extend to multiple nails in a stitched pattern. Key results are summarized in Tables 5 and

Table 5.—Multinail withdrawal results.

Nail type	Drive angle (°)	Withdrawal load, in.-lbf [N] (%)[a]	Difference vs. single nail, 90° drive angle (%)		Withdrawal energy, in.-lbf [N-m] (%)[a]	Difference vs. single nail, 90° drive angle (%)	
			Load	COV		Energy	COV
8d Common	90	165 [736] (22)	1	37	175 [19.7] (24)	33	37
Annular	90	321 [1,430] (15)	13	−10	252 [28.5] (26)	54	42
Helical	90	286 [1,270] (8)	−9	−68	200 [22.6] (12)	8	−17
8d Common	60	235 [1,040] (12)	43	−25	259 [29.3] (15)	98	−13
Annular	60	338 [1,500] (15)	19	−11	336 [38.0] (18)	105	−3
Helical	60	292 [1,300] (13)	−7	−48	247 [27.9] (17)	34	19

[a] Coefficients of variation (COV) are shown in parentheses.

6. Table 5 compares the average values per nail from multinail testing with the average values per nail from single fastener testing, whereas Table 6 compares the effect of drive angle for only the multinail configuration.

As shown in Table 6, the largest increase in peak load per nail produced by the 60° drive angle compared with the 90° drive angle was 42 percent for the 8d common nail. The annular and helical nails saw a more modest increase in capacity with the reduced drive angle. However, the annular and helical nails still have more load capacity than the 8d common nail at either of the drive angles tested. Withdrawal energy was 24 to 48 percent greater for all nail types at the 60° drive angle versus the 90° drive angle.

Summary and Conclusions

This study has focused on assessing the withdrawal capacity of three different types of nails: 8d common, annular, and helical. A baseline set of data was collected for single nails in accordance with ASTM D1761 (ASTM International 2006). Tests were performed until complete withdrawal occurred in order to quantify the total withdrawal energy. The average peak loads from testing were within 7 to 8 percent of the values predicted per the USDA (2010). The annular and helical nails had much higher peak load capacity than the common nails, and their withdrawal energy was also greater.

A new device was developed to subject multiple (six) nails to withdrawal loading simultaneously. Reinforced sheathing was used to transfer load from the hydraulic actuator to the nails, which is representative of actual structural response where there is load sharing among the nails. It was necessary to reinforce the sheathing in order to prevent nailhead pull-through. This device allowed the effect of using a stitched nailing pattern to be quantified in terms of average peak load and withdrawal energy per fastener, where the stitched fasteners were driven at an angle of 60° from the face of the stud in alternating directions. It was found that the stitched pattern resulted in significantly higher peak load capacity per fastener for 8d common nails but very similar peak load capacity for the helical and annular nails. Withdrawal energy was higher for all nail types using the stitched pattern. Additional testing with a larger sample set may allow adjustment factors to be developed to modify Equations 8-1 and 8-2 from the *Wood Handbook* (see Eq. 1 and Eq. 2, respectively) to account for multinail configurations and a stitched nailing pattern.

Table 6.—Comparison of 60° drive angle results with 90° drive angle results.

Nail type	Difference in peak withdrawal load (%)		Difference in withdrawal energy (%)	
	Load	COV	Energy	COV
8d Common	42	−45	48	−36
Annular	5	−2	33	−32
Helical	2	59	24	43

Based on these results, a stitched nailing pattern could be beneficial when attaching sheathing subjected to significant uplift forces in light wood-frame construction. However, it must be noted that the effect of stitched nailing pattern on lateral nail capacity was not assessed. Further, annular and ring shank nails still provide higher withdrawal capacities than common nails driven in a stitched pattern. Finally, this study has not assessed the effect of moisture content changes on withdrawal capacity, which could be significant.

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