Digital Commons @ George Fox University

Faculty Publications - Biomedical, Mechanical, and Civil Engineering

Department of Biomedical, Mechanical, and Civil Engineering

1996

Threaded-nail Fasteners - Research and Standardization Needs

B L. Wills
Texas A & M University - College Station

S G. Winistorfer

D A. Bender

David Pollock
George Fox University, dpollock@georgefox.edu

Follow this and additional works at: https://digitalcommons.georgefox.edu/mece_fac

Part of the Civil Engineering Commons, Mechanical Engineering Commons, and the Structural Materials Commons

Recommended Citation

Wills, B L.; Winistorfer, S G.; Bender, D A.; and Pollock, David, "Threaded-nail Fasteners - Research and Standardization Needs" (1996). *Faculty Publications - Biomedical, Mechanical, and Civil Engineering*. 33.
https://digitalcommons.georgefox.edu/mece_fac/33

This Article is brought to you for free and open access by the Department of Biomedical, Mechanical, and Civil Engineering at Digital Commons @ George Fox University. It has been accepted for inclusion in Faculty Publications - Biomedical, Mechanical, and Civil Engineering by an authorized administrator of Digital Commons @ George Fox University. For more information, please contact arolfe@georgefox.edu.

THREADED-NAIL FASTENERS — RESEARCH AND STANDARDIZATION NEEDS

B. L. Wills, S. G. Winistorfer, D. A. Bender, D. G. Pollock

ABSTRACT. *Threaded nail fasteners are commonly used in agricultural and commercial post-frame structures, yet there has been insufficient research to fully understand the effect of threads on withdrawal and lateral load resistance. The objective of this article is to review technical information on threaded nail fasteners and to identify problems facing manufacturers, designers, and users of threaded nail fasteners for engineering applications. Recommendations are given concerning research and standardization needs.*
Keywords. *Nail, Threaded, Annular, Helical, Withdrawal, Lateral, Connections.*

Nails are among the most common fasteners used in wood structures, yet the basis of the allowable design values is generally not well understood within the structural engineering community. In the United States allowable nail design values were included in the first edition of the National Design Specification for Wood Construction (NDS), which was published in 1944 by the National Lumber Manufacturer Association (NLMA, 1944). Significant changes in nail fasteners have occurred since the 1930s and 1940s, although most have involved advances in manufacturing methods or the introduction of specialty nails, rather than changes in design procedures. Historically, when new nail fasteners were introduced, the allowable design values were estimated from limited test data on similar nails, together with conservative engineering judgment.

Threaded nails are emphasized in this article due to their widespread use in agricultural and commercial post-frame structures, together with the fact that relatively little performance data are available for these fasteners. Since comprehensive test data for threaded nails are not available in the published literature, allowable design values similar to those for common, smooth-shank nails have been assigned to threaded, hardened-steel nails of the same pennyweight designation. However, field experience with threaded nails suggests that published design values are overly conservative (Geisthardt et al., 1991). Research is needed to expand the database on threaded nail performance over a broad range of sizes (6 to 90d) and thread characteristics. This need is intensified by the introduction of European yield theory in the 1991 NDS [American Forest & Paper Association (AF&PA), 1991]. The shift to European yield theory has also prompted many engineers and scientists to critically examine the need for a new nail classification system, as well as manufacturing and test standards.

The objectives of this article are to:

- Review technical information on threaded nail fasteners.
- Focus attention on problems facing manufacturers, designers, and users of threaded nail fasteners for engineering applications.
- Recommend approaches for solving these problems.

MANUFACTURING

The use of nails dates back to the days of ancient Egypt, Greece, and Rome. However, it was not until the mid-1800s that the nail manufacturing industry was revolutionized by the development of the automated wire-nail production machine for mass production. Today, there are approximately 5,000 different types and sizes of nails commercially available throughout the world, although only approximately 2,900 of these are used for wood construction applications (Ehlbeck, 1979). These nails not only differ by shank diameter size, length, head type, and point type, but also by metal or metal alloy material, shank surface coating, and shank characteristics.

During the manufacturing process, coils of wire are produced by drawing steel rod stock (approximately 7.11 mm diameter) through a series of dies to the diameter required for nail manufacturing. The steel wire is compressed along the major axis to form the nail head and pinched on the opposite end to form the point. Once the nail is formed, it may also go through a mechanical deformation process whereby threads are rolled into the shank surface. This last step is what differentiates "deformed-shank" (or threaded-shank) nails from plain- or smooth-shank nails.

The authors are **Brian L Wills,** Technical Representative. TrusJoist MacMillan, 3468 Blackwood Drive, Traverse City, Michigan (former Graduate Instructor, Agricultural Engineering Dept., Texas A&M University, College Station); **Steve G. Winistorfer,** ***ASAE Member Engineer,*** Research General Engineer, USDA-FS Forest Products Laboratory, One Gifford Pinchot Drive, Madison, Wisconsin; **Donald A. Bender,** ***ASAE Member Engineer,*** Professor, and **David G. Pollock,** **ASAE** ***Member Engineer,*** Research Associate, Agricultural Engineering Dept., Texas A&M University, College Station. **Corresponding author:** Donald A. Bender, Agricultural Engineering Dept., Texas A&M University, College Station, TX 77843-2117.

Shank Properties

Threaded-shank nails, commonly used in the post-frame construction and wood pallet industries, have mechanically deformed shanks with either annular or helical threads as shown in figure 1. An annularly threaded nail, commonly called a ring-shank nail, has multiple ring-like threads rolled around the shank in planes perpendicular to the nail axis. After the rolling process, the annularly threaded nail will have a smaller root diameter than the original wire diameter.

Helical threads are continuous multiple helix depressions rolled into the nail shank with resulting expansion approximately equal to the depression [American Society for Testing and Materials (ASTM), 1995a]. The thread of a helically threaded nail runs approximately two-thirds of the nail length, similar to the thread of a wood screw. Since the cross-sectional area before and after the helically threaded nail is formed is approximately the same, the design diameter is equal to the wire diameter.

Standards

Presently, Federal Specification FF-N-105B (1977) is the primary nail manufacturing standard in the United States. The nail criteria established by FF-N-105B are that the steel wire shall be of "good commercial quality" and satisfy a certain minimum cold bend angle criteria depending on the carbon content and the hardening process, except for mechanically deformed-shank nails which do not require cold bend tests. Details on cold bend tests for nails (and other test methods such as impact bend) are given in ASTM F680 (1995 b). In addition, a minimum ultimate tensile strength is specified for aluminum alloy wire, although there is no such requirement for steel wire.

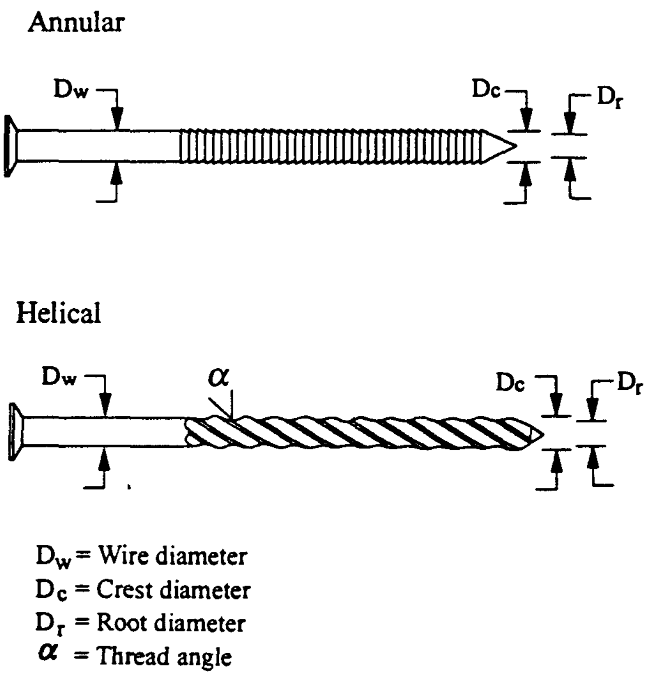

Figure 1–Dimensions of helical threaded-shank and annular threaded-shank nails. Thread expansions are equal to thread depressions for helical threads, therefore the effective wire diameter remains the same. However, with annular threads the effective diameter (root diameter) is less than the initial wire diameter.

The size and shape requirements in FF-N-105B include pennyweight (d), nail length, diameter or width of head, and wire diameter prior to deformation. Additionally, the NDS specifies that threaded nails be of high carbon steel and heat-treated and tempered for published NDS design values to apply (AF&PA, 1991).

The current state of standardization in the nail manufacturing industry permits significant differences among plain-shank and deformed-shank nails. The wire diameters of most plain-shank nails vary from 6 to 33% larger than diameters of threaded-shank nails of the same pennyweight designation (AF&PA, 1991), as summarized in table 1. For example, a 16d common plain-shank nail has a wire diameter of 4.11 mm (0.162 in.) compared to 3.76 mm (0.148 in.) for a 16d threaded-shank nail. With smaller nails (8 to 20d), the threaded-shank nail diameter is only 6 to 8% smaller than the plain-shank nail diameter. In larger diameter nails (20 to 60d), the plain-shank nail diameter continues to increase from 4.88 to 6.68 mm (0.192 to 0.263 in.) with each increased pennyweight designation. However, the diameter of the threaded-shank nail remains constant at 4.50 mm (0.177 in.) over the same range of pennyweights. These differences in wire diameter result in lower allowable withdrawal and lateral design values for large threaded nails as compared to plain-shank nails for the same pennyweight designation.

Pennyweight Classification System

The pennyweight system has been used for decades as an index of nail size, but over the years several anomalies and ambiguities have arisen. For example, a 12d common nail diameter is 3.76 mm (0.148 in.) as compared to a 12d threaded nail diameter of 3.43 mm (0.135 in.), representing an 8.8% difference. Also, nails used for joist hangers have shorter lengths than corresponding common nails of the same pennyweight due to the thin side member (hanger) and penetration restrictions dictated by supporting joists and beams. Loferski and McLain (1991) recommended the pennyweight system should not be used to specify nails for engineering purposes; rather, the nail diameter and length should be explicitly specified. Additionally, the nail classification should include some indication of nail bending yield strength.

We propose the following as two possible nail classification systems which would satisfy the previously mentioned requirements. The first system would involve creating nail grades based on bending yield strength of the nails, analogous to lumber grades. The manufacturer would

Table 1. Comparison of wire diameters of common shank and deformed shank nails (AF&PA, 1991)

Pennyweight Designation	Wire Diameter Comparison: Common Shank Diameter [mm (in.)]	Deformed Shank Diameter [mm (in.)]	Diameter Difference (%)
6d	2.87 (0.113)	3.05 (0.120)	–6.2
8d	3.33 (0.131)	3.05 (0.120)	8.4
10d	3.76 (0.148)	3.43 (0.135)	8.8
12d	3.76 (0.148)	3.43 (0.135)	8.8
16d	4.11 (0.162)	3.76 (0.148)	8.6
20d	4.88 (0.192)	4.50 (0.177)	7.8
30d	5.26 (0.207)	4.50 (0.177)	14.5
40d	5.72 (0.225)	4.50 (0.177)	21.3
50d	6.20 (0.244)	4.50 (0.177)	27.5
60d	6.68 (0.263)	4.50 (0.177)	32.7

label the containers with the nail diameter, length, and bending yield strength classification. For example, the current 16d common nail could be labeled as a “4.11A-89 common” in the International System of Units (SI), or a “0.162A-3.5 common” in the English system of units. This label designates a common nail with a high bending yield strength (signified by the “A”), 4.11 mm (0.162 in.) diameter, and 89 mm (3.5 in.) length. This system would require extensive education of contractor and designers, and could be difficult to monitor and enforce.

A second classification system, which would be easier for contractors and designers to implement, would require nail manufacturers to use wire with a minimum tensile strength for the production of nails used in structural applications, similar to the requirements for aluminum alloy wire nails. The designer could then specify the wire diameter and nail length, and would be guaranteed a minimum joint performance. This system could result in negative repercussions for nail manufacturers who may be currently using steel wire below whatever material standard becomes defined as the minimum. If required to upgrade steel quality to comply with minimum material quality standards, manufacturers could be faced with higher raw material costs as well as the possibility of increased wear and associated maintenance on machines and dies. Unfortunately, this system would also penalize manufacturers who produce higher strength nails since design values would be based on the minimum steel wire strength, and credit could not be taken for the enhanced performance of higher strength nails.

In short, a revised classification system of some type appears to be needed (from both safety/reliability and market clarity standpoints), although the design, implementation, and acceptance of such a system would be a challenge for manufacturers and users alike.

DESIGN

Over the past fifty years the NDS has gone through several revisions, but the scope has remained the same-to provide accurate wood design criteria and information to designers of wood structures. Approximately two-thirds of the 1991 NDS addresses mechanical fasteners—nails, spikes, wood and lag screws, bolts and timber connectors (Winistorfer, 1992). Fasteners in joints cart be placed under pure lateral (shear) load, pure withdrawal load, or any combination of the two. The NDS primarily addresses pure lateral and pure withdrawal loads for nail design values, although toe-nail provisions in the NDS address combined loading conditions to a limited extent.

Through field experience, threaded nails are believed to provide increased allowable capacity over the common nail (Geisthardt et al., 1991). However, code writing agencies do not have a comprehensive database for threaded nail strengths on which to base such a conclusion. Also, the limited research performed using threaded nails shows that differences exist in the thread geometry of different manufacturers, which can significantly affect strength.

As previously mentioned, the wire diameters of threaded-shank nails are slightly smaller than the wire diameters of plain-shank nails for the same pennyweight designation. Since wire diameter has a direct influence on allowable design values, the larger diameter of the plain-

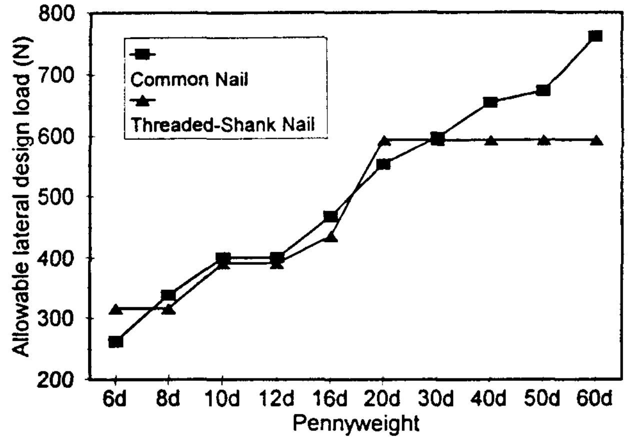

Figure 2–Comparison of lateral design values for different pennyweight designations, based on 12.7 mm (1/2 in.) side member thickness and a specific gravity of 0.50 (AF&PA, 1991).

shank nail is assumed to directly offset the increased withdrawal strength associated with the deformed shank of threaded nails. Similarly, for allowable lateral design values, the larger diameter of the plain-shank nail is assumed to directly offset the increased bending strength of the high carbon, heat-treated, tempered steel specified in the NDS for threaded nails. Since the diameters of larger threaded nails (greater than 20d) do not increase with pennyweight as do those of common wire nails, a ratio of common-to-threaded nail diameter is used to assign the allowable design values for threaded nails. For example, 30 to 60d threaded nails are given the same design values as the 20d common nail and the 70 to 90d threaded nails are given the same design value as the 40d common nail (AF&PA, 1993; Whistorfer, 1994). Figures 2 and 3 depict lateral and withdrawal design values for common and threaded nails, respectively.

The NDS explicitly recognizes the superior performance of threaded nails compared to smooth nails under conditions of variable wood moisture content. During cyclic moisture conditions, wood fibers expand and contract and lose contact with the nail shank, resulting in a

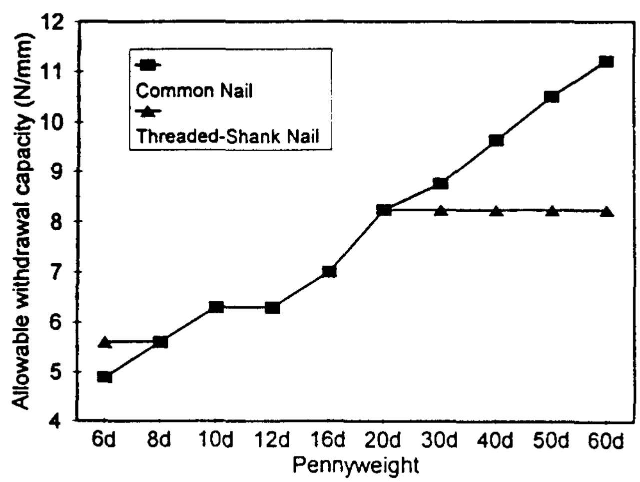

Figure 3–Comparison of withdrawal capacities for different pennyweight designations, based on a specific gravity of 0.50 (AF&PA, 1991).

75% reduction in allowable withdrawal design capacity of plain-shank nails (AF&PA, 1991). When using a threaded nail, the wood fibers remain locked into the nail threads and no decrease in allowable desire value is required.

As discussed earlier (and shown in table 1), threaded-shank nails have smaller wire diameters than smooth-shank nails of the same penny weight (over most of the penny weight range), which would normally result in lower withdrawal and lateral design values. However, because field experience and limited testing have shown threaded-shank nails to have increased strength capacity, the smaller diameter threaded-shank nails actually have the same design values (or nearly so) as common nails of the same pennyweight.

Lateral Design Values

Between the 1944 and 1986 editions of the NDS, relatively little change occurred in allowable lateral nail design equations. The allowable lateral design values for nails were based on proportional limit strength data for nailed connection tests in accordance with ASTM D1761 (1995d), and adjusted for duration of load, safety, and experience (AF&PA, 1993). Some researchers have reported that the proportional limit for laterally loaded nailed connections occurs at approximately 0.38 mm (0.015 in.) of joint deformation, as illustrated in figure 4 (USDA, 1987). One limitation of this empirical model is its failure to consider the effects of side member thickness on elastic connection performance. In 1962, the NDS first recognized the use of threaded hardened-steel nails and established their allowable lateral design values as identical to common nails of the same pennyweight for the range of 6 to 20d, and smaller than common nails for 40 to 90d nails due to the constant diameter of threaded nails in this range. Even with the changes in the design methodology of lateral connections in the 1991 NDS (discussed later), this convention remains virtually intact in the current NDS (fig. 2).

The 1991 NDS includes major changes in allowable lateral design values for connections based on the European yield theory developed by Johansen (1949). Johansen used theoretical models to predict the shear transfer through a bolted connection of wood members. The models have been expanded to include all dowel-type fastener connections. The yield model describes the yield strength of a single dowel-type connection. The NDS defines this yield point as the 5% offset yield load. The 5% offset yield load is found by drawing a line on the connection load-deformation curve parallel to the initial stiffness of the joint, offset by 5% of the fastener diameter (fig. 4). This yield point normally falls between the proportional limit and the ultimate capacity of the connection. The offset value is then reduced by a conversion factor, K_D, to arrive at the allowable design values for nails, which have been calibrated to provide similar design values to those found previously in the 1986 and earlier NDS editions. However, the 5% offset yield load is a more consistent predictor of joint performance than the 0.38 mm (0.015 in.) deformation-based model because it accounts for joints which exhibit different magnitudes of initial stiffness. As figure 5 illustrates, a stiff connection (A) may have only a slightly higher lateral load capacity than a less stiff connection (B) at 0.38 mm deformation. However, comparing 5% offset yield loads, Connection A has significantly greater lateral load capacity, since its true proportional limit occurs at a deformation level greater than 0.38 mm. The yield model also contains provisions to define specific connection configuration and material (wood and steel) properties.

In 1986, Aune and Patton-Mallory (1986a, b) applied the European yield theory to nailed connections. They determined three different yielding modes: 1) wood yielding (crushing) in either side or main member, 2) wood yielding in both members and nail yielding in one member; and 3) wood and nail yielding in both members (fig. 6).

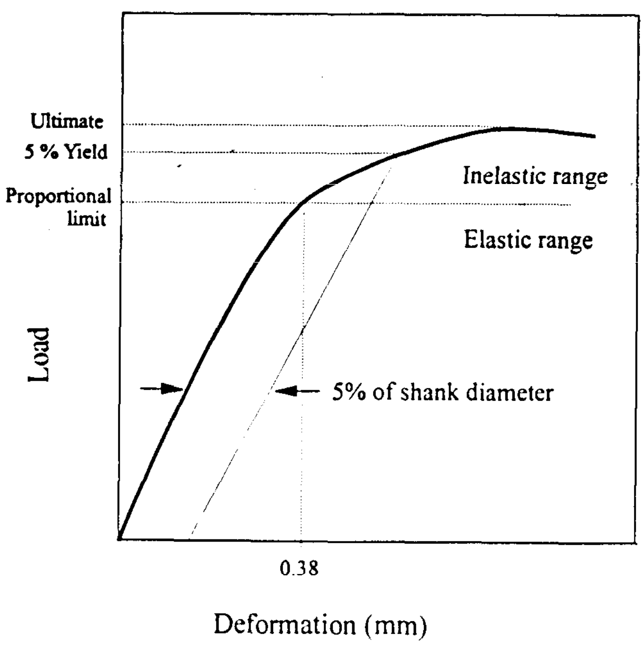

Figure 4–Comparison of load at 0.38 mm (0.015 in.) proportional limit, 5% offset yield point and ultimate capacity (Winistorfer, 1992).

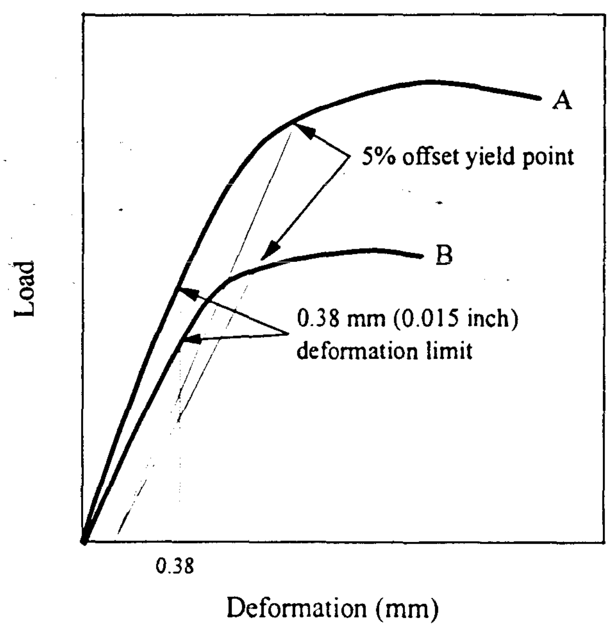

Figure 5–Comparison of proportional limit at 0.38 mm (0.015 in.) deformation vs. 5% offset yield point for two nailed connections. The 5% offset yield is a better indicator of nail performance.

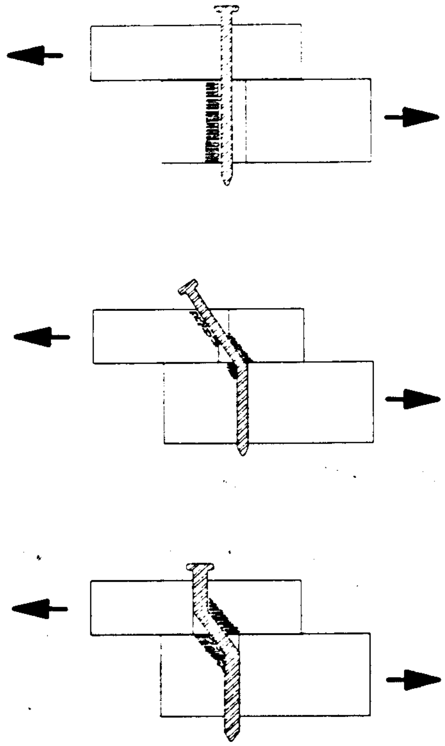

Figure 6–Three possible yield modes of nail connections as defined by Aune and Patton-Mallory (1986a, b).

The design equations found in the 1991 NDS are derived from the yield models and include variables for dowel bearing strength, nail bending yield strength, and connection geometry.

The 1991 NDS contains tables of the allowable values generated from the yield equations for particular connection configurations. However, caution is required when using these tabular values, which were generated using the effective shank diameter at the shear plane(s). As a footnote indicates, tabular values do not apply to annularly threaded nails when the threaded section is located at the shear plane. As mentioned earlier, the root diameter of the annularly threaded nail is less than its shank diameter, so a reduced diameter is needed to calculate allowable lateral loads when the threaded portion of the nail is positioned at a shear plane. Because helically threaded nails do not have a reduced cross-section, this footnote does not apply and use of the tabular values is acceptable.

Dowel Bearing Strength. The dowel bearing strength (F_e), also referred to as wood embedment stress, is a new material property defined as the compressive strength of the material (wood or steel) under the fastener. Wilkinson (1991) derived the dowel bearing strength values for wood members published in the 1991 NDS. Dowel bearing strength was tested for wood members with average specific gravities ranging from 0.37 to 0.50 (ovendry weight, volume at 12% moisture content basis), which covers many of the softwoods used for structural purposes in the United States. The tests included 10, 16, and 40d smooth-shank nails with diameters of 3.76, 4.11, and 5.72 mm (0.148, 0.162, and 0.225 in.), respectively. Wilkinson reported dowel bearing strength to be unaffected by the nail diameter and grain direction. Combining data from both parallel-to-grain and perpendicular-to-grain tests, Wilkinson established a relationship between specific gravity and dowel bearing strength.

Nail Bending Yield Strength. The European yield theory has caused additional research needs to surface. Among these is determination of nail bending yield strength. Loferski and McLain (1991) performed tests to arrive at the bending yield strength values found in the 1991 NDS. The nails were subjected to a simply supported, center-point loading. The load-deformation curve was plotted and the 5% offset yield load defined the nail yielding value. [This test procedure has since been adopted as ASTM F1575 (1995c).] The bending yield strength was observed to increase with decreasing wire diameter. This was expected since smaller diameter wire is drawn down through forming dies and therefore undergoes more strain hardening than nails of larger diameter. The common nails used in this study ranged in size from 6 to 20d. The bending yield strength for larger diameter nails (40 to 90d) were extrapolated from the test data. However, this extrapolation may not be appropriate since less strain hardening occurs in the larger diameter nails.

Another limitation of the Loferski and McLain study was that threaded nails were not considered. Consequently, the allowable bending yield strength for threaded nails was assumed to be approximately 30% higher than common nails due to the hardened steel commonly used for threaded nails (AF&PA, 1991). Loferski and McLain applied regression analysis to develop art empirical model for bending yield strength of common wire nails based on wire diameter. The coefficient of determination was low (R^2= 0.22), possibly due to variation in the quality of steel used in nails and the varying degree of strain hardening that occurs in the nail manufacturing process.

Currently, Federal Specification FF-N-105B does not contain a minimum quality standard for steel wire used in nails — it only specifies a "good commercial quality" steel. Consequently, nail manufacturers may use steels with a wide range of carbon contents, depending on product and manufacturing requirements. An alternative approach for predicting bending yield strength would be to use the grade of steel or a mechanical property of the wire such as tensile strength as a basis. Tensile strength is related to steel quality, and can therefore be tracked to raw material bar stock.

Connection Geometry. The 1986 NDS design values were assigned to each nail size and type for selected groups of wood species, and these values applied to all applications using a particular nail (National Forest Products Association, 1986). Such equations only considered the nail diameter and the lowest specific gravity of any wood species in the group. The European yield theory explicitly accounts for wood members having different specific gravities and thicknesses. Dowel bearing strength values for steel or wood members can also be used when designing connections according to the European yield theory.

Withdrawal Design Values

The empirical equation used to determine the allowable withdrawal design values for nails and spikes has changed only slightly since the 1944 edition of the NDS. The equation is based on research conducted at the Forest

Products Laboratory (FPL) in 1931 and revised and updated in 1958 and 1965 to determine the ultimate withdrawal resistance of nails embedded in 54 American softwoods and hardwoods, ranging in specific gravity from 0.32 to 0.74 (FPL, 1965). Based on the above research, the allowable withdrawal equation is

$$W_a = K\, G^{5/2}\, D \qquad (1)$$

where

- W_a = nail or spike allowable withdrawal value per unit length of penetration in the member holding the nail point [N/mm (lb/in.)]
- K = empirical constant including a reduction factor of 5 for duration of load and safety ($K = 9.515$ for SI units; $K = 1{,}380$ for English units)
- G = specific gravity of the member holding the nail point based on ovendry weight and volume
- D = wire diameter of the nail [mm (in.)]

During the 1970s the Forest Products Laboratory revised specific gravity data to be based on ovendry weight and volume at 12% moisture content instead of ovendry weight and ovendry volume. Converting the original allowable withdrawal design equation to account for the change in specific gravity yields a revised form for the allowable withdrawal equation for nails and spikes: (USDA, 1987).

$$W_a = K_{12}\, G_{12}^{5/2}\, D \qquad (2)$$

where

- K_{12} = empirical constant with the specific gravity conversion ($K_{12} = 10.82$ for SI units; $K_{12} = 1{,}570$ for English units)
- G_{12} = specific gravity based on ovendry weight and volume at 12% moisture content
- D = wire diameter of the nail [mm (in.)]

Both of these equations are valid and result in similar allowable design values. However, the AF&PA currently publishes equation 1 in the NDS commentary, while the U.S. FPL currently publishes equation 2.

The only two parameters used to determine withdrawal design values are the wood specific gravity and the nail wire diameter. The wood strength, or holding capacity, is directly correlated to the specific gravity of the wood and wire diameter give-s art index for the amount of surface contact between the nail and the surrounding wood. As the nail is driven into the wood, either by hand or pneumatically, the wood fibers are forced outward. This causes the nail to be wedged between adjacent wood fibers, providing resistance against nail withdrawal. Any broken wood fibers caused by nail driving will provide little contribution to the total nail holding capacity (Stern et al., 1973)

Review of Threaded Nail Performance Data

The threaded-shank nail is favored in demanding applications, such as in post-frame construction, due to its superior withdrawal resistance. Limited research shows the ultimate withdrawal resistance of a 5.11-mm (0.201 -in.) diameter threaded spike is approximately twice the resistance of a larger 5.51-mm (0.217 -in.) diameter plain-shank spike when driven into dry lumber (Ehlbeck, 1973). Stern (1969) reported that threaded nails provide as much as nine times the ultimate withdrawal resistance of plain-shank nails having the same diameter. Other studies display similar results for withdrawal resistance (Stern, 1963; Ehlbeck, 1976; Quackenbush, 1977).

Stem (1977) conducted a study using 8, 12, 16, 40, and 60d helically threaded nails. He observed an ultimate-to-allowable lateral load ratio of 7:1 for smaller diameter nails (8 to 16d), while 40 and 60d nails had ratios of 8.6:1 and 9.3:1, respectively. Since a ratio of 5:1 is generally considered adequate for softwood species (AF&PA, 1993), the allowable design values of helically threaded nails appear to be conservative, Hoadley (1977), like Stern, reported ultimate lateral strength values for hardened annularly threaded nails with 5.16- and 7.62-mm (0.203- and 0.300-in.) shank diameter and compared them to lag screws with similar diameters of 6.17 and 7.70 mm (0.243 and 0.303 in.). Hoadley observed that hardened annularly threaded nails carried 28% more lateral load than the corresponding lag screws. Since Hoadley and Stern did not report the lateral load at the 0.38-mm proportional limit or 5% offset yield, these values cannot be directly compared to values generated from previous or current NDS design equations. However, the results do attest to the increased ultimate strength provided by hardened threaded nails.

Besides the differences between threaded-shank nails and plain-shank nails, limited research shows significant differences within each type of threaded-shank nail. For example, thread angle and geometry vary widely among threaded nails (thread angle is illustrated in fig. 1). Helically threaded nails with a small thread angle (less than 20°) perform similarly to annularly threaded nails. When driven, the wood fibers are wedged between the helical threads which slightly increases withdrawal resistance. When driving a nail with a thread angle of approximately 45 to 65°, the nail will rotate or thread itself into the wood fibers, reducing the amount of wood fiber damaged, similar to the principle of wood screws and lag screws. Thus, a 45 to 65° thread angle appears to provide the greatest increase in withdrawal resistance over the plain shank nail. **A** large thread angle (greater than 65°) nail, like the 45 to 65° thread angle nail; will rotate into the wood, except with the longer helix the nail has the tendency to back out under axial forces (Ehlbeck, 1976, 1979). Thread geometry including the depth of depression and expansion of metal, also has an impact on withdrawal resistance. White and Gales (1990) and Ehlbeck (1976) showed that thread expansion, the difference between crest diameter and wire diameter, varies from 0.08 to 0.76 mm (0.003 to 0.030 in.), representing approximately a 123% difference in withdrawal resistance. According to Ehlbeck (1976, 1979), the optimum helically threaded nail should have a 45 to 65° thread angle with a thread expansion distance of 0.76 mm (0.030 in.).

Similar experiences occur in the manufacturing of annularly threaded nails. During an informal survey of nail manufacturers, Winistorfer (1992) found the root diameter to vary from 70 to 85% of the wire diameter. As stated previously, the root diameter has a major influence when calculating allowable lateral design values with the threaded portion of the nail in the shear plane.

In summary, previous research on threaded nails has focused primarily on characterizing the ultimate strength of nailed connections loaded either laterally or in withdrawal. Since most of the research on nailed connections was conducted prior to the adoption of design equations based on the European yield theory, properties such as nail bending yield strength, dowel bearing strength, and 5% offset yield point for threaded nail connections have not been reported in the literature. Additional research is also needed to establish a clear relationship between threaded shank variables and nailed connection strength. Comprehensive research is needed to clearly establish these properties for threaded nails, in order to provide improved connection design values in the NDS.

Summary and Recommendations

Since threaded nails were first recognized in the 1962 edition of the NDS, limited research has been conducted to fully understand their withdrawal and lateral strength capabilities. There is a critical need to update the database on threaded nail performance over a broad range of sizes (6 to 90d) and thread geometries. Federal Specification FF-N-105B does not contain specific requirements for thread geometries, so manufacturers fabricate their nail threads slightly differently to extend die and roller life, thereby reducing manufacturing and maintenance costs. Research has shown that commercially available threaded nails vary significantly in thread angle, thread expansion, and root diameter-each of which has a significant impact on strength (Ehlbeck, 1976; Ehlbeck 1979; White and Gales, 1990; Winistorfer, 1992).

In order for the design community to recognize the apparent superior withdrawal and lateral holding capacity of threaded nails, definitive research is needed to

- Characterize the effects of threaded shank variables (thread angle, thread expansion, root diameter) on lateral and withdrawal strengths.
- Develop minimum standards for threaded nail geometry, including the optimum thread angle and minimum thread expansion and root diameter.
- Determine whether the assumed 30% increase in bending yield strength of threaded, hardened-steel nails (over that of common nails) is valid.
- Develop and implement a new nail classification system for engineered applications using nail fasteners. Such a system should specify the nail type, steel bending yield strength, wire diameter, and length, but also must be practical, sensible, and useable.

Acknowledgments. Appreciation is extended to the Texas Agricultural Experiment Station, U.S. FPL and USDA NRI Competitive Grants Program through Grant No. 95-G-2481.

References

American Forest & Paper Association. 1991. ANSI/NFoPA NDS-1991. *National Design Specification for Wood Construction.* Washington, D.C.: AF&PA.

———. 1993. *Commentary on the National Design Specification for Wood Construction.* Washington, D.C.: AF&PA.

American Society for Testing and Materials. 1995a. Standard terminology of nails for use with wood and wood-base materials. Standard F547-77(reapproved 1990). Philadelphia, Pa.: ASTM.

———. 1995b. Standard test methods for nails. Standard F680-80 (reapproved 1993). Philadelphia, Pa.: ASTM.

———. 1995c. Standard test method for determining bending yield moment of nails. Standard F1575-95. Philadelphia, Pa.: ASTM.

———. 1995d. Standard test methods for mechanical fasteners in wood. Standard D1761-88. Philadelphia, Pa.: ASTM.

Aune, P. and M. Patton-Mallory. 1986a. Lateral load-bearing capacity of nailed joints based on the yield theory: Theoretical development. Research Paper FPL 469. Madison, Wis.: U.S. FPL.

———. 1986b. Lateral load-bearing capacity of nailed joints based on the yield theory: Experimental verification. Research Paper FPL 470. Madison, Wis.: U.S. FPL.

Ehlbeck, J. 1973. A new effective spike made in West Germany. In *Proc. of the 27th Annual Meeting of the Forest Products Research Soc.* (FPS), 42-51. Madison, Wis.: FPS.

———. 1976. Withdrawal resistance of threaded nails in wood used for building construction in Germany. In *Proc. of the 30th Annual Meeting of the Forest Products Research Soc.* (FPS), 90-106. Madison, Wis.: FPS.

———. 1979. Nailed joints in wood structures. Bull. No. 166. Blacksburg, Va.: Wood Research Laboratory, Virginia Polytechnic Institute.

Federal Specification FF-N-105B. 1977. Wire, cut and wrought nails, staples and spikes. U.S. General Services Administration (GSA). Reprinted by the Int. Staple, Nail, and Tool Assoc. (ISANTA), Chicago, Ill.

Forest Products Laboratory. 1965. Nail-withdrawal resistance of American woods. Research Note FPL-093. Madison, Wis.: U.S. FPL.

Geisthardt, A. C., C. Siegal and L. Shirek. 1991. Research and development: An industry perspective. ASAE Paper (unnumbered paper). St. Joseph, Mich.: ASAE.

Hoadley, B. 1977. Comparison of lag screw and threaded nails in a typical structural joint. *Forest Products J.* 27(12):40-47.

Johansen, K. W. 1949. Theory of timber connections. *Int. Assoc. for Bridge and Structural Eng. (IABSE) Pub.* 9:249-262. Zurich, Switzerland: IABSE.

Loferski, J. R. and T. E. McLain. 1991. Static and impact flexural properties of common wire nails. *J. of Testing and Evaluation* 19(4):297-304.

National Forest Products Association. 1986. *National Design Specification for Wood Construction.* Washington, D.C.: NFPA.

National Lumber Manufacturers Association. 1944. *National Design Specification for Stress-grade Lumber and its Fastenings.* Washington, D.C.: NLMA.

Quackenbush, J. E. 1977. Withdrawal resistance of various types of nails: Fluted-shank Norwegian nails verse similar-size American nails. In *Proc. of the 31st Annual Meeting of the Forest Products Research Soc.* (FPS), 1-7. Madison, Wis.: FPS.

Stern, E. G. 1963. Withdrawal resistance of plain shank and threaded nails of 2 1/2" length driven by hand-hammer vs. single powersert automatic nailer. Bull. No. 50. Blacksburg, Va.: Wood Research Laboratory, Virginia Polytechnic Inst.

————. 1969. Mechanical fastening of Southern pine – A review. Bulletin No. 87. Blacksburg, Va.: Wood Research Laboratory, Virginia Polytechnic Inst.

————. 1977. Recent research on performance of mechanical fasteners for wood at Virginia Polytechnic Inst. and State Univ. In *Proc. of the 31st Annual Meeting of the Forest Products Research Soc.* (FPS), 8-50. Madison, Wis.: FPS.

Stern, E. G., J. R. Reeves and W. C. Griggs. 1973. Mechanical fastening of wood, a review of the state of art. In *Proc. of the 27th Annual Meeting of the Forest Products Research Soc.* (FPS), 1-33. Madison, Wis.: FPS.

USDA. 1987. *Wood Handbook: Wood as an Engineering Material.* Agriculture Handbook No. 72. Washington, D.C.: USDA.

White, M. S. and T. L. Gales. 1990. Quality variations in helically threaded nails. *Forest Products J.* 40(11/12):64-66.

Wilkinson, T. L. 1991. Dowel bearing strength. Research Paper RP-505. Madison, Wis.: U.S. FPL.

Winistorfer, S. G. 1992. NDS nail design method comparison. *Frame Building News* (July/August): 32-35, 38-41, 44.

————. 1994. Nailed construction: A comparison of 1986 and 1991 National Design specification methods. *Transactions of the ASAE* 37(2):603-610.