Wood Fastenings

An Online Continuing Education Course for Engineers

Course Number: S-4009

Credit: 4 Hours / 4 PDH / 4 CPD

Wood Fastenings

The strength and stability of any structure depend heavily on the fastenings that hold its parts together. One prime advantage of wood as a structural material is the ease with which wood structural parts can be joined together with a wide variety of fastenings—nails, spikes, screws, bolts, lag screws, drift pins, staples, and metal connectors of various types. For utmost rigidity, strength, and service, each type of fastening requires joint designs adapted to the strength properties of wood along and across the grain and to dimensional changes that may occur with changes in moisture content.

Maximum lateral resistance and safe design load values for small-diameter (nails, spikes, and wood screws) and large-diameter dowel-type fasteners (bolts, lag screws, and drift pins) were based on an empirical method prior to 1991. Research conducted during the 1980s resulted in lateral resistance values that are currently based on a yield model theory. This theoretical method was adapted for the 1991 edition of the *National Design Specification for Wood Construction* (NDS). Because literature and design procedures exist that are related to both the empirical and theoretical methods, we refer to the empirical method as pre-1991 and the theoretical method as post-1991 throughout this course. Withdrawal resistance methods have not changed, so the pre- and post-1991 refer only to lateral resistance.

The information in this course comes from a variety of sources, including research results from the Forest Products Laboratory, a division of the USDA Forest Service. Design values should be modified for structural safety, based on the judgment and experience of the engineer of record.

Nails

Nails are the most common mechanical fastenings used in wood construction. There are many types, sizes, and forms of nails (Fig. 1). Most load equations presented in this section apply for bright, smooth, common steel wire nails driven into wood when there is no visible splitting. For nails other than common wire nails, the loads can be adjusted by factors given later in the course.

Figure 1. Various types of nails: (left to right) bright smooth wire nail, cement coated, zinc-coated, annularly threaded, helically threaded, helically threaded and barbed, and barbed.

Nails in use resist withdrawal loads, lateral loads, or a combination of the two. Both withdrawal and lateral resistance are affected by the wood, the nail, and the condition of use. In general, however, any variation in these factors has a more pronounced effect on withdrawal resistance than on lateral resistance. The serviceability of joints with nails laterally loaded does not depend greatly on withdrawal resistance unless large joint distortion is tolerable.

The diameters of various penny or gauge sizes of bright common nails are given in Table 1. The penny size designation should be used cautiously. International nail producers sometimes do not adhere to the dimensions of Table 1. Thus penny sizes, although still widely used, are obsolete. Specifying nail sizes by length and diameter dimensions is recommended. Bright box nails are generally of the same length but slightly smaller diameter (Table 2), whereas cement-coated nails such as coolers, sinkers, and coated box nails are slightly shorter (3.2 mm (1/8 in.)) and of smaller diameter than common nails of the same penny size. Helically and annularly threaded nails generally have smaller diameters than common nails for the same penny size (Table 3).

Withdrawal Resistance

The resistance of a nail shank to direct withdrawal from a piece of wood depends on the density of the wood, the diameter of the nail, and the depth of penetration. The surface condition of the nail at the time of driving also influences the initial withdrawal resistance.

For bright common wire nails driven into the side grain of seasoned wood or unseasoned wood that remains wet, the results of many tests have shown that the maximum withdrawal load is given by the empirical equation

$$p = 54.12G^{5/2}DL \quad \text{(metric)} \qquad (1a)$$

$$p = 7{,}850G^{5/2}DL \quad \text{(inch–pound)} \qquad (1b)$$

Table 1. Sizes of bright common wire nails

Size	Gauge	Length (mm (in.))	Diameter (mm (in.))
6d	11-1/2	50.8 (2)	2.87 (0.113)
8d	10-1/4	63.5 (2-1/2)	3.33 (0.131)
10d	9	76.2 (3)	3.76 (0.148)
12d	9	82.6 (3-1/4)	3.76 (0.148)
16d	8	88.9 (3-1/2)	4.11 (0.162)
20d	6	101.6 (4)	4.88 (0.192)
30d	5	114.3 (4-1/2)	5.26 (0.207)
40d	4	127.0 (5)	5.72 (0.225)
50d	3	139.7 (5-1/2)	6.20 (0.244)
60d	2	152.4 (6)	6.65 (0.262)

Table 2. Sizes of smooth box nails

Size	Gauge	Length (mm (in.))	Diameter (mm (in.))
3d	14-1/2	31.8 (1-1/4)	1.93 (0.076)
4d	14	38.1 (1-1/2)	2.03 (0.080)
5d	14	44.5 (1-3/4)	2.03 (0.080)
6d	12-1/2	50.8 (2)	2.49 (0.099)
7d	12-1/2	57.2 (2-1/4)	2.49 (0.099)
8d	11-1/2	63.5 (2-1/2)	2.87 (0.113)
10d	10-1/2	76.2 (3)	3.25 (0.128)
16d	10	88.9 (3-1/2)	3.43 (0.135)
20d	9	101.6 (4)	3.76 (0.148)

Table 3. Sizes of helically and annularly threaded nails

Size	Length (mm (in.))	Diameter (mm (in.))
6d	50.8 (2)	3.05 (0.120)
8d	63.5 (2-1/2)	3.05 (0.120)
10d	76.2 (3)	3.43 (0.135)
12d	82.6 (3-1/4)	3.43 (0.135)
16d	88.9 (3-1/2)	3.76 (0.148)
20d	101.6 (4)	4.50 (0.177)
30d	114.3 (4-1/2)	4.50 (0.177)
40d	127.0 (5)	4.50 (0.177)
50d	139.7 (5-1/2)	4.50 (0.177)
60d	152.4 (6)	4.50 (0.177)
70d	177.8 (7)	5.26 (0.207)
80d	203.2 (8)	5.26 (0.207)
90d	228.6 (9)	5.26 (0.207)

where p is maximum load (N, lb), L depth (mm, in.) of penetration of the nail in the member holding the nail point, G specific gravity of the wood based on ovendry weight and volume at 12% moisture content, and D diameter of the nail (mm, in.). (The NDS uses ovendry weight and volume as a basis.)

The loads expressed by Equation (1) represent average data. Certain wood species give test values that are somewhat greater or less than the equation values. A

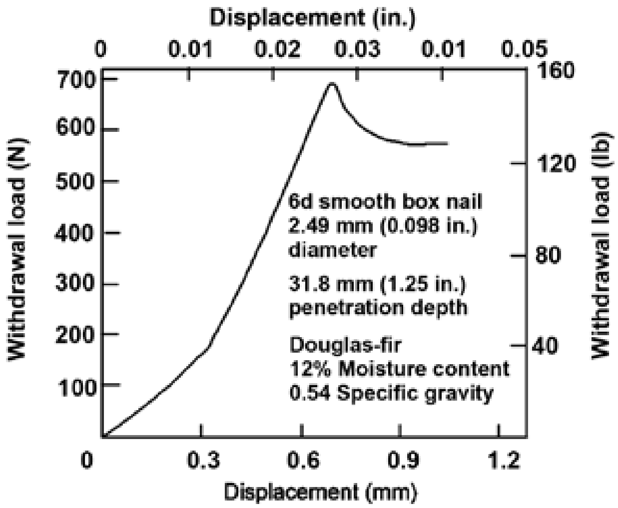

Figure 2. Typical load–displacement curve for direct withdrawal of a nail.

typical load–displacement curve for nail withdrawal (Fig. 2) shows that maximum load occurs at relatively small values of displacement.

Although the equation for nail-withdrawal resistance indicates that the dense, heavy woods offer greater resistance to nail withdrawal than do the lower density ones, lighter species should not be disqualified for uses requiring high resistance to withdrawal. As a rule, the less dense species do not split as readily as the denser ones, thus offering an opportunity for increasing the diameter, length, and number of the nails to compensate for the wood's lower resistance to nail withdrawal.

The withdrawal resistance of nail shanks is greatly affected by such factors as type of nail point, type of shank, time the nail remains in the wood, surface coatings, and moisture content changes in the wood.

Effect of Seasoning

With practically all species, nails driven into green wood and pulled before any seasoning takes place offer about the same withdrawal resistance as nails driven into seasoned wood and pulled soon after driving. However, if common smooth-shank nails are driven into green wood that is allowed to season, or into seasoned wood that is subjected to cycles of wetting and drying before the nails are pulled, they lose a major part of their initial withdrawal resistance. The withdrawal resistance for nails driven into wood that is subjected to changes in moisture content may be as low as 25% of the values for nails tested soon after driving. On the other hand, if the wood fibers deteriorate or the nail corrodes under some conditions of moisture variation and time, withdrawal resistance is erratic; resistance may be regained or even increased over the immediate withdrawal resistance. However, such sustained performance should not be relied on in the design of a nailed joint.

In seasoned wood that is not subjected to appreciable moisture content changes, the withdrawal resistance of nails may also diminish due to relaxation of the wood fibers with time. Under all these conditions of use, the withdrawal resistance of nails differs among species and shows variation within individual species.

Effect of Nail Form

The surface condition of nails is frequently modified during the manufacturing process to improve withdrawal resistance. Such modification is usually done by surface coating, surface roughening, or mechanical deformation of the shank. Other factors that affect the surface condition of the nail are the oil film remaining on the shank after manufacture or corrosion resulting from storage under adverse conditions; but these factors are so variable that their influence on withdrawal resistance cannot be adequately evaluated.

Surface Modifications—A common surface treatment for nails is the so-called cement coating. Cement coatings, contrary to what the name implies, do not include cement as an ingredient; they generally are a composition of resin applied to the nail to increase the resistance to withdrawal by increasing the friction between the nail and the wood. If properly applied, they increase the resistance of nails to withdrawal immediately after the nails are driven into the softer woods. However, in the denser woods (such as hard maple, birch, or oak), cement-coated nails have practically no advantage over plain nails, because most of the coating is removed in driving. Some of the coating may also be removed in the side member before the nail penetrates the main member.

Good-quality cement coatings are uniform, not sticky to the touch, and cannot be rubbed off easily. Different techniques of applying the cement coating and variations in its ingredients may cause large differences in the relative resistance to withdrawal of different lots of cement-coated nails. Some nails may show only a slight initial advantage over plain nails. In the softer woods, the increase in withdrawal resistance of cement-coated nails is not permanent but drops off significantly after a month or so. Cement-coated nails are used primarily in construction of boxes, crates, and other containers usually built for rough handling and relatively short service.

Nails that have galvanized coatings, such as zinc, are intended primarily for uses where corrosion and staining resistance are important factors in permanence and appearance. If the zinc coating is evenly applied, withdrawal resistance may be increased, but extreme irregularities of the coating may actually reduce it. The advantage that uniformly coated galvanized nails may have over nongalvanized nails in resistance to initial withdrawal is usually reduced by repeated cycles of wetting and drying.

Nails have also been made with plastic coatings. The usefulness and characteristics of these coatings are influenced by the quality and type of coating, the effectiveness of the bond between the coating and base fastener, and the effectiveness of the bond between the coating and wood fibers. Some plastic coatings appear to resist corrosion or improve resistance to withdrawal, while others offer little improvement.

Fasteners with properly applied nylon coating tend to retain their initial resistance to withdrawal compared with other coatings, which exhibit a marked decrease in withdrawal resistance within the first month after driving.

A chemically etched nail has somewhat greater withdrawal resistance than some coated nails, as the minutely pitted surface is an integral part of the nail shank. Under impact loading, however, the withdrawal resistance of etched nails is little different from that of plain or cement-coated nails under various moisture conditions.

Sand-blasted nails perform in much the same manner as chemically etched nails.

Shape Modifications—Nail shanks may be varied from a smooth, circular form to give an increase in surface area without an increase in nail weight. Special nails with barbed, helically or annularly threaded, and other irregular shanks (Fig. 1) are commercially available.

The form and magnitude of the deformations along the shank influence the performance of the nails in various wood species. In wood remaining at a uniform moisture content, the withdrawal resistance of these nails is generally somewhat greater than that of common wire nails of the same diameter. From tests in which nails were driven in the side grain of seasoned wood, bright annularly threaded nails, with shank-to-thread-crest diameter difference greater than 0.2 mm (0.008 in.) and thread spacing between 1.27 mm (0.05 in.) and 1.96 mm (0.077 in.), the immediate maximum withdrawal load is given by the empirical equation

$$p = 73.11G^2DL \qquad \text{(metric)} \qquad (2a)$$

$$p = 10{,}600G^2DL \qquad \text{(inch–pound)} \qquad (2b)$$

where p is maximum load (N, lb), L depth (mm, in.) of penetration of the nail in the member holding the nail point, G specific gravity of the wood based on ovendry weight and volume and oven dry moisture content, and D shank diameter of the nail (mm, in.). The expression is valid only for the threaded portion of the nail. Comparison of Equations (1) and (2) indicates that the bright annularly threaded nail can have withdrawal resistances that are double the values of common nails. For galvanized annularly threaded nails, the immediate with- drawal strength is slightly lower. However, under conditions involving changes in moisture content of the wood, some special nail forms provide considerably greater withdrawal resistance than the common wire nail—about four times greater for annularly and helically threaded nails of the same diameter. This is especially true of nails driven into green

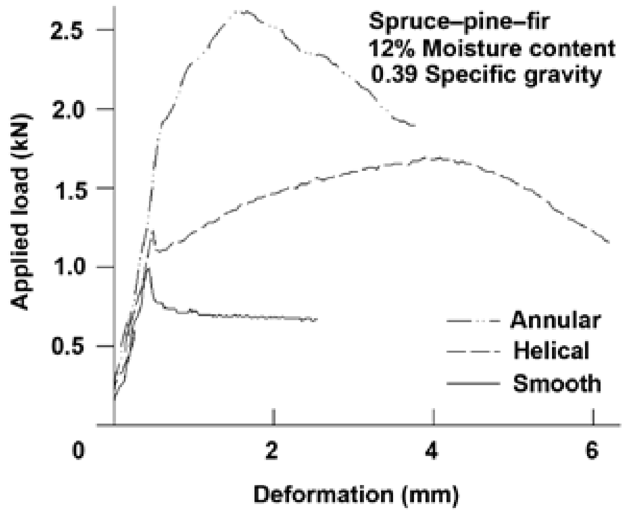

Figure 3. Typical load–displacement curves deformed and smooth shank for direct withdrawal of a nail.

wood that subsequently dries. In general, annularly threaded nails sustain larger withdrawal loads, and helically threaded nails sustain greater impact withdrawal work values than do the other nail forms (Fig. 3).

Nails with deformed shanks are sometimes hardened by heat treatments for use where driving conditions are difficult or to obtain improved performance, such as in pallet assembly. Hardened nails are brittle and care should be exercised to avoid injuries from fragments of nails broken during driving.

Nail Point—A smooth, round shank nail with a long, sharp point will usually have a greater withdrawal resistance, particularly in the softer woods, than the common wire nail (which usually has a diamond point). However, sharp points accentuate splitting in certain species, which may reduce withdrawal resistance. A blunt or flat point without taper reduces splitting, but its destruction of the wood fibers when driven reduces withdrawal resistance to less than that of the common wire nail. A nail tapered at the end and terminating in a blunt point will cause less splitting. In heavier woods, such a tapered, blunt-pointed nail will provide about the same withdrawal resistance, but in less dense woods, its resistance to withdrawal is less than that of the common nail.

Nail Head—Nail head classifications include flat, oval, countersunk, deep-countersunk, and brad. Nails with all types of heads, except the deep-countersunk, brad, and some of the thin flathead nails, are sufficiently strong to withstand the force required to pull them from most woods in direct withdrawal. One exception to this statement is for annularly threaded nails. Due to the increased withdrawal capacity for these type nails, nail head can be pulled into or through wood members. The deep-countersunk and brad nails are usually driven below the wood surface and are not intended to carry large withdrawal loads. In general, the thickness and diameter of the heads of the common wire nails increase as the size of the nail increases.

The development of some pneumatically operated portable nailers has introduced nails with specially configured heads, such as T-nails and nails with a segment of the head cut off.

Corrosion and Staining

In the presence of moisture, metals used for nails may corrode when in contact with wood treated with certain preservative or fire-retardant treatments. Use of certain metals or metal alloys will reduce the amount of corrosion. Nails of copper, silicon bronze, and 300 series
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series stainless steel n
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and steel in the presence of
appearance is important, such as with naturally finished siding. Use of stainless steel, aluminum, or hot-dipped galvanized nails can alleviate staining.

In general, the withdrawal resistance of copper, other alloy, and polymer-coated nails is comparable with that of common steel wire nails when pulled soon after driving.

Driving

The resistance of nails to withdrawal is generally greatest when they are driven perpendicular to the grain of the wood. When a bright nail is driven parallel to the wood fibers (that is, into the end of the piece) withdrawal resistance in wood ranges between 50% to 75% of the resistance obtained when the nail is driven perpendicular to the grain. The ratio between the immediate end- and side-grain withdrawal loads is nearly constant for all specific gravities. In contrast to the immediate withdrawal case, nails pulled after a time interval or after moisture content changes experience a decreased load in both side and end grain. For most species the decrease in the side grain withdrawal load is greater than in the end grain; therefore the resulting end- to side-grain ratio is larger.

Toe nailing, a common method of joining wood framework, involves slant driving a nail or group of nails through the end or edge of an attached member and into a main member. Toe nailing requires greater skill in assembly than does ordinary end nailing but provides joints of greater strength and stability. Tests show that the maximum strength of toenailed joints under lateral and uplift loads is obtained by (a) using the largest nail that will not cause excessive splitting, (b) allowing an end distance (distance from the end of the attached member to the point of initial nail entry) of approx-
rd the length of the nail, (c) driving the nail
° with the attached member, and (d) burying
the nail but avoiding excessive mutilation
n hammer blows.

thdrawal tests with multiple nail joints in
ttached is pulled directly away from the
w that slant driving is usually superior to
hen nails are driven into dry wood and
, and decidedly superior when nails are
r partially dry wood that is allowed to
or more. However, the loss in depth of
lant driving may, in some types of joints,
of slant nailing. Cross slant driving of
gh the side grain is usually somewhat
arallel-slant driving through the end

holes with a diameter slightly smaller
han the nail shank have somewhat
stance than nails driven without lead
prevent or reduce splitting of the
cularly for dense species.

Clinching

The withdrawal resistance of smooth-shank, clinched nails is considerably greater than that of unclinched nails. The point of a clinched nail is bent over where the nail protrudes through the side member. The ratio between the loads for clinched and unclinched nails varies enormously, depending upon the moisture content of the wood when the nail is driven and withdrawn, the species of wood, the size of nail, and the direction of clinch with respect to the grain of the wood.

In dry or green wood, a clinched nail provides 45% to 170% more withdrawal resistance than an unclinched nail when withdrawn soon after driving. In green wood that seasons after a nail is driven, a clinched nail gives 250% to 460% greater withdrawal resistance than an unclinched nail. However, this improved strength of a clinched-nail joint does not justify the use of green lumber, because the joints may loosen as the lumber seasons. Furthermore, laboratory tests were made with single nails, and the effects of drying, such as warping, twisting, and splitting, may reduce the efficiency of a joint that has more than one nail. Clinching of nails is generally confined to such construction as boxes and crates and other container applications.