Withdrawal Capacity of Joints Constructed with 9.5-mm and 15.9-mm Through-Bolts and Diameter Nominal 15-mm and 25-mm Pipe-Nut Connectors

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Abstract

Tests were conducted to determine the withdrawal capacities of 10-mm (nominal ⅜-in.) and 15.9-mm (nominal ⅝-in.) through-bolts with Diameter Nominal (DN) 15-mm (nominal ½-in.) and DN 25-mm (nominal 1-in.) pipe-nut connectors intended for use in light-timber frame construction. The capacity of unreinforced 15.9-mm through-bolts with DN 25-mm pipe-nut connectors was approximately 31.1 kN; the capacity of comparable reinforced connectors was approximately 71.2 kN. Likewise, the withdrawal capacity of smaller unreinforced 10-mm through-bolts with DN 15-mm pipe-nut connectors was approximately 13.3 kN; comparable reinforced connectors had a capacity of 17.8 kN. Similar 10-mm through-bolts with DN 10-mm pipe couplings had a capacity of 26.7 kN. Overall, results indicate that high-capacity joints can be constructed with through-bolt and pipe-nut connectors.

Through-bolts with steel dowel-nut connectors (Fig. 1a), have been used in furniture construction for many years—particularly in table leg to table top connections (Eckelman 1999)—but they have had only limited use in conventional timber frame construction. To obtain estimates of dowel-nut capacity in small-diameter timber, Eckelman and Senft (1995) investigated the withdrawal capacity of through-bolts with 38.1-mm (nominal 1½-in.)-diameter steel dowel-nuts in 150- to 175-mm (6- to 7-in.)-diameter yellow poplar (*Liriodendron tulipifera*) peeler cores and obtained withdrawal capacities greater than 89 kN. Subsequently, Wolfe et al. (2000) investigated the holding strength of dowel-nuts in Douglas-fir (*Pseudotsuga menziesii*) peeler cores and concluded that a 44.5-mm (nominal 1¾-in.)-diameter dowel-nut appears to be economically feasible at a design capacity of 44.5 kN. Further research with a space-frame roof system (USDA Forest Service, Forest Products Laboratory 2000) indicated that the performance of dowel-nuts in small-diameter ponderosa pine (*Pinus ponderosa*) round timber was superior to that in Douglas-fir peelers. Eckelman (2004) reported on the withdrawal capacity of a modified form of this construction—namely, a through-bolt with pipe-nut connectors (Fig. 1b)—in which a short length of pipe containing an embedded nut was used instead of a solid steel dowel. As opposed to solid steel dowels, these low-cost, high-strength connectors had somewhat less demanding tolerances and, in large sizes, allowed assembly and tightening at both ends of the through-bolt (or threaded rod). Subsequently, Eckelman et al. (2007) demonstrated the use of through-bolt with pipe-nut construction in small timber trusses.

This previous work by Eckelman (2004) and by Eckelman et al. (2007) was carried out with relatively large Diameter Nominal (DN) 40- to DN 100-mm (nominal 1½- to 4-in.)-diameter pipes. There is also a use, however, for smaller through-bolt with pipe-nut assemblies that are compatible with ready-to-assemble, light-timber frame constructions (e.g., joining a floor plate to a wall stud, as illustrated in Fig. 2) that are suited for transitional disaster relief housing or light-timber frames for housing, school, or agricultural uses in disadvantaged areas of the world. Accordingly, an exploratory test program was undertaken

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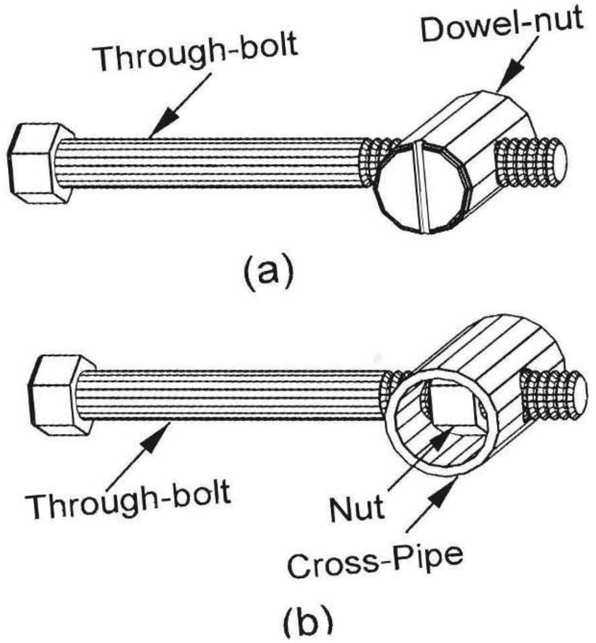

Figure 1.—(a) Typical through-bolt with steel dowel-nut connector and (b) typical through-bolt with pipe-nut connector.

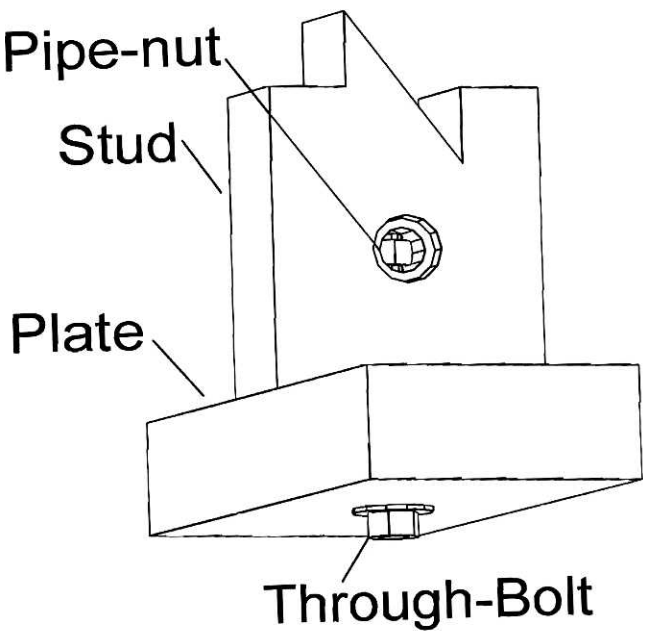

Figure 2.—Example of wall to floor plate connection using through-bolt and pipe-nut.

(1) to determine compatible pipe and nut sizes best suited for such constructions, (2) to obtain estimates of their holding capacities in various wood species, and (3) to obtain insights regarding their general performance characteristics.

Pipe-Nut Construction

The construction of a typical pipe-nut connector is shown in Figure 3a. The basic construction consists of a short length of pipe with a hole drilled through both sides to accommodate the through-bolt. A standard hexagonal nut is

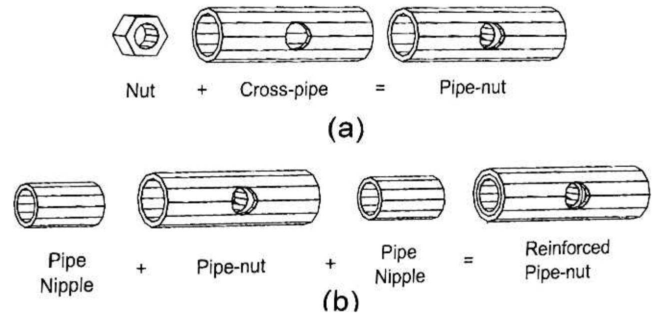

Figure 3.—(a) 15.9-mm (nominal ⅝-in.) through-bolt with 25-mm (nominal 1-in.) cross-pipe and (b) pipe-nut with 20-mm (nominal ¾-in.) pipe-nipple reinforcements.

then inserted edgewise into the pipe until the hole in the nut is aligned with the through-bolt hole.

An examination of the across-flat dimensions of various nuts and the internal diameters of various pipe sizes yields two likely candidates for pipe-nut construction. Specifically, in the case of a high-capacity connector for light-timber construction, a 15.9-mm (nominal ⅝-in.) hexagonal nut can be fitted in a DN 25-mm (nominal 1-in.) cross-pipe that has a 33.4-mm outside diameter and a 26.6-mm inside diameter. Insertion of the nut (with its longitudinal axis aligned with the axis of the through-bolt) in the end of the pipe results in a mild force fit that holds the nut firmly in place. Additionally, the pipe (and, thereby, the connector as a whole) can be reinforced by force-fitting short lengths (nipples) of DN 20-mm (nominal ¾-in.) pipe into each end of the cross-pipe, as shown in Figure 3b. This approach is feasible, because the outside diameter of a DN 20-mm pipe is 26.7 mm, as opposed to the 26.6-mm inside diameter of a DN 25-mm pipe.

Lower-capacity connectors, such as those that might be used to attach 38 by 89-mm (nominal 2 by 4-in.) studs to top and bottom wall plates, can be fabricated using 10-mm (nominal ⅜-in.) through-bolts and DN 15-mm (nominal ½-in.) pipes, which have a 21.3-mm outside diameter and a 15.8-mm inside diameter. In this case, a 10-mm hexagonal nut will slide easily into the end of the pipe, as shown in Figure 4a, and may be secured in place by applying a drop of adhesive in the space between the flat of the nut and the inside wall of the pipe. The resulting pipe-nuts can be reinforced by inserting short lengths of 15.9-mm-diameter steel rod into the ends of the cross-pipes or, more simply, by

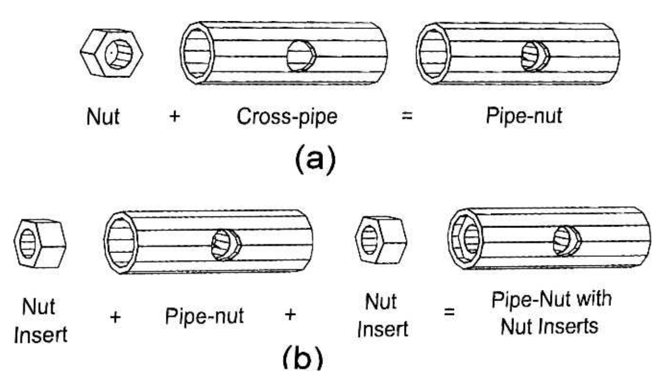

Figure 4.—(a) 15-mm (nominal ½-in.) cross-pipe with 9.5-mm (nominal ⅜-in.) nut and (b) cross-pipe with nut reinforcements.

inserting 10-mm nuts (with their longitudinal axes parallel to the longitudinal axis of the cross-pipe) into each end of a cross-pipe, as shown in Figure 4b. These nuts should also be held in place with a drop of adhesive.

DN 10-mm pipe couplings can also be used as cross-pipes with 10-mm through-bolts. Connectors constructed with these couplings have a higher load capacity than do those constructed with DN 15-mm cross-pipes, but the resulting pipe-nuts are more expensive than those fabricated from standard pipe. The couplings themselves measure 30.2 mm in length and are slightly larger in outside diameter (22.2 vs. 21.3 mm) than DN 15-mm pipe but have a slightly smaller inside diameter (15.2 vs. 15.8 mm) so that the hexagonal nut must be force-fitted into the end of the coupling, which can be done with a hammer and punch or by means of a small press.

Plan of Study and Objectives

The overall objective of the present study was to estimate the withdrawal capacity of through-bolt with pipe-nut connectors of sizes that would be satisfactory for use in disaster relief shelters and transitional housing as well as light-timber framing in general. Factors of particular interest were the simplicity and ease of fabrication of the connectors along with their structural capacity as functions of pipe-nut diameter, pipe-nut orientation relative to the member in which it is embedded (face to face or corner to corner; Figs. 5a and 5b), end placement (end distance) in members, and to a limited extent, wood species. The study was divided into three major parts.

Part I of the present study was conducted with 12.7-mm (nominal ½-in.)-diameter through-bolts and 25.4-mm (nominal 1-in.)-diameter steel dowel-nuts in nominal 89 by 89-mm (nominal 3½ by 3½-in.) square western hemlock (*Tsuga heterophylla*) specimens with end distances of 50, 75, and 100 mm with the longitudinal axes of the dowel-nuts oriented either from corner to corner of the specimens (Set 1-1; Table 1) or from face to face (Set 1-2; Table 1). These tests were conducted to obtain initial estimates of the holding capacity of dowel-nuts in members of this size as a function of end placement and cross placement (corner to corner vs. face to face) of the dowel-nuts as well the difficulties to be expected in construction of the joints.

Part II of the present study was conducted with 15.9-mm through-bolts with DN 25-mm cross-pipe connectors (hereafter termed 25-mm pipe-nuts). Specifically, tests were conducted (1) with both reinforced and unreinforced pipe-nuts oriented face to face or corner to corner in 89 by 89-mm western hemlock members at end distances of 50 to 100 mm, (2) with reinforced pipe-nuts in nominal 38 by 140-mm (nominal 2 by 6-in.) southern yellow pine (*Pinus echinata*) members at end distances of 50 to 150 mm and in western hemlock members at end distances of 50 to 100 mm, and (3) with nominal 100 by 100-, 75 by 75-, 50 by 75-, and 50 by 100-mm (4 by 4-, 3 by 3-, 2 by 3-, and 2 by 4-in.) hardwoods at end distances ranging from 50 to 150 mm.

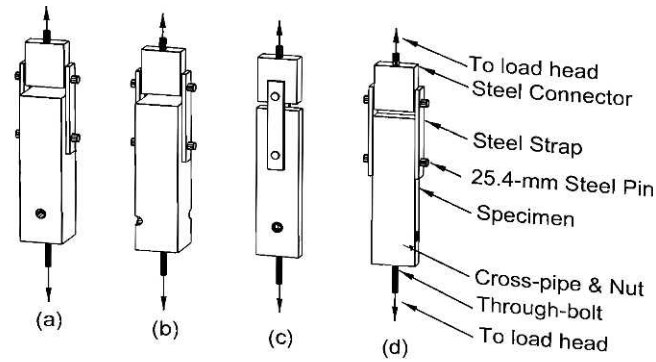

Figure 5.—Diagram showing placement of cross-pipe and nut in specimens. (a) Face-to-face insertion of the cross-pipe in a square member; (b) cross-corner insertion of cross-pipe; (c) face-to-face insertion of the cross-pipe parallel to the minor cross-sectional axis of a nonsquare rectangular member; and (d) face-to-face insertion of cross-pipe parallel to the major axis.

The first set of specimens in this part of the study (Set 2-1; Table 2) was tested (1) to provide estimates of the withdrawal capacities of 25-mm pipe-nuts in nominal 100 by 100-mm western hemlock and (2) to determine whether joints with the pipe-nuts oriented corner to corner have a higher load capacity than comparable joints with the pipe-nuts oriented face to face. Tests were conducted with both reinforced and unreinforced pipe-nuts to ensure that the maximum load capacities of the joints could be determined. The second set of specimens (Set 2-2; Table 2) was tested to determine the withdrawal capacities of 25-mm pipe-nuts in 38 by 140-mm southern yellow pine and 48 by 140-mm (1⅞ by 5½-in.) western hemlock members. Again, pipe-nuts reinforced with inserts were used to ensure that maximum load capacities could be determined. The third set of specimens (Set 2-3; Table 2) was tested to determine the withdrawal capacity of 25-mm pipe-nuts in hardwoods of various cross sections to provide information concerning the capacity of the pipe-nuts in nonstandard sizes of hardwoods with both relatively low

Table 1.—Withdrawal capacity of 25.4-mm (nominal 1-in.)-diameter steel dowel-nuts in 89 by 89-mm (nominal 3½ by 3½-in.) western hemlock members.

No. of specimens	Dowel-nut length (mm)	Dowel-nut diam. (mm)	Through-bolt diam. (mm)	D-nut end distance (mm)	Orientation[a]	Ultimate load, mean (SD) (kN)
Set 1-1						
3	100	25.4	12.7	50	c to c	19.6 (1.4)
3	100	25.4	12.7	75	c to c	21.9 (5.8)
3	100	25.4	12.7	100	c to c	34.4 (12.7)
Set 1-2						
6	100	25.4	12.7	50	f to f	20.2 (5.8)
3	100	25.4	12.7	75	f to f	25.1 (13.7)
3	100	25.4	12.7	100	f to f	32.2 (5.7)

[a] c to c = corner to corner; f to f = face to face.

Table 2.—Withdrawal capacity of 15.9-mm (nominal ⅝-in.) through-bolts with 25-mm (nominal 1-in.) pipe-nuts.

No. of specimens	Wood species[a]	Nominal specimen Width (mm)	Nominal specimen Depth (mm)	Pipe-nut Length (mm)	Pipe-nut Outside diam. (mm)	Through-bolt diam. (mm)	Insert diam. (mm)	End distance (mm)	Placement[b]	Maximum load, mean (SD) (kN)[c]
Set 2-1										
3	WH	89	89	100	33.5	15.9	None	50	c to c	20.3 (4.8)
3	WH	89	89	100	33.5	15.9	None	75	c to c	24.7 (3.9)
3	WH	89	89	50	33.5	15.9	None	100	c to c	32.5 (1.4)
3	WH	89	89	50	33.5	15.9	None	50	f to f	17.4 (1.4)
3	WH	89	89	50	33.5	15.9	None	75	f to f	25.6 (1.8)
3	WH	89	89	50	33.5	15.9	None	100	f to f	35.7 (13.8)
3	WH	89	89	50	33.5	15.9	26.7	50	c to c	21.0 (3.7)
5	WH	89	89	100	33.5	15.9	26.7	75	c to c	22.9 (7.2)
11	WH	89	89	50	33.5	15.9	26.7	100	c to c	35.5 (10.4)
3	WH	89	89	50	33.5	15.9	26.7	50	f to f	19.4 (5.3)
3	WH	89	89	50	33.5	15.9	26.7	75	f to f	31.1 (15.3)
3	WH	89	89	50	33.5	15.9	26.7	100	f to f	42.8 (9.1)
Set 2-2										
3	SYP	38	140	50	33.5	15.9	26.7	50	f to f	17.7 (1.6)
3	SYP	38	140	50	33.5	15.9	26.7	75	f to f	20.8 (1.8)
3	SYP	38	140	50	33.5	15.9	26.7	100	f to f	22.5 (4.7)
3	SYP	38	140	50	33.5	15.9	26.7	152.4	f to f	36.1 (0.9)
3	WH	38	140	50	33.5	15.9	26.7	50	f to f	14.6 (3.1)
3	WH	38	140	50	33.5	15.9	26.7	75	f to f	16.3 (2.4)
3	WH	38	140	50	33.5	15.9	26.7	100	f to f	23.4 (4.8)
4	WH	38	89	50	33.5	15.9	26.7	100	f to f	23.4 (23.4)
Set 2-3										
3	YPop	100	100	100	33.5	15.9	26.7	50	f to f	41.4 (7.9)
3	YPop	100	100	100	33.5	15.9	26.7	75	f to f	64.7 (11.4)
1	YPop	100	100	100	33.5	15.9	26.7	100	f to f	100.1 (NA)
6	WAsh	75	75	50	33.5	15.9	26.7	50	f to f	32.2 (2.9)
7	WAsh	75	75	50	33.5	15.9	26.7	75	f to f	56.5 (7.5)
4	WAsh	75	75	50	33.5	15.9	26.7	100	f to f	78.7 (20.4)
4	WOak	50	75	50	33.5	15.9	26.7	50	f to f	22.7 (2.1)
4	WOak	50	75	50	33.5	15.9	26.7	100	f to f	67.0 (6.4)
3	YPop	50	100	50	33.5	15.9	26.7	50	f to f	16.6 (2.3)
3	YPop	50	100	50	33.5	15.9	26.7	75	f to f	19.5 (2.9)
3	YPop	50	100	50	33.5	15.9	26.7	100	f to f	29.6 (9.2)
3	YPop	50	100	50	33.5	15.9	26.7	127	f to f	47.6 (2.9)
3	YPop	50	100	50	33.5	15.9	26.7	152.4	f to f	48.4 (4.7)

[a] WH = western hemlock; SYP = southern yellow pine; YPop = yellow poplar; WAsh = white ash; WOak = white oak.
[b] c to c = corner to corner; f to f = face to face.
[c] NA = not applicable.

and high shear strengths. These tests were conducted with reinforced pipe-nuts.

Part III of the present study was conducted with two smaller pipe-nut constructions, namely, 9.5-mm (nominal ⅜-in.) through-bolts with DN 15-mm by 50-mm-long cross-pipes (hereafter termed 15-mm pipe-nuts) and 9.5-mm through-bolts with DN 10-mm by 29.8-mm (1.17-in.)-long pipe couplings (hereafter termed 10-mm pipe-coupling-nuts). Specifically, tests were conducted with 15-mm unreinforced pipe-nuts oriented face to face along the minor axis of nominal 38 by 89-mm western hemlock members at end distances of 50 to 100 mm (Set 3-1; Table 3); with unreinforced (Set 3-2; Table 3) and reinforced (Set 3-3; Table 3) 15-mm pipe-nuts embedded along the minor axis of nominal 38 by 140-mm western hemlock members at end distances of 50 to 125 mm; with 10-mm pipe-coupling-nuts (Set 3-4; Table 3) in nominal 38 by 89-mm western hemlock members at end distances of 50 to 100-mm; with 10-mm pipe-coupling-nuts aligned along the major axis (Set 3-5; Table 3) of nominal 38 by 89-mm western hemlock at an end distance of 50 mm; and with 10-mm pipe-coupling-nuts (Set 3-6; Table 3) in nominal 75 by 75-mm white ash (*Fraxinus americana*) members at end distances of 50 to 75 mm.

The first set of these tests was conducted to obtain estimates of the withdrawal capacity of unreinforced 15-mm pipe-nuts in 38 by 89-mm western hemlock members as well as to obtain an initial determination of the capacity of the unreinforced pipe-nuts (Set 3-1). The second and third sets of test (Sets 3-2 and 3-3) were conducted to determine the withdrawal capacity of both reinforced and unreinforced 15-mm pipe-nuts in nominal 38 by 140-mm western hemlock members and observe the performance of both reinforced and unreinforced pipe-nuts. The fourth set of tests (Set 3-4) was conducted to determine the performance of 10-mm pipe-coupling-nuts in nominal 38 by 89-mm western hemlock members with the pipe-coupling-nut axis aligned with the minor axis of the member. The fifth set of tests (Set 3-5) was conducted with the axis of the pipe-

Table 3.—Withdrawal capacity of 9.5-mm (nominal ⅜-in.) through-bolts with 15-mm (nominal ½-in.) pipe-nuts and 9.5-mm through-bolts with 10-mm (nominal ⅜-in.) pipe-coupling-nuts.

No. of specimens	Wood species[a]	Specimen nominal		Pipe-nut/pipe-coupling-nut		Through-bolt diam. (mm)	Insert	End distance (mm)	Ultimate load, mean (SD) (kN)[b]
		Width (mm)	Depth (mm)	Length (mm)	Diam. (mm)				
Set 3-1									
6	WH	38	89	38.1	21.3	9.5	No	50	10.5 (2.7)
6	WH	38	89	38.1	21.3	9.5	No	75	15.5 (3.4)
3	WH	38	89	38.1	21.3	9.5	No	100	20.7 (2.7)
3	SYP	38	89	38.1	21.3	9.5	No	100	16.9 (1.9)
Set 3-2									
3	WH	38	89	38.1	21.3	9.5	No	50	11.6 (0.7)
3	WH	38	89	38.1	21.3	9.5	No	75	15.2 (2.1)
3	WH	38	89	38.1	21.3	9.5	No	100	15.8 (3.4)
Set 3-3									
3	WH	38	140	38.1	21.3	9.5	Yes	50	12.2 (1.0)
3	WH	38	140	38.1	21.3	9.5	Yes	75	14.1 (1.1)
3	WH	38	140	38.1	21.3	9.5	Yes	100	20.1 (2.4)
3	WH	38	140	38.1	21.3	9.5	Yes	125	21.7 (2.7)
Set 3-4									
3	WH	38	89	30.0	22.4	9.5	No	50	12.2 (2.8)
3	WH	38	89	30.0	22.4	9.5	No	75	19.4 (2.6)
3	WH	38	89	30.0	22.4	9.5	No	100	20.3 (1.2)
Set 3-5									
3	WH	89	38	30.0	22.4	9.5	No	50	16.1 (3.3)
Set 3-6									
2	WAsh	75	75	30.2	22.4	9.5	No	50	26.7 (NA)
2	WAsh	75	75	30.2	22.4	9.5	No	75	26.7 (NA)

[a] WH = western hemlock; SYP = southern yellow pine; WAsh = white ash.
[b] NA = not applicable.

coupling-nut aligned with the major axis of the member to determine the increase in capacity that could be obtained with this orientation. Finally, the sixth set of tests (Set 3-6) was conducted to determine the withdrawal capacity of 10-mm pipe-coupling-nuts in a high-shear-strength hardwood.

Specimen Preparation

Dimensions of the specimens are given in Tables 1 through 3. The western hemlock material along with the southern yellow pine were obtained from commercial sources. The white ash and white oak (*Quercus alba*) were obtained from Purdue University properties. All of the specimens were conditioned to 7 percent moisture content.

Constructions of typical specimens using through-bolt with pipe-nut connectors are shown in Figures 5a through 5d. Face-to-face insertion of the cross-pipe in a square member is shown in Figure 5a and cross-corner insertion in Figure 5b, whereas face-to-face insertion of the cross-pipe parallel to the minor cross-sectional axis of a nonsquare rectangular member is shown in Figure 5c and face-to-face insertion parallel to the major axis in Figure 5d.

Method of Test

All of the tests were conducted in a Riehle universal testing machine. For convenience in testing, a threaded rod was used in testing the specimens rather than bolts. Tensile tests of the standard-grade threaded rod used indicated that the points at which the deflection versus load curves differed from a straight-line response by at least 5 percent amounted to 17.8, 33.4, and 49 kN for 9.5-mm, 12.7-mm, and 15.9-mm rods, respectively, but it should be noted that failing loads could be much higher—at a rate of loading of 2.5 mm/min; for example, the ultimate load capacity of the 9.5-, 12.7-, and 15.9-mm threaded rods used in the tests averaged 26.7, 52.0, and 77.8 kN, respectively. A Grade 2 rod was used in most of the tests, but in a few cases, a high-strength rod was used to be able to determine the ultimate load capacity of a pipe-nut. During testing, when a machine load remained constant at its maximum value without wood failure, the test was halted to determine if the embedded nut was ''pulling through'' the wall of the cross-pipe or if the threaded rod was yielding. If pull-through occurred, the machine load was taken as the maximum capacity of the pipe-nut.

Results and Discussion

The withdrawal capacities of the specimens are given in Tables 1 through 3 and are illustrated in Figures 6 through 10. Because tests were terminated before pull-through of the embedded nuts occurred, the most severe damage to the pipe-nuts was ovalization of the hole in the wall of the pipe along with a slight outward distortion of the adjacent pipe wall.

The most common observable mode of wood failure was development of a split that extended from the end of the member to the cross-pipe. Presumably, such failures arose from the combination of shear parallel to and tension perpendicular to the grain. Compression failures of the wood beneath the cross-pipes were not observed. Failures were usually sudden, with total loss of load; however, at high load levels, ''dramatic'' failures often occurred in which the specimen shattered into several pieces.

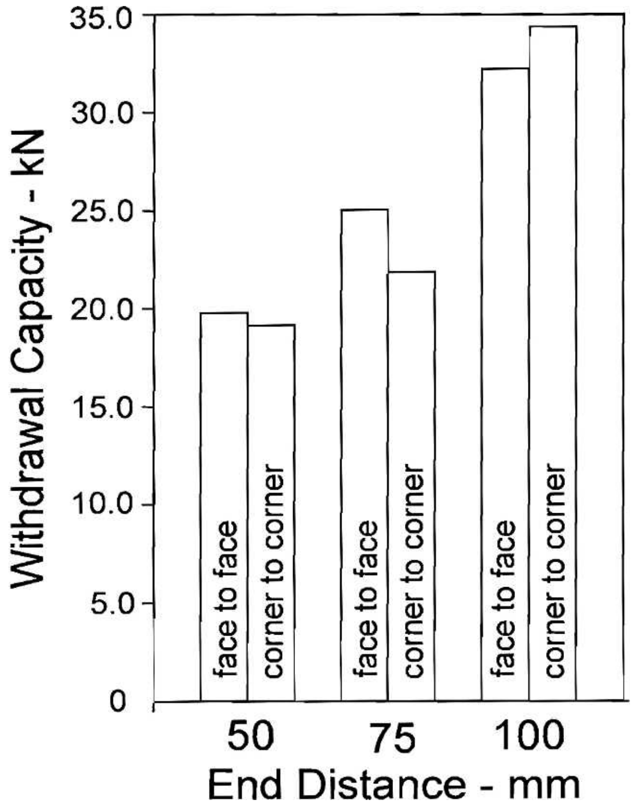

Figure 6.—Withdrawal capacity of 25.4-mm (nominal 1-in.) dowel-nuts in 89 by 89-mm (nominal 3½ by 3½-in.) western hemlock members.

25.4-mm-diameter steel dowel-nuts

The withdrawal capacities of the 25.4-mm-diameter steel dowel-nuts in 89 by 89-mm western hemlock members are given in Table 1 and are shown graphically in Figure 6. As can be seen, there was a relatively regular increase in withdrawal capacity from approximately 17.8 to 31.1 kN as end distances increased from 50 to 100 mm. It must be noted, however, that wide variations in individual withdrawal values were found within given end-distance categories. Whether the dowel-nut was located in the corner of the specimen (Set 1-1; Table 1) or the face (Set 1-2; Table 1) did not appear to cause a major difference in withdrawal capacity.

In general, these results tend to indicate that useable withdrawal capacities can be obtained with dowel-nut connectors of this size even when the dowel-nut is located relatively close to the end of the member. Combining results for corner-to-corner tests with those for face-to-face tests, coefficients of variation ranged from an average of 17.8 percent for 50-mm end distances to 40.6 and 26.6 percent for 75- and 100-mm end distances, respectively. Thus, positioning the dowel-nut closer to the end of the member did not increase variability in withdrawal capacity.

25-mm pipe-nuts

Withdrawal capacities of 25-mm pipe-nuts in nominal 89 by 89-mm western hemlock specimens are listed in Table 2 (Set 2-1) and are illustrated in Figure 7. As can be seen, face-to-face orientation of the pipe-nuts produced essentially the same results as corner-to-corner placement. Likewise, the reinforced pipe-nuts produced essentially the same results as the unreinforced pipe-nuts. The unreinforced pipe-nuts, however, were slightly ovalized around the through-bolt hole at the highest load levels, whereas the reinforced pipe-nuts were not. The average coefficient of variation of the specimens with a 50-mm end distances was 19.1 percent, compared with 25.8 and 23.4 percent for 75- and 100-mm end distances, respectively. These results again tend to indicate that end distance did not affect variability of withdrawal capacity.

Withdrawal capacities in the face of nominal 38 by 140-mm southern yellow pine and western hemlock specimens are listed in Table 2 (Set 2-2) and are illustrated in Figure 8. As can be seen, at a 50-mm end distance, the southern yellow pine specimens had a nearly 17.8-kN withdrawal capacity, compared with a 14.7-kN withdrawal capacity for the western hemlock. Increases in capacity of both the southern yellow pine and the western hemlock specimens as a function of end distance were modest (except for the 150-mm end distance in the southern yellow pine specimen). In the case of the southern yellow pine, specimens with 75- and 100-mm end distances had 17.3 and 25 percent greater capacity, respectively, than those with a 50-mm end distance; likewise, western hemlock specimens with 75- and 100-mm end distances had 11 and 60 percent greater capacity, respectively. Coefficients of variation were 8.7, 8.6, and 21.1 percent for 50-, 75-, and 100-mm end distances, respectively, in southern yellow pine and 21.2, 14.6, and 20.5 percent for 50-, 75-, and 100-mm end distances, respectively in western hemlock specimens. Thus, variability in withdrawal capacity appeared to be no greater in specimens with 50-mm end distances than in those with greater end distances.

Withdrawal capacities of 25-mm pipe-nuts reinforced with inserts in hardwood specimens are listed in Table 2

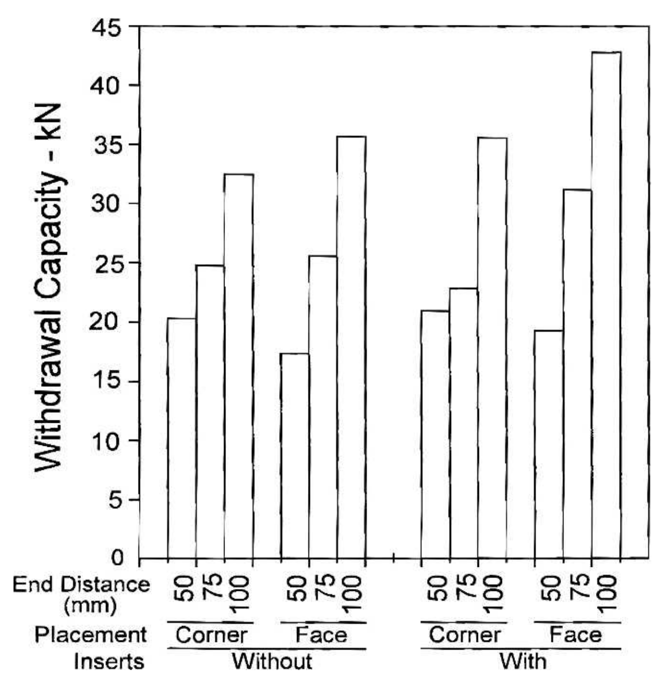

Figure 7.—Withdrawal capacity of 15.9-mm (nominal ⅝-in.) through-bolts with 25-mm (nominal 1-in.) pipe-nuts in nominal 89 by 89-mm (nominal 3½ by 3½-in.) western hemlock members.

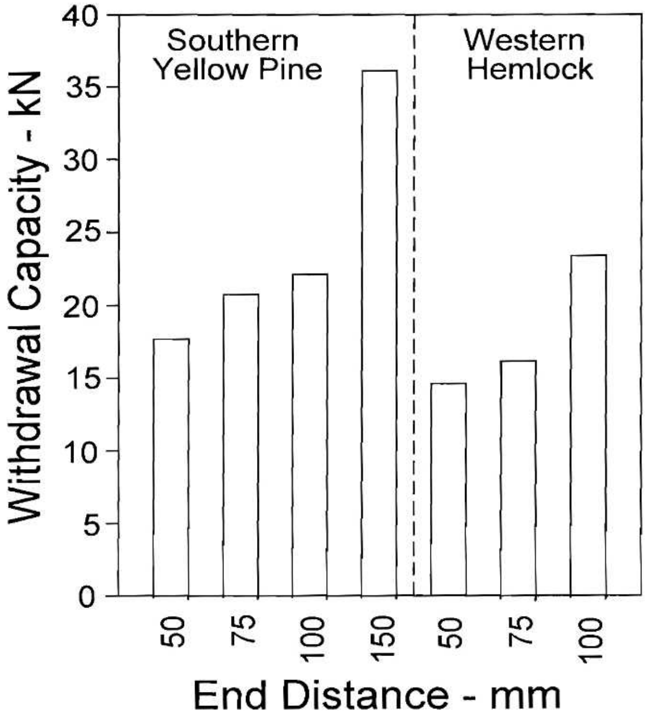

Figure 8.—Withdrawal capacities of 15.9-mm (nominal ⅝-in.) through-bolts with 25-mm (nominal 1-in.) pipe-nuts in nominal 38 by 140-mm (nominal 2 by 6-in.) southern yellow pine and western hemlock members.

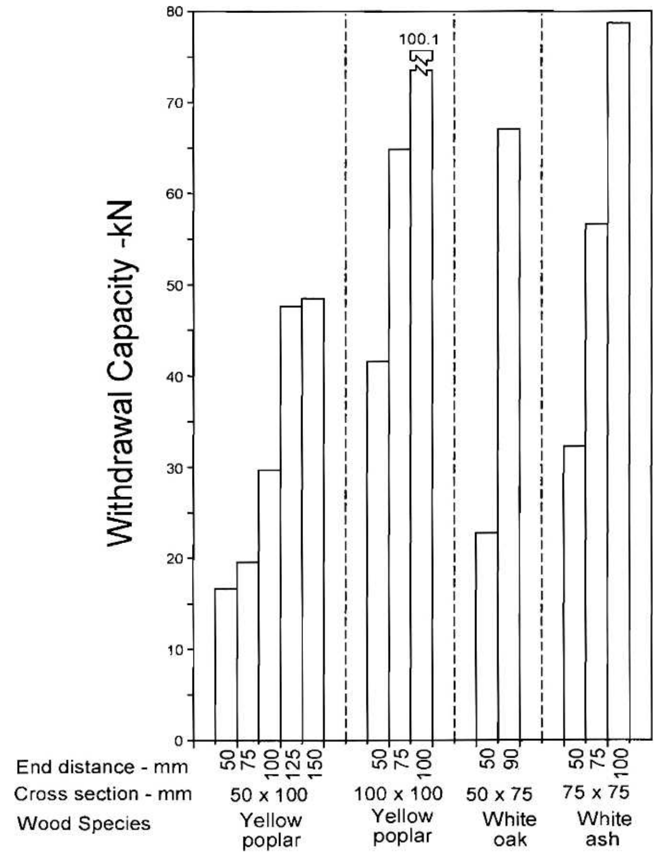

Figure 9.—Withdrawal capacities of 15.9-mm (nominal ⅝-in.) through-bolts with 25-mm (nominal 1-in.) pipe-nuts with inserts in yellow poplar, white oak, and white ash members.

(Set 2-3) and are illustrated in Figure 9. The withdrawal capacity of nominal 50 by 100-mm yellow poplar specimens with end distances of 50 to 150 mm ranged from 16.6 kN for specimens with 50-mm end distances to 48.4 kN for specimens with 150-mm end distances. Coefficients of variation amounted to 13.5, 14.5, 31.1, and 6.1 percent for nominal end distances of 50, 75, 100, and 150 mm, respectively. Thus, the coefficients of variation for the smaller end distances are essentially in keeping with those for greater end distances. The average withdrawal capacity of the specimens with nominal 125-mm end distances was 47.6 kN, or essentially the same as that of the specimens with 150-mm end distances. This result may indicate that withdrawal capacity does not increase as end distance increases above 125 mm in specimens of this geometry. Overall, the higher values obtained with yellow poplar compared with western hemlock presumably reflect the higher shear parallel to and tension perpendicular to the grain strength values of yellow poplar.

The withdrawal capacity of the nominal 100 by 100-mm yellow poplar specimens increased from 41.4 to 64.7 kN as end distances increased from 50 to 75 mm. Coefficients of variation were 19.1 and 13.6 percent for the 50- and 75-mm end distances, respectively. In one of these tests, slight distortion of the pipe-nut occurred at the 73.4-kN level. Testing of a single specimen (Set 2-3; Table 2) with a 100-mm end distance was stopped at the 100.1-kN load level because of yielding of the pipe-nut wall. These tests tend to indicate that the distortion-free withdrawal capacity of 25-mm pipe-nuts with inserts is somewhat less than 71.2 kN, although they can continue to carry load at well above this level.

The withdrawal capacity of the nominal 75 by 75-mm white ash specimens with 50-, 75-, and 100-mm end distances was 32.2, 56.5, and 78.7-kN, respectively. Coefficients of variation amounted to 9.1, 13.2, and 25.9 percent for 50-, 75-, and 100-mm end distances, respectively. An examination of the pipe-nuts used in the tests of specimens with 100-mm end distances indicated that the pipe-nuts could carry loads of 71.2 kN without noticeable distortion, but the walls of the pipe underwent substantial distortion at the 89-kN load level. Hence, it again appears that the upper limit of load capacity of 25-mm pipe-nuts reinforced with inserts is a little less than 71.2 kN.

The withdrawal capacity of the nominal 50 by 75-mm white oak specimens with 50-mm end distances averaged 22.7 kN, whereas the withdrawal capacity of the specimens with a 100-mm end distance averaged 67 kN. As can be seen, there is a 295 percent increase in withdrawal capacity of the white oak specimens as the end distance is increased from 50 to 100 mm, which compares favorably with a value of 245 percent for yellow poplar.

Overall, individual test results indicated that unreinforced 25-mm pipe-nuts begin to show minor distortion at 31.1 kN and substantial distortion above 44.5 kN. It appears, therefore, that the upper limit for 25-mm pipe-nuts without inserts should be somewhat less than 31.1 kN. Distortion of the 25-mm pipe-nuts with inserts began at approximately 71.2 kN, and substantial distortion occurred above 89 kN. Thus, the upper limit for 25-mm pipe-nuts with inserts should be approximately 66.7 kN. It should be noted,

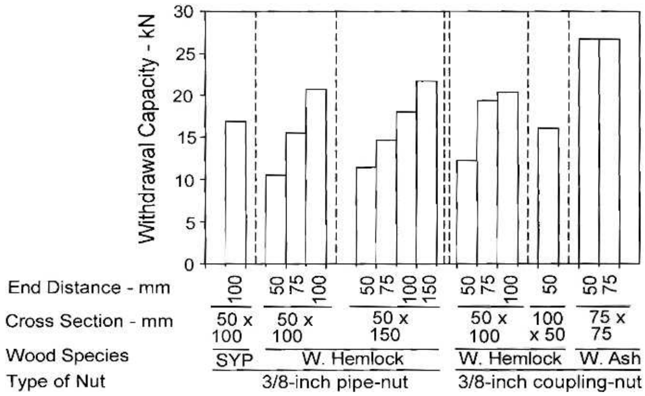

Figure 10.—Withdrawal capacities of 9.5-mm (nominal ⅜-in.) through-bolts and 15-mm (nominal ½-in.) pipe-nuts and of 9.5-mm through-bolts and 10-mm (nominal ⅜-in.) pipe-coupling-nuts in southern yellow pine (SYP), western hemlock, and white ash.

however, that the yield strength of the 15.9-mm rod was approximately 48.9 kN, so joint strength will be limited by through-bolt rather than pipe-nut capacity unless high-strength rods or through-bolts are used.

15-mm pipe-nuts

Results of the tests with 15-mm pipe-nuts are given in Table 3 and are illustrated in Figure 10. As can be seen, the three 38 by 89-mm western hemlock specimens (Set 3-1; Table 3) with 15-mm pipe-nuts and 50-, 75-, and 100-mm end distances failed in a regular, stepwise manner. The coefficients of variation for these specimens were 25.5, 22.2, and 13.2 percent for 50-, 75-, and 100-mm end distances, respectively. For purposes of comparison, the single set of nominal 38 by 89-mm southern yellow pine specimens with 100-mm end distances had slightly less capacity than the western hemlock specimens.

Because reinforcement of the pipe-nuts did not substantially increase the withdrawal capacity of the 38 by 140-mm western hemlock specimens (Set 3-3 vs. Set 3-2), the results for specimens with both reinforced (Set 3-3) and unreinforced (Set 3-2) pipe-nuts with 50- through 100-mm end distances were pooled in Figure 10. As can be seen, withdrawal capacity increased in a regular, stepwise manner. Coefficients of variation were 7.3, 10.8, and 16.2 percent for end distances of 50, 75, and 100 mm, respectively. Again, the low coefficient of variation obtained with 50-mm end distances is to be noted. Slight distortion of the through-bolt hole in the unreinforced pipe-nuts occurred above 13.3 kN and became noticeable at 17.8 kN. Slight distortion of the through-bolt hole in the reinforced pipe-nuts occurred at the highest load levels, but no distortion of the pipe wall itself was observed. Overall, results of the tests indicate that the upper limit for unreinforced 15-mm pipe-nuts—without through-bolt hole distortion—is approximately 13.3 kN and that the corresponding upper limit for reinforced pipe-nuts is approximately 17.8 kN.

The withdrawal capacities of 9.5-mm through-bolts with 10-mm pipe-coupling-nuts in 38 by 89-mm western hemlock specimens (Set 3-4; Table 3) were essentially the same as those for 15-mm pipe-nuts; however, no distortion of the through-bolt holes was noted at any load level. As a matter of interest, one set of tests was carried out with the pipe-coupling-nut aligned with the 89-mm axis of 38 by 89-mm western hemlock members (Set 3-5). For a 50-mm end distance, a withdrawal capacity of 16.1 kN was obtained—an increase in withdrawal capacity of 31.5 percent over that with the pipe-coupling-nut aligned with the minor axis (Set 3-4).

Tests of the withdrawal capacity of 10-mm pipe-coupling-nuts in nominal 75 by 75-mm white ash specimens (Set 3-6) were terminated at the 26.7-kN load level because of yielding of the threaded rod. None of the through-bolt holes in the couplings was distorted at this load level.

Conclusions

Face-to-face orientation of 25-mm pipe-nuts in square members produces essentially the same results as corner-to-corner placement. Positioning pipe-nuts 50 mm from the ends of members does not increase variability in withdrawal capacity compared with 75- and 100-mm end distances. The distortion-free capacity of 25-mm pipe-nuts without reinforcement is judged to be approximately 31.1 kN, whereas the distortion-free capacity of similar pipe-nuts with reinforcing inserts is judged to be approximately 71.1 kN.

Likewise, the distortion-free capacity of unreinforced 15-mm pipe-nuts is judged to be 13.3 kN, whereas the distortion-free capacity of comparable reinforced pipe-nuts is judged to be 17.8 kN. The 10-mm pipe-coupling-nuts have substantially greater capacity than the 15-mm pipe-nuts—no distortion of the pipe-coupling-nut was noted at the 26.7-kN load level.

Overall, results of the tests indicate that high-capacity joints can easily be constructed with reusable through-bolt and pipe-nut connectors. Quality control during premachining operations is of some concern, because ideally, the longitudinal axis of the through-bolt relief hole should intersect the longitudinal axis of the pipe-nut. Use of shorter end distances, which may be feasible because of the favorable results obtained with 50-mm end distances, makes it possible to obtain needed precision with simple jigs.

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