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# MINIMUM NAIL PENETRATION FOR WOOD STRUCTURAL PANEL CONNECTIONS SUBJECT TO LATERAL LOAD

In 1998, APA conducted a dowel bearing strength analysis of the required depth of nail penetration for wood structural panel connections in shear walls and diaphragms. The results of that analysis showed that the lateral connection strength, calculated per the 1997 National Design Specification (NDS[1]) for Wood Construction, was not affected by going from 1-5/8 inches to 1-1/2 inches for 10d common nails (0.148 x 3 inches) and from 1-1/2 inches to 1-3/8 inches for 8d common nails (0.131 x 2-1/2 inches). Based on that work, new minimum nail penetration requirements were placed in the shear wall and diaphragm tables in the 2000 International Building Code (IBC). The analysis conducted by APA is covered fully in APA Technical Report No. T98-22, *Nail Penetration and Framing Specific Gravity Factors for Shear Walls and Diaphragms.* The same analysis procedure is repeated in this paper but following the 2005 NDS provisions. The results from the 2005 NDS show that even smaller penetrations will provide full lateral connection strength.

## APA Nail Penetration Guideline Background

Before the 1991 NDS, nail lateral load design values were based on a simple empirical equation. The empirical equation predicted the design load of a single-nail connection and was defined as the load at which point the fastener deformation (joint slip) was 0.015 inch. According to the Wood Handbook[2], the empirical equation was intended to apply to connections in which the thickness of the side member was at least half the penetration of the nail in the main member. In many cases, a joint which contains wood structural panels may have a side member that is less than was assumed when the original empirical equation was developed. According to the Wood Handbook, the recommended minimum penetration was implemented "to maintain a sufficient ratio between ultimate load and the load at 0.015-inch deformation." Eleven nail diameters (11 x D) penetration was required for lateral connections of Douglas fir-larch or southern pine. Other wood species had greater required minimum penetrations. Since the base of the shear wall and diaphragm tables are Douglas fir-larch and southern pine lumber, 11 x D penetration was applied to the tables. The diameter for a 10d common nail is 0.148 inch; thus, the required penetration for full capacity of the connection was taken as: 11 x 0.148 inch = 1.628 inches, which rounds to 1-5/8 inches.

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The 1991 NDS made significant changes to the method by which connections are designed. These changes were based on work conducted by the U.S. Forest Products Laboratory. [3,4] New equations were introduced which accounted for the bearing strength of the side and main member, and the yield strength of the nail. Another significant change was that the minimum penetration was slightly increased to 12 nail diameters (12 x D) regardless of the species of lumber. The 12 x D minimum penetration was implemented as a conservative simplified approach (the previous version of the NDS had various minimum penetration depths for different lumber species). Unfortunately, the change caused a conflict with the minimum penetration (11 x D) specified in the shear wall and diaphragm tables.

The 1997 version of the NDS made no further changes to the method used for connection design. For nailed connections, four yield modes were checked. The design value for a single nail is based on the minimum of the four yield modes. If the penetration is less than 12 x D, but greater than 6 x D, then a depth of penetration factor, $C_d$, was used.

The 2005 NDS included slight changes to calculations so that all six yield mode equations are used and the depth-of-penetration factor is removed. The reason for no longer using the depth-of-penetration factor is that the dowel bearing length of the member receiving the nail is accounted for in the yield equations. It should also be noted that Tables 11Q and R of the NDS footnote that 10D penetration is required. NDS, however, does not require this provision and the table footnote appears to be provided for conservatism. For consistency, the 2005 NDS yield equations (as found in the provisions, not the tabulated values) are used in this analysis.

**2005 NDS Analysis**

In order to evaluate the effect of penetration on lateral connection strength for a variety of conditions, calculations using the 2005 NDS yield equations were performed for two different nail sizes, 8d and 10d common, and four different typical combinations of species, or equivalent specific gravity (SG), as follows:

- Framing SG = 0.5 with wood structural panel (plywood or OSB) SG = 0.5
- Framing SG = 0.5 with wood structural panel (plywood or OSB) SG = 0.42
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Framing is the main member and the wood structural panel is the side member.

Figure 1 shows a portion of one case considered; it is a plot of single-nail calculated design connection strength as a function of penetration depth and thicknesses of a side member. Figure 1 is based on a 10d common nail (nail diameter 0.148 inch), and the side and main member were assumed to be have SG = 0.42. The six yield equations in the NDS were considered to find the nominal design value. Figure 1 shows graphically that penetration depth has no effect on lateral connection strength (see horizontal strength line for different penetration) until a certain value. In this paper, that value is called the minimum penetration depth. In Figure 1, the minimum penetration depth is 1.1 inches for 1-1/8-inch panels fastened into framing, 1 inch for 23/32-inch panels fastened into framing and 0.8 inch for 15/32-inch panels. The minimum penetration depth is 6D in the 2001 NDS, thus, a 6D cutoff line is shown in Figure 1.

Minimum penetration depths were recorded for all the permutations described. The maximum penetration depth was then selected as the most conservative depth to apply to all permutations considered. The summarized result of this analysis is shown in Table 1.

**Figure 1. Lateral load of a single 10d nail as a function of nail penetration and side member thickness. Side member and main member have assumed SG = 0.42.**

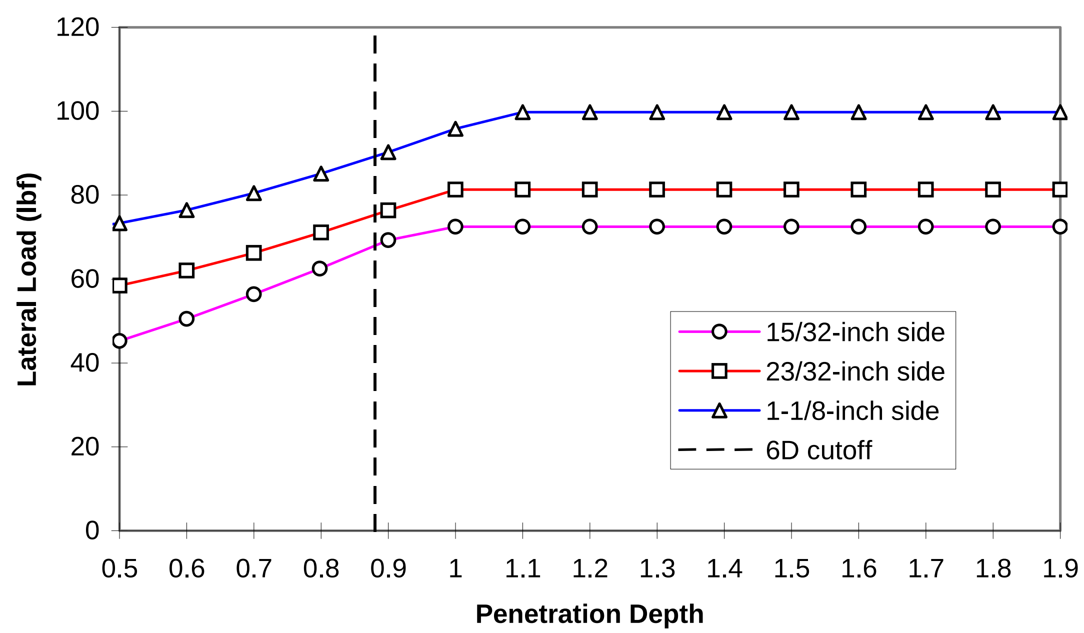

**Table 1. Minimum nail penetration (inches) required to develop full connection capacity.**

| Nail Diameter (in.) | APA Rated Sheathing | APA Rated Sturd-I- Floor® | Side member thickness (in.) | Min. fastener penetration for specific gravity = 0.42 to 0.5[a] |
|---|---|---|---|---|
| 0.148 (10d common[b]) | -- | 48 oc | 1.125 | 1.2 |
| | -- | 32 oc | 0.875 | 1.2 |
| | 48/24 | 24 oc | 0.719 | 1.1 |
| | 40/20 | 16 oc, 20 oc | 0.594 | 1.1 |
| | 32/16 | -- | 0.469 | 1.0 |
| | 24/16 | -- | 0.437 | 1.0 |
| | 24/0 | -- | 0.375 | 1.0 |
| 0.131 (8d common[b]) | -- | 48 oc | 1.125 | 1.1 |
| | -- | 32 oc | 0.875 | 1.1 |
| | 48/24 | 24 oc | 0.719 | 1.0 |
| | 40/20 | 16 oc, 20 oc | 0.594 | 1.0 |
| | 32/16 | -- | 0.469 | 1.0 |
| | 24/16 | -- | 0.437 | 1.0 |
| | 24/0 | -- | 0.375 | 1.0 |

(a) Four specific gravity combinations for both main member (framing) and side member (plywood or OSB) of 0.5 and 0.42 were considered. These were 1) 0.5 side, 2) 0.5 main with 0.42 side, 3) 0.42 main with 0.5 side, and 4) 0.42 main with 0.42 side.
(b) $F_yb$ = 90,000 psi for 10d common, $F_yb$ = 100,000 psi for 8d common.

## Summary and Conclusion

Based on the 2005 NDS yield equations, it can be shown where small penetrations start to have an effect on lateral connection strength. Table 1 shows what minimum penetration is necessary to develop the full lateral connection strength for common nailed wood structural panel-to-framing applications.

Technical Services Division



[1]American Forest & Paper Association. 2005. National Design Specification for Wood Construction. AF&PA. Washington, D.C.

[2]Wood Handbook: Wood as an Engineering Material. 1987. Agricultural Handbook 72. U.S. Department of Agriculture. Washington, DC.

[3]Aune, P. and Patton-Mallory, M. 1986. Lateral Load-Bearing Capacity of Nailed Joints Based on the Yield Theory: Theoretical Development. Res. Pap. FPL 469. USDA Forest Service, Forest Products Laboratory. Madison, WI.

[4]Aune, P. and Patton-Mallory, M. 1986. Lateral Load-Bearing Capacity of Nailed Joints Based on the Yield Theory: Theoretical Development. Res. Pap. FPL 470. USDA Forest Service, Forest Products Laboratory. Madison, WI.