Provisions Of NDS-2005

The National Design Specification For Wood Construction (NDS) provides detailed requirements for design of wood structures and components. For this evaluation, the 2005 version (NDS-2005) is used. Based on copies of NDS code pages attached to the 2007 calculations, Mr. Thom used NDS-2005.

Design of connections made with nails and screws is included in general requirements for "dowel" type fasteners (Chapter 11).

- ➡ Correct interpretation and use of code provisions for dowel type fasteners requires careful study of code provisions and reference to Commentary discussion. Some key code provisions are less than clear and can easily lead to incorrect calculations.

- ➡ For evaluation of connections subject to tension force, the NDS code does not clearly address the essential (and easy to overlook) requirement to verify that fastener strength is adequate on both sides of the connection.

Chapter 10 (Mechanical Connections) includes the following key provisions relevant to this evaluation;

10.1.4 Mixed Fastener Connections

Methods of analysis and test data for establishing reference design values for connections made with more than one type of fastener have not been developed. Reference design values and design value adjustments for mixed fastener connections shall be based on tests or other analysis (see 1.1.1.3).

Provision 10.1.4 certainly means that nails (or screws) and light-gage steel connectors should not be considered to act together without test data to substantiate behavior. This provision might reasonably be considered not to apply to shear capacity of nails and screws acting together. However, for withdrawal capacity, it is reasonable to assume that nails and screws should not be considered to act together, without test data.

10.1.5 Connection Fabrication

Reference lateral design values for connections in Chapters 11, 12 and 13 are based on:

(a) the assumption that the faces of the members are brought into contact when the fasteners are installed, and

- ➡ Although the very brief Commentary discussion of 10.1.5 focuses on bolted connections, this provision should be considered to mean that code provisions are not strictly valid for the valley truss connection, due to the gap under valley truss bottom chord.

Design & Analysis Of Valley Truss Connections

Proper design and analysis of valley truss connections is complicated by the gap between valley truss and main roof truss. Standard NDS-2005 code provisions are not entirely valid for this condition. However, Technical Report 12 (American Wood Council) provides alternate equations that allow for consideration of a gap between members.

Another key issue is the need to address connection strength on both sides of the dividing line ("joint") between valley truss and main truss.

For valley truss connections, with nail (or screw) installed at an installation angle of 30 degrees from vertical, the nail is inclined only slightly (5 degrees) with respect to grain of the main truss top chord ("main member").

☑ For evaluation of connection capacity in the main truss, appropriate method of analysis is to consider the nail (or screw) to be resisting combined withdrawal and lateral loading.

Mr. Thom attempted to use the correct method for the screw connection. However a key mistake was made which (favorably, but only in part) resulted in much less calculated capacity value than is the case for correct application of code provisions.

As noted above, for connections that must resist tension force, code provisions only account for connection capacity in the "main" member, which contains pointed end of nail or screw.

Since the uplift force is not perpendicular to longitudinal axis of the main member, the nail or screw must resist a tension force component and a lateral force component, at the same time.

The code includes (11.4) provisions for screws and nails loaded by combined lateral and withdrawal loads.

Unfortunately, due to deficiency of the code as written, it is easy to make the mistake of interpreting the Z'alpha value to be a lateral force, when in fact it is the angled force itself, shown as the dark arrow in Figure 11F (but not identified). This Z'alpha force is the "P" force discussed in the Commentary.

☑ For evaluation of valley truss connections, the Z'alpha force is the wind uplift force.

Angle alpha is the angle between the inclined force and the main member, with the fastener (nail or screw) installed perpendicular to grain of the main member.

For evaluation of valley truss connections in this report, a simplifying assumption is made that the nail or screw is perpendicular to the main truss top chord (main member) for purposes of using code equation 11-4.2. However, actual geometry is used to calculate penetration of nail or screw into main member.

Angle alpha is therefore equal to 90 degrees minus the installation angle.

As explained in the Commentary, capacity can be checked for known force components (withdrawal & lateral) using the much more understandable "interaction" equation (C11.4.2-2) that is used for other combined load conditions for all materials (wood, steel, concrete).

Code equation 11-4.2 is written so that allowable value of the inclined force (Z'alpha) can be calculated directly, without having to perform a check for any particular known loads.

Equation 11-4.2 is based in part on capacity (Z') for lateral force by itself. This calculation involves the valley truss as well as the main truss. However, equation 11-4.2 is also based on capacity (W'p) for tension force by itself, which only involves the main truss, not the valley truss. Therefore, as noted above, tension capacity of the connection in the valley truss is not accounted for by standard code provisions.

➡ For valley truss connections with nails or screw, capacity may be governed by the relatively weak wedge of wood adjacent to upper part of nail or screw in the valley truss.

Calculations for connection capacity have been performed based on combined withdrawal and lateral load, per standard equations from NDS-2005 (attached). Withdrawal capacity is calculated using NDS provisions. However, lateral capacity per NDS-2005 does not include a gap between the two members. Therefore, Technical Report 12 is used to calculate lateral (shear) capacity that must be input into the NDS equation for combined withdrawal and lateral load.

☑ The most reliable method of determining capacity of valley truss connections using angled nails or screw is to perform load testing. Design capacity would then be based on measured ultimate capacity (using appropriate "failure" criteria) and an appropriate safety factor consistent with general NDS provisions.

Toenail Connections; General

For calculating withdrawal strength from the main roof truss (main member), code provisions for toenails are not appropriate since nail (or screw) is very nearly perpendicular to grain of main member. However, basic understanding of code provisions for toenails may be useful for evaluation of the upper part of nail, in the valley truss.

Toenail withdrawal capacity (per code provisions) is governed by behavior of the nail within the "main" member (holding nail point). Apparently (since there is no explanation in the code), the "upper" part of the nail, in the "side" member (valley truss), is assumed to always have more capacity than the lower part (in main member), probably due to head of the nail resisting pull-through.

Therefore, it is reasonable to conclude that withdrawal capacity of the nail in the side member (valley truss) should be equal to or greater than withdrawal capacity of the nail in the main member, for standard toenail conditions; that is, for nail slanted with respect to grain of main member. The gap effect should not be a significant consideration for this calculation.

Unfortunately, code provisions for "toenail" connections have never been as clear as for other nailed connections. Lack of clear code instructions often results in confusion among design professionals, including experienced engineers.

A two-page design guide (Design Aid For Toenail Connections) issued in 2007 by the American Wood Council (AWC) provides some clarification of requirements. However, the Design Aid does not completely resolve key outstanding issues. There remains more than enough confusion as to the proper design and analysis of toenail connections.

The NDS does not clearly define what "withdrawal" means for a toenail. According to the diagram in the 2007 Design Aid, with toenail oriented 30 degrees from longitudinal axis of a wall stud (connected to wall base plate), "withdrawal" force acts along the stud axis, not along axis of the nail as might be expected.

Reason for the toenail factors (withdrawal and lateral) is partially explained in the Commentary. However, definition of "withdrawal" is still not clearly explained or shown.

Basically, provisions for design of toenail connections were derived for the specific connection of a wall stud to wall base plate. Application to other connections with angled or slanted ("toe") nails has not been clarified in the NDS (or in just about every text book this writer has seen).

Code provisions and Commentary do not address sensitivity of toenail capacity to deviations from the code-specified installation geometry. For example, if the angled nail is installed at an angle of 45 degrees with respect to "vertical" (which is line of action of "withdrawal" force), the code is silent on how such deviation (from the specified 30 degrees) may affect "withdrawal" capacity.

<u>Screw Connections</u>

For combined withdrawal and lateral loading, form of equation (11.4-1) for wood screw capacity is very similar but slightly different than form of equation (11.4-2) for nail capacity. However, the difference in form makes a large difference in calculated capacity.

Code provisions for withdrawal strength and lateral resistance are for wood capacity only. Values for lateral resistance in standard tables are based on assumed steel strength (bending yield, Fyb) for the screw, per notes with the tables.

Although often neglected, strength of the screw should also be checked, especially for relatively large design capacity. See NDS 10.1.2, 10.2.3 and 11.2.2.3.

Standard material specifications for wood screws do not specify steel strength (only dimensions and thread). See Commentary C11.1.4.

For a screw subjected to axial tension and bending due to lateral force, knowledge of steel strength is important, especially in recent times due to risk of inadequate quality control with some manufacturers (foreign and domestic).

Due to gap between valley truss and main truss, bending of wood screw (in the gap) could greatly reduce design capacity per standard calculations that neglect effect of the gap. Strength of steel would then be much more important.

Code provision (11.1.4.3) requires "lead hole" (drilled) for "all wood screws subject to lateral loads regardless of wood specific gravity" (C11.1.4.3).

Provision 11.1.4.2 requires lead hole for wood screws "loaded in withdrawal" when specific gravity (G) is greater than 0.5, which is the case for Southern Pine (G = 0.55).

- ➡ Strict application of code provisions for wood screws requires drilling lead holes for every screw.

Toenail Connections; Application To Wood Screws

Main reason that there are no "toenail" provisions for wood screws is likely that, since withdrawal capacity of the lower part (of screw) is generally much greater than for nails, the upper part may not always have more capacity than the lower part, especially considering tendency of the "wedge" of wood (upper part) to split away. Evaluation of a lower limit using capacity of lower part (as suggested for nails) is therefore not reasonable for screws.

- ➡ For screw installed through side of valley truss, capacity of the upper part (in valley truss) must also be checked. However, there are no specific code provisions addressing strength of the upper part.

General Dowel Equations (AWC Technical Report 12)

"General Dowel Equations For Calculating Lateral Connection Values" (Technical Report 12), published in 1999 by the American Wood Council (AWC), includes "general dowel equations" that allow for calculation of lateral capacity with a gap between wood members.

Form of the general dowel equations is significantly different than form of the yield mode equations in NDS-2005. However, the same yield modes are used in Technical Report 12 (TR12) as in NDS-2005. For zero gap, results should therefore be the same, as confirmed by communications with technical staff of the American Wood Council.

Detailed calculations show that, for zero gap, results using equations in TR12 are the same as results using equations from NDS-2005.

As explained in TR12 (1.2.2 & Table 6), "tabulated" connection values in NDS-2005 are based on the "5%" dowel bending strength, which is therefore used for calculations performed for this report.

When a gap is considered, lateral (shear) capacity is less than without the gap, as expected.

General dowel equations from Technical Report 12 are therefore used for this evaluation to calculate lateral (shear) capacity of nail and screw connections.

Provisions Of TPI Code

Design of prefabricated ("metal plate connected") wood trusses is governed by the standard ANSI / TPI 1 code.

The general building code references the TPI code. In 2003, the general building code in effect would have been IRC 2000, which referenced TPI 1-95.

IRC 2006 references TPI 1-2002.

Responsibility For Connection Design

In the 1995 edition (TPI 1-95) of the standard TPI code governing design of wood trusses, detailed listing of responsibilities for truss designer were included in the "non-mandatory" section. However, these responsibilities were generally considered to be standard.

Truss designer was delegated responsibility for design of connections between a common truss and a "truss girder", which is essentially a large truss that supports other trusses. Although the intent was generally understood to mean all "truss-to-truss" connections, valley truss connections were not specifically included in the actual code provision.

With the 2002 edition, detailed truss designer responsibilities were moved forward into the "mandatory" section. The connection requirement (2.1.2.9) remained the same as the 1995 version except that connection of "field splices" was changed to "field assembly of trusses", which might be considered as including valley truss connections.

IRC 2006 includes essentially the same requirements, with the last category being "field splices" as per TPI 1-95.