Evaluation of Engineer Documents

Detailed evaluation of documents (letters, calculations, plans) prepared by engineer for builder is appropriate and necessary to demonstrate the overall conclusion that valley truss connections using only nails and screws do not have adequate design capacity.

Based only on preliminary evaluation of available design plans, the overall structural design for wind resistance appears to be adequate, for Exposure Category B. Tiedown connectors are specified for the main roof trusses. Various connectors are specified for header beams and wall framing to resist direct uplift and overturning uplift forces due to wind.

The relatively weak valley truss connection is not consistent with what appears to be adequate design for other connections that must resist wind.

If Exposure Category C is applicable for any house, overall structural design for wind resistance may not be adequate.

Responsibility For Connection Design

Before wading into details of letters and calculations, the essential issue that must be addressed, at least to the extent feasible, is the reason that Mr. Thom became involved in design of valley truss connections at all, considering that Truswal had issued a standard connection drawing.

In available documents, there is no indication that Mr. Thom consulted Truswal about the proposed design change. There is also no explanation as to the reason why Mr. Thom was (apparently) asked by Del Webb to modify valley truss connections specified on the Truswal connection drawing. The most likely reason was to reduce cost for labor (primarily) and materials. Another potential reason may have been to validate as-built connections.

Of course, any structural design change implemented to reduce cost must not reduce structural capacity below that required by the building code.

Even with the gap under valley trusses, the H4 connector should have been relatively easy to install on the high side, where edge of the valley truss bottom chord bears on the main truss. However, a different connector could have easily been used if necessary (as specified on design plan sheet S4.1).

Letter of July 7, 2005

- Written description (in letter) of connection requirements, specified on the valley truss connection drawing by Truswal, is grossly incorrect.

Failure to properly read the clear requirements noted on the Truswal drawing indicates lack of adequate experience by person responsible for the evaluation.

There is no clear reference to *"Drawing that we prepared.........using 2-12d nails..."*.

As described elsewhere in this report, there are significant flaws with the Truswal drawing.

However, the Truswal drawing does clearly specify that; (1) There must be a nailed connection between valley truss bottom chord and each main ("base") truss, and (2) There must also be a Simpson H4 tiedown connector installed at every other main truss (spaced at 2'-0") with valley truss verticals (spaced at 4'-0") over a main truss.

Mr. Thom incorrectly states that (according to the "vendor") the Truswal drawing specifies nailed connections at every main truss OR connections with H4 tiedowns at every other main truss. In fact, notes on the Truswal drawing clearly specify nailed connections AND Simpson H4 tiedown connectors.

Reference to discussion with an unidentified "vendor", to assist with understanding of the Truswal drawing, indicates that Mr. Thom delegated this task to some other person without proper experience. At the very least, lack of any identification for the alleged vendor demonstrates poor quality of evaluation, as does constant misspelling of Truswal.

- ➡ There is no valid reason that Mr. Thom should have had to depend on some mysterious "vendor" to read the Truswal drawing.

If, as appears to have been the case, Mr. Thom (or other person) did not understand connection requirements on the Truswal drawing, Mr. Thom should have made attempts to contact one or more Truswal engineers responsible for the Truswal drawing. Preferably, a written request should have been submitted, asking for clarification of connection requirements. Response from Truswal should have been a reasonable expectation, especially considering size of this project.

Required capacity of tiedown connections (per Truswal) is not listed on the Truswal drawing. However, in tables published by the manufacturer (Simpson Strong Tie), design uplift capacity of the H4 connector is 360 pounds for Southern Pine wood (both members) or 235 pounds with SPF / Hem-Fir wood. Design capacity is based on use of the standard Load Duration Factor for 1.60 for wind loading. Capacity is not reduced if short, 1-1/2 inch 8d nails are used.

As specified on the available Truswal valley truss drawing, all members are to be Southern Pine. It is very likely the top chords of main roof trusses are also Southern Pine. Therefore, design capacity of each H4 connection for the Truswall valley trusses is very likely intended to be 360 pounds.

Calculations For Nail Connection (2-12-07)

As explained elsewhere in this report, to the extent that any calculations using code provisions may be considered valid, design capacity of nail connection should be based on code provisions for combined withdrawal and lateral loading, not on toenail provisions.

Calculations for the nail connection (dated 2-12-07) are deficient, for the following reasons;

- Incorrect assumption of equal distribution of wind uplift force to all connections between valley trusses and main trusses.

- Use of incorrect tributary area to calculate wind uplift force applicable to each connection. As previously noted, correct tributary area of 8.0 square feet is double the 4.0 square feet used for the basic calculation.

- Calculated value of design capacity (using any standard provision of the NDS code) is not valid since nails extend through the gap under valley truss. An air space between the two members is not consistent with basic condition of code provisions for wood-to-wood contact.

Though not an error, reporting numerical results to the hundredths decimal, such as 148.56 pounds uplift capacity and 19.89 psf net wind uplift pressure, indicates inexperience. Use and reporting of "precise" values is not consistent with well-known uncertainties inherent in engineering calculation procedures and determination of design forces. Variability between engineering theory and actual behavior is one of the main reasons we must design structures for "design" capacity that is much lower than ultimate "failure" capacity.

Distribution Of Wind Uplift Force To Connections

Most conservative position of valley truss, relative to connections, is the position shown on the Truswal drawing (valley truss connection), with each valley truss vertical web directly over the supporting main truss. For such position, all uplift force from the vertical web is resisted only by the primary connection directly under the web. Intermediate connections (between vertical webs) do not resist any force unless the primary connections fail.

- The calculation (2-12-07) is therefore based on the grossly flawed assumption that all connections resist uplift force equally.

Unless a vertical web is located midway between two roof trusses, uplift force will be unevenly distributed to the two nearest connections. Therefore, every connection does not provide the same resistance for any given wind loading.

For design of connections to resist wind uplift force applied to valley trusses, the most conservative position of valley truss must be considered effective. There is no practical way to ensure that the most conservative position does not occur.

Although some connections might be designed for less pressure than Zone 2 (if applicable) the most practical design will generally be to design all connections for the largest wind uplift. Therefore, design uplift force to be resisted by connections should be based on Zone 2 pressure.

Design Uplift Force

Calculation of force applied to each connection is incorrectly based on calculating total uplift force on the entire triangular roof area for one set of valley trusses and then dividing by the total number of connections for that set of valley trusses. Such method "averages down" maximum uplift force with the implicit assumption that all connections must work together.

Force applied to each connection must be determined by considering behavior of the valley trusses, which are subjected to varying wind pressures and total force.

Most important is the position of the valley truss vertical webs relative to connections, since wind uplift force is applied to connections through the vertical webs.

Tributary Area For Each Connection

Vertical uplift values listed in column 4 of each table (sheets 2 & 3; 2-12-07) are the VP1 pressures using notation of this report.

Wind uplift force applied to valley truss connections must first be applied to the valley truss web verticals and then to the valley truss bottom chord. Wind uplift force VF1 must therefore be calculated as VP1 times tributary area applicable to the vertical web.

For design of each valley truss connection, tributary area must be determined for that connection only, unless load-sharing can occur with other connections. However, for the most conservative position of the valley truss (as shown on Truswal drawing), with vertical web directly over a main truss, load-sharing does not occur. Each connection under the vertical web must have full design capacity to resist wind force from the vertical web.

- ☑ For the most conservative position of a valley truss, connections between vertical webs do not resist any uplift force, unless the primary connections begin to yield in failure.

Tributary force applicable for each interior valley truss vertical web is 2.0 feet spacing of valley trusses times 4.0 feet spacing of vertical webs, or 8.0 square feet. Therefore, for determination of wind pressure to be used, a tributary area of 10 square feet is appropriate.

- ➡ On markups of roof framing plans, wind uplift pressures used are incorrectly based on tributary area of 100 square feet. This mistake results in lower design uplift force than required using correct analysis.

This key error is most important for Zone 2 pressures. For the 6 on 12 roof slope, net uplift pressure (per ASCE 7-2005) of 48.4 psf for tributary area of 10 sf is 36% greater than the 35.6 psf uplift pressure for tributary area of 100 sf. For the 7.5 on 12 slope (or 7 on 12), the difference, though not as severe, remains significant (35.6 psf compared to 30.4 psf).

Force diagram (sheet 2) correctly shows (without clear notation) that the "components & cladding" wind uplift pressure (designated WP1 for further discussion) acts perpendicular to the roof surface formed by valley trusses. However, the contention (per note) that the horizontal component of WP1 is not effective is correct only if wind pressure on each opposing slope of the valley truss is equal, such that they cancel out.

For further discussion, vertical and horizontal components of WP1 are designated VP1 and HP1.

Vertical component of the uplift pressure (VP1) results in a vertical force (designated VF1) that is transferred down (through vertical web of valley truss) to connection between valley truss and main truss.

If use of code provisions for toenail connections were considered valid, there would be no need to consider effect of horizontal force component since "withdrawal" of toenails (per code Design Aid) is defined for nails at the 30 degree angle with respect to design force. Design capacity of each toenail would then be calculated with the toenail factor applied. Design capacity (74 lbs) in the calculation of 2-12-07 would then be correct.

However, the as-designed orientation of the nail does not comply with standard orientation of a "toenail", which is installed at angle with respect to grain of the main member (that contains point of nail). Instead, code provisions for combined lateral and withdrawal load must be used.

Complicating analysis is the wide gap between valley truss and main truss, which is not consistent with the standard configuration of a joint. Uplift force will cause bending in portion of nail within the air space.

- ➡ The best way to accurately determine design capacity of the nailed connection, to resist wind uplift force applied by the valley truss, is to perform load testing of the actual connection.

Installation Requirements

In the sketch on sheet 1, only one nail is shown. Apparent (unstated) intent is that the second nail is to be installed alongside, with the same position relative to each truss member.

However, installing two 12d nails side-by-side within the 1-1/2 inch thickness of the main truss top chord, without splitting the top chord, requires relatively careful installation. Depending on such care to obtain design capacity is wishful thinking at best, as clearly demonstrated by numerous problems with as-built nailed connections at Sun City, as described in the Island Packet articles and as indicated in the letter of March 8, 2007 by Mr. Thom.

Letter Of February 13, 2007

There is no explanation as to the reason Del Webb Communities requested this letter, however it is reasonable to surmise that Del Webb representatives must have expressed concerns about the nailed valley truss connections.

Explanation that design uplift loads are based on a tributary area of "4 square feet" is grossly inconsistent with explanation in item 2 of "summary observations" as well as the clear use of lower wind pressures based on 100 square feet tributary area in calculations written on roof framing plans.

- ➡ For connection design, tributary area must be only the area applicable to the specific connection, not the area applicable to an entire set of valley trusses, or even to one valley truss. Stated conclusion of summary observation 2 is therefore a major error.

Standard Figure 301.2(8) from IRC 2003, for determination of roof wind pressure zones, is included with calculations of 2-12-07. However, in the letter, no explanation is provided for how roof areas subject to Zone 2 pressures were determined (calculated).

Identification of Mr. Thom as "Principal" of a corporation indicates that others were working for Mr. Thom. Considering also the lack of hand-written name or initials in the title block on calculation sheets, it is reasonable to at least question whether Mr. Thom or someone else performed the calculations.

Letter of March 8, 2007

Mr. Thom neglects to discuss his own nail-connection drawing, previously provided to the developer, showing the nailed valley truss connection. Attributing damage to "careless use of the air powered nail driver" highlights the inherent risk of nailed connection that should be considered during the design process.

- ➡ Installation of two 12d nails from one side, at the same elevation, results in risk of splitting bottom chord of the valley truss, especially with gap underneath. Such risk increases greatly when uplift load must be resisted by the nails. This positioning also requires relatively small edge distance in the main truss top chord. Even small deviation (skew angle) of the nail line from centerline of main truss top chord results in risk of splitting the main truss.

Description of "total uplift" capacity of the "valley set" (Model 8304) as being 5,200 pounds (for connections with nails only) is grossly incorrect, as described elsewhere in this report, for the basic reason that it is essentially certain that some connections must resist much more uplift force than other connections. See Photo 1 for better understanding of this condition.

For position of valley truss shown on the Truswal drawing, only connections directly under the valley truss vertical web members resist uplift force, unless and until those connections fail.

- ➡ Truswal drawing specifies the H4 tiedown connector under each vertical web member for the obvious purpose of providing complete resistance to wind uplift forces.

- ➡ Nailed connections are specified (by Truswal) for the purpose of providing essential lateral bracing for each main (base) truss, not for resisting wind uplift force.

Although the Truswal drawing itself was flawed, it did at least show the basic principle that connections do not resist uplift force equally.

<u>Calculations For Screw Connection (3-7-07)</u>

Calculation for the single screw connection is based on an appropriate force diagram. However, the vertical uplift force is not clearly identified as being derived from the vertical component of components and cladding pressure that is (by code definition) applied normal to roof surface.

Listed screw diameter (0.138 inches) is less than the standard root value (0.152 inches) listed for typical #10 wood screw in Table L3 of NDS (appendix L). Apparently, this diameter has been calculated by converting millimeter value (3.25 - 3.55) for "Minor Dia" listed on product information sheet. However, the average 3.40 mm is 0.133 inches.

Uplift capacity is a function of screw diameter, primarily due to the gap effect, although it is not a major factor.

As previously noted, an attempt was made (in screw calculations) to use the appropriate provisions of the code, for combined withdrawal and lateral loading.

- ➡ However, a key mistake was made (sheet 3) by misreading the NDS code to interpret the Z'alpha force (equation 11.4-2) to be a lateral force when Z'alpha is in fact the inclined force shown by the dark arrow in Figure 11F of the code.

This mistake caused confusion, leading to mental gymnastics in an attempt to work "backwards" into an allowable uplift capacity, "calculated" to be 225 pounds. As shown in this report, correctly applying code provisions (even taking into account the gap) results in much greater design uplift capacity; 321 pounds for installation parameters of original calculation.

However, the best way to obtain reliable design capacity values for the screw connection would be to perform load testing.

Design Plan Details; S2.0

Note allowing elimination of roof sheathing under valley trusses should also have explained that top chords of main roof trusses must have adequate lateral bracing provided by other method.

Design Plan Details; S4.1

There is no information to determine when the valley truss connection detail was first included in building design plans.

- ☑ Detailed structural analysis of details on S4.1 has not been performed for this evaluation. However, details appear to demonstrate thorough design for wind uplift forces applicable to main roof trusses as well as for lateral wind forces for the entire building.

However, the valley truss connection detail is not adequate.

- ➡ Option for Simpson tiedown connectors at "alternate" main trusses only, without any connection for intermediate main trusses, would result in lack of essential lateral bracing for top chord of the main trusses (without connections). Along with the note (S2.0) allowing elimination of roof sheathing under valley trusses, such connection method would result in a major structural design defect if implemented for construction.

Design capacity of the alternate H2.5 connector is 415 pounds with both truss members being Southern Pine.

The apparent design concept, as stated in letters by Mr. Thom, was for specified connections (nails or screws or connectors) to provide total wind uplift capacity for a set of valley trusses, using the key assumption that wind uplift force is distributed equally to all connections for the entire set of valley trusses. This is the reason that lesser number of H2.5 connectors are specified, since they have greater unit capacity.

- ➡ As described elsewhere in this report, the basic design concept of the valley truss connection detail on sheet S4.1 is grossly defective.

Type of nail (common, box, sinker) is not specified. For this evaluation, the nail diameter (0.135") listed in calculations by Mr. Thom (2-12-07) is used.

Specified location for top-of-nail height (1.25 inches) is greater than the 1.08 inches used in calculation by Mr. Thom to (apparently) determine uplift capacity. Compared to the original calculation, nail penetration into the main truss top chord is reduced, which also reduces nail uplift capacity.

As shown elsewhere in this report, it is important to determine sensitivity of nail capacity due to changes of installation parameters.

Unless nails are installed with a tool that can maintain the specified installation angle (30 degrees), it is very likely that workers will install nails within a wide range of angles, some of which are greater than 35 degrees.

For the uneven distribution of wind uplift force to the various connections that must be considered for a conservative design, connections with reduced capacity will tend to be overstressed and even fail at much lower windspeeds compared to other connections with greater capacity.

Before specifying such connections for large numbers of houses, a test should have been conducted to determine how workers would actually install angled-nails using standard methods. The results almost certainly would have shown that design capacity must be reduced to account for installation tolerances.

Per NDS code provisions, lead holes must be drilled for all wood screws. This requirement should have been specified with the plan detail.

- ➡ Tension strength of wood screw should have been specified, along with requirement for submittal of certification.