Summary Of Conclusions

Conclusions of this evaluation are summarized below. The entire report must be read to understand all conclusions.

- ➡ Overall conclusion is that design of valley truss connections using two (2) 12d nails, as specified on available design plan (S4.1), and per calculations (Feb 2007) by engineer for builder, does not provide adequate level of design capacity to resist wind uplift force required by the governing building code.

Key Conclusions

1. Required wind uplift capacity, per calculations performed for this report, based on Exposure Category B and Zone 2 wind pressure per ASCE 7-2005, is 222 pounds (7:12 roof slope) and 322 pounds (6:12 roof slope).

2. Unless load testing demonstrates otherwise, allowable (design) uplift capacity for two (2) 12d nails is reasonably considered to be limited to 138 pounds maximum, for expected variation of installation tolerances. This capacity is much less than required for most valley truss conditions, even considering lower Zone 1 wind pressures that might be applicable for roof surfaces outside of the Zone 2 "edge" strip along each side of the ridge. For 6:12 roof slope, design uplift capacity of the double-nail connection is only 43% of required capacity.

3. Design (allowable) uplift capacity calculated using standard (code-specified) procedures is likely not conservative due to lack of accounting for various aspects that are not easily included in the mathematical model. More reliable and conservative design capacity is therefore best determined by load testing. Design capacity based on load testing must be based on "failure" load (defined appropriately) divided by safety factor that is consistent with general wood design standards.

4. Exposure Category C appears to be applicable only for a small number of houses along north side of Route 278. However, further evaluation of site characteristics around perimeter of the development should be performed. Required wind uplift capacity for Exposure Category C is 274 pounds (7:12 slope) and 395 pounds (6:12 slope).

Determination Of Design Capacity

5. For the valley truss connection specified on design plans (S4.1), design uplift capacity of connections with nails or screws must be calculated based on NDS provisions for combined withdrawal and lateral load, not on "toenail" provisions. Nails installed from low side of valley truss are effectively perpendicular to grain of the main truss top chord and uplift force (from valley truss) is applied at an angle with respect to the nail.

6. Due to gap between valley truss and main truss, use of standard code provisions (per NDS-2005) to calculate design lateral (shear) capacity of nail and screw connections are not completely valid. Technical Report 12 (TR12) by American Wood Council provides "general dowel equations" that allow for calculation of reference lateral (shear) capacity considering gap between connected members.

7. For withdrawal, design capacity for upper part of nail or screw (in valley truss) is not specifically addressed by standard code provisions. The need for careful consideration of whether upper part of fastener may control withdrawal capacity is one reason that load testing should be performed to accurately assess capacity of nail or screw connections.

8. Toenail provisions may be useful only to indirectly "determine" withdrawal capacity for upper part of nail (in valley truss), based on an assumption that pullout capacity from valley truss is at least equal to withdrawal capacity of "standard" toenail from main member. Using such approach, capacity for upper part of nail is 81 pounds per 12d nail (162 lbs for 2 nails), which is greater than uplift capacity per separate (governing) calculations for parameters specified on design plans.

<u>Basic Design Requirements</u>

9. As specified in the IRC building code (Chapter 3), the IRC code shall not be used for wind design when basic wind speed is 100 mph or greater. Since basic wind speed is 130 mph, one of the specified reference codes must be used.

10. Based on provisions of standard reference code (ASCE 7-2005) for determination of wind uplift pressures on roof surfaces, and reasonably conservative engineering judgment as necessary, the use of Zone 2 wind pressures for design of valley truss connections is most appropriate, unless published research is produced to show otherwise.

11. For the 7 on 12 roof slope, required uplift force for Zone 2 pressure (on entire tributary roof surface) is only modestly greater than for Zone 1 pressure. The difference is much greater for the 6 on 12 roof slope.

12. Calculated design uplift capacity of nail and screw connections (for main member only), based on combined withdrawal and lateral loading, is sensitive to installation parameters (installation angle & top-of-nail height). Changes of installation parameters are most important for nail connections due to relatively low design capacity.

13. Design capacity must be based on realistic (and conservative) tolerances for installation parameters that produce the lowest capacity. Failure of one weak connection can result in a cascading failure ("zipper" effect), as load previously resisted by the failed connection is redistributed to adjacent connections.

Calculated Design Capacity Of Nail & Screw Connections

14. For installation per design plans (S4.1), calculated design uplift capacity of connection using 2-12d nails is 160 lbs. This maximum limit on capacity is less than minimum required uplift capacity (222 lbs) calculated for this report, and much less than; (1) Required uplift capacity (360 lbs) listed on valley truss diagram by Builders FirstSource / MiTek, and (2) Design capacity (360 lbs) for the H4 tiedown connector specified on the Truswall valley truss connection drawing, based on Southern Pine wood members.

15. For installation angle of 40 degrees and top-of-nail height of 1-1/2 inches, calculated design uplift capacity is 69 pounds per nail (138 lbs for 2 nails). For valley trusses connected only with 12d nails, this value should conservatively be considered the maximum available design capacity.

16. For installation per design plans (S4.1), calculated design uplift capacity of single-screw connection is 307 pounds. This capacity is adequate for all valley truss sets with roof slope of 7 on 12 or greater. For roof slope of 6 on 12, screw capacity is less than required for Exposure Category B (322 lbs) and much less than required for Exposure Category C (395 lbs).

17. For connections with single screw added to existing nails, design capacity must be that of the screw (acting alone) if wood was damaged by nails or if nails were otherwise improperly installed. Also, per NDS 10.1.4, adding capacity of different fasteners is generally not allowed without load testing to demonstrate compatibility.

Evaluation Of Engineer Documents

18. Calculations prepared in 2007 by engineer for builder include significant errors. Most critical is the incorrect use of 4.0 square feet tributary area (for valley truss connection) when 8.0 square feet is required for the most conservative position of valley truss.

19. Interpretation of connection requirements on the Truswal connection drawing, as described in letter of July 7, 2005 by engineer for builder, is grossly incorrect. The Truswal drawing clearly specifies nails at every connection and, in addition, H4 tiedown connectors under each vertical web of the valley truss.

20. Required uplift capacity for valley truss connections reported by engineer for builder, via hand-written calculations on copies of roof framing plans, are much less than uplift forces calculated using appropriate conditions of analysis. Engineer incorrectly assumed that wind uplift is resisted equally by all valley truss connections for each "set" of valley trusses. In fact, alternate connections must resist greater force for all positions of valley trusses, except for the highly unlikely condition of valley truss vertical webs midway between main trusses.

Truswal Valley Truss Connection Drawing

21. Position of valley truss shown on the Truswal connection drawing is conservative for determining the maximum uplift force to be resisted by any connection. However, the Truswal design (with nails-only at every other connection) does not provide the same uplift resistance for the condition when valley truss vertical webs are over (or close to) main trusses with the nail-only connection. Therefore, the overall Truswal connection design, with nails (only) at every other connection, is not adequate.

Design Solution

22. Determining the most effective design solution (for valley truss connections) requires careful consideration of all requirements and potential effects. Design and analysis is complicated by the need (in this case) for valley truss bottom chords to provide lateral bracing for top chords of main roof trusses, due to lack of roof sheathing (on main trusses) under the valley trusses.

23. The most reliable design solution requires installation of secure tiedown connectors at every intersection between valley truss and main support truss. With use of tiedown connectors, the need for nails or screws can be eliminated for new construction.

Existing Construction

24. Many valley trusses on existing houses, with nail-only connections, do not have adequate capacity to resist uplift pressure from high-speed winds. It is reasonable to conclude that damage can be expected in the event of windspeeds even less than the 130 mph specified by the building code.

25. Obvious damage may not occur for many years, after nailed connections have been strained and weakened by several high-windspeed events. Severe damage could then occur for windspeed much less than design windspeed specified by code.

26. For existing conditions shown in Photo 1, valley trusses will remain connected to main trusses even if nailed connections fail, since tiedown connectors have adequate design capacity and overload capacity. However, if nailed connections fail, essential lateral bracing for main trusses, currently provided by valley truss bottom chords, becomes deficient and truss top chords could easily be damaged.

Recommendations

27. Remedial work should be performed to provide adequate uplift capacity for at-risk valley trusses, based on detailed inspection of actual conditions and further engineering analysis, as recommended in this report.

28. Further structural analysis of as-designed and as-built houses should be performed by at least one independent, qualified professional engineer to determine whether houses have adequate structural capacity to resist code-specified wind forces. Analysis is especially important for houses that should have been designed for Exposure Category C wind pressures.