Research Report

Lay-On Gable Frame Connection: An Analysis of a Toe Nail Connection Visible After Sheathing is Installed

SRR No. 1505-02

Structural Building Components Association (SBCA)

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Introduction:

A lay-on gable frame is typically connected from the top during truss placement, but after sheathing is installed, this connection is no longer visible for the building inspector to verify. This creates a need for an alternate connection that is visible from below. The goal of this report is to analyze a simple, cost-effective, toe nail connection between the lay-on gable frames and supporting truss system that is visible after sheathing is installed.

Analysis:

Overview

Uplift pressure on the building is determined using *ASCE 7-10*. The pressure is then converted to a point load using an assumed tributary area based on a typical configuration. This loading force is then compared to the connection capacity of fasteners determined in accordance with the *National Design Specification* (*NDS*) *for Wood Construction*.

Design Load

To provide a general analysis that will be applicable to a majority of situations encountered, certain assumptions were made, which are listed in Table 1. Given the objective of the report and nature of the problem, roof uplift loading is the focus. Trusses are part of both Components and Cladding as well as Main Wind-Force Resisting Systems and, therefore, need to resist loading imposed by both. Components and Cladding loading will control this design.

Loading Assumptions	
Description	**Value Assumed**
Code	*ASCE 7-10*
Controlling Load Combination (ASD)	0.6D + 0.6W
Dead Load	Asphalt Shingles 2 psf 3/8" OSB Sheathing 1.1 psf Lay-On Gable Self-Weight 0.9 psf Total = 5 psf
Method	Components & Cladding – Method 1
Mean Roof Height	$h \leq 30'$
Building Shape	Regular Shaped Building
Roof Style	Hip Roof with $4/12 \leq \theta \leq 12/12$ $18° \leq \theta \leq 45°$
Basic Wind Speed	≤130 mph
Occupancy Category	II
Enclosure Category	Enclosed
Importance Factor, I	1.00
Topographic Factor, K_{zt}	1.00
Exposure Category	C
Adjustment Factor for Building Height & Exposure, λ	For Exposure B & h = 30', λ = 1.00

Table 1: Assumptions

With these assumptions established, the uplift pressure can be determined from *ASCE 7*. Figure 1 shows a portion of the applicable table used, with the area of interest highlighted. The negative sign means the pressure is away from the structure, as in uplift for the roof. Zone 2 is used because of the typical location of a lay-on gable not at the corner of a structure, which would be Zone 3, and the possibility that the connection in question is at the hip, which is Zone 1 or 2. Zone 2 is more severe and is a conservative assumption. By taking a conservative and appropriate value of 10 square feet for an Effective Wind Area, a maximum design uplift wind pressure of 48.4 psf is found. This pressure is used later in the depicted calculations.

Components and Cladding – Method 1 | **h ≤ 60 ft.**

Figure 30.5-1 (cont'd) | **Design Wind Pressures** | **Walls & Roofs**

Enclosed Buildings

Net Design Wind Pressure, p_{net30} (psf) *(Exposure B at h = 30 ft.)*

	Zone	Effective wind area (sf)	Basic Wind Speed V (mph)																	
			110		115		120		130		140		150		160		180		200	
Roof 0 to 7 degrees	1	10	8.9	-21.8	9.7	-23.8	10.5	-25.9	12.4	-30.4	14.3	-35.3	16.5	-40.5	18.7	-46.1	23.7	-58.3	29.3	-72.0
	1	20	8.3	-21.2	9.1	-23.2	9.9	-25.2	11.6	-29.6	13.4	-34.4	15.4	-39.4	17.6	-44.9	22.2	-56.8	27.4	-70.1
	1	50	7.6	-20.5	8.3	-22.4	9.0	-24.4	10.6	-28.6	12.3	-33.2	14.1	-38.1	16.0	-43.3	20.3	-54.8	25.0	-67.7
	1	100	7.0	-19.9	7.7	-21.8	8.3	-23.7	9.8	-27.8	11.4	-32.3	13.0	-37.0	14.8	-42.1	18.8	-53.3	23.2	-65.9
	2	10	8.9	-36.5	9.7	-39.9	10.5	-43.5	12.4	-51.0	14.3	-59.2	16.5	-67.9	18.7	-77.3	23.7	-97.8	29.3	-120.7
	2	20	8.3	-32.6	9.1	-35.7	9.9	-38.8	11.6	-45.6	13.4	-52.9	15.4	-60.7	17.6	-69.0	22.2	-87.4	27.4	-107.9
	2	50	7.6	-27.5	8.3	-30.1	9.0	-32.7	10.6	-38.4	12.3	-44.5	14.1	-51.1	16.0	-58.2	20.3	-73.6	25.0	-90.9
	2	100	7.0	-23.6	7.7	-25.8	8.3	-28.1	9.8	-33.0	11.4	-38.2	13.0	-43.9	14.8	-50.0	18.8	-63.2	23.2	-78.1
	3	10	8.9	-55.0	9.7	-60.1	10.5	-65.4	12.4	-76.8	14.3	-89.0	16.5	-102.2	18.7	-116.3	23.7	-147.2	29.3	-181.7
	3	20	8.3	-45.5	9.1	-49.8	9.9	-54.2	11.6	-63.6	13.4	-73.8	15.4	-84.7	17.6	-96.3	22.2	-121.9	27.4	-150.5
	3	50	7.6	-33.1	8.3	-36.1	9.0	-39.3	10.6	-46.2	12.3	-53.5	14.1	-61.5	16.0	-69.9	20.3	-88.5	25.0	-109.3
	3	100	7.0	-23.6	7.7	-25.8	8.3	-28.1	9.8	-33.0	11.4	-38.2	13.0	-43.9	14.8	-50.0	18.8	-63.2	23.2	-78.1
Roof > 7 to 27 degrees	1	10	12.5	-19.9	13.7	-21.8	14.9	-23.7	17.5	-27.8	20.3	-32.3	23.3	-37.0	26.5	-42.1	33.6	-53.3	41.5	-65.9
	1	20	11.4	-19.4	12.5	-21.2	13.6	-23.0	16.0	-27.0	18.5	-31.4	21.3	-36.0	24.2	-41.0	30.6	-51.9	37.8	-64.0
	1	50	10.0	-18.6	10.9	-20.4	11.9	-22.2	13.9	-26.0	16.1	-30.2	18.5	-34.6	21.1	-39.4	26.7	-49.9	32.9	-61.6
	1	100	8.9	-18.1	9.7	-19.8	10.5	-21.5	12.4	-25.2	14.3	-29.3	16.5	-33.6	18.7	-38.2	23.7	-48.4	29.3	-59.8
	2	10	12.5	-34.7	13.7	-37.9	14.9	-41.3	17.5	-48.4	20.3	-56.2	23.3	-64.5	26.5	-73.4	33.6	-92.9	41.5	-114.6
	2	20	11.4	-31.9	12.5	-34.9	13.6	-38.0	16.0	-44.6	18.5	-51.7	21.3	-59.3	24.2	-67.5	30.6	-85.4	37.8	-105.5
	2	50	10.0	-28.2	10.9	-30.9	11.9	-33.6	13.9	-39.4	16.1	-45.7	18.5	-52.5	21.1	-59.7	26.7	-75.6	32.9	-93.3
	2	100	8.9	-25.5	9.7	-27.8	10.5	-30.3	12.4	-35.6	14.3	-41.2	16.5	-47.3	18.7	-53.9	23.7	-68.2	29.3	-84.2
	3	10	12.5	-51.3	13.7	-56.0	14.9	-61.0	17.5	-71.6	20.3	-83.1	23.3	-95.4	26.5	-108.5	33.6	-137.3	41.5	-169.5
	3	20	11.4	-47.9	12.5	-52.4	13.6	-57.1	16.0	-67.0	18.5	-77.7	21.3	-89.2	24.2	-101.4	30.6	-128.4	37.8	-158.5
	3	50	10.0	-43.5	10.9	-47.6	11.9	-51.8	13.9	-60.8	16.1	-70.5	18.5	-81.0	21.1	-92.1	26.7	-116.6	32.9	-143.9
	3	100	8.9	-40.2	9.7	-44.0	10.5	-47.9	12.4	-56.2	14.3	-65.1	16.5	-74.8	18.7	-85.1	23.7	-107.7	29.3	-132.9
Roof > 27 to 45 degrees	1	10	19.9	-21.8	21.8	-23.8	23.7	-25.9	27.8	-30.4	32.3	-35.3	37.0	-40.5	42.1	-46.1	53.3	-58.3	65.9	-72.0
	1	20	19.4	-20.7	21.2	-22.6	23.0	-24.6	27.0	-28.9	31.4	-33.5	36.0	-38.4	41.0	-43.7	51.9	-55.3	64.0	-68.3
	1	50	18.6	-19.2	20.4	-21.0	22.2	-22.8	26.0	-26.8	30.2	-31.1	34.6	-35.7	39.4	-40.6	49.9	-51.4	61.6	-63.4
	1	100	18.1	-18.1	19.8	-19.8	21.5	-21.5	25.2	-25.2	29.3	-29.3	33.6	-33.6	38.2	-38.2	48.4	-48.4	59.8	-59.8
	2	10	19.9	-25.5	21.8	-27.8	23.7	-30.3	27.8	-35.6	32.3	-41.2	37.0	-47.3	42.1	-53.9	53.3	-68.2	65.9	-84.2
	2	20	19.4	-24.3	21.2	-26.6	23.0	-29.0	27.0	-34.0	31.4	-39.4	36.0	-45.3	41.0	-51.5	51.9	-65.2	64.0	-80.5
	2	50	18.6	-22.9	20.4	-25.0	22.2	-27.2	26.0	-32.0	30.2	-37.1	34.6	-42.5	39.4	-48.4	49.9	-61.3	61.6	-75.6
	2	100	18.1	-21.8	19.8	-23.8	21.5	-25.9	25.2	-30.4	29.3	-35.3	33.6	-40.5	38.2	-46.1	48.4	-58.3	59.8	-72.0
	3	10	19.9	-25.5	21.8	-27.8	23.7	-30.3	27.8	-35.6	32.3	-41.2	37.0	-47.3	42.1	-53.9	53.3	-68.2	65.9	-84.2
	3	20	19.4	-24.3	21.2	-26.6	23.0	-29.0	27.0	-34.0	31.4	-39.4	36.0	-45.3	41.0	-51.5	51.9	-65.2	64.0	-80.5
	3	50	18.6	-22.9	20.4	-25.0	22.2	-27.2	26.0	-32.0	30.2	-37.1	34.6	-42.5	39.4	-48.4	49.9	-61.3	61.6	-75.6
	3	100	18.1	-21.8	19.8	-23.8	21.5	-25.9	25.2	-30.4	29.3	-35.3	33.6	-40.5	38.2	-46.1	48.4	-58.3	59.8	-72.0

Figure 1: *ASCE 7* Applicable Loading Table (*ASCE 7* Figure 30.5-1)

Configuration

Figure 2 shows the assumed typical truss layout. Trusses are assumed to be a maximum of 24" o.c., and the lay-on gable frame members are a maximum of 24" o.c. This shows both the connection location under analysis as well as the tributary area of that connection. The connection point represents the worst-case location of a typical layout based on the largest tributary area.

Figure 3 shows the details of the assumed connection under analysis.

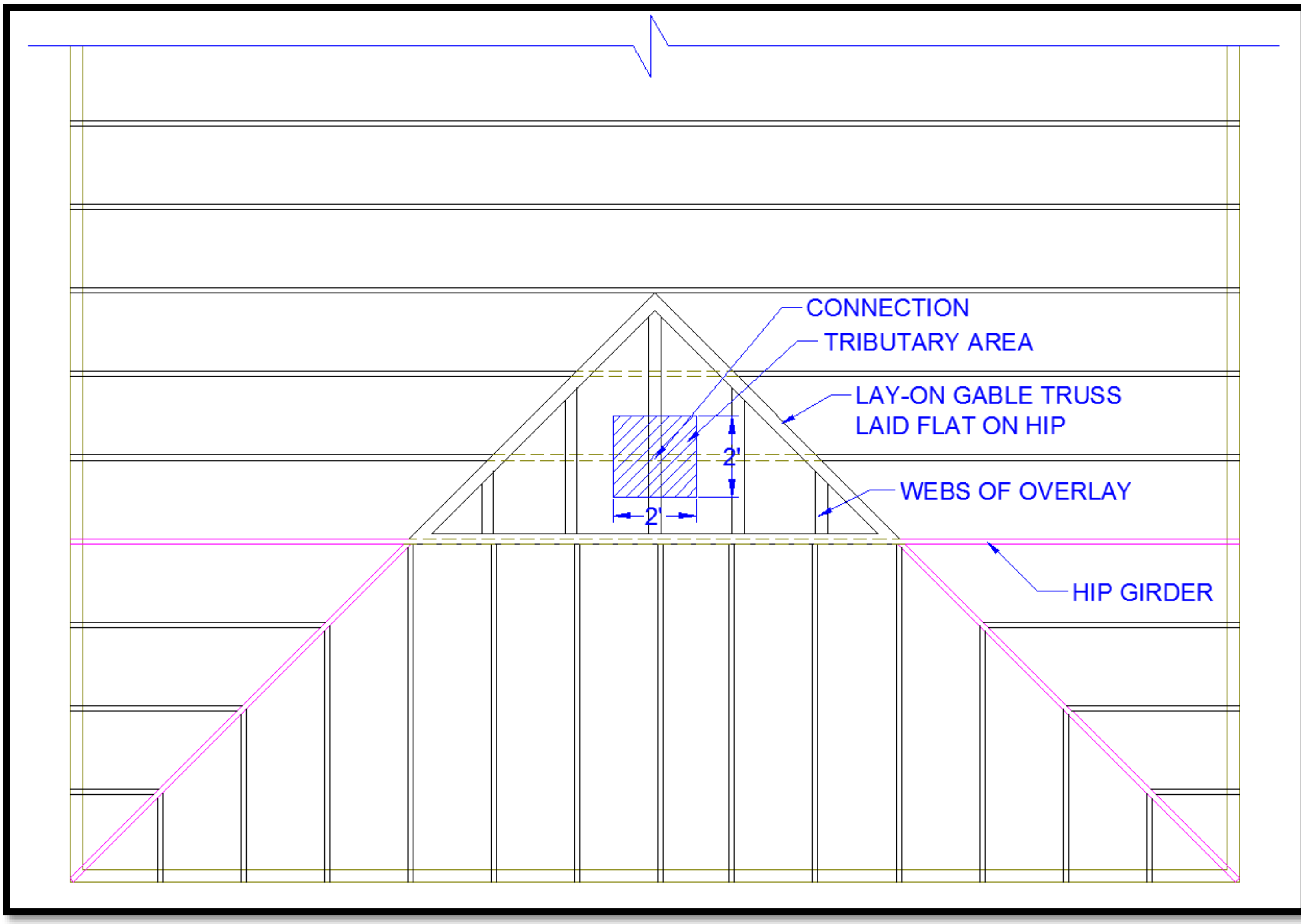

Figure 2: Truss Layout

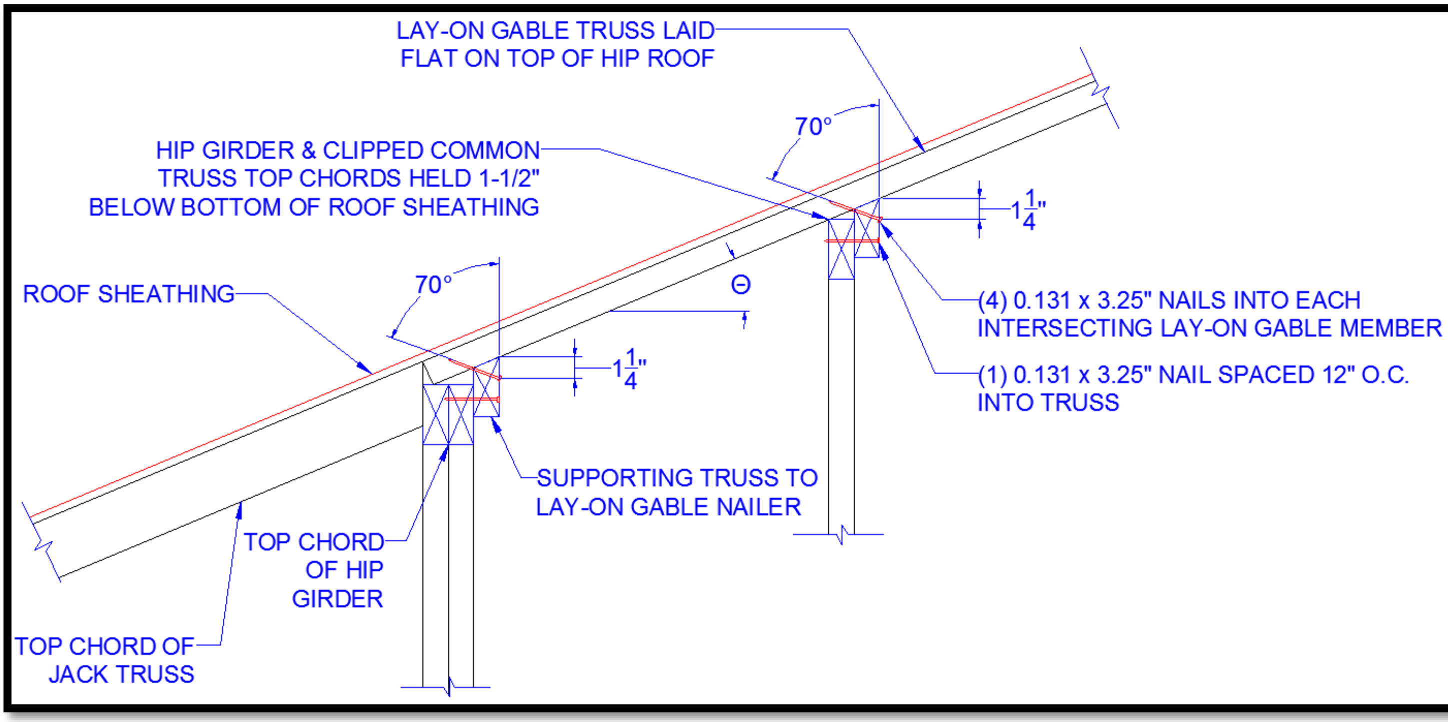

Figure 3: Connection Details

Table 2 provides the required spacing and edge distances for the fasteners. Figure 4 provides a visualization of the spacing and edge distance minimums.

Minimum Fastener & Edge Distances Minimums			
Supporting Truss			
Description	**Description**	**Description**	**Description**
Edge Distance	*NDS* Table 11.5.1C Perpendicular to Grain Loaded Edge	4D	4 x (0.131") = ½"
Spacing Between Rows	*NDS* Table 11.5.1D Perpendicular to Grain L/D=11 > 6	5D	5 x (0.131") = 5/8"
Lay-On Gable			
Description	**Reference**	**Value**	**Calculated**
Edge Distance	*NDS* Table 11.5.1C Parallel to Grain L/D=11 > 6	1.5D	1.5 x (0.131") = 3/16"
Spacing Between Rows	*NDS* Table 11.5.1D Parallel to Grain	Max of 1.5D and 1/2 spacing between rows	1.5 x (0.131") = 3/16" 0.5 x (0.655") = 5/16"

Table 2: Fastener Spacing & Edge Distance Minimums

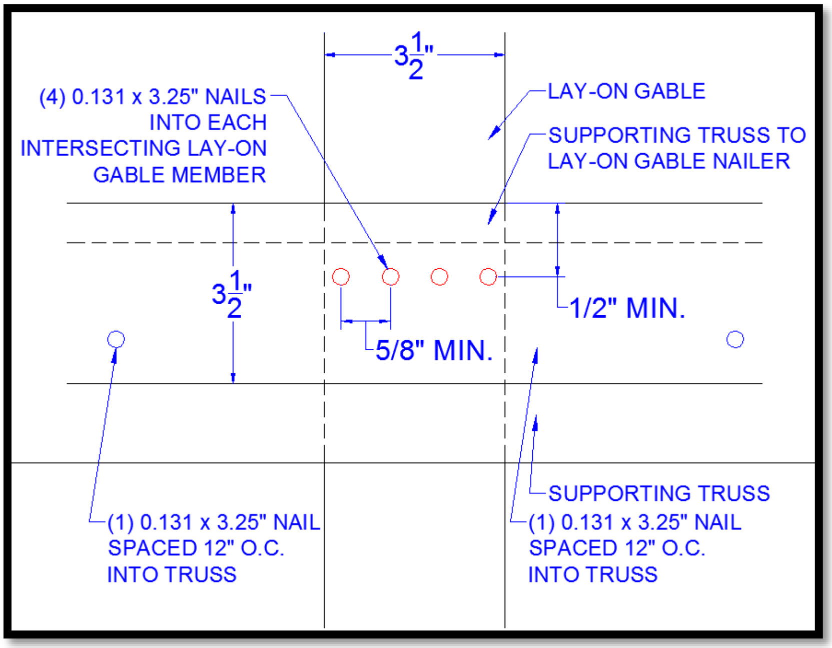

Figure 4: Visualization of Fastener Spacing & Edge Distances

Capacity

The connection can be looked at as two parts. The first part of the connection is the toe nail into the lay-on gable. This connection is made with (4) 0.131 x 3.25" nails at each lay-on gable web location. These nails are toe-nailed into the truss at a 70° angle from the vertical as shown in Figure 3. The second part of the connection is the beveled member attached to the hip truss, which provides a nailing surface for part 1 of the connection described above. Figure 5 shows a more detailed view of the connection. Table 2 lists the assumptions used during the capacity calculations.

Capacity Assumptions	
Description	**Value Assumed**
Framing Material	Spruce Pine Fir (SPF)
Framing Specific Gravity	0.42

Table 3: Capacity Assumptions

To analyze the capacity of part 1 of the connection, the applied force is decomposed into two orthogonal forces, lateral and withdrawal, with respect to the toe nail. These applied forces are compared to the lateral and withdrawal capacity values calculated according to *NDS*. Since a range is assumed on the roof slope, the upper and lower bounds will be analyzed to ensure the required capacity is available throughout the range; Figure 5 shows how the angle of the roof slope impacts the calculations. The slope of the roof is used to calculate the angles needed for these calculations as shown.

Figure 6 shows the calculations of the design load. The assumed adjustment factors are applied to the uplift pressure obtained from *ASCE 7*.

Figure 7 and Figure 8 show the calculations for the lower and upper bounds of the roof slope, respectively. The capacity terms follow the nomenclature found in *NDS*.

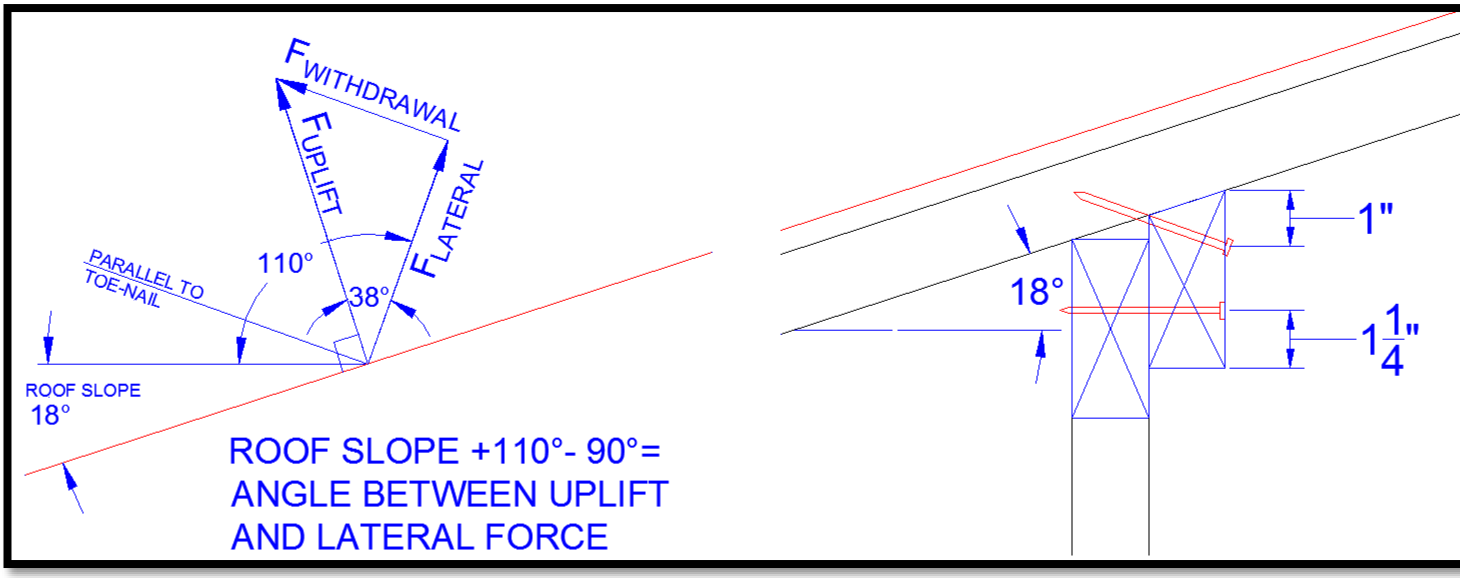

Figure 5: Visualization of Pure Withdrawal & Pure Lateral Loading

Design Load

Adjustmet Factors:

$$\lambda := 1.00$$
$$I := 1.00$$
$$K_{Zt} := 1.00$$
$$LC_{wind} := 0.6$$
$$LC_{dead} := 0.6$$

Obtaining Uplift Pressure:

$$p_{net\_30} := 48.4\ \mathbf{psf}$$
$$p_{net} := LC_{wind} \cdot \lambda \cdot K_{Zt} \cdot I \cdot p_{net\_30}$$

Obtaining Uplift Point Load:

$$A_t := 2\ \mathbf{ft} \cdot 2\ \mathbf{ft} = 4\ \mathbf{ft}^2$$
$$P_{uplift} := p_{net} \cdot A_t = 116\ \mathbf{lbf}$$

Reducing Uplift Point Load with Dead Load:

$$DeadLoad := 5\ \mathbf{psf} \cdot A_t = 20\ \mathbf{lbf}$$

Design Uplift Point Load:

$$P := P_{uplift} - LC_{dead} \cdot DeadLoad = 104\ \mathbf{lbf}$$

Figure 6: Design Load Calculations

Design Loads

$F_{UPLIFT} := P = 104\ lbf$

$RoofSlope := 18\ °$

$\Theta := RoofSlope + 110\ ° - 90\ ° = 38\ °$

$F_{WITHDRAWAL} := F_{UPLIFT} \cdot \sin(\Theta)$

$F_{WITHDRAWAL} = 64.127\ lbf$

$F_{LATERAL} := F_{UPLIFT} \cdot \cos(\Theta)$

$F_{LATERAL} = 82.079\ lbf$

Capacity per 0.131 x 3.25" Nail

$C_D := 1.6$ $\qquad n := 4$

$C_{eg} := 1.0$ <--Per NDS Commentary C11.4.2 & C11.5.4.2

$C_{tnw} := 0.67$ $\qquad C_{tnz} := 0.83$

From Table 11N

$W := 21\ \frac{lbf}{in} \cdot 1.5\ in$ $\qquad Z := 82.0\ lbf$

$W = 31.5\ lbf$ $\qquad Z = 82\ lbf$

$W' := W \cdot C_D \cdot C_{eg} \cdot C_{tnw}$ $\qquad Z' := Z \cdot C_D \cdot C_{eg} \cdot C_{tnz}$

$W' = 33.768\ lbf$ $\qquad Z' = 108.896\ lbf$

Capacity per (4) 0.131 x 3.25" Nail Connection

$W_{group} := n \cdot W'$ $\qquad Z_{group} := n \cdot Z'$

$W_{group} = 135.072\ lbf$ $\qquad Z_{group} = 435.584\ lbf$

$F_{WITHDRAWAL} \le W_{group} = 1$ $\qquad F_{LATERAL} \le Z_{group} = 1$

$$\frac{F_{WITHDRAWAL}}{W_{group}} + \frac{F_{LATERAL}}{Z_{group}} = 0.7$$

Figure 7: Capacity Calculations for Roof Slope = 18°

Design Loads

$F_{UPLIFT} := P = 104\ \mathbf{lbf}$

$RoofSlope := 45\ °$

$\Theta := RoofSlope + 110\ ° - 90\ ° = 65\ °$

$F_{WITHDRAWAL} := F_{UPLIFT} \cdot \sin(\Theta)$

$F_{WITHDRAWAL} = 94.401\ \mathbf{lbf}$

$F_{LATERAL} := F_{UPLIFT} \cdot \cos(\Theta)$

$F_{LATERAL} = 44.02\ \mathbf{lbf}$

Capacity per 0.131 x 3.25" Nail

$C_D := 1.6$ $\qquad n := 4$

$C_{eg} := 1.0$ <--Per NDS Commentary C11.4.2 & C11.5.4.2

$C_{tnw} := 0.67$ $\qquad C_{tnz} := 0.83$

From Table 11N

$W := 21\ \frac{\mathbf{lbf}}{\mathbf{in}} \cdot 1.5\ \mathbf{in}$ $\qquad Z := 82.0\ \mathbf{lbf}$

$W = 31.5\ \mathbf{lbf}$ $\qquad Z = 82\ \mathbf{lbf}$

$W' := W \cdot C_D \cdot C_{eg} \cdot C_{tnw}$ $\qquad Z' := Z \cdot C_D \cdot C_{eg} \cdot C_{tnz}$

$W' = 33.768\ \mathbf{lbf}$ $\qquad Z' = 108.896\ \mathbf{lbf}$

Capacity per (4) 0.131 x 3.25" Nail Connection

$W_{group} := n \cdot W'$ $\qquad Z_{group} := n \cdot Z'$

$W_{group} = 135.072\ \mathbf{lbf}$ $\qquad Z_{group} = 435.584\ \mathbf{lbf}$

$F_{WITHDRAWAL} \le W_{group} = 1$ $\qquad F_{LATERAL} \le Z_{group} = 1$

$$\frac{F_{WITHDRAWAL}}{W_{group}} + \frac{F_{LATERAL}}{Z_{group}} = 0.8$$

Figure 8: Capacity Calculations for Roof Slope = 45°

Part 2 of the connection needs only be evaluated for lateral resistance because the uplift force can be resolved into a vertical and horizontal force. The horizontal force is resisted by the sheathing and truss system, which is out of the scope of this report. This connection utilizes (1) 0.131 x 3.25" nail every 12" o.c.; this equates to (2) nails supporting the 2' tributary area under analysis. Figure 9 and Figure 10 show these calculations for the lower and upper bound of the roof slope respectively.

Design Load

$F_{UPLIFT} := P = 104\ lbf$

$RoofSlope = 18\ °$

$\Theta := RoofSlope + 110\ ° - 90\ ° = 38\ °$

$F_{LATERAL} := F_{UPLIFT} \cdot \cos(\Theta)$

$F_{LATERAL} = 82.079\ lbf$

Capacity per 0.131 x 3.25" Nail

$C_D := 1.6$ $\quad n := 2$

$C_{eg} := 1.0$ <--Per NDS Commentary C11.4.2 & C11.5.4.2

$C_{tnz} := 0.83$

$Z := 82.0\ lbf$ From Table 11N

$Z = 82\ lbf$

$Z' := Z \cdot C_D \cdot C_{eg} \cdot C_{tnz}$

$Z' = 109\ lbf$

Capacity per (1) 0.131 x 3.25" Nail @ 12" o.c. Connection is (2) nails per 2 feet

$Z_{group} := n \cdot Z'$

$Z_{group} = 217.792\ lbf$

$F_{LATERAL} \le Z_{group} = 1$

Figure 9: Bevel Member Capacity Calculations for Roof Slope = 18°

Design Load

$F_{UPLIFT} := P = 104\ lbf$

$RoofSlope = 45\ °$

$\Theta := RoofSlope + 110\ ° - 90\ ° = 65\ °$

$F_{LATERAL} := F_{UPLIFT} \cdot \cos(\Theta)$

$F_{LATERAL} = 44.02\ lbf$

Capacity per 0.131 x 3.25" Nail

$C_D := 1.6$ $\quad n := 2$

$C_{eg} := 1.0$ <--Per NDS Commentary C11.4.2 & C11.5.4.2

$C_{tnz} := 0.83$

$Z := 82.0\ lbf$ From Table 11N

$Z = 82\ lbf$

$Z' := Z \cdot C_D \cdot C_{eg} \cdot C_{tnz}$

$Z' = 109\ lbf$

Capacity per (1) 0.131 x 3.25" Nail @ 12" o.c. Connection is (2) nails per 2 feet

$Z_{group} := n \cdot Z'$

$Z_{group} = 217.792\ lbf$

$F_{LATERAL} \le Z_{group} = 1$

Figure 10: Bevel Member Capacity Calculations for Roof Slope = 45°

Analysis Results:

Part 1 and part 2 of the connection are determined to be adequate by the above calculations. Therefore, the load path of this connection is verified as being adequate for the design loading using the discussed assumptions. The connection with the largest tributary area was analyzed to show that the connections adjacent, with smaller tributary area, therefore smaller loadings, will also be adequate. Any project specific variables that reduce the loading, as well as better materials and fasteners, will make the connection more conservative.

The connection described in this report is determined to have adequate capacity to resist the applied uplift loads.

References:

American Society of Civil Engineers, Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7-10).

American Wood Council, National Design Specification® for Wood Construction (AWC/NDS), 2015.