Resisting Wind Uplift

by Robert Randall, P.E.

This month's column is prompted by a reader's question about my July '96 column, "Framing With a Raised Rafter Plate." This builder writes:

I have built many roofs using the raised rafter plate detail (see Figure 1). You correctly note the benefits of this detail, but your recommendation for using strap connectors confuses me and I wondered if you could clarify a couple of points. You suggest that the straps improve uplift resistance. But doesn't the weak link now become the one or two toe-nails used to hold the joists to the top plate? I imagine that lapping the plywood sheathing over the rim joist and nailing it often with 6d nails into the header makes for a secure header-to-wall connection. But the box header usually has only two or three nails into each joist end, with an additional one or two toe-nails through the joist into the top plate. No matter how well the joist is nailed to the rafter end, the weak link in the system is the joist-to-wall connection (when it comes to uplift, not spreading).

Uplift vs. Spreading

This question highlights an important point about the eaves connections in Figure 1. Not only do these connections have to resist the tendency of the

Holding Down the Roof

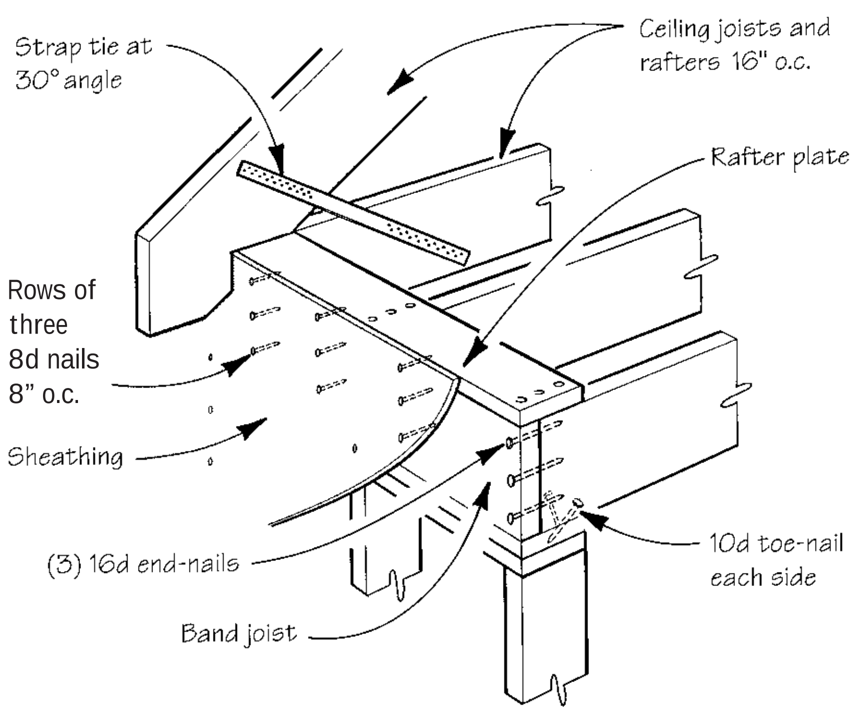


Figure 1. Framing a roof on top of a raised rafter plate allows room for extra insulation above the top plates, but it may weaken the important connection between the ceiling joists and the rafter ends. Using a rated strap tie at every rafter maintains this connection, which helps prevent the roof from spreading. The strap tie also transfers uplift forces from the roof to the ceiling joists.

Common Nail Design Values in Hem-Fir Framing
(based on *NDS* 1991 tables & adjustment factors)

Nail Size:	**8d**	**10d**	**16d**
Direction of Load:	Lateral	Withdrawal	Lateral
Application:	Through 1/2-in. sheathing into band joist and rafter plate	Toe-nail ceiling joists into top plate, 2 inches penetration	End-nail band joist into ceiling joist ends
Adjustment Factors:	Wind loading: 1.6	Wind loading: 1.6 Toe-nail in withdrawal: .67	Wind loading: 1.6 Nailing into end-grain: .67
Design Value:	63 lb. x 1.6 = **100.8 lb.**	25 lb./in. x 2 in. x .67 x 1.6 = **53.6 lb.**	122 x .67 x 1.6 =**130.7 lb.**

roof to spread apart, but they also have to resist uplift forces from the wind (and earthquakes in seismic zones). The original article dealt mainly with rafter spread. But the detail in question also addresses uplift, because the 30-degree angle of the strap allows it to work effectively as both a horizontal tie and a vertical tie. (The pitch of the angle should equal the ratio of the horizontal force to the anticipated vertical force.)

In this article, I'll analyze this detail to find out whether the construction can withstand a typical severe wind load.

Wind Load Design for Eaves

The design of structures for wind loads is a very complex subject and is covered in incredible detail (yet differently) by many codes. My purpose here is not to explain how to design for wind loads, but to analyze how well the detail in Figure 1 can resist typical uplift loads in a high-wind region. For this article, I'll assume that the BOCA code applies and we are in a 110-mph wind region in an exposed location. The design wind pressure will be 37.2 psi on walls. For a 4/12-pitch roof, an uplift factor of .75 applies, so the design wind lift is 28 psf. Figure 2 shows a typical wind lift calculation using this value.

Holding Capacity of Nails

The connections in Figure 1 depend entirely on nails, so the first step in determining the strength of the assembly is to figure out the holding capacity of each individual nail. Design values for nails vary widely, depending on the size and type of nail and the species of lumber used. There are also adjustment factors for such things as load duration, excessive moisture, high temperature, nailing into end-grain, and toe-nailing. The *National Design Specification for Wood Construction* (*NDS*, 1991 edition) explains these factors in detail, and gives tabulated design values for many nail types and wood species. The table on page 57, derived from the *NDS*, gives capacities for the nails shown in Figure 1, with the appropriate adjustment factors applied, and based on Hem-Fir framing lumber.

Note that a nail can be loaded either laterally (load perpendicular to the shank) or in withdrawal (load parallel to the shank). The *NDS* specifies different values and correction factors depending on the direction of load; obviously, a nail loaded in withdrawal has much less holding capacity than a laterally loaded nail. I advise against ever depending solely on nails loaded in withdrawal for a framing connection.

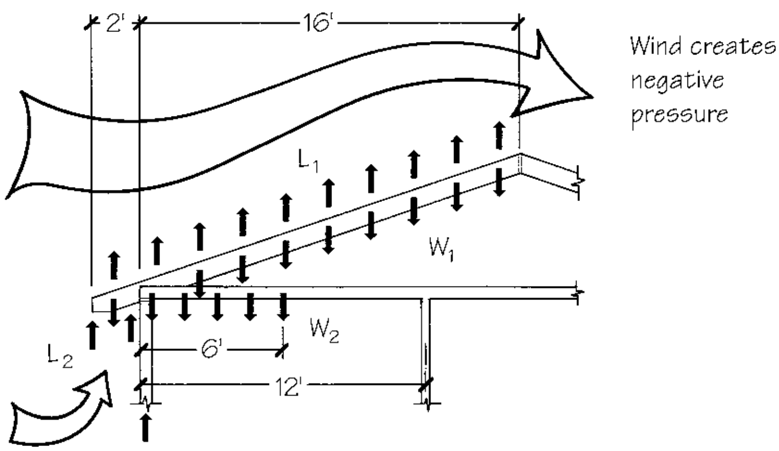
Plywood–Band Joist Connection

With that background, we can answer the question posed: Isn't the weak link the connection of the ceiling joists to the top plate?

In this case, the plywood lapping the band joist is a lot stronger than the reader thinks. Note from that chart that every 8d nail into the band joist can withstand a little more than 100 pounds of lateral (in this case, wind lift) load. So if the plywood is nailed with two 8d nails into the band joist and one into the rafter plate every 8 inches (or three nails altogether every 8 inches), as in Figure 1, the band joist is held down with six nails per rafter, or 600 pounds of resistance. That's more than enough to handle the uplift loads in the sample calculation in Figure 2.

The reader's letter mentions 6d nails, commonly used to nail off sheathing. The design value for 6d nails in this situation would be 78 pounds per nail, so it would take more nails to achieve the same result.

Sample Wind Lift Calculation



L_1 = Roof Lift = 18 ft. x 1.33 sq. ft.* x 28 psf = 671 lb. per rafter

L_2 = Eaves Lift = 2 ft. x 1.33 sq. ft.* x 28 psf = 75 lb. per rafter

Total Lift on Roof = 746 lb. per rafter

W_1 = Roof Dead Load = 18 ft. x 1.33 sq. ft.* x 7 psf = 167 lb. per rafter

W_2 = Ceiling Dead Load = 6 ft. x 1.33 sq. ft.* x 5 psf = 40 lb. per rafter

Net Lift at Top Plate = $L_1 + L_2 - [W_1 + W_2]$ = 539 lb. per rafter

Number of square feet of roof per linear foot of rafter at 16 inches on-center

Figure 2. **Wind creates negative pressure, which exerts a lifting force on the roof. The eaves overhang is also subject to direct positive wind pressure, which must be added into the total design wind load. The dead loads from the roof and ceiling assembly are subtracted from the wind uplift for a total net uplift.**

Ceiling Joist to Band Joist Connection

The plywood does a good job of holding down the band joist. But note that in Figure 1, the strap ties are attached to the ceiling joists, not to the band joist. If the wind tries to pick up the roof, the straps will transfer the force directly to the ceiling joists. So a careful analysis needs to look at the nails holding the joists in place. First, there are the three 16d end-nails through the band joist. At 130.7 pounds each, these three nails can resist 392 pounds total — not enough to satisfy our sample design requirement. But there are also a couple of 10d toe-nails through each ceiling joist into the top plate, which gives another 107 pounds of resistance. Because the rafter plate clamps the joist ends in place, we can also count the 8d nails securing the sheathing to the rafter plate — one every 8 inches, or two per joist. These nails are also laterally loaded, which gives another 100.8 pounds per nail, or 201 pounds per joist. So the sum total of the nails holding the ceiling joists to the band joist is

392 lb. + 107 lb. + 201 lb. =
700 lb. resistance

The strap tie detail, with the plywood properly nailed, should be plenty strong enough for most wind load conditions. For extremely severe circumstances — coastal or other high-wind zones, highly exposed locations, tall buildings, and so forth — engineered design is always in order. There are any number of rated metal connectors available from Simpson or USP that can easily solve wind load design problems.

Good Practice

My suggestion to a cautious builder is to spend a few minutes and a few dollars to incorporate these simple recommendations:

- Nail sheathing with 8d nails at 6 inches on-center along both wall plates, all band joists (in vertical rows of three nails), and all studs. Be sure that plywood seams do not fall near ends of studs at floor platforms. In two-story houses, install the plywood so that it laps the band joist and ties the first-story studs to the second-story studs. The sheathing is what holds the house together in a wind (see *Practical Engineering*, 11/96).
- Be wary of tall structures, large overhangs, and low-pitched roofs. Wind lift on a large overhang, including porch roofs, can peel a roof right up. Low-pitched roofs are particularly subject to aerodynamic lift.
- Give some thought to the eaves connections. Minimum code nailing practices cannot hold a candle to a strong wind. If you have any doubts, add a few hurricane ties; they're not that expensive.
- Reread the May 1996 *Practical Engineering* column on eaves ties. Make sure the rafter-to-eaves tie connection is adequate, especially where you have a long span, low pitch, or heavy snow loads.
- Never set rafters 24 inches on-center if the ceiling joists are 16 inches on-center. The rafter-to-ceiling joist connection is extremely important.

Some readers may have noticed that there is a potential for conflict between these recommendations addressing wind uplift and the recommendations addressing lateral wind loads in the November '96 *Practical Engineering* column by Philip Westover ("The Strength of Plywood Sheathing"). If you meet lateral bracing requirements by placing the plywood edges to land on the top plate, then you should use steel straps across the band joist and rafters to address wind uplift. However, if you install the plywood so that it bridges from the wall plates across the band joist, as in my detail, you may need to add blocking along the bottom edge of the plywood, if it breaks in the middle of a stud, to handle horizontal wind shear forces. ■

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