Straight Talk About

Hip and Valley Rafters

by Robert Randall

Don't underestimate the importance of proper sizing and sturdy connections when building these heavily loaded structural members

Hip and valley construction, including the proper sizing of hip and valley rafters, is an aspect of wood frame construction that is not generally well understood and is often poorly executed. There are two important structural aspects of hip and valley rafters: sizing the member and providing support at the ends.

In plan view, hip and valley framing are similar: In either case, a main structural member — the hip rafter or valley rafter — runs diagonally between the high (ridge) corner and the low (eaves) corner of an area of intersection of two sloping roofs. At outside corners, this is a hip rafter; at inside corners, it's a valley rafter. Because their geometry is similar, the same calculations can be used to analyze either hip or valley rafters.

Determining Hip and Valley Loads

The *tributary area* is the portion of the roof from which loads are transferred onto the hip or valley rafter.

Calculating Tributary Load (W) on Hip & Valley Rafters
(at equally pitched roof intersections)

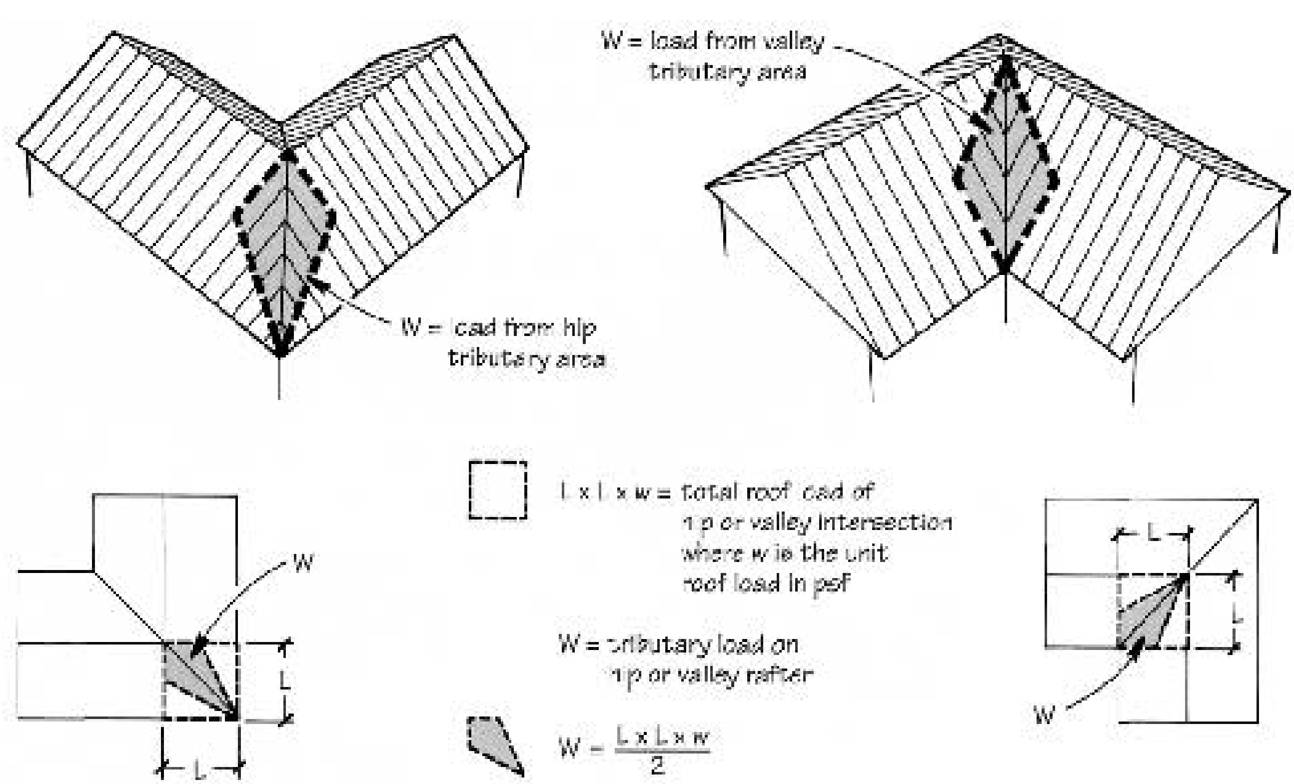


Figure 1. *A hip or valley rafter picks up half the load of all the jack rafters feeding into it — its so-called tributary load. In plan view, this tributary load is kite-shaped. Note that the hip's tributary area is wider at the top, the valley's is wider at the bottom.*

The tributary area includes half the span of each jack rafter, which results in a kite-shaped figure (see Figure 1). These dimensions are measured in the horizontal plane only — you can usually ignore the slope when calculating roof loads.

As shown in Figure 1, the tributary area includes half the area of the entire hip or valley intersection. Note that I'm showing the hip or valley area as a square, which is the case for the intersection of roofs that have equal slopes. This is the most common type of hip or valley construction, and the subject of this article.

Sizing Hip and Valley Rafters

I'll skip a lot of heavy calculations and jump to one obvious result of this applied load, namely a predictable pattern of *deflection***.** In many engineering analyses, deflection is as much a concern as *bending stress*, or the tendency to break. In other words, the hip or valley may sag (Figure 2, next page) and cause cracking walls and ceilings or leaking roofs (more likely in valleys) before the danger of outright collapse occurs. This is of particular concern where cathedral ceilings are involved, because ceiling finishes are more likely to crack when they're applied directly to rafters.

Sizing rules of thumb. There are several rules of thumb floating around for sizing hip and valley rafters made from dimensional lumber. One of these, for example, says to take the size of the jack rafters, increase it by one lumber size (to allow room for the long bevel cut at the top end), and double it up. Thus, 2x8 jack rafters would feed into a doubled 2x10 hip rafter. For the most part, such rules of thumb have worked reasonably well for two reasons:

1) There are secondary effects, such as diaphragm loads borne by plywood sheathing, tension loads carried by wall top plates, and truss effects of adjacent rafters and collars, that may combine to provide a significant portion of the required support for the hip or valley rafter. Most frame buildings benefit from such structural "redundancies," although these effects are difficult to quantify dependably and are usually ignored by engineers for structural design purposes.

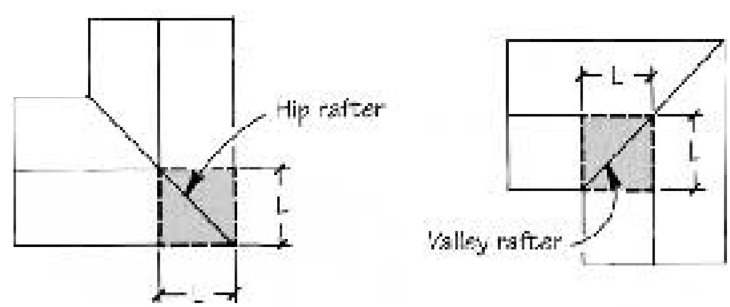
2) Hip or valley rafters sized by one of the rules of thumb will typically be fairly close to correct in smaller structures. But the error increases dramatically as the size of the structure increases. This probably accounts for the pronounced sag in the roof in Figure 2, which is a relatively large hip roof.

This article is prompted in part by the trend toward larger homes, as well as modern styles using low-pitched designs, either of which may counteract or nullify the structural redundancies described above.

The formula used to calculate deflection for hip and valley rafters takes the length of the hip or valley rafter and increases it to the *fifth power*. This means that if you *double* the length of the hip or valley rafter, you don't just double its tendency for deflection; you increase deflection by a factor of 2^5, or *32 times as much* as the deflection in the shorter length!

The table "Sizing Hip & Valley Rafters," below, summarizes a lengthy series of sizing calculations for various roof design loads. But choosing the right size hip or valley rafter is only

Hip & Valley Rafter Sizing Table (for equally pitched roof intersections only)



L in feet	15 psf live load	30 psf live load	45 psf live load	60 psf live load
4	2x6	2x6	2x6	2x8*
5	2x6	2x6	2x6	2x8
6	2x6	2x8	2x8	2x10
7	2x8	2x10	2x10	2x12
8	2x10	2x12	2x12	(2) 2x12
9	2x10	(2) 2x12	(2) 2x12	(2) 2x12
10	2x12	(2) 2x12	(2) 2x12	LVL 11 7/8
11	(2) 2x12	(2) 2x12	LVL 11 7/8	LVL 11 7/8
12	(2) 2x12	LVL 11 7/8	LVL 11 7/8	LVL 14
13	(2) 2x12	LVL 11 7/8	LVL 14	(2) LVL 14
14	LVL 11 7/8	LVL 14	(2) LVL 14	(2) LVL 14
15	LVL 11 7/8	LVL 14	(2) LVL 14	(2) LVL 14
16	LVL 11 7/8	(2) LVL 14	(2) LVL 14	(2) LVL 16*
17	LVL 14	(2) LVL 14	(2) LVL 16	(2) LVL 16
18	LVL 14	(2) LVL 14	(2) LVL 16	*
19	(2) LVL 14	(2) LVL 16*	*	
20	(2) LVL 14	(2) LVL 16		

*Deflection limited

Note: *The calculations behind this table are based on the following:*

10 psf dead load	F_b wood = 1,000 psi
L/240 deflection	E wood = 1,000,000 psi
No slope adjustments	F_b LVL = 2,800 psi
	E LVL = 2,000,000 psi

Figure 2. *The sagging hip rafter in this roof is more than 20 feet long. Because it was undersized, it has permanently deflected under the tributary load from the jack rafters.*

half the battle; you've still got to properly support the apex connection.

The Apex Load

Standard hip and valley rafters are treated by engineers as "simply supported beams with the load increasing uniformly toward one end." The load "increases uniformly" as the jack rafters grow longer — toward the ridge in the case of a hip and toward the top plate in the case of a valley. By definition, in beams with uniformly increasing loads, one-third of the total load on the beam is transferred to one end, two-thirds to the other end. We engineers depict the loading on such beams with schematic sketches like the ones in Figure 3.

The high (ridge) end connection of a hip or valley rafter must support a major concentrated load — $\frac{2}{3}$W for hips, $\frac{1}{3}$W for valleys, where W is the total load on the hip or valley rafter. I refer to this as the *apex load*. In the most common hip construction, two hip rafters meet at an apex with a ridge running off in a different direction. The vertical load from the two hip rafters is then equal to $\frac{4}{3}$W — a big load! This point load must be provided for in the building design.

Providing End Support At the Apex

During the house inspections that I do as part of my engineering consulting work, I have seen situations where the framer used a temporary 2x4 or 2x6 strut to hold up the apex during construction of a hip roof, then left the strut in place after the roof was finished. Over time, the eaves con-

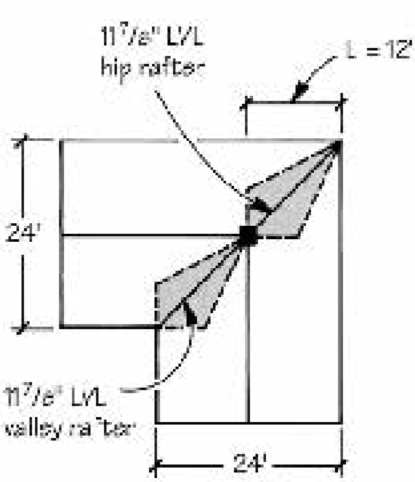
Supporting Hips & Valleys: Two Case Studies

Here are two examples that illustrate two different approaches to apex support of hip and valley rafters. In both cases, the hip or valley rafters have been selected by using the "Hip & Valley Rafter Sizing Table" on the previous page. The roof loading calculations in each case demonstrate how the apex loads are arrived at. These are not intended as general solutions for all similar roof designs. Each roof structure must be individually examined for the best support solution. This is especially important in large-span roofs, which can place very large tributary loads on hip and valley rafters, and in cases where all posts and horizontal members such as collar ties have been deleted to create a cathedral ceiling.

— R.R.

Case 1: Support Post

This is a typical L-shaped roof. The apex load comes from the hip rafter on one side and the valley rafter on the other. A center support post (a triple 2x6 or the equivalent) carries the 3,600-pound point load vertically down through the walls below to a foundation footing.



Design load (w) = 40 psf snow load + 10 psf dead load

To calculate total load (W) on hip or valley rafter:

$$W = \frac{w \times L^2}{2}$$

$$= \frac{(40\text{ psf} + 10\text{ psf}) \times 12^2}{2}$$

= 3,600 lb. for each hip and valley rafter

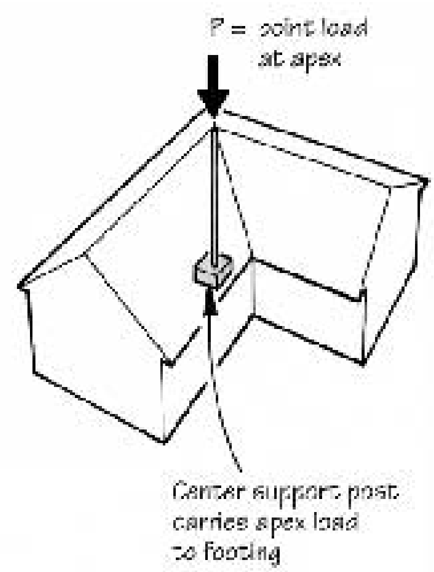
To calculate total apex load (P):

P = hip apex load + valley apex load

= $\frac{2}{3}$ (W) + $\frac{1}{3}$ (W)

= $\frac{2}{3}$ (3,600 lb.) + $\frac{1}{3}$ (3,600 lb.)

= 3,600 lb.



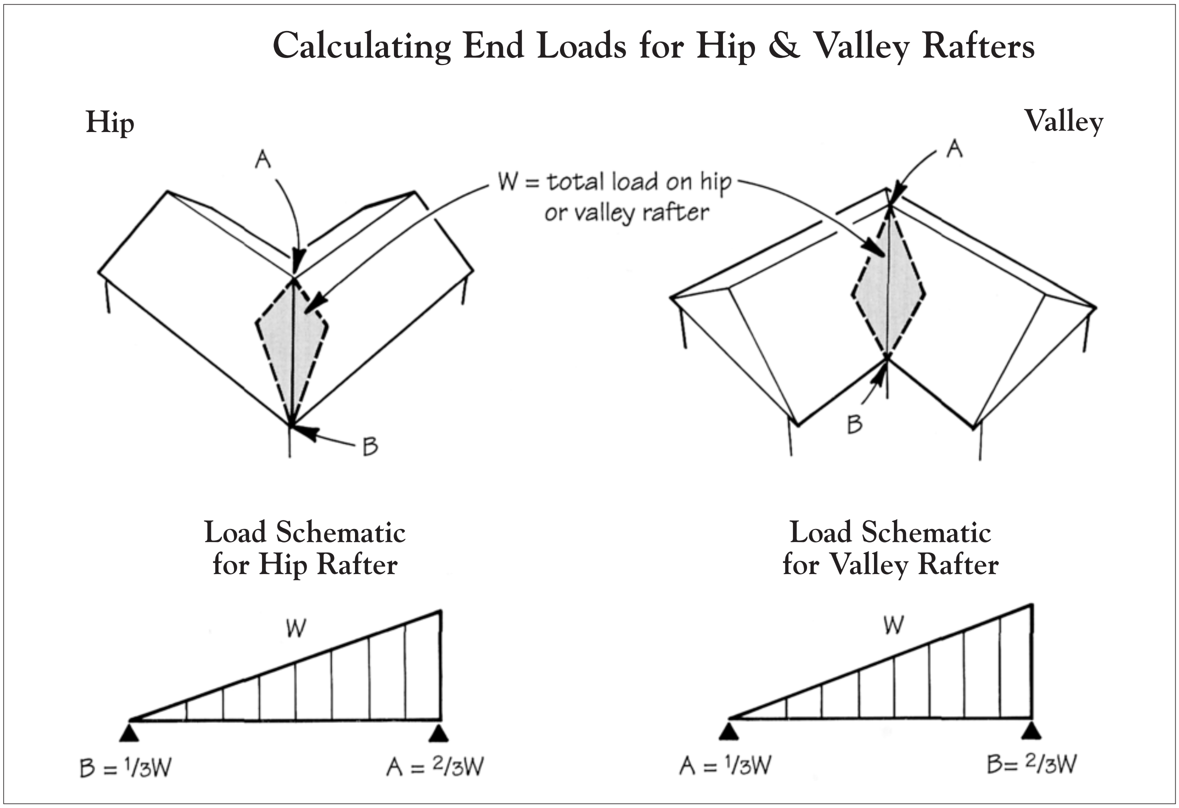
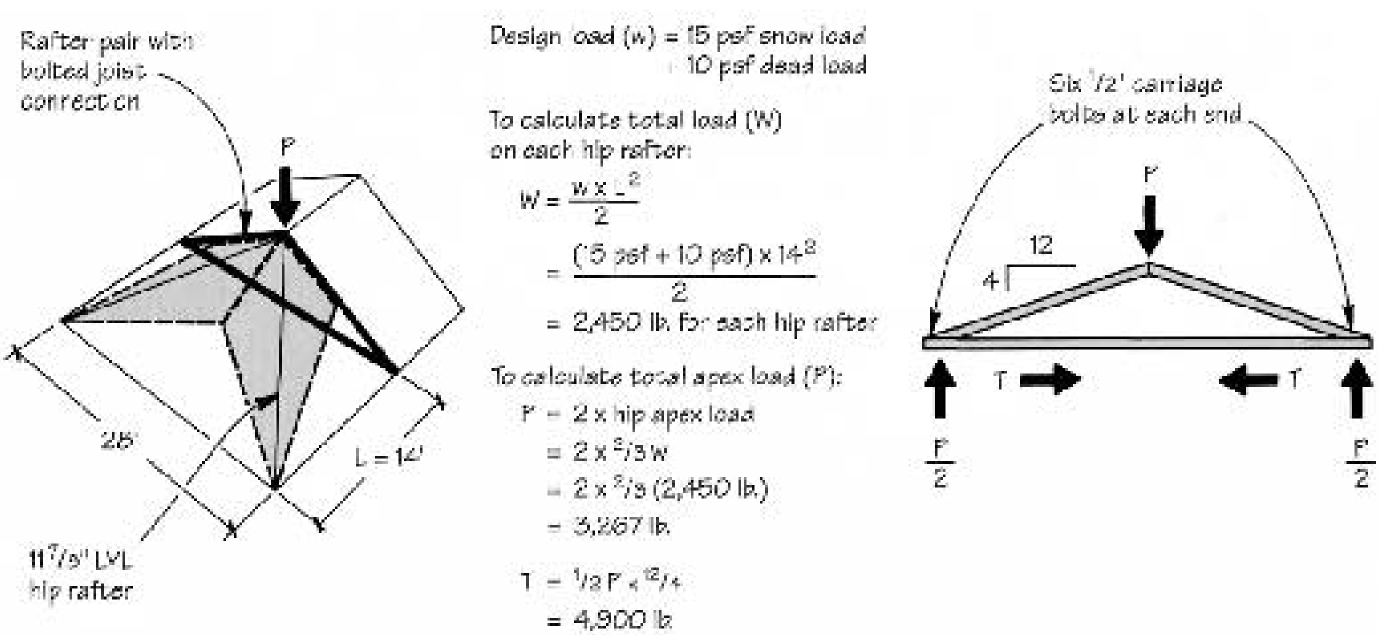


Figure 3. *Because the loads on hip and valley rafters increase from one end to the other, the loads distributed to the end supports are not equal: one-third of the load goes to one end, two-thirds to the other. For valleys, the larger share of the load is transferred to the lower end — the exterior wall in the drawing at left. For hips, the two-thirds load is carried at the top, or ridge, end.*

Case 2: Rafter Truss

In this typical shallow-pitched hip roof, the apex load is carried by a pair of rafters to the top plates of the exterior walls. Since the tension increases as the roof pitch gets lower, this creates a large tension load (4,900 pounds) in the ceiling joist. The rafter/joist connection requires six 1/2-inch carriage bolts at each end to handle this tension. This case is based on southern loading conditions; in northern latitudes, where heavy snow loads are common, the bolts can be applied to two sets of rafters, with the ridge beam sized accordingly to distribute the load.

The connection of the hip rafters to the ridge must be able to accommodate the total apex load (3,267 pounds, or twice that up North). The author often specifies 3/16-inch bent plate-steel connectors with carriage bolts for these connections.



Apex Support for Large Hip Roofs with Cathedral Ceilings

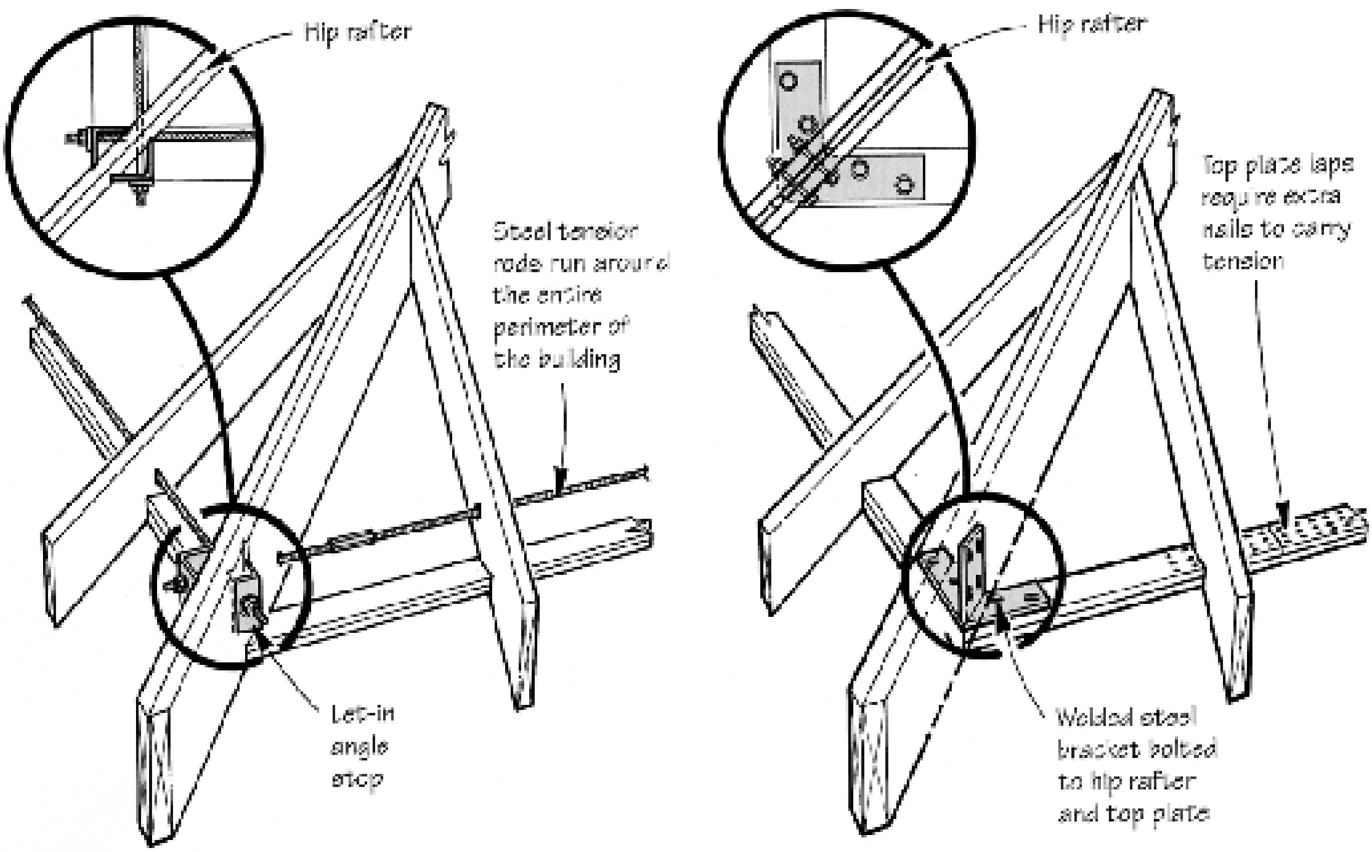


Figure 4. *In large hip roofs with full cathedral ceilings – typical of contemporary open-space design – there are no support posts or restraining horizontal members, such as collar ties, to resist the spread of the rafters. In such cases, the author often uses steel rod tension ties (left) around the perimeter of the building. The tension ties prevent the bottom ends of the hip rafters from spreading and thereby support the apex. In an alternate detail (right), the double 2x6 top plates act as the tension members, and welded steel brackets secure the hip rafters at the corners.*

nections had slipped, allowing the structure to settle and bowing the "temporary" strut by as much as 3 inches. When the strut snaps, the progressive sagging will accelerate.

Another common sight is a strut about halfway down the length of the hip or valley rafter. The intention is good, but usually the strut transfers major roof loads onto one or two attic floor joists, resulting in sagging and/or cracking of the ceiling below.

So how should you support these large apex loads? Depending upon the design of the house, I usually recommend one of three different approaches: a center post, a rafter "truss," or tension ties.

The center post is often the simplest solution (see Case Study 1, page 38), although post sizing can get complex. I typically use a triple 2x6 or 6x6 post in the attic, and quadruple 2x4s, laterally braced with 2x blocks or skinned with plywood, in the walls below. It's important to align the load path of the post from floor to floor. Don't bring the post down onto a header or girder unless the girder has been designed to handle the load — the large point load could easily overload a typical built-up wood beam.

The rafter truss (Case Study 2, page 39) will work with either hips or valleys or a combination of the two. The apex load is carried by a pair of rafters to the top plates of the exterior walls, creating a large tension load in the attached ceiling joist, which must resist the spreading tendency of the rafters. The rafter/joist connection typically requires several 1/2-inch carriage bolts at each end. In northern latitudes, where severe snow loads prevail, the bolts might be applied to two sets of rafters, with the ridge beam sized accordingly to distribute the load.

The tension tie is a solution I have used with large hip roofs with cathedral ceilings (Figure 4).The steel rod provides enough horizontal restraint at the eaves to prevent the hip rafters from spreading.With smaller hip roofs it is sometimes possible to provide the needed horizontal restraint by adding structural wood members or steel strapping, but this should only be undertaken on a case-by-case basis with the guidance of a licensed engineer. ■

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