Q. Rafter Ties and Shallow-Pitch Roofs

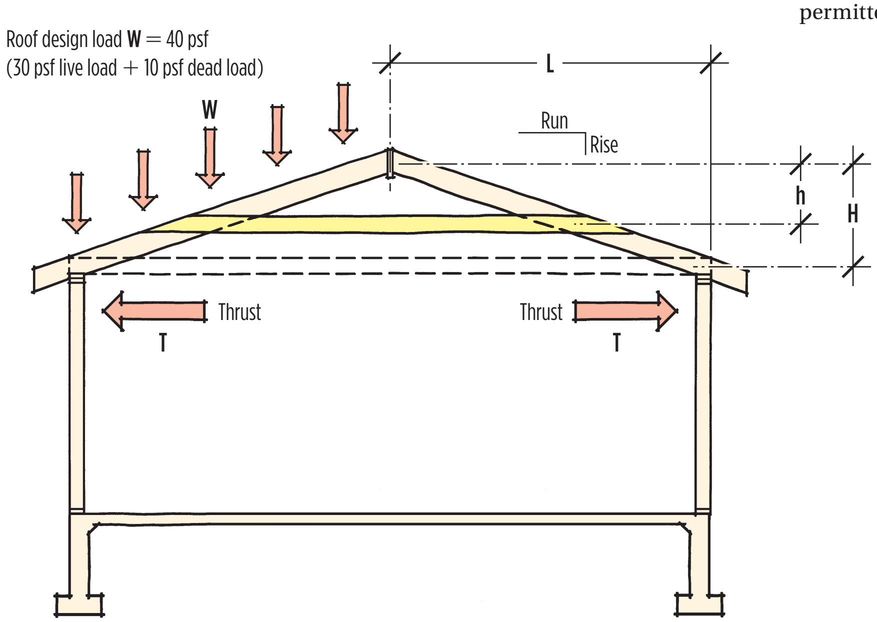
My clients have a garage with a conventionally framed 4/12 roof that they want to convert to living space. They like the idea of a vaulted ceiling but not the expense of the new structural ridge it would require. As a compromise, can I replace the existing ceiling joists with rafter ties?

A. *Jordan Truesdell, a structural engineer in Blacksburg, Va., responds:* In a simple gable roof, the rafters carry live and dead loads that push both down and out against the top of the supporting walls. This horizontal load — or thrust — can be considerable, especially on a low-pitched roof. To resist thrust, the IRC calls for a structural ridge (required for any roof with a pitch less than 3/12) or for each pair of rafters to be securely connected to each other by a continuous ceiling joist (R802.3, 2006 IRC).

Code does allow joists to be installed above the top plate, but only under certain conditions. Previous building codes permitted rafter ties to be placed as high above the plate as two-thirds the distance between the top plate and the ridge, but the 2006 IRC now limits this height to one-third the distance between the plate and the ridge (see Footnote A, Table R802.5.1, 2006 IRC). If your garage is 24 feet wide and has a 4/12 roof, the new rafter ties can be placed no more than 16 inches up from the plate without additional engineering.

From a practical perspective, it's difficult to use high rafter ties on a low-pitched roof because the force in each tie increases with the inverse of the pitch. And when rafter ties are used above the plate, the rafter span must be reduced by as much as 33 percent compared with the span allowed when the ties are at the plate. Here's a formula I use to determine tie force: T = W/2 x H/h x run/rise, where W equals rafter load, H equals height of ridge, and h equals distance from ridge to center of tie (**illustration, left**).

In this example, when W = 960, the tie-force tension at the plate when there are rafters 24 inches on-center with a 4/12 pitch and a 12-foot span is 1,440 pounds. Moving the rafter ties up only 16 inches from the plate (the maximum allowed by code) increases



Formula:

L = rafter span

W = load on rafter (L × rafter spacing × roof design load)

H = height of ridge above plate

h = distance between tie and ridge ($h \geq \frac{2}{3}H$)

T = tie force $\left(\frac{W}{2} \times \frac{H}{h} \times \frac{run}{rise}\right)$

Number of 16d nails per connection = $\frac{T}{100 \text{ lbs./nail}}$

Example:

L = 12'-0"

W = 12'-0" × 2'-0" o.c. × 40 psf = 960 lbs.

H = 4'-0"

h = 2'-8"

$$T_{(at\ plate)} = \frac{960 \text{ lbs.}}{2} \times \frac{4'\text{-}0''}{4'\text{-}0''} \times \frac{12}{4} = 1{,}440 \text{ lbs.}$$

$$T_{(at\ raised\ tie)} = \frac{960 \text{ lbs.}}{2} \times \frac{4'\text{-}0''}{2'\text{-}8''} \times \frac{12}{4} = 2{,}160 \text{ lbs.}$$

$$\text{Nails per connection} = \frac{2{,}160 \text{ lbs.}}{100 \text{ lbs./nail}} = 21.6 \text{ or } 22 \text{ nails}$$

the tie force from 1,440 pounds to 2,160 pounds. Compare this with a similarly framed 12/12 roof that has similar loads: The tie force at the plate is 480 pounds — and only 720 pounds when the ties are 4 feet up from the plate (again, the maximum allowed by code).

It's easy to underestimate the number of fasteners needed for each rafter-to-rafter-tie connection (and at any center splice in this assembly). To find the number of fasteners per connection, divide tie force by 100 pounds per nail (typical capacity of a 16d nail). As you can see, even at the plate, 15 nails are required for each connection in your 4/12 roof; move the rafter ties up and you'll need 22 nails per connection. Another option that would require fewer fasteners would be to use bolts instead of nails (see *Practical Engineering,* 5/96, for a bolt-and-nail schedule).

Unless the rafters are significantly overdesigned and you can find a way to nail the new ties in place without splitting the existing lumber, it's unlikely you'll be able to raise the ceiling by more than about 15 percent of the total roof height without the help of a structural engineer.

Q. New Deck Footings Near an Old Foundation

Plans for a freestanding deck call for new piers about 2 feet from the house foundation. Is it necessary to dig down to the bottom of the house's footing to reach undisturbed soil, or would the dirt around the foundation of a 60-year-old house be compacted enough to be considered undisturbed — in which case we could simply dig to below the frostline (per code)?

A. *Dave Crosby, an excavation contractor in Santa Fe, N.M., responds:* Because undisturbed soil is usually more reliable than backfill, I typically make the extra effort to dig down to it, especially if the backfill contains soft soil (anything I can easily dig without a pick or bar). However, if the undisturbed soil is a long way below the frostline or has a lot of silt and clay — and I'm confident that I have good, compacted fill — I may dig only to the frostline. In either case, whether the soil is disturbed or undisturbed, what I'm looking for is adequate load-bearing capacity.

Bearing strength is a function of the soil's composition and density. Dense (because it's either undisturbed or has been compacted), well-graded soil that is properly drained and has little or no expansive potential should easily support a deck with properly sized footings. The age of the house and the surrounding soil is irrelevant, because no matter how long soil sits there, it won't compact itself. So be sure to address the soil's composition and density in the design of your footings and piers, and test the soil whenever you're in doubt.

You also have to be careful about lateral loads caused by placing your deck footings too near the foundation. Loads spread out through the soil underneath a footing at about a 45-degree angle, so that at a depth of 2 feet under a 2-foot-by-2-foot footing, the zone of influence is about 4 feet by 4 feet, or 16 square feet. Depending on the elevation of the bottom of your piers, deck loads could create lateral pressure on the foundation wall.

Side loading isn't a problem in my area (seismic zone 2), because we're required to build strong foundations. If your foundation wall is reinforced cast concrete and the floor joists run perpendicular to the deck footings, it shouldn't be an issue for you, either. But if the foundation is fieldstone set in lime mortar, you'll need to be careful about those lateral loads.

Q. Quick Fix for a Noisy Circulation Fan

My client's metal fireplace is supplied by a makeup air system with a built-in circulation fan. This fan — which plugs into an accessible outlet — is triggered by a heat sensor in the fireplace. While effective, it's also very loud. To reduce the noise, I'd like to replace the fan's on/off switch with a variable-speed control. Is that possible? The manufacturer doesn't seem to offer anything.

A. *Rex Cauldwell, a master electrician in Rocky Mount, Va., responds:* Noisy single-speed fireplace fans are common. To reduce the fan's speed — which can help solve the problem — I use a Dial-A-Temp control (866/667-8454, northlineexpress.com). This device (**see photo, below**) plugs into a 120-volt receptacle; the fireplace fan, in turn, plugs into it. Rated for motor loads up to 3 amps and 300 watts, it has both an on/off switch and a variable-speed switch. It costs about $20.

Remember that you can't use a light dimmer on a fan motor. Dimmers are designed for resistive devices — like the filament of a light bulb — and operate by lowering the voltage to the lamp. A fan motor is a capacitive and inductive device that needs a relatively constant voltage to keep it from overheating and burning out. A motor speed controller like the Dial-A-Temp contains electronics designed to create variable resistance while maintaining the constant voltage required by the fan motor.