Simple King Truss for Ridge Beam Support

by Robert Randall, P.E.

The triangle formed by a pair of rafters and a joist is the most basic form of truss, and has been in use in one form or another for centuries. The two rafters can be envisioned as leaning against each other, just as you might lean a ladder against a wall. The vertical forces on the rafters are all transferred to the outer corners of the base of the triangle, which typically bears on the building walls below. The load transfer creates a horizontal force, which I refer to as *rafter thrust*. This thrust is restrained by the horizontal joist, which provides a restraining force to keep the base of the triangle (and the walls below) from spreading (see Figure 1).

The outward thrust of the rafters under load creates a tension force in the horizontal joist. As long as the connection between the rafter and the joist can carry this tension force (and assuming the rafters are correctly sized for bending), the roof will stand with no sagging at the peak. If the connections slip, as may happen under heavy snow loading, the roof may sag or even collapse (see *Practical Engineering*, 5/96).

It is important to realize that in this simple rafter-joist truss, the rafters get no vertical support at the peak. In many old buildings there may not even be any ridge member at all. All vertical loads are carried by the exterior walls.

Structural Ridge Option

Another way to carry vertical roof loads is to use a structural ridge: a beam that supports the rafters at their peaks and transfers loads to support points, which are typically posts at each end and along the span. Half of the uniform load on each rafter is carried by the structural ridge, reducing the load on the wall by one-half. Since the peak of each rafter is supported vertically by the ridge, there is no tendency to slide downward and no resulting outward thrust at the eaves. Structural ridges are thus useful where the designer wants to omit joists or collar ties — in cathedral ceilings or in a shed dormer addition where headroom is limited.

But sometimes due to floor plan constraints below, it's not possible to put a post under the end of the structural ridge. In this case, I sometimes use an enhanced version of the rafter-joist triangle described above instead of a post. By engineering the rafter-joist connections, it's possible to use a rafter-joist triangle to carry the point load from the end of the ridge beam out to the exterior bearing walls. I refer to this construction as a *king truss*.

Calculating the Loads

A structural ridge, like the one in Figure 2, must be sized to carry a total load equal to half the total load on all the rafters it supports. Of the total load on the structural ridge in Figure 2, half is carried by the king truss at one end, the other half by a post at the opposite end. We'll call this point load *P*; the calculations in Figure 2 show how to derive it. For the sake of this example, we'll assume a 30 psf live load and a 10 psf dead load; in many parts of the country the live load will be less. Remember, too, when calculating roof tributary areas to account for roof overhangs.

Once *P* is known, we can calculate the thrust, *T*, in the joist, then design the connection to resist it. I usually use bolts due to the heavy loads and the critical nature of the connection. Whenever possible, I use double-shear bolting, which means that one member is sandwiched between two others to which the force is being transmitted. Double-shear

Ridge Board vs. Structural Ridge

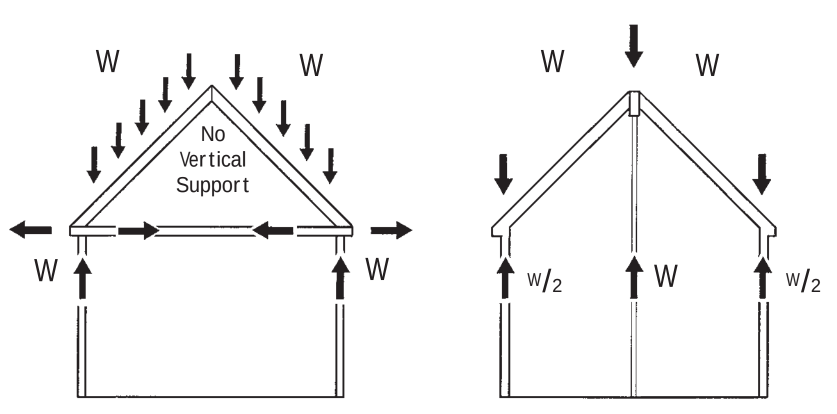
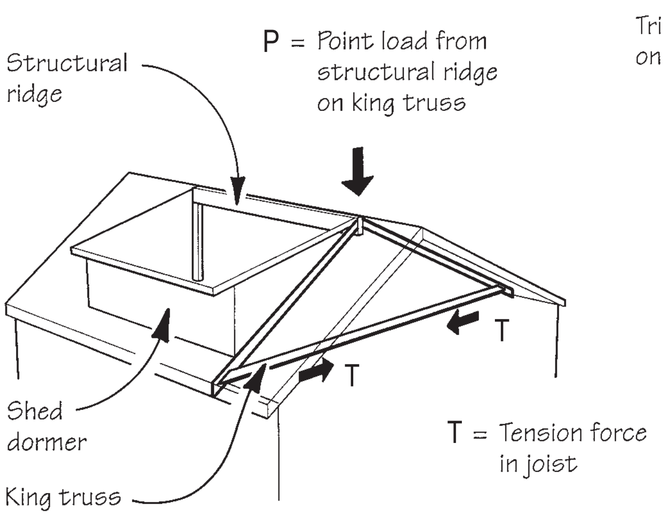
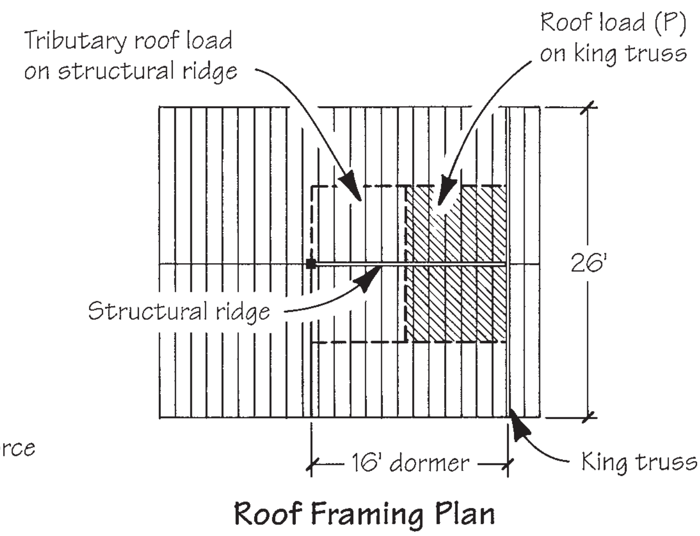


Figure 1. In a roof framed with a nonstructural ridge board (left), the uniform load on the rafters creates an outward thrust at the top of the exterior walls. The ceiling joist acts in tension to resist this force. With a structural ridge (right) — typically a beam supported by columns — the outward thrust is removed.

Calculating Load on a King Truss





Assuming a total (dead + live) roof design load of 40 psf:

$$\mathbf{P} = \frac{26'}{2} \times \frac{16'}{2} \times 40\text{psf} = 13' \times 8' \times 40\text{psf} = 4160 \text{ lb.}$$

$$\mathbf{T} = {}^{1}/{}_{2}\text{P} \times \frac{\text{Run}}{\text{Rise}} = \frac{4160}{2} \times \frac{12}{10} = 2496 \text{ lb.}$$

Divide T by bolt capacity to calculate number of bolts (N) required for joist-rafter connection:

$$\mathbf{N} = \frac{\text{T}}{\text{bolt capacity}}$$

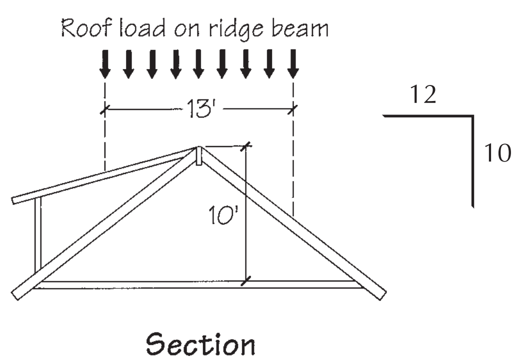


Figure 2. To design a rafter-joist king truss to support the end of a structural ridge, the engineer must calculate the tension force, *T*, that will be induced in the joist. First, the tributary roof load flowing to the end of the ridge beam is calculated, then this point load, *P*, is used to calculate the tension force in the joist. The designer then specifies the bolts needed to carry this tension force at the rafter-joist connections.

bolting can carry twice the force of single-shear bolting (where two members are simply bolted face-to-face).

In almost all cases, the limiting condition is the connection design. Rarely does the capacity of the rafter or joist for axial loading (tension along the length of the joist or rafter) prove to be a problem, although it should always be considered. The number of bolts is determined by dividing the thrust, *T*, by the capacity of the bolt to be used.

The bolting chart, see next page, is intended as a guideline. It is based on use of S-P-F framing lumber, with the numbers of bolts based on single-shear applications. If double-shear bolting can be incorporated (that is, if you can double up either the joist or the rafter), the bolt count can be cut in half.

Note that as roof pitch decreases, the required bolt count increases dramatically. This is why we engineers like to see generous roof pitches, aside from water-shedding benefits. Note also that some of the bolt counts are marked "not recommended"; in these cases, the axial (tensile) strength of the joist or rafter might be at issue, as well as the practical difficulty of finding room for a large number of bolts. In some cases, it may be practical to spread the bolts over two or more rafter-joist connections, creating multiple king trusses to support the end of the ridge beam.

Putting the King Truss to Work

This king truss concept becomes a part of many of my residential structural designs where either a cathedral ceiling or a large dormer prevents the normal use of regular rafter-joist triangles at common spacings. It also serves to carry the apex loads from hip or valley rafters (see "Straight Talk About Hip and Valley Rafters," 5/94) in cases where an interior post is impractical.

For new construction, it's simplest to incorporate the structural ridge beam in the same way as you would a nonstructural ridge board, using a generous number of toe-nails through each king truss rafter (Figure 3). The downward force from the vertical ridge loads will cause a wedging action that will create a large friction force to lock the ridge in place.

For retrofit applications, the ridge can be hung below the existing ridge, or inserted between existing rafters, which might be sistered in some designs. The

Structural Ridge Installation Details

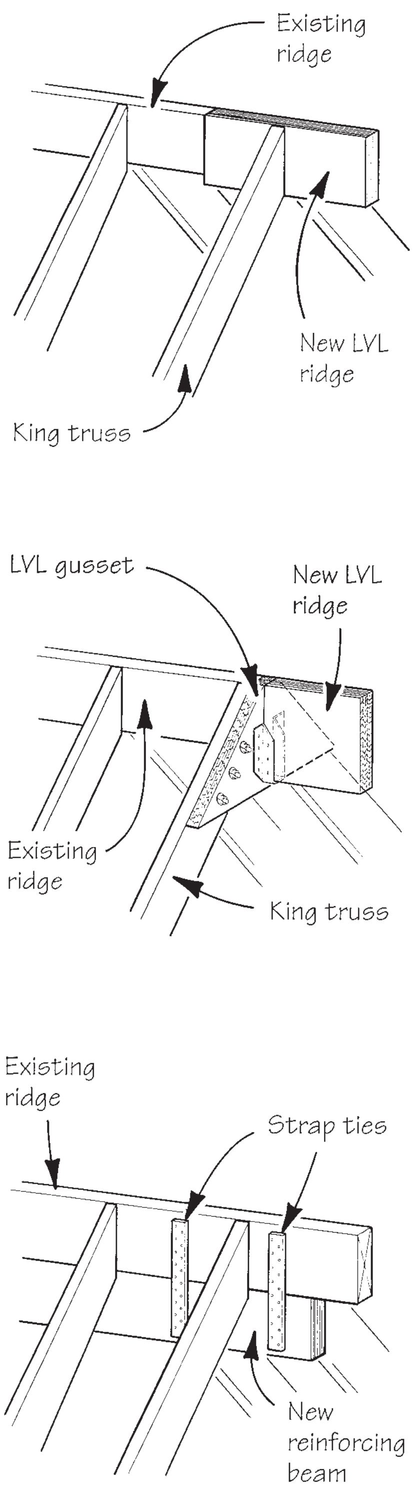


Figure 3. When supporting a structural ridge with a rafter truss, the beam can be sandwiched in place just like a nonstructural ridge (left), supported by a hanger attached to a gusset plate (middle), or even hung by straps from an existing ridge board (right).

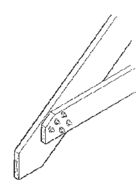
Number of Bolts Required for King Truss Joist-Rafter Connections

To use this chart, calculate the point load, *P*, at the top of the king truss (always round up), then find the number of bolts required for the roof pitch. Note that where seven or more 1/2-inch bolts are not recommended, fewer 1-inch bolts may work. The number of required bolts assumes a single-shear connection. Reduce bolts by half for double-shear connections. The chart is based on use of S-P-F 2-by lumber (specific gravity = 0.42). In some, but not all cases, fewer bolts would be required if a stronger grade of lumber were used. Use of lower grades, such as redwood, eastern softwoods, S-P-F (south), western cedars, western woods, or northern species would in some cases require more bolts. When in doubt, the designer should refer to the *NDS* tabulated bolt design values, which were used as the basis for this chart.

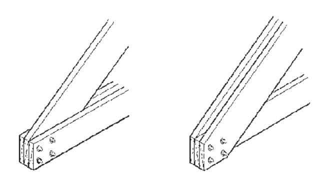
	Point Load (P) on King Truss				
Roof Pitch	**1000 lb.**	**2000 lb.**	**3000 lb.**	**4000 lb.**	**5000 lb.**
12/12	2 / 1	4 / 2	5 / 3	7* / 4	9* / 5
10/12	2 / 1	4 / 2	6 / 3	8* / 4	10* / 5
8/12	3 / 2	5 / 3	7* / 4	9* / 5	12* / 6
6/12	3 / 2	6 / 3	9* / 5	12* / 6	14* / 7*
4/12	4 / 2	8* / 4	12* / 6	16* / 8*	20* / 10*
3/12	5 / 3	11* / 6	16* / 8*	21* / 11*	26* / 13*

Key: Number of 1/2-inch-diameter bolts / Number of 1-inch-diameter

*Not recommended



Single-Shear Connection



Double-Shear Connections

ridge beam might also be mounted with hangers to a suitably designed gusset fastened securely to a pair of rafters.

The connection of the regular rafters to the structural ridge also requires attention. These rafters have no thrust forcing them against the ridge, and therefore need a connection designed to carry half their tributary load. This may be accomplished by an appropriate number of toe-nails or, for enhanced confidence, a joist hanger, such as the field-sloped Simpson LSSU series or the USP (Kant-Sag) TMU series.

In a king truss design, it is very important that each connection be considered carefully and adequate fasteners provided for all calculated loads. This is an area that warrants consulting an engineer for a design review. In my experience, more field failures occur due to connection design deficiencies than from any other cause.

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