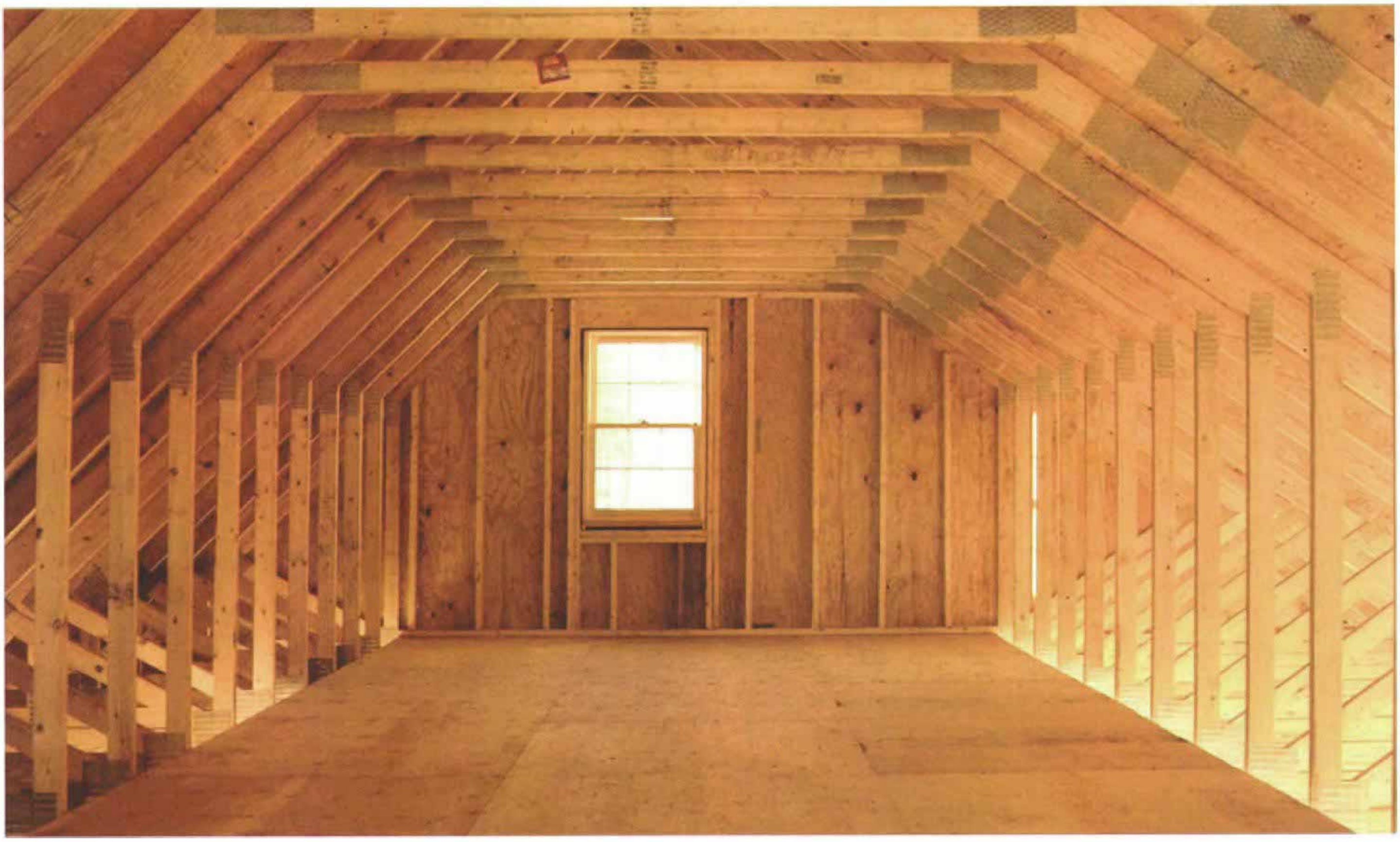
Fine Homebuilding

June/July 1994 No. 89



***Attic storage with a truss.*** **Not all trusses eliminate attic storage or attic-level living spaces. Attic trusses carry extra loads on the bottom chord and provide a room-size cavity between webs.**

# All About Roof Trusses

## Trusses can be used to frame even complex roofs, but they must be installed and braced properly

by Stephen Smulski

Not too many years ago, you didn't find roof trusses in homes with anything more elaborate than a gable roof. Thanks to computers and sophisticated design software, that era is long gone. Name just about any roof these days—gable, hip, saltbox, mansard or gambrel—and it can be framed with engineered trusses. Precision-made from dimensional lumber and metal connectors called truss plates, prefabricated trusses have revolutionized residential roof construction over the last three decades. Roofs on more than 75% of all new houses in the United States are built with trusses instead of with conventional 2x framing, and it's not hard to understand why.

Trusses give builders a bigger bang for their buck. Truss-framed roofs can be erected more quickly and with less skilled labor than stick-built roofs. Closure against the weather is faster because trusses and roof sheathing often can go up on the same day. Trusses mean more flexible floor plans because they can span longer distances without interior bearing walls than conventionally framed roofs. Trusses are efficient in their use of lumber. Where a conventionally framed roof might require 2x8 rafters spaced 16 in. o.c., for instance, trusses for the same roof might be made entirely of 2x4s and spaced 2 ft. o.c. and use 15% to 25% less wood.

When you're used to beefy 2x rafters, trusses take a little getting used to: They look spindly. But once they are set and braced properly, trusses are stronger than stick-framed roofs. A truss is really a series of triangles, a geometric shape that is difficult to distort under load. Unlike common rafter stock, much of the material that goes into roof trusses is machine tested for strength and is held together by engineered truss plates sized for the loads they will carry (for more on how roof trusses actually work, see sidebar p. 42).

For all their advantages, though, roof trusses must be handled differently than regular 2x rafters. They have strength only in a vertical po-



Photo this page: Courtesy Wood Structures, Inc.

sition and can't be banged around a job site like a 2x12. Proper installation techniques and bracing are critical, and trusses can't be modified in the field without radically altering their strength.

How does the cost of a trussed roof compare with a conventionally framed roof? The answer depends on the complexity and the size of the roof. But because trusses use less material, they look more attractive as the cost of framing lumber continues to rise, and high-quality framing stock becomes harder to get. The only real way to know is to price both options, but keep in mind that a conventionally framed roof takes more skill to build.

**Shapes and sizes**—Trusses are as varied as the houses they go on (drawings right) and can be combined to create complex roof shapes. Some trusses look similar—the king post, queen and Fink trusses, for example, all have the same shape—but can be distinguished by the signature web patterns inside. Because each web design distributes force differently, these trusses are rated for different loads and spans even though they look very much alike.

Residential roof trusses range from 15 ft. to 50 ft. long and from 5 ft. to 15 ft. high. Length and height are determined by roof pitch and span plus cantilever, if there is any. Tall trusses are sometimes made as two separate trusses so that they can be shipped over the road without hitting power lines and overpasses. Called piggyback trusses, the two parts are joined on site with plywood or metal gusset plates.

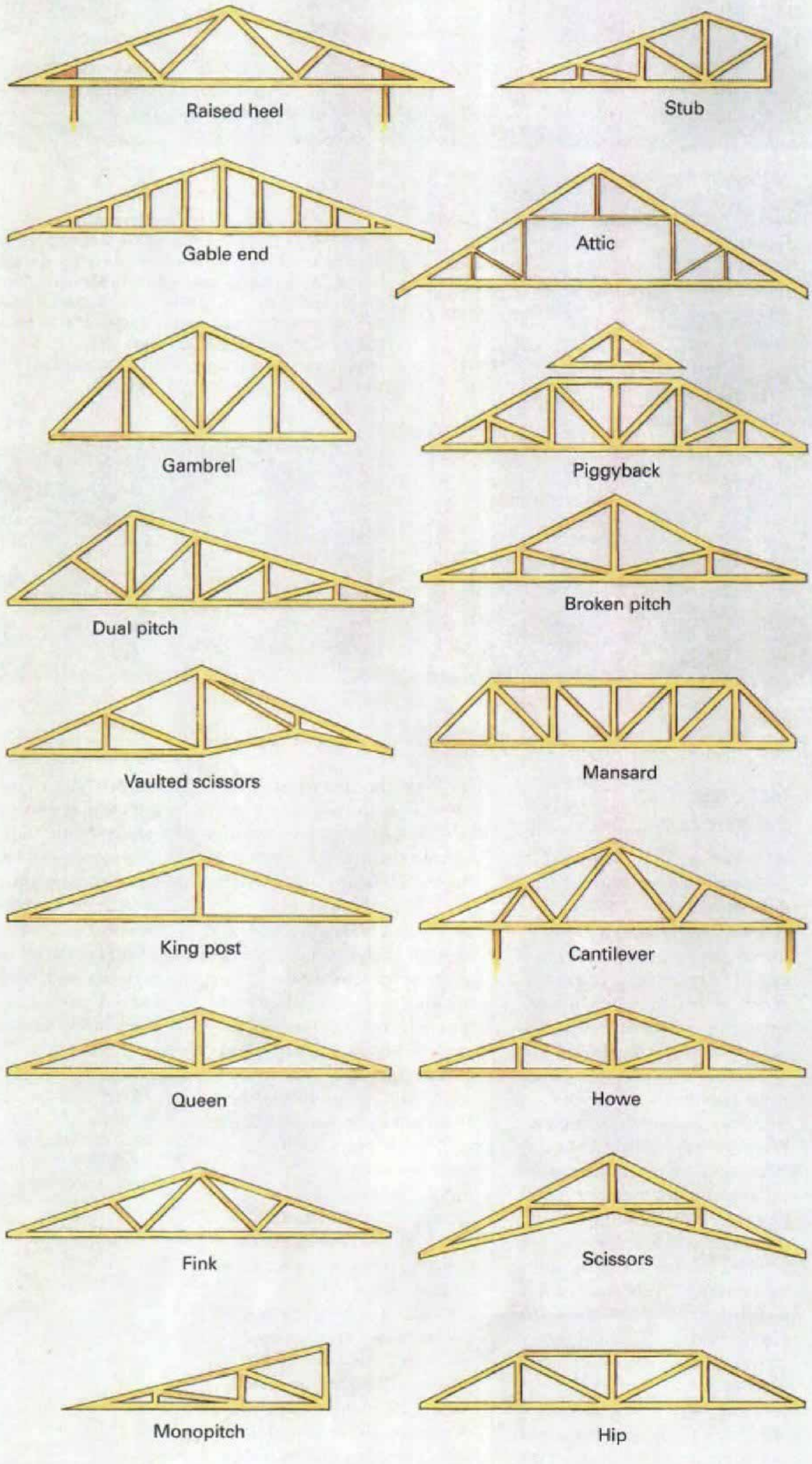
Where common trusses can't be used or aren't appropriate, special trusses fill the bill. What if, for instance, plans call for a chimney or a dormer that's wider than the normal spacing of the trusses? If you're framing a roof conventionally, you just head off one or more rafters to create the oversize hole. But trusses can't be cut. Instead, master and split truss sets are used. Truncated in midspan to form the opening, split trusses are headed off to full-span master trusses on both sides to create the opening in the roof framing.

Most roof trusses have webs that run at an angle between top and bottom chords. One exception is the gable-end truss (also called a gable-end frame in the industry) in which webs run vertically. These trusses ride atop a building's end walls and must be supported along their entire length, so they function more like a wall than a truss. Shorter than the last common truss by the depth of its top chord, a drop-top gable-end truss makes ladder-framing wide overhangs a snap.

Trusses eliminate attic storage or living spaces because webs get in the way—at least that's the oft-heard but unfounded concern. In fact, there are attic trusses that are perfect for steeper roofs and garages because they are designed with room-size central openings (photo facing page).

Combinations of several kinds of trusses are used to frame the roofs of L-, T-, H- or U-shaped houses. To eliminate the partition between the main house and the ell, girder trusses, consisting of two or three trusses fastened side by side, span the opening where the two legs of the house meet. Common trusses on the main house are clipped flush at one end and hung from metal

**Roof choices.** *Trusses come in styles other than a simple gable. Manufacturers say just about any roof shape can be framed with a combination of trusses, from hip and mansard to cathedral ceilings and saltboxes. When truss shapes are similar, as in the king post, queen and Fink trusses, different web patterns determine maximum loads and spans.*




Drawings: Christopher Clapp

*At the factory.*
**Roof trusses are turned out quickly and precisely, thanks to computer-controlled cutoff saws and special assembly tables. At Wood Structures, Inc., in Biddeford, Maine, trusses are assembled either on huge, fixed tables (above) or on movable bases (left). When finished, trusses are moved into the yard on carts that keep trusses upright (below).**

hangers on the girder truss. A series of step-down valley trusses installed on top of the common trusses of the main roof extends the ell roof back to the main roof. It's a trussed version of valley framing with conventional 2x stock. Hip roofs are framed similarly with common, girder and step-down hip and jack trusses. Scissors trusses and vaulted scissors trusses give instant cathedral ceilings. With single- and double-cantilever trusses, porches, entrance roofs and wide overhangs are simply extensions of the truss.

Common trusses are fabricated with a variable top-chord overhang and a variety of soffit-return details for box and closed cornices. And where thick ceiling insulation that extends to the outside of the top plate and an airspace above are needed, raised-heel trusses do the trick.

**Specifying trusses**—With so many choices, specifying trusses might seem daunting. Not so. In fact, truss manufacturers take virtually all of the sting out of ordering a roof. A basic specification starts with a list of each type of truss that will be needed (common, gable-end, etc.) and how many of each. Other information the manufacturer needs includes the span of the roof, the pitch, the top-chord overhang, the kind of end cut and soffit-return details you want, gable-end preferences and any special loading requirements (for a slate roof, for example, or HVAC equipment that is to be mounted in the attic). The specs for my 22-ft. square garage were pretty simple: 10 common trusses; two gable-end trusses; 8-in-12 pitch; 22-0-0 span; 1-ft. overhang, plumb cut, no soffit return. Many of the larger truss manufacturers and building-material sup-

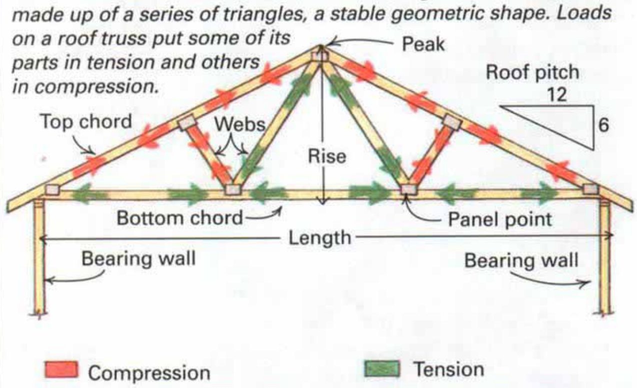
## *Strength in triangles*

**Triangles are naturally rigid geometric shapes that resist distortion, in fact, you can't change the shape of a triangle unless you change the length of one of its three legs. That's the secret to the strength of a roof truss. Regardless of its overall shape, all of its chords and webs form triangles. Stick-built roofs operate on the same principle, with rafters, ceiling joists and collar ties forming the triangles. The pieces that make up a truss work together. Cut any one of them, and the truss is compromised and weakened.**

**Under the weight of sheathing and roofing, a roof truss as a whole is stressed in bending. Its chords and webs, however, are stressed principally in either tension or compression (drawing right). Top chords, which are in compression, push out at the heel and down at the peak. The bottom chord, firmly fastened to the top chords, is stretched in tension to resist outward thrust. The result is a stable, self-balancing structure.**

**Loads on the individual pieces that make up a truss can be dramatically different. Let's suppose the truss in the drawing has a span of 30 ft., a total rise of 7 ft. 10 in. and a pitch of 6-in-12. Under typical roof-design loads (42 lb. per sq. ft. on the top chord and 10 lb. per sq. ft. on the bottom chord), the compression force between panel points in the top chords varies between 2,400 lb. and 2,079 lb. Along the bottom chord, forces in tension run from 2,124 lb. to 1,459 lb., depending on where along the span they're measured. Contrast those forces with those working on the webs—what a difference! The two short web pieces experience 505 lb. in compression, and the two long webs have to resist 743 lb. in tension. The relatively light forces are why web pieces don't have to be stress-rated and why materials used in top and bottom chords usually do.**

**One important difference between stick-built and truss-framed roofs is that ceiling joists rarely span the width of the building. Instead, they bear on interior partitions as well as on exterior walls. Trusses are almost always designed to bear only on exterior walls, with the webs connecting the top and bottom chords, providing intermediate support. That opens up many more possibilities for floor plans. —*S. S.***



**Roof loads at work.** *Trusses are strong because they are made up of a series of triangles, a stable geometric shape. Loads on a roof truss put some of its parts in tension and others in compression.*

pliers carry stock trusses in sizes and styles most popular in their areas. With no production lead time, you can order stock trusses on Monday and have the roof closed in by Friday.

Specifying trusses for complex roofs is easier, not harder. All you really have to do is take the framing plan to your building-materials supplier or to one of the nation's 1,500 or so truss fabricators, and they'll do the takeoff for you. Most truss manufacturers purchase the machinery, the plates and the engineering services of one of about eight connector-plate manufacturers. Plate makers actually engineer and design the trusses, and truss manufacturers assemble and sell them. Some truss manufacturers have in-house engineers and design software.

**Design and fabrication**—Once the specs are known, trusses are designed by a computer, with building-code required roof, ceiling, wind and snow loads, as well as any special loading conditions, taken into account. An engineering drawing details the forces that develop in each chord and web under the design loads. Engineering specs also include lumber species, size and grade for each chord and web; gauge, size and orientation of each connector plate; truss dimensions and pitch; and the location of permanent bracing. Engineering drawings are supplied by the truss manufacturer, who passes them on to the contractor. If you're responsible for setting the trusses, and you didn't get a copy of the drawings, be sure to ask for them.

Integrity of the truss depends on the integrity of its metal plate connectors. Stamped from 16-, 18- and 20-ga, structural steel coated with zinc, plates have many integral teeth 5⁄16 in. to 9⁄16 in. long. There are about eight teeth per sq. in., and plates are sized according to the level of stress they have to transfer between members.

Trusses are made mostly from southern pine, Douglas fir and the woods of the spruce-pine-fir group. That includes eastern and Sitka spruce, lodgepole, red and jack pine and western and balsam fir. Truss manufacturers start by cutting 2x members so that they are the right length and have the correct angles at the ends. Some factories use computer-driven saws that can change settings in about half a minute and produce multiple cuts very rapidly and precisely. The kind, the size and the grade of lumber for each chord and web on the cutting list is based on how great a force each must resist while under load. Highly stressed as a rule, chords are usually made of lumber that has been stress-tested to ensure performance. Webs, because they are usually subjected to lower stresses, are more likely to be #2, #3 or even stud grade.

**At the factory**—There are two common methods for building trusses in a factory (photos facing page). In one, pedestals with electromagnetic bases are arranged in the shape of the truss on a steel floor, with one pedestal at each panel point. Once all of the pedestals are in place, chord and web pieces are laid out, their ends tightly butted, and then clamped. Connector plates are positioned on both faces of the joint, and a hydraulic C-clamp suspended from a gantry squeezes the teeth of both plates into the wood simultaneously.

Another way of making trusses is to assemble them on huge metal or wood tables. The tables are drilled to accept a series of pins and clamp fixtures that hold the truss pieces in place. Chords and webs are placed in the jig, then panel points are lifted, and connector plates are slipped underneath. Another plate is set on the exposed face at each panel point. Both plates are pressed into the wood at once by a mechanized roller that travels the length of the table.

It may take a couple of experienced workers 30 or 40 minutes to lay out pieces for a new truss on one of these tables. But once the pins and the clamps have been adjusted correctly, workers can put their measuring tapes away; all they have to do is pick up precut pieces of stock, put them in the jig and add the connector plates.

To complete the process, and to assist builders in setting the trusses, most truss manufacturers affix brightly colored "Caution," "Warning!" and "Danger!" tags at critical locations such as cantilever bearing points and permanent lateral bracing sites. Don't ignore them.

Completed trusses are stacked, banded and stored in the truss yard, either vertically or horizontally. When stored on their sides, trusses are elevated off the ground on stringers spaced to minimize lateral bending.

**Delivery, handling and erecting**—Trusses are hauled by truck, with trusses either lying on their sides or cradled vertically (often upside down) in a special trailer—trucks can haul up to a half-dozen roofs at the same time. Ideally, trusses are unloaded at the job site with a forklift or a crane, but most are gingerly dumped on level ground. Trusses should always be elevated off the ground and protected from the weather under a loosely draped tarp. When unloaded vertically, the bundle of trusses that rests on its top chords should be braced on both sides to prevent it from falling over and to keep trusses from toppling when the band is broken.

Depending on the truss span and the height of the building, trusses are erected either by hand or by crane, and occasionally by forklift. With one-story buildings, trusses under 30 ft. usually can be raised manually, but longer trusses should be hoisted by crane. A crane is a must for buildings over one story (photos p. 44), regardless of truss length. Whether carried or hoisted, trusses should always be held vertically when moved. When held horizontally, lateral flexing and bouncing can overstress the connections in the truss, causing plates to loosen or pop out. Long trusses are especially vulnerable to this problem.

Installation starts with a gable-end truss. Setting trusses by hand on a one-story building might go like this: With its peak pointing down, a gable-end truss is carried into the house, and its ends are positioned carefully on top of the sidewalls (top photo, p. 45). Then, with a worker at each sidewall, the rest of the crew uses Y-shaped poles to rotate the truss until it's upright (middle photo, p. 45). To prevent damage during lifting, two poles should be used. Each pole should be positioned at the panel point closest to the quarter points of the span. If only one pole is used, it's placed at the peak. After carpenters make sure the overhang is correct, the bottom chord is toenailed to the end-wall top plate with 16d nails (bottom photo, p. 45).

Once the gable-end truss is in place, it must be braced to the ground. Common trusses are then raised sequentially in the same way. Each should be secured in place with temporary lateral bracing that goes back to the gable end (more on this later). That's why it's essential that the gable-end truss be securely braced to the ground—all other trusses will be braced against it. It's also very important that the 2-ft. o.c. spacing be maintained at the heel and the peak of each truss and that each goes up square and plumb.

**Setting trusses with a crane**—Good rigging practice prevents damage when setting trusses by crane. No truss should ever be lifted by its webs. Trusses up to 20 ft. long can usually be lifted with a cable looped around the top chord at midspan (drawing p. 44). A tag line, which doesn't support weight but gives you a way of steering the truss when aloft, is lashed to one heel and is used to guide the truss into position. Trusses up to 40 ft. long are typically hoisted at two symmetrical lifting points separated by half the span. Again, cable ends are secured around the top chord. A tag line is needed as well. Lifting 40-ft. to 50-ft. long trusses without lateral flexing generally requires a spreader bar with three cables. Typically one-half to two-thirds of the truss' length, the bar is centered over the truss. Cable ends looped around the top chord should point in slightly. Tag lines attached to both heels increase control.

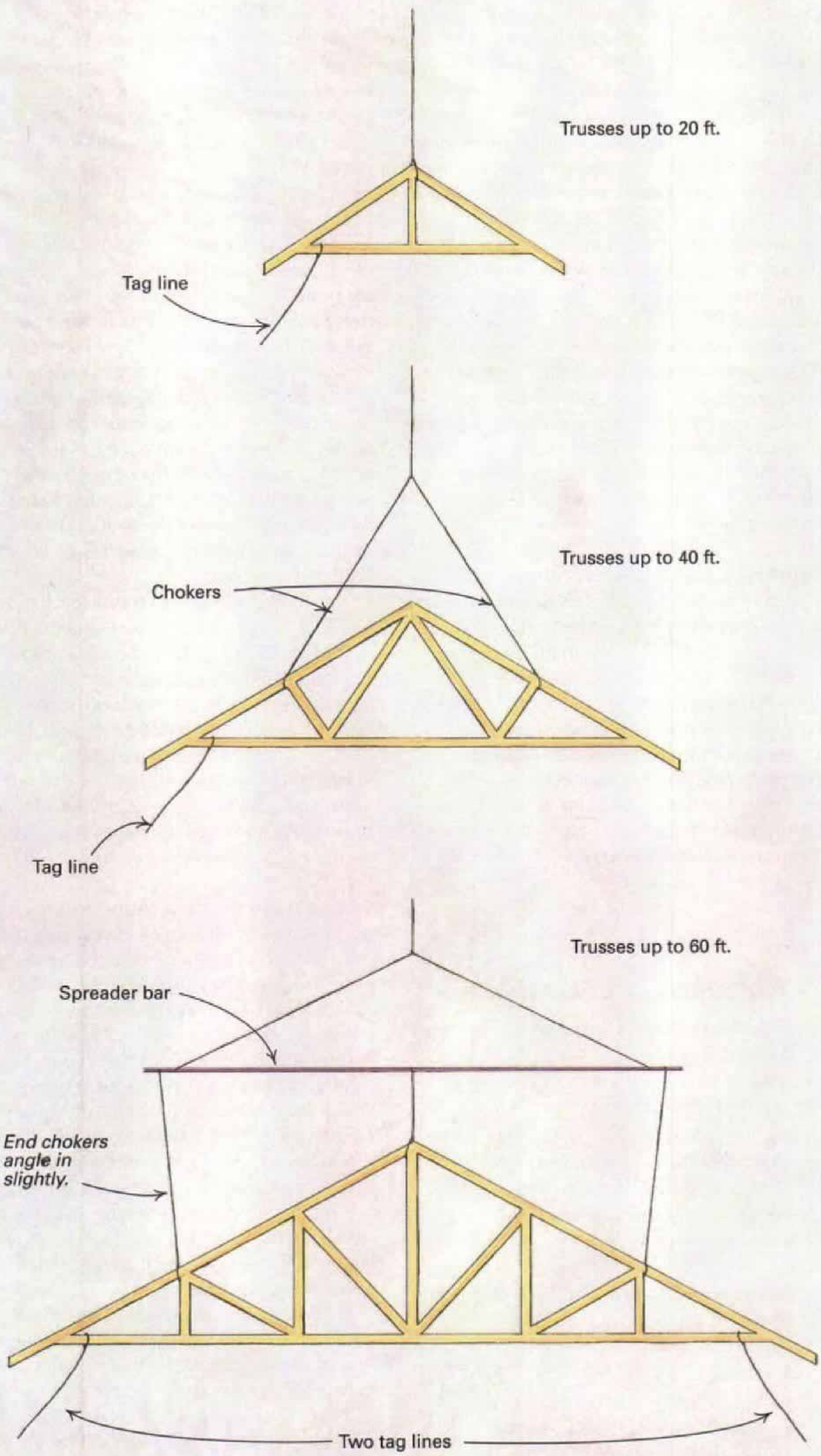
Once in place, trusses are customarily toenailed to the top of the wall with 16d nails through slots in the heel plates. While adequate in most instances, toenailed fasteners can withdraw under the uplift forces exerted by high

## *For more information*

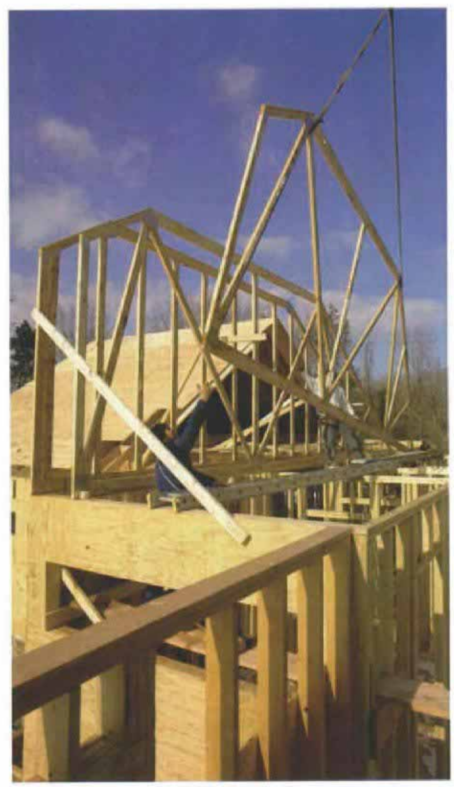
***The Truss Plate Institute***
**583 D'Onofrio Dr.**
**Suite 200**
**Madison, Wis. 53719**
**(608) 833-5900**
**(Ask for HIB-91, *Commentary and Recommendations for Handling, Installing and Bracing Metal Plate Connected Trusses, $7.*)**

***Wood Truss Council of America***
**5937 Meadowood Dr.**
**Suite 14**
**Madison, Wis. 53711-4125**
**(608) 274-4849**
**(Ask for *The Metal Plate Connected Wood Truss Handbook,* $39.95.)**

**Lifting trusses by crane.** *To set larger trusses, and any truss on the second floor, a crane will be required. For spans up to 20 ft., a single line from the peak works fine. For spans up to 40 ft. long, two chokers should be used, each at a quarter point on the top chord. For trusses up to 60 ft., a spreader bar is a good idea. Three chokers, the two outside lines slightly pointed in, should be attached. In all cases, a tag line helps control the truss.*




***Going up? Get a crane.***
**Large trusses, and any roof truss headed for a second-floor installation, go up by crane. This piggyback truss (above) is being lifted by two chokers with a tag line for control. Pallets and 2xs beneath the stacked trusses on the ground help prevent bending. With a gable-end truss in place (below), the rest of the roof quickly follows. The gable-end truss on this roof has been braced securely, and trusses installed subsequently are tied to the gable-end truss to prevent the trusses from tipping over.**



winds. This became evident in the aftermath of Hurricane Andrew in south Florida. If you want uplift resistance, you've got to use metal framing anchors or straps for truss-to-wall connections. Scissors trusses are a little different. Because these trusses have a significant horizontal thrust by nature, one heel must be free to move so that the truss won't push walls out of plumb when it's under load. The solution is a framing anchor with a horizontal slot (for more on framing anchors, see *FHB* #43, pp.4449).

Trusses should never be attached rigidly to interior partitions because this can induce bending forces that trusses aren't designed to carry. When trusses are nailed directly to interior partitions, cracks can open at wall-to-ceiling junctions, or partitions might be lifted right off the floor because of something called truss rise (for more on truss rise, see *FHB* #81, pp. 54-59).

**Temporary bracing prevents collapse**—After the heels have been nailed, the top chord of the truss must be secured by temporary lateral bracing. Starting at the heel and working up to the peak, 2x4 bracing is usually installed along the top chords at about 8-ft. intervals, with the correct interval depending on the truss span. Bracing should span four or five trusses and should be fastened to each truss with two 16d nails. The ends of the 2x braces should overlap at least two trusses. Bottom chords need to be braced, too, at intervals of about 10 ft. across the span. Although I've never seen it in use, there is a product called the Truslock (Truslock, Inc., Rt. 1, Box 135, Calvert City, Ky. 42029; 800-334-9689) that's designed to brace trusses quickly while maintaining the correct spacing. The Truslock is a folding metal brace that locks over the top chords of trusses as they are set. Even with the Truslock in place, proper bracing of gable ends and bottom chords is still necessary.

While helpful for maintaining on-center spacing, lateral bracing won't prevent connected trusses from tipping over as a unit, just like a row of dominoes. To prevent this catastrophe, trusses must be braced diagonally, either across the top chords or through the webs. With the first option, bracing is laid at a 45° angle across several trusses on both sides of the peak. A row of this diagonal bracing should start about every 30 ft. as you walk the ridge, so most houses will get only one or two lines of diagonal bracing. When run through the webs, bracing starts beneath the top chord against the web closest to the center of the gable-end truss. Descending at a 45° angle, the bracing should cross several trusses, nailed to each web as it passes, and end at a web just above the bottom chord. Through-the-web diagonal bracing is often left in place.

Bottom chords are also braced diagonally in each corner of the building. In all cases, 2x4 bracing is fastened with two 16d nails to every truss it passes. Like those found in the brochure truss manufacturers provide to the contractor with every shipment of trusses, these guidelines are based on the recommendations of the Truss Plate Institute (see For more information, p. 43).

***For small trusses, poles will do.*** **First-floor trusses with relatively short spans can be poled up. Supported by two outside walls (top), trusses are rolled upright with a Y-shaped pole (middle). When the truss is plumb, it must be braced to other trusses and toenailed in place. In this installation, the use of two poles would have been better.**

Don't ignore them. Inadequate temporary bracing is the chief cause of truss collapse during erection.

**Closing in**—With the trusses in place, top-chord temporary bracing is removed, truss by truss, as sheathing is laid. Ideally, each panel is fully nailed with the proper-size fastener at the recommended spacing before moving on; a panel tacked in place with a few nails may not provide the same resistance to lateral movement as the just-removed bracing. With a crane on site, you may be tempted to hoist all of the sheathing to the roof at once. Don't do it. Trusses can buckle, be damaged or broken under the concentrated load exerted by such heavy weights.

The size, the location and the methods of attachment of permanent bracing is the responsibility of the building's architect, designer or engineer. Permanent bracing works with the building's other structural elements to achieve structural integrity. Top chords of trusses are assumed to be permanently braced by the roof sheathing. Long webs and bottom chords not braced by a rigid ceiling, as in a garage or over a suspended ceiling, for example, may need to be permanently braced to prevent lateral buckling. In residential construction, permanent diagonal bracing running through the webs isn't usually necessary. Plywood sheathing provides enough resistance to racking when combined with bracing nailed to bottom chords in the corners. According to the Truss Plate Institute, building codes around the country require that roof trusses be braced, leaving detailed instructions to the truss manufacturer or the designer of the building. In some areas, like hurricane-prone south Florida, local codes may have special requirements for permanent bracing.

**Damaged trusses**—What should you do about the odd truss with a broken web or a popped plate or two? The temptation is to pound the plate back in or sister a 2x over the break. But the right thing to do is to contact the truss manufacturer for advice. Why? First, once a truss is damaged, it no longer acts like a truss. Second, whoever does the repair assumes responsibility. And in today's litigious society, that's no small matter. For the same reasons, never cut, notch, drill or modify a truss without first seeking engineering advice. More likely than not, the truss engineer will come up with a workable repair scheme. □

*Stephen Smulski is a consultant in wood performance problems in Shutesbury, Mass., who also inspects truss manufacturers on behalf of The Truss Plate Institute. Photos by Scott Gibson except where noted.*

Photos this page: Courtesy of Southern Forest Products Association