TIMBER FRAMING

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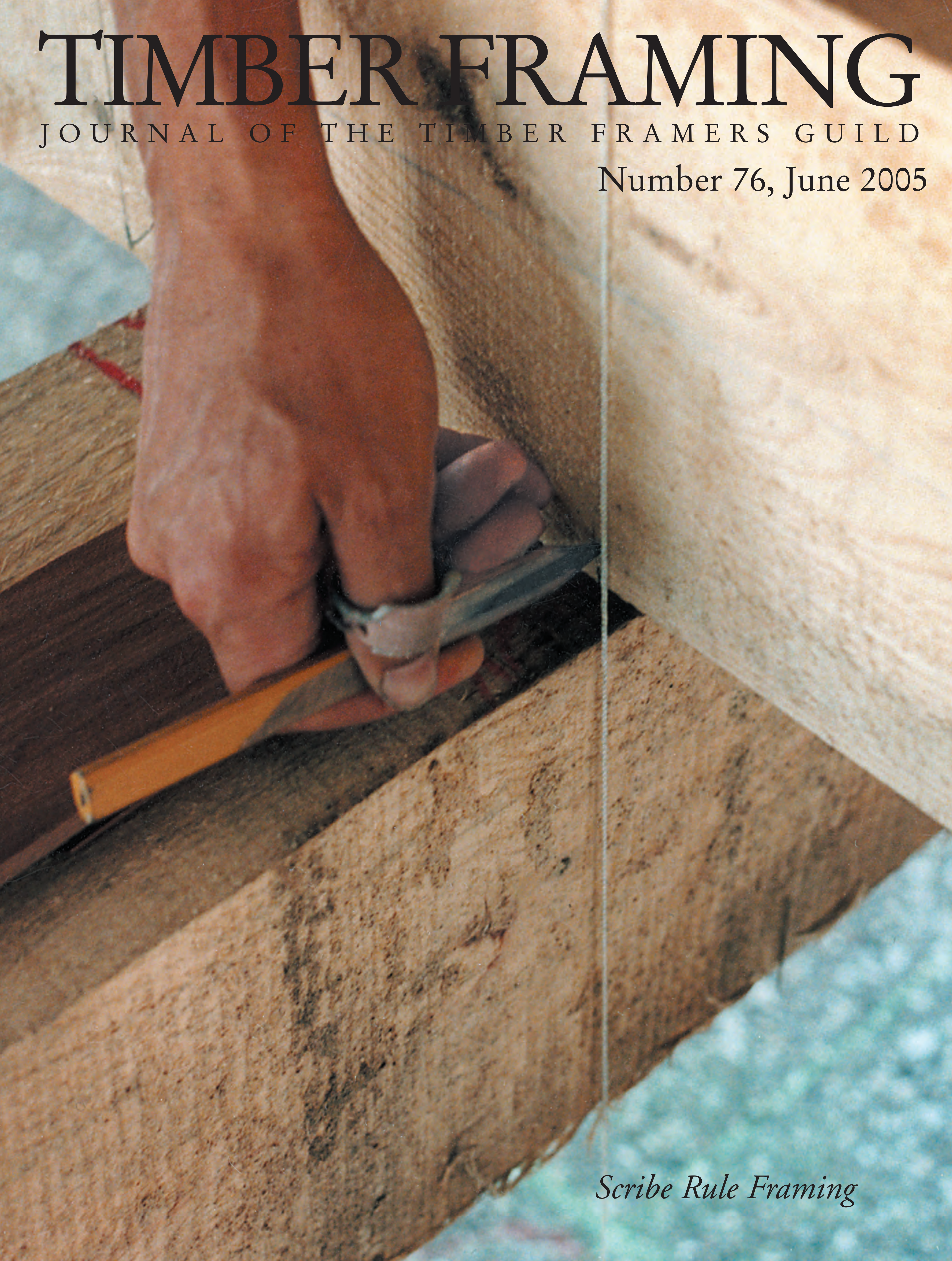

Scribe Rule Framing

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On the cover, plumb bob scribing the crossing of two timbers. The timbers have been leveled and placed in their assembled orientation, aligned with a chalked layout struck on the floor. The pencil has been shaved for ease in sighting and marking one side of the string, held fairly taut by the unseen plumb bob at the floor. Photo by Will Beemer.

www.tfguild.org
888-453-0879

Editorial Correspondence
PO Box 275, Newbury, VT 05051
802-866-5684 journal@tfguild.org

Editor Kenneth Rower

Contributing Editors
Guild Affairs Will Beemer, Joel C. McCarty
History Jack A. Sobon
Timber Frame Design Ed Levin

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1985

Notes & Comment

Director on the Run

FROM Ferry Farm (Virginia) to the New Hampshire Preservation Alliance demonstration (N.H.), back to Ferry Farm and then immediately on to the Salem (Oregon) Rotary Pavilion for a pow-wow, then a full Western Conference at the base of Mt. Hood (ditto), then the monster project itself in Salem, and now off to Illinois for our first "Professional Development Workshop," *aka* the Selman Pavilion (actually in Indiana). And here it is only May.

The event in Virginia, a period barn for Ferry Farm, the boyhood home of George Washington in Fredericksburg, proved an adventure in cheerful endurance. Mountains of high-quality Virginia white oak were slowly transformed into a hand-raised, kingpost-trussed, English-tying-joint barn on the soggy banks of the Rappahannock River. I missed the worst of the weather. Everyone else on the team acquired some experience in underwater timber framing, with days of horizontal rain and low temperatures. Spring is cold in Virginia. One forgets.

Ferry Farm

Nice to be on a job site where lasers (to align the scarfed plates) and adzes are gainfully employed at the same time. The raising itself was a bit of a struggle, a gentle lesson in the mixed virtue of absolute precision in joinery and a demonstration why there are so few timber frames in the world with braced principal purlins. On the other hand, the Corps of Cadets from Virginia Military Institute in Lexington turned up with a very slick mobile derrick they had made over the winter for this job, and it proved to be exactly the thing to sling those big trusses into place with lots of human power operating at a safe distance.

Of the dozens of TFG events I've participated in, the Salem pavilion, a public performance space in the downtown park, had by far the most extensive front-end planning, and it was over the top in the health and safety department. Each tool and cord was inspected and, if accepted, recorded in a log to ensure that we knew what we had and could provide insurance protection for the equipment under our care. Big power tools were kindly provided, with training, by Mafell, NA.

We were blessed with a mostly seasoned crew of 51, looking for new experience or practice with scribe rule, compound joinery and tricky raising issues. The weather for the foreseeable future looked very good. No sooner did I finish telling our Rotary hosts that we were more or less on schedule (I presented a slide show at their weekly luncheon) than I learned that the scribe guys thought they were a half-day behind. Was that more on time or less on time? There was plenty of interest in the scribing, and two teams of five got the lowdown from English scribers Steve Lawrence and Gordon Macdonald. This training, augmented by our night school program, was in large part why we were here.

Even with all this preparation—an extensive health and safety plan, rigorous fall protection enforcement, cheerful blessings from the OSHA inspectors and precision layout of the anchor points—the raising day-and-a-half was anything but anticlimactic.

The planning and training proved their worth during a machine-heavy raising: *three* cranes, two scissors lifts, two articulated manlifts plus an extenda-boom forktruck. First a horizontal twin-line lift picked the half-truss flat and gently rolled it to vertical, followed by the main pick of the four truss-bosspin-assembly (14,000 lbs.) rigged with two spreader beams. Lifted high enough to clear the masonry, the assembly was rotated 45 degrees to align with the columns, while the manlifts maneuvered below to meet the hip posts as they descended (not without incident) into the galvanized receivers. All good work, and new territory for most of us.

Salem, Oregon, Rotary Pavilion

Old Guild hands might chafe under the yoke of planning and regulation that sat all over this job, but it looks like the future from where I sit. This change grows from the belated realization that good professional practice and personal longevity (perhaps even profitability) require first-class event planning and a serious safety program. The people from OSHA who fill us with apprehension can, it turns out, be morphed into allies and consultants. I think they were so astonished to be asked for advice that they went the extra mile to evaluate our safety plan (our fall protection standards exceed theirs) and to give us access to an excess of training and certification materials. Likewise, the managers at Sunbelt, lender of all the materials-handling equipment (at Ferry Farm, too), were happy to provide forktruck and manlift certification training and testing on site, on a schedule that did not much disrupt our days. On the front end of the event, several members took advantage of our offer to provide boom truck (up to 30 tons) professional training and certification on site, for a modest fee. Look for these programs to be repeated at conferences in the near future.

Plates for Angola, Indiana, Selman Pavilion

No sooner did the last jack rafter come home in Salem, I was off cross-country for the Selman Pavilion project, the Guild's first professional development workshop, hosted in Illinois by Trillium Dell Timber Works (though the building will rise in Angola, Indiana). As I write, this job is halfway along. Two 100-ft. multi-scarfed purlin plates protrude from both ends of the workshop.

All Guild workshops offer professional development, of course, but this event is our first effort to teach directly the competencies in the developing curriculum package. The workshop portion is organized around specific modules, taught through morning and evening sessions, with plenty of opportunity in the shop next door for application of newly won knowledge.

Why move in these directions? No one my age, and scarcely anyone in North America even now, learned this trade from his father or entered the craft with a complete set of business skills looking for a great commercial opportunity. Most everyone I have met over the years is what Tedd Benson used to call a reluctant businessman. Many of us have flailed about over the last 20 years trying to bring the same level of precision to our business and professional practices that came more easily to our joinery. Mature companies in the trade have perhaps made the transition from craft to manufacturing, at least in part to support modern compensation packages and progressive employment arrangements. So be it.

Training in a consistent and verifiable skill set, as is done on other continents with more persistent timber framing traditions, is part of the future for North American timber framers. Rigorous planning and safety standards are positive signs of professional practice in the marketplace, and will lead to beneficial effects on employee health and safety and conceivably on insurance premiums as well. The Guild has a special obligation to lead the way, since we have historically exposed our volunteer participants (willingly enough) to the corrosive effects of job site chaos and especially to the risks of high work, far from home, unprotected by good systems or insurances. —Joel C. McCarty

Joel McCarty is executive director of the Guild for development.

TIMBER FRAMING FOR BEGINNERS

X. Introduction to Scribing 1

SCRIBING is one of the techniques in a skilled timber framer's repertoire, and one all of us will use at some point in our careers. Trim carpenters use it to fit baseboards to irregular floors or cabinets to wavy walls; log builders use it to set their next course of logs on top of the one below, or to fit a post base to a rock plinth. Its goal is to make curved, bowed, twisted or otherwise irregular surfaces fit each other perfectly by transferring or marking the profile of one onto the other and removing material from the latter to accommodate the former (Fig. 1).

In these cases one surface is already in place and you're laying out to make the other match its profile, often with dividers or compasses to transfer the pattern over a short distance. Only one piece needs to be aligned, marked and cut to fit the other already in place. In timber frame layout, however, the timbers are in a stack in your yard, and their potential arrangements and orientations are myriad. Often two or more uncut pieces (such as a post, beam and brace assembly) need to be aligned and referenced to plumb and level planes and the profiles of each piece transferred to all the others (since tenons need mortises). In addition, the transfer distance increases as the the scribing setup gets higher, making errors more significant and limiting the tools suitable for the task.

An assembled scribed frame looks much more natural than a square rule frame, with the former's pieces flowing from one to the other without the gains and housings so unsightly to some (Fig. 2). But scribing is also more labor intensive. It requires more handling and moving of material and more room for layout, yet offers less room for mistakes. If an error is made, an entire assembly may have to be set up again for layout in the yard. However, an efficient and skillful scriber can work as fast as a square rule timber framer, as many of our friends in Europe (where they use much irregular timber) have shown.

Photos Will Beemer unless otherwise credited

Fig. 1. Marking dividers fitted with cross levels are used in log layout to transfer the profile of one nonplanar surface to another. The tool is calibrated against a reference surface and then held plumb and level.

As in most building, it's important first to understand the concept of *reference planes* within the structure. Reference planes are typically found at the top of floor framing, the outside of exterior walls, the top of rafters, the centerline of ridges and on one side of aisles or bays. Measurements and dimensions on plans are conventionally taken from these planes. (For more on reference planes and reference faces, see "Introduction to Layout," TF 63.) But you are just as likely to find framing plans showing intervals dimensioned to timber centerlines, especially on interior frames. In the built structure, wonky or irregular timbers will move in and out of these reference planes, but the scribe layout person will know how to make it all work. If a reference plane is a surface that functionally needs to be flat, such as a floor or sheathed wall or roof, then the members need to be straight, flattened or used elsewhere. Reference planes that are not actual surfaces, however, do not require flatness in the timbers.

The layout procedure requires setting uncut timbers in a given assembly (a floor, wall, bent or roof) over one another in their proper relationships and then transferring irregularities from one timber to the adjoining one at the joint locations (Figs. 3 and 4). This is usually done first with the major timbers in the assembly and with the assembly in a horizontal, leveled position, although it is also possible to scribe pieces into a frame after it is up. Minor timbers such as joists, girts and braces can be scribed later using quicker methods after the major frame is securely try-assembled.

The assembly is most often laid out horizontally because gravity allows us the convenience of plumb and level as reference planes. By aligning frame timbers in a predetermined orientation to these planes, you can use tools such as plumb bobs, dividers and spirit levels to transfer joinery accurately.

There are several scribing methods, then, to transfer measurements vertically through uncut timbers stacked in their proper orientation, including plumb bobbing (such as French scribe), tumbling (to be explained) and bubble scribing, a method we learn from modern log builders. Other methods such as double cutting and mapping do not require these vertical setups. Again, scribing is labor intensive, and efficiency of movement is crucial to its success. Each method has its advantages in certain applications.

LINING THE TIMBERS. Regardless of the scribing method used, you need to know how the timber you're laying out relates to level and plumb and the reference planes, both in its layout position and in the final frame. Major timbers, especially if twisted, waney or curved, or that appear in two assemblies (such as corner posts and plates that take part in both wall and roof frames), will have level marks on one face if sawn or hewn roughly square. Round timbers, which don't have "faces," will have level marks on their ends, as will major square timbers.

Rob Hadden

Fig. 2. Square rule assemblies (above left) show abrupt gains and reductions at many joints. Scribe rule assemblies (right) appear to flow together.

Fig. 3. Timber yard at St. Marie-among-the-Iroquois Museum, Syracuse, New York. Workers have positioned a roof truss to be scribed over a completed crossframe. Hewing bunks and sawing trestle in the background. Except for the power cord, the spirit levels and the suspicious red steel toolbox, the scene might have occurred from the Middle Ages to the end of the 19th century.

Fig. 4. Marking for joints in multiple member assembly. Timbers have been stacked in the proper orientation and carefully leveled with shims, then clamped to keep them from shifting. Upper member has been both centerlined and joint lined, lowest timber centerlined only.

Fig. 5. Level-lining square timbers at the ends preparatory to striking connecting lines on faces. Objective is to describe a true plane.

Fig. 6. Striking centerlines joining plumb and level lines on log-ends. Bumps in surface can sometimes require segmental striking.

These level marks become our primary reference points, defining a level plane, and are very useful if the timber is twisted. The level marks on each end are often connected down the length of the timber by a chalk line, both to locate joinery on that face and to level the timber lengthwise (Figs. 5-7).

Not all timbers need to be lined or have level marks. You don't need to waste your time on short minor timbers and those that are straight and square (or close enough). You may only need to mark one reference plane, not two (for level and plumb) if joinery only occurs in one face. Remember, efficiency is key, so don't line the timbers if you don't have to. Experience will help you decide when it's necessary.

Let's look now at how the level marks and lines are established; later, you'll see how to use them during the setup for scribing. First, place the timber on the sawhorses or bunks with the primary reference face up. This reference face is also the face that will be up in the timber's first assembly. Measure the shoulder-to-shoulder length on the top face, add enough for tenons and crosscut the timber to length. Sometimes extra length is required for you to align and shim timbers during the setup, but the point is not to have 4-5 ft. of extra length, which could exaggerate the discrepancies in the timber and offset the joinery unnecessarily.

Using a torpedo or 2-ft. spirit level placed across the face approximately midway along the timber, shim the timber until the vial reads level. If there is not a flat place for the spirit level, make one with a plane working across the grain. Mark along both sides of the level on the face, remove the level and connect the corners of these marks to make an X inside the rectangle. The French call this the feather mark (Fig. 8). It will be the surface you level when setting up the timber in the scribing assembly (Fig. 9).

Next, you want to establish a level plane through the timber, which you will use to locate joinery along its length. As you look down the timber, imagine the joinery that will occur and how it will land among the sweeps, curves and knots along the timber. If one edge of your mortises (and tenons) is to be 2 in. (on average) from the reference arris, you may want to have a snapped line representing that. Or you may want to keep your joinery centered, and thus snap a line that follows the center of the log or timber as closely as possible. You might also do this if you wanted all of your smaller section timbers centered on the larger ones, rather than your reference faces flush on one side. The point to remember here is that whatever line you snap to establish the level plane, it's set at some known distance from the joinery and the reference planes of the building. When two mating timbers are assembled, the lines should meet.

Let's look at a couple of examples of how the level marks and lines help us orient the timber. Say you have a twisted post and you place your level mark in the center of the length, leaving the surface unaltered. This means that the top end of the timber would meet the plate slightly askew, and the bottom end going into the sill would be slightly askew the other way. But what if you wanted the post to meet the plate flush across the whole joint and didn't care if the post was skewed a lot down at the sill? In that case you would put the level mark up at the plate end, or else plane down

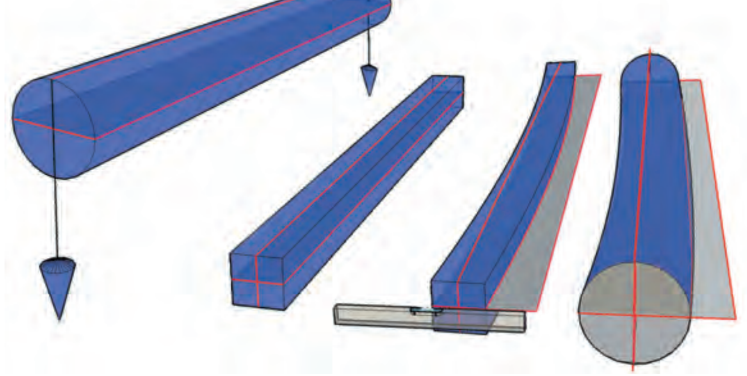


Fig. 7. Examples of lined timbers. Lining is practically indispensible for timber in the round and for twisted or crooked square timber.

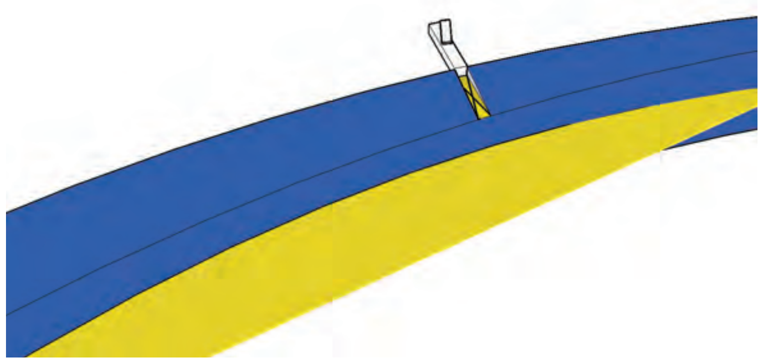
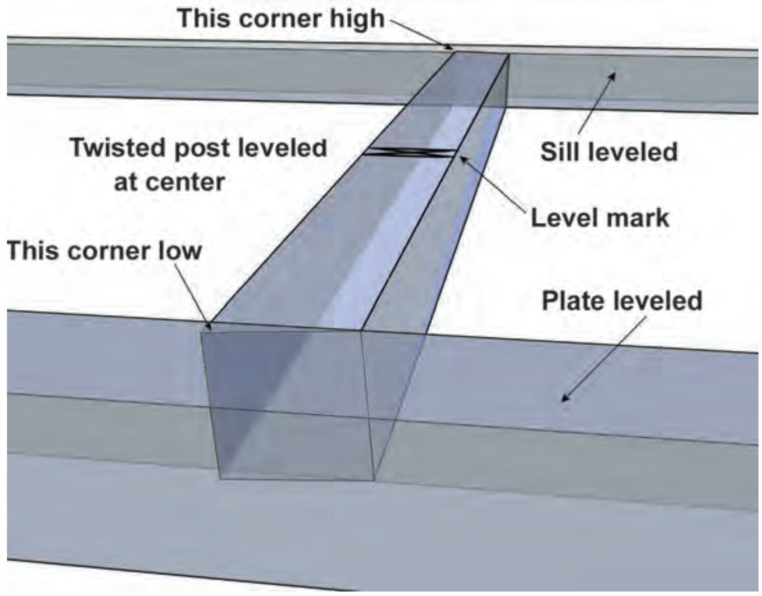


Fig. 8. Planing a level flat across a severely twisted surface. Flat is parallel to imaginary plane that ignores bow and twist.

Fig. 9. Dave Carlon tapping up the wedge to tilt a timber surface into level. Area under level will be hatched for later reference.



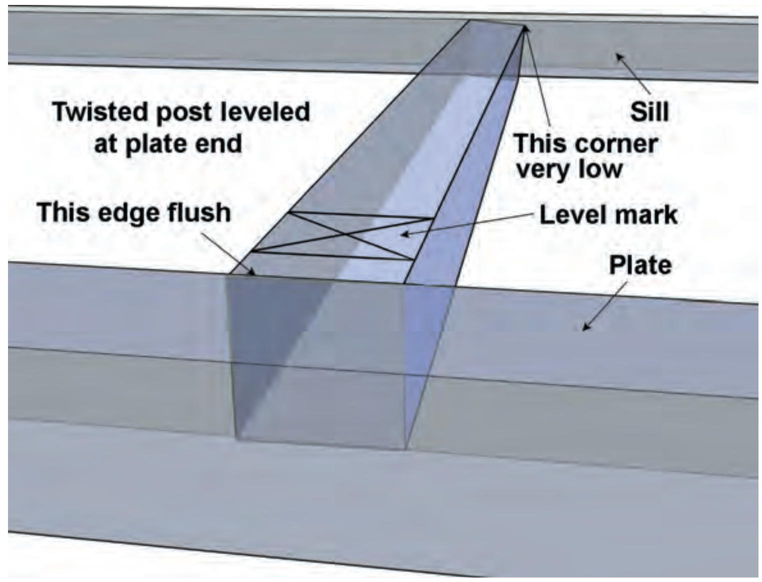


Fig. 10. By aligning level planes, the framer can choose whether to distribute the distortion or where to concentrate it.

an area for the level near the midpoint that was parallel to the reference surface up at the plate shoulder (Fig. 10).

Or perhaps you are framing in a forked post that has been flattened on two opposite faces. Now you have *three* ends that need to be in the same plane. Set the timber on a level floor and block it up so that the centers of all three ends at the shoulder marks are the same distance above the floor (thus level) and plane a flat spot at midlength until a level placed on it reads true, then make the level mark. Laser, builder's or water levels can also be used to level up the timber, especially if you don't have a level floor to work on. Shim all three ends of the forked piece up to the same elevation as indicated by the level, then establish using the level mark at midlength as before (Fig. 11).

Whatever the piece at hand, after the level mark is established choose where to line the timber. For timbers that will end up in two different assemblies, you usually line all four faces. For other timbers, you only need to line the faces that will receive joinery. You need to consider the timbers that will be joined to the one you're working on. If you're lining an exterior post, and the upper reference face is the outside of the building, you will want the post to be flush with all the other timbers' outside faces. If your joinery is to be laid out with 2-in. mortises and tenons 2 in. from the out-

Fig. 11. A forked member requires three ends in plane (one end unseen.)

side face, then make a mark at the shoulder points 2 in. down from the reference arris, which is the line at the meeting of your primary (top) and secondary reference faces.

If your timber is twisted, or "in winding" as the British say, you need to "unwind it" to make sure the plane you establish with your chalk lines is parallel to your level mark. Place a stick (such as a 2-ft. level, framing square or length of wood of uniform thickness) on the level mark. At the shoulder marks at each end, place the 2-in. blade of a framing square and shim until its upper edge is parallel to the level stick. Now you have three level lines across the timber, but they don't necessarily make a plane (Fig. 12).

If you use framing square blades for all three sticks, you can sight across the squares to detect any curvature in the timber. Keeping them parallel crosswise, shim the squares again until they are aligned lengthwise. Now you have a level plane. At each end of the timber, measure down the same distance on the secondary reference face (either 2 in. as suggested above or half the thickness of the timber if you're doing centerlines) and mark a point. Roll the timber to bring up the secondary face and snap a line through these two points. It's easier to get an accurate line if you snap it from above rather than from the side, and it helps to have another person sighting you or using a level to make sure you're pulling the line plumb before snapping.

If the sweep allows the line only to hit at the hump in the center, you need to plumb up from the shoulder marks and sight from one mark to the other or use the line to mark the high point. Then you can snap in stages from the high point to each shoulder mark (Fig. 13). If the timber has a sweep on a face that prevents the line from hitting, you will need to do some carpentry gymnastics. First, shim the timber so that your level mark on the primary face (now on the side rather than the top) is plumb. Then plumb down from the chalk line at various points to get marks to snap from in stages (Fig. 14).

Often the end cut is close enough to the shoulder that you can also screw on plumb boards to tie the line to if you're working alone. Your eye becomes an invaluable tool here and will aid your efficiency if you can sight the points along the plane accurately and quickly.

For timbers that are far from straight, you may find during this process that you need to move the line away from the ideal location for the joinery. For example, you may find that the chalk line for the joinery actually leaves the curved timber along its length, and intermediate timbers would not even hit if you left the line where it is. You may need to move the joinery at the ends to get enough relish at the other joinery along the length. If that still doesn't work, you can try turning the timber and starting over—or rejecting it entirely. Again, your eye can help you make these decisions at the beginning and save time.

You might have a post that needs to be oriented with the sweep to the outside of the building. (This would push the siding out if the joinery were made flush at the ends, so it's preferable to orient the sweep some other way. But let's say it's unavoidable.) You might then want to move the joinery out so that the timber is flush at the greatest part of the sweep and the ends inset from the plate and sill. With the timber's primary face up and the level mark true, run a string across the high point so that the two ends of the string are the same distance above the face. Measure down 2 in. from the string to locate the edge of the mortises and tenons; this can also be done with framing squares and torpedo levels. Then turn the timber and mark the chalk line on the secondary face as you normally would. Rotate the timber back so that the primary face is up and re-level. Snap a reference line on this face if needed for joinery. From where these two lines meet the ends of the timber, transfer and mark lines level and plumb across the ends to the other face(s). Then roll the timber and snap lines on these faces. These lines not only locate the joinery but will also be used to level the timber lengthwise in the setup. The lines across the ends will help you reestablish the chalk lines if they degrade.

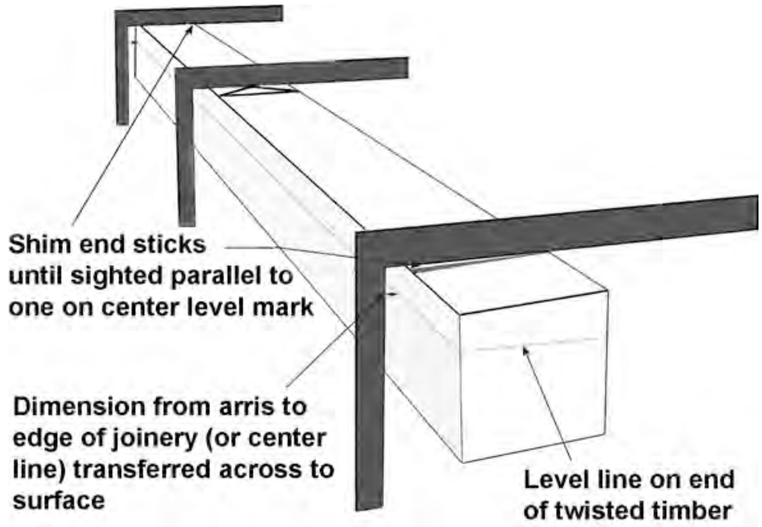


Fig. 12. Use of three winding sticks to develop true plane from twisted surface, with reference to given level mark.

Round timbers are lined a bit differently since there are no faces to put a level mark on. Start with the ends, establishing level and plumb lines in a location where the joinery appears to work well. Lines snapped along the length of the timber connecting these marks should also accommodate joinery that is needed.

Accurate lining is critical for the success of the scribe method, and will seem to take a long time at first. But your speed will increase as your eye becomes more critical and accurate, and you don't need to line *all* timbers. Lining is especially needed with pri-

Fig. 13. Snapping a chalk line in segments on a bumpy surface.

mary timbers, ones that appear in two or more assemblies, and those that are round, twisted, curved, waney or severely out of square. Joists, rafters, braces, minor girts and studs usually do not have to be lined if they're reasonably straight and square. After lining all timbers that need it, you are ready to set up for scribing.

It should be pointed out that some workers prefer to line timbers destined to appear in two assemblies *after* they complete the first assembly but before dismantling it. Timbers are placed and wedged by eye in whatever way looks best in a roughly level first assembly, then scribed, cut and reassembled. Only then does the worker plane a feather mark for level and strike the chalk lines for the second assembly. The advantage here is that new requirements sometimes appear in an initial layup that make one want to change things around, which cannot be done if the timbers are lined and level-marked before ever seeing an initial assembly.

THE first assembly to be scribed is usually a major horizontal frame such as the lowest floor or, in the case of buildings with masonry walls, the wall plates and tie beams. These are done first because upon completion they will establish the level footprint of the building, and the other assemblies such as walls can be laid up on top of them and to the exterior dimensions that have been established. If you didn't have this floor as a template, you would need instead to have a full-scale drawing of the building on a layout floor or take tedious measurements at each lay-up to reestablish the building dimensions. Another option if you are laying out the frame over bare ground is to establish reference strings at some set distance out from the perimeter of the frame, much like batter boards for a foundation layout. It's also possible to use the foundation itself as your scribing platform if it's a slab or shallow crawlspace.

Let's propose a hypothetical floor frame and see the various ways you can apply the scribing methods. The outside dimensions of the frame are 12 ft. by 16 ft. If the foundation is already in place, it may be possible to place the timbers right on it and not take any measurements at all before scribing. But for illustration let's use the simplest (and potentially least accurate) form of scribing to lay out the sill corners: mapping, also called distance scribing, mental scribing or measured scribe. In this system, the mating timbers don't have to be stacked for layout, or even brought near each other. The irregularities of one timber are measured and noted, then accommodated for in a separate layout of the joinery on the other piece.

In our example, the long, mortised sill at its corner measures ¼ in. less than the nominal 8 inches across, and the opposite long sill measures ½ in. greater than 8 inches. Thus the shoulder-to-shoulder length of the short sill between them will be 12 ft. – 7 ¾ in. – 8 ½ in., or 10 ft. 7 ¾ in.

What if the long sill timber is severely twisted? Here's where the level mark and lines become very useful. Set the timber up so that the level mark and the line along the length are level. At each end set a level on the face at the shoulder line and measure (with a bevel gauge or rule) the amount the face is twisted, then transfer those measurements to the mating sill (Fig. 15).

The more individual deviations from ideal, the more unwieldy mapping becomes. You have to record, remember or otherwise keep track of all these variations. As you can see, mapping an entire frame would be very tedious mentally, even if it saved you the work of actually stacking the timbers. It also requires that timbers be reasonably close to square and straight, free of wane and not too twisted, to keep the number of variables down. If you don't have the room to move timbers around much or do a stacked setup, and can only work on one timber at a time, mapping may be appropriate for you. Or you might forget scribing entirely and go to square rule if your timbers are reasonably close to square.

Tumbling is another easy and quick form of scribing, but restricted to smaller, relatively undistorted timbers and joints occurring over small flat areas. Here the beams to be scribed must be set over the ones they will meet, as in most of the other scribing methods, and the lines projected directly with a straightedge instead of remotely as in mapping.

Fig. 14. Plumbing down from the stretched line to get snapping points. For this procedure, the level mark on the log end is plumb.

If you wanted to tumble the floor joists in our first assembly, you would first lay out, cut and assemble the main perimeter sills, then set the joists on top of them above their final locations. Scribing allows us to put the unlined joists and other minor timbers in rather arbitrary positions (as long as they will do their job structurally) because their shoulders will be transferred directly no matter at what angle the two pieces meet. If the tops of the sills are level, take a joist and roll ("tumble") it to one side so that the top arris now rests on the sill. Mark the shoulder-to-shoulder length and roll the timber back up.

Take the straightedge and hold it against the inside face of one sill and tap the joist along until the shoulder mark meets the straightedge. Mark this line on the joist and then do the same on the other side. Go to the other end of the joist; place the straightedge on that sill's inside face and tap the joist back until that shoul-

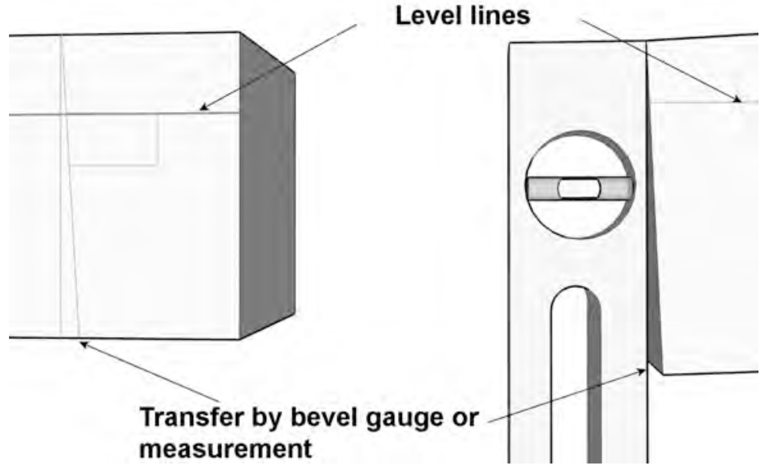


Fig. 15. Scribing non-orthogonal shoulders in right-angle connections.

der mark lines up. Transfer the lines up on both sides. Add tenons or whatever additional length is needed to occupy housings or drop-in pockets. While tumbling is fast, it's best restricted to small pieces because you move the timbers a lot.

If the twisted sills are not level on top, we cannot immediately tumble the joist because the twist in the sill prevents the arrises of the two timbers from meeting when the joist is rolled. We need to take a few extra steps by lining the joists and then measuring the distance between the sills and transferring that to the reference line on the side of the joist (Fig. 16).

Another method used in place of tumbling or in combination with it is double-cutting, helpful on waney timbers. The mortises will have been cut ahead of time, and then short tenons are cut on the ends of the adjoining timbers, leaving plenty of material ahead of the shoulder line (established by tumbling) to account for the expected variation in the mating face. Insert the tenon all the way into the mortise (making sure the timbers are level with your lines and level marks), and set dividers to the widest distance between the faces. Scribe the profile of the mating face to create the shoulder, and make a second cut to this line (Fig. 17).

This method is preferable to tumbling for larger joints, when transferring up with a straightedge might be less accurate. You can still use tumbling to get your shoulder-to-shoulder length.

BEFORE moving on, it might be interesting to compare techniques in Japan, where there is often not enough working room for direct scribing. As related in the *sumitsuke* series by Michael Anderson (TF 26, 28 and 29), Japanese framers will square rule the shoulder-to-shoulder lengths, thus requiring gains or housings in receiving timbers, but scribe the profile of the housing to accept the tenoned piece, which is often round or faceted in section. Since they can't scribe the profile directly from one piece to the other, they will transfer it to a centerlined profile board with straightedge and careful measurements and carry that board over to the housing in the other timber, always working to joint centerlines. Conversely, in France we saw carpenters scribing the shoulder-to-shoulder length and angles, but square ruling the mortises and tenons down a set distance from a reference face (but see TF 34-36).

Mapping, tumbling and double-cutting are used when timbers are reasonably square and straight. As timbers get wilder, you need to get them one right over the other at the joint location and use more exacting techniques to get the variations transferred accurately. The principal scribing tools are the plumb bob and the bubble scribers. Plumb bobs are used with sawn or well-hewn material, while bubble scribers are best suited for round material. Plumb bobbing is the traditional way of scribing in France and England, where straight timber was customarily reserved for high uses. The technique was carried over to colonial America and prevailed before square rule layout came into use about 1800. In the plumb bob method, uncut timbers are stacked in tiers, leveled and placed carefully in their proper orientation, and the joinery intersections are transferred vertically with dividers, pencils and a good eye, using the plumb bob running down through the assembly at the joint location for true reference (Fig. 18 facing page).

Scribing can be very fast and accurate (once the setup has been established), but requires a practiced eye and steady hand. If there are many repeated assemblies of the same configuration to construct, such as multiple roof trusses, then it makes sense to create a full-scale drawing of the assembly on a layout floor with the principal reference planes marked with chalk lines. This may even make sense for unique assemblies, since the drawing is easier to measure out than moving timbers and tape measures around, and if you inadvertently bump a timber out of alignment during layout you have the drawing to reference it to directly.

However, you might not have a layout floor big enough or clear enough to do a full-scale drawing, in which case you will have to set up on blocks or sawhorses, moving each timber into place and measuring its alignment, and then being very careful not to move it during scribing. (Clamps can help, as in Fig. 4.) If you are doing your layout over bare ground in a yard, you could lay down wide planks on which to snap chalk lines. The planks themselves can be set to stakes along one or both edges to maintain alignment.

The floor drawing, according to its nature as a plan or elevation, will have lines representing the outside of the building, the tops of floors, girts and roof, the centerlines of posts or the lower sides of braces. Except for perhaps the centerlines of posts, these do not rep-

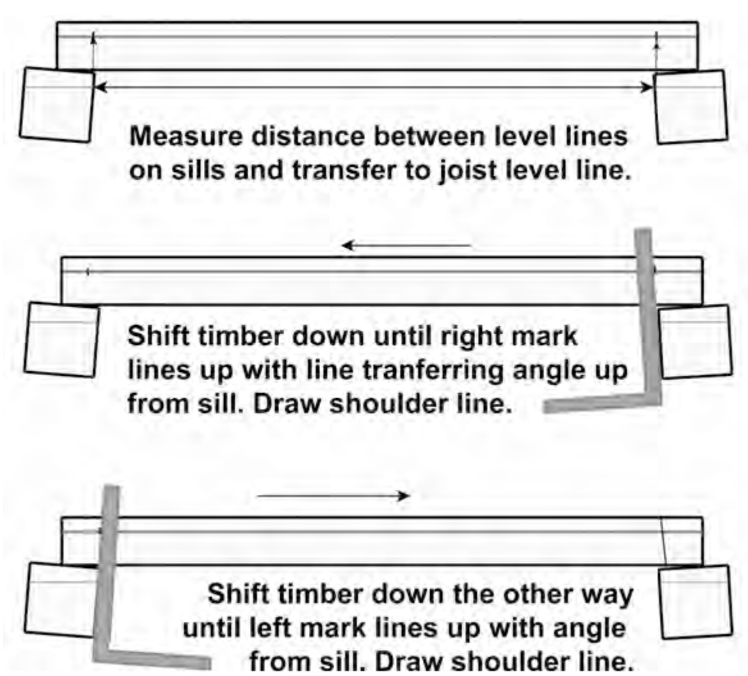


Fig. 16. Tumbling is a straightforward marking operation unless the pieces meet twisted surfaces, requiring additional steps to produce the necessary non-orthogonal shoulders.

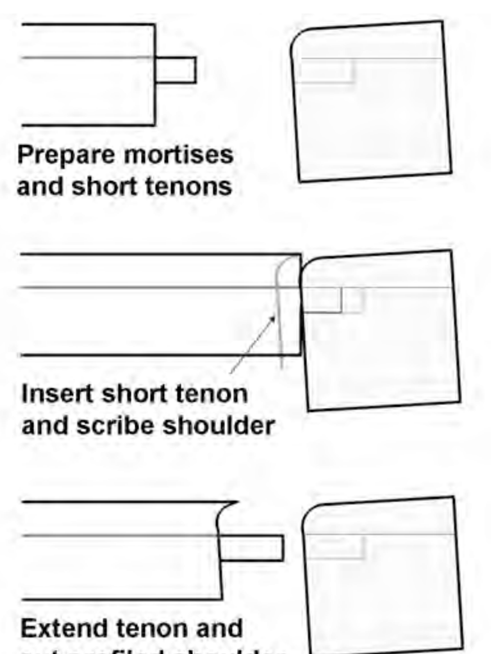


Fig. 17. Double cutting. Timbers are jointed provisionally with reference to common level line and cut a second time to obtain perfect fits at the shoulders.

resent the same lines you have snapped along the length of the timbers (the latter usually represent the location of the joinery). Developing the floor drawing requires knowledge of geometry, proportion and other math to assure accuracy, and traditionally these secrets were the domain of the master carpenter. Even today, once a knowledgeable and skilled person lays out the drawing, the math-challenged crew can still tackle the scribing without tape measures.

Once the floor drawing is complete, be careful not to obliterate your lines by walking on them until layout is complete for all the assemblies using that drawing. Place the timbers over the drawing, starting with major timbers such as posts on the bottom, using the plumb bob (or a level held plumb) to align the appropriate face (outside of end post to outside of building, for example) to the drawing. At the same time, shim the timbers on blocks so that both the feather marks and the lines on the sides are level.

Leave enough room under the first tier of timbers for the plumb bob to swing freely, and use the same size blocks under all timbers so they are level with each other as well (we assume the layout floor is level). Place the second tier on top of the first, using no blocks, making sure not to jostle the first set. These might be tie beams and wallgirts that connect from post to post. Shim and level them as you align them to the drawing; minor timbers may not be on the floor drawing as their location is somewhat arbitrary. A third tier could then be placed, such as braces between the tie beam and the posts. This procedure requires quite a bit of blocking under the post end while the other end rests on the tie beam, an instance where adequate uncut length is needed to block up a timber sufficiently to have clearance for marking the joinery.

Level and align this tier as the others. It is important that the chalked reference lines on each tier be the same distance from the lines on the tier above or below it. Some scribers prefer to go only two tiers high, scribe and assemble that much, then scribe the braces into the assembly. This approach may be safer as you can be sure the major assembly has no mistakes before tackling the braces, but it requires much more setup time re-leveling everything. The confident and efficient scriber will try to get as many of the timbers in the setup as possible scribed at the same time.

With the timbers all aligned to the drawing and each other, and leveled in both directions, you are ready to scribe. Because the assembly is level in two directions, dropping the plumb bob through it gives the third axis, and you can accurately lay out the joinery in space using these planes of reference. For example, take the tie beam to post joint. Drop the plumb bob so it swings free just above the floor and the string touches at least one corner of both beams. Now you can see the irregularities in the face of the beam.

To mark the top beam, align a sharp carpenter's pencil with a flattened face to be level and parallel to the arris of the timber below. Place it on the same side of the string as the lower timber and mark, taking into consideration the difference between the string and the corresponding corners (Fig. 18).

If the timbers are different widths, the distance between the marks on one timber will be the width of the other. You can use the chalk lines on the side as additional reference points, as when the joinery comes together these lines on each timber should meet. Repeat the process on the lower timber, aligning your pencil with the arris of the upper one. If the discrepancy between the string and surface is too great to eyeball accurately, take the measurement with dividers and transfer it. If necessary, use the dividers as well to transfer the width of the joinery above and below the chalk line.

Repeat this process on both sides of the joint and at both ends of the timber. If the timber is coming in at an angle (a brace, for example), be sure to trace this angle on the side of the timber for reference. If there is a through tenon, you'll want to have enough length to scribe the exit on the backside of the mortise. Remove the timbers from the setup one at a time when layout is complete, immediately connecting the scribed points to outline the joinery.

It must be noted here, before you cut any joinery, that every time you make a cut you should be sure to connect any points or lines that might be needed later. Lost lines are difficult to recover since you have no surfaces to measure from once the assembly has been dismantled. As you're scribing, try to visualize the final joint when assembled, because cuts may not be square or even in a plane, especially in round material or timbers with wane or obstructions. Timbers coming together at an angle other than 90 degrees in unsquare faces may produce a joint layout that looks impossible as you're getting ready to cut it, but may have made sense during layout. When you're checking mortises for depth and squareness, remember that you can't use a square on the surface, but must refer back to the feather mark. Make sure it is plumb or level, then check the mortise with your square referencing to level or plumb.

In the next article, we will continue with plumb bob scribing and examine in detail how to scribe an angled brace and timbers that appear in two assemblies. We'll also look at scribing round logs into square or round timbers using mitered joinery and bubble scribes. Finally, we'll summarize some rules of thumb to make scribing more efficient and describe how you can tell if an old timber frame was scribed or not. —WILL BEEMER

Will Beemer is co-executive director of the Guild for administration and education. This article is first of a short series on scribing.

Fig. 18. Scribing assembly for post, beam and brace at St. Marie-among-the-Iroquois. Main timbers are lined. French method includes floor layout lines and cast plumb bob with flat bottom. Small rabbet plane cuts flats across the grain of hewn timber to produce level reference stations or "feather marks."

TTRAG Proceedings 2005

South-central Ohio and its barns formed the backdrop for the 2005 symposium of the Guild's Traditional Timber Framing Research and Advisory Group, its 14th annual public get-together, held in March at Salt Fork State Park in conjunction with the Friends of Ohio Barns. Some 146 repair and restoration specialists and barn enthusiasts visited barns, bridges (covered and uncovered) and a few houses, and heard presentations on historical and technical themes. A new tying joint was discovered in a barn. Presenters in addition to Larry Sulzer included Rudy Christian (Malabar Farm working barn), Steve Gordon (Ohio's historic barns), Arnold Graton (St. Helena's Church, Beaufort, S.C.), Arron Sturgis (New England barn repair), Brian Mulcahey (GPS location of historic structures), Don Hutsler (log buildings and sawmills), Jan Lewandoski (covered bridge repair) and Jack Sobon (timber repair techniques). See also back cover.

The Leavenworth-Lang-Cole Hay Press and Barns

Larry Sulzer

IN the mid-19th century, as the human population in the nation's cities grew quickly, so also did the population of horses, mules and oxen within the cities. Your main means of transportation was horses, or hay burners as they were sometimes called, and you bought your "fuel" at the haymarket in town. Obviously, the hay needed to feed the large numbers of urban livestock was grown in the country and later transported to the city. Transporting loose hay long distances to the city was inefficient and so the concept of a hay press was born, essentially a heavy timber stationary bailing mechanism.

The Mormon hay press was a significant Indiana invention. In 1843, Samuel Hewitt, who lived close to Madison, improved upon presses of the past and patented the improvements, calling his the Hewitt Press. He later became a Mormon and the invention became known as the Mormon hay press.

The Leavenworth-Lang-Cole hay press was constructed in 1849-50 in Crawford County, Indiana, near the mouth of the Blue River, about a half-mile upstream from its confluence with the Ohio River. This location allowed the pressed hay bales, each weighing 200 to 300 lbs., to be slid down a chute and then transported by flat hay boats up and down the river. This vertical press was an integral part of a specially designed barn that measured about 60 ft. wide by 130 ft. long. This press was one of the many located along the Ohio River in commercial operation through most of the last half of the 19th century. Hay press barns once numbered in the hundreds up and down the banks of the river. The barn is the only restored and publicly accessible one of its kind in the entire country. By the turn of the 20th century, such presses were becoming obsolete as steam-powered baling machines took center stage. In 1913, the Leavenworth press survived flooding. It was last operated in its original location in a demonstration, about 1918.

From 1918 until the late 20th century, the Lang-Cole family used the barn for farming purposes. By 1990, the condition of the barn was rapidly deteriorating and an initial effort was mounted by local history buffs and Historic Landmarks Foundation of Indiana to save the press. By this time, fewer than a dozen hay presses remained in the entire United States, none operational or open to the public. In 2000, Dr. Jack Cole donated the barn and press to O'Bannon Woods State Park, where the barn has been reconstructed and the press made operational for public demonstrations.

Operating the press takes two or three attendants and a draft animal such as an ox to make a 300-lb. bale of hay in about 10 to 15 minutes. The ox is attached to a sweep at ground level and led counterclockwise one revolution to lift the beater or press, a 1000-lb. weight, up to the third level.

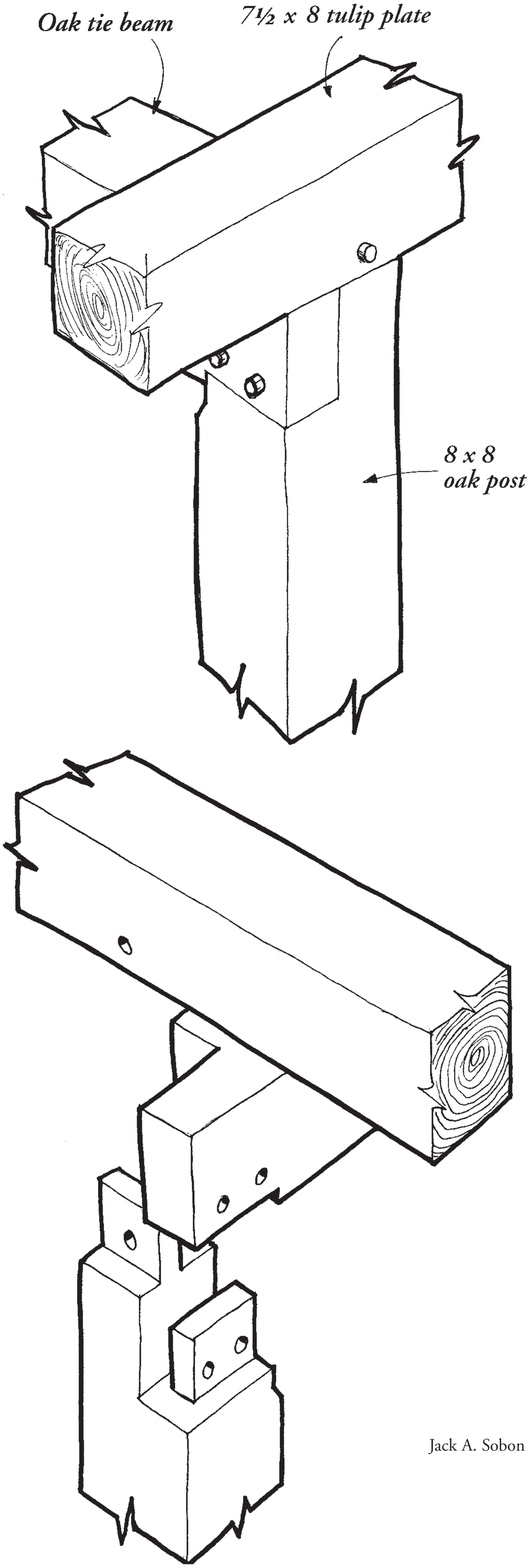
On the second level, one or two attendants fork loose hay into a baling compartment. Once the compartment is filled and closed, the ground level attendant pulls a trip lever, allowing the weight to drop down to the baling compartment and press the hay. The weight is lifted back up to the third level by the action of the ox. The ground level attendant then pulls the rope to open the door to the baling compartment, thus allowing the second level attendants to fork more hay into the compartment. This process is repeated about six times until a full bale is made.

The second-level doors to the baling compartment are opened and the bale is manually laced with twine. The ox is once again led counterclockwise to raise the press off the finished bale. Using hay hooks, attendants pull the bale out of the compartment, and the process starts all over again for the next bale.

A press in use before Hewitt's was called the jump press because men would actually jump on the hay in the compartment to help press it. Hewitt's improved press was quite appreciated in its day.

Jarrett Manek

The Lang-Cole barn, reconstructed in an Indiana state park, complete with its 1850 Mormon hay press. At right, the three-story press being moved into position. Hay was forked in on the second story and pressed by a beater dropped from the third. An ox yoked to a sweep at ground level provided power to lift the beater via pulleys.



Jack A. Sobon

At top, assembled view of new tying joint found in the Ringer Farmstead Barn, Cambridge, Ohio. Above, rotated and exploded view of the joint. Both plate and tie are joined to the post as in the English tying joint, although transposed. But they are not joined to each other.

HISTORIC AMERICAN ROOF TRUSSES

V. The Evolution of Roof Trusses

THIS article is fifth and last in a series to discuss and illustrate the form, function, joinery and origins of historic American timber-framed roof trusses, showing typical examples with variations. Previous articles in the series have treated Scissor Trusses (TF 69), Queenpost Trusses (TF 71), Kingpost Trusses (TF 72) and Composite and Raised Bottom Chord Trusses (TF 74). A related anticipatory article, "The Close Spacing of Trusses," appeared in TF 67.

It is impossible for a native speaker to speak incorrectly.
—Benjamin Whorf

We must labor to be beautiful.
—W.B. Yeats

VERNACULAR ORIGINS. The truss form emerged from the timber framing methods of classical antiquity in the Mediterranean region and only during the last two centuries became shaped by engineering analysis and design. Truss construction has always been associated with the high end of vernacular carpentry; trusses are rarely found in private homes or barns, but almost always in prestigious public buildings such as temples or churches, or in bridges. While we have only a small body of evidence for the exact form of the trussed roofs of antiquity, we have abundant extant examples of long-span roof systems from the Middle Ages through the Renaissance. The variety of forms and the inventiveness of their framers seem without end. Many of these pre-modern roof frames are fully realized trusses with a captured kingpost hanging the middle of the tie beam, and the ends of the rafters restrained within the same tie (Fig. 1).

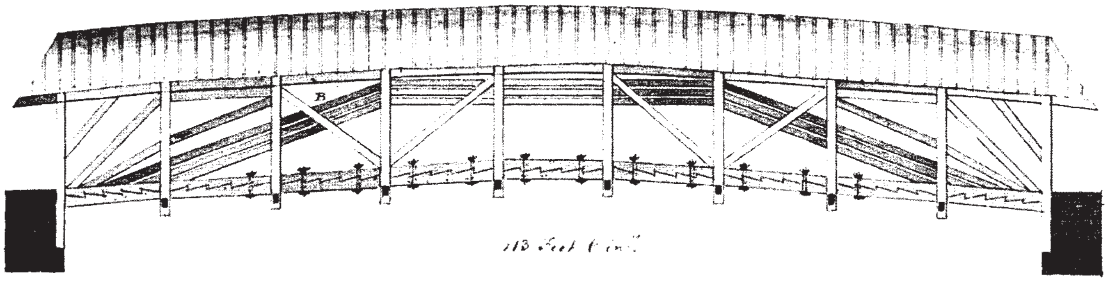
Will Beemer

Fig. 1. St. Catherine's Church, Honfleur, Normandy, late 15th century.

Multiple kingpost and queenpost examples exist in Switzerland in the work of the self-taught designers and builders Jakob, Johannes and Hans Ulrich Grubenmann. Their longitudinal roof truss in the Reformed Church at Grub (1752) and the Bridge on the Linth (1766) represent the culmination of an established central European tradition of *hängewerk*—that is, using posts in tension to suspend tie beams or truss bottom chords (Figs. 2 and 3).

Grubenmann-Sammlung Teufen, Switzerland, used by permission

Fig. 2. Lengthwise truss, Reformed Church at Grub, Switzerland, 1752.



London, Sir John Soane's Museum, used by permission

Fig. 3. Bridge on the Linth at Ziegelbrücke, Switzerland, 1766, detail, after Cristoforo Dall'Acqua and Michael Shanahan, ca. 1792-3.

Other examples of these old, complex frames, with their indeterminate load paths and superfluous or only-occasionally functioning members, do not qualify as trusses in the modern sense of the term, but they certainly participate in the form. Their builders intended these constructions to span a greater distance than an unassisted beam could; they affixed the feet of rafters against outward thrust and limited bending stresses by correct positioning of timbers and their loads, achieving triangulation among the members; and their work has been remarkably successful and long-lived.

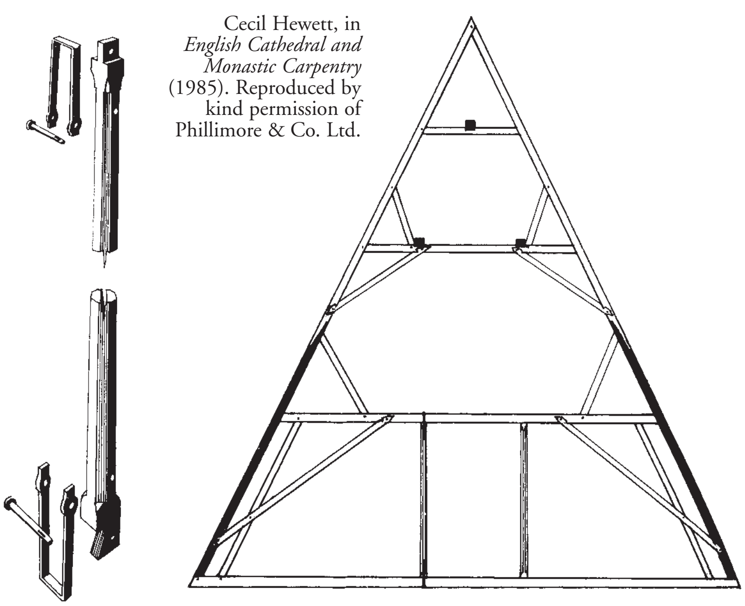
David Yeomans' excellent book *The Trussed Roof* (1992) suggests that what we today call the truss was not in use in England before its introduction from Italian sources in the 16th century. The relative absence of fully realized trusses in Cecil Hewett's compendious surveys *English Historic Carpentry* (1980) and *English Cathedral and Monastic Carpentry* (1985) reinforces this point. However, Hewett's illustration of the council chamber roof at the Tower of London has all the elements in place: a pendant kingpost with perpendicular joggling at the head, a tension joint at its foot suspending a cambered tie beam, and the principal rafters bearing neatly on the tie beam ends over the posts (Hewett 1980, 186). Hewett dates this roof frame to between 1370 and 1580. Additional elements in the frame, purlin posts that rise from the tie beams, are largely picked up by rising curved braces and thus don't participate in truss action. The Angel Choir high roof at Lincoln Cathedral (before 1280) is an example of a roof frame that doesn't look to us to be a truss but has all the listed characteristics (Fig. 4). Queenposts, hung on tenons and iron straps from a double-braced (and thus stiffened) collar beam, drop to support the longer tie beam below using a side-lapped dovetail and an iron U-strap (Hewett 1985, 32).

Metal reinforcement. With the possible exception of the bronze trusses in the portico of the Pantheon in Rome, which may have been bronze-clad timber (Mark, 203), ancient truss members were exclusively wooden for almost two millennia until experimentation with iron and steel roof frames began in the late 18th century. Early iron bridges such as the famous arch bridge at Coalbrookdale, Shropshire, designed by T.M. Pritchard in 1777, reflect their origins in timber design by using metal mortise and tenon and dovetail connections.

Metal was frequently if inconsistently incorporated into trusses as early as the Middle Ages, when wrought iron straps with forelock bolts were used to reinforce tension joinery such as the kingpost-to-bottom chord connection. The Grubenmanns' 18th-century Swiss bridges sometimes included iron counterbraces in the form of slender rods. In a striking example, the 1805 Central Moravian Church in Bethlehem, Pa., has long iron links, let in and bolted to the underside of the single-piece timber bottom chord, which join rising yokes at the ends to capture the thrust of the principal rafters (TF 74, 9).

A further use of metal found at both the Grubenmanns' Schaffhausen Bridge (1756-8) and Central Moravian Church is the placement of sheet iron between the butting members in compression joints, perhaps reflecting German influence in Pennsylvania. J.G.R. Andreae's 1776 description of the Schaffhausen Bridge reported "a piece of tin is put in the joint, to prevent the brace pressing or eating into the butting points" (Maggi and Navone, 217, and see also illustration TF 74, 8). Without a suggestion of any German connection, these sheet metal bearing pads also show up in the remote towns of Montgomery and Enosburg, Vermont, in the top chord butt joints of lattice truss bridges built by the Jewett brothers between 1860 and 1890. In the early 1830s, the long-span, low-pitched urban church roofs of the New York and New Orleans architect James H. Dakin were supported by multiple kingrod trusses, but still used timber for tie beams, braces and principal rafters (Dakin collection).

Wholesale replacement of wooden members with iron or steel beams had to wait for the 19th century. Published investigations into the strength of materials and quantitative analyses of frames began to appear. A history of these early experiments is given by Peter Barlow, the English mathematician and researcher, at the beginning of *An Essay on the Strength and Stress of Timber* (1824). The influence of these analyses on illustrations and discussions in builder's guides was partly responsible for the reduction of the profusion of inventive earlier forms to the relatively few, highly rationalized forms found in 18th- and 19th-century church attics in the New World. Gasparini and Provost remind us that "the concepts needed to analyze statically determinate trusses were defined largely in the 17th and 18th centuries . . . . Yet there appears to be no evidence that the principles of mechanics were applied to the rational design of trusses before the 19th century" (Gasparini and Provost, 21-22).



Cecil Hewett, in *English Cathedral and Monastic Carpentry* (1985). Reproduced by kind permission of Phillimore & Co. Ltd.

Fig. 4. Elevation and tension post detail of the Angel Choir high roof at Lincoln Cathedral, before 1280.

RATIONALIZATION AND EVOLUTION OF TRUSSES. An early example I have found of a practicing framer exploring quantitatively derived strength properties for wood is an undated note by John Johnson, a well-known framer of public buildings and bridges in northwestern Vermont and southern Quebec, active between 1794 and 1840, and Surveyor General of Vermont. Discussing the capacity of a bridge, Johnson wrote:

> An average of the experiments of Emerson and Barlow will give the adhesive strength of one of the posts at 297 tons, which is almost double to the weight of the whole bridge, whereas the weight of the bridge that can depend on one post cannot exceed 25 tons and will not reach near that amount. But allowing 25 tons it leaves for the bridge to sustain independent of itself 816 tons (John Johnson Papers).

Johnson, who was mathematically sophisticated and worked in decimal feet, has calculated the dead load of his bridge and, while allowing an extra amount for safety, figured how many of its tons the most heavily loaded post could carry, giving him as much as 25 tons per post. The remaining capacity of the posts, the 816 tons available for live loadings, he has determined by using experimentally derived strength values for wood expressed as pounds per square inch multiplied by the cross-sectional area of his posts. Although this fragment of Johnson's doesn't contain all his calculations and doesn't add up, we can explore it usefully.

"Adhesion" means tension, and the bridge weighs around 150 tons, likely for a large double-barreled Burr Arch of the sort Johnson built. His typical posts were 10x11 or 110 sq. inches in section, but for strength calculations he would probably use the cross-section between the joggles, likely 6x10 or 60 sq. in. Multiply this by the values in tension found in Barlow for fir or pine, somewhere between 7500 and 12,000 psi., similar to modern values, and you get about 300 tons of tensile capacity in each post.

How Johnson decides to ascribe 25 tons to each post, admitting it is much too high, is a mystery. Posts on bridges carry dramatically different loads depending upon their location in the truss, and Johnson knew this because he often varied his panel width cleverly to reflect it, and he was good at trigonometry. Somehow he arrives at this safe figure. Each post has only to bear 25 tons while the rest of its capacity, 272 tons per post, is available for live load.

But if the total load capacity of the bridge, 816 tons, is divided by 272 tons, we arrive at a puzzling bridge of but three posts. Possibly Johnson is discussing one of his big bridges composed of 56-ft. span kingpost trusses one after the other on piers. We have to accept that we don't know what this bridge looked like or how Johnson calculated anything other than the dead load and the tension capacity, but we do know he does so using internationally generated data, "the experiments of Emerson and Barlow."

Though Emerson's works do not survive, Peter Barlow called him the "standard" and included his values alongside his own in the latter's seminal work on the strength and stress of timber (Barlow, 3-4). Johnson probably owned a copy of the book or was shown one at the University of Vermont in Burlington, where he built many of the early large structures. Perhaps in the fragmentary quotation we see the tentative, first intersections of quantitative analysis with a craft-based tradition that sized wooden members according to practical experience and by visual proportioning to obtain the appearance of adequate strength. The intersection of craft tradition and quantitative analysis remains incompletely resolved 200 years later.

Truss Simplification. In addition to the spread of published truss designs influenced by experiment and analysis, in an increasingly scientific and materialistic intellectual culture in both Europe and America, a second influence on the simplification of truss design was the popularity of neoclassical architecture for large halls, particularly in the American post-Revolutionary period. This style's emphasis on open audience rooms instead of the aisled naves, dense with columns, of Gothic Europe demanded longer clear spans in even simple country churches. Some of the great variety of forms mentioned earlier performed successfully because their spans were modest, usually under 40 ft.

A third reason for truss design simplification was the availability in the New World of immense timber. The construction of powerful trusses with but a few members, correctly disposed, became economical and appealing. This form contrasted with the great church and cathedral roofs of the Middle Ages, whose frames were composed of a multiplicity of members of various lengths, some of them quite long but remarkably slender, such as 6x6 tie beams 35 ft. long or 5x5 principal rafters often even longer.

A final reason for simplification, perhaps related to the availability of large, long timber, was the explosion of long-span wood truss bridge construction and technology in North America in the late 18th century and throughout the 19th. The unprecedented clear spans, commonly exceeding 150 ft. and reaching as far as 360 ft., and the fact that many were designed for railroad traffic, took bridge truss construction out of the realm of vernacular experience and invention. Eventually these criteria generated a succession of trained or self-taught engineers producing patented designs—Burr, Johnson, Whipple, Haupt, Long, Howe—or, like Sganzin and Mahan, writing texts on civil engineering then used in new engineering curricula at American colleges such as West Point.

The same 19th-century builder's guides that illustrated church roof trusses (Tredgold, Shaw, Bell) began to include bridge truss designs and, unlike late 18th-century English works such as Price or Langley, included in their illustration plates none at all of the old complex roof systems. A. C. Smeaton, in *The Builder's Pocket Companion* (1852), advised that "systems of framing are most effective which are most simple," but lamented: "At present the designing of roofs is governed almost entirely by experience and no fixed laws can be appealed to" (Smeaton 67, 75). In his *General Theory of Bridge Construction* (1856), the American Herman Haupt, while praising the talents of the Grubenmanns, said of the famous Schaffhausen Bridge: "With many excellencies this bridge had also serious defects, and it is certain that a much smaller quantity of timber, judiciously arranged, would have far greater strength" (Haupt 145).

In rare cases, new truss types first applied in bridge design, particularly the Town Lattice truss, were introduced into the church roof systems of the early and mid-19th century. The Second Presbyterian Church (1835) of Madison, Indiana, has a plank lattice roof system as does the First Presbyterian Church (1832) of

Joseph D. Conwill

Fig. 5. Town Lattice truss adapted to scissor form, supporting roof of First Presbyterian Church, Fayetteville, N. C., 1832. A rare instance.

Fayetteville, N.C. (Fig. 5 facing page). Other examples, some designed by Town's firm itself, exist in North Carolina, Alabama and New York City (Conwill, 6).

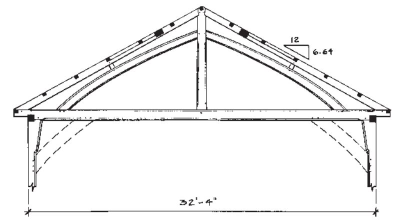
Variations. The rationalization of truss design to only a few good forms did not exclude extensive variations. Having examined several hundred sets of roof trusses in the eastern US, I have yet to see any that are exact copies of another or of a published plan in every detail. Church roof frames in the 18th and 19th centuries were still cut on site, usually by an experienced and confident local framer with a book in hand or a drawing by an architect, or working near some built examples that he had examined. Variations might arise from that framer's idea of good practice or from a church committee's order to copy the design of another nearby church, or occasionally from an architect's design, which sometimes included the truss configuration but rarely its joinery details.

At Woodstock, Vt., in 1836, an indenture between the Methodist-Episcopal Church trustees and a builder for the construction of a new timber-framed church specified three times in five pages that various parts of the work be carried out "as well as the Universalist Chapel is." The 1847 plans for the Brimfield, Mass., Congregational Church included a detailed truss drawing, perhaps because the form was modern, using iron queenrods rather than timber queenposts (TF 71, 14). Robert Smith's designs for raised bottom chord roof systems in and near Philadelphia also specified iron-reinforced joinery, probably because of the difficulty of making this truss form work (TF 73, 16). At Huntington, Vt., in 1872 the framer must have seen Benjamin's *Practical House Carpenter* (1830) but changed some of the joinery in a conservative or perhaps regional direction, preferring the older wedged half-dovetail at the foot of the kingpost to the inset bolt specified by Benjamin (TF 72, 24). Lee Nelson's study of post-to-chord tension joints in the trusses of the Delaware Valley in the 18th and 19th centuries finds stub tenons with U-straps or hanger bolts and no wedged dovetails, suggesting regional patterns (Nelson, 11-24).

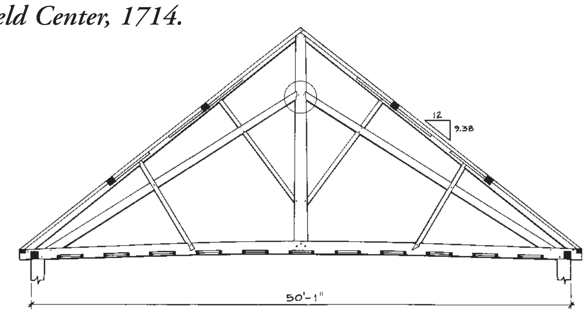
Double-Raftered Trusses. The material requirements of timber construction, particularly finding room for the joinery in the cross-section of a member otherwise abundantly strong, when combined with any given framer's notion of the aesthetics of framing made all these 18th- and 19th-century trusses partly modern and partly ancient. The weakness of the relish of a mortise in double horizontal shear, the condition at the end of a tie beam that receives a rafter foot, led many framers to build double-raftered trusses with the inner, heavily loaded principal rafters bearing at their bottom ends a foot or two inside the support points on the tie beam—thus introducing bending (though apparently of an acceptable amount) into the tie beam—and at their top ends in secure joggles near the kingpost head. In some cases, the upper rafters of the set might not even bear at the kingpost head.

This form differs from typical American, English and Continental trusses with inboard single principal rafters carrying a superimposed deck of commons via principal purlins. Examples of the double-rafter form are myriad and in our survey include the meetinghouses at Lynnfield Center, Mass. (1714) and Strafford, Vt. (1799), the Congregational Church at Windham, Vt. (1800), the Central Moravian Church at Bethlehem, Pa. (1806) and the Sutton, Vt., Baptist Church (1832).

Double-raftered trusses existed in England and continental Europe at earlier dates as well. In Fig. 6, Hewett illustrates a relatively modern looking double-raftered kingpost truss in the high roof of the south transept of Lichfield Cathedral (1661-9), which he calls, along with the roofs over the rest of the church, "probably the best post-medieval roofs for a great church that exist in England" (Hewett 1985, 66).



Lynnfield Center, 1714.



Strafford, 1799.

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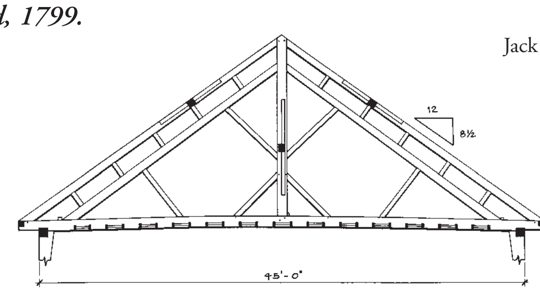
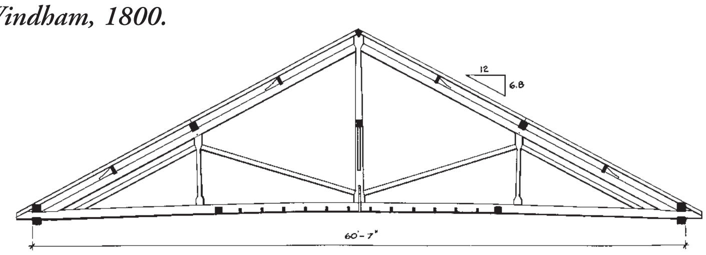


Windham, 1800.



Castleton, 1833.

Fig. 5. Typology of American double-raftered trusses. Only Castleton carries a separate deck of rafters, European style.

Cecil Hewett, in *English Cathedral and Monastic Carpentry* (1985). Reproduced by kind permission of Phillimore & Co. Ltd.

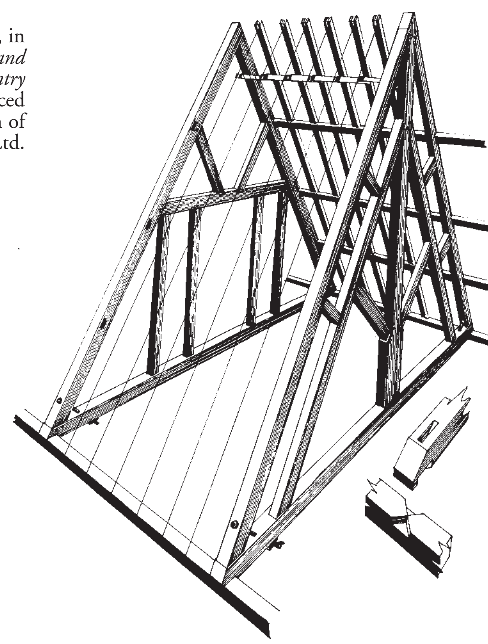


Fig. 6. Lichfield Cathedral, high roof of the south transept, repaired 1661-69 after the ravages of the English Civil War. Heavy forelock bolts reinforce rafter-to-tie joint where relish is short.

Patrick Hoffsummer et al. illustrate numerous medieval double-raftered examples including the Church of Notre-Dame at Étampes (1177-87) and the late 15th-century roof above the choir at the Cathedral of Notre-Dame in Reims (Figs. 7 and 8 below; Hoffsummer, 186 and 306).

France Saïe-Belaïsch, Centre de recherche sur les monuments historiques, Paris. Used by permission.

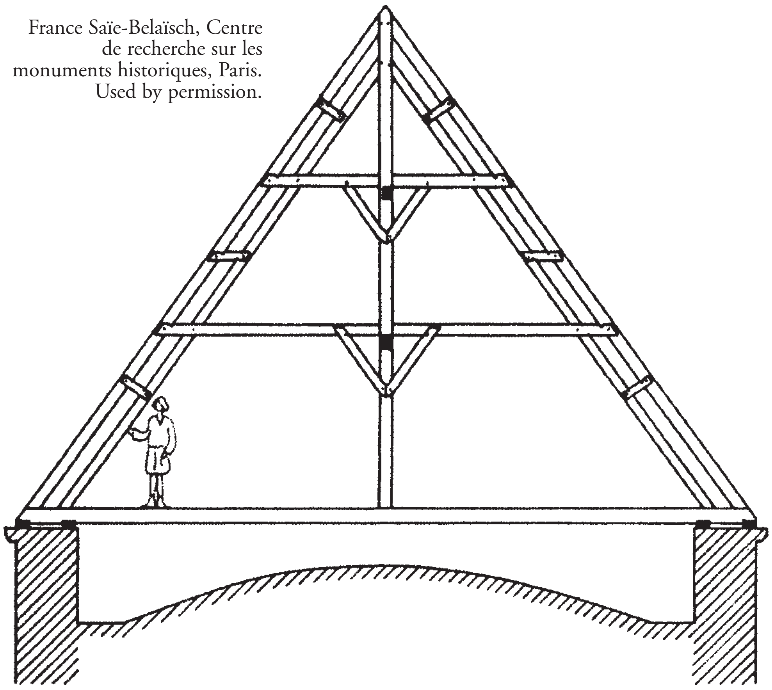


Fig. 7. Notre-Dame d'Étampes, 12th century. Doubled rafters are frequently bound together.

Archives photographiques, Centre de recherches sur les monuments historiques, Paris. Used by permission.

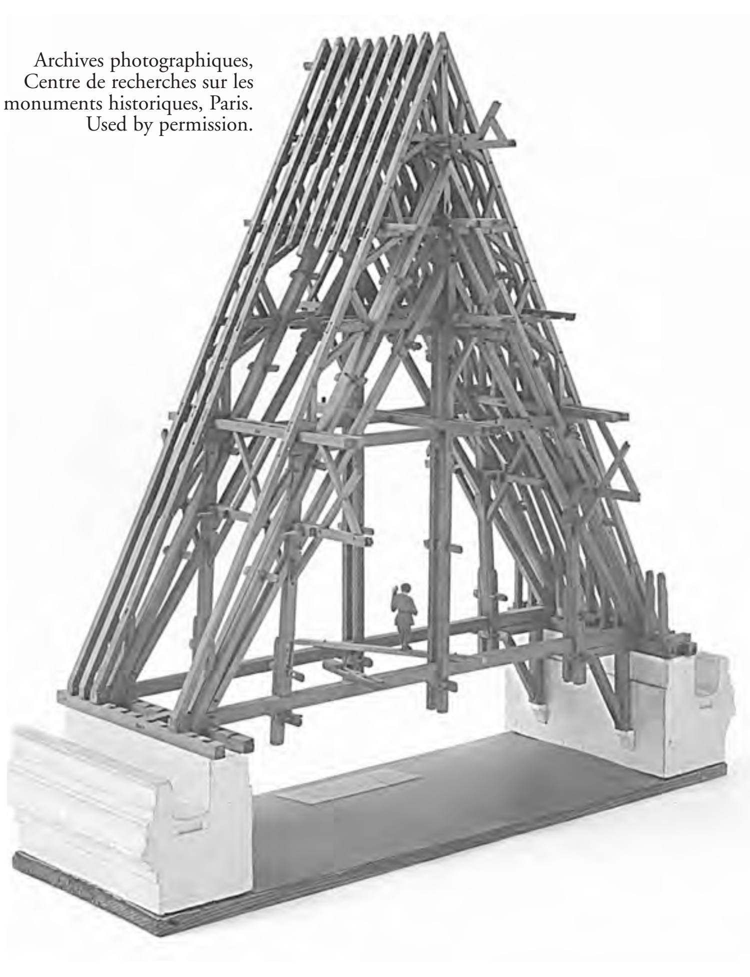


Fig. 8. Cathédrale Notre-Dame at Reims, 15th century, exceptional timberwork superbly modeled by Henri Deneux in the 20th century. The tie beam is hung from the collars as well as from the inner rafters.

An extensive glossary entry discusses these double principals under the term *sous-arbalétrier* (or sub-principal rafter), mentioning that their slope is often less steep than the outer principals and that sometimes they are curved (Hoffsummer, 201 ff.). Meetinghouse trusses at Strafford, Vt. (1799), exhibit such inner rafter slopes, among other archaic features, and at both Lynnfield Center, Mass. (1714), and Rindge, N.H. (1798), have curved inner rafters indicating the persistence of the form even among rural American framers without the ability to view the great store of examples found in the churches of England and the European continent.

The canted struts connecting these double rafters together and then running down to the kingpost are sometimes not in line, to avoid mortising the inner rafter excessively at a single location. Again, the possibility of some bending is accepted rather than abandoning the long love affair with the mortise and tenon joint and simply butting the struts at the rafters (Fig. 6 previous page). But as the 19th century progresses toward the 20th, the 1879 Barton, Vt., Congregational Church is using unmortised struts set in shallow gains, tacked with a nail (TF 69, 12).

GOOD VERNACULAR PRACTICE. The many roof frames examined in this series, even when combined with published drawings and descriptions of other trusses, number but a small percentage of what exists and what once existed. The trusses we looked at have all been standing in the northeastern US between 120 and 290 years and have periodically borne immense snow loads and sustained hurricane winds. With a couple of exceptions, those we examined qualitatively, investigating by eye and probative mallet taps, we found to be in excellent—yea, like-new condition—and thus examples of successful vernacular truss work.

The use of large-dimension timber wherever possible constitutes good practice in this endeavor. It makes up for errors and the traumas of existence. (If a frame is going to be strong, it should look strong.) Of the trusses we saw, only the Stowe, Vt., Community Church (1863) surprised us by its openness and slenderness. (medieval trusses frequently used slender members, but there were great numbers of members and they were densely framed.) Nearly all the rest produced an instinctive and emotional sense of strength and confidence. In his study of Connecticut meetinghouses, J.F. Kelly observed:

> An examination of existing roof trusses makes it at once apparent that most of the early builders, excepting such men as Hoadley and Town, were working mainly by "rule of thumb" and had no exact knowledge of engineering. The fact that the trusses they devised have supported the loads imposed upon them . . . is due in most cases to the tremendous size and strength of the oak timbers employed and the lavish use of material, rather than to the correctness of design. In many instances, the use of less material, arranged in better accordance with the laws of engineering, would have produced much stronger trusses (Kelly 1948, xliii).

Kelly was correct that large timber allows a framer to stretch some of the laws of engineering, but he was probably wrong in assuming that they didn't know when and why they were doing so. When Kelly conducted his remarkable survey in the 1940s, there were plenty of structural engineers around to pontificate on the topic of trusses, but perhaps not a single traditional framer alive to defend his work.

Species choice. In historic trusses and timber framing in the eastern US, species choice was mostly determined by conventional practice, what was available locally and the required length of members. The builders of coastal New England's 17th-century frames, close to their English antecedents, at first used white oak, the New World species most like English oak, and then mixed oak species. The preference for oak in New England persisted late into the 18th century. When settlers moved to the interior where oak was less common, beech and other hardwoods were substituted.

From the late 18th century to the middle of the 19th, kingposts, struts, braces and studs might be mixed hardwoods, but the longer and larger members such as tie beams, principal rafters and plates were increasingly of various softwoods. For a multi-span kingpost truss bridge across the Richelieu River at St. Jean, Quebec, John Johnson placed one of the great timber orders of all time, asking for 231 pieces of 18x16x53 for "strings," 99 pieces 14x12x53 for "upper ditto" and 99 pieces 12x12x51 for "rafters," all white pine. He also wanted "5 tons iron" (Johnson Papers).

By the mid-19th century, frames were often all softwood, floated down or shipped in from timbered regions to the north and south. St. Peter's Church (1769) in Freehold, N.J., has trusses and a steeple built of oak and yellow pine, probably local. By 1854, the Salem, N.J., Presbyterian Church, on Delaware Bay much farther south than Freehold, has trusses and a steeple built of white pine, a tree not indigenous to the area. The timbers at Salem still contain the miscellaneous pins that helped bind them together in rafts of square timber as they were floated down the Delaware River from northern Pennsylvania or upstate New York. In Vermont, early trusses in the Connecticut or Champlain Valleys were mostly framed of white pine, hemlock and mixed hardwoods, all available there, while in the interior mountainous regions spruce framing predominated. At all periods of truss history, even that of ancient Rome, the immensely long sticks of wood that might be needed for plates or tie beams tended to be large pine, spruce or larch (Mark 1993, 200-203).

Quality of wood may be more important than species. Trusses made of all spruce, hemlock or old-growth pine seem to perform as well as those with substantial hardwood elements, across equal or greater spans. The efficiently arranged hemlock and pine timbers at Castleton Vt., Federated Church (1832), perform as well as the profusion of mighty oak and pine members do at Bethlehem's Central Moravian over nearly identical 60 and 65 ft. spans.

Species are often mixed within a frame and species choice was sometimes related to workload. In John Johnson's many lumber lists for trusses, he sometimes specified that the kingposts be "oak or yellow pine" and that all the other members be "white pine" (Johnson Papers). The architect Asher Benjamin was quite specific in *The Practical House Carpenter:* "Timbers in the foregoing examples of roofs, I have assumed to be of white pine, but if they should be made of hard pine, the size may be reduced somewhat, or if of oak, a considerable reduction may be made. It is best to use hardwood for kingposts" (Benjamin 1830, 86).

An instructive archive of sawmill business papers sheds some light on timber choice in frames in the early 19th century. Sumner and Page's sawmill in Hartland, Vt., rafted hundreds of thousands of board feet of timber, boards and shingles down the Connecticut River to southern New England every year. In 1819 Sumner responded to a request for "extra long pine" structural timber with the answer that "trees that will make such plank are very valuable" (Sumner Archive). He was probably hesitating because of the contemporary demand for clear white pine for large-scale classical revival architectural finish elements. For example, in 1824 John Moore of Savannah, Ga., wrote to D.H. Sumner that he wanted "clear white pine, 1-2 inches thick" and that he would pay $35-40 per thousand board feet. At the time, Sumner was selling merchantable grades of pine, hemlock, spruce and oak for $7 to $15 per thousand, some of it up to 60 ft. long. The problem in the 1819 request was that "extra long" pine would have to come from immense, high quality old-growth, with lots of clear lumber in the log, that was far more valuable sawn into boards. (Nonetheless, and possibly at great expense, St. Paul's Episcopal Church, built 1822 at nearby Windsor, Vt., included ten 7x13 50-ft. pine timbers in its scissor truss roof frame.)

In 1823 Sumner received an answer to a query of his own about selling spruce timber in Connecticut. David Wyse, a lumber dealer in Middletown, replied "Have made some inquiry and found that some do not like spruce timber as well as they like chestnut or oak." Wyse told Sumner he might get $9-10 per thousand for spruce as opposed to $10-15 per thousand for oak and chestnut. By the mid-19th century, spruce and Southern yellow pine had gained wide acceptance as framing timber even outside their growing regions. The 1869 scissor trusses in the Church of the Holy Apostles in midtown Manhattan are all spruce acquired somewhere in the interior of northeastern North America.

The aesthetics of framing. The dramatic entasis of the kingpost at the Castleton Federated Church, necked down from 11½x10 at the joggles to barely 5x10, can only be attributed to the framer's concern that his frame proportionally reflect load at every point and in that way be beautiful, rather than maintain surplus capacity. (The Castleton framer was Thomas Dake, famous for interior joiner's work such as pulpits and entryways.) In general, the earlier the truss the more likely it is to contain tapered rafters, tie beams with hewn or natural as well as induced camber, entasis in the kingpost, and curved inner rafters; Lynnfield Center, Strafford and Rindge provide us good examples. The later trusses illustrated in builder's guides such as Benjamin, Nicholson and Tredgold are drawn rectilinear and substantial, all the members uniform in section along their length other than at the joggles, stout looking and without curves or tapers.

While this notion of the aesthetics of framing is manifest in centuries of exposed decorated joinery, its persistence into the 19th century, when the great roof frames were concealed above plaster ceilings, suggests a particular devotion to craft on the part of

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Fig. 9. Kingpost at Castleton Federated Church, 1832, much reduced below the head joggles to reflect its simple function as a tension member.

framer and worker, and a view of beauty unwedded to decoration. The shaping of the kingpost at Castleton was expensive, making it proportional but not stronger, and any beneficial reduction of truss weight was minimal.

Joggles. Where principal rafters or upper chords meet the kingpost head, what is the importance of normal bearing? Of the roof trusses investigated for these articles, five presented normal (perpendicular) bearing between principal rafters and kingpost head joggles; six had some lesser degree of joggled slope or small bearing shoulder; and four allowed the tenon, friction and compression on the brace shoulder, together with any pins, to do all the bearing. Fig. 10 illustrates various angles of joggle incidence.

There appeared to be no difference in their performance. At Strafford there is no joggling for the outer rafters at the head of the post (nor for the struts near the foot of the post), and likewise at Windham there are joggles neither for rafters nor for struts. What then prevents the rafter upper tenon from pushing out the relish of its mortise at the kingpost head? The answer may lie in the tremendous friction developed by compression of the rafter's end shoulders into the side grain of the king- or queenpost at the mortise cheeks. Or it may be that the weight of the roof counteracts any non-axial moment developed at the joint. Builder's guides from Palladio through Price and Benjamin and beyond reinforce our intuitive belief that normal bearing in a joggle at a post head is crucial. But, according to our examination of large church roofs, it isn't.

Hoffsummer's survey of French roof frames finds rarely a joggle in the Middle Ages, where the generally very steep pitches would make normal bearing difficult to create without gigantic post widths. The low angle between rafter and kingpost in these steeply pitched roofs is conducive to non-axial slippage, but the latter may be counteracted by the greater size of bearing shoulder produced by this angle, and most of these roof frames provide plenty of relish anyway in the kingpost above the mortised connections of the rafters. Kelly's survey of Connecticut meetinghouses carefully illustrates the bearing angles and shoulders of 57 trussed roof systems, dating from 1753 to 1836, a period that begins before and then coincides with the widespread introduction of builder's guides depicting well-engineered trusses.

The results are presented in Fig. 11, with the church roof frames divided into three categories: normal bearing with joggles (top line); some joggling or shoulders but always less than normal bearing (middle line); and no joggles at all (bottom line). Trusses with perpendicular bearing at their joggled shoulders, as recommended in the builder's guides, become more common over time, but the unjoggled or slightly joggled forms don't diminish correspondingly, rather they coexist during the time period, which is one of transition. (The square rule displaces the scribe rule in those same years, and the cut nail displaces the wrought.) In my research, church attics after about 1845 never contain trusses without normal bearing between rafters and kingpost joggles.

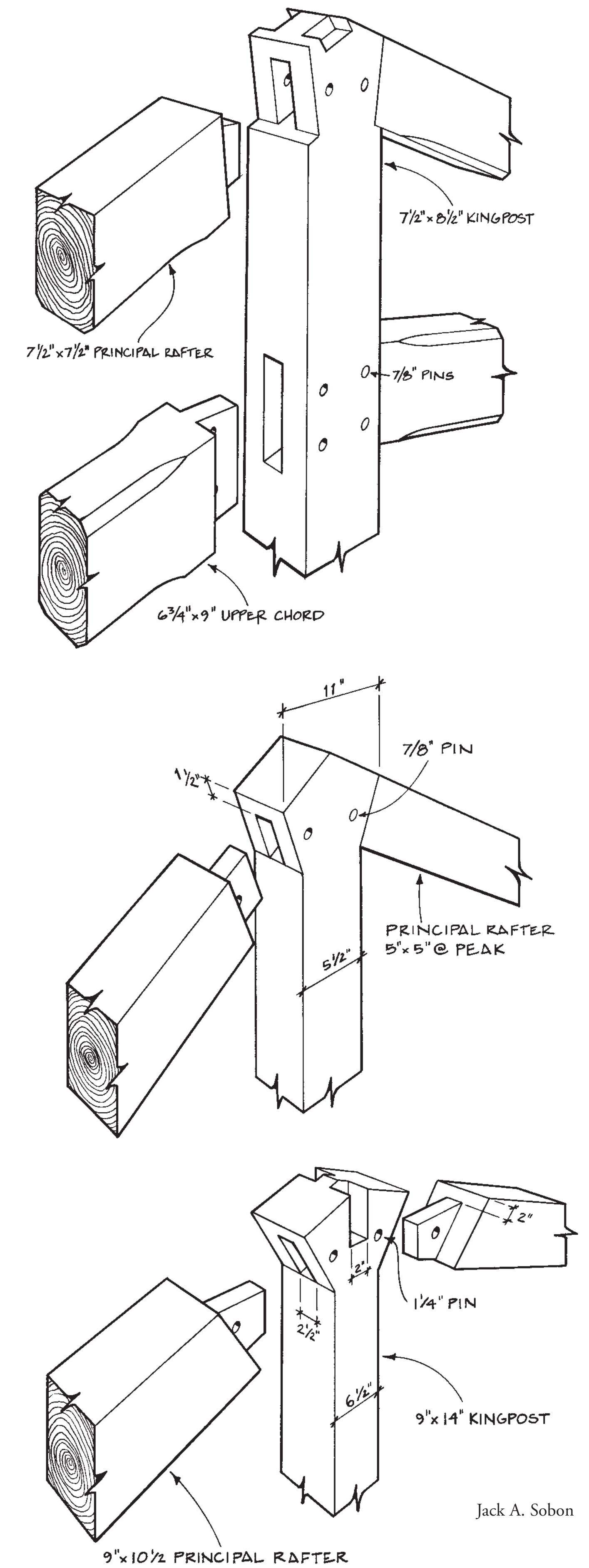

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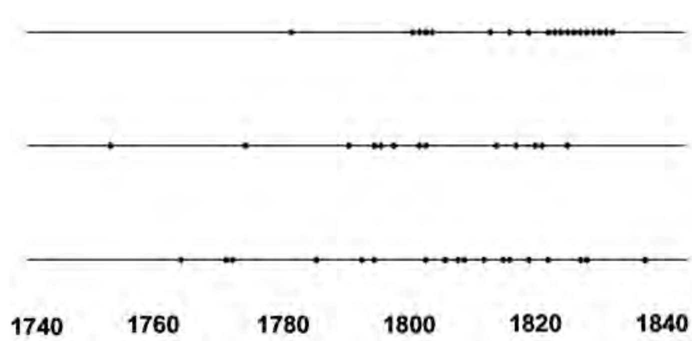
Fig. 10. Joggle angles at the kingpost head vary substantially, from negligible or nearly so (top, Lynnfield Center, Mass., 1714), to normal or nearly so (middle, Shrewsbury, N.J., 1769) to well undercut (above, Portsmouth, N.H., 1807). Some kingpost heads have no joggle at all.



Ed Levin

Fig. 11. Frequency distribution of joggle types over time. Bottom line represents no joggle, middle line some joggle, top line normal bearing.

However, any survey of the vast array of American wooden bridges finds no builder ever trying to get away without joggles or normal shoulders at main brace and strut connections, perhaps because roof load is not carried by the main braces of a bridge, instead coming down the posts to be transferred to the main braces as axial load and doing little to restrain non-axial (lateral) movement. Or perhaps the practice is a comment on how much greater and more dynamic bridge loadings are compared to typical roof truss loads.

Double-rafter considerations. Ideally, the load coming down long principal rafters mortised or housed in a tie beam should arrive over a wall post or, at least, over a sturdy plate supported by a nearby post. But to do so leaves little relish between the mortise or housing and the end of the tie beam, a particular consideration for the low-pitched rafters of neoclassical churches with their large horizontal thrust component. The early introduction of a double or inner rafter placed farther inboard allowed more relish between the joint and the end of the beam and, equally important, distanced the joint from leakage and consequent rot caused by ice damming at the eaves in cold regions. This provision seems to be good practice even when weighed against the disadvantage that it delivers the majority of a truss load to the tie beam as much as 3 ft. inboard of the supporting wall, with some bending resulting. At the Strafford Town House, the outer rafter's relish had failed at four locations and the load had shifted entirely to the inner rafters at those slopes. At Lynnfield, 20th-century tie beam rot deprived the outer rafter of any bearing at one truss end, but was not catastrophic thanks to the inner rafter's bearing the load. The inner rafter and tie beam were able to bear the load nearly 2 ft. inboard of the wall with minimal bending, and this despite the removal for stylistic reasons in 1785 of large curved braces that once rose from the wall posts to the bottom of the tie beam.

At the Craftsbury, Vt., Town Hall, there are actually triple rafters, all tenoning into a 38-ft. 8x10 tie beam. The outermost is an 8-in.-dia. spruce log flattened on top that rises from the overhanging end of the tie to tenon into a mortised ridgepole carrying the tops of the common rafters in the same plane. The first inner rafter is a 6x7 tenoning into the kingpost and bearing on the tie beam about a foot from the wall. The second inner rafter is a 6x6, also tenoning into the kingpost and bearing on the tie beam nearly 5 ft. inside the plate. The kingpost picks up the tie beam with a wedged half dovetail joint that is now pulling itself open, probably because of the troublesome positioning of the shortest, stiffest rafter of the array, the inner 6x6 (Fig. 12).

If load goes to stiffness, any depression of the kingpost by roof loading on the upper rafter system will push down the second inner rafter upon an unsupported length of tie beam and tend to force the kingpost joint apart. In this assessment of the forces, the upper part of the kingpost is in compression while its lower part, below the junction with the second inner rafter, is in tension.

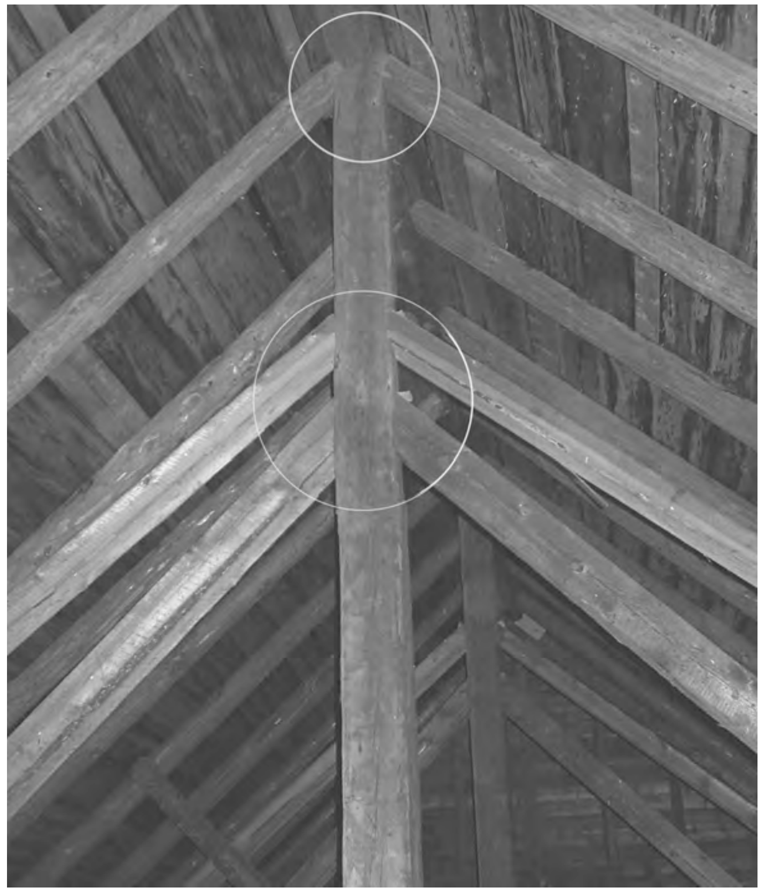


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Fig. 12. Triple-rafter array at Craftsbury, Vt., Town Hall, mid-19th century. Uppermost rafters terminate in ridgepole (upper circle); inner rafters prop the kingpost (lower circle), offering unconventional path for roof load to tie beam (lower photo).

Ironwork. The assistance of metal at tension joinery in trusses is both venerable and desirable. Most of the truly long spans in our study use metal rods, bolts or U-straps as the primary tension connection between king or queenpost and bottom chord. These examples include the 59-ft. truss at St. John's Portsmouth (1807), the 65-ft. truss at Central Moravian (1805); the 52-ft. queenpost at Rindge (1797), as well as Castleton (60 ft., 1833), Brimfield, Mass. (54 ft., 1847) and Stowe Community (50 ft., 1863).

The 50-ft. scissor truss at St. Paul's Windsor (1822) allows the bottom of the kingpost to continue for almost 12 in. below the chord crossings, providing enough relish to obviate the need for metal. At First Parish Church in South Berwick, Me. (1826), the kingpost enjoys almost 24 in. of relish at the bottom. In addition, at both Windsor and South Berwick, the rafters are bent outward around the kingpost to leave more net section intact for the tension joinery. The 42-ft. scissor truss at Barton, Vt., Congregational (1876) employs kingrods, but this practice is partly attributable to the late date. Most of the trusses with spans under 50 ft. use all-wood tension joinery, either the wedged half-dovetail at Lynnfield Center (1714), Windham (1800), Peacham, Vt., Congregational (1806) and Huntington (1870), or the through tenon with multiple pins at Christ Church Shrewsbury (1769), the Strafford Meetinghouse (1799) and Sutton Baptist (1832).

Camber and Domes. Trusses have long been built with camber, producing a shallow vault transverse to the long axis of the building or, if the camber is slight enough, allowing the roof system to sink and

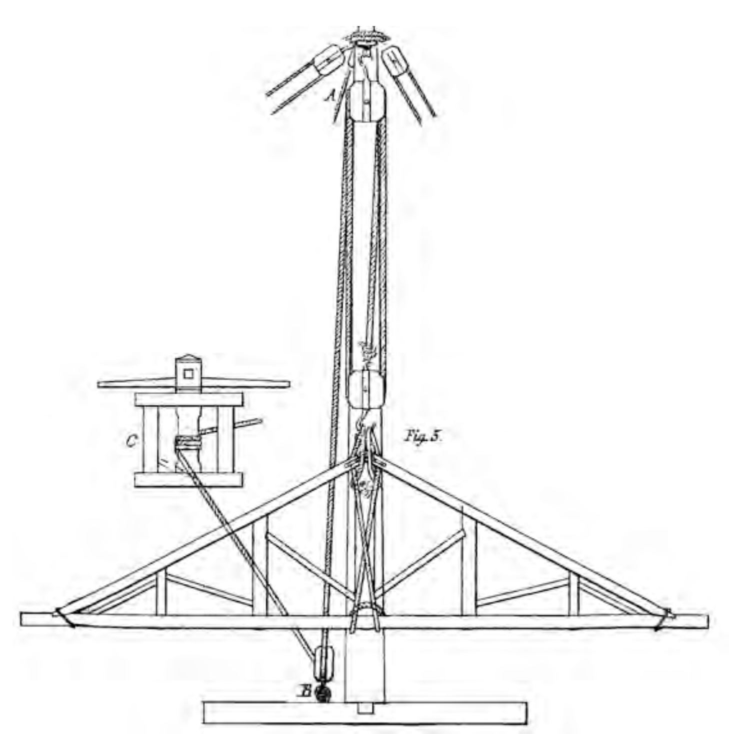

Fig. 13. Chester Hills' Fig. 5, an 1836 truss-lifting rig, showing footed gin pole with tensionable guys (A), anchored load pulley (B), windlass (C) and well-lashed demonstration truss. No tag line.

settle to near level. Nicholson observed: "In all timber there is moisture, wherefore all bearing timber ought to have moderate camber, or roundness on the upper side, for till that moisture is dried out the timber will swag with its own weight." He also recommended "that all beams or ties be cut, or in framing forced to a roundness, such as an inch in twenty feet in length, and that principal rafters also be cut or forced in framing" (Nicholson, 77). The inch in 20 feet recommended would probably compensate for shrinkage across fat kingpost heads, compression at heavily loaded joints and reduction in length from twist and other sources of deflection in the truss, but a great many trusses are cambered far more. Castleton has 2 in. in 20 ft. and the meetinghouse at Rindge as much as 8 in. in 20 ft., likely evidence the builders were trying for a vaulted effect.

Less obvious is the cambering of an entire truss system along the longitudinal axis of the building as well, producing a shallow dome over the audience room. This effect was obtained at Rindge (1797), Windham (1800) and Peacham (1806) by shortening the king- or queenposts toward the center of the roof, producing camber differences as great as 8 in. (Peacham) or 11 in. (Rindge) among the trusses. In the shallow domes in the two cases carefully measured, Peacham and Rindge, the residual transverse camber left in the trusses after 200 years is still almost twice as great as the original longitudinal camber built in by progressive shortening of the queenposts at each truss, working from the ends of the building toward the middle truss of greatest camber.

The aesthetic objective is not quite clear; the dome is not part of a sphere but of some ellipsoidal solid. The term "globe arch" is in use in some of the construction documents cited by Kelly in *Early Connecticut Meetinghouses*, referring to a saucer-shaped dome, but the examples he quotes and illustrates, such as the 1825 South Britain, Conn., Congregational Church, have much more depth and are picked out in paint and moldings as an obvious design feature (Kelly, II, 205). They are usually built under scissor trusses (which make room for the necessary curvature) by suspending curved-edge boards from the trusses and lathing them (Kelly, I, xlvi). I believe that the three shallow domes that we found in Vermont, all created by the cambering of the truss timbers alone, were intended to be felt rather than seen and as such have been little noticed.

HOW WERE TRUSSES ERECTED? At Castleton, the remains of a sort of fixed derrick exists in the attic, its 10x10 posts cut off below the roof and braced in both directions, probably to allow them to help lift trusses lying already framed on a scaffold at plate height.

There is sufficient evidence for the use of scaffolding in erecting trusses. The *1786 Rule Book of the Carpenters Company of the City and County of Philadelphia*, discussing kingpost and other long span trusses, specified "All scaffolding necessary for raising the above roofs, to be charged for by the time spent thereat" (Peterson, 5). Accounts of the tragic events at the raising of the meetinghouse roof system at Wilton, N.H., in 1773 described carpenters standing on staging that ran across the tie beams, already in place and propped at midspan by posts. From this elevated staging, and perhaps scaffolding built upon it, the carpenters were inserting kingposts and spars (rafters) into the joints of the tie beam, a piece-by-piece assembly, when the staging collapsed, killing five people (Clark, 1997).

Another truss-raising method is described in Chester Hills' *The Builder's Guide* (Hartford, 1836) and shown in Fig. 13 at left:

> Fig. 5 shows the method of raising a truss by a gin pole. This should be of a suitable length to raise the truss to its destined height and should be made either of pine or spruce, so as to be easily raised or lowered, a stick that is from 10 to 12 inches in diameter at the bottom and from 6 to 8 inches at the top will be sufficiently large to raise a truss from 60 to 90 foot span. . . . In raising the trusses of a church they should be put together on the main floor and well secured . . . when you have got one raised and placed to its proper place and well braced, slip the gin along to where the second one is to stand. A good set of hands working under a master workman will generally be able to complete the whole in one day.

Lifting trusses from the main floor as described here requires a tall gin pole, perhaps 35 to 50 ft. for most churches. From contemporary eyewitness accounts, such as those of raising the Stowe Community Church steeple in 1863, we know that gins as tall as 100 ft. in a single stick were in use even in rural areas (*History*, 8).

One raising procedure is very clear from the evidence of a great number of truss systems. Their builders did not attempt to engage the ceiling joists at the same time as the heavy trusses were being erected. They did frequently engage tenoned longitudinal connecting girts or X-bracing between the king- or queenposts of successive trusses, or they inserted one or two spacing girts at the tie beam level, the latter tenoned in or dropped into dovetail housings. But for the numerous ceiling joists, at least four different strategies were employed to allow them to be entered into the tie beams afterward, flush with the lower edge.

Long chase or pulley mortises might be provided in the tie beam at one end of a bay of joists and closed mortises in the tie at the other end, as at Rindge or the 1715 Hatfield, Mass., Meetinghouse. An analogous method, used at Brimfield, Mass., and Newbury, Vt., was to tenon joists into a mortise at one end and into an L-shaped slot on the other, the latter entering from the bottom of the tie and sliding over to the right position. A third method was to cut back the tenon shoulders at one end of a ceiling joist and chop its mortise extra deep in the tie beam, allowing the joist to be inserted deeply enough at one end to clear the face of the tie beam at the other. The joist then could be shifted safely to enter its far end into the mortise in the far tie beam; a nail tacked into the overlong tenon at the near end kept the joist in place. This system can be found in the 65-ft. trusses of the 1826 South Congregational Church at Newport, N.H. A fourth system, used at the 1815 Chenango Forks, N.Y., Methodist Church, provides stopped grooves open at the top to allow notched joists to be dropped in (Fig. 14). With closely spaced trusses such as those at South Strafford Universalist (TF 67, 25), the problem of ceiling joists is simply avoided by nailing heavy furring on 24-in. centers directly to the bottom of the tie beams as the ceiling base.

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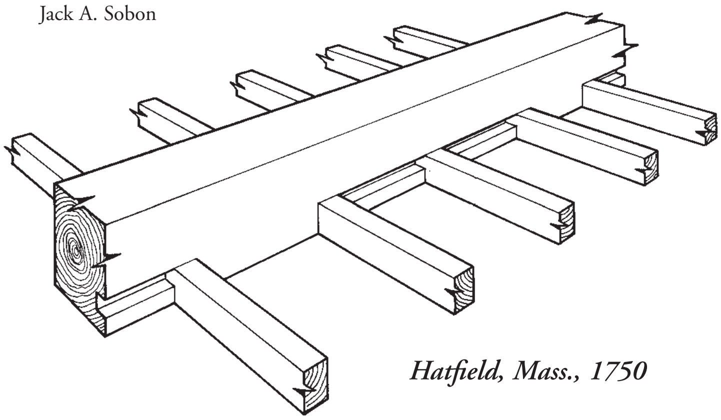
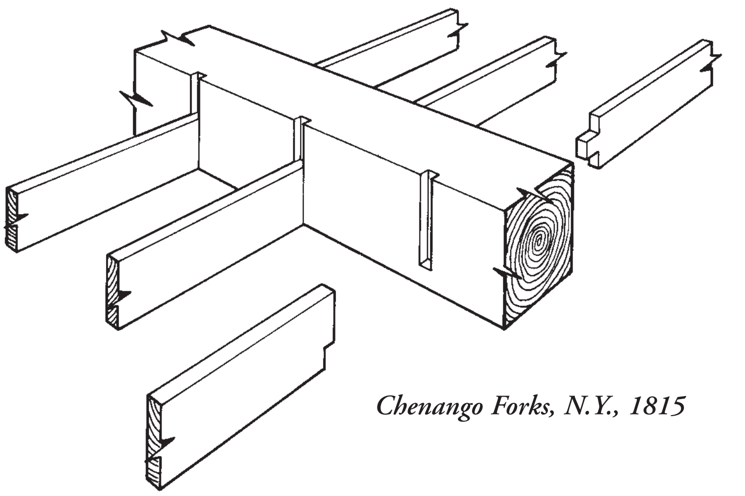
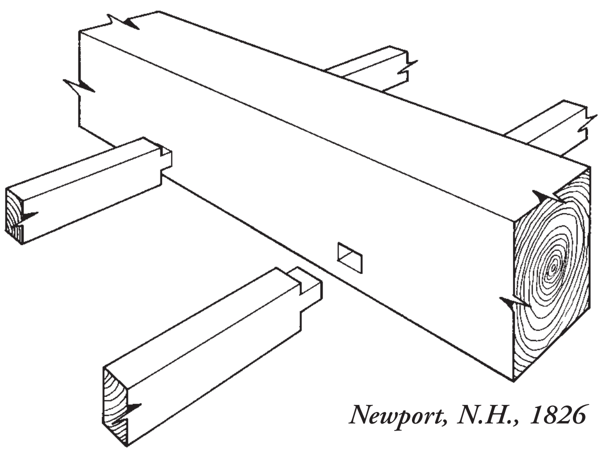


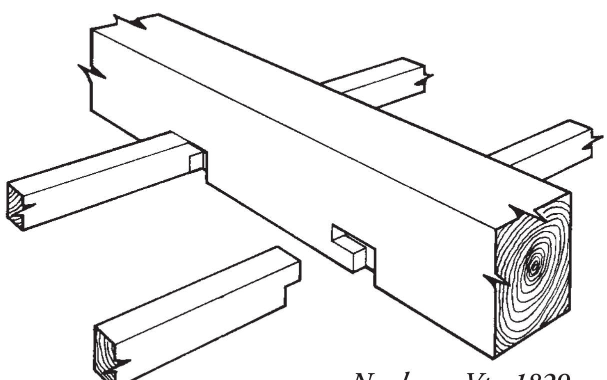
Hatfield, Mass., 1750



Chenango Forks, N.Y., 1815



Newport, N.H., 1826



Newbury, Vt., 1829

Fig. 14. Four strategies to admit ceiling joists between erected trusses.

WHY DO TIMBER TRUSSES GET IN TROUBLE? In our research, we generally looked at very successful examples. The notable exception was at the Waterbury Center, Vt., Community Church (1831), where undersizing of the main braces (upper chord members) of the queenpost truss had resulted in buckling and excessive compression at joints, sagging the entire truss (Fig. 15).

If undersizing of members was rare, incorrect understanding of truss behavior was more evident. The Village Congregational Church (1854) in Croydon, N.H., has three spruce kingpost trusses and a queenpost truss, the last at the back of the steeple, all spanning 36 ft., all with long-term problems due to misunderstanding truss form. Rather than the tie beam (the truss bottom chord) crossing the plate to receive the foot of the principal rafter (truss upper chord), the tie beam tenons into the side of the 8x9 plate and is secured with two 1-in. pins; the 2-in. tenon is 5 in. long. The principal rafters, rather than bearing on the tie beam, instead bear on the plate in a sort of birdsmouth joint. The result has been to force the plate outward off the tie beam tenon, first cracking the mortise cheeks then bending and shearing the pins. The resulting deflections in the truss, as great as 9 in., have caused distortions in the roof and sidewall and cracking of wallpost heads.

A version of the same design had been carried out, also in spruce, in the United Church of Craftsbury Common, Vt., in 1816, but with significant differences that made it work successfully. At Craftsbury, a 10x9 tie beam tenons into a 15x9 plate using a 3-in. thick through-wedged half-dovetail lying flat. An outer

Ken Rower

Fig. 15. Waterbury Center, Vt. (1831) has been patched up and cabled following queenpost truss failures. One evident cause is undersized main braces (white arrow), which descend from the queenposts to the tie beams and must withstand considerable compression.

principal rafter carrying its share of a deck of common rafters bears upon this plate, but an inner principal rafter is at work as well, 2 ft. inboard of the plate. The inner rafter induces local bending into the tie beam, visible to the eye, thus its service must be to carry much of the compressive loading on the truss. Combined with the resistance of the large and powerful tension connection between plate and tie beam, the result is that the plate is not being forced off the tie beam tenons at all. It is possible that the plate is as large as it is primarily to provide room for the wedged half dovetails to develop adequate tension capacity. The Craftsbury Common example shows that there may be no rules that cannot be broken by a knowledgeable framer—the meaning of our first epigraph.

Underestimation of steeple loads. Of all the causes of truss failure attributable to the dead load of the structure (rather than to roof leakage and consequent rot, or to hurricane winds), the weight and sometimes the dynamic loading of the steeple are the most common. The 18th- and 19th-century churches of eastern North America typically carried storied steeples that towered 30 to 150 ft. above the peak of the roof, heavy in themselves and subject to movement in the wind. Through much of the 18th century, these steeples rose from a tower with an independent foundation at one end of the meetinghouse, and posed no threat to the roof system. With the adoption of neoclassical styles in the late 18th century, continuing through much of the 19th, the steeple was moved onto the house itself, its framing resting on sleepers lying across the tie beams from the front wall back to the first interior truss and sometimes beyond. This configuration poses no problem if vertical framing such as posts or vestibule walls are positioned under the interior truss to carry the steeple loads to the ground, and such is the case at the 1826 Weathersfield (Vt.) Meetinghouse. However, for reasons of fashion, such was not the case in hundreds of churches in New England, which featured an open choir above the vestibule, thus omitting support for the truss and allowing the weight of the rear of the steeple to deflect it via the sleepers.

As the truss deflects while the front wall of the church remains stable, the steeple tilts backward into the church, giving a yet larger percentage of its load to the interior truss. Framers were aware of the problem but generally underestimated it. The construction of a queenpost truss using the rear steeple posts as the queenposts was common and helpful, but deep compression of the joints, compression buckling of the main braces and broken relish at the tie beam ends continued to allow deflection.

At St. Paul's Windsor, where the rear of the steeple sits several feet behind the vestibule wall, its loading has produced 3 in. of additional deflection in the first truss compared to its neighbors. This deflection has developed in spite of the framer's elaborate attempts to bring most of the steeple load forward to the vestibule wall (TF 69, 6). Generally, deflection of the first interior truss by a steeple is eventually slowed or arrested when the rearward component of its rotation jams hard against the connectors and braces from the following trusses, the roof decking, the ceiling joists and lath. One often finds later reinforcements, such as flying braces at the 1829 Newbury, Vt., Methodist Church (Figs. 16 and 17).

AN important conclusion to be drawn from this study and from research into historic truss forms in Europe is that truss form evolution has been nonlinear. Fully realized and rationalized trusses existed in antiquity and were built occasionally in western Europe throughout the intervening centuries, when they coexisted alongside complex and indeterminate roof frames covering (and today still covering) some of the largest and most sophisticated structures ever built, the Christian churches and cathedrals of the Middle Ages and the Renaissance. Rather than seeing the timber framers of the period roughly 600-1600 as lost in a dark age of engineering ignorance, having forgotten the wisdom of the ancients, we should understand this period to be the historic high-water mark of timber framing in the West, and its framers to have been self-expressive, creative and daring under the constraints and challenges placed upon them. The development of modern truss forms and their joinery conventions after 1600 reflects partly the Enlightenment rejection of medieval conventions and partly an accommodation of architectural style to engineering ambitions for longer spans and, in the case of bridges, spans more heavily and dynamically loaded as well. The observed reduction of the variety of truss forms in the 19th century and the tendency to copy both form and joinery from books reflect the industrial revolution's demotion of skilled craftsman to laborer, and laborer to virtual slave, as much as any improvement in the roof systems of churches. Most of their spans, typically 40 to 60 ft., could have been roofed successfully with a variety of frames, both trusses and their vernacular structural relatives.—JAN LEWANDOSKI

Jan Lewandoski of Restoration and Traditional Building in Stannard, Vt. (janlrt@sover.net), has examined hundreds of trusses and steeples.
Research and advice for this series of articles were contributed by Ed Levin, Ken Rower and Jack A. Sobon.

Fig. 16. Aftermarket seat for flying brace at Newbury Methodist (1829) to help resist sinking back of steeple added to church.

Ken Rower

Fig. 17. Long brace (white arrow) flies back from rear post of steeple frame at Newbury to lodge near good support in next tie beam (left).

Bibliography

Barlow, P. *An Essay on the Strength and Stress of Timber,* London, 1824 (first ed. 1817).
Bell, William. *The Art and Science of Carpentry Made Easy,* Philadelphia, 1857.
Benjamin, Asher. *The Elements of Architecture,* Boston, 1843.
——*The Builder's Guide, Boston, 1839.*
——*The Architect or Practical House Carpenter,* Boston, 1830.
——*The American Builder's Companion,* sixth ed., Boston, 1827.
Clark, C.E. *The Meetinghouse Tragedy,* Hanover, N.H., 1997.
Conwill, Joseph. "Town Lattice Roof Trusses in Madison, Indiana," *Covered Bridge Topics,* vol. LXLL, no. 2, 2004.
Dakin, James H. *Collection of architectural drawings,* New Orleans Public Library, nutrias.org/~nopl/dakin.
Gasparini, D. and Provost, C., "Early Nineteenth Century Developments in Truss Design in Britain, France and the United States," *Construction History,* vol. 5, Ascot, Berks.,1989.
Haupt, Herman. *General Theory of Bridge Construction,* New York, 1856.
Hewett, Cecil. *English Cathedral and Monastic Carpentry,* Chichester, 1985.
—*English Historic Carpentry,* Chichester, 1980.
Hills, Chester, *The Builders Guide,* Hartford, 1836.
History of the Stowe Community Church, Stowe, Vermont, 1981.
Hoffsummer, Patrick, et al., *Les charpentes du XIe au XIXe siècle, Typologie et évolution en France du Nord et en Belgique,* Paris, 2002.
Johnson, John. *Undated manuscript,* University of Vermont Special Collections.
——*Bill of Timber for Burlington Courthouse, 1802,* University of Vermont Special Collections.
Kelly, J. Frederick. *Early Connecticut Meetinghouses,* vols. 1 and 2, New York, 1948.
Lewandoski, Jan et al. "The Close Spacing of Trusses," TF 67, 2003.
——"Scissor Trusses," TF 69, 2003.
——"Queenpost Trusses," TF 71, 2004.
——"Kingpost Trusses, TF 72, 2004.
——"Composite and Raised Bottom Chord Trusses," TF 74, 2004.
Maggi, Angelo and Nicola Navone, eds. *John Soane and the Wooden Bridges of Switzerland,* London, 2003.
Mark, Robert, ed. *Architectural Technology up to the Scientific Revolution,* Cambridge, Mass., 1993.
Nelson, Lee. "Early Wood Truss Connections vs. Wood Shrinkage," *APT Bulletin*, vol. XXVII, no. 1-2, 1996.
Nicholson, Peter. *The Carpenter's New Guide,* Philadelphia, 1837.
Peterson, Charles, ed. *The 1786 Rule Book of the Carpenters Company of the City and County of Philadelphia, 1971*. Annotated facsimile.
Sganzin, M.I. *An Elementary Course of Civil Engineering,* translated from the French, Boston, 1827.
Shaw, Edward. *Civil Architecture,* Boston, 1836.
Smeaton, A.C. *The Builder's Pocket Companion,* Philadelphia, 1852.
Sobon, Jack A. *Historic American Timber Joinery,* Becket, Mass., 2002.
Sumner, D. *Archive,* Vermont Historical Society, Montpelier, Vt.
Tredgold, Thomas. *Elementary Principles of Carpentry,* Philadelphia, 1837.
Yeomans, David. *The Trussed Roof,* Aldershot, 1992.

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Step-lap joint repairs to plate and rafter intended to conserve as much original fabric and to be as little seen as possible. The new rafter ends were cut by Peter Smith and the plate and post repairs executed by Michael Lanoue, craftsmen with the David E. Lanoue group in Stockbridge, Mass. Jack Sobon designed the repairs and showed them at TTRAG 2005 in a talk on restoration techniques.