TIMBER FRAMING

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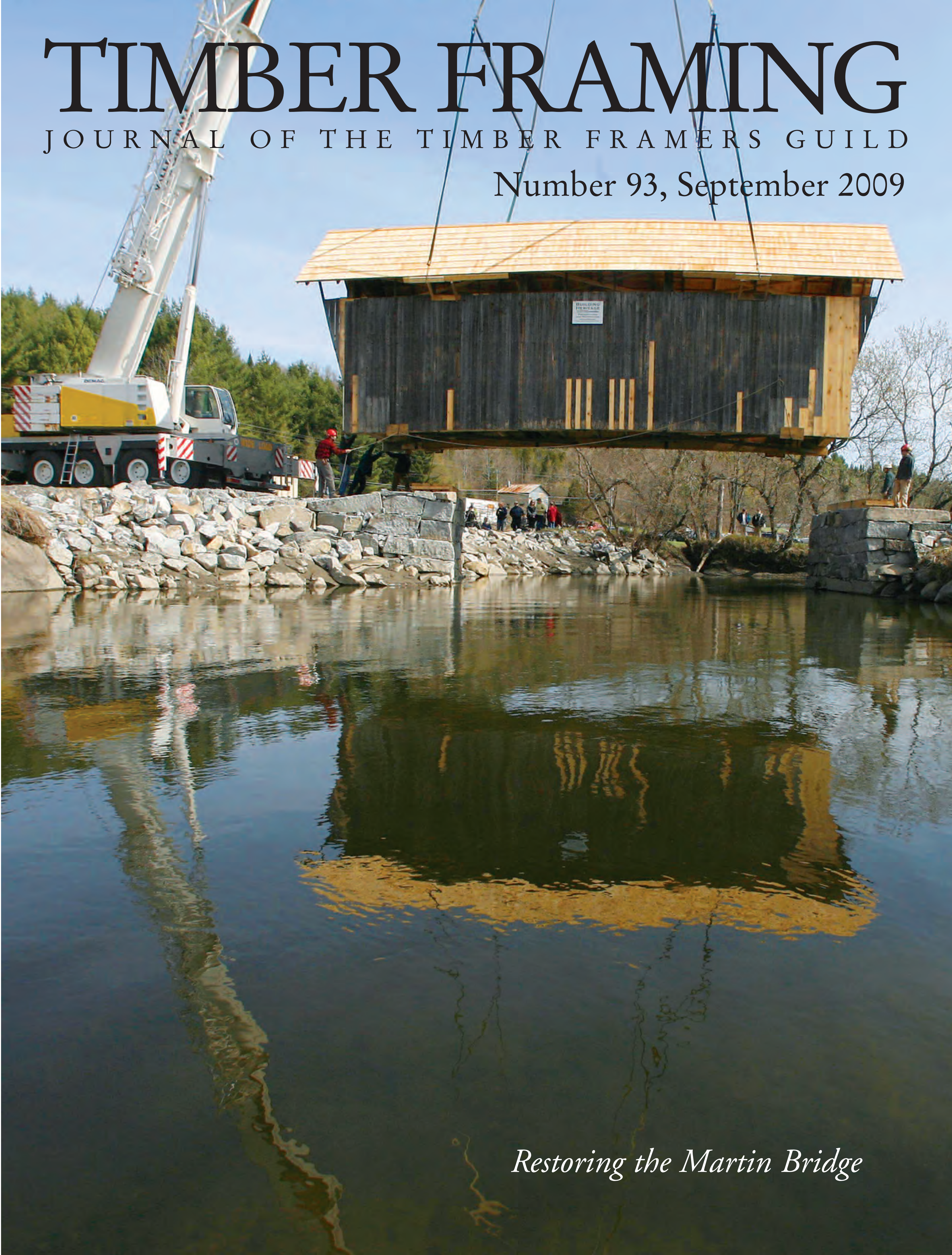

Restoring the Martin Bridge

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On the front cover, the Martin bridge, Marshfield, Vermont, lifted into place. Photo by Toby Talbot, Wide World. Story page 6. On the back cover, view through the restored bridge to pastures beyond. Photo by Eliot Lothrop.

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1985

Notes & Comment

Iron and Wood in Brasstown

I HAVE been witness to a major Guild working event in the beautiful mountains of Appalachia in westernmost North Carolina, a jovial conflagration of timber framers and blacksmiths at the John C. Campbell Folk School in Brasstown. Between reconnoiter, setup and takedown, I was there for about three weeks of good, hot weather, much of it in the company of 45 new friends and old. From magnificent No. 1 and No. 2 local pine and oak (both white), we built a large and somewhat complex new shop for the school's blacksmithing program, arguably the nation's best and most varied.

I was able to experiment with some of that new media monkey business, including site-made short videos for Twitter and Facebook, which allow us to reach out to some new onlookers in their natural, digital habitat. There has been quite a spike in visitor traffic to Guild web addresses, something none of us could have predicted or even conceived of back at the charter Guild conference in Hancock Shaker Village in 1985. Further, we were trailed by a trio of cheerful young men with big video cameras, who were making some sort of documentary for the school, as well as another enthusiastic fellow with a video blog habit. I'm sure we'll find a way to use some of it to tell the Guild's tale to the curious and uninitiated.

The Folk School was founded in 1925 by Olive Dame Campbell (John's widow) and Marguerite Butler, who wanted to replicate the Danish *folkehojskole* tradition of providing the highest level of rural craft training and exploration to adults in a nonjuried and encouraging environment. It has grown into a remarkable institution with a comfortable campus and a wildly varied program. The school holds 800 classes a year in subjects ranging from fine art to writing, with a good deal of hands-on stuff in the middle: instrument-making, woodcarving, pottery, textiles and, of course, at the center, blacksmithing. This is the part of the world where the Foxfire books and magazine came from, so there has been a preexisting respect for craft work practiced at the highest levels; the Folk School has thrived, and their programs expanded to the point that they needed a new core facility for the blacksmithing component, which they call the New Forge.

In my experience in the construction world, most of the trouble that isn't self-induced falls at the boundaries between trades. Our experience at the Campbell Folk School was considerably different. Perhaps in part because the blacksmiths were the real clients, the end users of the building, we had little trouble getting their attention and cooperation. The school has for years been the recipient of a weeklong volunteer commitment from some of the best leaders and participants in their program. The school provides modest lodging and excellent food in return for a week's worth of

Photo Joel C. McCarty

Photo Julie Clark

repair, upgrade, creation, modification and riotous fun, concluding in the alarming tradition of anvil-shooting. Does any of this sound familiar?

So here we are, surrounded and encouraged by a group of enthusiastic and talented people, maybe a little more accustomed to solo work, maybe a little broader in the shoulders than most of us, though still altogether familiar in spirit (and appetites). There were enthusiastic blacksmiths every time we turned around. Not content to hang back in the shop and wait for requests for parts and pieces, the senior man set up a portable forge in our cutting barn early on and took orders for tool repair and the fabrication of whimsical bottle openers and scribes, rapidly becoming what the late David Crocco would have termed an attractive nuisance. Once Blacksmith Work Week began (the second week of our stay), it was hard to turn around without bumping into a grinning, be-sooted man or woman anxious to make, modify, straighten or ornament some component of this quirky building.

The New Forge is designed to embrace two reinforced concrete silos (and barely miss a third) left behind from the old forge's previous incarnation as a Tudor-and-concrete dairy barn. The silos were neither precisely round nor particularly plumb nor predictably consistent in any dimension, but they looked fine after the delightfully wacky Romanian stucco crew gave them a three-coat upgrade.

Our job was to cut and raise a pretty large and tall frame in a pocket site constrained by freshly cast and quite tall concrete retaining walls on two sides, the three silos on another and the original structure about 5 ft. off the slab on the remaining side. Then there was a creek, and a little bridge, and a broken water main, a few days of real rain and that special orange soil that is so good for making bricks. Gabel Holder ran the assembly and raising crew (Whit Holder ran the whole show) and reported that on his first morning of bent-assembly he counted five diesel engines running on site—a big excavator for the county moving a water line, the backhoe moving fill, the concrete pumper doing the retaining wall, the skid-steerer delivering timbers and, way over on the *other* side of the silos, our little boom truck, an aid to assembly. I think he forgot (or maybe couldn't hear) the dump truck and the big air compressor.

Throughout the series of critical-path management adventures that culminated in the two-crane, three-man-lift, no-scaffold raising of about 25,000 bd. ft. of nicely cut material, the smiths dashed about making things. Each of the 22 columns wore a handmade and thoroughly ornamented iron boot (seen in part above left, accompanied by a smiling Julie Clark) cleverly designed to provide and disguise a robust anchor of concrete, epoxy, steel and timber, and of course we needed eight bracket gizmos to land the purlins and jacks. Did I mention the dormer that had to be attached to the silos in more than a few unpredictable places? All custom-fabricated right next door at a furious pace, while providing plenty of opportunity to deploy the rare word *cacophonous*.

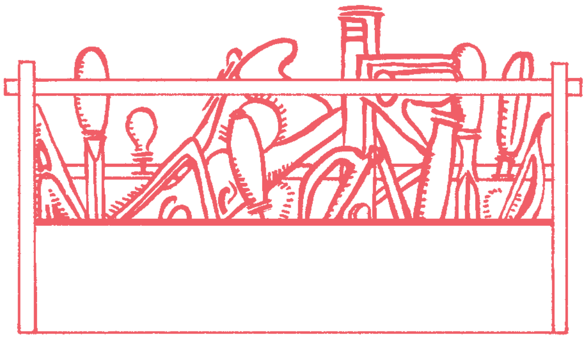
Not to be outdone, at the last possible moment the timber framers elected to ornament each of the over-running floor joist ends with a full-scale anvil carving (above, middle). Delighted grins and backslapping all around. Themselves not to be outdone, the smiths then elected to team-build a kind of giant nail to pierce the intersection of two curved members and the kingpost in the entry bent. This project necessitated much late-night pounding in the shop, six or eight men (*moi compris*, above right) with sledge hammers encircling a swage block holding a white-hot, tapered iron blank 4 ft. long, rhythmically (more or less) slamming those sledges onto the nail by turns. Add a side of world-class folk music, dance, local food and a diverse and enthusiastic collection of artists and artisans swarming about every day—it began to look a lot like home.

WHAT does it mean? These are tougher and more discouraging times than many of us have seen in our craft careers. Guild membership is down significantly, our scholarship fund has taken a body blow in the markets and the future is perilous to contemplate. Why bother with timber framing or blacksmithing or flute making? Is it naught but self-indulgent folly? Ornamentation of a wealthy but bankrupt and dissolute culture? Diversion for the idle and underengaged?

I am reminded of Roger Angell's transcendent essay detailing the seven games of the 1975 World Series (especially the sixth). Craft, apparently pragmatic or solely aesthetic in its contribution to the structure and fabric of the world, revels in a spiritual component directly proportional to the care and intensity with which it is practiced, and impossible to ignore. Timber framing does not of itself do all that much to make the world a better place. Though durable structures from lightly modified organic materials are better than some of what we are asked to build (or renovate or live in), the real and positive change to our interior and exterior worlds comes when craft pushes and pulls us beyond where we were sure we could go in skill and in passion. It's a privilege to keep the company of timber framers—and wait 'til you meet the smiths!

—Joel C. McCarty

TOOLS



A NEW JAPANESE SAW

TRADITIONAL Japanese saws are quite different from Western saws, and their beneficial differences, if by now fairly well known, are worth reviewing. Because Japanese saws work with a pull stroke, the body of the saw does not need to resist bending. It can be thin, the teeth can be set to a narrower kerf and harder steel can be used, hence the longer lasting cutting edge. Teeth are sharpened on three surfaces (rather than two) to clean out the kerf and quickly remove sawdust. For all these reasons, the work can be faster and more precise.

After the Second World War, some Japanese companies developed a new generation of saws. They used modern technology to mass-produce saws instead of hand-forging them one by one—and with very high quality. Not only did the cost go down, but also the blades of the new design were scientifically precise from heel to toe, and the saws included handles made with new materials.

Conventionally, saw makers set their own saw teeth, knowing that a larger degree of set will ease the saw body's movement but the cut surface will be rougher. Smaller sets give smoother surfaces and no set will give the smoothest. On the other hand, if there is no set, the saw body will be squeezed in the kerf and very difficult to move. Traditional Japanese saw makers scrape the middle of the saw body and try to minimize the degree of set.

The new generation of Japanese saws has more benefits than traditional Japanese saws.

1. The typical new saw folds to protect its blade and is easy to carry. Alternatively, saws that do not fold are beautifully designed with cases that can be easily removed and put on.

2. The teeth have no set, therefore the cut surface is very smooth, approximating a planed surface. Instead of setting the teeth to clear the saw body, clearance is obtained by taper grinding the saw body away from the teeth. Thus the saw body is not squeezed and the tool cuts faster.

3. Hard steel is used for the body and the teeth are accurately sharpened.

4. The handle is of new material and design, for easy and firm grip.

5. Most traditional Japanese saws are very difficult to sharpen. In Japan the sharpening of traditional saws must be done by a professional saw sharpener. But the new generation of saws have high quality quick-change blades, and sharpening is thus not necessary.

All the new-generation saws are good for pruning and small-scale carpentry work, as well as small delicate work. Recently, the Silky company has produced a new large saw, called the Katanaboy 500, first shown to me at Dick Gmbh in Metten, Germany (www.dick.biz), and of course available here at www.silkystore.com ($99.95). This saw is made for quite large stock and will be very useful to timber framers and log builders. I used the Katanaboy 500 to cut a 20-in. log; it was easy to control and had a very clean cut. It also ranks as the world largest folding saw, very convenient to carry into the field. —Toshio Odate

Toshio Odate is an accomplished craftsman and author in Woodbury, Ct.

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2

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Photos Laure Olender

The author lays out axial line on old pine log (1), squares around with *sashigane* and *sumisashi* (2), begins cut with Katanaboy 500 (3), keeps sawing despite observer hovering close behind (4), pauses to lubricate saw with camellia oil (5), makes himself comfortable to deepen cut (6), completes cut (7), stands with saw raised in triumph (8).

Restoring a Queenpost Truss Covered Bridge

Unknown photographer

Fig. 1. Historic photo of the Martin bridge over the Winooski River, Marshfield, Vermont, ca. 1890.

BY most accounts, the Martin covered bridge, which spans the Winooski River in Marshfield, Vermont, was built by Herman Townsend for Harry Martin, circa 1890 (Fig. 1). Townsend was primarily a barn builder and there is no record of other bridges built by him. The Martins owned a farm along the Winooski, with rich soil and pastures on both sides of the river, and used the bridge to gain access to their fields. It is believed to be one of the last remaining agricultural bridges in Vermont.

In 2004 the Martin bridge was given to the town of Marshfield in lieu of overdue property taxes. It had been neglected for so long that one of the corners had sunk approximately 18 in. and the structure was severely racked. The bridge lacked any sort of bedding timbers and the 10x10 spruce bottom chords that sat on granite abutments had rotted back several feet. Town volunteers realized that if they wanted to save the bridge they needed to move quickly. They hired a crane service to pull the bridge off the river and place it on large cast concrete blocks in an adjacent field.

There it sat until last summer, when we were hired to restore the bridge and place it back over the river. We began with a thorough inspection, carefully labeling and documenting all the framing members. The queenpost-trussed bridge was 12 ft. wide and spanned 44 ft. 7 in., with 13-ft. clearance under the tie beams. (This perhaps disproportionate height allowed for passage of loaded hay wagons.) The bridge was framed entirely in white spruce. Because of the rotted chord ends, the main braces had spread and the bridge's original camber was largely lost. One of the trusses still retained just under 2 in. of camber while the other truss had flattened entirely.

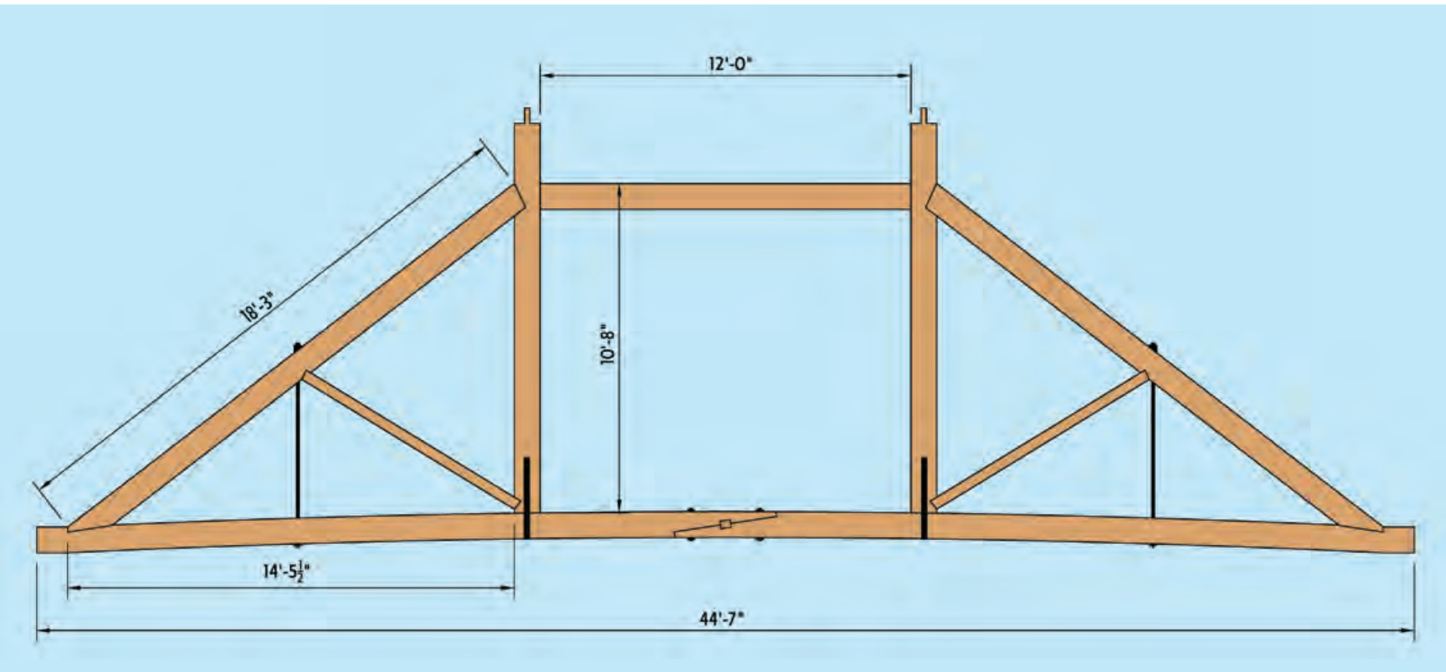
We began disassembly by removing and labeling all of the random-width spruce siding, to be stored inside a shipping container. Most of the double-layer 2-in. floor planking had rotted but almost all of the joists were solid. The spruce board roofing was in need of replacement but much of the roof framing was solid. Except for substantial braced ties tenoned to the tops of the queenposts and the portal posts, the roof system was lightly framed (2x4 rafters with 2x3 purlins) and well nailed, so it made more sense to keep it intact. We connected the cripple studs on top of the upper ties with sistered 2x10s and plywood as well as diagonal bracing (Fig. 2). With the pegs removed at the post tops and the timbers tagged, a boom truck removed the roof system and placed it on cribbing next to the bridge. Finally, we laid down the two portal bents, followed by the two queenpost trusses.

All the structural members of the queenpost trusses were 10x10s except for 4x10 struts between the main braces and the base of the queenposts. The queenposts joined the bottom chords with stub tenons 3 in. thick and substantial iron stirrup straps. The straining beams were tenoned and pegged to the queenposts.

At their top end, the main braces were deeply notched into the queenposts and toe-nailed, while the heel joined the bottom chord in a 2-in. deep diminished housing with two through-bolts set square to the top of the strut. At roughly the midpoint between the queenposts and each end of the bridge, a ¾-in. iron rod suspended the bottom chords from the main braces. The struts were notched into the main brace just uphill of this rod and helped keep the main brace from deflecting under the bending induced by the iron rod.

Photos Eliot Lothrop

Fig. 2. Removing roof frame after bracing and reinforcement in place.



John Jordan after Micah Whitman

Fig. 3. Drawing of Martin bridge queenpost truss with triangle dimensions implying camber.

Through careful inspection of the truss joinery and simple trigonometry, we deduced that the trusses were originally built with a little over 5 in. of camber. The triangle formed by a queenpost, its main brace and the top surface of a bottom chord is dimensioned in Figure 3.

Solving for the angles in this triangle, we found the angle between the bottom chord and the queenpost was obtuse, indicating a chord rising from its end toward the queenpost. A level line projected over from the point of the main brace heel intersected a plumb line projected down from the queenpost 5³⁄₁₆ in. below the actual foot of the post. We believed this deviation represented the amount of intended camber. Initially startled by such a high number for such a short bridge, we then compared old photos of the bridge with computer drawings of what the bridge would look like with over 5 in. of camber and decided that we must be on the right track.

Fig. 4. Trusses exposed. Note heavy stirrup straps at bottom of queenposts and short, twinned braces at top. Struts between main braces and queenposts have been removed. Original camber in scarfed bottom chord has disappeared. All timbers tagged with disks.

WITH the trusses exposed, we tagged all the members (Fig. 4). Once all of the timbers were apart, we were able to fully inspect everything. Both bottom chords as well as one of the queenposts and a main brace were in need of replacement. The other three main braces were mostly good and only needed simple repairs at their feet. We replaced the upper 5 to 7 in. of thickness of each main brace for a distance of approximately 30 in., using a bladed abutment at the top end. The new wood was bolted to the rest of the main brace using traditional cast-iron ogee washers between the fasteners and the wood. The pair of bolts that fastened the main brace heel to the bottom chord would also capture the new wood (Fig. 5).

After cutting the new pieces and completing all the structural repairs in the three remaining main braces, we were ready to reassemble the trusses. First, we fitted up the scarfed bottom chords and fastened them with six through-bolts and ogee washers. In a supplemental change to the original scarf design, we added an oak shear block to each joint. All the remaining pieces of the truss were fitted and the heels of the main braces brought into their housings in the bottom chords. At this point, the bottom chords were still straight and roughly 5 in. remained between the queenpost shoulders and the top of the bottom chords.

For the first truss, we introduced the camber into the bottom chord by rigging comealongs from each straining beam intersection to three evenly spaced points along the bottom chord between a queenpost and the heel of its main brace. Once the queenpost-to-bottom chord joints were tight, we installed the stirrup straps, iron rods and struts. For the second truss, we used the iron rods along with the comealongs to introduce the camber and found this method to be more efficient. We were able to reuse all four of the original rods (by rethreading their ends after cutting them out of the old trusses), as well some of the original wooden blocks fitted under the iron washers, one angled and one a spacer, where the rods came up plumb through the main braces.

With the trusses built and laid out on the ground, we set about building four piers of solid cribbing to set the ends of the bottom chords on as the bridge was reassembled. We stood up the two trusses with the aid of a crane (Fig. 6).

After adding the two portal bents, we brought in the roof framing skeleton (seen in the background of Fig. 5), which by this time had had any rotted material stripped and replaced. One unforeseen obstacle was that we had locked the rack into the roof frame with all of our temporary bracing, which made it impossible simply to lower the frame back down onto our six posts now forming a square and level plan. Instead we had to engage one side first, lowering it just enough until the tie mortises on that side registered on their post and brace tenons. We then pulled the second side of the roof horizontally, until its mortises lined up with the posts and braces on that side, and lowered it down.

Before the crane operator left, we made sure to have him fly four of our eight 8x10 white oak bedding timbers over to the far shore, to avoid our driving downstream to the next bridge and traversing a half-mile field with them.

Almost all of the original floor joists went back into the bridge, as did the lateral floor X-bracing. We replaced the 2x4 lateral X-bracing in the roof system with 3x5s connected to the top of the tie beams instead of to the top plate at random locations, as the original bracing had been.

To avoid cutting into the important juncture of queenpost, straining beam and main brace, the original builders had shortened the braces between the queenposts and the roof ties and then twinned them to compensate for the diminished effect of shorter braces. (The post-to-roof braces at the portals had typical 3-ft. leg lengths; at the queenposts the legs were 2 ft.) To reinforce all the post-to-roof braces, however, we installed ¾-in. steel rods welded to plates set flush against the outside of the posts just below the level of the brace feet. The rods ascend at 45 degrees through the posts to the top surface of the ties, where they are fastened via washer and nut over an oak angle block.

A new cedar roof of ½x6 untapered shingles 24-in. long and with a 16-in. exposure replaced the original spruce covering of the same specification. The job was complicated by the bridge camber, which prevented striking straight chalklines for each course in the usual way. Instead, we made a jig with a runner at one end to ride against the bottom of each course and a nail driven through 16 in. up that would scratch a line for the next course. We also checked the shingles as we went to ensure that, while plumb at midspan, they tipped out of plumb at each end of the bridge.

Fig. 5. New cambered chord and repaired main brace in reassembled queenpost truss.

Fig. 6. Truss rising on blocking. Twinned braces prepositioned and strapped to top of queenposts, ready for tie beams. Portal bents will be added, then roof structure.

We sheathed the bridge with an entirely new layer of random-width inch boards, on top of which we reinstated the original siding boards in their original locations. Similarly, over the floor joists we laid new 2x10 planks and covered them with mostly original material. Ed Leterneau, a local sawyer, came up with his Woodmizer mill for a few hours and made 2x10s of the portions of beams that we weren't able to reuse as bottom chords or main braces. With those and just a couple of new boards we were able to complete the top layer of flooring.

Unsure of the exact weight of the bridge but sure it must weigh close to the original, and wanting everything to go smoothly for our first bridge-moving experience, we hired the same crane company (Valley Crane of Vernon, Vermont) who had removed the original bridge from the river five years before. They came with a 165-ton crane and 70,000 lbs. of counterweights. Using two long spreader beams, we were able to drop cables to wrap underneath the bottom chords and back up at both ends of the bridge. Although there was virtually no pressure on them, we reinforced both eaves where the cables would rub, to protect the overhang. In a matter of minutes the bridge was swung over onto the abutments, squared up on the bedding timbers and set down (cover image). It wasn't until the cables went slack and swung to the middle that the crowd of onlookers realized the weight was off the crane and began to clap.

Our crew of four had a great time restoring the Martin bridge and we feel grateful to have had the opportunity. It was a fulfilling process to work with the town of Marshfield to help preserve one of its historic landmarks. Seeing members of the community walk across their newly restored bridge was a genuine affirmation of why we work as preservation carpenters. —Eliot Lothrop and Micah Whitman

Eliot Lothrop (eliot@buildingheritage.com) and Micah Whitman (formicah26@yahoo.com), with Mark Ansley and Miles Jenness, comprise Building Heritage (www.buildingheritage.com) in Huntington, Vt.

The Abyssinian Meeting House

Don Perkins

Fig. 1. Abyssinian Meeting House, Portland, Maine, 1828, under the temporary protection of a portable airplane hangar.

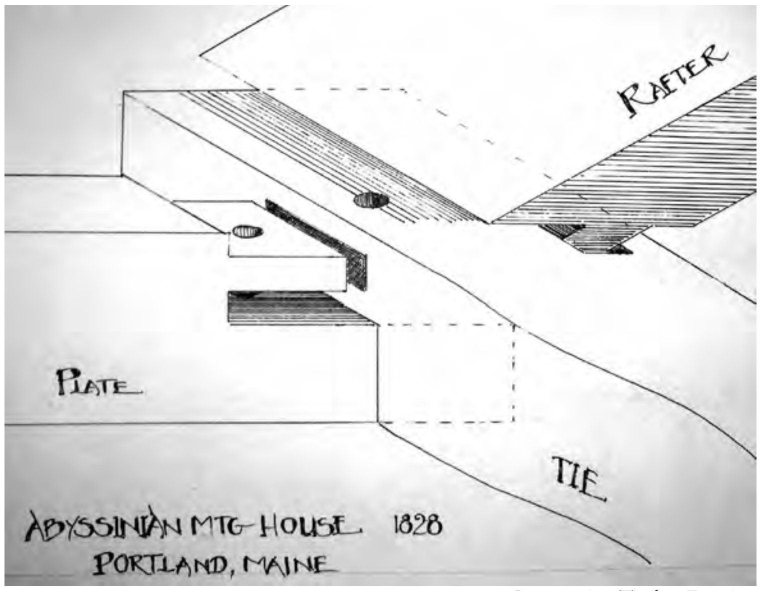
THE Abyssinian Meeting House must have a guardian angel. Over the years in Portland, Maine, fire, neglect, homeless drug addicts and the passage of time tried to bring down the third-oldest African-American meetinghouse in the country, built in 1828 (Fig. 1). It sits at the base of Munjoy Hill at the eastern end of Portland's downtown peninsula, a bustling waterfront section in the 19th century. In 1826, free blacks, long tired of the back-row treatment they encountered in Portland's churches, decided to build their own. Those who sat in the Abyssinian's pews witnessed prominent abolitionist speakers like Frederick Douglass and William Lloyd Garrison. The building was part of the Underground Railroad and served as an African-American school when northern schools were segregated.

In 1998 historians and community leaders founded the Committee to Restore the Abyssinian Meeting House and purchased the vacant building from the City of Portland for back taxes. The building had been severely altered over the decades, its frame relentlessly compromised. Used as an African-American meetinghouse until 1917 and remodeled into tenement apartments in 1924, the 38x50-ft. building's kingpost roof trusses had lost their bottom chords, and the tie beams at the second floor level had been hacked to provide headroom. One wall had bowed 9 in. and windows had been broken out. Transients had painted the walls and ceiling of the upper apartments black, and orange and avocado walls on the bottom floors testified to the fashions of former decades.

To assess the long-suffering building and begin accurate repairs, the restoration committee hired Arron Sturgis of Preservation Timber Framing, Berwick, Maine. To protect the structure during the complete reconstruction of the roof frame, the company set a portable steel-and-fabric airplane hangar 42 ft. wide over the top of the Abyssinian, which also allowed the necessary demolition to begin last winter, a brutal one along the Maine coast. The crew (Fig. 2) removed layers of drywall and plaster (including a dead cat found in a wall by Pete Dellea), hauling it to a dumpster in barrels, to expose the building's bones. Beholding an all-but-wrecked frame after weeks of interior demolition, members of the crew were impressed that it still stood. Foreman David Ford, who later remarked on the folly of "cutting the heart, lungs and spleen right out of the building," called it "a nightmare." Dan Boyle summed it up as "war-torn." Brian Cox wondered how it had remained square with so many structural members removed. Meanwhile, the Abyssinian's former life was slowly revealed.

Don Perkins

Fig. 2. The PTF Abyssinian crew, from left: David Ford, Brian Cox, Wyl Smith, Pete Dellea, Dan Boyle, Scott Lewis and Shawn Perry.



Preservation Timber Framing

Fig. 4. Plate joins jowled gable end tie in unusual tenoned and lapped joint. Lap echoes arrangement at intermediate ties.

Flooring on the first level showed mortises where the original pews were set (Fig. 3). Empty mortises in the exterior wallposts outlined the former choir loft. Original window openings, long since boarded over, were discovered. After stripping, the ravaged, five-bent pine frame stood before the crew: hewn 6x10 posts and sawn wall studs, braces and common rafters. Much had been damaged by fire or water. In 1866 a devastating fire ripped through Portland; 1500 structures burned and 12,000 people were left homeless. The Abyssinian and the 1807 Portland Observatory on Munjoy Hill, another fine timber-framed building, were the only neighborhood structures to survive the blaze. Accounts report that William Wilberforce Ruby, an African-American member of the Portland fire department, saved the Abyssinian by putting wet blankets on its wood-shingled roof.

With the frame exposed, structural assessments were made by an engineer, who proposed unacceptable repairs such as steel bracketing that would not be in keeping with the original framing. An end wall, with its 40-ft. 10x12 ties cambered 4 in., yielded the pattern for the missing truss chords. The end wall tie beam connection to the plate proved unusual, though not surprising in context (Figs. 4 and 9).

Finding the five 40-ft. 10x12 tie beams to complete the king-post trusses proved challenging. Ultimately sawn spruce was provided by Joel Currier at Currier Farms in Danville, Vermont. To aid in executing the trusses and other lengthy work, a local businessman donated a nearby vacant lot as a workyard. The cambered bottom chords required bending with straps and comealongs, using a strut and a second beam to work against (Figs. 5 and 6).

IT'S clear the Abyssinian was a structure its builders intended to last, with its large, redundant timbers and stout joinery. When whites think of joiners and carpenters in early New England, the image of a white man of European descent almost certainly comes to mind. We know that the trade was brought by the English, and forms like the English tying joint preserve the origins of the technology. Today, a mention of contemporary American timber framing will bring forth images of the work or the writing of Jack Sobon, Tedd Benson, Richard Babcock, Ed Levin, Steve Chappell and other whites less famous. So it may be surprising to some to contemplate 18th- and 19th-century black joiners arriving with slicks and chisel rolls or attaching an evergreen to a freshly raised roof peak.

Don Perkins

Fig. 3. Exposed flooring showed original pew mortises.

Committee to Restore the Abyssinian Meeting House

Fig. 5. Cambering lower chords for trusses and scribing struts.

Committee to Restore the Abyssinian Meeting House

Fig. 6. Dan Boyle in the workyard mortising an end sill patch. Note joist pockets, stud mortises and bladed scarf half to join rest of sill.

Don Perkins

Fig. 7. Arron Sturgis of Preservation Timber Framing and Leonard Cummings of the Committee to Restore the Abyssinian Meeting House standing under the roof frame, almost all new work.

Reportedly there were 16 registered joiners in Portland when the Abyssinian was built in 1828. There is no hard evidence that black joiners built the Abyssinian, but those involved with the building today think it more than likely. In particular, Portland's Abyssinian noticeably resembles Boston's earlier African Meeting House (1806), known to have been funded and built by blacks.

Most of us would be hard-pressed to come up with the name of an African-American figure who contributed to the craft, but scholars know that blacks in America, both slave and free, learned woodworking, including joinery, at a high level. John Michael Vlach, Professor of American Civilization and director of the Folklife Program at George Washington University, has published extensively on African-American crafts and tradespeople. His essay "Us Quarters Fixed Fine" in *By the Work of Their Hands* (1991) includes historical excerpts demonstrating the skill of black carpenters and joiners. Southern white tradesmen often owned slaves and trained them to earn their masters money.

In 1879, W. D. Goodman recorded an account of how one black man actually crafted his way to freedom. In 1826, Emperor Williams was born a slave in Nashville and in 1841 was sold to a builder named James McIntosh. Williams became a master mason and foreman under his owner. After McIntosh's white carpenters could not complete a challenging piece of cornice work, the master offered Williams his freedom if he could complete it. Williams accepted the challenge, taking the plans home where he studied them on the floor of his cabin all night. The next day Williams completed the cornice and earned his freedom.

In late-1700s and early-1800s Charleston, an important slave port that preserves an extensive historical archive on African-American matters, white tradesmen protested the hiring of black carpenters. Such strife prompted the institution of a system that sought to document and regulate black tradesmen in the labor market, according to Harlan Greene in *Slave Badges and the Slave Hire System in Charleston, South Carolina, 1783–1865* (2004). No slave could be employed without displaying a metal badge.

On the cover of Vlach's book is an 1854 portrait of Haywood Dixon, a slave carpenter in Green County, North Carolina. Dixon is seated for the formal portrait proudly holding a carpenter's square. Vlach also quotes from Whittington Bernard Johnson's dissertation, "Negro Laboring Classes in Early America, 1750–1820," to relate that "Due largely to prosperity, expansion, and population growth after 1763, carpentry eventually surpassed cooperage as the most commonly practiced trade among black artisans."

It appears this was not just run-of-the-mill rough carpentry. In the 1930s, the Federal Writers Project carried out an assignment under the umbrella of the Works Progress Administration. Over 2000 ex-slaves were interviewed to document their history. Among the stories is evidence of skilled African-American workmen. One J. H. Beckwith is recorded as having two United States patents, one for a 10-unit brickmold, the other for a sliding door.

Vlach believes that black joiners worked in obscurity simply because they were for the most part anonymous individuals in those times, and their labor took on a similar quality. There are a few figures, however, who managed to leave a name for themselves. Horace King (1807–1885) was a prominent covered bridge builder in the South and is remembered in *Bridging Deep South Rivers: The Life and Legend of Horace King* (2004), by John S. Lupold and Thomas L. French Jr. Born a slave in South Carolina and owned by contractor John Godwin, King's building talents were recognized by Godwin, who helped develop them. King built many lattice-truss bridges over rivers in Alabama, Georgia and Mississippi. Godwin eventually freed King in 1846.

It is more than plausible that skilled free blacks—carpenters among them—found their way north to places such as Boston and Portland. Indeed, as Preservation Timber Framing discovered, the

Committee to Restore the Abyssinian Meeting House

Fig. 8. Scarfed kingpost repair and extra-long stirrup strap to relieve tension at scarf. Trusses are double strutted and purlins are fully windbraced. New timber is spruce. Translucent portable airplane hangar placed over building made work possible in almost any weather.

Abyssinian's frame typology suggests the influence of an immigrant group. Some joinery is atypical for New England, and some that might be expected, such as the English tying joint, is missing.

THOUGH the Committee to Restore the Abyssinian was formed in 1998, it was nearly a decade before it was able to place the building on the National Register of Historic Places in 2006, and funding is a continuing long-term effort. Arron Sturgis says the restoration is typical of how many early New England churches were built in the first place. "It took congregations years to build their buildings," he says. "That's no different here with the restoration; it's a community-based project."

In May the initial goal was reached of stripping the building and restoring the floor plan. In a major effort, the roof frame was removed and completely rebuilt (Figs. 7–9). A wood-shingled covering has been proposed but will have to go before local code officials for a variance since the fire department has banned wooden roofs in the downtown Portland area. "We're in negotiations with them," Arron Sturgis says. "We have a fire retardant we can apply to the shingles. Because of the historic significance of the building, we're hoping for a positive result." —Don Perkins

Don Perkins (don@ourbarns.com) is a writer and barn enthusiast living in southern Maine. The Abyssinian Meeting House website is www.abyme.org.

Don Perkins

Fig. 9. Intermediate lower chords lap the continuous plate.

R J Misiolek

Fig. 1. Mechanically laminated beams handle unusual loads, preserve beauty of natural timber and offer decorative possibilities. Folding wedges to develop shear resistance at beam interfaces are seen partly installed and stacked on shop floor at Cascade Joinery, Bellingham, Washington. Iron straps remain to be completed to cinch assembled beam against being driven apart by reaction to wedging.

Mechanically Laminated Beams

FOR many hundreds of years, builders have found needs and applications for timbers bigger than any that they could readily find within the trees from local forests. An obvious solution lies in bundling smaller timbers to make larger ones (Fig. 1). This can work well, and even ease construction, but it is not as structurally efficient as using solid sections of the same size. Builders, even early ones, recognized the value of generating some composite action between components of a bundle, with attendant gains in load capacity, reduced member sizes, or both. Modern glue technologies can yield composite action at least on a par with Mother Nature's. Before we had reliable glues, however, we relied on mechanical connections to induce composite action.

Builders have applied a lot of ingenuity and effort in developing composite action among grouped timbers. The literature contains many examples of mechanically laminated beams, some nearly breathtaking in their elegance, others in their costliness. Innately, none of them can offer the same degree of composite action as solid or glue-laminated timbers. Even given modern forests of smaller trees and modern gluing techniques, however, there are still some undeniable reasons to mechanically laminate smaller timbers into bigger ones. Most concern aesthetic impacts in our exposed and celebrated timber structures. Some building owners simply have trouble with the "stripiness" and the industrial appearance of modern gluelams, while very deep natural solid beams such as 8x16s can distort unattractively during seasoning.

Building realities can also make mechanical lamination a tempting option even for contemporary builders interested in replacing large timbers that are still available as solid sawn timbers. With the ability to assemble larger beams from an assortment of smaller ones, shops can maintain smaller inventories. Those inventories can also be used more fully, and to good effect, because keyed beams hide a couple of faces, providing a good place to put larger knots where they are subjected to minimal bending stresses and where they might conceivably contribute to local shear force resistance.

Design, Analysis, Detailing. Keys in mechanically laminated beams resist interlayer slip between the individual laminae of the beam, thereby inducing composite action. While simply sprinkling a lot of keys along the beam can be effective, actually understanding the micro issues of the individual keys, and the macro issues of the assembled beam and its overall role in the structure, quickly becomes involved.

Specific design concerns with keys include their proportions, slope, grain orientation, shape and material. Most wooden shear keys are rectangular solids, about three to four times longer than they are deep, and their grain can be oriented to run with or across the grain of the beam (Fig. 2). The basic design option is whether to slope the keys with respect to the surface of the beam or to set them level. Sloped keys have a more direct load path, and can be simpler to fit, but their internal shear stresses are more complex. (They also resist interlayer slip in only one direction.) Unsloped or level keys resist slip by transferring bearing forces from one beam

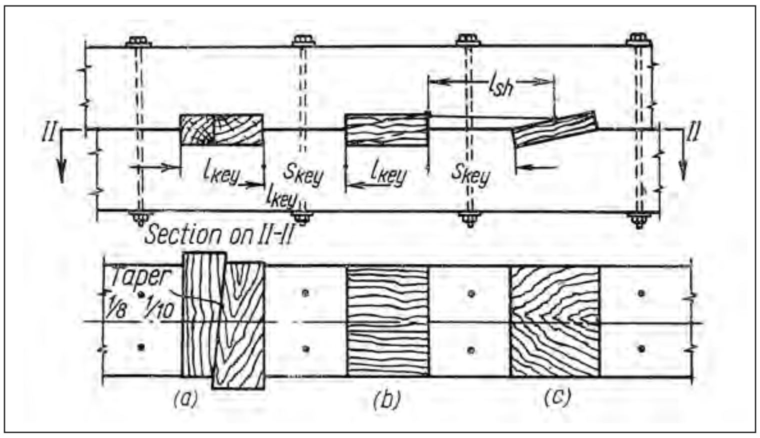


Fig. 2. Detail of G. G. Karlsen's drawing in *Wooden Structures* (1967) comparing (a) cross-grain, folding-wedge, level key, (b) parallel-grain level key and (c) parallel-grain sloped key.

layer at one notch edge to the other beam layer at the distant notch edge. This eccentric load path crushes one half of each notch face and induces internal shear stress in the key as the force is shifted from one side of the key to the other.

A second option is whether to orient the grain of the key parallel or perpendicular to the grain of the beam. Keys whose grain runs with the beam's can fail in crushing at the bearing surfaces and in shear parallel to the grain. If such keys are sloped, they present a more complex shear transfer path and are far less likely to fail in shear. Keys whose grain runs across the grain of the beam can fail in compression perpendicular to the grain, and in what might be called "rolling shear" across the fibers, rather than shear parallel to the grain as in a level key oriented with the grain.

Keys oriented with their grain parallel to the beam's must be cut from wider stock. They are more fragile than one might imagine; typically they are made of manufactured or glued-up stock. Nor is end-grain-to-end-grain bearing as stiff as designers might think (the National Design Standard even prohibits designing past 75 percent of allowable compressive capacity in some cases): the sawn ends of cellulose cells cut into one another.

A third option is how to shape of the key. For many reasons, from allowing preloading to relaxed fabrication tolerances, wedge-shaped keys are handy for designers and builders alike. The keys can be single wedges, fitted to commensurately tapered notches, or matched pairs (folding wedges) used between parallel bearing faces.

Keys have been made from many materials, but a classic protocol is to use hardwood keys in softwood beams and cast-iron keys in hardwood beams. Hardwood keys are almost always installed such that they are compressed perpendicular to the grain. This side-grain bearing governs the crushing capacity over the end-grain bearing of softwood beams (for most combinations of wood species), but this can actually be a desirable feature if wedged shear keys are used. This discrepancy in bearing capacities at the contact faces makes it easier to induce fairly uniform compression in the keys during fabrication. Modern engineered wood products like Parallam can be used as keys, for increased bearing and shear capacity and handier sizing. To avoid losing composite action as unseasoned keys shrink, large keyed beams require gluing up dry stock for their commensurately large keys.

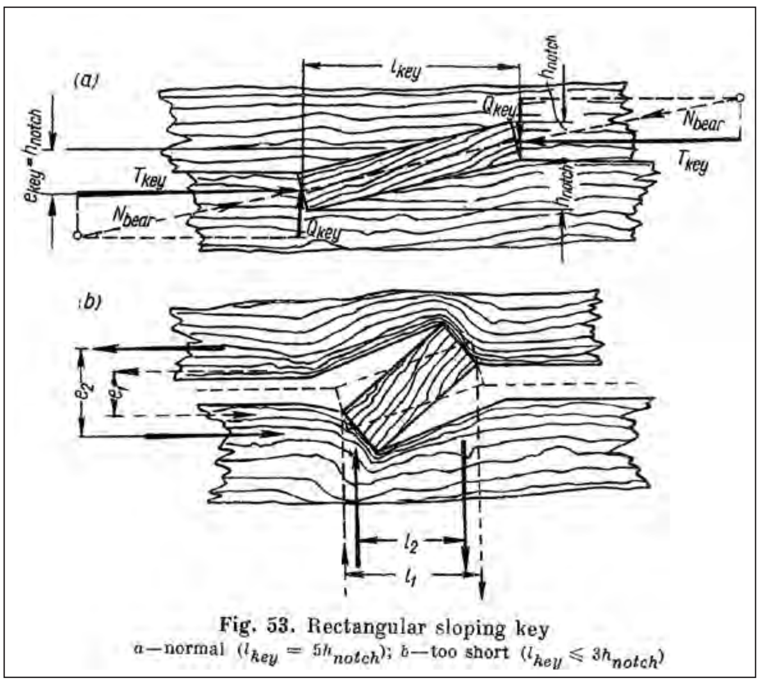
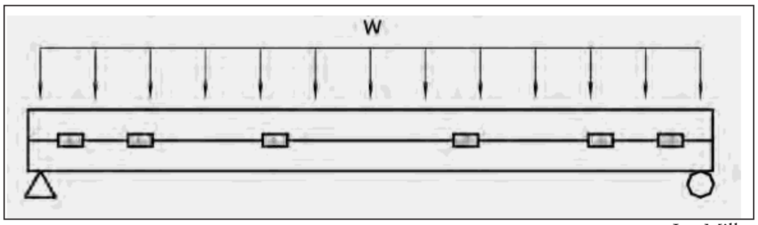


Fig. 3. Karlsen's drawing showing effect of length on rolling tendency of rectangular sloping key. At *a*, key is five times as long as height of notch. At *b,* key is less than three times height of notch.

Shear keys resist slipping between the two laminae into which the keys are fitted. Whether sloped or level, keys transfer forces on an innately eccentric load path—one that tends to pry the two laminae apart. All keys, including level keys, "want to roll," and this tendency must be prevented (Fig. 3).

The two common ways to prevent laminae from separating because of key prying are by internal fasteners or external clamping straps. Both methods involve fabrication, performance and aesthetic considerations.

In addition to the micro design issues involved with the keys themselves, we also need to look at their macropositioning within the beam. In practice, these micro-macro distinctions are handled not separately but holistically. For any combination of key dimensions and beam and key material, there is a minimum key spacing that ought to be held. If the keys are too close to one another, the interkey chunks of the beam will simply shear off. Once this minimum spacing is met, however, the designer is left with several considerations. *Shear* keys are eponymous, in that they ought to be located where the laminated beam is resisting shear forces. In practice, this means the keys are generally more effective when located near the beam supports. In uniformly loaded applications (with the resulting linearly variable shear force along the beam), the key spacing can gradually increase toward midspan, which is a nice way to visibly reflect the variable shear action in the finished beam (Fig. 4).



Joe Miller

Fig. 4. Diagram of uniformly loaded built-up beam with key spacing increasing toward midspan.

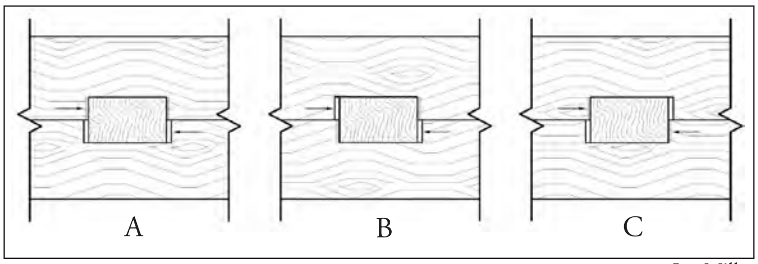
Point loading, on the other hand, makes for zones with uniform shear forces to resist, and evenly spaced keys can reflect this.

We have already mentioned the iterative nature of key detailing; a first stab at a key dimension can well prove to require an unworkably large minimum spacing. More, and smaller, keys can often generate more composite action than a few heavy ones.

A holistic and even more esoteric process is also required when analyzing a structure with any composite members. The range of shear key effectiveness in generating composite action is none through total, and neither limit is actually achievable. For example, keying two 8x8s together will result in a beam that is somewhere between a 16x8 (no composite action) and an 8x16 (full composite action). When combining two square timbers, generating full composite action makes the resultant beam twice as strong and four times as stiff when compared with two timbers that can slide freely by one another. In a simple application, this means that a fully composite beam can carry twice as much load before breaking and will deflect a quarter as much. Some historic papers on the topic claim simple keyed beam efficiencies in the 50 percent to 80 percent range. In more complex, "redundant" structures—ones with multiple load paths—the load share carried by any path is a function of its relative stiffness. This means that the thorough analyst needs to establish the degree of composite action, model that in the structure, and then assess whether that amount of keying makes the beam strong enough to resist the attracted load. It might even happen that an overloaded keyed beam could be rendered acceptable by reducing the keying specifications. It is also possible that a temporarily overloaded keyed beam might be resuscitated by simply jacking it and replacing the crushed or sheared keys.

Fabrication Realities. The issues confronted in fabricating a key-laminated beam are rich in aesthetic, economic and structural questions. Many timber framers have a straightforward definition of craftsmanship: minimal gaps, at least initially. This protocol, though, can make for problems when fitting shear keys. Getting a single level key to fit "snugly" against four separate potential bearing faces cut in two large timbers can be a frustrating exercise. Getting all the keys along a beam to fit at the same time can be downright maddening, expensive and unlikely.

The two most direct ways to simplify the fitting process are to use wedged keys and to introduce deliberate initial gaps. Wedged keys can be singular, fitting between nonparallel bearing faces, or paired (folded), bearing on parallel faces. Wedges allow for "tuning" the keys, or equalizing the initial compression they feel, through balanced tapping installation. The desired induced composite action can be very sensitive to key stiffness, both initially and as loading is applied. A very small amount of initial "gap takeup" when the assembled beam is loaded can translate into significant losses in both stiffness and strength. The four potential bearing faces yield four combinations of two faces that bear initially, and only one of those combinations is the one sought. When the fabricator tries to make all four potential bearing faces snug, it is nearly inevitable that one of the pairs of opposing bearing faces will tighten first, and that many of them will be in the wrong direction, resisting interlayer slip in the direction opposite the one that will occur with loading. It is much more effective to use (and far easier to produce) wedged shear keys that fit into dados overcut so that the intended bearing faces always bear first during fit-up (Fig. 5).



Joe Miller

Fig. 5. Possible fits for unsloped keys. *A* can occur in either top or bottom layer (bad—no transfer of shear forces—two chances). *B* can occur if keys bear on opposite faces from those required to transfer shear force (bad—no transfer of forces—one chance). *C* can occur if keys bear on proper faces required to transfer shear force (good—what's intended—one chance).

An advantage of sloped keys is that they need not have deliberately gapped housings, since they bear on only two faces (see Fig. 2). The disadvantage, though, is that sloped keys resist slip in only one direction. Though improbable, if by chance unsloped keys can be installed to work in both directions, they may yield a beam that can generate at least some composite action even under reversed loading. For most beams, this reversibility is not any special advantage—gravity loads generally act in only one direction and sloped keys can point up, toward midspan. Lateral loads, on the other hand, can and do reverse direction, and with equal magnitude.

To the extent that posts and beams (and knee braces) are involved in resisting these lateral loads, keyed versions would be much more effective (Fig. 6). Knee braces can introduce interesting interactions among posts and beams, even as they resist simpler gravity loading. A very stiff and long knee brace, for instance, could reverse the shear in the beam between the brace mortise and the post. Again, load paths are redundant and carry load in proportion to their relative stiffness; a very limber post makes for an anemic knee brace and a braced beam that can act as though it were just simply supported.

Before leaving the nitty-gritty of fabrication, we note certain possibilities of detailing. Wedged keys, for example, allow a fabricator to camber the beams. Simply driving the wedges in harder can do it, with limber enough timbers and low enough taper angles. Alternatively, timbers can be bent before or as wedges are installed. While this technique can be a potent way to fight off sag under live loading, it usually makes initial key installation much trickier.

Benson Woodworking

Fig. 6. If lateral loads are high, keyed posts as well as beams can be appropriate.

Especially deep beams can be assembled from more than two members, from non-square members and even from differently sized members. Each of these introduces complexities and opportunities. Tall stacks of timbers, for instance, get involved because of the varying bending and shear stresses, up and down, within any given cross section. The closer they are to the neutral axis of the assembled beam, where the shear stresses in the assembled cross section are larger, the bigger the shear keys need to be. Meanwhile, the designer would prefer smaller keys and notches the closer they are to the top and bottom of the assembled beam, where the bending stresses are greatest.

Finally, it can be tempting to use heavy springs under the heads of through bolts used as clamps, in an effort to maintain prying resistance even as the timbers shrink (Fig. 7).

Randall Walter AIA

Fig. 7. Clamping bolts on keyed beam seen above are fitted with springs under their heads to take up shrinkage in keys and members.

Historic Examples. Keyed beams have a long and varied history. Cases of keyed beam usage have been documented over the last 300 years in Europe, many in bridges (Fig. 8).

Ben Brungraber

Fig. 8. Bridge in Austria relies on sloped-key-laminated girders for load bearing. Diagonal members in "truss" brace roof structure only.

Jacob Leupold (1674–1727), the versatile German mechanic and instrument maker, in 1726 depicted early instances of keyed beams used for their composite behavior (Fig. 9).

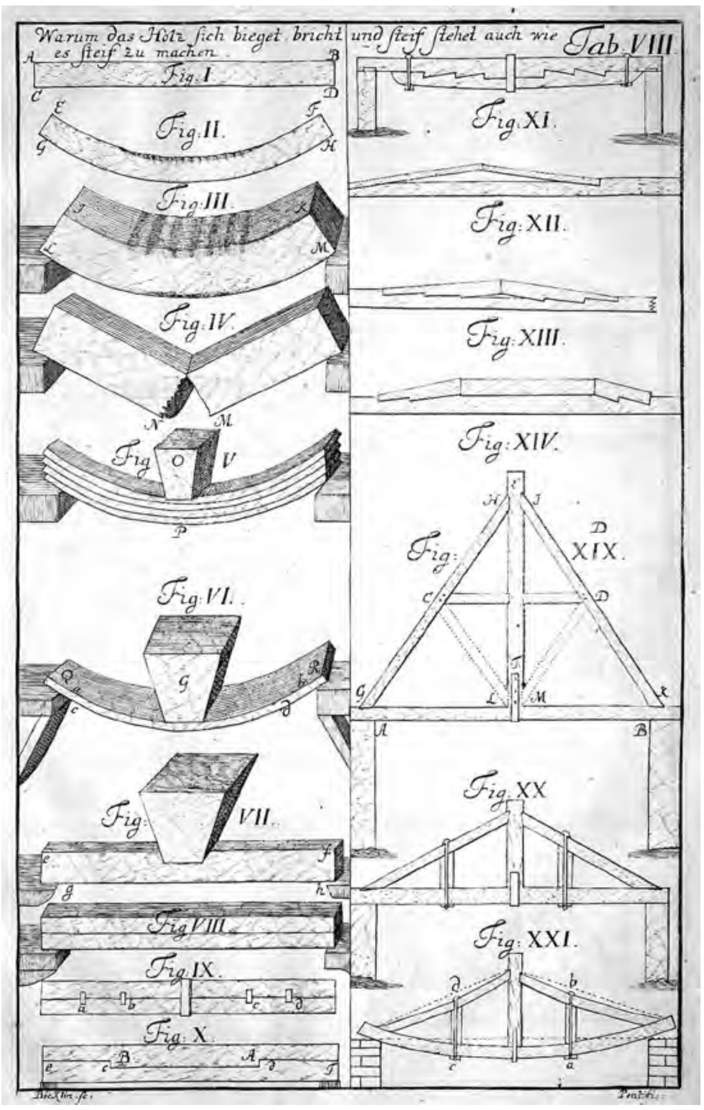
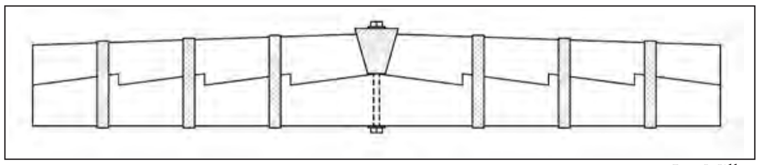


Fig. 9. Jacob Leupold's 1726 didactic drawings of long-span problems and solutions, including keyed beams.

Nearly a hundred years later, Thomas Tredgold (1788–1829), a British railway engineer and one of the founders of modern civil engineering, described built-up and key-laminated beams in some detail in his *Elementary Principles of Carpentry* (1820). Tredgold advocated for a tapered top on the upper layer of the keyed beams, so that solid metal bands could be used for clamping and, while he did acknowledge keys could be used to generate composite action, he also recommended a joggled beam that used a cast-iron wedge to forcefully mate the bearing faces before putting the beam in service and iron straps to keep the laminae together (Fig. 10).



Joe Miller

Fig. 10. Tredgold's proposal for a joggled and strapped composite beam using a cast-iron wedge drawn down to tighten the bearings.

The idea of a joggled beam was nothing new, but Tredgold's recommendation was unequivocally bad by any standard. The strength of a beam is a function of its depth squared; joggling a beam to produce interaction reduces the effective depth and thus the beam's efficiency. Belief in one's ability to match all the bearing faces of a joggled beam seems quite optimistic, and any benefit a cast-iron key would provide in forcefully mating all the bearing faces would prestress (and probably overload) the bottom layer in tension before any actual load were applied—and that assumes we ignore the bolt-hole drilled right through the point of maximum bending stress.

Nearly 70 years after Tredgold's work, Edgar Kidwell, an American engineer familiar with copper mining in Michigan and a professor at the newly formed Michigan College of Mines, performed full-scale tests on a large variety of built-up beam configurations, publishing the results as "The Efficiency of Built-up Wooden Beams" in an 1897 publication of the American Institute of Mining Engineers (Fig. 11).

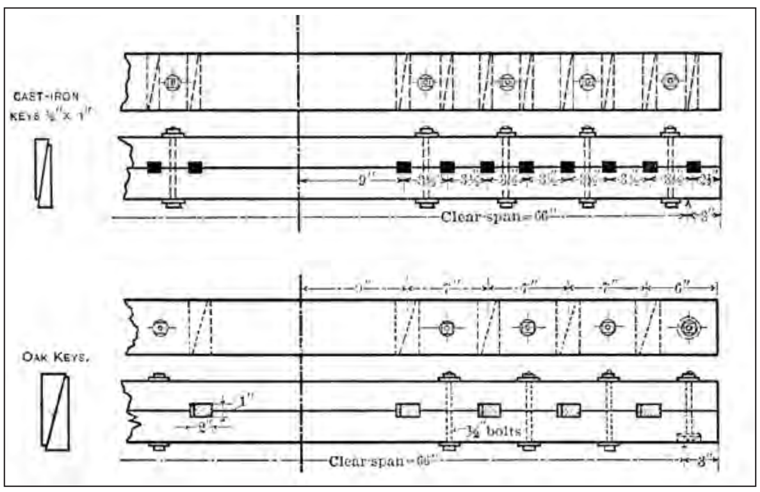


Fig. 11. Kidwell's 1897 drawings of key-laminated beams he modeled, of equal span but with folding wedges of different materials. A larger number of small keys tended to perform better than larger but more sparsely spaced keys. Wedge slopes of 1:8 to 1:10 were recommended.

Kidwell's testing was extremely thorough, and his main findings about key clamping, orientation and the like were essentially the same as those recent research arrived at independently. (Kidwell also unabashedly and succinctly debunked Tredgold's earlier recommendations.)

At the same time Kidwell was using keyed beams for mining timbers, railroad engineers were using them for bridge girders and roof structures. As railroaders were already keen to use metal, cast-iron keys were commonly employed, to the point that certain cast-iron keys were commercially available to anyone for use in built-up beams. Such keys can still be clearly seen in a railroad service building in West Lebanon, New Hampshire (Fig. 12).

Ben Brungraber

Fig. 12. Directional iron keys in built-up beam, West Lebanon, N.H.

Shortly after the turn of the 20th century, mechanically laminated timber beams diminished rapidly in use because of a shortage of materials as well as the advent of structural steel and reinforced concrete. Their use has been revived when warranted by their aesthetic appeal.

Contemporary Examples. For examples of large keyed beams, it is hard to imagine anything grander than a structure in central California framed by Cascade Joinery (Bellingham, Washington) for this "all-large project." The clamping hardware was a celebrated opportunity, a preferred alternative to concealed lag screws, and appropriate to this amazing collection of long-span beams and clustered posts (Figs. 1 and 13).

Jeff Arvin

Fig. 13. The "Birdhouse," a 2000-sq.-ft. addition to a private duck-hunting lodge in California, with clustered posts and keyed beams.

Clustered posts appear again in the work of Randall Walter AIA of Benson Woodworking in Walpole, New Hampshire, who used a copse of heavy keyed posts to support keyed beams in a house in Wawona, California. As large and spectacular as the recycled timbers may be, the keys are in a class unto themselves. The client, who builds high-end auto components, used his own facilities to cast and plate the keys, which are housed and bolted to the timbers (Figs. 14–16).

Fig. 14. At Wawona, California, cluster columns use housed decorative cast keys bolted through timbers to produce composite action.

Randall Walter AIA

Fig. 15. Elaborate washers seen on keyed beams and posts are cast in same style as keys. Decorative ends are cut on solid recycled beams.

Fig. 16. At Wawona, through-bolted cast-aluminum keys electroplated with copper and bronzed fit rectangular housings. Bolt heads lie flush.

Randall Walter AIA

Fig. 18. Keyed hip and purlins meet at top of post at Massachusetts' Tewksbury Country Club. Purlin clamping bolts are spring loaded.

On a smaller scale are the keyed beams in a simple bent building in New Hampshire's Lake Country, built by Hunter Timber Frame Structures in Alton for an owner who wanted a post-free great room. Rather than using yet another hackneyed transverse hammerbeam, author Ben Brungraber designed two decoratively striking longitudinal keyed beams, big enough for an interesting effect and set high enough not to feel oppressive. Two interior posts supporting the roof are simply cut off and land on the keyed beams. Note that the single point load, arriving from above at midspan, makes for simple uniform key spacing (Fig. 17).

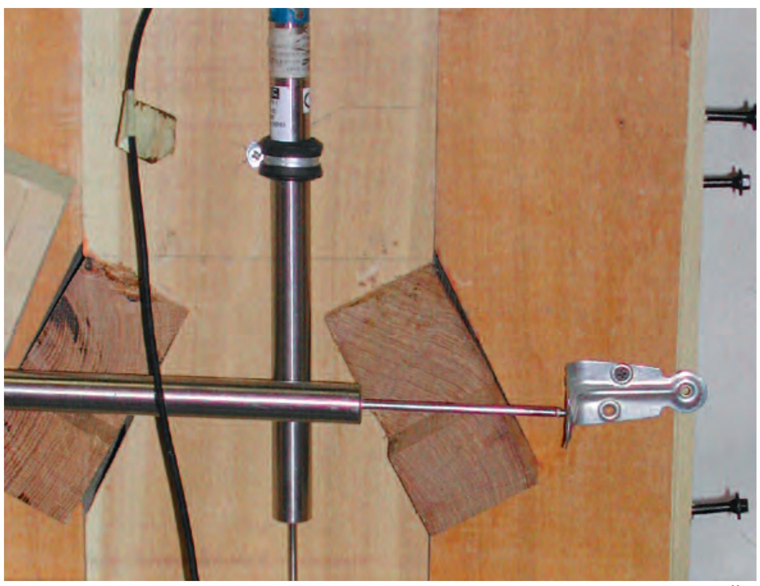
Scott Hunter

Fig. 17. In New Hampshire, triple-laminae white pine beams with sloping, folding-wedge keys. Gaps in central lamina fall at area of no stress and will be occupied by a tie beam joining the keyed beams.

When building a new clubhouse for the Tewksbury Country Club in Massachusetts, north of Boston, Benson Woodworking had only recently started keying beams and recognized an opportunity to lose unprecedented amounts of money by tooling up for the many very large keyed elements designed into the frame. The 72-ft.-square open main room has only four interior posts. A three-piece keyed hip rafter crosses the top of each post on its way from corner to crown. Each post also supports two heavy, widely spaced keyed girts, on which the jack rafters break. Rather than key together three solid timbers to get the required depth, we used deep, heavy shear blocks. This shape exacerbated the load flow eccentricity and accompanying prying action, and very heavy coil springs were installed on the upper ends of the through-bolt clamps to maintain clamping even after shrinkage. This solution was appealing if not entirely successful (Fig. 18).

Keyed Beam Testing. To design keyed beams to comply with modern building codes, a method of accurately predicting not only a keyed beam's strength, but also its stiffness, is critical. Many theorists have developed mathematical models to analyze a beam with interlayer slipping, a great starting point for author Joe Miller's recent research at Michigan Technological University. The theory was expanded, first to account for beams with more than two laminae and, as well, the effect of very widely spaced keys, which are prone to compression and rotation. An analytical model was developed requiring not only the modulus of elasticity of the key and timbers, but also the grain orientation, key inclination, and the number and stiffness of clamping connectors. All of these parameters come into play when determining the amount of interlayer slip in a keyed beam.

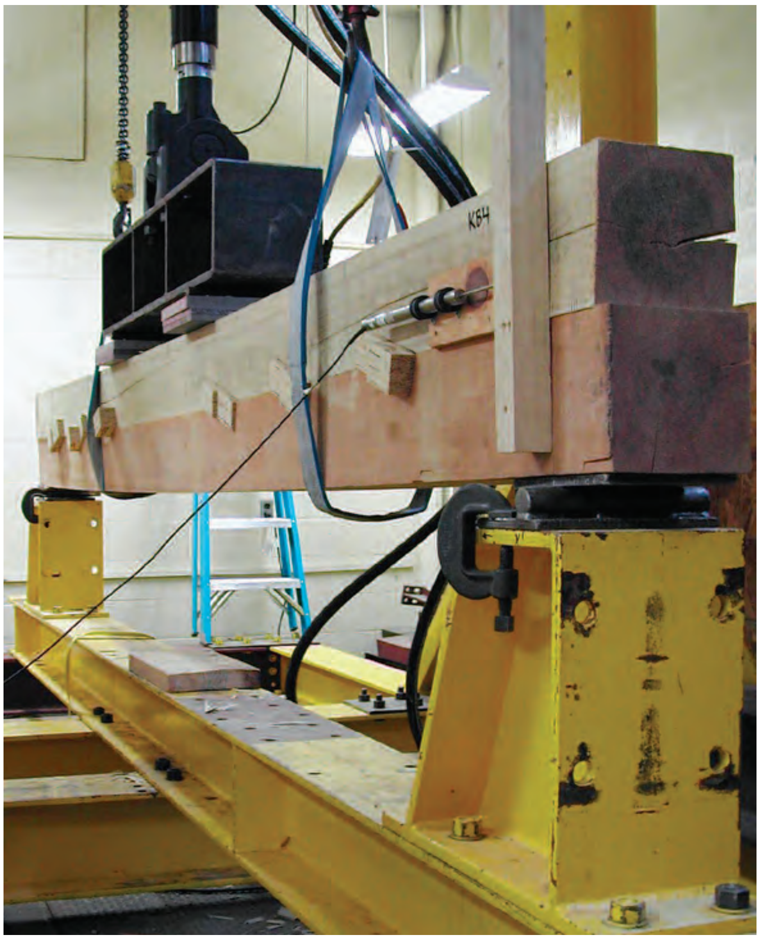
Small-scale testing on individual key configurations determined their actual stiffness, to be compared to predicted stiffness. As anticipated, the keys compressed and tried to rotate; longer keys oriented along the grain of the beam compressed more, but were much less prone to rotating, showing that a delicate balance determines optimal individual key configuration (Fig. 19).



Joe Miller

Fig. 19. Small-scale testing at Michigan Technological University: white oak keys in yellow poplar timbers, excessively loaded.

The analytical model's predicted results closely matched the actual key stiffness from physical testing. With a bit of confidence in predicting the stiffness of individual shear keys, the next step was to jump headlong into predicting the capacity and stiffness of full-scale keyed beams. Several keyed beams, stacked 8x8 yellow poplar timbers, were loaded with one-third-point loads until failure. We recorded the amount of vertical displacement and the applied load as well as the amount of slip between the laminae until the keyed beams failed. White oak keys (compressed perpendicular to the grain) as well as Parallam PSL keys (compressed parallel to the grain) were tested. Fig. 20 shows a keyed beam with Parallam PSL shear keys.



Joe Miller

Fig. 20. Full-scale test, at Michigan Technological University: poplar 8x8 members with sloping Parallam folding-wedge shear keys.

Once adjusted for timber and key moisture content and specific gravity (both of these affect the element's stiffness), the analytical model quite accurately predicted actual beam behavior. As expected, the keyed beam behaved somewhere between how simple stacked beams would behave and how a full-depth solid beam would behave. Predictions were borne out that hardwood keys loaded perpendicular to the grain would crush before the end grain of the corresponding timber notch, and that, when keys were installed with end-grain to end-grain bearing, the fibers would interpenetrate. Both of these phenomena were regularly observed during our keyed-beam testing (Figs. 21–22).

Testing a few keyed beams, however, was not sufficient to fully vet the analytical models. We required additional data. Rather than conduct more tests, which take time, money and a lot of material, we judged Kidwell's test data sufficiently complete to be compared with our analytical model. By happy coincidence, we conducted our tests at the same university (then called the Michigan College of Mines) where Kidwell had conducted his, 110 years earlier. Kidwell had tested several different species of keyed beams made

Joe Miller

Figs. 21–22. At left, side-grain crushing in sloped white oak shear keys. At right, end-grain interpenetration of PSL key in poplar housing.

from two and three laminae, using both hardwood and cast-iron keys. In all cases, within a reasonable coefficient of variation for wood species, Kidwell's test results had been consistent with the predicted results from the analytical model.

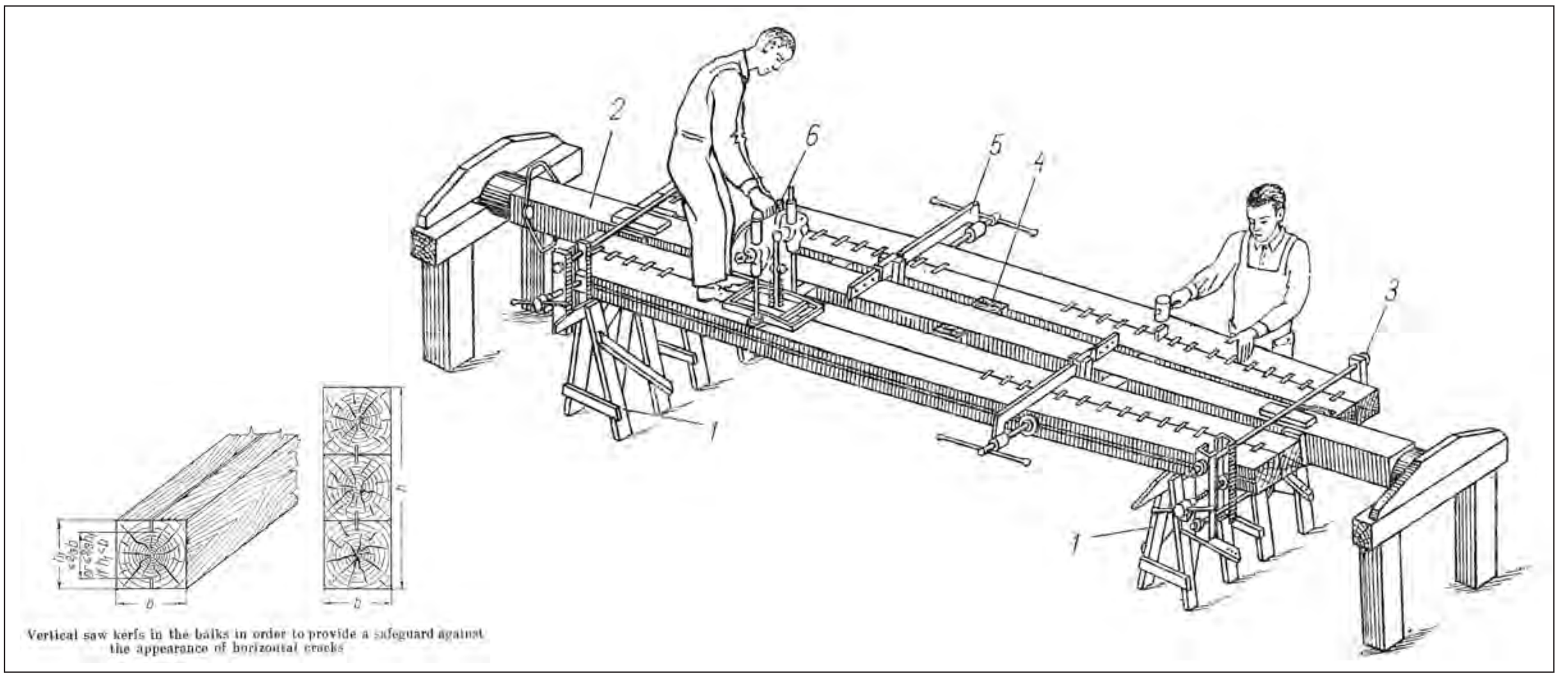
The downside of the analytical model, however, is the amount of computational effort required: it is mathematically intense. The pragmatic engineer wants this process to be simplified and easily implemented. To this end, the European Union's *Eurocode 5* models the interlayer slip using an effective (adjusted) modulus of elasticity and section modulus. While convenient, this method still requires calculating the individual shear key stiffness and is only applicable for uniformly spaced shear keys on a beam subjected to a sinusoidally distributed transverse load. In other words, the simplification is quite restrictive.

So where does all this leave us? With an analytical model able to accurately predict the stiffness and strength of a keyed beam, regardless of key configurations, location and number of laminae, but needing significant computational effort. At this point, no shortcuts or simplifications appear possible to be made to the process. Keyed beams, deceptively simple in concept, are hard to analyze and fabricate.

The Future of Keyed Beams. As long as framers continue to build timber structures, from time to time we are going to want solid timbers larger than are practically available. Keyed beams will fill part of this demand but, given material and architectural restrictions, we are always going to want a little bit more. The next logical step in delivering more out of the same amount of material is to prestress keyed beams, such that their internal stresses will counteract part of their external load stress. This technique falls under the same theory as that of slightly offsetting key notches and using a pair of opposing wedges to forcefully realign them, inducing some positive camber. But inducing large amounts of camber by using opposed wedges will most likely result in localized crushing of individual keys and notches, which effectively limits this method to countering at most the structure dead weight.

The cambering theory is taken a bit further in Derevyagin's beams, named after the Russian engineer who developed them, and consisting of timbers bent across a loading frame in opposite fashion to their in-service deflected shape. While the timbers are bent, notches are made by chain mortiser at the proper spots, and wood plates inserted into the notches. Once released from the loading frame, the natural tendency for the beams to spring back is resisted by the wood plates, resulting in a positively cambered beam. The internal stresses in what will be the top layer of the beam in service are still substantially in tension, whereas the bottom layer is mostly in compression. Figs. 23–24 show the fabrication of Derevyagin's beams, kerfed on the unseen faces against checking on the seen faces.

The bending of the timbers against the loading frame results in much larger prestressing and cambering than is possible just by



Figs. 23–24. Karlsen's drawings showing fabrication of Derevyagin's beams. Stout fixed spine provides anchor for pair of built-up beams clamped around spacer blocks before mortising and keying. Members are kerfed on unseen faces.

driving wedges. An additional purported benefit of Derevyagin's method is that the configuration pinches the wood plates such that eccentric prying forces are reduced, while simultaneously providing some clamping force to keep the laminae together. The authors are at work on a version of Derevyagin beams that, instead of wood plates fitted to kerfs, relies on pegs in drilled holes in the shear plane, where the bearing faces remain parallel and vertical. Fastening the beam with SIP screws will restrain the keys from rolling.

Conclusions. We continue to design, fabricate and install key-laminated beams and posts, convinced that they offer aesthetic, structural and inventory benefits (Fig. 25). We have learned much about the realities of fabricating these surprisingly sophisticated structural elements. The fabrication tolerances can be daunting, even without considering the dimensional changes wrought by new timbers shrinking in place, while "dry" recycled timbers can be quite waterlogged and unexpectedly deteriorated, causing problems if assembled into keyed beams. We expect and hope to continue developing our expertise in their use. There are compelling aesthetic, structural, economic and green justifications for using mechanical lamination. We wish the very best to others in their beam-keying efforts. —Ben Brungraber and Joe Miller

Robert L. (Ben) Brungraber, PhD, PE (ben@ftet.biz), and Joe Miller, PhD, PE (joe@ftet.biz), with Mack Magee, MS, and Duncan McElroy, PE, make up Fire Tower Engineered Timber in Providence, Rhode Island. Ben Brungraber was for many years Operations Director and "chief worrier" at Benson Woodworking. This article was developed from presentations he made to an ASCE Structures Congress and (with Anders Frostrup) to the Guild, and from the PhD dissertation of Joe Miller.

Bibliography

Eurocode 5: Design of Timber Structures. EN 1995-1-1:2004(E). Brussels: CEN, 2004.

Forchheimer, P. "Über Zusammengesetzte Balken." *Zeitschrift des Vereines deutscher Ingenieure,* 36:100-103, 1892.

Goodman, J. R. *Layered Wood Systems with Interlayer Slip.* Dissertation, University of California, Berkeley, 1967.

Hoor, D., J. Natterer, K. Mohler, and K.-H. Goetz. *Timber Design and Construction Sourcebook.* New York: McGraw-Hill, 1989.

Karlsen, G. G., DSc, ed. *Wooden Structures.* A. B. Kuznetsov, trans. Moscow: Mir Publishers, 1967.

Kidwell, Edgar. "The Efficiency of Built-up Wooden Beams." *Transactions of the American Institute of Mining Engineers,* 2/1897–7/1897:732-818, 977-993. See also http://books.google.com/books?id=WEwLAAAAYAAA&printsec=titlepage&source=gbs_summary_r&cad=0#PPA732,M1

Leupold, Jacob. *Theatrum Pontificiale: oder Schauplatz der Brücken und Brücken-Baues*. Leipzig: C. Zunkel, 1726.

Snow, J. P. "Wooden Bridge Construction on the Boston and Maine Railroad." *Journal of the Association of Engineering Societies*, 14:500-512, 1895.

Strukel, M. *Der Brückenbau.* Kuopio, Finland: O. W. Backman, 1900.

Thelandersson, Sven and Hans J. Larsen, eds. *Timber Engineering.* UK: John Wiley & Sons, 2003.

Benson Woodworking

Fig. 25. Many small keys produce desired composite action in Douglas fir beam in contemporary timber frame.

TTRAG 2009

THE Traditional Timber Framers Research and Advisory Group held its 18th annual public symposium at the Union Bluff Meeting House, York, Maine, April 17–19, with two days of plenary presentations, demonstrations, tours of a private barn nearby, Fort McCrary Blockhouse and the buildings of Old York, and a slide show. The presentations ranged over forest ecology, preservation opportunities and case studies, and local and Maine history, and one provided glimpses of timber frames in Nova Scotia, but the majority of framing information was in the narrated slide show. Excerpts follow from three such narratives.

Gerald David

Iron strapping at principal truss joins lower chord, tension leg and princepost (drawn at right below). Wood sticks carry ceiling.

Nantucket's Second Congregational Meeting House, 1809

Gerald David, MLB Restorations

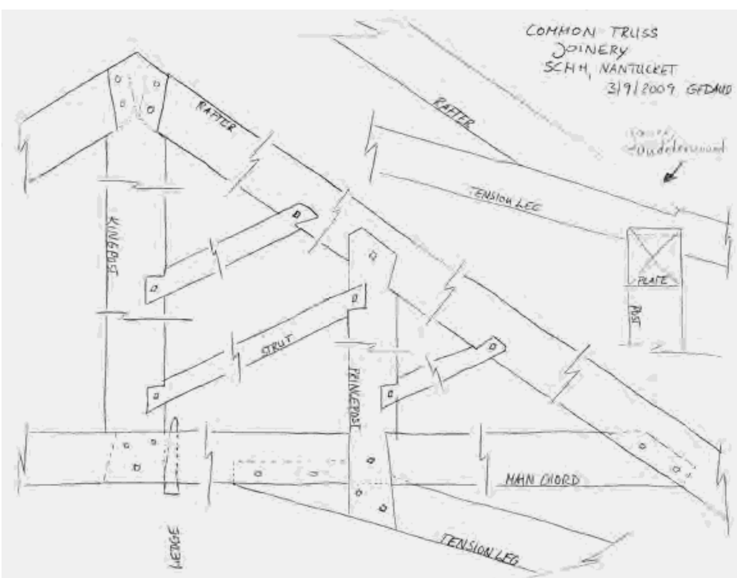
THE original plan of Nantucket's Second Congregational Meeting House was a 65x55-ft. rectangle, with an eaves height of 32 ft. A pavilion was added to the front in 1830. The sanctuary has a painted plaster ceiling with a large oval dome in the center. The ceiling is suspended by simple sticks from the roof trusses.

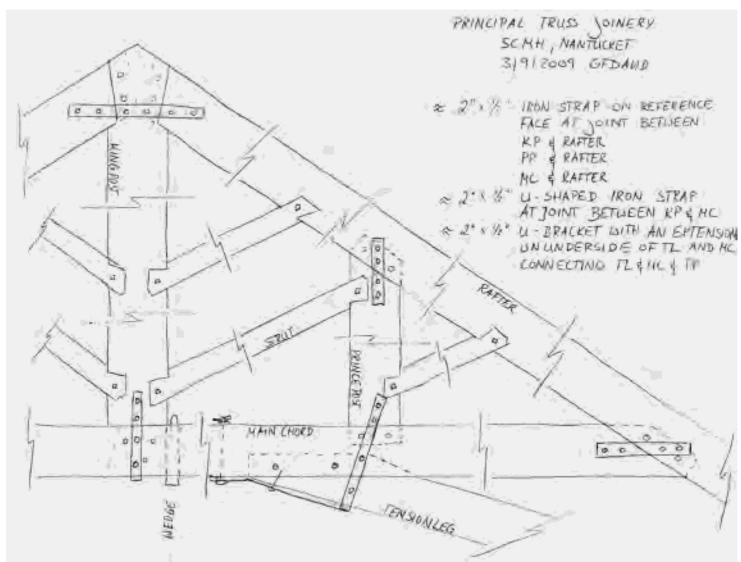
The sanctuary is spanned by kingpost trusses with raised tie beam, princeposts and what we referred to as "tension legs" rising from plate to tie beam. Eight struts per truss have half-dovetail lap joinery and are spiked in place. There are 14 trusses, every third one a beefier principal truss with tenoned joinery at the princeposts rather than the lapped joinery of the common trusses. There are also original forged iron straps and brackets on the key joints of the principal trusses, which have performed admirably. In addition to its extensive lap joinery, unusual for the date, a curious aspect of this roof frame is irregular placement of individual members from truss to truss. The timber sections are also quite varied, even within a truss.

In addition to identifying and repairing obvious local failures, we identified the connection among princepost, tie beam and tension leg in the common trusses as a design weak point of the roof structure (drawing, lower left). Together with engineer Janet Kane, of Burlington, Vermont, we designed a reinforcing bracket that we were able to install in full on the four outside trusses and in part on the trusses adjacent to the ceiling dome rising into the church attic, where clearance was limited.

Meeting house obscured behind pavilion with tower, added 1830.

Lap joinery at kingpost. Notched lap at left resists tension.





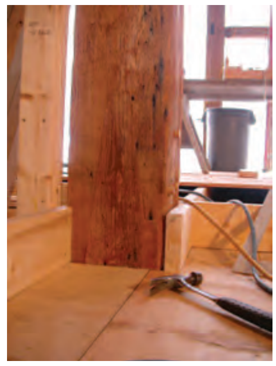
Wilmers Barn

David E. Lanoue, Inc.

Photos Peter Smith and David Lanoue

Wilmers barn, 1827, viewed from the east, Berkshire County, Mass. Oak, chestnut, hemlock and pine. To be converted to guest house.

Clapboard saved and packed away in felt. December takedown always risky. No injuries. On to the warm shop.



Post repairs in shop and installed in restored frame. Gerard Laflamme at left, Mike Fountain above.

Walkout wall assembly flown in.

First bent raised.

Last bent raised.

Purlin posts, purlins and roof ridge added.

Tenoned rafters brought up one by one.

Staged up for roof boarding.

House frame built over barn frame.

Sheathed and wrapped. Winter again!

All done.

Photos Jan Lewandoski

Figs. 1–2. Gaysville Community Church, 1863, and interior staging to carry loads from damaged area in attic above.

Figs. 3–4. Inner end of paired 5x12s, carried on lengthwise 8x8. At right, Chris Patton fits housed thrust block against truss rafter.

Fig. 5. Heavy bolt clamps paired 5x12s to truss rafter, shares thrust with housed oak block. New shaved end for round common rafter, dovetailed patch for plate just visible under nearer 5x12.

Gaysville (Vermont) Community Church, 1863

Jan Lewandoski

AN extremely common mode of truss failure, difficult to remedy, is caused by deterioration at an extremity, with damage or failure of the tie beam end, the foot of the principal rafter and likely the plate at the tie beam connection. Sometimes the problem spreads to common rafters, inner principal rafters and even wallposts, always affecting their joints at the extremities. The first stage of decay is usually caused by roof leakage, generally much worse near the eaves because of ice damming or wind blowing sheets of metal roofing free, or simply more accumulated water arriving at the bottom of the roof. In the 1863 Gaysville church, the problem had been made much worse by the addition of a poorly flashed exterior chimney that cut through the eaves at the end of a tie beam.

The Gaysville Church (Fig. 1) has a somewhat unusual roof frame. Tie beams 8x9, 42 ft. long and 36 in. on center, span the interior. Tapering spruce pole rafters (about 10 in. maximum diameter) tenon into the tie beam ends where the latter cantilever over the plates to form the eaves. At the peak, the rafters tenon into a five-sided ridge, to form a series of simple triangles the length of the roof. Necessary support for the long tie beams is provided indirectly by three kingrod trusses spaced about 12 ft. apart, each built on one of the 42-ft. tie beams. The principal rafters of these trusses, much lower pitched than the common rafters, tenon into their tie beams about 12 in. inboard of the plate. Wrought iron 1-in.-dia. kingrods drop from the peak of the inner principals to carry end-to-end longitudinal 8x8 spruce timbers that cross and half-lap over each of the tie beams at midspan.

The leakage at the chimney had rotted 6 ft. of tie beam and 3 ft. of plate, and the roof rafter had been cut off to allow the chimney to pass. The inner truss rafter was seated in the rotted material of the tie beam, which had failed and dropped almost 3 in. below the plate into the main room of the church, breaking the plaster ceiling. As is often the case, when we were called to repair Gaysville, the church had just installed a new standing seam roof over the problem, so our challenge was to repair this truss without opening the roof. The longitudinal timber and an inner truss provided the opportunity.

First we supported the damaged tie beam all the way from the ground, using timber cribbing in the crawl space, a timber frame structure that churchgoers could walk through in the lower part of the main room, and structural scaffolding at two different locations above (Fig. 2). We then dismantled the inner truss, dovetailed a repair section into the plate, scarfed a repair end on the tie beam and scarfed a new 8 ft. section of round spruce pole into the common rafter, tenoning it into the new tie beam end. At this point everything was restored within its original form, but the scarfed tie was not strong enough to bear the inner truss rafter.

Consequently we brought two 5x12 spruce timbers 24 ft. long in through a decorative louver in the attic, and notched them so they would hook over the central longitudinal timber at one end (Fig. 3) and over the plate at the other (Fig. 4). These secondary or upper tie beam segments were spaced to clasp the inner truss rafter and actually take its main thrust. The inner truss principal rafter was still tenoned into the tie beam, now repaired, but before allowing it to bear fully there, we intercepted it with restraint at the two 5x12s. A 1½-in.-dia. bolt clamped the three together and picked up both vertical and horizontal loads, and a 3-in. white oak shear block, shouldered into the 5x12s and shouldered as well against the inner principal rafter, also picked up that rafter's horizontal thrust (Fig. 5). The great strength of the paired 5x12s was also used to hang the repaired tie beam on suspension rods at two points and to strut to the scarfed common rafter above.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