TIMBER FRAMING

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Adaptive Reuse in Massachusetts

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TIMBER FRAMING, Journal of the Timber Framers Guild, appears in March, June, September and December. The journal is written by its readers and pays for interesting articles by experienced and novice writers alike.

TFG 1985

TOPICS

A Rookie's Diary

I WAS a local volunteer for the Guild's Red Mill Pavilion project in Portland, Michigan, last August. This was my seventh year with the Portland farmers' market and my second with Friends of the Red Mill. I had joined the Timber Framers Guild in March and from the moment I saw the pavilion model I knew I wanted to help get it up.

Day 1 I got to the site early but the timber framers were already working. While walking through the pavilion construction area, I noticed there were only six big posts. Since I had glanced at the plans, I knew there were supposed to be eight big posts on each side. So, I said to Todd, the post leader, "Hey, you only have six posts. You need eight posts." Todd looked at me over the top of his glasses, then went back to work. I thought, "He's busy. I can take care of this."

I trotted down to the place where the wood was. There were a couple of 12x12s. I trotted back up to the work site and stopped one of the telehandlers, operated by Chris. I said, "That guy in the pavilion needs two more posts. Can you get them for him?" Chris said, "Sure, I can get them when Todd needs them. Why don't you report to the brace station." Based on Chris's inflection, I do not think it was a question.

I reported to the brace station just in time to see Drew using the largest hand-held circular saw I have ever seen.

I said, "Wow. That looks dangerous!"

Standing next to me, Dan said, "Yes, I sliced my thigh and cut my femoral artery with a saw like that. Lucky I didn't bleed out before they got it pinched off."

Then Drew said to me, "Hey. Sorry. I don't want to be a saw hog. Would you like to try this?"

I stepped back and blurted, "No. I want to learn how to mark things before I cut things."

Dan said, "Tim, can you teach this guy how to mark things?"

Tim said, "Let me see your pencil." I reluctantly showed him.

He said, "Let me show you how to sharpen a pencil." Then he introduced me to a timber-framing tool I had never used, an eraser.

I asked, "Before we get started, which counts most, speed or accuracy?"

Tim responded, "Both."

But, based on subsequent experience, I would say that with this group accuracy counted most. For instance, Dan, Tim and Evan (visiting from another station) were discussing the distance between spring points on the small braces. They all whipped out their calculators. They agreed the necessary number (missing from the project engineer's drawing) was $38\frac{29}{32}$ in. There ensued a discussion about revising the layout to yield something people could understand, such as $38\frac{7}{8}$ in., or $38\frac{15}{16}$ in. so people could get some practice paring. After less than an hour, the three agreed to compromise. The compromise was $38\frac{29}{32}$ in.

I marked three small braces that day and got two right. Not a bad average if you are hitting a baseball. Not a good average if you are a timber framer. Their average was 100 percent.

Day 2 Today we tackled the math on the big braces, for which the project engineer included even less information on the drawing. Given the amount of fun these people have figuring out the distance between spring points, I began to suspect the project engineer was not as incompetent as I initially thought.

I marked out three big braces. Two were right! Woo hoo! Tim informed me gently that we did not have enough material to waste one-third. I didn't know what to do. Tim said, "You know that eraser I gave you? Use it."

Day 3 I accompanied my spouse to an appointment.

Day 4 Reporting for duty, on time, sir, I asked Tim what he wanted me to do. He said, "Go talk to Will." I had only been working two days. My error rate was 33 percent. Then, I skipped a workday. I figured I was being fired. I imagined the speech: "Thank you for your service. But we don't need your services now."

Will said, "We are setting up a carving station. Stop crying. Do you have any carving tools?"

"I do," I cried.

Will said, "Vicky will be on station with you as soon as she finishes the hip [something-or-others]."

I ran home to get my carving tools and to print out the letters in 624 points so they could be transferred to the Douglas fir beam which had been tastefully planed in all the right spots. To my horror (I should have said something to prevent this), the letters got glued as templates to the face of this beautiful Douglas fir beam. Possibly this was a spot where speed counted more than accuracy.

Vicky asked me how long I had been carving. I said since 1985. She said she was one year old in 1985. However, Vicky has seniority in the TFG, so I deferred to her.

Like any good boss, she asked, "What should we do?"

I showed her my basic carving chisels. Using a half-inch chisel, a tiny tool for her since she was used to a 2-in. framing chisel, Vicky did a great job on her first letter. But there is a time when caring for yourself is smarter than learning a new art. Suffering from a cough and obviously in distress, after doing what she could Vicky wisely called someone to care for her.

Day 5 As I whacked away at these paper things pasted to the beam, Pat appeared and said she'd been assigned to me.

"Great," I said. "Here's a chisel. Start cutting over there."

"I've never carved before," Pat said.

"Don't worry, I have Band-Aids."

Fortunately, Pat's husband Ron appeared on a break from his real assignment and gave her some tips and chipped some wood. This happened several times, which basically saved the project.

I was trying to get this project done but people kept showing up to help. I took a breath and tried to remember that this was a community project. So I realized that it would be good if I could work with people.

Day 6 Mike appeared, to carve. I wondered why he was there. He said there had been a shout-out on Facebook asking for anyone who knew anything about carving and was willing to sacrifice themselves to the community.

I gave Mike a chisel and said, "Carve your name in that wood." He did really well—only one spelling error, so he was hitting 75 percent. Since my average was lower, Mike was now my master carver. Later, Tony appeared and said he could only stay for an hour but would be back tomorrow. I gave him a chisel and asked him to carve his name in the wood. He did a really good T, so I said, "Come back tomorrow."

Pat said, "You need to have steel-toed shoes; you must register and attend a safety meeting."

Oh man, I forgot that! Pat immediately became my head of human resources.

Lisa appeared, to volunteer. We started laying out letters and Nancy, Lisa's mom, appeared to talk menu for their dinner for the timber framers. Nancy was standing between the sticks, between me and my tools.

I asked, "Nancy, would you mind standing over there in the hot sun, so as not to interfere with progress on this project?"

She said, "Of course not, Lee. I understand that progress may demand some sacrifice on the part of older individuals, who, if we did not exist, you would not have been born."

Later, Nancy said, "I feel light-headed." Then she fainted with more grace than I usually see in a faint. Several timber framers ran over to assist, to make sure Nancy was okay. Someone called 911. I told Nancy to close her eyes. Occasionally I asked how she felt.

Once she said, "I feel okay but I get this occasional tingling on my face."

Tony Sporer (artistic director), left, and Mike Judd (master carver).

I said, "That is the wood chips, Nancy."

She asked, "Are you still carving, Lee?"

I responded, "Nancy, we are on a schedule here."

She said, "I understand."

The carving station health and safety record was now the worst on the project (and the only one to be visited by 911). But Nancy was okay. She was probably just dehydrated.

Day 7 I took half a day off to accompany my spouse to knee surgery. I worried this would cause another reassignment. In the afternoon, when I got to the carving station, Tony, Mike and Pat had things well in hand. With occasional help from Ron, they were cleaning up the carving. Tony had the best idea for darkening the letters. He immediately was appointed artistic director, not just because he had an original idea but also because he could differentiate between five shades of brown.

Pat and Ron announced they were taking the weekend off to go on the longest garage sale in the world. I felt sad to lose them but I knew they must do what they must do.

Last raising day, cupola flying.

Day 8 Tony, Mike and I got an early start on Saturday, eager to complete our assignment. Here I should mention mission creep. That is when your job expands because someone remembers that Boy Scout Troop 58 should be carved on the beam. Later someone else says that will make the carving look unbalanced, so "Timber Framers Guild" should be added to the other side next to the logo. I only mention mission creep so you will be aware you may encounter it. Fortunately the carvers could handle it, and by the end of the day, we were proud and happy to have completed our assignment an hour early. Tony, Mike, Ed and I celebrated with Judy's blueberry pie, happy that Day 8 was a market day.

Day 9 This was the second Sunday and the framers had the day off. More than half of them were at the site because they enjoy timber framing on their days off.

Leon and Evan were working on the cupola, Leon cutting the 2x6 tongue-and-groove ash, Evan nailing it in place.

I became the timber handler. My job was to keep Leon supplied with boards to cut, pick up pieces that might be stumbling hazards and occasionally hand a board up to Evan. With two guys on the ground, Evan started to fall behind. Dan came to help. Then Mike came to help. Three guys on the roof were enough to keep up with Leon but eventually they were bumping into each other. So they started taking turns. By the end of the day, the roof boards were in place and the cupola station had a perfect safety record. I was very proud.

Day 10 Lots of material was moving and the walls were going up. Given my vast experience, I thought it best to stay on the porch and offer helpful advice or answer questions.

Day 11 The crane set five trusses. The first truss had the carving. These darn allergies surprise me at the most inconvenient times.

Day 12 The last truss was set and the cupola flew. The crane departed. The wetting bush was put in place. I reviewed the contract looking for loopholes to keep these people here.

Day 13 I spent the day on the porch in awe, watching people move everywhere, securing big chunks of wood.

Day 14 It was time for the family photo. Many framers had already departed for home, but the ones still here gathered on the top of their creation. Few things beat creating something great. Doing it with 60 others makes it even greater.

Chris and Tim were still cutting mortises and tenons. Clearly, they did not want to leave Portland. Turned out this was the bonus bench station. Framers here were building benches with oak legs, ash seat and ash back. There were through-tenons (whatever those are) with walnut wedges. The first bench was really pretty. I tried to steal it. I could not even lift one end. I asked Chris for keys to a telehandler. Surprising me, he declined.

Day 15 The farmers (note small switch in spelling) set up for the market near the pavilion but not in it. People kept bumping into each other because they were looking at the building rather than watching where they were walking.

I introduced Sarah and John to some of the farmers. They were waiting for Carl to return from dropping Tim at the airport. Then they would be gone too. I didn't say good-bye because these darn allergies prevented me from speaking clearly right then. Darn allergies. —Lee Hunsberger

Guild Notes & Comment

The New Guild

FOLLOWING on the enthusiasm of the Manchester 2014 unification conference, where the reuniting of the Timber Frame Business Council with the Timber Framers Guild (amicably divorced since 1995) was proposed and discussed, and the positive membership votes of both groups last April, the reconstituted Guild, complete with new bylaws, a new executive director and a board enlarged from nine to twelve directors, held its first conference—which happened to be the Guild's 30th Annual and its 26th Western—the last weekend in October at the Coeur d'Alene Resort in Idaho. Inspiring in spirit and wide-ranging in content, it drew above 200 people and was judged a financial success even before the record-setting fundraising auction.

In a featured speech, the artist Richard La Trobe-Bateman, a moderate provocateur, a British pixie without the pointed hat, explained the evolution of his structural thinking after graduation from the Royal College of Art, where he was much impressed by the teachings of David Pye, whose books *The Nature and Art of Workmanship* and *The Nature and Art of Design* many of us have encountered. Richard began by building chairs, then tables, then bridges, which continue, and all of which are about self-expressing structural systems, whose tension and compression members might as well be painted in red and blue, respectively, so starkly do they contrast. The elegant, sometimes weightless-looking bridges he showed us are all on private property, leading one of our timber engineers to sniff, "Hmm, never had to meet a code." Such is the freedom of art.

In other plenary talks, Alex Wilson, founder and executive editor of *Environmental Building News* and a luminary in the world of sustainable building, introduced us to the notion of *resilience,* the ability of buildings to withstand extraordinary events such as flood or tempest, where relatively small investments in anticipatory design can provide substantial advantages later. And to conclude the conference, John Abrams (South Mountain Company, Martha's Vineyard), designer, builder, author and long a friend of the Guild, reflected on critical changes in businesses as biological events—not whether they might be good or bad, but how they work.

BUT what of the new Guild? What's the biology of our critical changes? There are clues on our new website, which announces the style of the new Guild by its upbeat language and thorough monetization, with ads on every page unrelated to any content (something to do with search engine optimization), and an elaborate structure its builders call "intuitive," but which visitors will find it takes a while to learn (six- and eight-item dropdown menus under three main headings, plus nine top-menu options). Under *Communications > TFG Companies*, we find a list of Guild benefits to member companies, concluding thus:

> Few of these [benefits] are likely to appeal to a guy with a chisel in his hand, yet each one is vital to a well-run, prosperous company. And each and every one of these items can be enhanced and expanded—if we have financial support from companies. The TFG will not thrive on individual memberships alone.
>
> Timber frame companies have been benefiting from the Guild's strong brand for many years. Now, with the integration of company members, the Guild has the opportunity to expand its focus from a solely craft-based vision to one that includes outreach to specifiers and end-users (architects, engineers, general contractors, and building owners—the people who make buying decisions), increasing even further the Guild's value to member companies. Our business-related efforts should be less about "Expand the Demand." It should be more focused on "Build the Guild." The Guild's ongoing story is much more appealing to specifiers, buyers, and prospective customers than a group of companies "growing the pie." In the context of the Guild's more compelling story, we can give them all the information they can possibly want or need to become informed users and customers. If the Guild rises to the challenge of improving operations and offerings, and expands its focus, then it can further build a strong, vital community that will be the tide that lifts all boats.

The writer says in successive sentences that the Guild will not thrive on individual memberships alone, and that timber frame companies (while not members of the Guild but rather of the Business Council, or of neither) have been benefiting from the Guild's strong brand for years. It's probably true that timber framing companies have benefited more from the Guild's public panache and steady educational activities than from the work in the commercial trenches by the Business Council.

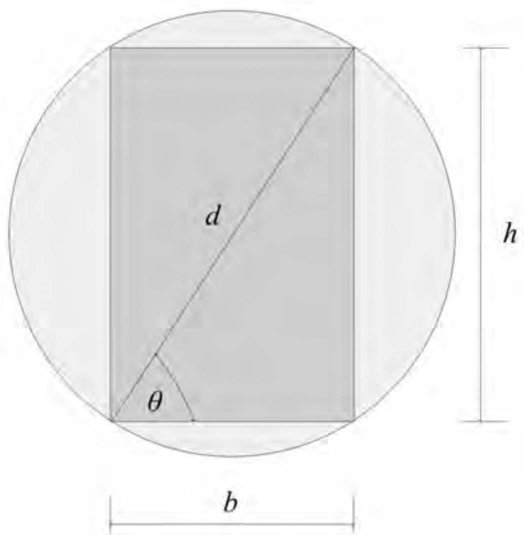
But, as for individual memberships, the Guild's "strong brand" was built precisely on individual membership dues (before 1995, augmented by company memberships that proved unneeded after the divorce), and then, as the Guild really got moving in big public projects and large conferences, with substantial augmentation from project and conference income. Conferences drew 350 or 400 people, and budget flows exceeded $900,000. Membership rolls climbed to 1800 before the recession of 2008 and remained at 1400 as late as 2012. Whatever the Guild did, including some 75 public projects, was built on individual memberships and project income (and, in later years, Guild auctions and online store sales, as too-small conferences made losses). Sponsorship played no role except to fund specific events at conferences. Advertising played no role except to support our print publications directly, in displaying goods and services of plausible interest to Guild members.

Today, after our 2013 troubles and 2014 reorganization, we have some 900 individual members, a budget flow under $500,000 and a new funding model. Sponsorship ("Visionary Partners") provides an amount of funding roughly equal to individual membership dues. Company memberships are expected to contribute another half of one of those units, and project income will be what luck and good management produce; the store and the annual auction abide. May the new model do as well as the old. —Ken Rower

Optimal Conversion of Logs to Timbers

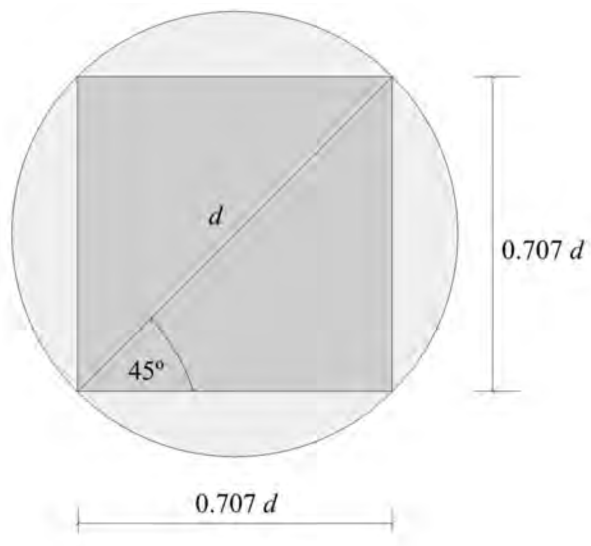
IN preparation for the apprentice training program last February hosted by Frameworks Timber in Fort Collins, Colorado, Curtis Milton, chair of the Apprenticeship Training Committee, prompted an examination of the relationship between the trade-based understanding of converting logs into timbers and the engineering principles behind the conversion. The question becomes, what are the proportions of a rectangular timber cut from a round log that maximize the use of the material? As with most such questions, the definitive answer is "It depends."

First consider the mathematical approach. Given an ideal, circular-section log with diameter d, we can inscribe a rectangle of breadth b and height h (Fig. 1).



1 Rectangle inscribed in a circle.

Drawings Dick Schmidt



2 Optimal post cross-section.

Timber dimensions b and h are related to the diameter d by the simple trigonometric functions $b = d\cos\theta$ and $h = d\sin\theta$.

Since we know d, we need only find the angle θ to find our timber dimensions. The optimal value of θ depends on what we want to optimize, or more specifically, maximize. Three geometric properties of the timber cross-section are likely candidates: area, section modulus and moment of inertia. The maximum area gives us the strongest post; the largest section modulus gives us the strongest beam in bending; and the greatest moment of inertia yields the stiffest beam in bending. As expected, optimizing for each of the different criteria gives different results.

Start with maximum area. The area of the rectangle inside the circle is

$$A = bh = d^2 \cos\theta \sin\theta$$

As an application of Newton's differential calculus, we note that the optimal value of θ in this equation is that for which the first derivative of A equals zero, hence yielding a maximum value of the function. Application of this principle gives

$$dA/d\theta = d^2 (\cos^2\theta - \sin^2\theta) = 0$$

Solving for θ, we obtain the well-known result $\theta = 45°$. So the optimal cross-section for a post (Fig. 2) is a square of dimension

$$b = h = d\cos 45° = 0.707\,d$$

Next, consider section modulus S, the cross-section parameter that determines a beam's ability to resist bending moment. For a given material, the larger the section modulus, the larger the bending moment the beam can carry. A rectangular cross-section bent about its strong axis has section modulus

$$S = bh^2/6 = (d^3/6)\cos\theta \sin^2\theta$$

We again maximize this expression by setting the first derivative equal to zero:

$$dS/d\theta = (d^3/6)(2\cos^2\theta \sin\theta - \sin^3\theta) = 0$$

This equation is satisfied when $\theta = 54.7°$, and the resulting proportions of the beam cross-section (Fig. 3) are

$$b = d\cos 54.7° = 0.577\,d$$
$$h = d\sin 54.7° = 0.816\,d$$

Finally, we get to moment of inertia I, the cross-section parameter that governs deflection of a beam subjected to bending moment. For a given beam span and loading, the larger the value of I, the smaller the deflection. A rectangular cross-section bent about its strong axis has moment of inertia

$$I = bh^3/12 = (d^4/12)\cos\theta \sin^3\theta$$

Maximizing one last time, we have

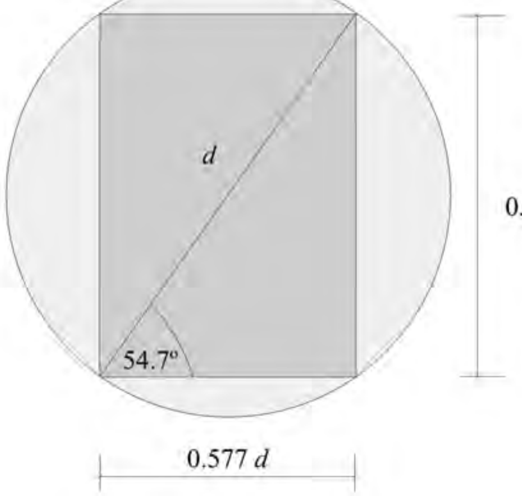
$$dI/d\theta = (d^4/12)(3\cos^2\theta \sin^2\theta - \sin^4\theta) = 0$$

This equation is satisfied when $\theta = 60°$, with the proportions of the beam cross-section (Fig. 4) given by

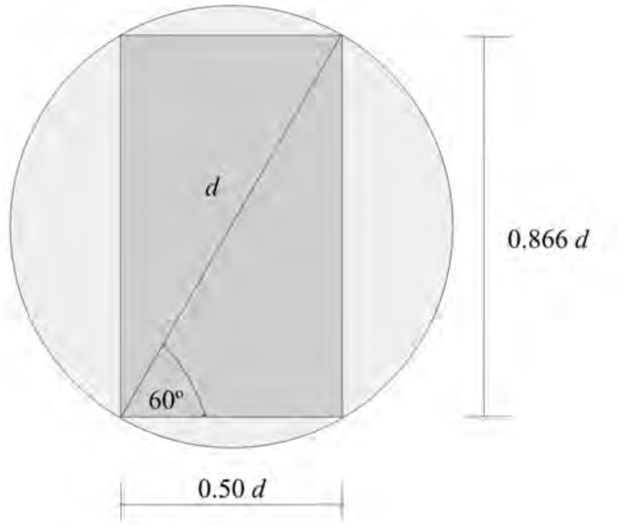
$$b = d\cos 60° = 0.50\,d$$
$$h = d\sin 60° = 0.866\,d$$

Suppose we want to lay out one of these optimal cross-sections on the end of our log. Do we need a protractor to lay out those the angles, or is there a direct geometric construction approach?

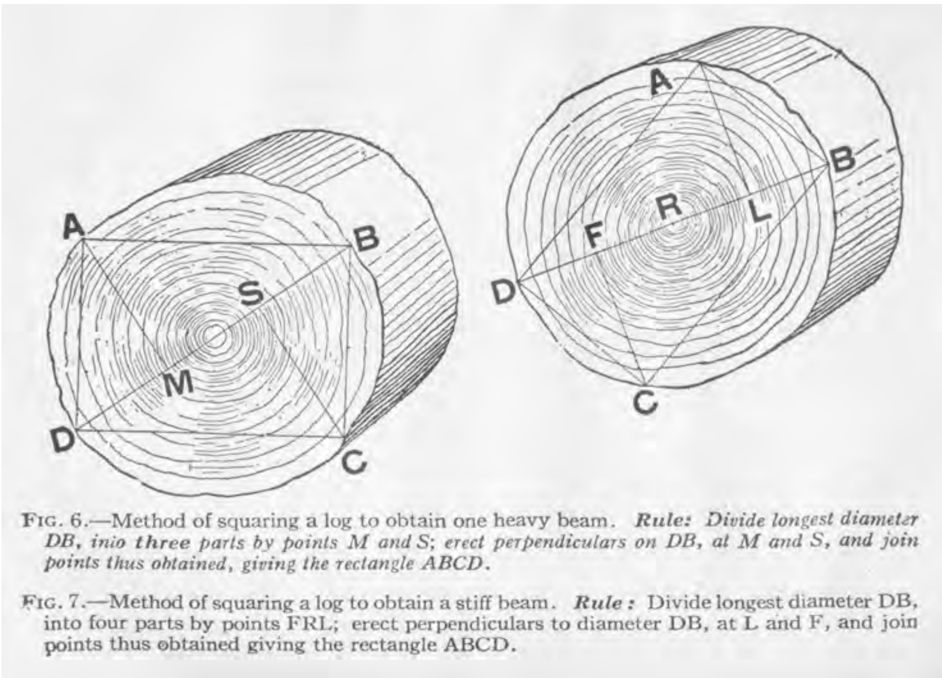
What's truly intriguing with the direct approach is how sweetly it works for all three optimal cross-sections. The approach long known to the trades (and pointed out by Will Beemer, a principal



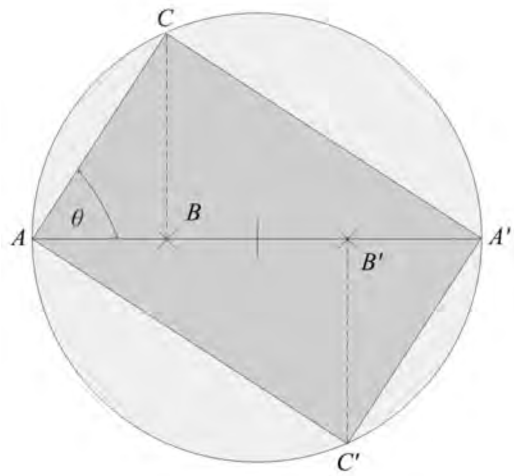
3 Optimal beam cross-section for strength.



4 Optimal beam cross-section for stiffness.



Audel's Carpenters and Builder's Guide #1, 1923



5 At left, methods illustrated in *Audel's Guide* to obtain strongest and stiffest beams from log.

6 Above, generalized layout for both methods.

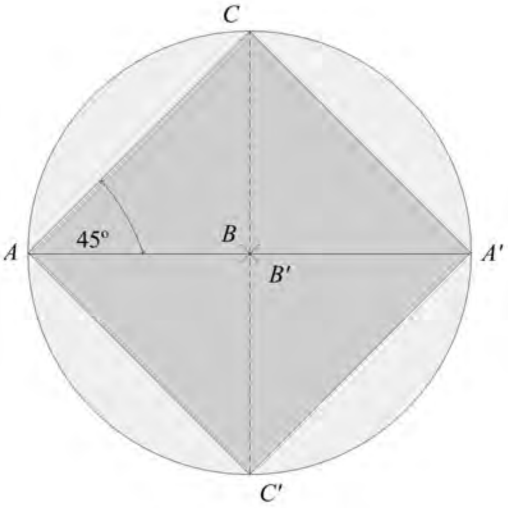
Gabel Holder

designer of the Guild's apprentice program, who discovered it in the 1923 edition of Graham and Emery's *Audel's Carpenters and Builder's Guide #1*) is illustrated in Fig. 5.

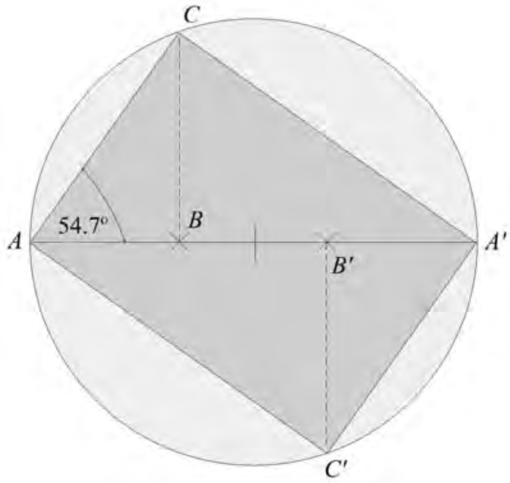
To generalize the approach demonstrated in Fig. 5, consider the layout in Fig. 6. Strike diagonal line $A - A'$ on the cross-section of the circular log. Mark points B and B' equidistant from the center of the log. Strike vertical lines from B and B' respectively to the circumference of the circle at points C and C'**.** Now inscribe a rectangle with corners A, C, A' and C'**.** The proportions of the rectangle depend only on the location of point B.

Given the exponents in their dimension, we can regard area, section modulus, and moment of inertia as second-order, third-order, and fourth-order quantities, respectively. (Area is measured in square units, section modulus in cubic units, moment of intertia in quartic units.) Hence, to test the direct layout approach, let's partition the log diameter successively into two, three, and four parts, as suggested in Fig. 5, and compare the resulting rectangles to the optimal sections in Figs. 2–4.

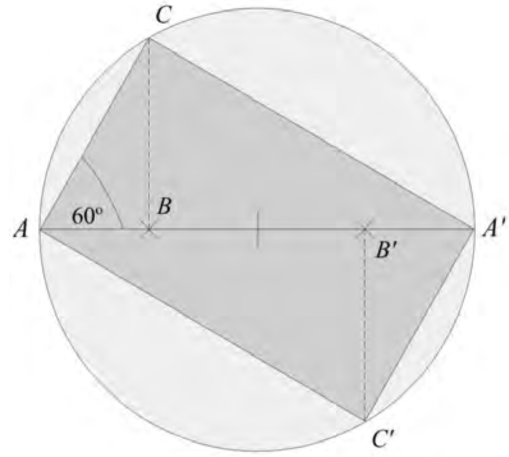
At left, framer Will Truax converts loblolly pine log to deep rectangular beam, Charleston, S.C., 2007.



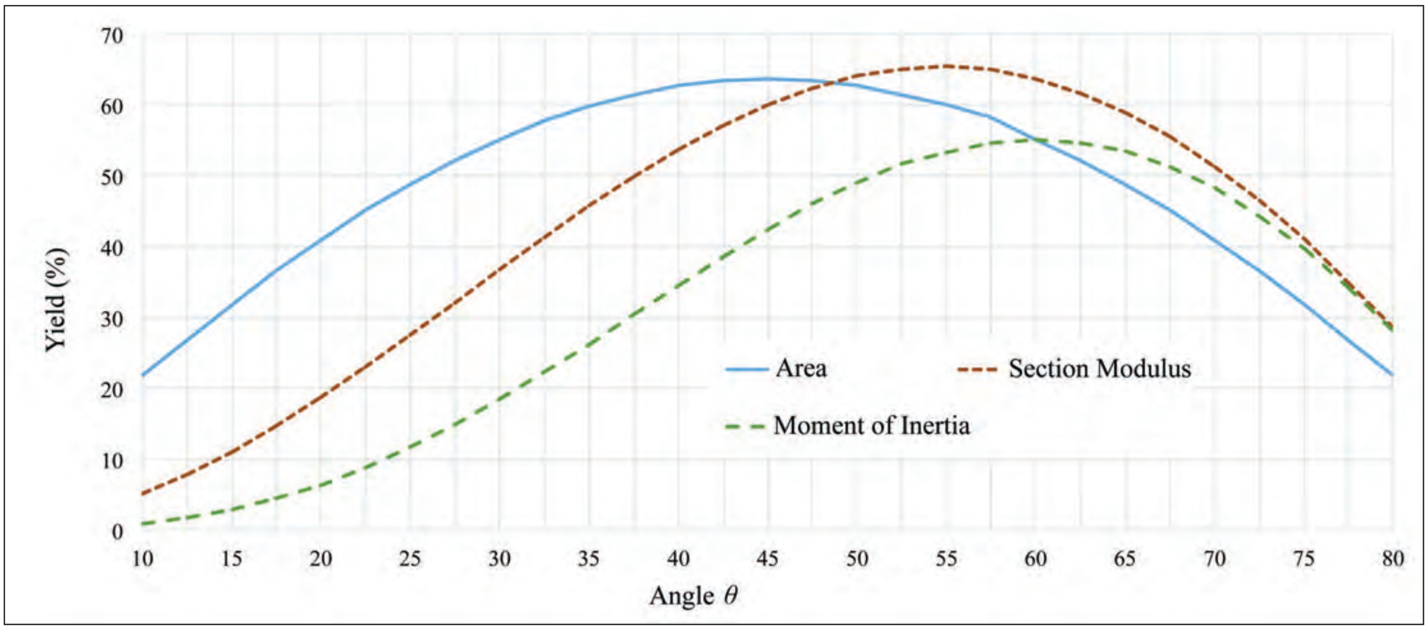
7 **Direct layout of post.**



8 **Direct layout of beam for strength.**



9 **Direct layout of beam for stiffness.**



10 **Round log conversion yield.**

For the post cross-section, divide the diameter into halves, which places both B and B' at the center of the circle (Fig. 7). For beam strength, partition the diameter into thirds with B and B' at the third points (Fig. 8). Finally, for beam stiffness, lay out by quartering the diagonal and placing B and B' at the quarter points (Fig. 9).

A quick check of the geometry of the rectangles in Figs. 7, 8 and 9 reveals that they are indeed identical to those obtained by the mathematical approach. Hence, we conclude that the partitioning approach known to the trades is consistent with the principles of mechanics. Is the link between the two truly a consequence of the order of the dimensions of area, section modulus, and moment of inertia? Or is it just a convenient coincidence, while some other more fundamental principle is at play? An answer to these questions is under development.

In reviewing a draft of this article, my colleague Mack Magee observed yet another curiosity: the length of line segment AB in Figs. 7, 8 and 9 is in each case

$$AB = d\cos^2\theta$$

—an expression that also yields the ½, ⅓ and ¼ fractional divisions of the diameter A–A'.

We've seen that removal of material from a cylindrical log to obtain a rectangular timber results in a loss of area, section modulus and moment of inertia relative to those properties of the log. But how much is lost by converting the round to the rectangular?

Fig. 10 illustrates the relationship between the angle θ and the percentage of yield from the log. The optimal post has an area 63.7 percent of that of the log. The strongest rectangular beam is 65.3 percent as strong as the log, and the stiffest rectangular beam is just 55.1 percent as stiff as the log. The fact that each of the curves in Fig. 10 is relatively flat near its peak suggests that we have some latitude in selecting the dimensions of our rectangular timbers while still achieving near-optimal yield. For instance, a beam cut with proportions $h/b = 1.5$, corresponding to $\theta = 56.3°$, has a yield that is nearly indistinguishable from the optimal values for both strength and stiffness. Proponents of the golden ratio may be interested to know that, for $h/b = 1.618034$ (where $\theta = 58.3°$), section modulus yield is 64.6 percent and moment of inertia yield is 54.9 percent, both very near the optimal values for beams. —Dick Schmidt

Dick Schmidt (dick@ftet.com), chair of the Guild's Timber Frame Engineering Council, recently retired from the faculty of the Department of Civil and Architectural Engineering at the University of Wyoming to work as a timber frame engineer with Fire Tower Engineered Timber.

David Holdredge

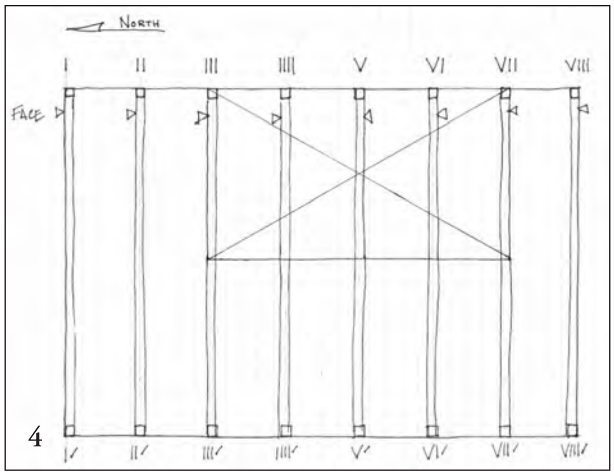
1 Barn frame in Alfred, Me., ca. 1802, photo 2014. One bay already missing.

2 Timbers in shop for assessment.

3 Extracting core for dendrodating.

4 21x44-ft. portion to be reused from original 44x63-ft. frame plan.

Photos Peter Smith unless otherwise credited



Jack Sobon

Adaptive Reuse in Massachusetts

LAST fall, while looking for older framing timbers to assemble into a roof frame for a new structure, we learned of the disassembled timbers of a very early 19th-century barn (Fig. 1) taken down by a single person using a Lull lift and, at times, a chainsaw. With only a few pictures to look at displaying the barn's form before takedown, we acquired it and brought it to our shop (Fig. 2). Though we do a significant amount of new construction, we also specialize in restoration and preservation of traditional architecture. This includes repurposing a historic frame for a contemporary client.

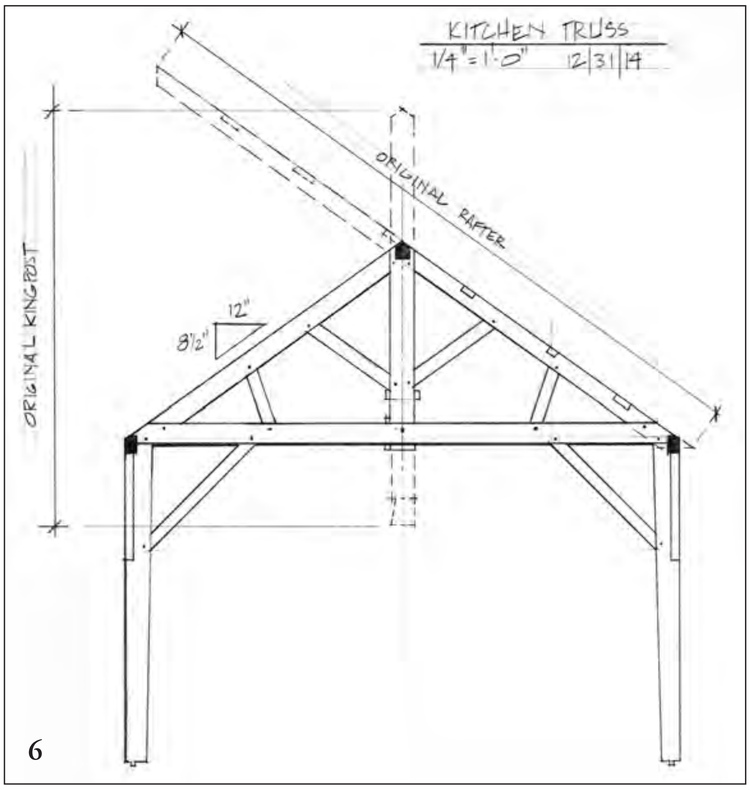
With all of the salvaged pieces laid out on the shop floor, the building's pathology and history could be studied. Bill Flynt, of Historic Deerfield, Massachusetts, conducted a dendrochronology study (Fig. 3), identifying white pine, hemlock, spruce and white oak, with most of the softwoods dating to 1802 and the riven white oak braces dating earlier (some as early as 1762), indicating reuse of those materials.

David Lanoue, Jack Sobon, Marc Lanoue and Peter Smith then conducted what could be described as a forensic carpentry study of the barn, using small metal tags and blue painter's tape for labeling, and stacks of graph paper to document and catalogue the building. The building parts along with the handful of images provided by the dismantler demonstrated that the barn originally had a 44x63-ft., eight-bent, scribe-rule frame, with English tying joints, kingpost trusses providing principal rafters, an interrupted ridge beam and common purlins. (At some point in its history, one bent had been removed and the barn re-sided.) The barn was also extremely well braced, each bay having eight braces as well as wall girts, and central ridge braces at each kingpost.

As a scribe-ruled frame in the English tradition, it displayed plumb and level lines and 2-ft. marks on posts and principal rafters, and Roman numerals and "flags" labeling each member for location. Race-knifed and chiseled marriage marks could be found on each joint. Once these were catalogued, Jack was able to sketch out the original form of the barn (bent view Fig. 4).

One intriguing discovery emerged when examining the riven white oak braces, dendrodated much earlier than the rest of the frame. Outboard of their existing shoulders, the tenons showed the

5 Brace tenon with overcut earlier shoulder line and remnant peg-hole arc.



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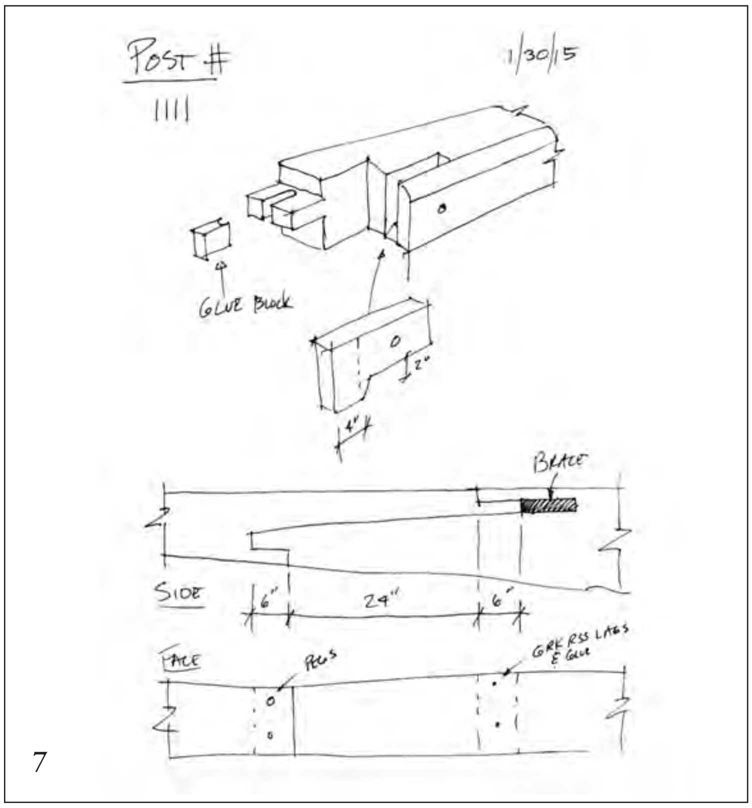
Drawings Jack Sobon

6 Original vs. adapted timber lengths. Kitchen frame is about one-half the width and two-thirds the length of original barn.



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7 Working drawing for English tying joint teazle-tenon repair and plate-tenon replacement, with scarfed addition to post.

overcut of an earlier sawn shoulder line and the tenon ends retained the arc of an earlier peg hole (Fig. 5), indicating that these braces had been used in a longer length before the building of the 1802 barn in Maine.

While the frame was studied and documented in the shop, the company also had clients for whom a conceptually similar frame had been planned as a kitchen ell to be built with miscellaneous recycled barn parts. The design called for an antique frame, not an amalgamation of assemblies that were clearly missing pieces or obviously had been rearranged. With the acquisition of the Maine structure, this space could be framed with all of the material coming from a single barn in nearly its original configuration, by attenuating and rejoining the frame (Fig. 6).

As in any adaptive reuse project, the frame's structural integrity had to be assessed and accounted for. The new 21x44-ft. kitchen ell would have a 2x6 panelized wall system and 2x10 rafters and a laminated veneer lumber ridge applied to the timber frame. These would help with engineering requirements and allow installation of insulation and mechanicals external to the frame.

With that sorted out, the frame's repairs were then broken down into three categories: aesthetic repairs, minor structural repairs and major structural repairs.

Aesthetic repairs were made to address minor rot and empty mortises and peg holes. Minor structural repairs included filling peg holes in braces, correcting teazle-tenon damage, replacing tenons, fitting short new post bottoms, and so on. Major structural repairs were made mostly in posts and tie beams, where 25 percent or more of the timber needed replacing. In each of these repairs, the goal was to retain the original joinery and carpenter's marks wherever possible. All the repairs, patterned after those found historically in barns and churches around the country, but with the addition of polyurethane glue, were designed collaboratively with Jack Sobon to use traditional joinery (Fig. 7).

When repairing old joinery in posts and braces, an important first step was to plumb and level the workpiece so that those joints could be used in the new scribing (Fig. 8).

For each visible repair, the goal was to achieve a seamless furniture fit and finish that might be undetectable to the layperson, and even to many professionals. For unseen repairs, the objective was simply to ensure that the timbers would be structurally sound at the end of the process. All the timber was treated with an insecticide to kill any existing bugs as well as to prevent future infestation.

In addition to careful workmanship, one perhaps unique advantage assured that this work would be historically and visually consistent. All of the replacement timber—from face patches to filler blocks—came from the same architectural fabric. The original barn frame was so much larger than what we required that all of the repair materials could be obtained from unneeded timbers. One could not have asked for a better scenario when working with historic fabric to build a new space.

Marc Lanoue and Peter Smith performed the vast majority of the repair and scribing work. Marc in particular rescribed, cut and fitted the five kingpost trusses with their new struts (Figs. 9 and 10).

After completing the trusses and reconstituting the posts, Marc and Peter worked together to scribe the longitudinal and transverse sections. Since the new frame would be much smaller, only the tie beams and posts that were in the best shape would be necessary. Bents III–VII would be used in the new arrangement, chosen primarily because they had the least amount of rot.

For the aesthetic repairs, empty mortises were covered with face patches carefully selected from timbers with a similarly hewn finish. Once a patch was selected, the mortise would be recut to accept a face patch roughly ⅛-in. larger. First, a line was knifed around the mortise to describe its new size, then roughly cut with a chisel, trimmed plumb with a Fein tool as far as it would reach,

and finally finished with a framing chisel. With a filler block inserted into the mortise with polyurethane glue, a 1-in.-thick patch was then fitted on top to blend in with the existing face. All the timber's irregularities were accounted for in the process. If there was a slight bow or twist in the original hewn surface, saw kerfs were cut in the underside of the patch to within ⅛ in. of the top surface. This allowed the patch to conform to any uneven hewn surface, thus avoiding raised edges. If the timber surface showed historic holes from powderpost beetles, a scratch awl produced similar pockmarks in the new face patch. Old tool marks from chisels, hammers, or race knives were also replicated with the same tools to ensure a consistent surface (Fig. 11).

Minor structural repairs were rarely visible (Fig. 12), including a number of minimal post bottom repairs. but those done to joinery were complicated by the anticipated scribing and reuse of existing mortises. To avoid complications later, it was necessary that each piece be plumbed and leveled for the repair.

All the layout for major structural repairs was driven by the joinery. For example, even if the majority of a post needed to be replaced, the jowled top was preserved, saving both the teazle tenon and the plate tenon in the tying joint. As in the minor structural repairs, workpieces had to be plumbed and leveled with snapped chalk lines during layout. In one piece, over 6 ft. of rot was removed from a post just below its brace mortise. Then, a post

8 Pieces to be rescribed to new assemblies were plumbed and leveled before repair operations.

9 Rescribed roof frame test-assembled in shop. Marc Lanoue resizes timber, taken from elsewhere in original frame, to become replacement purlin.

10 Marc Lanoue rescribing a kingpost truss. Reused members are about half original length.

11 Sequence of timber preparation after grain and surface match: a) trimming after knifing and roughing in, b) deepening walls with framing chisel, c) setting filler block and glue, d) fitting patch. Depth of filler block matters.

12 Repaired brace ends with patched or entirely new tenons.


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13–15 Major repairs, defined by 25 percent or more replacement material, sometimes reached more than 50 percent. Left above, Marc Lanoue surveys repair work in progress. At far left, preparation, and at left, glueup, of major timber insert. Sides of recess were Skilsawn from applied level surface.

16 For English tying joint frame, walls are raised first, then tie beams drop over posts and transverse braces to form stable box for setting roof members.

17 Lapped purlins drop in last.

18 Covering new structure with original boarding, to be seen from inside. Note bevel at upper edge of wall plate to provide broad nailing surface for roof boards. Insulated weather roof framed in 2x10s will cover boarding.

from another location in the barn was put in with a tabled and pegged scarf joint to replace the lost material. Posts in the finished kitchen ell frame averaged five to seven repairs (Figs. 13–15).

With the repairs finished, Marc and Peter could focus on scribing the rest of the frame, in the French tradition with a full floor diagram and lofted timbers, using plummets, levels and line lasers. The preserved 2-ft. marks on posts and principal rafters allowed original joinery to be reused in its original locations. Purlin locations, wall upbraces and kingpost struts all remained in their original locations. Where there was a usable existing mortise or lap joint, it was incorporated into the new frame.

The raising took three days with a crew of four (Figs. 16–18). Original roof boarding went on first, then more boarding and felt paper to yield a flat surface for the weather-roof buildup. Prebuilt wall panels were then flown in with the crane and fastened to the frame to dry it in for winter. —James Hess with Peter Smith

Peter Smith is a preservation carpenter at David E. Lanoue, Inc., Stockbridge, Mass. James Hess, a recent graduate of the American College of the Building Arts in Charleston, S.C., is a new employee.

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Photos Steve Lawrence unless otherwise credited

The Sky Pilot Suspension Bridge

THE town of Squamish lies on the south coast of British Columbia, a little north of Vancouver at the end of Howe Sound. First settled in the 1870s, it has been an industrial town for most of its history. Logging, mining, railroads and a busy port were all mainstays of the area.

More recently it has become a center for outdoor recreation, thanks in no small part to the Stawamus Chief. The Chief, famous among rock climbers, is one of the largest granite monoliths in the world. Its sheer walls rise over 2300 ft. from the waters of Howe Sound. Squamish, on the highway from Vancouver to the popular ski destination of Whistler, also offers mountaineering, hiking, mountain biking, wind surfing, fishing and kayaking, and its culture reflects these diverse outdoor activities.

A group of businessmen with backgrounds in local tourism and adventure developed a plan to build a gondola lift to take visitors to a new lodge and the high country up behind the Chief. After some years of planning, they launched the Sea to Sky Gondola project in 2013, and contracted us to design and build three of its features—two timber viewing platforms (the Chief lookout and the Spirit lookout) and a 282-ft. suspension bridge of steel and wood, called the Sky Pilot, linking the Spirit lookout with the lodge and leading to the Chief lookout (Figs. 1 and 2).

One of the primary challenges for the work was the accommodation of our designs on the landscape, which in this case was solid granite. In the course of a summer, we made several site visits with surveyors to gather data for the designs, and produced engineering and shop drawings. Drawings for the bridge were by the structural engineer Robin Zirnhelt of western Canada's ISL Engineering & Land Services (Figs. 3 and 5).

Another challenge of the work was the access to the mountain-top site via a rough, winding logging road that runs 10 miles up the back of the mountain. The road claimed a few victims, the biggest a mobile crane brought in to construct the lodge that got stuck on a corner part way up. When it finally got to the top, the self-erecting tower crane didn't self-erect. Parts of it had been damaged in the trip up the hill, and it buckled under load as the crane began to raise its mast. After inspection it was declared a write-off! A regular truck crane was brought in to do the job thereafter.

Our own transportation problems were about access to our work sites. By the time we began construction work early in September, one end of the proposed bridge was blocked by the construction of the new lodge building at the top of the gondola and the other was accessible only by a 5-ft.-wide hiking trail. This meant that the only machinery we could get to our work sites was

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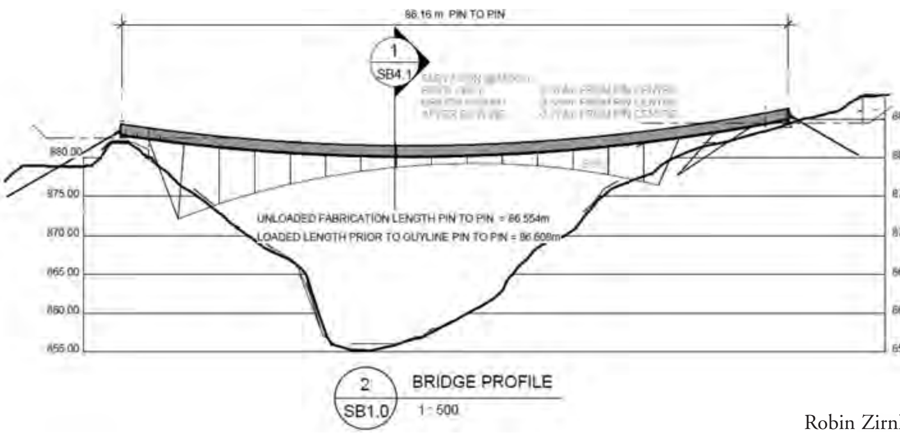

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Robin Zirnhelt

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1 **Spirit lookout and bridge to lodge. Bridge stanchions are 7 ft. high.**

2 **Chief lookout. Douglas fir walkway projects 32 ft. on 12x20 floor beams.**

3 **Elevation drawing (adapted) showing 37m drop to ground from bridge.**

4 **Bell 214 medium-lift helicopter carrying leg structure for Chief lookout.**

a mini-excavator, and that to one end of the bridge site only. We decided that the most cost-effective way to get our materials to the sites was by helicopter and so planned our installation work around that. Packs of materials (and eventually assemblies, as in Fig. 4) were delivered at each end of the bridge site and at the lookout sites and from there had to be maneuvered and positioned by hand.

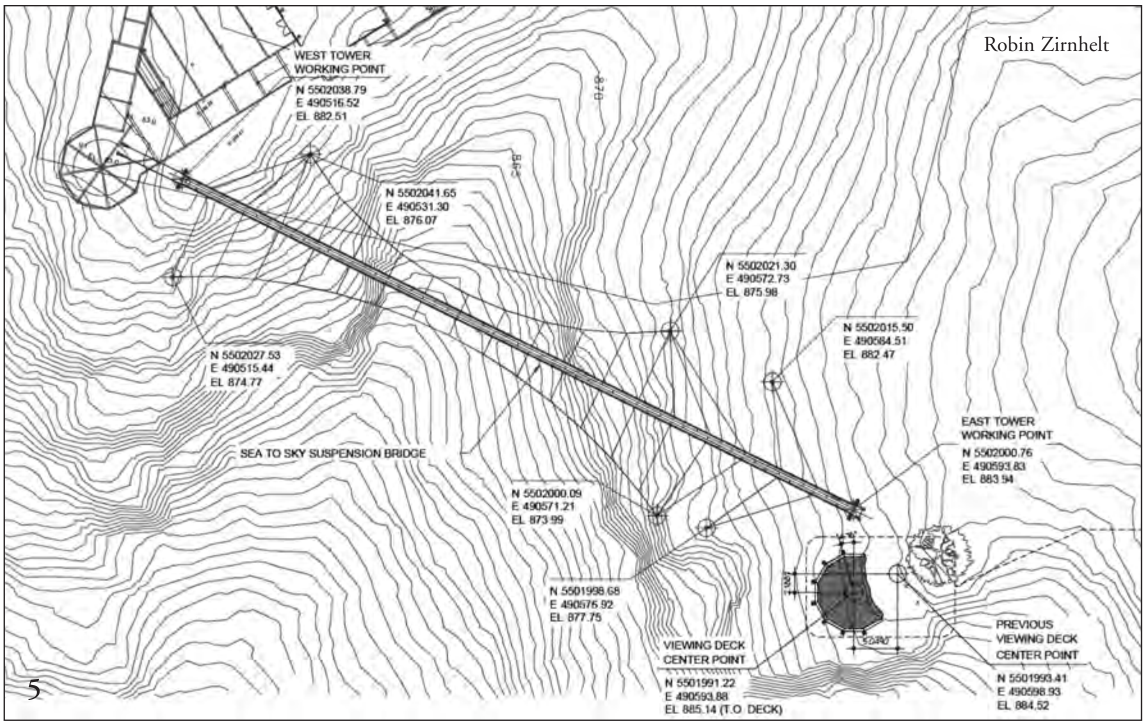
Heli-lifting Helicopters come in many sizes but are generally light-lift (500 to 2250 lbs.), medium-lift (2000 to 6000 lbs.) or heavy-lift machines. The heavy machines used for heli-logging and heavy construction can lift as much as 20,000 lbs. Hourly rates range from $1500 to $15,000. We used both light ($2500/hr) and medium ($5500/hr) machines on this project and had to wait four weeks for the medium machine to become available for 30 minutes of work.

Typical preparation for heli-lifting starts with careful planning of material packs. Knowing what everything weighs, and in what sequence it has to fly and to where, are critical to getting best value. We always pre-rig our lifts with slings, tag lines, etc., to save time. Once you start, the turns usually come every few minutes depending on travel distance to the drop zone. There is rarely time to mess with rigging.

A briefing is held with the pilot, rigger (if supplied) and one's crew. Pack lists, sequence, drop zones, communications and safety plans are all reviewed. Pilots always need to know what they are lifting and will inspect each pack for rigging and general security. They are at pains to tell you that if anything goes wrong, they and the machine come first and that means they drop the load if they have to!

Communication is usually by radio but sometime by hand signals. We typically assign one person to hook the load and signal the pilot when it's ready. At the drop zone there may be two or more crew to position the load plus a signalman to do radio communications and guide the pilot. When the load is safely on the ground, the signalman gives the pilot the all-clear to release the hook, which is remotely operated from the cockpit.

Helicopter lifting is intense. Things move fast and you want them to for the cost. Communication at the drop zone is all but impossible for anyone but the pilot and signalman. For this reason you need experienced crew and diligent preplanning and communication around who does what and when. With the noise and downdraft from a machine 100 ft. above you, and a few thousand pounds of materials swinging around in front of you, there is no time to talk about a new plan if things don't go right.



5 Plan view of bridge and web of guywires over steep territory. Spirit lookout platform seen at lower right. Chief lookout 1km distant.

6 Drilling setup for guyline rock anchors to hold bridge stanchions. Heavy pipe assembly guyed in several directions stabilized pneumatic-powered drill. Lodge deck posts surround rock anchors.

7 Recording results of pull-testing using 360,000 lbs. of thrust developed by 200-ton hydraulic jack. Acceptable movement was .040 in.

Having dropped packs of material, we began our construction work with the Spirit lookout and, after laying out the post bases, we drilled and resin-set the anchor bolts and assembled the deck and guardrail system. The timbers were all Douglas fir, and a stainless steel mesh was used for the guardrail to provide maximum safety for small visitors. This was the easy part of the work.

Bridge anchors While the lookout was under construction, we were working out the placement of the bridge ends. The design of the bridge stanchions and anchors required that they be placed with high accuracy on the landscape, and surveyors were used to provide us with marker pins at the working points for each end of the bridge and with offsets from the working points.

Layout to a sixteenth on the surface of a mountain was a significant task. We used a combination of surveys, wood templates, Sketchup models and strings to calculate and place the layout points. Once we had the layout we could start drilling the bridge stanchion anchor bolts. It was not possible to get a mobile drill rig to the sites, so all the drilling equipment had to be hand portable.

We hired a subcontractor with the gear and expertise to carry out our anchor bolt drilling requirements using a pneumatic drill that looks like a road drill. Having drilled the eight anchor bolts at the bridge posts each end, we installed a wood template that provided us with more layout for the bridge guyline anchors.

The guyline rock anchors were monsters. The 2½-in.-dia., 30-ft.-long threaded steel bars weighed 1000 lbs. each and had to be grouted into the granite. Our next task was to drill 4-in.-dia. holes 26 ft. deep into the rock with very high accuracy, as the bars must not bend in aligning with the bridge when installed. We devised a stand to hold the portable drill and align it to our layout. The mounting structure itself was held in position with many small temporary anchors to locate the base of the stand and guy the top, holding it securely during the drilling operation (Fig. 6).

Each of the two rock anchors at each end was designed for a factored service load of 1200 kiloNewtons or 270,000 lbs., necessary because of the high snow loads in this location. Coastal snow can be very wet and heavy, and the entire length of the bridge was designed to carry 2 cubic meters of wet snow, weighing 612kg (1350 lbs.), per lineal meter.

The drilling crew was very good at drilling holes in rock but not so hot at pinpoint accuracy. I had to ensure that their drill was perfectly lined up before they started. My Sketchup model was invaluable in calculating the placement of the drill. At the east end, the rock anchors were very close to the bridge posts, but at the other end, where the bridge stood on a knob of rock, the anchors were 30 ft. away and 12 ft. below the level of the bridge.

Once lined up, the drilling went smoothly. It had taken days to get the gear on location and set up and it now took two hours of ear-splitting noise accompanied by vast clouds of dust to complete each hole. We then had to transfer the gear by carrying it all around the gorge to the other end of the bridge and repeat. After drilling, the bridge posts were assembled, the anchor rods slid into the holes, and all the parts aligned and checked for position. Half-inch-dia. tubes were taped to the side of the anchor rods and through them cement grout was pumped into the holes to fill them from the bottom up. When the grout was set, we pull-tested each anchor with supervision from our geotechnical engineer. The pull-test load was 1.33 times the working load. That's 360,000 lbs. We used a 200-ton hydraulic jack to try to pull the rods out, while measuring any movement to a thousandth of an inch. All the anchors passed the test (Fig. 7).

We now had the two ends of the bridge complete and were ready to start rigging the cables. Early on in the conceptual design of the project, someone had pulled a piece of ¼-in. yellow poly rope across the gorge to mark the general position of the bridge. This came in handy now as we used it to pull a ½-in. rope and then a ½-in. wire rope across. We anchored the wire rope to one of the bridge posts at each end and tensioned it to make a sort of clothesline, which we then used to run a snatch block across the gorge, pulling the bridge cables from one side to the other.

Wire ropes The 1½-in.-dia. bridge cables had been prestretched and cut to length, and Spelter sockets were fitted to each end with epoxy resin. Spelters provide 100 percent of the rope strength in the termination. The ropes had to be of equal length within a sixteenth or so. The supplier had employed a surveyor to measure the length for cutting and fitting the sockets.

We set up each of the four spools of rope on a stand at one end where we could use our mini-excavator to lift and position them. One end of the rope was attached to the snatch block on the clothesline and pulled across the gorge using a smaller rope. As the cables drooped into the gorge the weight of them began to pull the

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8 One of four spools of wire rope, now all paid out, successively drawn across gorge after setting initial "clothesline" with snatch block to pull cables.

9 Installing joists and decking. Rope specialists in ha
while deckers clipped into cables using fall-arrest sy

rest of the cable off the spool. We rigged a brake on the spool to hold it back and prevent us losing the cable down the gorge. Once we got the end to the far side we attached it to the bridge post, and pulled back from the spool side to tension the cable and attach the other end to the bridge post (Fig. 8). We used a 3-ton Tirfor winch rigged with a snatch block to tension the cables to approximately 10,000 lbs. and make the attachments.

Having repeated this process four times, we now had the bridge cables in place and could start the decking. The deck has steel joists on 5-ft. centers and 2½-in. Douglas fir decking fastened to the joists with carriage bolts. We started at one end and worked our way across. Several of our team were rope-access techs and simply hung from the upper cables while installing the joists. Others installed the decking, working on top and using fall-arrest systems anchored to the top cables (Fig. 9).

Next was the guardrail system. Stainless steel ¼-in. wire ropes ran horizontally with doubled 3⁄16-in. wire ropes running vertically from the ends of the joists to the top bridge cable. They were clamped together at their crossing with some slick little stainless cross clamps made specifically for the purpose to create a stiff and strong guardrail. As we installed the vertical ropes we kept measuring to ensure that the top and bottom bridge cables were equidistant.

The last operation was to install the catenary guyline system. The bridge was designed with a lateral bracing system that reduces the sway and bounce common on small suspension bridges. A ¾-in. wire rope runs parallel to the bridge on each side, anchored at each end, and ¼-in. guylines run from it perpendicular to the bridge attached at every third joist.

After installing all the parts we had a hell of a time getting them all adjusted evenly. It was like playing whack-a-mole! Eventually we got to grips with it, and the finished catenary guylines pull the bridge deck down and sideways to dampen out movement as people walk across (Fig. 10).

Chief lookout In construction order, the third structure in the project was actually the Chief lookout. Perched on the edge of a cliff overlooking the top of the Stawamus Chief and located about 1 km down a walking trail, access was a challenge here too. The beams for this deck are 12x20 and 32 ft. long, and we had no chance of surface-transporting them to the work site, let alone

11 Setting triangular X-braced legs for Chief lookout.

in harnesses hung directly from cables to set joists
st system.

10 Completed suspension bridge is stabilized by ¼-in. guylines stretched from curving ¾-in. wire rope catenary to every third joist (15-ft. intervals).

getting them installed. We assembled the two large pieces down at the base station area and installed them by helicopter.

The legs of the lookout stand on steel bases bolted to the timber legs, with 1¼-in. threaded rod pins resin-anchored into the rock. With surveyor's elevations given, we drilled carefully such that when the rods later hit the bottoms of the holes we knew we were level.

12 Heli-lifting 8 x 32-ft. deck frame for Chief lookout.

Anyone who has worked much with resin-set anchor bolts will know the hassle of a bolt that doesn't go right home first time, and the fight against time to get it in (or out) before the resin sets. With a helicopter doing the lifting it had to be a first-time fit, so we did a dry fit first to be sure it would go right. With our preparations made and the crew briefed, the helicopter came in with the leg assembly and we had to line up the two base pins. Helicopters have a remarkable level of control when doing such operations but still nothing like a crane. We pushed and pulled the legs around trying to get them lined up, and after what seemed like ages got them in. All was good and the helicopter lifted the legs up and clear to hover while we squirted the evil-smelling goop into the holes. Second time around the thing pretty much fell into place, and before we knew it the pins were in and we were frantically attaching temporary bracing so the pilot could release the hook (Fig. 11).

First lift done, we were now ready for the second, the deck assembly. Two beams, joists and decking with the guardrail system stacked on top made a 5000-lb. lift (Fig. 12). The ends of the beams had to align over anchor bolts set in the rock. All went smoothly, and in 10 minutes we had the majority of the structure in place. We installed the guardrail systems and constructed a small stairway to provide easy access to the lookout. We finished off the job with cedar split-rail fencing, which I thoroughly enjoyed making. I had found a few nice cedar logs beside the access road and spent a pleasant day in the woods bucking and splitting them.

All in all, construction took about five weeks and was thoroughly good fun, with a great mix of challenges and successes in a stunning location. You know how one job sometimes leads to another? Well, this one led us to a mountain top in Japan, but that's another story. —Steve Lawrence

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Medieval Germanic Roof Structures 3

IN the last issue (TF 117), I described how medieval Germanic framers responded to ever-increasing roof spans and volumes by keeping their familiar basic system of primary and secondary frames in a three-dimensional structure but adapting the supporting members with a variety of techniques such as crossed braces, posts and masts. Their courage as builders was attested to as well by the super-frame over St. Stephan's Cathedral, Vienna, some 116 ft. high and 133 ft. wide, unfortunately burned during World War II.

As a building archaeologist looking back in time at historical timber framing, I have a different perspective from framers who actually design and erect related structures today. On the one hand, I have the advantage of spanning time and can see where ideas came from and where they will eventually lead. On the other hand, I am disadvantaged in not being able to comprehend in detail the individual framer's motives, restrictions, theories and abilities.

When looking at medieval Germanic carpentry, there is little left to analyze outside of the structures themselves, so the latter must become the focus of any investigation aimed at entering the minds of framers working over 500 years ago. Still, some roof structures may offer a small insight into the philosophy behind them.

THE medieval roofs over the nave and choir of Regensburg Cathedral in Bavaria (N49° 01.170′ E012° 5.885′), seen in Fig. 1, are still in their original condition despite being over 550 years old. The cathedral nave itself took over a century to build. The first new bay at the eastern end was protected by a small, low-pitched roof which later was extended out farther to cover a second. By the middle of the 15th century, the great west façade with its integrated towers had been started and the walls between them and the eastern part of the nave filled in. The low-pitched roof could have been extended over the complete space, but instead it was decided to replace it with a new, complete and much steeper roof frame.

Photos and drawings Philip Caston

1 Regensburg Cathedral, begun 1273. Roof frames 1442–48.

A dendrochronological investigation revealed that the timber for this structure was felled in the year 1442. The frame must have been designed around that time and the erection probably took place shortly afterward, possibly the following summer. The same design was reused with slight modifications again six years later for the new choir roof. Both designs incorporate a unique constructional feature—the design reflects not just the intended uses of the structure but also, as we will see, the erection procedure. It was designed especially to be built!

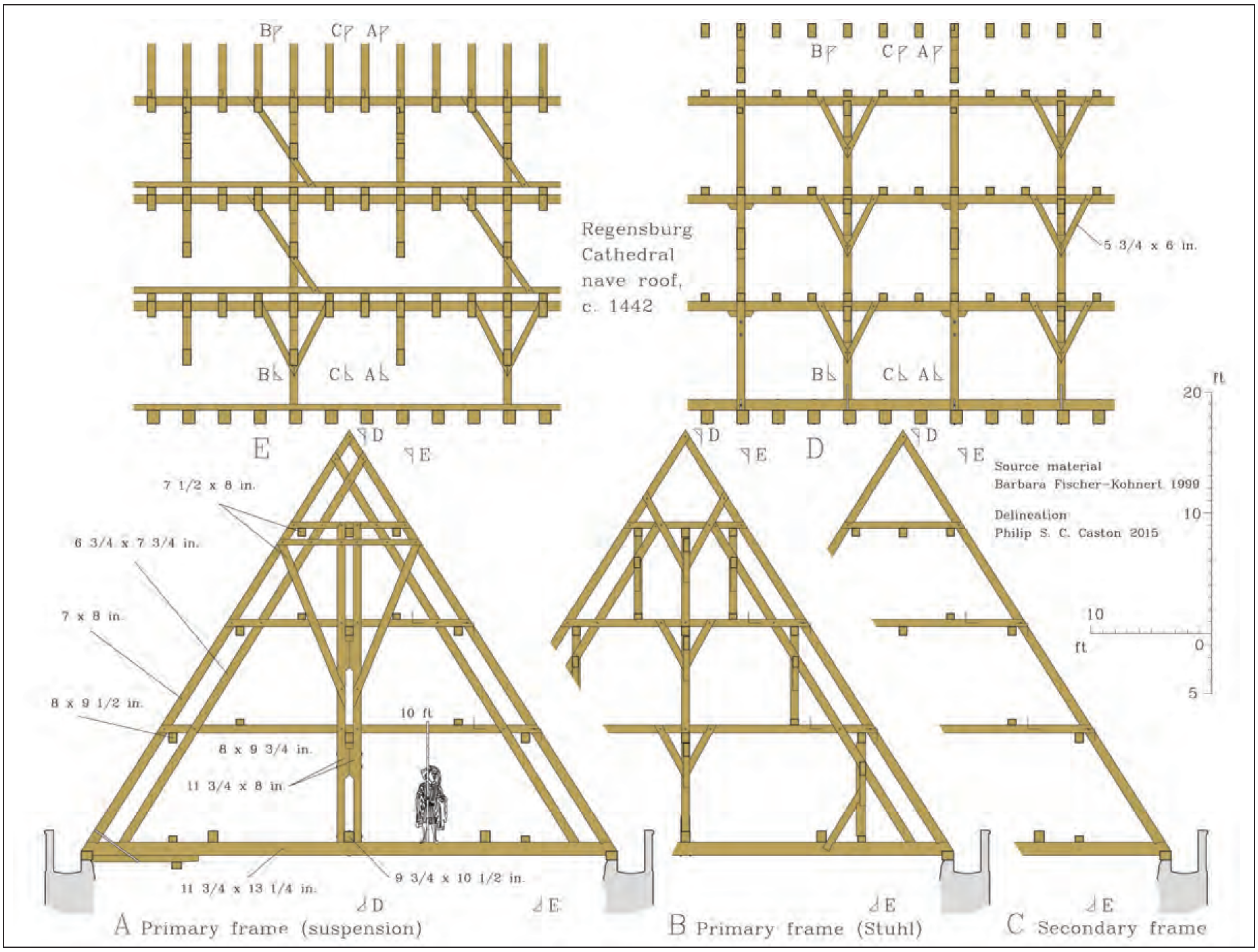
I first encountered the design in 1987 when I enrolled in a graduate course in building conservation at Bamberg University in Bavaria. The two professors running the course were researching Regensburg Cathedral. Luckily for me, one of them, Manfred Schuller, was a building archaeologist interested in roof structures. His father Helmut had built a diorama (see back cover) that showed how a primary frame was made, including the process of transforming a trunk into a beam. The diorama stood in the hall outside his office; I got to look at it almost every day. It was so self-explanatory that I was instantly hooked on historic carpentry.

Both professors were keen to offer their students small research projects in and around their cathedral. I got to climb around both roofs and even drew their purlin ends, which connected with the walls. While I was not actively involved in the roof research, I certainly picked up on the new scholarly observation, under discussion by Schuller and my fellow student Barbara Fischer (now Fischer-Kohnert), that there were two different primary frame types in the structure. Fischer-Kohnert was one of the first people to record German structures with accurate measured drawings, and Schuller was the first to publish the new thinking in 1989, describing the roof structure as a rhythm of primary frames (A and B) interspaced with secondaries (C) in the following pattern: A CC B CC A etc.

In the nave roof structure it can be seen that both primary frames incorporate the idea of a statically balanced triangle held together with three collar beams. The collars are supported by or support numerous longitudinal collar purlins.

The two primary frames work differently (Fig. 2).

Frame type A (partial photo Fig. 3) features a pair of 11¾x8 posts flanking the central axis. The posts touch at two places along their length and are bolted together at the lower junction, but they are otherwise reduced to 8-in.-sq. sections that clasp various purlins along their length. These posts were apparently designed to be suspended and are each hung from the upper collar beam by a half-dovetailed lap and by steeply raking diagonals. The diagonals likewise have half-dovetailed laps at each end. Dovetailing alone is not conclusive proof of a member designed to be in tension, as it was the preferred medieval jointing detail, but doesn't preclude it either, as tenon joints at those points would. The lower ends of the posts, however, are attached to the lowest axial purlin at the tie by straps and other hardware (Fig. 2, Section D). Bolts and straps would have been expensive at the time and



2 Regensburg elevations of primary and secondary crossframes and sections showing longitudinal support. Section *D–D* shows bracing and distribution of crossframes. Section *E–E* steps through the structure to show successive *stehender Stuhl* assemblies in a single plane.

there must have been some reason for that choice of fixing. Also, the tie beams were suspended below the axial purlins and similarly required the use of iron bolts and washers to attach them.

If the posts were simply to stand on the tie beams, there would be no need for such an expensive and over-engineered joint, but the design makes sense if the posts were to carry the weight of the purlins and beams, which would have been quite considerable. The horizontal bolts could have sliced their way through the parallel grain of the lower ends of the posts, but the shoes and straps spread the load over a greater surface, reducing any point-load damage. Clearly, the posts were suspended and carried the four tiers of axial purlins. Additional passing braces help distribute the resulting tension forces down to the wall plates.

In this frame, as in the secondary frame, the remaining collar purlins are, however, not supported, so how are they suspended? The answer can be found in frame type B, where the collar purlins, together with posts under each purlin and a sort of sill under the posts form a *stehender Stuhl,* a supporting frame or truss with upright members and here a longitudinal wall-like frame, repeated on three tiers under the pitched rafters and linked to one another via passing braces that run from tie beam to upper collar beam.

Schuller and Fischer-Kohnert noticed that numerous collar beams had sagged below the sills under their own weight, leaving the stehender Stuhl assemblies suspended from the passing braces.

The passing brace does not transmit the path of forces to the tie beam directly at the wall plate, but some way into the free span. This could cause a deflection of the tie beam, but it would be less than would be caused by a stehender Stuhl post, which acts even farther inboard along the beam.

My own observations of real roof structures and 1:20 scale wooden models we have made in workshops lead me to think that, in addition to the basic geometry, it's the quality of joints and fitting of pieces that determine the true path of forces, and that any serious attempt to quantify forces must take that into account.

Hans Mühlfeld in his 1934 book *Das deutsche Zimmermannsdach* (The German framed roof) proposed that the Stuhl served only to aid the assembly and does not carry any vertical forces at all in the completed structure. These are interesting ideas when considering the two frame types in the Regensburg Cathedral roofs.

Frame type B also has a central post, but unlike in type A it is a single 8x8 reduced further (up to three-quarters) in section at points where the adjacent laps occur on different faces. At every tier a pair of upper braces in the frame plane and another pair in the longitudinal plane tie the post to a collar beam and a purlin. The half-dovetailed lapped ends would be capable of suspending the central post, but this was probably not uppermost in the designer's mind. This can be deduced from the overall layout of the passing braces, which do not connect to the central post and are not attached to the uppermost collars in the usual half-dovetail lap, but here are small triangular shapes that don't fit well. One enigma, though, is why the lower ends of the central posts are

3

bolted to a tie beam purlin as if suspended. The bolts pass up through the tie beam and are flattened into straps that flank the purlin and central post, to which they are nailed.

Fischer-Kohnert in her PhD thesis *Das mittelalterliche Dach als Quelle zur Bau- und Kunstgeschichte* (The medieval roof as a source for building and art history), published 1999, postulates that Regensburg's frame type B has a twofold function. First, it contributes to a useful workstage during assembly, then after completion its role changes to supporting collar purlins at midspan. The framer was very much aware of the assembly sequence and introduced elements into the design that would ease erection but at the same time also contribute to the statics of the finished structure.

To explain the assembly in detail, Manfred Schuller analyzed the measured drawings and had a wooden model built at a scale of 1:20. This model would lead him to introduce model-building into the curriculum, which has since produced a large collection of scale-model historic Germanic roof structures. Years later it would serve as a precedent for my own courses and students.

Using the model to physically rebuild the choir roof in part and guided by the restrictions imposed by the overlaps and joints, he determined a plausible assembly sequence that would also apply to the slightly different nave. All the members had to be individually hauled up to the crown of the external walls at some 100 ft. above the ground. The first pieces to be set were the wall plates, followed by the tie beams spanning 42 ft. Together with three sill rows laid over the ties, they produced the frame of a horizontal work platform above the already completed vaulting. The posts of frame type B were erected next. The outer posts would have been stabilized by the lower braces, then the collar purlins would have been set on top of the posts, followed by the first tier of collar beams, which would have formed support for a new work platform. This sequence would have been repeated again in the next tiers until the third collar platform was completed. The posts in each tier were then connected by the passing braces tying each tier together and bracing the whole assembly. So far just the members of frame type B, all the collars, tie beams, purlins and sills have been used, and the horizontal distance between each frame type B at 18 ft. is just enough for the purlins and sills to carry themselves. The design is practical from an erection standpoint, as it provides the framework for multiple working platforms to aid the assembly.

But the suspended central posts of frame type B are too weak to carry their load. This is where frame type A comes in. The twin central posts in frame type A are clearly laid over the collars as witnessed by the lap joints. Finally, the steeply raking diagonals complete the frame with its suspension posts and change the path of forces completely. The collar purlins and sills now span much shorter distances and, if the type B frames should sag (as they did), the A frames would take over the support. The collar purlins and sill now span the same 18 ft., but at a different location between the type A frames.

This is a well-thought-out design that can accommodate different paths of forces that arise both during assembly and in service. If time is the fourth dimension, then this is a four-dimensional roof that adapts its members to the passage of time (the sagging beams) to maintain its load-carrying function. Also, the designer was ingenious at incorporating framer-friendly elements to make the raising safe and efficient.

PÖLS Ingenuity is not just required in the construction of large-scale roofs but can also be found at a small scale. A good example can be seen in the diminutive choir roof of the parish church of the Assumption of Mary in Pöls, Styria, Austria (N47° 13.210' E014° 34.860'), seen to the right of the tower in Fig. 4. This unique structure formed part of my 1996–98 investigation of some 190 historic roof structures in the Mur-Mürz Valley in the Austrian province of Styria. Though dendrodating its timbers has not been successful, the church is known to have been completely rebuilt after 1480 and the late-medieval style of construction also suggests that the roof structure was built around 1490.

The roof over the choir at Pöls has a freespan just under 21 ft., smaller than the earliest Germanic roof spans with no substantial internal support (see TF 116), yet it's divided into primary and secondary frames incorporating a stehender Stuhl under each end of the main collars and a third stehender Stuhl framed longitudinally. In such a small roof structure, this would seem to be an overuse of Stuhl supports (Figs. 5–7).

Unlike the earliest Germanic roofs, the choir roof structure at Pöls extends over a polygonal termination, some of whose rafters and roof covering exert a horizontal force longitudinally into the roof space. The roof structure as a whole then has to resist individual frames being pushed over. The framer thus fitted a rigid assembly along the central axis, made up of posts and collar purlins, and substantially stiffened by crossed bracing in the upper part where the most force from the end rafters would be exerted (Figs. 5, 8).

Possibly that longitudinal frame alone is enough to stabilize the structure. Why then the use of two additional parallel frames? An additional stehender Stuhl at each side of the roof frame would further stiffen the structure longitudinally, and the practical assembly advantages of a work platform as surmised in the Regensburg Cathedral roof could have been considerations in the final design, but the larger similar church nave roof design in the neighboring village of St. Oswald might also have played a role.

The remains of the larger medieval roof in St. Oswald would seem to be similar to St. Mary in Pöls. St. Oswald's original 1470 church roof was replaced at a later date, but a walled-up post-and-beam assembly that survived inside its 1475 tower shows similarities in detailing to the structure in Pöls (Fig. 5).

It would appear that both St. Mary in Pöls and the church at St. Oswald shared an unusual detail. The long, steeply raked passing braces that connect the collars and rafters to the central posts were butted and nailed with iron spikes at their lower ends, not joined by lap or mortise (Fig. 9).

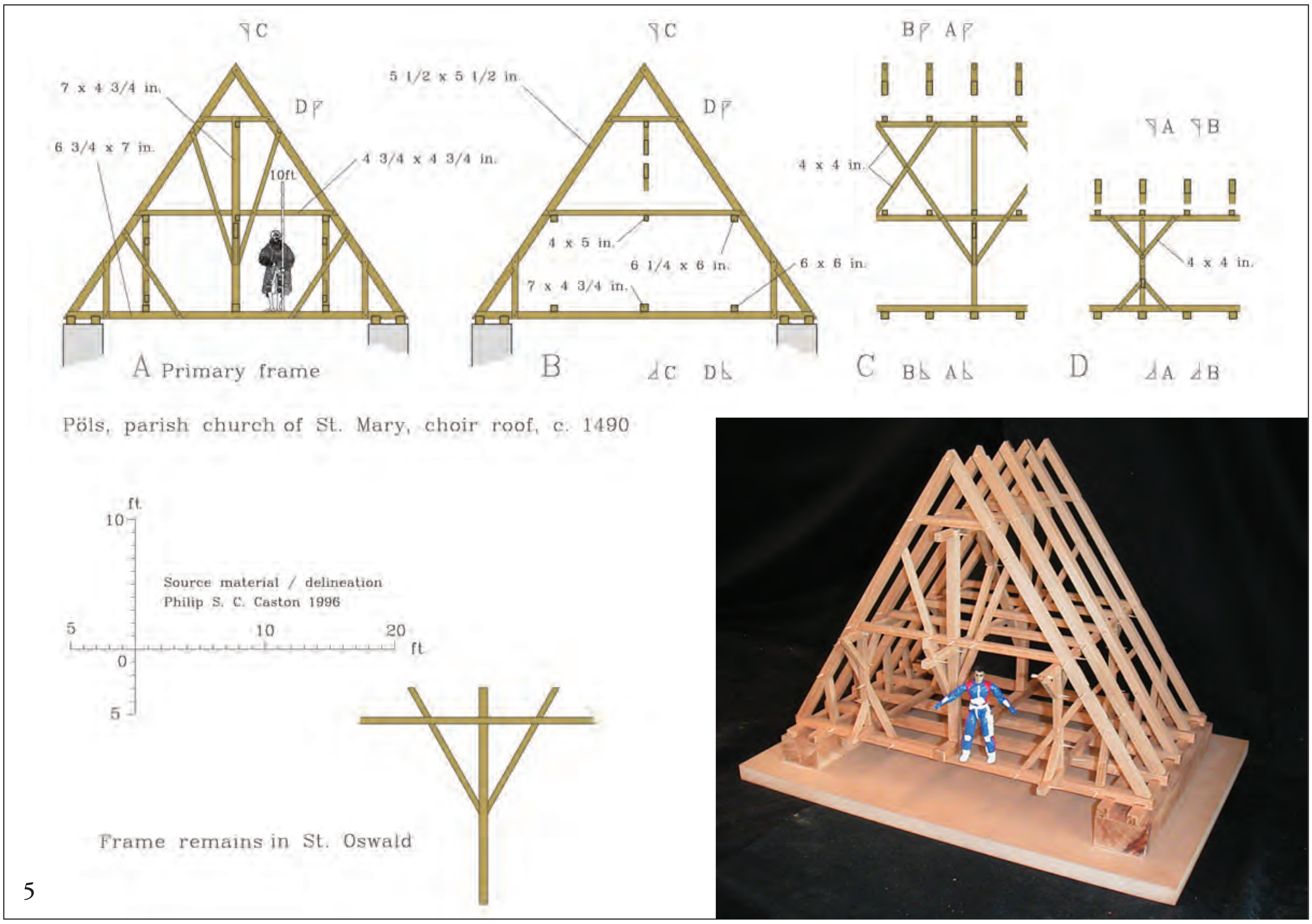
3 Detail of suspended post, purlin collar beam and steeply inclined brace in frame type A, seen against later brick firewall, Regensburg Cathedral choir roof.

4 St. Mary Catholic parish church, Pöls, Styria, Austria, later 12th century. Despite severe damage by fire in 1480, much of original walls survives. Nave roof and spire framing are younger, but framing over choir (right of tower) is probably original late-15th-century rebuild.

5 St. Mary choir roof 1:20 model built by Ronald Caston, 1999, with elevations and sections showing primary and secondary frames. Without figure and 10-ft. scale rod, roof structure could be thought twice as large.

During the Middle Ages and until the arrival of industrial production at the end of the 18th century, wrought iron was an expensive commodity and therefore used sparingly. Medieval roof structures are predominantly all wood, malleable iron being reserved for use only in special situations. Pöls, however, is close to an iron ore deposit (a town called Eisenerz—Iron Ore—is not far away) that has been continuously open-mined since that time. Access to relatively cheap iron fastenings may explain their use at Pöls, and iron spikes appear in a few other local roof structures too. The steeply raked braces could have been lap-jointed easily in the traditional manner, as in Fig. 6, at their lower ends. This would have been a requirement if the central posts were to be suspended from them, but this is clearly not the case here, since the posts are simply supported on a sill that crosses the tie beams.

One of the joints does not butt properly, allowing inspection of the adjacent surfaces, where it can be seen that there are no

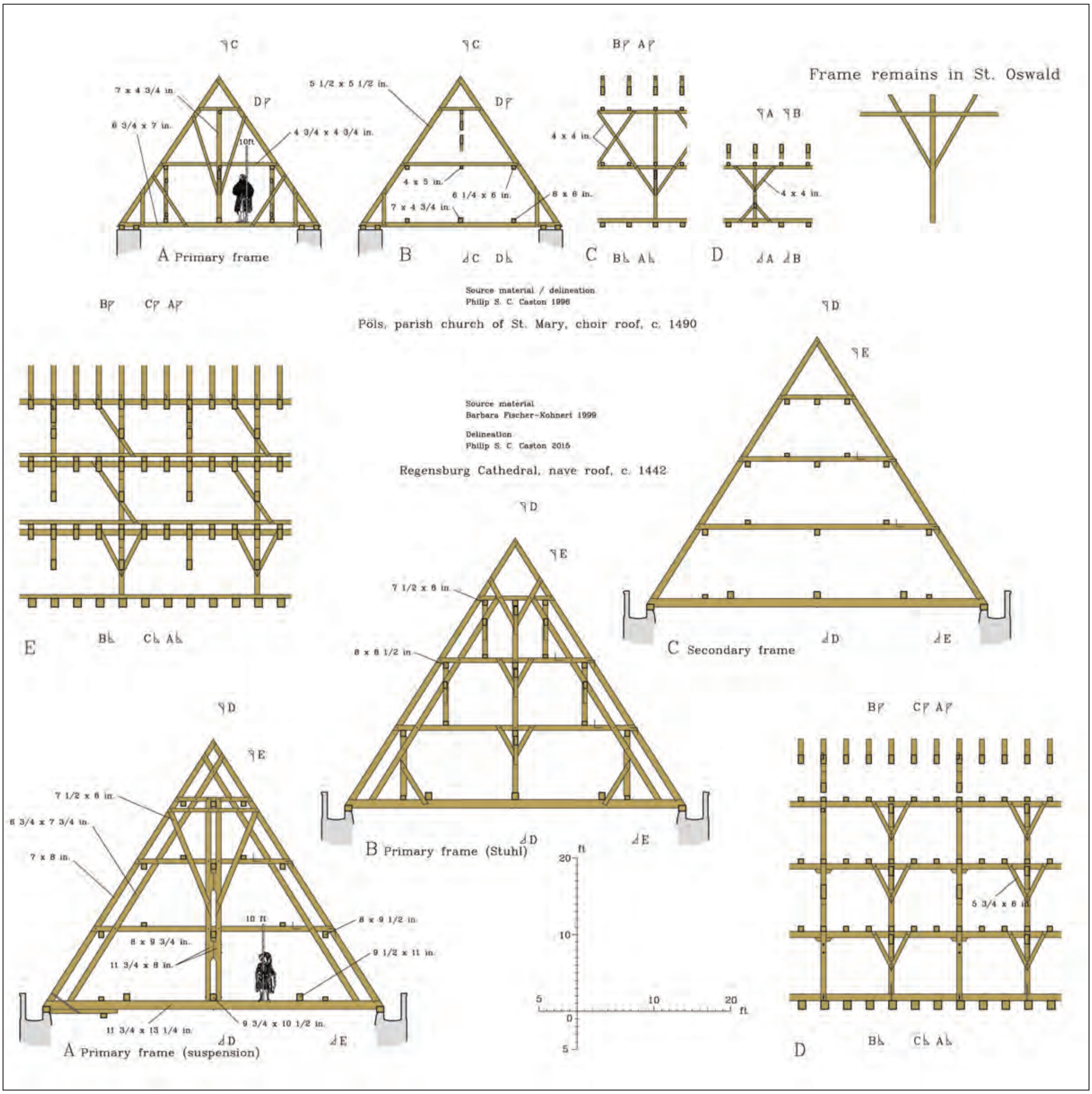


6 St. Mary choir roof, stehender Stuhl under collars, posts K-braced longitudinally, passing brace connecting tie beam with rafter.

7 Roof space crowded with post and braces, individual members proportionally reduced to design based on larger span.

8 X-braced upper portion of longitudinal frame. Upper ends of rafters over polygonal termination of choir impart horizontal force.

9 Detail of common-level brace connections on four sides at one central post. Unusual butted and spiked joints, instead of typical lap joints that would have required alternating connection levels for brace-counterbrace pairs to avoid weakening post unduly.



10 Regensburg Cathedral nave roof framing (middle and bottom), St. Mary choir roof framing (top left) and remains of medieval roof over church at St. Oswald (top right), delineated at common scale to show relative size of each structure.

secret notches or other fastenings. In another joint, the spike with its flat head is not even driven home completely. Perhaps the carpenter was in a hurry.

The frame members at Pöls are quite small in section (6¾x7 tie beams, 4x4 steeply raking braces, 5½x5½ rafters), their dimensions being just slightly over half those of similar members in other medieval roofs in the vicinity. This is roughly the same proportion as the freespan in Pöls is to that in St. Oswald. Also, the posts, collar beams and braces are similarly proportional. Compared to the St. Oswald roof structure, that in Pöls is at almost half-scale. (Fig. 10 compares all frames discussed here.) It's a great shame that not more of the original St. Oswald roof survives to confirm the possibility of influence.

Toward the end of the 15th century, central Europe was still under threat from the Turks. In August 1480, some 16,000 Turkish invaders poured into the Mur-Mürz Valley, destroying religious buildings and thus eradicating any older timber framing. The immense rebuilding program undertaken later would have strained resources and personnel, and it was against this background of extreme circumstance that the Pöls church was built. An extant design and a necessity to build quickly could have come together to get the choir roof up and the choir dry again.

—Philip S. C. Caston

Philip Caston (caston@hs-nb.de) has been studying roof framing in central Europe for 25 years. This article is third in a series charting the development of Germanic roof framing.

1, 2 Harper Point Photography

1, 2 House in Bellevue, Colo., 1965 sq. ft., framed in dry Douglas fir, designed and built by Frameworks Timber, Fort Collins, on foundation of earlier frame lost to forest fire.

3, 4 Seasonal house, Nelson Island, B.C., 1100 sq. ft., framed in Douglas fir, designed and built by Kettle River Timberworks Ltd. in Burnaby. Materials delivered by barge and helicopter.

3, 4 Dom Koric

Guild Conference Slide Show 2015

THIS year's annual conference slide show in October at Coeur d'Alene, Idaho, featured images of recent work by Guild members and friends. A small selection appears here. Additional images will appear in the March journal.

Michele Beemer

Models built in workshop at Heartwood School, Becket, Mass., using French drawing and layout methods taught by recently minted Compagnon Patrick Moore, far right. Far left, Will Beemer, school's director. Students as well as their teacher are all Heartwood alumni.

At right,bell tower 15 ft. tall, 4 ft. 6 in. square in plan, designed and built of white pine by Brian Malone in Carbondale, Colo., at Sustainable Settings, a non-profit ranch.

Brian Malone

Kris Calvin

5, 6 Ponderosa pine performance pavilion in workshop and on dedication day in Sisters, Ore., built by Earthwood Timber Frame Homes of Oregon with the Kiwanis Club, both of Sisters. Above, Jason Soen fits "keystone" and Rod Zade drills for pegs. At right, Sisters Dance Troupe celebrates.

Outlaw Photography

Doug Self

7, 8 Trapezoidal-plan tribute stage 17x33 ft., Driggs, Idaho, designed and built in Douglas fir by Teton Timberframe of Driggs. Rafters leave level bearing at rear, land at varying heights on laminated arch, thus need individual backing angles. Engineering by Jennifer Anthony of Missoula, Mont.

Adam Riley

Joe Miller

At left, full-scale tension test at Trillium Dell Timberworks, Knoxville, Ill., of 16-ft.-high mocked-up segment of hanging Port Orford cedar screen, part of walkway at new Writers Theatre in Glencoe, designed by Studio Gang, Chicago. Hydraulic jacks atop upper I-beam push up on steel tubes clamped to 12x24 upper chord. Battens 2x3, fastened at top with series of fully threaded screws, are wedged and spread at bottom to be captured in compound dovetail housings. Engineering by Joe Miller, Fire Tower Engineered Timber, Providence, R.I.

At right, acoustic shell, Tippet Rise Art Center, Fishtail, Mont., 1900 sq. ft., of Douglas fir and marine plywood. Conceptual design by ARUP, timber frame design and construction by Gunnstock Timber Frames, Powell, Wyo. Engineering by Fire Tower Engineered Timber.

Laura Vikland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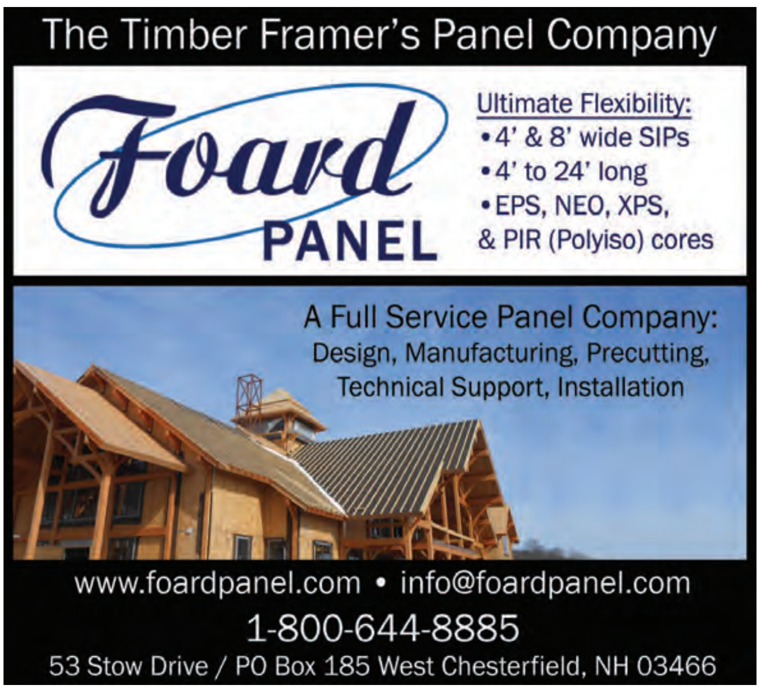
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