TIMBER FRAMING

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Chinese Covered Bridges

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On front cover, Jie Long bridge near Zhangkeng Village, Dongkeng, Jingning County, Zhejiang Province, China, early 20th century, one of around 100 "corridor" covered bridges built over a wooden arch still standing in China. On back cover, barn in Somerset Township, Somerset County, Penna., ca. 1876, 115 x 57 ft. (originally 43 ft. with 14 ft. added when split in 1920). Well known for the large message "DRINK MILK" painted on its side and visible from the Pennsylvania Turnpike at mile marker 105. Photo Fred Will.

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1985

BOOKS

Architecture of Relationship

Norwegian Wood: The Thoughtful Architecture of Wenche Selmer, by Elisabeth Tostrup. Princeton, N.J., Princeton Architectural Press, 2006. 9¾x11¼ in., 208 pp., 246 illustrations. ISBN 9781568985930. Hardcover, out of print (see review).

WHEN I stopped into the local bookstore and on a whim paged through *Norwegian Wood*, a tribute to an architect I had never heard of, I became gradually aware that I had to bring home this beautiful book. Later I loaned my copy for extended periods to two different friends, and they too bought the book. Wenche Selmer's work is like that: it gets under your skin, asking you to look closer, to return and look again. Author Elisabeth Tostrup, herself an award-winning architect and a professor, is also a gifted writer. She describes each of Selmer's designs with warmth, and a sharp eye for detail informed by her own practice and research.

The book explores Selmer's architecture with tours through a dozen houses, examining details of construction and function through photographs and thoughtful text. It is also a loving portrait of Wenche Selmer: the professional, the working mother, the partner and the teacher, a compelling story.

Selmer lived from 1920 to 1998, mainly in Oslo and southern Norway. She maintained a forty-year residential architectural practice—appropriately—from her home, and taught for many years at the Oslo School of Architecture. Early in her education, she apprenticed briefly as a furniture maker, and she put this experience to use, designing many of the furnishings of her houses. Her designs, if they appear simple, are striking in their harmony and balance. She was attentive to the evolving needs of the families who would live in her houses, and to the often modest finances they had to work with. That she applied her skill to making careful and creative use of tight budgets and sites rather than working on grander projects may have hurt her candidacy for full professorship at the School of Architecture, as Tostrup observes. Nonetheless, she was highly regarded for her skills both in design and in teaching.

After examining Wenche Selmer's life and influence from multiple vantages, Tostrup brings us to the visual heart of the book: the designs. Each house is accompanied by a small floor plan and a short essay outlining its history and describing features which may not be otherwise spotted, but the photographs are what make this book. They capture more effectively the spirit of Selmer's work than even the author's most thoughtful words. The variety of directions from which many of the houses are photographed are helpful in getting a truer feel for the space inside, and for the way the house sits in the landscape, winter and summer. There are occasional pages of construction details, fun to look at—particularly the massive fireplace section—though the structural details are not very relevant by today's codes and energy standards. At the back of the book is a brief glossary of Norwegian terms and place names such as *svaberg*, the bare rock found where island (*holmen*) meets sea (*hav*). These terms help to make sense of the places, such as Beltesholmen, featured in earlier pages, a friendly touch.

For timber framers, Tostrup's book is both a source of design inspiration and a meeting with a kindred spirit. Wood is everywhere in Wenche Selmer's designs. Wood clads the walls, the ceilings, the floors, the countertops, even the light fixtures. Indoors, it is never painted, leaving the grain and knot patterns to soften the straight lines of the boards. Exposed timbers support the ceilings, laid over posts and beams well integrated into the plan of the house.

Selmer's timbers do their jobs quietly, without fanfare. Her ceilings are generally modest in height; the exposed joists overhead give visible proof of shelter and add another rhythm to the patterns of lines made by the boards enclosing the space, as seen at right. The job of bracing the structure is generally left to the walls. Her designs commonly combine overhead timber with stick-framed walls, which she prefers for the flexibility they allow in bumping walls in and out to shape the house. Four-by-eight joists sit atop stud walls, with no superfluous framing such as end posts and a timber beam to outline the wall, but Selmer's designs could be easily adapted to include some timber joinery. Erecting a full timber frame and wrapping it with a structural enclosure, however, would violate Selmer's ideals of simplicity and economy. In her designs, everything has a purpose, and often two; redundant posts would be not only unnecessary, they would clutter the walls.

Almost half of Selmer's designs are for summerhouses, the small dwellings and cabins that are, for Scandinavians of even modest means, an important place of retreat and connection to the mountains, forest and sea. Many of the designs echo local building traditions of tiled or sod gable roofs, board-on-batten siding and multipaned windows, but Selmer plays with these themes in interesting ways. She may pull the walls back under the gable triangle or the eaves of the roof to create sheltered spaces to chop firewood or strip off skis; exterior doors may be accentuated to the eye by running the door boarding at right angles to the orientation of the siding; vertical siding boards over battens may vary in width to create interesting patterns of shadow lines.

These little houses are tucked into beautiful but challenging sites. Selmer showed great sensitivity in settling a house gently into its surroundings. This care for the relationship between house and landscape was a consistent theme in her work, whether the site was a rocky islet or a sloping urban lot in Oslo. Tostrup writes:

> Situating the house in the terrain was a main issue for Selmer. Not only would she sometimes spend the night in a sleeping bag onsite to experience the sunset and sunrise, but she also carried out detailed surveys with a measuring tape and leveling telescope. . . . The landscape and vegetation, the sun and wind conditions, and the views were all carefully considered in her designs. Other elements such as fences, pergolas, and terraces contribute to the intimate connection between the house and the site, creating surprising spatial effects.

A striking example of this connection is Kisteglad, a summerhouse broken up into three little buildings clustered in a rugged cove (above right). Settled on a stone terrace beside the water, with

wooden docks and walkways that appear to float just above the surface of the sea, this little cluster is tucked among humps of bare granite bedrock, with tough vegetation in the sheltered pockets. One big shoulder of rock rises between the buildings and seems to be as much a part of this little compound as are the wooden structures; one can easily imagine this rock draped with children. The stone terrace and the boardwalks are scribed to the edges of the rock, flowing around them just as the nearby water does.

Indoors, the pattern changes to clean, straight lines, but the connections to place are kept through well-sited windows and doors, and with the ubiquitous wood paneling. Selmer's detailing avoids trim wherever possible. The wall paneling is lapped neatly onto window and door jambs as the only finish. An interesting detail recesses the baseboard behind the wall paneling, which is stopped a few inches above the floor.

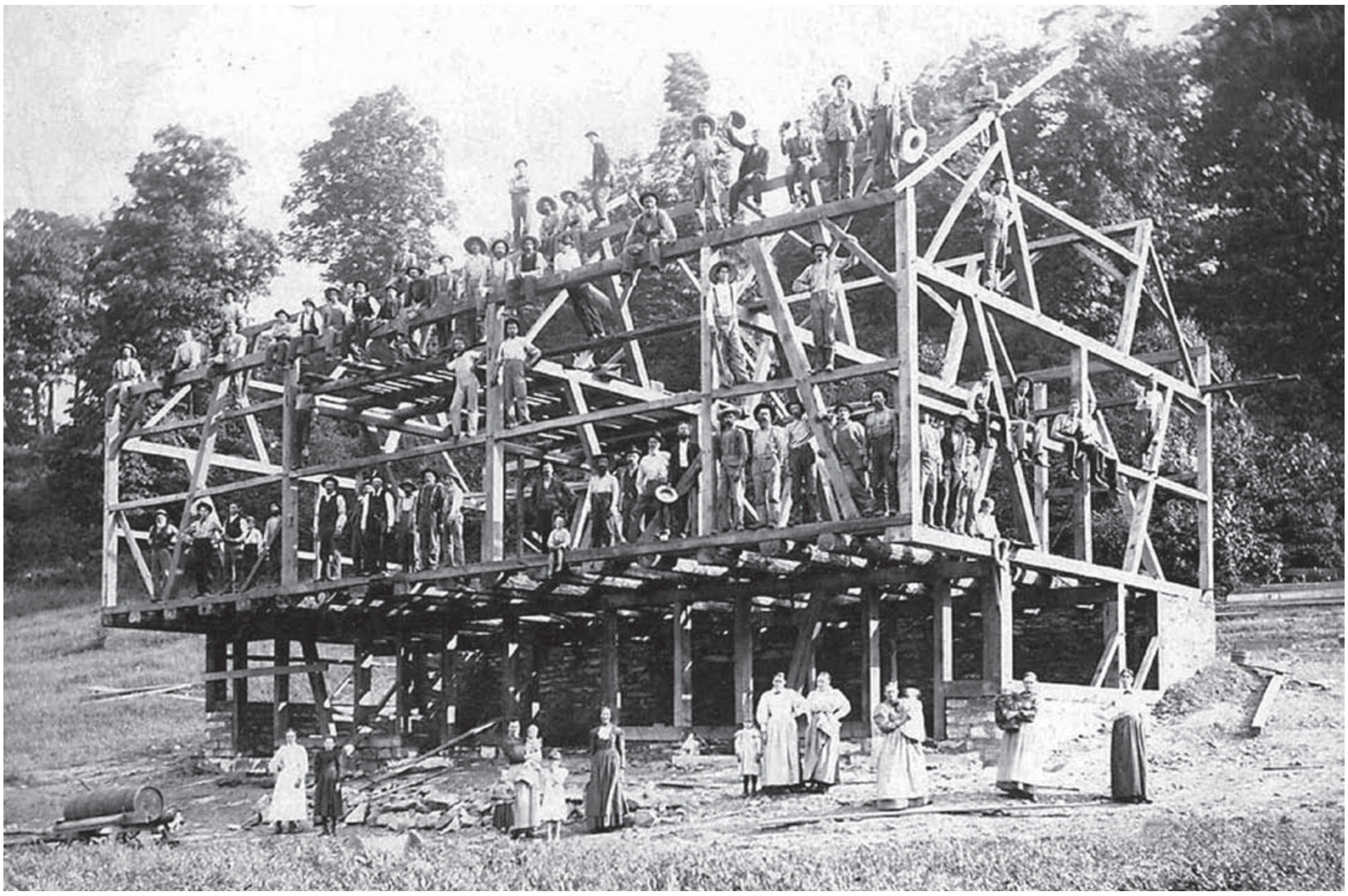
Selmer's work is imbued with both economy and generosity. It is economical of space, material, and construction costs, but in such a way as not to deprive, but to pare down to beautiful essentials, revealing a wealth of light, space and usefulness. She generally favors open, flexible floor plans, with sliding doors to create separation when wanted. Carefully placed windows and alcoves make smaller rooms feel spacious. Hallways are almost nonexistent—instead, wide passages combine with galley kitchens, bunks, or sofas to make fullest possible use of the space. Even Selmer's furniture is efficient; her built-in sofa benches integrate almost-invisible drawers for storage, and often a well-placed sliding door enables the couch to double as a private guest bed. A Selmer house works: with quiet elegance it facilitates interactions between people and with the surrounding landscape.

Good design is timeless, and this book captures a master designer at work, with Tostrup as a knowledgeable and sensitive guide. The book is currently out of print. If it can be had through a library, it is well worth having in hand. Otherwise, go to papress.com/html/book.details.page.tpl?isbn=9781568985930, an electronic edition provided by the publisher, the Princeton Architectural Press.

—Sarah K. Highland

Sarah K. Highland (sarahkh@lightlink.com) is a builder and teacher in Ithaca, New York. She last wrote on live-edge timber layout, in TF 104.

Split Barns of Somerset County, Pa.



Somerset County Historical and Genealogical Society, used by permission

1 Forebay barn raising, Somerset County, Pennsylvania, mid to late 19th century. Forebay extends out on log joists cantilevered over stout timber-framed basement wall on stone foundation, with timber sill for barn wall laid over log ends. German-style sill-to-plate bracing still in fashion here, though knee braces begin to appear.

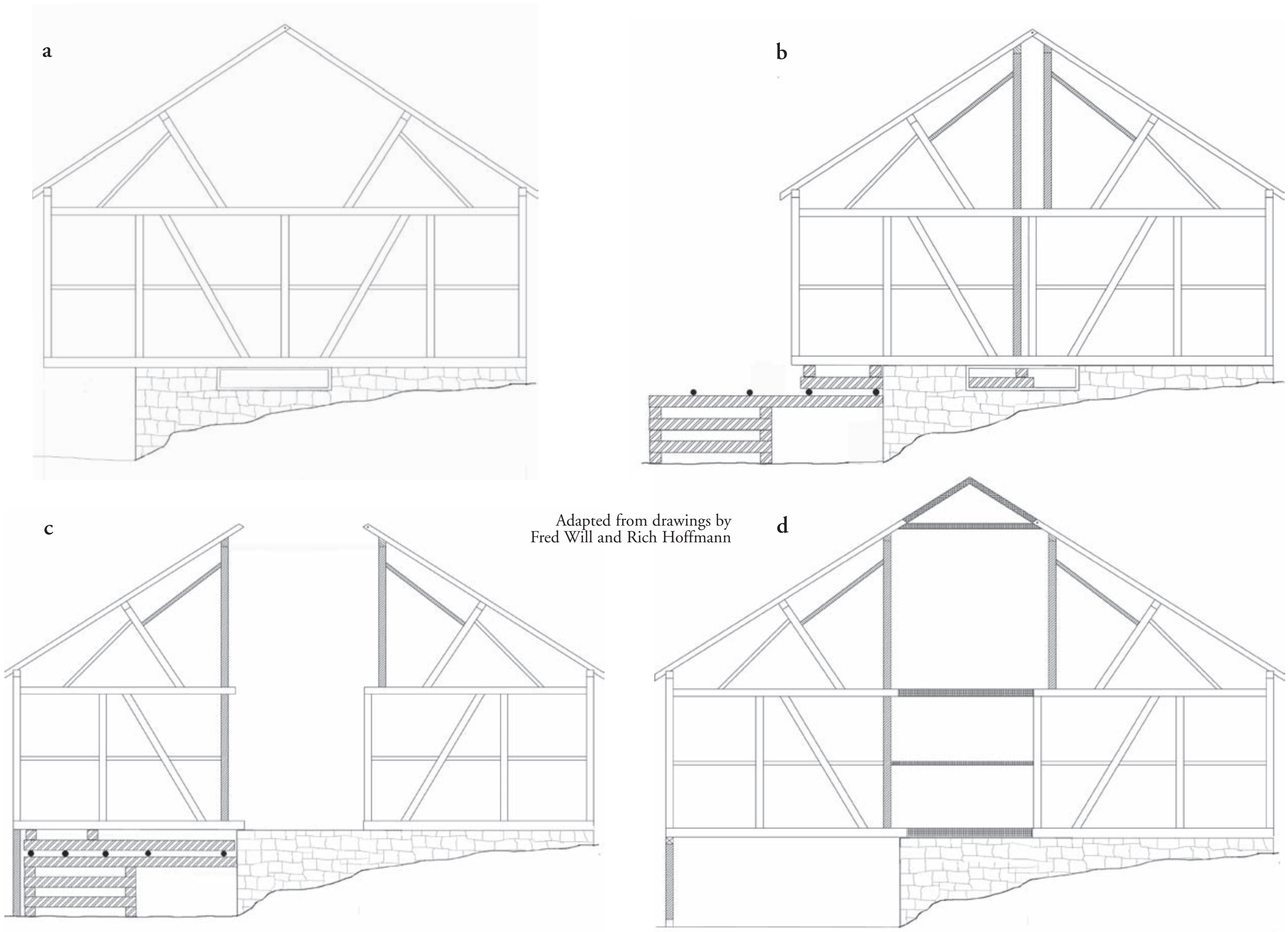
SOMERSET COUNTY, in western Pennsylvania directly above the Maryland line, was settled in the late 18th century. The 1800 census counted some 10,200 souls, increasing to 82,000 in 1920 and declining to 77,742 in the last census in 2010. Somerset's 1081 square miles are not crowded! Somerset County is also the highest point of the Pennsylvania Turnpike and requires a five-mile climb to the Allegheny Tunnel. The Allegheny Plateau at 2200 ft. is where winter travel is the most uncertain and the trees are bare of leaves well into the spring. For most Americans, Somerset County is also the place where Flight 93 crashed near Shanksville on September 11, 2001.

Immense and highly decorated bank barns are to be seen on the plateau dairy country, where the rigorous climate required large structures to store winter forage and house cows and draft horses in the stable below (Fig. 1).

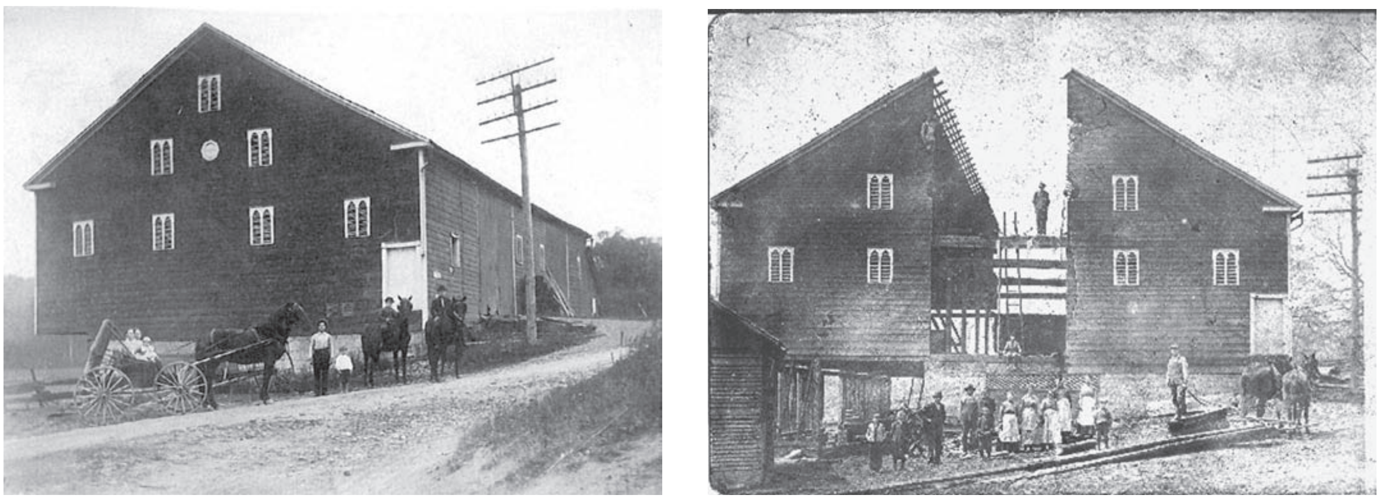
Until the advent of the combine in the 1930s, local barns also needed to store sheaves of wheat and oats until the community thresherman could arrive with his steam engine and grain separator. On the Great Plains the shocked grain remained in the field until threshing, but in the humid East the grain would have sprouted.

This volume of forage and grain in the straw and the rise of commercial dairying made possible by daily railroad transport of fluid milk to the growing cities motivated many farmers to replace a gable roof with a more voluminous gambrel style. (One barn authority believes this practice is the origin of the term "raising the roof.") The gambrel roof was one method to increase storage capacity, but a more dramatic approach in Somerset County was to widen the barn by splitting it down the center, moving one half outward and filling in. Only decades after their construction in the 1875–1900 period, barns were severed for their full length at the basement joists, the tie beams and up to where the rafters were pinned at the peak.

These structures were for the most part forebay-style bank barns, in which a portion of the barn's width at the threshing floor level is cantilevered over outside space below as a shelter for livestock, while the entrance to the threshing floor is from the higher ground and the entrance to the stable from the lower. Upon splitting, while the fully supported bank side of the barn remained in place, the downhill half of the barn with cantilevered forebay was rolled out onto cribbing beyond the foundation end wall, in a move 8 to 14-ft. probably accomplished by jacks, levers and rollers. The space gained on the threshing floor and in the loft was thus augmented by equal space at the stable level without any of the effort of excavating rocky Pennsylvania soil, and the large new space below might be enclosed easily (Figs. 2–3).



2 Representative sequence of widening typical bank barn in Somerset County. In *a*, end view of typical bank barn with forebay. In *b*, timbers added anticipatory to severing all transverse members, and cribbing built with track for rollout of half-barn on needle beams. In *c*, half-barn at destination, inner end supported on basement wall, new wall built under former forebay. In *d*, new members pieced in to new central aisle and enlarged opening below (as much as 20 ft. wide and length of barn), ready for enclosure as desired.



3 Miller barn, ca. 1868, 44x95 ft., Jefferson Township, Pa., 1912, and during 14-ft. widening ca. 1920. Demolished 2013.

The forebay-style barn is produced by extending the joists that span the width of the basement out over one foundation wall, henceforth called the forebay wall. In the widening process for these Somerset County barns, the forebay was eliminated by constructing a new timber wall as much as 20 ft. away (12-ft. widening plus 8-ft. forebay) from the original forebay wall that remained in place, thus creating a covered, walled-in space 20 ft. wide the length of the barn. Large doors were added at each end of this new space to allow equipment to drive parallel to the original forebay wall for mucking out the stables.

Certainly this operation had to occur in the spring when the loft was empty and be completed before the first cutting of hay in early June. The severed 10x12 basement joists were connected with 3-in. plank on both sides, secured by spikes, and likewise for the tie beam

4, 5 At left in background, Saylor barn, originally 37x85 ft., Milford Township, Pa., ca. 1883. Standing in front, Mahlon (the builder) and Martha Will Saylor shortly after their marriage in 1893. At right, barn, widened in 1927 to 50 ft., with added milk house today.

6 Rafters extended after splitting, posted purlin under long run.

7 Hay car, extended rafters and scalloped siding (Saylor barn).

connectors. Rafters were extended to the new peak by adding a length of 2x6 plank or in some instances small diameter poles, consistent with existing round rafters (typical barns Figs. 4–7).

Many Somerset County barns had a purlin on post set 8 ft. in from the long wall that carried short rafters to the plate, while longer rafters stretched to the ridge. A second posted purlin between the first purlin post and the ridge might support the long upper span (Fig. 6). Preparatory to splitting, new posts and purlins might be added if necessary to support the extended rafters to the new ridge.

Most of the connections are crudely done with plank and spikes instead of scarfing joints (Fig. 8). Some farmers used this opportunity to eliminate troublesome timber connections that interfered with the newly available hay handling equipment (Figs. 6 and 7).

Photos Fred Will and Charles Leik

8 Oak tie beam splice, roughly fashioned after barn splitting.

9 Gable end of widened barn stiffened against wind by shallow horizontal truss, seen in most split barns at both ends at or near tie beam level.

10 Model of split barn commissioned by authors and built by Andy Ebersol of Airville, Pennsylvania, using Michigan beech (from coauthor's family farm) for original barn timbers and contrasting Brazilian cherry for infill pieces. Note horizontal truss.

Thirty-nine barns (and one church) have been identified as widened, of which 30 are extant. Others have been lost to razing, fire or collapse from neglect and snow loads. Some split barns originally 42 ft. wide now measure 54 ft. at the threshing floor level. Obviously, the structural integrity of a split and widened barn was often severely compromised. One solution to stiffen the broadened gable ends from heavy winds was a horizontal truss located about two-thirds of the distance between the mow floor and rafter plate (Figs. 9 and 10).

Why did they do it? Wouldn't it have been easier to extend a barn with additional bents? Or, better, why not a second barn that lessened the ever-present danger of fire taking everything? We may never have an authoritative answer, but we can speculate that widening the barn kept the dairyman's workplace under one roof and created economical space by closing the forebay. And the new hay-handling equipment available in the late 1800s could be installed at the same time to fill the cavernous mow.

This equipment consisted of a steel track running the ridge of the barn, on which a hay car traveled (Fig. 7). Heavy hemp ropes running through pulleys on the car lifted loose hay (the mobile hay baler was not introduced until the 1940s) from wagons with slings or hayforks and then the hay car traveled to deliver its load.

Some of the motivation for enlarging barns by splitting may have been human vanity. The barn along with a farmer's acreage was the mark of his success, and size mattered! Another 4 ft. of height and 12 ft. of width at the threshing floor were statements, as were the classical or decorative elements applied to the new exterior wall spaces, such as intricate stars made practical by the invention of the powered fret saw.

Beyond matters of prestige, it's fair to say the barn took precedence over the house in the farmer's mind. The coauthor's German-born grandfather Anton Leik possessed an old house and barn on 120 acres when he built his new 36x80 barn in 1915. Even though he was growing five children, the new house had to wait until 1918. The barn was where the dairyman arrived early and worked late for two milkings, 365 days a year. Before retiring each night, grandfather with lantern in hand made one last visit to be certain the stock was quiet and all was well. Everything depended on that building and the well-being of the livestock.

We believe most widenings occurred in the early years of the 20th century, but we did learn of one done in the early 1950s. A Korean War veteran reported that he returned from the service to find his father and grandfather expanding the barn. He immediately left for other employment. Perhaps the prospect of milking even more cows prompted that decision!

Besides splitting and widening, there were other expansion options for a barn, of which the most common, cheapest and easiest was to extend the roofline downward from the wall plate's typical 24-ft. height on the forebay side and enclose it on three sides. Some examples exist of lengthening barns by adding additional bents, with the original end bent moved outward.

The single split church (architecturally speaking) we found, the Oak Dale Church in Salisbury, reveals its history in faint lines on the clapboard siding and in the garret. There is a basement but a ceiling conceals the underside of the joists, which might display additional evidence of the split. —Fred Will and Charles Leik

Fred Will (barnstar@comcast.net), a lifelong resident and a descendant of 18th-century settlers of Somerset County, has been documenting barns for over 10 years and has a database of over 300. Also an active cooper who demonstrates at historic events and museums, he is a member of the National Barn Alliance and a director of the Historic Barn and Farm Foundation of Pennsylvania. Charles Leik (caleik@gmail.com), of Great Falls, Virginia, is a past president of the National Barn Alliance and serves currently on the board of the Guild. A native of Michigan, he frequently travels through Somerset County en route to the family farm.

Chinese Covered Bridges

AS an academic working in the fields of building documentation, building archaeology and surveying, I don't often get the chance for hands-on experience in timber framing. In fact, I have never built a full-size timber frame. But as a professor at Neubrandenburg University of Applied Sciences in Germany, I can get close, because I teach a course called Building Archaeology/Building Recording/Model Making and I have at my disposal a workshop specifically for making wooden models. I have been researching timber roof frames and wooden covered bridges for over 20 years.

For the last 12 years my students have helped me build over 30 different frame models at a scale of 1:20, mainly Central European roof frames, but of late we have been concentrating on covered bridges, including some in North America. One of these bridge models, which I had taken to an international conference in Germany, attracted the interest of an eminent Chinese scholar there, and he got me an invitation to a conference in Pingnan, Fujian Province, in the mountainous eastern part of China in 2009. It was right in the heart of Chinese covered bridge country and I was privileged to visit several bridges with two American and a horde of Chinese colleagues.

Seven counties in neighboring Fujian and Zhejiang provinces, on the coast south of Shanghai, are working together to get some 20 historic wooden covered bridges recognized by UNESCO as part of the World Cultural Heritage. They have already been successful in getting several master carpenters to be included as a so-called "element" (Chinese traditional architectural craftsmanship for timber-framed structures) in the "Representative List of the Intangible Cultural Heritage of Humanity," a fantastic endorsement for any framer.

To promote these unique wooden bridges, conferences are held every two years, hosted by a different county. At the same time, infrastructure and tourist facilities are being modernized in the region. At the 2011 conference in Qingyuan, Zhejiang Province, I witnessed the opening of a new covered bridge museum—a multimillion building in anybody's currency, incorporating the latest audiovisual equipment (with *The Bridges of Madison County* running continuously), dioramas, wooden scale models, bridge timbers, tools and part of an actual bridge. I have seen nothing on this scale in North America or Europe.

In 2013 there were several smaller venues including the Fifth Annual China Taishun Covered Bridge Culture Tourism Festival, at which the Baijian Covered Bridge in Sixi, Taishun County, Zhejiang Province, was "twinned" with the Roberts Bridge, Preble County, Ohio, a delegation from Ohio being present to sign the official proclamation.

At the Pingnan conference in 2009, a young woman named Liu Yan introduced herself to me as my "sister"—meaning that we had had the same PhD tutor in Germany (in German called the equivalent of "doctorfather," hence the academic family relationship), she of course some 20 years later than myself. She was just embarking on investigating the arch structures found under some 100 or so of China's covered bridges. She wanted to build a model and had already worked for a carpenter building a real bridge using traditional methods.

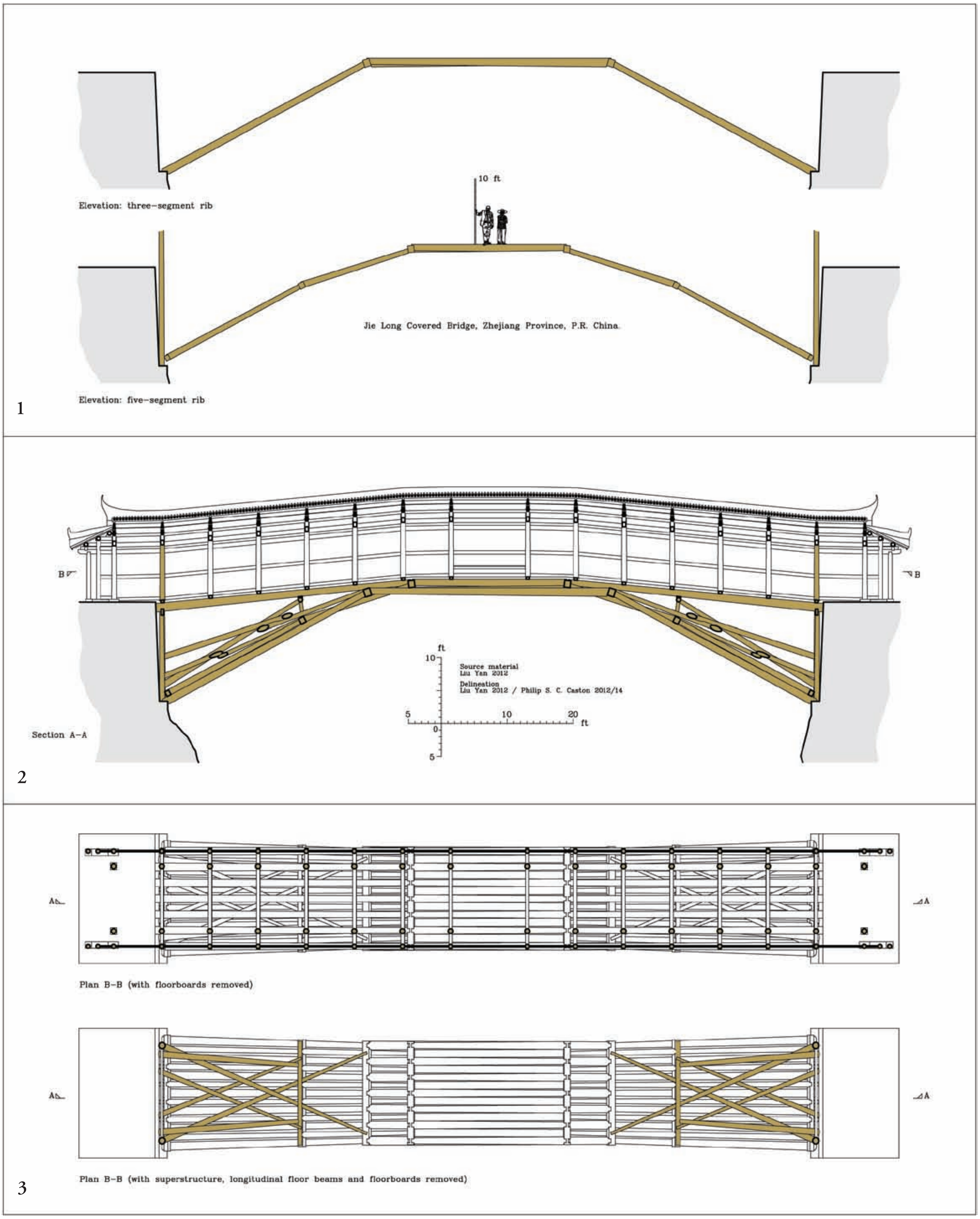
This was a great opportunity for us both. We agreed that she should come to Neubrandenburg and that we should build a model together. Yan could supply the dimensions and details of a real bridge and her knowledge of Chinese carpentry and joints. I would supply the wood, the workshop and tools, and my experience in model framing. Several books on erecting the arch and "lounge" or "corridor" superstructure of this type of bridge had already been published, and by pooling all this information we felt confident that we could build our own model. We would both gain a valuable insight into the methods and problems of building a Chinese wooden covered bridge.

IN order to compare the trusses, framing details, assembly sequences and general construction of different types of covered bridges around the world, I had chosen a span of 90 to 100 ft., which gives a roughly 5-ft.-long model at a scale of 1:20. Yan's collection of bridge measurements revealed that the Jie Long bridge (cover photo) near Zhangkeng Village, Dongkeng, Jingning County, Zhejiang Province (N 27° 49.059′ E 119° 44.739′), built in 1917, would not only provide a suitable length but was sufficiently well recorded to allow us to study the details.

Together Liu Yan and I produced a set of working and detail drawings, which I laid out on the tables and floor of the workshop (Figs. 1–3). We also worked up a bill of materials from which I purchased the lengths of rectangular and cylindrical pine we would need. I then enlisted two students (one Chinese) to help with the drilling and cutting of the individual pieces. The four of us produced two identical models of the bridge and some smaller study models and details during three weeks in May and June 2012. The first model was built up as the individual pieces were finished. The assembly sequence we used did not reflect that of a real bridge and after it was finished it was stored and has never been disassembled. With the knowledge and experience gained, we produced the second model, disassembled it, then reassembled it in a sequence we think is realistic, each step being documented.

The bridge design relies on a built-up segmental wooden arch to span between two stone abutments, with a "corridor" superstructure resting on top. The corridor is connected to the arch near the abutments at both ends. (In other bridge designs, it often sits independently over a stone arch, a cantilever or just a simple beam.)

Jie Long's support structure comprises alternating ribs of three- and five-segment arches of peeled logs set end to end, with square-section beams interposed transversely to make the end joints. The three-segment assemblies spring from the bottom ledge of each abutment and must have been the first pieces to have been set in place, on scaffolding to hold them steady until the five-segment arches could be interwoven and the whole structure stiffened up. The upper ends of the inclined three-segment arches are tenoned,



Philip Caston and Liu Yan

1 At top, elevations of three-segment and five-segment ribs. Three-segment ribs spring directly from small steps at abutment faces, five-segment ribs from sill set over three-segment ribs.

2 At middle, longitudinal section reveals basic elements of "corridor" superstructure and arch and bracing substructure of Jie Long bridge. Arch extends up into corridor and produces familiar humpback form.

3 Above, plan views. Upper view, floorboards removed, lightweight superstructure compared to massive rib members in segmented arch. Lower view, superstructure, floorboards and floor beams removed to reveal crossed bracing of transverse beams against abutments and commander columns. Frog's leg support includes transverse beam under longitudinal floor beams at midspan.

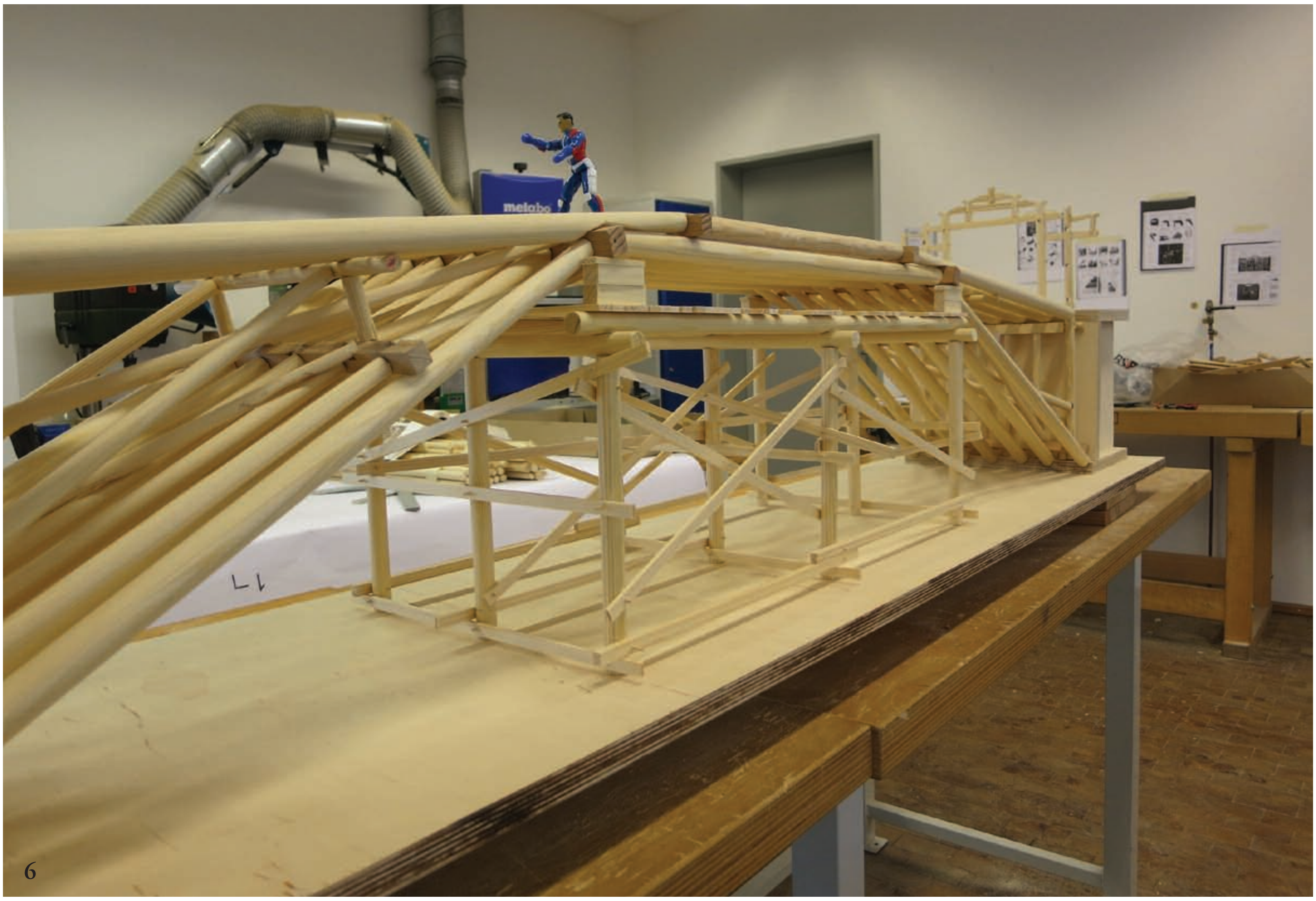
Photos Philip S. C. Caston

and each mortised transverse beam was hammered on to the seven tenons simultaneously. The final pieces to be inserted into each three-segment arch were the horizontal longitudinal members spanning between the two transverse beams. These were lowered in from the top, secured by drop-in dovetail tenons.

The stiffening of the structure occurs when the five-segment arches are inserted. The lowest inclined members of these are laid over the inclined plane of the three-segment arches. Their lower ends are tenoned into a transverse beam that rests against posts rising up the face of each abutment on both sides. The two outer posts at the abutments (*jiangjunzhu*, or "commander columns") extend through the deck and up into the corridor as aisle columns (*langzhu*) as seen in Fig. 4. They later form cross-frames with a sill, two inner columns (*buzhu*), two short beams (*meiliang*) and one long beam (*daliang*), and tie the corridor to the arch (as seen in Fig. 6, upper right, in front of the posters on the wall).

The second level of inclined members is woven under the three-segment arch transverse beams and secured at their lower ends with lap joints. The upper ends are tenoned and as before all six tenons have to be simultaneously inserted into the transverse beam. As with the three-segment arches, the last pieces to be inserted are the horizontal members that form the final floor deck. With all members interwoven, the structure forms a beam in a segmented shape (Fig. 5). We proved this by removing it from the abutments, i.e., taking away any horizontal counterforce, and the arch stood up by itself.

Having replaced it in the model, the next pieces to be assembled were two layers of crossed bracing and a further transverse beam and bracing system called a frog's leg (Fig. 6). The round transverse beam is set at a height to support the floor beams spanning from the level part of the arch to the abutments, at almost the middle of that span. The scaffolding underneath can now be removed and the arch–floor deck assembly becomes self-supporting.



6

The corridor can then be added cross-frame by cross-frame, bay by bay, from the commander columns inward to the center and outward to the portals (Fig. 7).

Each bay consists of a cross-frame and bay-long interties that join onto the next. All that remains to finish the carpentry is to add the remaining short posts (*aizhu*), upper beams (*meiliang*), purlins (*heng*) and rafters (*chuan*).

4 First model of Jie Long bridge, built 2012, complete in all jointing details and currently on loan to museum in Austria.

5 Three- and five-segment ribs alternate transversely to form completed segmented arch. Segment ends offer seven tenons or dovetails (three-segment ribs) or six (five-segment ribs) to join square-sectioned transverse beams within plane of arch. Transverse beams prestress ribs when beams are hammered into position on tenons.

6 Support structure finished, incorporating both three-segment and five-segment ribs interwoven with transverse beams. Crossed bracing, frog's leg supports and slightly inclined floor beams all wedged or mortised in abutment and arch stiffen assembly. Commander columns extend through deck at far end and with added members become first transverse frame.

7 Transverse frames of corridor, all identical, started from center of arch and held in place by interties.

7

AFTER the 2013 conference in Zhenghe I had the chance to see a real bridge under construction. Yan took us to see a building site she had been told about during her research. Again in the company of American colleagues, we hired a minivan and a driver and drove up into the mountains to Ganzhu village, Anxi, Qingyuan County, Zhejiang Province (N 27° 29.986′ E 119° 02.247′).

The village lay at the end of a long and narrow road, high up but still in a valley. There was no real infrastructural reason for the bridge as the road already extended to the village, but for the *feng shui* a bridge was needed and the villagers paid for it themselves. A little way down the valley from the village a leveled children's playground complete with lavatories had already been built, right next to the proposed bridge crossing. When we arrived, the playground had been taken over by a team of framers who had turned it into their outdoor workshop. They had put up a simple beam and pole frame, anchoring it to two handball posts, and draped light tarpaulins over all giving some shelter over their workspace. The tarpaulins, mainly of thin translucent blue, red and white cloth, bathed the whole area in an eerie magenta light (Fig. 8).

Even before entering we were greeted by the high-pitched whine of a circular saw and the shrill chafing of logs being sawn up into manageable planks. Judging by the size of the blade, belt driven from a tractor, this saw could handle anything and probably had already cut up the largest logs into the raw beams we saw lying around. A very nice gentleman showed me how he sharpened the ripping teeth with a file (Fig. 9).

Three people attended the circular saw, including an extremely elderly man who seemed to fetch and carry enormous pieces of timber, all China fir I believe, known to us as Cunninghamia and similar to Western red cedar. Further in, at least seven other framers were at work with various tools. The boss allowed us in to take photographs and to ask questions.

The first impression was of a storehouse for finished parts. There was nothing assembled, just piles of components. The workers were obviously very far into the job, with everything from stacked columns and highly carved beams to simple mortised blocks on view. Several pieces were being worked on. I could identify all the pieces belonging to the corridor, but none belonging to the arch. That was because the arch had already been assembled (Fig. 10).

This new bridge was much shorter than the Jie Long bridge, the original of our model, but I could instantly recognize the same structural elements: the three- and five-segmented rib members, the various transverse beams, the crossed bracing and frog's legs, the deck members and the four commander columns (Figs. 11–12). For a brief moment I mixed the experience of being on the building site with the memory of our model bridge and felt as if I had actually built a Chinese bridge, for real.

Back to earth again, I began to study the tools lying around. As if on show and just waiting for me, they were strewn everywhere to peruse. Everything seemed familiar, from traditional hand tools to modern portable power tools, but something was missing. There was no drawing, no plan or section. Yan asked the boss. His answer: as far as the corridor is concerned, they don't need one. A traditional Chinese framer knows a basic set of dimensions by heart, handed down from master to apprentice over generations. When it comes to actually marking the individual heights of the

8 Tent workshop charged with stacked parts and shavings, individual framing operations in between. No evidence of individual members being assembled or tested for compatibility.

9 Filing blade of large table saw, trailer mounted and belt driven by two-wheel tractor, which also draws saw to next building site.

10 Completed bridge arch and commander columns, half-mile from Ganzhu village in background. Far right, current road curves its way upstream on western side. At left, new bridge road under construction, cut out of the embankment on eastern side.

11 Arch intrados at eastern abutment. Woven-in square-section transverse beams locked to ribs at arch joints.

12 Lower end of main arch at western abutment. Inclined members of segmented main arch and abutment form solid perimeter on which frog's leg bracing and commander columns directly bear. In turn, commander columns support lower ends of two crossed braces and outer longitudinal floor beams.

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beams on columns, which can vary from job to job, these "new" dimensions are set out on a "long rule" or "drafting rule" (*gaochi* or *zhangchi,* Fig. 13).

That is not the end of new dimensions, however. When the floor deck is inclined, such as here, then the framers need hypotenuse lengths, not horizontal runs. For these dimensions the framers use a table of measurements, which I found on a long unfolded sheet on a pile of cut and marked timbers (Fig. 14).

The dimensions listed are the clear widths in all directions between columns, which vary from a regular grid dimension by the thickness of the column. As these thicknesses are all unique, so are the clear widths which, having been individually calculated, are recorded in the table in semi-graphic form according to their position in the bridge.

As I continued around the workshop, I came across a collection of everyday tools—an electric chainsaw, a claw hammer, various chisels and gouges, two planes (which are pushed, not pulled, as I saw demonstrated), a set square, a frame saw and an ink pot. The pot (with brush) is fixed to a holder and a roll of string which passes through it. The string is used in the usual way to strike lines, the brush to write identifying information on a timber (Fig. 15).

On the other side of the workshop, the frame saw was being put to good use on a workpiece supported by two Chinese trestles. All the trestles in the workshop were handmade on site by lap-jointing two logs at right angles and tenoning a third leg right through the lap joint to form an inclined cross. Numerous portable power tools can be seen in the background. To the right a carver grinds a groove into a decorated beam (Fig. 16).

13

13 Drafting rule (*gaochi*), marked on all four sides with real heights of beams and purlins, to be used at a scale of 1:1. Rule is traditionally left in roof of bridge on completion to aid in repairs or alterations later.

14 Table of measurements, schematic representation of bridge with clear-width dimensions noted between columns.

15 Traditional and modern tools found side by side, in profusion. Individual timbers labeled with ink, majority of saw lines with pencil or marker.

16 Bow saw, chisel and angle-grinder in simultaneous use in magenta glow. Cup of green tea leaves in hot water in foreground. No soft drinks or alcoholic beverages to be seen.

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17 Dragon's head beams piled up outside workshop. Spheres appear carved out of solid but in fact are made apart and inserted.

18 Power tools do bulk of heavy and arduous work, hand tools do final finishes. Carpenter uses small straight gouge to add more detail to basic routed ornamentation.

19 Trimming a shoulder with a straight fishtail gouge, short timber on tripods. Note mortise layouts on long timbers behind carpenter.

The ornate carving on the dragon's head beams was achieved in several stages with different tools. The first step was to remove large unwanted volumes of wood with a saw, then with power tools to incise more detail into the surface; final finishing was done by hand. The spheres in the dragons' mouths were not carved out of the solid but turned elsewhere and driven forcefully into place (Fig. 17).

For the carving along the side of the beams, templates were made up and traced in pencil or marker onto the prepared surface of the beam. Then the background was hollowed out using a router. Finally, the surfaces were reworked using hand tools, in this case a straight gouge to leave a clean-cut surface (Fig. 18).

Other less ornate pieces were also made using the same basic steps. While this short tenoned beam (*meiliang*) is receiving a finely chiseled surface (Fig. 19), other pieces were finished simply with the axe alone.

There were several tape measures lying around the workshop. The Chinese generally use the metric system today, but they also have a long tradition of their own weights and measures. On the building site, the two most relevant units are the Chinese inch (*cùn*) and the Chinese foot (*chi*). These traditional units have changed over the centuries and are unified today with the metric system. The modern Chinese foot is one third of a meter, that is, 333mm or 13.11 in. The modern Chinese inch is one tenth of a foot, i.e., 33mm or 1.3 in.

Many questions remain to ask, including the role of chants and poems sung on the building site to recite sizes and other information, the roles of the individual team members, and how the bridge is actually assembled. Our time was up, we had to move on, but I came away with memorable images and a fantastic experience. Altogether, I almost did build a Chinese bridge for real.

—Philip S. C. Caston

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Best Practices for High-Performance Houses

HOW to build an inviting energy-efficient home that delights the owner with its comfort and indoor air quality? We must first recognize that while homeowner goals may be different, they are not in conflict with typical builder priorities of cost, schedule and risk. With tighter financing and increased competition in new home construction, general contractors have allowed first costs to override competing concerns. This is a mistake, especially for clients on the threshold of retirement and building their last house. This demographic group—primarily baby boomers—makes the majority of purchases of new custom and semi-custom houses in the US. These buyers are willing to invest in quality to achieve higher levels of comfort and a healthful living environment, while reducing their utility bills and environmental impact. Unlike first-time buyers, these empty-nesters want a house sufficiently adaptable and flexible to accommodate seasonal guests. This often involves the occasional use of upper level or basement spaces by extended family, while the owners live on one level. The main floor plan and amenities should accommodate the owners' physical limitations as they age.

Ed Shure

1 Half-finished timber-framed house under construction in Montezuma, Colorado, built into hillside to minimize impact of expected avalanches while reducing overall heating loads by 40 percent. High-thermal mass of masonry fireplace will offset heat loss from north-facing glass in great room to come.

The ideal high-performance house is affordable, comfortable, healthy, energy efficient, aesthetically pleasing and functional for a lifetime. The structure itself should last centuries. The living space should be accessible and useful for its occupants. To achieve these aspirations requires a design-build team that shares these goals and works together to reach them. The traditional hierarchy of owner, architect, builder and subcontractor in a bid-build relationship rarely achieves these objectives. In construction trades, compliance with building codes is the target, though the codes represent a minimum standard for health, safety and public welfare. If the ideal goals are realized, it is most often by coincidence, not intent. To assure good results, the owner must accept responsibility for establishing and communicating personal goals with the added requirements for the building—orientation on the site, structure and systems.

Most owners underrate their ability to direct a design which produces a pleasing living environment. In theory, bid-build methods should achieve this result. Yet as Albert Einstein observed, "In theory, practice and theory are the same. In practice they are not." In practice, an integrated design-build team with the owner as leader will consistently attain desirable results.

The architects or master builders of antiquity were skilled in the art of designing buildings. They used earth forms and sun, wind and water as expressive elements in design, with a greater impact on building comfort and performance than most man-made features. Structures were oriented appropriately to take advantage of these natural phenomena, especially with respect to the thermal environment. Modern building technology and design favor mechanical methods for neutralizing thermal environments, at a high energy cost and with poor indoor climate results. Lisa Heschong, in *Thermal Delight in Architecture* (1979), argues that our emphasis on central heating and air-conditioning has actually damaged our thermal coping and sensing mechanisms. While considering rituals that enhance our lives, such as hearth fires, saunas, Roman and Japanese baths and Islamic gardens, she observes that passive solar design is fundamental to creating an environment for thermal delight. In practice, the structural prerequisites to building an appropriate thermal envelope are proper site orientation and embracing or incorporating thermal mass, using what is there (such as an earth bank as in Fig. 1) or adding to it (such as a trombe wall).

Solar performance Building orientation is the driver for solar thermal performance. For heating-dominated climates, the long axis of the building should be oriented east–west, or slightly favoring an eastern orientation. For most designs, this creates the maximum direct heat gain on the south face. In the northern

2 For optimal passive solar performance, overhang and windows on a south façade should be sized to provide full shade in summer and full sun in winter. Here, if top of 24-in. window is 12 in. vertically below eaves (36 in. to bottom of window), at 45-degree sun angle eaves would need to extend 36 in. from wall to fully shade window. Midwinter sun at 15 degrees would shine on wall approximately 10 in. below eaves, fully illuminating window. General case is embodied in trigonometry diagrammed at bottom, where tangent of given sun angle Ø equals length of opposite side (vertical) divided by adjacent side (eaves offset from wall). Given two values, the third can be calculated.

Al Wallace

3 Thermal heat gain from floor-to-ceiling south-facing glass without shading is mitigated somewhat by high thermal mass provided by interior architectural elements and substantially by high-performance reflective glazing.

hemisphere, the sun is highest in the summer and lowest in the winter. The average elevation above the horizon is equal to the latitude with a seasonal variance approximating +/- 15 degrees. Appropriate shading during summer months is provided by seasonal vegetation or roof overhangs. A well-placed deciduous tree or other leafy summer foliage serves as a natural solution to shade a southeast, southern or west wall.

Passive solar performance is optimal when the building's long axis receives full sun in winter yet is fully shaded in summer. For example, in Texas at 30 degrees north latitude, the sun averages 45 degrees above the horizon in midsummer and 15 degrees in midwinter. The amount of seasonal shading from the roof on south-facing glazing is easily determined by drawing a scaled section of the south-facing wall with the roof overhang and windows. The necessary eaves offset from the wall for full summer shading is determined by the angle of the sun (Fig. 2).

Since the sun rises and sets to zero azimuth (at the horizon), overhangs are ineffective for shading for east- and west-facing windows. Eastern solar exposure warms the home in the morning, usually desirable. However, glazing exposed to the setting western sun transmits harsh light and challenging summer heat gains. To mitigate these unfavorable conditions, such glazing should be eliminated, or installed with a reflective coating that rejects heat, or placed behind appropriate window shades or interior architectural features. Sometimes south-facing glass cannot be protected by shading of any kind and other tactics must be adopted to improve comfort (Fig. 3).

Many designers make the mistake of specifying floor-to-ceiling glass in the hope of improving passive solar performance or capitalizing on views. Wall-height glazed doors or two-story wall-height windows (such as in timber-framed great rooms at gable ends) are usually bigger than necessary to provide superior views; the spaces they illuminate are usually uncomfortable, with extreme interior temperature fluctuations unless mitigated by thermal mass. More-modest glazing can be rewarding (Fig. 4).

Thermal mass Thermal mass is a measure of a material's resistance to change in temperature and is crucial to good passive solar performance. Objects with high thermal mass absorb and retain heat. The most basic forms of climate patterns are diurnal temperature cycles—the temperature variance from day to night. High thermal mass slows the rate at which a space is heated by the sun, or conversely, loses heat when the sun is down. By moderating temperature swings, thermal mass within the building naturally increases comfort and energy efficiency. There are exceptions based on climate zone. With an outside temperature uncomfortably hot during the day and uncomfortably cold at night, internal thermal mass works well. If the weather pattern does not follow this cyclical pattern, however, or if the mass is not thermally iso-

Al Wallace

4 Windows under roof overhangs on northwest wall provide views in Aspen, Colorado, without sacrificing energy efficiency caused by oversized glazing. Structure at right provides substantial shading on first floor from western sun.

lated from the outdoor atmosphere, the temperature of thermal mass trends toward the prevailing outside temperature.

This is one of the challenges of insulated concrete forms or straw-bale walls. These high-mass systems typically have half the conductive resistance (insulation or R-value) recommended by energy codes. In a moderate climate such as North Carolina, the thermal mass of these walls effectively balances diurnal temperature swings. However, in a heating-dominated northern climate, subzero weather gradually decreases the temperature of the concrete core, causing the thermal mass to cool the interior space.

A more effective method that works for both temperate and extreme climates is to provide thermal mass inside well-insulated, conditioned space. Before the 20th century, high-mass residential buildings consisted of large timbers and masonry. Following the turn of the century, mass residential construction completed its transition to light framing. Passive solar designs in the 1970s often compensated for the lack of thermal mass in contemporary structures by incorporating a trombe wall. This masonry wall was built on the southern side of a building with a glass external layer and a high heat capacity internal layer separated by a hallway or layer of air. While thermally effective, this practice limits the design options for south-facing walls. As alternatives, I have successfully incorporated the following methods to increase thermal mass: 1) installing 5/8-in. Type-X drywall on all interior walls and ceilings, 2) facing the exterior side of below-grade concrete walls with rigid foam insulation, 3) using lightweight gypsum concrete as an underlayment with hydronic radiant-heated and radiant-cooled floors, and 4) incorporating natural rock or slate flooring in sunlit spaces. These cost-effective methods substantially increase thermal mass and structural stability while incidentally providing excellent sound attenuation.

Thermal envelope and relative humidity The building envelope is the structure that isolates inside from outside space and consists of walls, roof, windows and doors. This thermal envelope limits conduction and convection between the two environments. Conduction is heat transfer through the building structure and is typically controlled with insulation and the thermal resistance of glazing. Convection is air movement into and out of the building. Low-energy houses should be tightly sealed and then provided with controlled ventilation for fresh air. Contrary to conventional wisdom, building thermal performance and indoor air quality are degraded more by problems with convection than insulation. A leaky house with good insulation is more likely to have greater comfort issues than a tight house with poor insulation. The "Goldilocks effect"—hot upstairs, cold downstairs, warm somewhere in the middle—is most likely caused by leaks. Overly dry air, which contributes to allergy and respiratory ailments, is attributable to excessive air infiltration, especially during winter months where the differential pressure between inside and outside is greatest. The science of psychrometrics supports this observation.

Relative humidity is the measure of moisture in the air relative to the limit it can carry (saturation) at a given temperature. Humans tend to be most comfortable when relative humidity (RH) is between 35 and 50 percent. At 60 percent RH, the air feels muggy and can cause indoor mold problems. Below 30 percent, the air is too dry and can cause skin and respiratory issues. By definition, air is saturated at 100 percent. This condition may be referred to as the dew point, saturation point, condensation point or 100 percent relative humidity. In psychrometric terms, the physical volume of water is measured as grains of moisture per pound of dry air. Dew point is affected by temperature and absolute humidity. Hot air is able to support more water in vapor form than cold air. Given a fixed amount of moisture in a volume of air, the relative humidity can vary dramatically based on air temperature.

Consider the impact on indoor air humidity using the following example of a house with substantial indoor temperature variations. A fixed volume of water is suspended as vapor in a west-facing upper level room at 90 degrees Fahrenheit (F) with a humidifier maintaining 47 percent humidity. While this space would be too warm, it would not feel humid. If this upstairs air were then circulated to a well-shaded main floor at 70 degrees, the RH would increase to 90 percent. This is a reasonable air temperature, yet the air would be uncomfortably muggy. Vent the same air into a 65-degree crawlspace and it would become saturated supporting only 93 percent of the moisture of the upstairs room. Since the air is saturated, 7 percent of the water condenses on the floor or colder surfaces within the crawlspace. Though relative humidity changes substantially, temperature is the only variable in this example.

Now assume a poorly sealed home in cold winter conditions, with the house leaking cold outside air into the crawlspace and attic, a common occurrence, or even directly into the living space around unsealed doors and windows. At 20 degrees F, this outside air can hold only 15 grains of moisture per pound of air. When the dry outside air with this fixed amount of moisture is heated to 70 degrees inside the house, the relative humidity of that air drops to 14 percent. It would be challenging, if not cost prohibitive, to install and operate a humidifier to provide comfortable humidity levels under these conditions.

Cooling performance High humidity has a negative effect on cooling performance. The impact is greater with low-energy houses. In order to cool a structure, heat energy consisting of sensible and latent heat is removed from the interior. Sensible heat is the energy released with a temperature change of dry air. Latent heat is the energy contained in the water vapor, or generally the energy absorbed or released during a phase change from a gas to a liquid or vice versa. The total cooling load is the sum of the sensible heat load and the latent heat load, and cooling equipment must handle both loads to create a comfortable environment. Warm air passing through a cold heat exchanger coil loses sensible heat as the air temperature drops. Additional energy is transferred as water condenses on the coil, in a process also known as latent heat extraction. With higher humidity and greater condensation, the coil is less effective at removing sensible heat. This must be considered when sizing cooling equipment.

Air conditioners and heat pumps are rated in total and latent cooling capacity, with the latent capacity generally limited to 25 percent of total capacity. This limitation is based on compressor output, on the air flow created by the blower, and on the size of the condensing coil—industry conventions that balance cost with energy efficiency. Increasing the proportion of sensible capacity increases the equipment's efficiency rating, so manufacturers limit latent capacity. This is a challenge where the latent cooling percentage of total cooling load exceeds 25 percent. In a dry climate, the total cooling capacity of standard equipment is usually sufficient to also meet the peak latent load. With high humidity, cooling equipment effectively sized to only the total cooling load may not be able to meet the latent cooling load as well.

If a house in Atlanta has a *total* cooling load of 50,000 BTUs, the *latent* load may be 20,000 BTUs with high humidity. The same house in Colorado might also have a total cooling load of 50,000 BTUs, but a latent load of only 10,000 BTUs in the relatively drier climate. An air conditioner with only 25 percent latent capacity (12,500 BTUs) would work well in Colorado but not in Atlanta, where the house at 72 degrees would feel clammy. For high-performance houses this is more problematic: the only way to dehumidify is to cool, unless the house is equipped with a whole-house dehumidifier. If the air-conditioning rarely runs, especially during spring and fall, you have no moisture removal from the air conditioner.

Low-energy houses exacerbate this problem. A high-performance building envelope reduces sensible heat gain—the gain from hot outside air or the sun. While it slightly reduces moisture from the outside through air infiltration, the same envelope retains moisture from occupant activities. This human-created latent heat results from breathing, cooking, bathing, washing or growing plants (or improperly ventilated combustion). The consequence is to reduce the total cooling load while only slightly reducing the latent cooling load. In other words, you are reducing air temperature gains, but not substantially reducing humidity-holding latent heat. The net effect is to increase the percentage of latent cooling load to total cooling load, which in humid climates quite often exceeds the latent cooling capacity of the equipment.

As houses are tightened and indoor humidity rises, latent cooling becomes a critical consideration. Many contractors use rules of thumb when sizing equipment and most count on the central cooling system or an energy recovery ventilator to adequately dehumidify such houses.

This is a mistake when sizing equipment for low-energy homes. Designers must always perform detailed room-by-room load calculations. In the heating and cooling industry, the standard for these calculations for residential structures is the Air Conditioning Contractors of America's *Residential Load Calculation* (Manual J). Ideally, HVAC specification is an iterative process beginning early in design, which balances the cost of building envelope upgrades with the performance of heating and cooling systems.

Testing Since building performance is highly dependent on the installing contractors' expertise, the homeowner should request testing by an independent energy rater during construction. (This is a requirement for Energy Star–rated homes.) An energy rater inspects the elements of the structure most directly impacting insulation, air sealing and ventilation. Using a blower door test and conducting physical inspections, the rater can identify envelope problems during construction before drywall installation. The Building Performance Institute (BPI) and Residential Energy Services Network (RESNET) are leading organizations for rater certification. Both organizations teach the same principles of building science, energy loss and heat flow in a house. RESNET certification includes duct testing and energy modeling.

In architecture and engineering schools, while students may be versed in specific technologies, a holistic approach in the field is missing and critical to achieving homeowner goals. Integrated design-build methods should place a priority on building orientation, thermal mass, the building envelope and indoor environment.

Building orientation is the first key determinant to comfort and energy efficiency. With appropriate thermal mass, the building will then store or reject solar energy while providing inertia against temperature fluctuations. The building envelope is the thermal boundary consisting of walls, roof, doors and windows, and it's dependent on insulation and air tightness. High-performance building standards go well beyond code compliance and can produce elegant, energy-efficient houses that last a lifetime.

—Al Wallace

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Scribing a Post to a Rock

I'VE always loved the way trees will occasionally grow right on top of a boulder, roots wrapping around the shape perfectly. Scribing exposed timber posts to rocks can bring a similar organic, unified beauty into our framing.

Of course, the technique could be applied to a post landing right on ledge but ordinarily the first step is to choose the rock well. It should be broad enough that the post does not overhang, but not so broad that positive drainage away from the post is impaired outdoors. Smoothness definitely helps for scribing, cutting and fitting. A relatively flat bottom on the rock makes for good bearing on a bed of crushed stone or a freshly poured concrete footing. From a practical perspective a squished sphere to make the scribe smooth and the angles low meets all these criteria, with a little lumpy thrown in for personality. Here in Vermont, rocks like this abound, and most rivers will cough up a few when searched.

1

The next step is deciding how to scribe—vertically or horizontally? A very tall post and a reasonably small rock might make horizontal scribing attractive, where the post is lying on its side above the rock, which is also held perpendicular to its ultimate orientation. Generally I find it easier to scribe the post vertically onto the rock. You can do this with an individual post or an entire building if it's small enough. When scribing posts individually, it's important to locate them in all three axes, *X*, *Y* and *Z*. I like to drill plumb down into the rock where center-of-post will be and set a pin, or a Timberlinx connector when a tie-down is required, in the rock (Fig. 1).

My next step is setting the post onto the rock for scribing. Usually I have already cut the rest of the post joinery and so can use the shoulder as my vertical reference. Knowing where that shoulder needs to end up in the building, I then find the height of the lowest point on the rock where the post will eventually make contact. It helps to leave a little extra. Too short in the end obviously will be really bad, but lots of extra length makes for longer scribing distance and deeper drilling into the bottom of the post, both of which can lead to inaccuracy.

Once the post is rough-cut to length, I drill into the bottom, being careful to maintain alignment parallel to the centerline. For square stock that's easy, but for rounds and forks you'll need to have well-marked centerlines on at least three faces to be able to do this accurately. Now the post can be slid down onto the pin, braced plumb and rotated to proper alignment (Fig. 2). While one can use the centerlines for that rotational alignment, I like to use the mating timber when possible, the plate that will ultimately sit on top of the post for example, or the top tenons in the case of a forked post. Bigger lever arms make for more accuracy. At this point the scribe distance can be calculated.

If the rock isn't too soulful, the post isn't too big (or soulful!), and if I haven't been too conservative in rough-cutting, this distance is usually just a few inches, and I can use a simple pair of dividers, judging plumb with my naked eye (Fig. 3, scratched line overdrawn by Sharpie for photo). Bigger scribe distances or serious funk (root flare anyone?) might call for log or bubble scribes with built-in levels, which can ensure that one is scribing plumb.

Taking care of my future self, I'll make marriage marks on both post and rock as aids for templates and for alignment during prefit —perhaps just the four corners for a square post meeting a reasonable rock (Fig. 4). With the post removed I then scribe cardboard female templates of the rock surface using those marks. From these I make male templates with which to test the bottom of the post as I carve it to fit the rock (Fig. 5).

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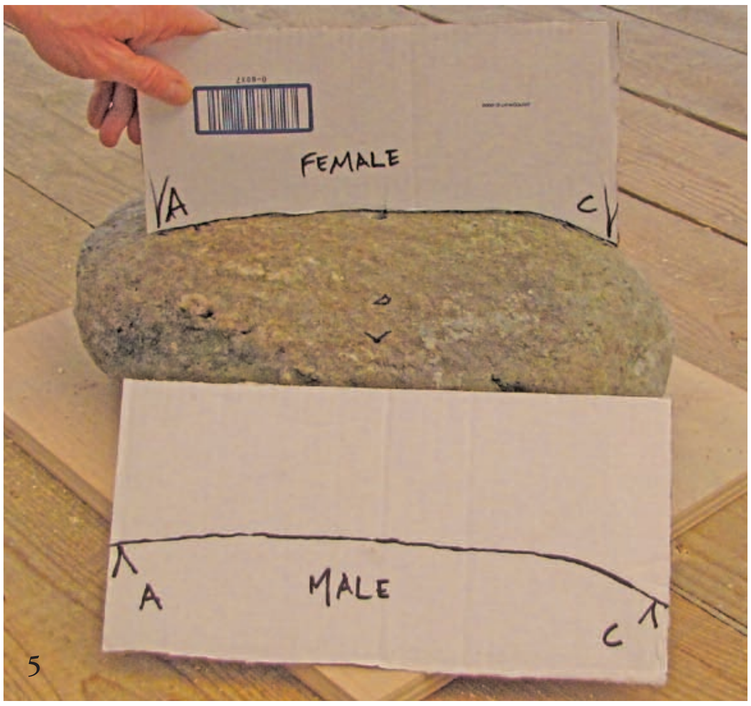

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Finally, it's time for cutting. These days I'm partial to an electric chainsaw and a 4-in. angle grinder with an Arbortec carving wheel, but a gouge and mallet will do the job with a little more elbow grease (Fig. 6). If you know the anticipated load on the post, you can decide how much of the center of the post is safe to relieve, checking with templates as you go. Just a half-inch of bearing around the perimeter of a 7x7 gives 13 sq. in., which translates to 4500 lbs. of load bearing in #2 Eastern white pine, provided the slope of the rock surface is gentle (Fig. 7). In dire circumstances one can resort to construction adhesive to increase bearing area. A thin piece of copper is elegant insurance against moisture wicking in case the rock is porous (sandstone, some limestones). After post setting (Fig. 8), copper foil will crush to the contours of most rocks and can be cut flush . —Josh Jackson

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Resistance to Uplift and Overturning In Timber-Framed Steeples

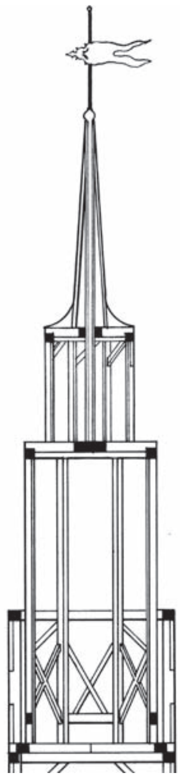
Octagonal steeples, with octagonal spires not built through,
but resting upon them . . . are dangerous experiments.
—Gwilt, J., *The Encyclopaedia of Architecture*, London, 1862

IN earlier articles on historic American church steeples, we discussed methods of keeping tall steeples in position, including telescoping of interpenetrating frames, telescoping in which an interior armature is constructed, clasping of descending timbers by partners and, finally, use of a pendant mast (see especially TF 83 and 86). Frequently these methods were used in combination, although simple telescoping of stages of decreasing plan, alone, is most commonly found. Even where these techniques were prudently in use, the stylistic desire for an open and airy bell deck surrounded by square pilasters or an octagonal colonnade was epidemic in the late 18th and 19th centuries all over the Northeastern US.

The open belfry eliminates the possibility of telescoping or pendant timbers descending from the lanterns, cupolas or spires above, because they will be visible as they pass or crowd around the bell unless they are cased. The exposure of the heavy bell is not as reckless as it seems. The bell deck and bell usually appear in the belfry but actually bear on the plates of a larger square lower tower telescoped below, often all the way to the bottom chords of the roof trusses (Figs. 1 and 2). The four or eight (and occasionally six) belfry posts surrounding the bell, and ultimately carrying the one or more stages above it, though not in telescoping fashion, almost always rise from within a lower tower, where they increase in size and are furnished with complicated cross-bracing for a concealed distance between 8 and 36 ft. below the bell deck.

The posts only incidentally support the bell and its dynamic loads when they pass through and are flashed to the bell deck. The stages above the bell are indeed just tenoned (and often bolted) onto some framing, such as a heavy crab, or girts tenoned or bolted to the belfry plate. An exception to this configuration is the great steeple at Middlebury, Vermont, where the framing is so dense and the architectural features so large that the square pilasters of the open bell level contain not four but eight large posts, representing the telescopic framing of two stages: the belfry and the first octagonal lantern above it.

What keeps stages above the open bell deck from blowing away any more often than they do? One reason is their aerodynamic shape: they are almost always octagons and cones. A second can be tying down the stages inside the structure. The problem arises of tying down tall, frequently very tall (40 to 80 ft.), spires in brick or stone churches with masonry towers, in which the only timber element other than some floor framing is the spire. While it is possible to conceal timber frame stages within the masonry, it is not often done, considered either unnecessary or a positive danger to the masonry walls in case of movement of the flexible timber frames under wind loading, or damage to the masonry if the timber elements burn. Nonetheless, merely tacking a 70-ft. spire to a wooden top plate laid in mortar on top of a typical 18 to 24 in. of brick or stone was rarely thought adequate. Other methods were employed to resist uplift and overturning.



Jack A. Sobon

1, 2 Clock, bell, lantern and spire stages of Strafford Meeting house, Strafford, Vermont, 1799. Just for pretty, lantern posts and spire framing must terminate at top of open belfry.

3 Facing page, Bethany Church tower, Montpelier, Vt., 1868.

The easiest to accomplish and most common of these was to attach long wrought-iron rods, typically 1-in.-dia., from the spire rafters to points often 30 ft. lower, affixing to an eye-bolt in the masonry or to a timber let into the brick or stone. These exist as the sole system of tie-down at the First Baptist Church (1867) of Fairhaven, Vermont, and as supplementary systems at Bethany Church (1868) in Montpelier, the state capital. They are supplementary as well at the First Presbyterian Church (1854) of Salem, New Jersey, and in a myriad of other churches. This solution is imperfect, however, because iron rods expand and contract seasonally and slacken over time, and the longer the rods—in theory better because they bring the tie-down loads deeper in the tower—the more slack will develop. A small increase in length in these vertical rods, combined with the fact that they offer no lateral stiffness, can allow substantial overturning to begin under wind loading, further stretching the rod or bending the eye-bolts at their points of attachment.

Improved forms of spire retention were recently found in two mid-19th-century Vermont churches, and others may come to light.

Photos and drawings Jan Lewandoski unless otherwise credited

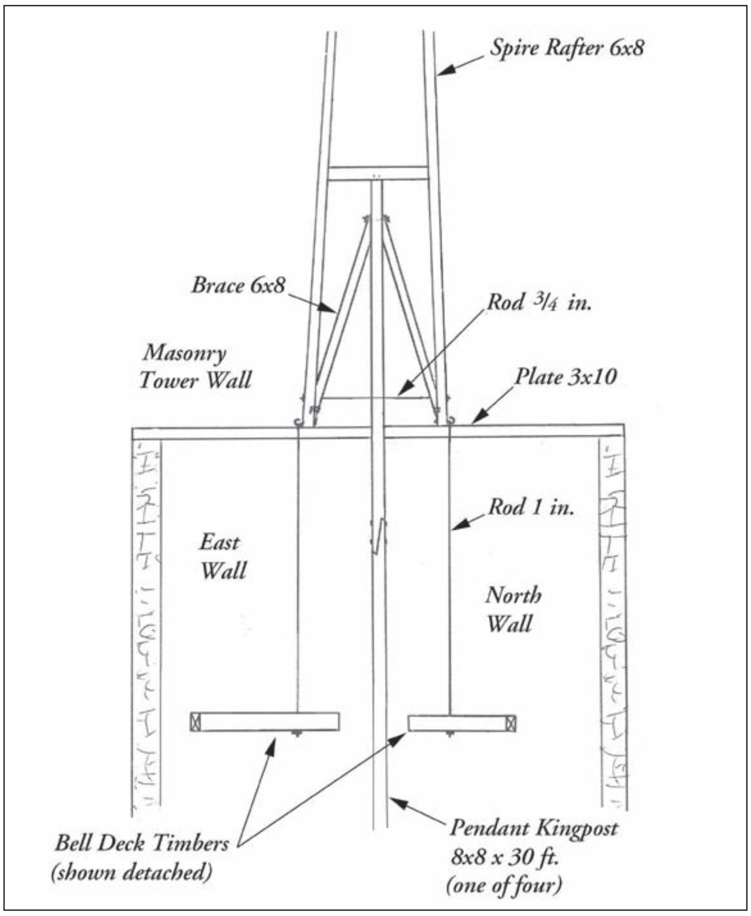
Bethany Church, Montpelier All that remains of Bethany's original 1868 construction is the 155-ft. steeple of stone and timber and a supporting portion of the old church, now much remodeled and added to. The square tower of the steeple is built of sandstone and red quartzite (a hard metamorphic sandstone), with Champlain limestone quoins, cornices, window surrounds and other architectural elements. This stonework is fully lined with brick (Fig. 3).

The 75-ft. timber-framed spire is covered in gray slate pierced by numerous wooden dormers, all in a highly perpendicular, pointed Gothic style. The spire's exterior section where it springs from a 3x10 plate atop the stone tower is 16 ft. square but soon changes to octagonal, acquiring some buttressing from lower pitched framing at the four corners to the exterior of the octagon. The 6x8 spire rafters are scarfed along their length and spiked at their feet, with short tenons where they engage the 3x10 plate. This plate has no mechanical connection to the stone tower wall other than a bed of mortar and the accidental projection of some nails into some of the joints of the stonework.

Resistance to uplift and overturning is provided otherwise. In each of the four locations where a pair of spire rafters flanks a corner of the square stone tower, the octagon spire framing crosses on the diagonal and a sort of kingpost truss emerges. Main braces (or "upper chords") 6x8 rise steeply from tightly wedged shoulders low on the rafters and tenon at their top ends into a 32-ft. 8x8 timber (the "kingpost") near its apex. A ¾-in. tie rod serves as the "lower chord" of this assembly, passing through the kingpost while the post, scarfed, continues down, pendant, for a total length of 32 ft. The actual apex of the post is 18 in. higher, where it tenons into an 8x8 beam joining the pair of spire rafters with which we began (Figs. 4 and 5).

4 Pair of spire rafters with crossbar about a third of the way up, suspending braced pendant kingpost, Bethany Church.

5 Below, view taken on diagonal through 16-ft.-square tower to show stabilization scheme including added tie-downs at rafter feet. System is repeated at each tower corner.



6 Above, Bethany Church, wrought-iron hold-down rod attached to spire rafter foot and bell deck timber a stage below.

7 At right, College Street Congregational Church, Burlington, Vermont, 1866. Spire was set alight by arsonist October 2013.

These four posts are in tension only, from their own mass and gravity, as they descend unattached to anything surrounding for 18 ft. into the stone and brick tower. In addition to the wedged shoulders forcing the main braces into the kingpost, the iron rod transfixing this ensemble at the level of the wedged connection prevents spreading or buckling of the spire rafters. Not totally rigid, the pendant kingpost mechanism, which has a long scarf joint at about midlength, displays a sort of springiness to the touch, traceable to the tight affixing in its upper few feet and no connection to anything for 20 ft. below. For the spire to lift off (they rarely do because of their shape) or overturn (they try all the time), the four truss-like assemblies would have to be pulled out of the tower or bent and broken laterally.

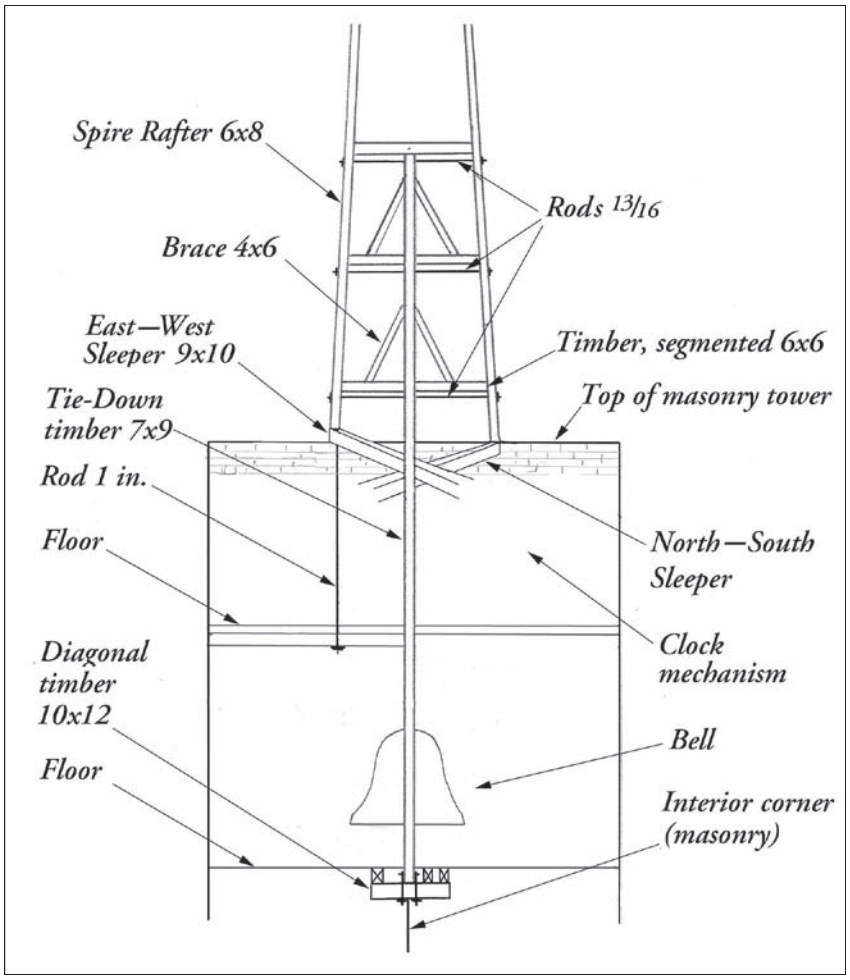
A parallel system of descending wrought iron rods exists alongside the pendant-post mechanisms, attached to iron hooks low on the spire rafters rather than to the post or its braces (Fig. 6).

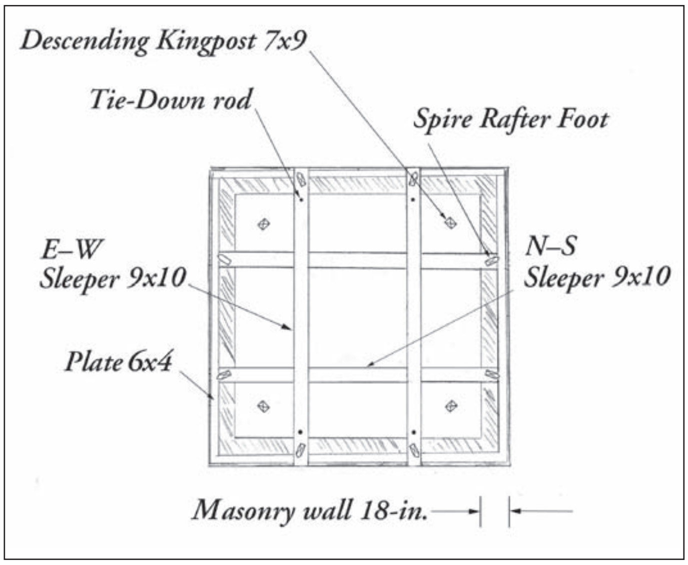
The rods drop from the plate and attach to wrought hooks in the wood framing under the bell deck, and other rods drop from the bell deck timbers about 14 ft. more to timbers let into the stonework and carrying a lower floor. As with all ferrous rods that have been in position for many years, they are currently slack to the touch and offer no turnbuckles for tightening. (One wonders how they were tensioned in the first place since they are not nutted at either end.)

While lack of failure doesn't prove success, it's hard to imagine this 75-ft. spire remaining in place through 145 years of northern New England weather, otherwise attached only by a few spikes and unpinned short tenons to a 3x10 bedded in mortar on top of 75 vertical ft. of stone.

College Street Congregational Church (1866), Burlington I made the acquaintance of the spire framing of the College Street church two days after a deranged arsonist had broken in, climbed to the base of the spire, doused it with gasoline and torched it. The slate-covered wooden spire was engulfed in flames and charred beyond salvation, but remained standing. I was asked to delineate its historic structural system with a view toward eventual reproduction. This large edifice is in the pointed arch style but appears considerably less perpendicular and high gothic than Bethany (Fig. 7).

The tower and body of the church are constructed of local yellow sandstone; quoins and trim are of gray Isle LaMotte (Vermont) limestone. The timber-framed spire is a tapering octagon rising 60 ft. above the top of the 16-ft.-square masonry tower walls. Because of the destruction and ultimate dismantling of this spire early last November, more can be said about its construction than about the spire at Bethany, where the frame disappears into claustrophobic darkness above. The College Street spire used 6x8 rafters that tapered to 4x5 at the top, scarfed at least once in their length. The eight rafters joined a short, faceted octagonal block at the top, with an iron ring forced down around the entire ensemble to keep it together. Sheathed by inch boards, the spire was then covered in the costly unfading red slate from New York State. This spire frame, like Bethany's, appears to have been all softwood, mostly spruce.





8 Elevation of College Street tower and one of four spire rafter tie-down assemblies. View taken on diagonal through 16-ft.-square tower, showing attachment of 7x9 tie-down at top and bottom of system and additional 1-in. rod from top of sleeper to underside of floor at top of bell stage.

9 At top, plan view of College Street sleepers and masonry walls, section taken at top of tower.

10 Above, pentagonal tenoned and bolted spire rafter foot.

As seen in Figs. 8 and 9, the College Street spire had a tie-down and anti-overturning system similar in form to Bethany's, but with a different theory at work. A 4x6 plate surmounted the masonry wall at its outer edge, but the rafters didn't land directly on it. The maximum diameters of the octagon (14 ft. 6 in.) landing on sleepers inboard of the plate placed the rafter feet right over the centerline of the 18-in. masonry walls of the square tower.

Two pairs of 9x10 horizontal sleeper beams crossed each other and the plate at right angles, spaced 6 ft. apart so that their eight ends correctly received the feet of the eight spire rafters. Two sleepers sat on top of the masonry wall and lapped over the plate while the remaining two sat immediately below in pockets in the masonry. Four of the spire rafters were thus 10 in. longer than the other four.

The two upper beams had tie-down rods 8 ft. long that dropped through to the underside of a floor beam below the clock deck joists, where they were fastened by nuts and washers. These beams and joists were pocketed into the masonry as well. The two lower sleepers presumably were considered sufficiently restrained by the weight and resistance of the upper two 9x10s.

In addition to affixing the spire firmly to sleepers tied by rods to a heavy floor 8 ft. below, a timber system somewhat similar in appearance to Bethany's was in place. Spruce 7x9 timbers 30 ft. long tenoned up into a horizontal 8x8 timber joining two spire rafters about 12 ft. above the spire base, at the four locations where the octagon spire rafters cut across the square corners of the masonry tower. The descending timbers were further joined and suspended in apparent tension between each pair of spire rafters by two levels of interrupted 6x6 timbers shouldered and spiked into both the rafters and the 30-ft. timber. From these 6x6s rose 4x4 diagonal braces shouldered and spiked into the 30-ft. timber. Iron rods fixed the assembly at each of the three horizontal crossings.

The feet of the eight spire rafters were transfixed by ¾-in. diagonal bolts through rafter and sleeper. The foot of each 6x8 rafter had a 2x7 tenon, 3 in. long and centered, that entered the sleeper on the long axis of the rafter and thus obliquely to the sleeper. In an unusual refinement, the foot of each rafter was also cut to the shape of an irregular pentagon around the tenon that sloped from zero at the outside point of the rafter to about ½ in. proud behind the tenon (Fig. 10).

The effect was to produce a bearing surface in the sleeper normal to the vertical axis of the rafter, surprising to find because with a pitch so steep as well as the rigidity of a boarded octagonal cone, plus a tenon and a bolt, there was virtually no horizontal rafter thrust left to resolve by this surface. Another mystery is why the framer bothered to reduce the footprint of the rafter to an irregular pentagon rather than cutting the entire foot normal to the rafter axis and merely dapping its entirety into the sleeper.

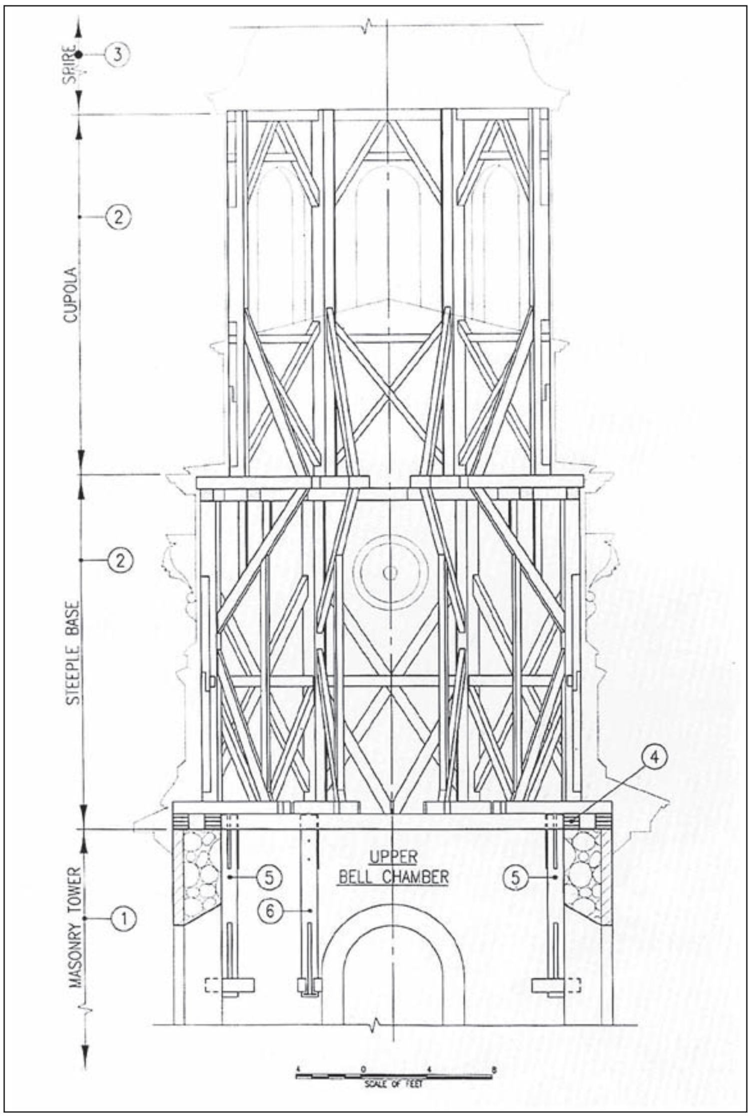
11, 12 Above, charred sleeper still in place at top of College Street tower, spire rafters gone. Tie-down rod drops 8 ft. to bell deck framing below. At right above, cut fragment of sleeper and plate, mortise and housing on top surface skewed for octagonal-spire rafter foot.

13 College Street descending timbers, not pendant as at Bethany, but firmly bolted at their feet to short stout members embedded in corners well down in masonry tower.

14 Christ Church, Philadelphia, 1760, lower terminus of composite steeple stage tie down.

A sleeper in situ is shown in Fig. 11. The bearing surface and mortise for one of the oddly shouldered spire rafter tenons can be seen in the top surface of the sleeper fragment shown in Fig 12.

At Bethany Church the long descending timbers tightly trussed to rafter pairs are pendant, unsupported and moveable at the bottom, in some sense acting as counterweights or cantilevers. At College Street these similar timbers were footed upon short 10x12 timbers inserted into the masonry walls diagonally across each of the four interior corners (Fig. 13). On each side of the timber, iron brackets were through-bolted to it and the brackets in turn bolted through the diagonal timber below, effectively tying down the spire even deeper in the tower (see Fig. 8 detail). This system contributes much more lateral stiffness, and thus resistance to overturning, than tie-down rods alone would have.



Keast and Hood, Philadelphia

15 Framing elevation of two stages of Christ Church steeple beneath spire, showing tie-downs (labeled 5) into corners of upper part of masonry tower.

The configuration is not entirely unprecedented. Robert Smith's Christ Church steeple in Philadelphia (1760), at the time of its construction the tallest building in the Western Hemisphere at 195 ft., has a system of timbers bracketed and bolted to short diagonals set into masonry corners (Figs. 14 and 15).

The timbers in Philadelphia, however, are short vertical members tying down telescoping stages one atop the other, not long members trussed after great length to the rafter pairs themselves as in Vermont, and thus a less sophisticated and daring design.

In England, both Wren and Gibbs stabilized tall masonry spires with pendant timbers hung from ironwork at the capstone, which had been done in towers in ancient China and Japan as well. The unusual method in the two Vermont churches is to have attached the four long trailing timbers directly and firmly to the rafter pairs.

The architect for College Street was J. D. Towle and for the nearly contemporary Bethany, Charles Parker, both of Boston. Both men designed numerous churches but appear to have had no professional connection. It's likely that the timber engineering was left to the framer anyhow, and I found only the name of the College Street master builder, Elmore Johnson of Burlington.

—Jan Lewandoski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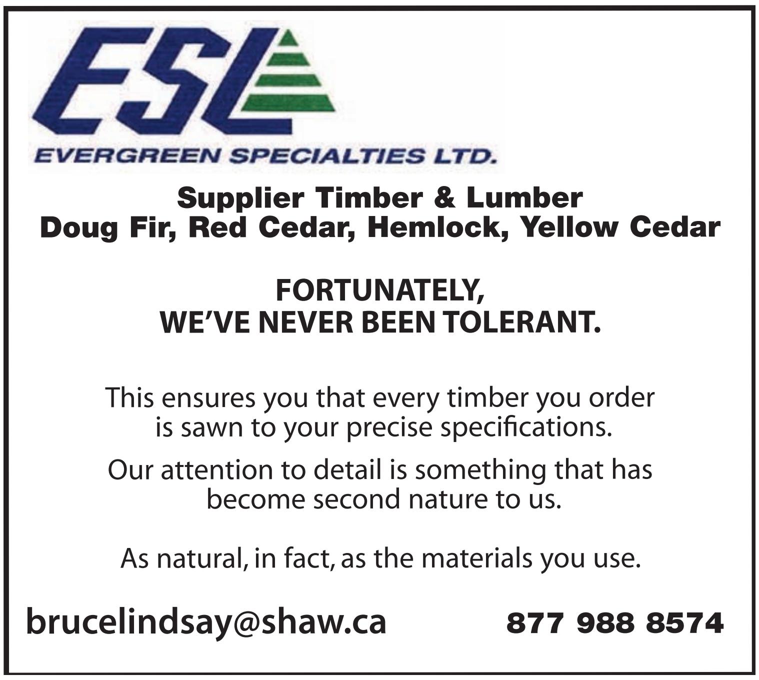
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