TIMBER FRAMING

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French Apprentices Visit New England

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On the front cover, visiting French carpenter Martin Lorentz, left, positions rafter over purlin while Heartwood School student Ben Theriault holds collar beam at the ready during raising of new clasped-purlin-roof white pine barn frame in Stockbridge, Massachusetts. Small block props purlin for access. Photo by Will Beemer. On the back cover, frame complete and filled with French apprentices in a display of Franco-American solidarity. Frame design by Jack A. Sobon, standing in center in straw hat. Photo by Alejandro de Onis.

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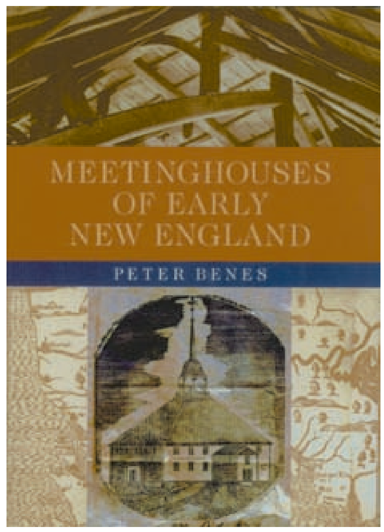
TIMBER FRAMING, Journal of the Timber Framers Guild, appears in March, June, September and December. The journal is written by its readers and pays for interesting articles by experienced and novice writers alike.

1985

BOOKS

New England Meetinghouses

Meetinghouses of Early New England, by Peter Benes. Amherst and Boston, University of Massachusetts Press, 2012. 10x7¼ in., 446 pp., hardcover. $49.95.



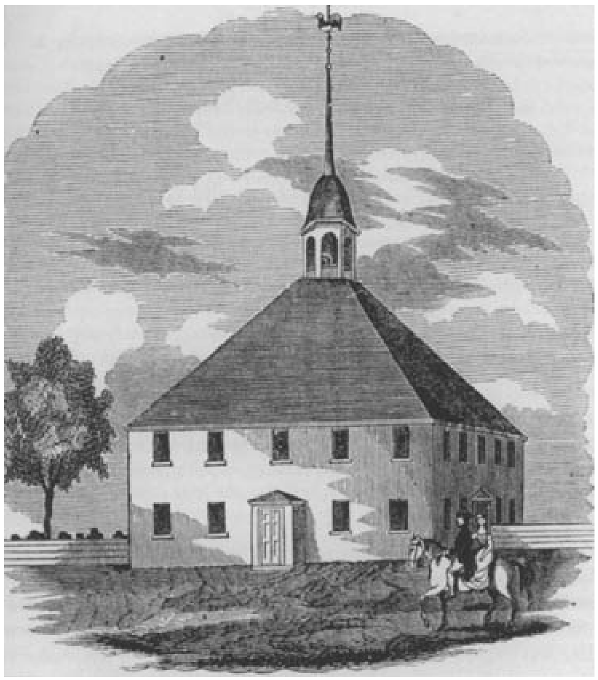
THE title of this book is modest and there exist other similarly titled studies of this appealing topic. Peter Benes's book stands far above most of them in depth of scholarship (his own and that of others cited) and in his attempt to identify and classify the entire body of religious buildings built in New England and eastern Long Island between 1622 and 1830. Benes, founder in 1976 and since then director of the Dublin Seminar for New England Folklife (now at Boston University), offers a fascinating narrative with generous and convincing data, not only providing numbers of total meetinghouses raised in the period (at least 2189, he says) but also charting these meetinghouses by period, religious denomination, presence or absence of attached standing bell tower and, finally, current disposition of the survivors, whether they now be church, town hall or other.

Benes gives credit where due and frequently mentions Frederick Kelley's "magisterial" *Early Connecticut Meetinghouses* (two large-format volumes, New York, 1948) as well as Edmund Sinnott's *Meetinghouse and Church in Early New England* (New York, 1963). Kelley's book goes to greater depth on a smaller number of churches and includes invaluable line drawings of the trusses, while Sinnott's book includes an attempt to group meetinghouses by evolving architectural form and style. Benes has had the benefit of much recent scholarship on the topic. He is kind enough to cite and footnote our book *Historic American Roof Trusses* (Becket, Massachusetts, 2006).

Early in his introductory chapter, Benes clears the air about the distinction between meetinghouse and church. English Puritans considered the church a "covenanted body of people gathered to practice Christian teachings" who could do this in any structure. In the 17th and 18th centuries, emigrating to America, they built meetinghouses to serve both religious and civic functions under the same roof. They shared a Calvinistic suspicion of Catholicism (or

"Popery"), the Church of England (Anglican) and its "steeplehouses," and generally any attempt to mediate between man and God by material means. The Anglican Church, not to mention its Catholic predecessor, by contrast saw a church as an "ecclesiological and architectural reality," a building specifically designed unmistakably for the worship of God. The distinction made, Benes and most other commentators nevertheless continue to use the terms interchangeably, probably because many churchgoers did so themselves until recently.

Meetinghouses of Early New England is a history of New England society expressed through its most important buildings, its churches, but Benes has relatively little to say about their frames. He has written a social, not a technological, history. Nevertheless, reasons remain to make this book of interest to timber framers.



Old-Town Meeting-House, Newbury, Massachusetts. Reproduced by Benes from Joshua Coffin, *A Sketch of the History of Newbury, Newburyport and West Newbury (1845).*

First, Benes is talking about a time and place in world history, not that long ago or far away, when 95 percent of the monumental architecture was timber framed, and for more reasons than just the availability of big trees. These churches were built quickly in frontier communities in urgent need of a meetinghouse, one that was expandable or expendable as the population grew (a certainty), and didn't cost as much as stone or brick. In addition, in the presence of the original forest, no doubt many a builder thought that he could probably do something great in timber.

Next, much as we can't understand why barns have the form and style and size and alterations they may have without some knowledge of a region's agricultural history, we can't understand why a church is framed or finished in a certain fashion without knowing the religious history of the region. Following the 17th century with its dissenting Puritans and their mistrust of churchly architecture and decoration, tastes changed. Immigration of Anglicans and other established religionists, increased education, wealth and desire for status, divisions among the old congregations, and a softening of the hard edges of the Puritan doctrines all led to the construction of edifices that again looked like churches.

Architectural pattern books were arriving in the colonies by the middle of the 18th century, allowing, for example, the steeple at Providence's First Baptist Church to be modeled on Christopher Wren's St Martin-in-the-Fields in London. Particularly after 1789 (coincidentally the year of the signing of the US Constitution) some carpenters and architects began to specialize in churches, and the published designs of Price, Bulfinch, Hoadley, Damon, Carter and Benjamin became widespread along with their classical architecture. Church and state became increasingly separate between 1620 and 1830, and consequently meetinghouses became de facto exclusively religious.

Third, Benes dispels myths of American history that we accept without question and that obstruct our interpretation of relict features we may discover in an old church. A good example is the historic use of exterior and interior color, on which Benes is particularly strong. The white-with-green-shutters appearance of New England and New York state villages is largely a phenomenon of the 19th and 20th centuries. White was just one minor choice among many before 1830, when meetinghouses were documented as Spanish brown, lead gray, stone color, peach blossom, green, blue, spruce yellow, even "orange with chocolate trim" or a color "suitable for the house of God."

A further reason to examine this book is the ample documentary evidence the author gives for the expansion and alteration of meetinghouses by splitting them in two and pulling them apart transversely or longitudinally; for the movement of bell towers, steeples and cupolas to different locations on and around the building; and for the reorientation of the entire structure, whether 90 degrees or across town. When you are in a church attic looking at the frame and can't make sense of something, be open to the possibility that large frame revisions were made long ago.

A fifth reason is that as framers with an interest in the historic origins of our vernacular structures—such as where in the world the "English" barn comes from, or the swing beam—we will find this same sort of discussion pursued by Benes and other scholars he cites relative to the architectural origins of the 17th-century New England meetinghouse, such as one shown below at Newbury, Massachusetts: foursquare in plan with a pyramidal roof and usually no steeple. Many architectural historians in the past felt this form sprang from the ground of the Massachusetts Bay Colony, but researchers have with a bit of success been running down its origins elsewhere, to religious dissenting communities on the European continent outside of England, where English dissenters had been forced to flee. Huguenot churches in Holland and Flanders, where Englishmen took refuge, were described as "largely built of wood, like the churches of Muscovy" (p. 84). Discussion of origins is a mainstay of our traditional timber framers' meetings.

A final reason to read Benes is to apply the author's research methods to our own subject matter of historic framing. Of the thousands of churches built in New England and Long Island before 1800, Benes believes only 205 still exist, and most of those from the late 18th century. To trace the evolution of their styles and forms, he must look in church and town records, building contracts, what he calls "memory drawings," old paintings, mid-19th-century photographs, and old newspapers and diaries. If we could make the time to look into enough church roof systems, at their trusses and steeple frames, we might start to identify the patterns and evolution of historic engineering as Peter Benes has done with clusters of styles and exterior color schemes. Our group of practicing framers has something to offer not much mentioned in this book: an awareness of the remains of earlier or reused framing in attics and walls, and what those remains might suggest.

Reading this beautifully made and beautifully written book yields all sorts of insights into colonial American society, its religious and political concerns and how they were expressed architecturally and aesthetically. Benes says relatively little about Vermont or Maine, but those states arrived late in the game. It remains up to us to follow the work of accomplished historians such as J. Frederick Kelly, Abbott Lowell Cummings and Patrick Hoffsummer, or engineers such as Herman Haupt and David T. Yeomans, to give the hidden structure of these large wooden buildings their place in the sun of history. —Jan Lewandoski

Jan Lewandoski (janlrt@sover.net) operates Restoration and Traditional Building in Stannard, Vermont.

French Apprentice Tour

AT the Guild's first Western Conference, at Timberline Lodge in 1986, French carpenter Frédéric Brillant attended from his redoubt on Vashon Island, Washington, and pointed out simpler, better ways to deal with compound angles than our own learned presenter offered. Later he appeared at Eastern conferences, in one case in a parking lot, unannounced, to demonstrate layout techniques most of us had never seen before, and in 1990 at Troy, New York, Frédéric formally demonstrated what he called "traditional Continental roof layout." Since then, the Guild and some of its members have sought to learn more from our French *confrères* through work exchanges and tours in France and by inviting French *compagnons* to present at our conferences and workshops. We reached a new level of cooperation in July when 20 students and three masters of the Compagnons du Devoir came to the United States for the first time in an educational work program.

An ancient guild of craftsmen, the Compagnons du Devoir (roughly, companions of duty) share a passion for building excellence and architectural history. Dating back to the 13th century, the *compagnonnage* system in France provides training, guidance, housing and meals for young workers. In all there are 21 different trades within the brotherhood, including the building, metallurgy, transport, leather and food industries. One hundred compagnon houses throughout the country and abroad serve as bases for training, providing lodging, meals and classroom space for all in the program, from the youngest apprentice to the master craftsman.

In France, compagnons historically built the great châteaux, forged the iron for the hardware and the gates, wove the silk for clothing, and so on—and they continue to build today in all the trades. Surprising examples of their work include the Statue of Liberty, prefabricated of copper at Gaget, Gauthier & Cie in Paris to the design of sculptor Frédéric-Auguste Bartholdi, and later assembled section by section in New York Harbor, as well as the assembly and erection of the Eiffel Tower, raised by carpenters (*charpentiers*) who understood the techniques required to build tall structures.

In the time-honored compagnon system (see TF 97), *lapins* (rabbits, or apprentices), some starting as young as 14, spend two years following a rotation of six weeks in workshops and two weeks in school. They endeavor to become *stagiares,* who travel for three years (or more) working six months at a time in different shops on their *tour de France,* and then, as *aspirants*, strive to become compagnons (masters) by completing a *chef d'œuvre* (masterpiece). A compagnon must take it to heart to pass on the knowledge, as well as the values and ethics of compagnonnage, by teaching for three more years. Only one in 20 apprentices makes it to the level of mastery.

The tradition of travel remains and is the best way to extend the apprentices' knowledge of their trade, of languages and of other cultures. Each year the Compagnons du Devoir sponsor tours for their rabbits, sending them abroad for three weeks to see the scope of another country's trade and prepare them for their travels as stagiares. Usually up to 1300 apprentices from throughout France are on tour each year.

The 20 rabbits came to New England for three weeks from Rouen led by one of their own compagnon instructors, Christophe LeMerre, himself accompanied by compagnons Boris Noël and Martin Lorentz, who work ordinarily at Valentin, S.A.R.L. (LLC), builders and restorers in Troyes. Boris, with long experience, supervises 25 workers at Valentin and led the 2003 Guild tour of northern France, and worked as well in the US at Bensonwood in 2004. Martin has been traveling and working at different shops since completing his tour de France.

Following is a log of the American trip, constructed from apprentice reports and participation in their travels.

July 7 Departed Rouen on buses for the Paris airport. Flight arrived at the airport in Boston around 10:00 PM. local time. Took the bus to youth hostel downtown.

July 8 Boston. On Sunday morning, visited the Museum at MIT to see robots and holograms; attended lecture in English on DNA. Lunch at Subway. In the afternoon, shopped in the city and procured two 15-passenger vans for the rest of our trip.

William Holtz

Katie Hill

Martin Lorentz

Facing page, French apprentices on tour at Bensonwood, Walpole, N.H., cutting sills and plates indoors for a replica of Thoreau's cabin near Walden Pond and outdoors laying sills and joists. The cabin will be raffled off to raise money for the Fall Mountain Foodshelf, a local charity. Above left, apprentices cool off in the Sugar River under the massive 122-ft.-span Wright's railroad bridge (1906) at Newport, a Town-Pratt double lattice with clasped arch. Above right, inside the 62-ft.-span multiple-kingpost truss Dingleton Hill Bridge (1882) at Cornish. Keyed sisters on braces are oversized to meet posts above failed original joinery, invisible in photo. Below, learning the dropcut at Bensonwood.

July 9 New Hampshire. We rose at 5:00 AM and departed for the Bensonwood company in Walpole, N.H. We arrived at 9:00 at the *atelier* (workshop) and were received by Dennis Marcom and Tedd Benson. Toured the design offices that used CADwork and the various workshops that built walls, floors, roofs, stairs and timber frames. In the afternoon we prepared to design and build a replica of the cabin near Walden Pond in Concord, Mass., immortalized by American author, philosopher and naturalist Henry David Thoreau, to be completed on Wednesday and Thursday. We then went to our lodgings at Rochambeau Lodge nearby, where we will sleep and prepare our own meals for the next week.

July 10 After breakfast, we visited a Bensonwood project (annex of a nature school) and then returned to the shop for lunch. In the afternoon we went to visit the former Bensonwood shop and to a project finished about three weeks ago for filmmaker Ken Burns. We then went to Northcott Woodturning, which manufactures 600,000 *chevilles* (pegs) a year, and were admirably received. We then went to a pizza party, where there was a folk dance and a very good atmosphere. The wood-fired oven weighed 20 tons, and the baker was inspired by French crafts.

July 11 On this day we were in three groups, a *compagnon* instructor with each group, two in the panel shops (one for the walls and the other the floors and roofs) and the last group preparing the timberwork for Thoreau's cabin. We returned to the lodge at 4:00 PM to cool off in the pond, then had dinner.

July 12 We rose at 5:30 AM and had breakfast. We arrived at Bensonwood at 7:00 for a long 11-hour day. We continued our work in the company and began raising Thoreau's cabin. After lunch (pizza) we completed the raising and then had a barbecue at Bensonwood and played volleyball. To finish the evening, we bathed in the pond until 9:00 PM before entering the sauna, taking a shower and going to bed.

July 13 Today we visited six *ponts couverts* (covered bridges) with Ben Brungraber, also two timber-framed projects Bensonwood had built. Lunch at McDonald's. During the afternoon, we continued our visits to the bridges with a swim at the last one before returning to the lodge and the meal in the evening before going to bed.

July 14 Bastille Day! Today we hiked to the top of Mount Monadnock for magnificent views of the hills, then cleaned the lodge. We rehearsed the songs for this evening's festivities. After a pizza dinner we passed a super evening at Burdick's in Walpole where we sang the "Marseillaise" and several compagnonnage songs. for the community.

William Holtz

July 15 Massachusetts. We rose at 7:00 AM, had breakfast and packed our suitcases. Dennis Marcom came to see us off, and at 10:00 we departed, stopping in Northampton, Mass., for a lunch of fish and chips. We arrived around 3:00 PM at Bard College at Simon's Rock in Great Barrington, our lodging for the next week. We ate dinner at 5:30, then were released for the rest of the day to swim in the pool, play squash . . . .

July 16 Arrived at the Heartwood School in Washington, Mass., where we received an explanation of American layout systems, square rule versus scribing. We erected a 12x16-ft. timber frame previously cut by a class and awaiting shipment. During the raising, the layout system was further explained along with peg locations and drawboring. We dismantled the frame after lunch and then cut braces (already laid out), made pegs with drawknife and shaving horse and brought out 12 pairs of rafters to lay out.

July 17 Hancock Shaker Village tour in the morning: saw machine shop with water power, round barn, woodworking shop, blacksmith shop (we liked the knives being made). Returned to Heartwood in the afternoon to finish braces and rafters; used Woodmizer sawmill to cut rafter tails; used axes, adze and spokeshaves to cut curves in rafters. Laid out and cut step-lapped rafter seats. Made more pegs. One team broke a shaving horse head and made a new piece. We really liked the hand tools, axes and saws.

July 18 Teams split up and went respectively to the David E. Lanoue shop and a work site in Stockbridge. In shop, peeled logs, scored and hewed, planed lots of timbers. Learned to sharpen smoothing planes. On site, used recycled roof boards for barn restoration, then roofing paper and plywood. We saw three intersecting barns and repair techniques with scarfs and learned to erect pipe staging. New tool we had never used: a cap nailer for roof covering.

July 19 Crews reversed between Lanoue shop and work site.

July 20 Working with Heartwood apprentices, raised a barn frame in Stockbridge designed by Jack Sobon and with joinery cut by Gordon Simmering, Dave Bowman and Neil Godden. This was a beautiful frame 30 ft. x 40 ft., with a clasped purlin roof and curved raking struts above the tie beams, and looked very European. We cut and planed rafters by machine and by hand.

July 21 We hiked Monument Mountain (great views), shopped in Great Barrington and went to a demonstration in East Otis by 2012 Husky World Chainsaw Carving Champion Ken Packie.

At left, French apprentices directed by Heartwood School student Ben Theriault (at right in bandanna) lay out rafters in Washington, Mass. At top, Martin Lorentz, seated at the Millers Falls boring machine, and Boris Noël, standing at right, compagnons who came from Troyes to help supervise the 20 French apprentices (or rabbits). Above, apprentices intently shaving pegs split out from block.

Facing page at top left, compagnon Christophe LeMerre of Rouen, the apprentices' instructor there, takes his place at the end of a wall plate, far left, and enjoys a witticism by French apprentice Marc Rabuteau (disguised as "Dave") before the outshot wall lift. At top right, earlier lift of exterior wall on opposite side of barn. English tying joint structures such as this barn are raised not in bents but in wall assemblies including the tenoned plate, which are then connected transversely by tie beams that drop over the tenon at the top of the post jowl and lap over the plate, providing a completed box for the erection of the roof frame members that follow. See back cover photo for view of completed frame.

Facing page at bottom left, French apprentices help sheathe barn under restoration in Stockbridge by Lanoue & Co., using 200-year-old roof boards. At bottom right, apprentices practice using American-style handplanes at the Lanoue workshop, after sharpening lessons.

Photos Will Beemer

July 22 **Vermont, New Hampshire.** Sunday is travel day, and we drove to our lodging for the next week at Lyndon State College, Lyndonville, Vermont, stopping at the American Precision Museum in Windsor, where we met with Guild Executive Director Joel McCarty and received souvenir Guild pins. We saw many antique machines that helped revolutionize American industry.

July 23 One group went to the Garland Mill near Lancaster, N.H., to see a water-powered sawmill demonstration, help replace some timbers under the mill, replace 100-year-old shiplap siding boards and clean out the diversion dam upstream.

Another group went with Jan Lewandoski (Restoration and Traditional Building, Greensboro Bend, Vermont) to see some of his nearby work. At the First Congregational Church (1829) in Lyndon Corner, we saw the building being cribbed and raised, and truss and steeple repairs. Students got to climb into the steeple and see how telescoping steeples were built. At the Freewill Baptist Church (1829) in Sheffield we saw more steeple repairs. Then we went to the Bread and Puppet Museum and barn (1860) in Glover. Saw giant papier-mâché puppets and uniquely decorated barns. At the Old Stone House Museum and new barn built by the Guild this summer in Brownington, we participated in a riving demonstration of white cedar fence rails. At the Fisher Railroad Bridge (1902) in Wolcott, we saw a double lattice truss with repairs. Last we visited Jan's own barn with its triple bypass joint for tie at plate.

July 24 Broke into two teams again. One went to Gilford, N.H., to help Josh Jackson and David Hooke (TimberHomes LLC). Laid out, cut and installed let-in wall girts and window framing for a newly erected frame, completely sheathed roof with shiplap boards and weatherproofing, laid tongue-and-groove decking.

The other group went to the Wooden House Company (John Nininger and Gerald David) in Wells River, Vermont, to peel white pine logs (massive, 24-in. dia. and very clear) and learn to notch and how to use a tower crane. Helped lay out and cut a small timber frame to be erected on a float in a town parade.

July 25 Groups reversed and repeated July 24 itinerary, completing shiplap siding at the TimberHomes site and the timber frame at Wooden House. Watched a soccer game at the college in the evening.

July 26 Groups reversed and repeated July 23 itinerary.

July 27 Departed Lyndonville at 9:00 AM for Boston and the evening flight home.

—Will Beemer

English–French Glossary

Wood Species

ash	frêne
beech	hêtre
cedar	cèdre
chestnut	châtaignier
fir	sapin
hemlock	pruche
larch	mélèze
locust	robinier
maple	érable
oak	chêne
pine	pin
spruce	épicéa

Tools

adze	herminette
axe, hewing axe	hache, doloir
bevel gauge	sauterelle, fausse équerre
bitbrace	vilebrequin
chalk line	cordex
chisel	ciseau
clamp	serre-joint
drawknife	plane
drill bit	mèche à bois
electric drill	perceuse
framing square	équerre de charpentier
handsaw	scie égoïne (slang: *zag*)
Skilsaw	scie circulaire
ladder	échelle
level	niveau à bulle
mallet	maillet
pencil	crayon
plane	rabot
plumb-bob line	fil à plomb
shaving horse	banc à planer
spokeshave	vastringue
tape measure	mètre à ruban

Frame Anatomy

backing	délardement
birdsmouth	barbe
brace	lien
collar beam	entrait retroussé, faux entrait
dormer	lucarne
hip, hip rafter	arêtier, chevron d'arêtier
jack rafter	empanon
kingpost	poinçon
level cut	coupe de pied
mortise	mortaise
peg, pin (trunnel)	cheville
plate	sablière (haute), panne sablière
plumb cut	coupe de tête
post	poteau
purlin	panne
rafter	chevron
ridge, ridge purlin	faîtage, panne faîtière
roof	toit
roof surface (inclined)	versant
sill	sablière (basse)
strut (in truss)	contrefiche
tenon	tenon
tie beam	entrait
truss	ferme
truss upper chord	arbalétrier
valley, valley rafter	noue, chevron de noue
wall	mur

Measurement

foot	pied
height	hauteur
inch	pouce
length	longueur
pitch	pente
width	largeur

Facing page, apprentices try their luck in the log pond at Garland Mill in Lancaster, N.H. Above, apprentice keeps scriber plumb and level as he traces profile for saddle notch at the Wooden House Company in Wells River, Vt. At right, apprentices in the Fisher railroad bridge in Wolcott, Vt., a 103-ft.-span Town-Pratt double lattice bridge, pause during commentary by bridge and steeple specialist Jan Lewandoski, second from left. Below, an apprentice crew poses after a day sheathing the roof, decking the floor and fitting wall girts on a new frame by Josh Jackson and David Hooke, in Gilford, N.H.

Photos Will Beemer

Covered Bridge Truss Engineering

JOSEPH D. CONWILL, photographer, editor and author of books on covered bridges and a frequent contributor to these pages, has the distinction of having visited every covered bridge in North America, uniquely qualifying him to compile the survey "Covered Bridge Truss Types" in TF 102. His classification of the best known truss types (and a few not so well known) focused on bridge history and demographics. My purpose here is to supplement Mr. Conwill's survey with a discussion of truss function and engineering.

In any discussion of how covered bridges work, *truss* is the key word. In the evolution of timber bridges from their beginnings as simple beam structures, the development and implementation of the truss is the pivotal step. It's reasonable to assume that the first bridges were uprooted trees that accidentally and conveniently spanned streams. Our ancestors extrapolated from these, felling stouter and longer logs, laying several side by side, planking over the top, and so on. An improvement on their fortuitous forebears, these evolving beam bridges could traverse longer distances and carry heavier loads, but their span and capacity were limited by the strength and stiffness of beams in bending.

For all but the shortest spans, a house or bridge floor will get bouncy well before it breaks. In residential floors, we care about stiffness. It's not cool if china rattles when we cross a dining room, or if a plaster ceiling cracks when people dance on the floor above. For the purposes of this argument, however, so long as it doesn't break, it's okay if a bridge sags within agreed limits under a heavy truck at midspan. In engineering terms, for bridge girders over long spans, *strength* governs rather than *stiffness*.

Several parameters control the reach of beam bridges. Material, obviously: on average, steel is 20 times stronger and 30 times stiffer than timber, which goes a way toward explaining the obsolescence of covered bridges. Likewise member size: strength rises and falls with the square of the depth of the beam, stiffness with the cube of the depth. And finally length: strength is inversely proportional to the square of the span, stiffness to the cube of the span.

A helpful set of facts, but by itself this math doesn't go far to clarify the difference between beam and truss. Suppose we span 24 ft. with an 8x8 No. 1 Douglas fir beam and load it with a single midspan point load. Ignoring the weight of the timber and any other dead load, if we limit deflection to L/300, the beam can carry 1100 lbs. If instead allowable bending stress (1350 psi for No. 1 Douglas fir) is our criterion, the magnitude of the acceptable point load grows to 1600 pounds.

Now suppose we truss the beam, by erecting a post at midspan and springing diagonal struts from the beam ends to the top of the post. Our beam is now the lower chord of a kingpost truss, such as pictured at right. Retaining our point load at midspan, the chord and the kingpost are in tension, the struts in compression.

In effect, we are picking up the loaded chord at midspan and channeling the load up the kingpost, then down and out via the struts to the abutments. The chord still feels a bit of bending, but vastly reduced, in favor of tension or compression along the axis of the member. To produce chord bending stress equivalent to that induced by the 1100-lb. load on our 8x8 beam, we would need to freight the newborn truss with an astonishing 290,000 lbs. As the reader intuits, such a load would clearly kill the bridge by other means long before the chord failed in bending, but the advantages of truss over beam are abundantly clear.

Continuing along these lines, if we instead limit load effect by L/300 deflection, we're still carrying a 200,000-lb. load. Move on to keep maximum axial stress in all members within allowable limits (1000 psi compression, 825 psi tension for No. 1 Douglas fir posts and timbers), and allowable point load drops to 72,000 lbs. Finally, if we build a fairly realistic truss by limiting joint tension to 20,000 lbs., our live load is still a respectable 20,111 lbs. Chord bending stress is now a measly 94 psi, a mere 7 percent of the 1350 psi allowable stress back when our chord was a simple beam.

To sum up, in going from a simple beam to a kingpost truss, we have increased load capacity by a factor of 18.3, from 1600 lbs. to just over 20,000 lbs. In the truss we are carrying 99.5 percent of the load via tension and compression, in the process reducing residual bending stress to a negligible amount. And we could double or triple the span while carrying this same load and stay within allowable limits.

To emphasize the structural advantages of frame members carrying loads in compression or tension over those members carrying load in bending, our beam-truss comparison used single midspan point loads. Locating all load directly under the kingpost in the truss maximizes the capacity of the truss to channel load axially, while all of the similarly applied load on the simple beam must be borne in bending. If instead of a concentrated load we apply a uniform line load to both structures, then trussing multiplies load capacity by 16 times when limited by deflection and by four times when limited by bending stress. Such is the advantage of truss over beam.

A word about the truss illustrations. Bridge truss layout is shown in black and white. Accompanying load diagrams map resultant axial forces under uniform floor and roof load, with compression in blue and tension in red. The widths of color bands are proportional to the magnitude of force in the individual members. As shown earlier, bending stresses are minimal so we needn't bother diagramming them, nor shear stresses. Red arrows represent locations and directions of support (abutment) reactions to bridge load.

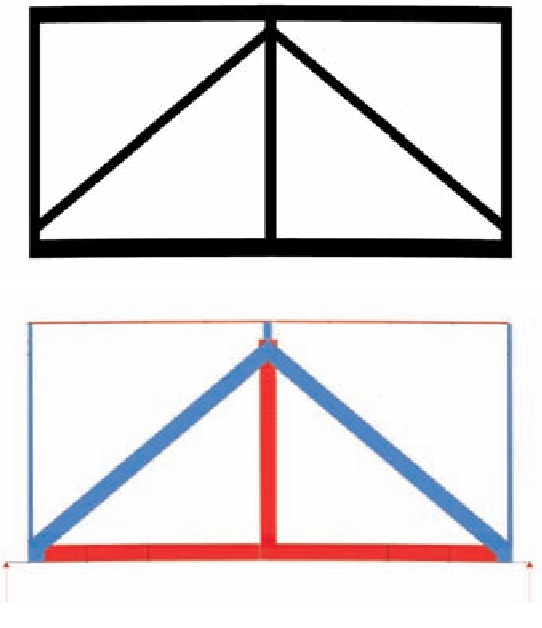
Kingpost truss In our example above we relived the evolution from beam bridge to basic truss, and the kingpost truss, as Joseph D. Conwill observed, is indeed the ancestral form of timber truss bridge, covered and uncovered. The *panel* of a truss is the area enclosed between chord joints, that is, the space between adjacent struts or posts. A kingpost truss is a two-panel truss.

Queenpost truss Next step up the ladder is the queenpost truss, with the outer panels duplicating the left and right halves of the kingpost truss, and the center panel featuring a *straining beam* just below the top chord of the bridge, loaded in compression.

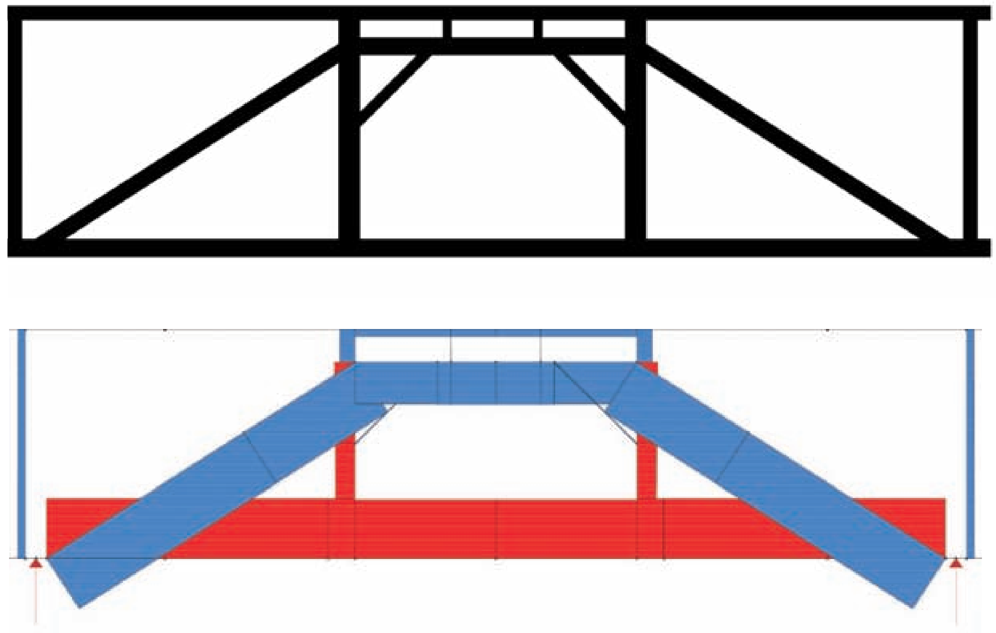
A glance at the force diagram is instructive since the load path comes to the fore via broad swaths of primary color, exposing what we might call the "inner bridge." With the queenpost truss, what stands out boldly is the quadrilateral of lower chord, struts (also called *main braces*) and straining beam, evoking the familiar trapezoid of thousands of steel highway bridges.

Conversely, the queenpost load diagram also reveals that the apparent top chord really serves only as a plate to carry the rafters, with little or no bridge function, the end posts likewise. In that chord we would see some significant bending stress, since it is not really integrated into the truss. This is also true of kingpost trusses, where apparent top chords and end posts are really roof rather than truss elements, a situation clarified by numbers of existing unroofed kingpost and queenpost trusses, also known as *pony trusses* because they are generally of small scale.

Multiple-kingpost truss Stretching beyond the limited span capacity of two-panel and three-panel trusses like the kingpost and

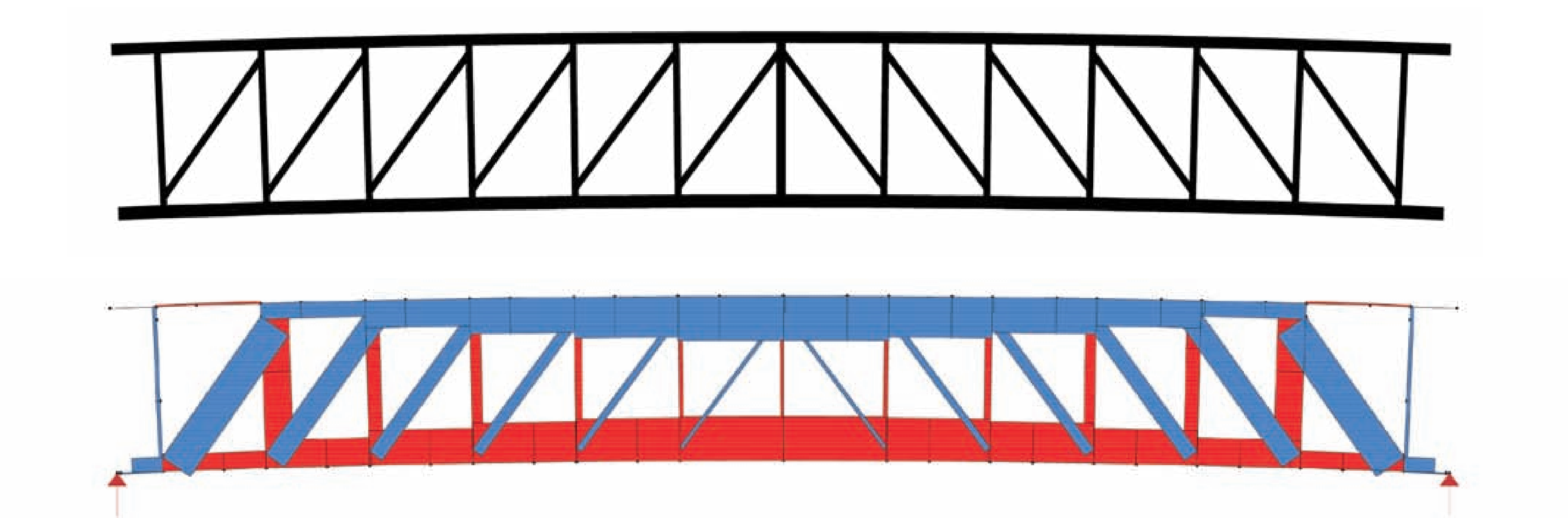


KINGPOST TRUSS



QUEENPOST TRUSS

Drawings Ed Levin



MULTIPLE-KINGPOST TRUSS

queenpost, builders began to bridge distances up to 100 ft. and beyond, using trusses with more and more panels. As its name suggests, the multiple-kingpost truss repeats the basic kingpost truss panel, each panel adding a post in tension and a strut in compression, the struts rising up and in toward the center of the bridge, where they reverse direction.

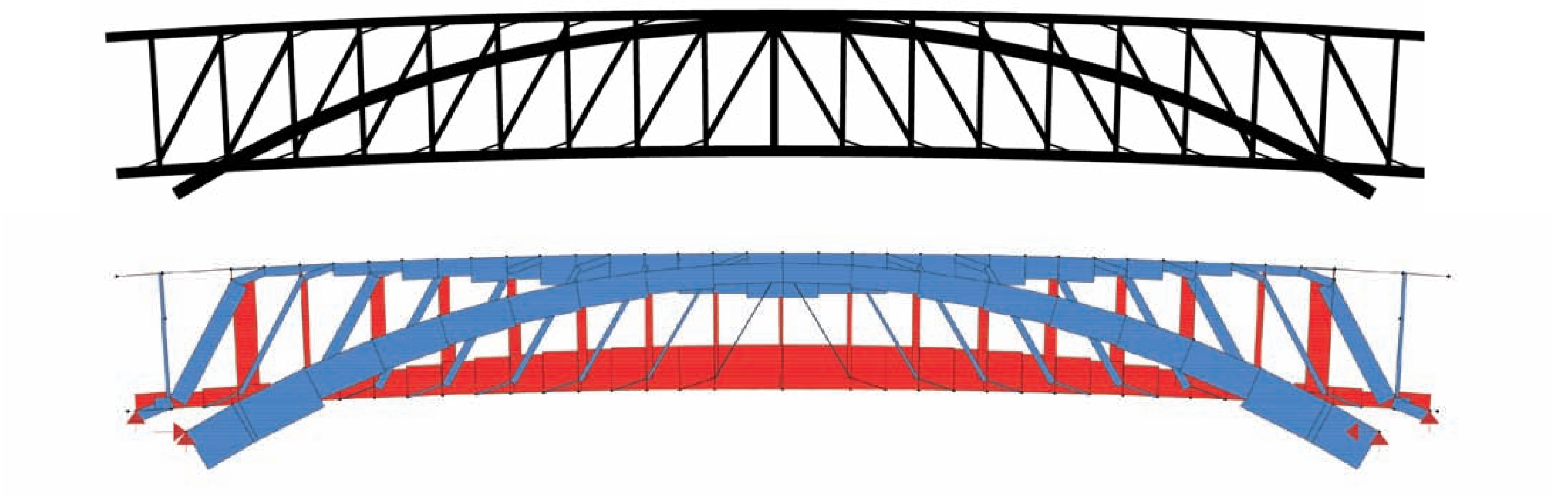
Examination of the multiple-kingpost load diagram reveals that the struts and posts accumulate load proceeding from midspan out toward the abutments. The verticals and diagonals in the middle of the bridge are lightly loaded, and the force they carry grows incrementally approaching the supports, with the outermost pair of posts and struts carrying the greatest tension and compression. Meanwhile, chord forces grow in the opposite direction, the lower chord in tension, upper chord in compression, with force values minimal at the abutments, maximum at midspan.

In ideal truss layouts all members align *centroidally*—that is, the centerlines of all chord, post and strut elements intersect at the panel points of the truss. But the requirements of wooden joinery and the geometry of bringing more than two bulky timbers together at one panel point often force one or more members off center. As shown in the multiple-kingpost drawing (and in Figs. 3 and 4 of the Conwill article in TF 102), struts strike posts a short distance below or above chords, introducing *eccentricity*, a word and a condition that make engineers cringe.

When a diagonal compression strut impacts a post, the force it delivers can be resolved into vertical and horizonal components. The vertical component pushes up or down on the post, loading it axially, but the horizontal one pushes sideways against the post. When the strut bears on the post at a spot remote from the panel point, the strut's horizontal force then imparts both bending and shear stress to the post because of the vertical separation between the strut-to-post and post-to-chord intersections. Over the long haul, these products of eccentricity can have serious consequences and strut side thrust can actually fracture or crush the end of a post (photo).

Milton S. Graton, used by permission

Truss overload amplified strut force to destroy this post bottom in the 1866 Bedell Bridge at Newbury, Vt.



BURR TRUSS

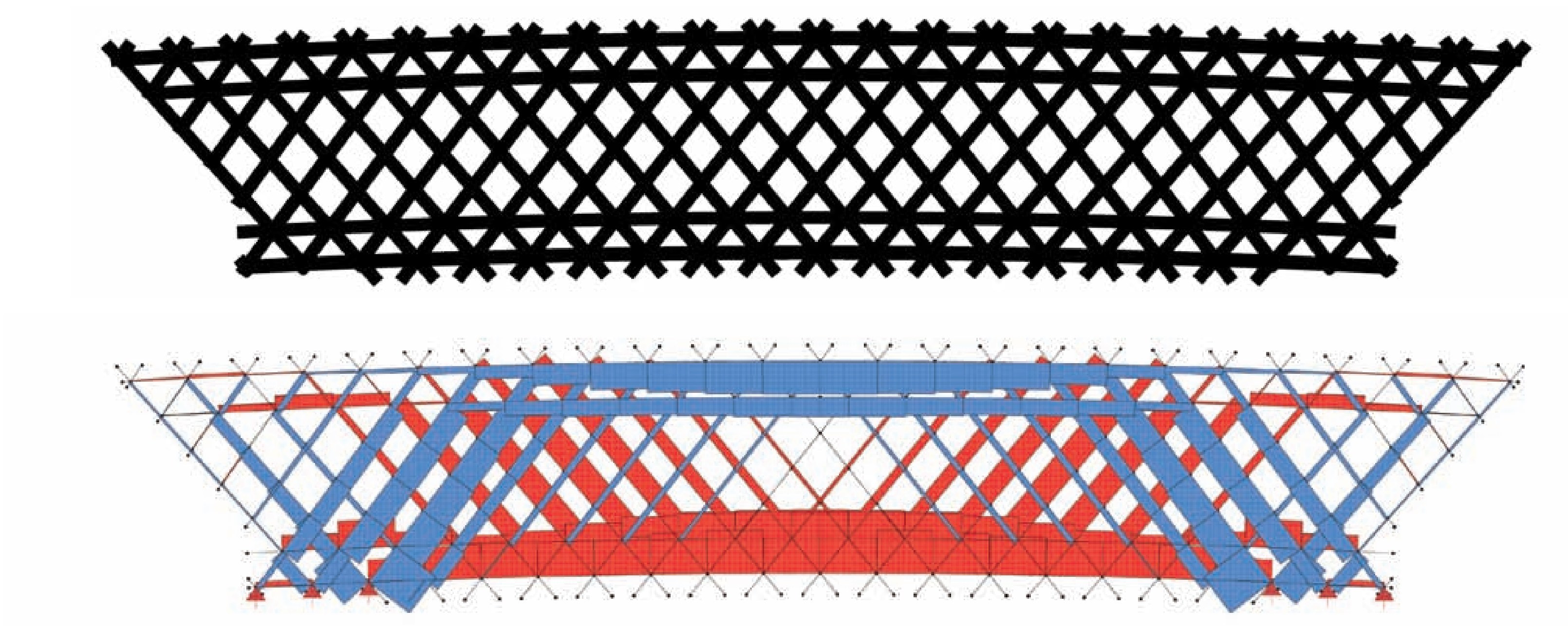
Burr truss Theodore Burr's early-19th-century innovation was to combine an arch with a multiple-kingpost truss, the two interlocked and sharing the load. Burr bridges are built with single trusses flanked by two arches or with double trusses sandwiching a single arch, normally one such assembly on each side of the roadway.

The coupling of arch and truss, a potentially powerful structural mechanism, is also an analytical challenge to engineers to sort out the nature of the interconnection and the load-sharing between the two. But it does introduce vulnerability and possible deficits: toward the ends of the bridge, the arches descend down through the lower chords (locally weakening those chords) after which they are outside the covered bridge enclosure, below the floor and exposed to the weather and moisture carried onto the bridge by vehicles. The feet of the arches are in danger from high water and river ice and, at their spring points, to rot beginning in endgrain or subsidence of the abutments, either of which could convert the arches from a support into a substantial dead load on the bridge.

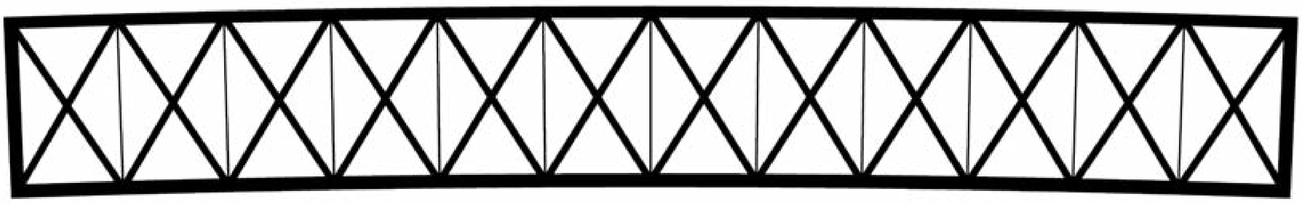
To counter eccentricity in the posts, check braces are found in Burr trusses and in later multiple-kingposts. These short, low-angle struts are fitted near the post ends at points directly opposite the incoming strut footprints, respectively rising up to the upper chords or down to the lower chords. They stiffen the posts against the strut side thrust discussed earlier, and provide a more direct and stiffer load path for the horizontal strut force component into the chords. Eccentricity is not much of a problem in short spans but, as bridges stretch out, increasing post and strut load accumulates toward the abutments as we can see in the color diagrams, thus the desirability of check braces. The use of these braces, also called *chocks* (as in wheel chocks), and called *kickers* by 20th-century bridge builder Milton Graton, is mentioned in the journals of Vermont bridge builder and timber framer John Johnson (1771-1834).

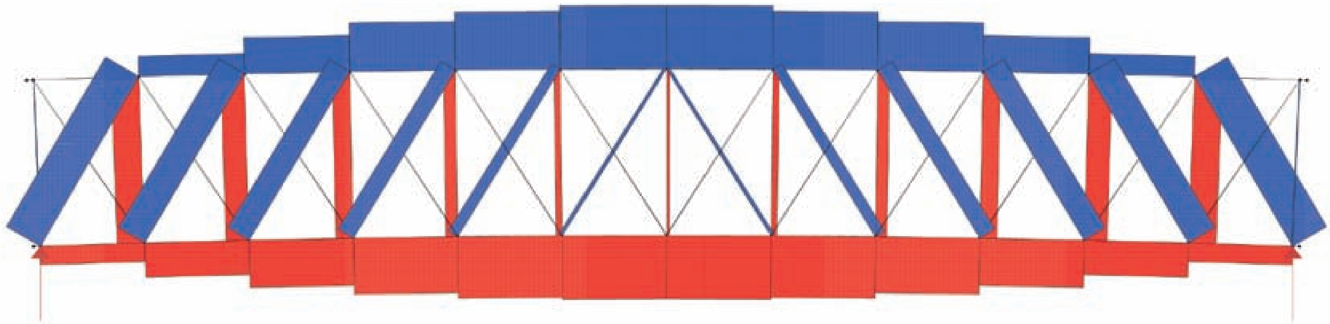
Looking at the Burr load diagram, we see the pattern familiar from the multiple-kingpost truss: compressed diagonals and upper chords with tensed verticals and lower chords, and with post and strut forces increasing toward the ends of the bridge, chord loading maximum at midspan and the posts and upper chords in the end panels essentially unloaded, existing to support the roof rather than the roadway.

Town Lattice truss Architect and engineer Ithiel Town took covered bridge construction in a new direction, away from its craft roots in timber framing and toward modern mass production. His Town Lattice bridge (patented 1820) required little or no joinery, instead comprising overlapping layers of planks laid diagonally, with heavy bridge pins, often 2-in. dia., at the crossings, typically two pegs at lattice intersections, three pegs at lattice-chord crossings. With two or more pegs per crossing, each connection has moment capacity and collectively they impart stiffness to the truss without joinery.

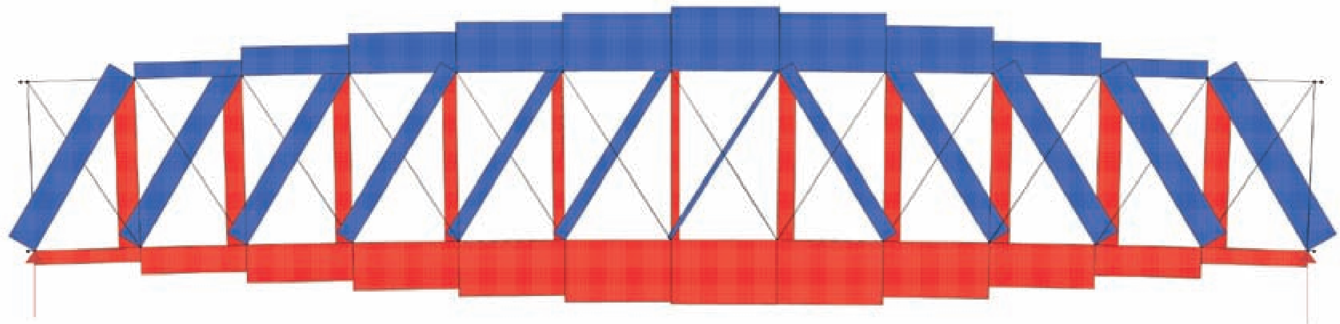


TOWN LATTICE TRUSS





HOWE TRUSS



HOWE TRUSS
SECOND LOAD CASE

In addition to inventing a truss design whose repetitious fabrication did not require highly skilled craftsmen, Town's commercial arrangements were also forward looking. He licensed the use of his designs at a dollar per foot of bridge (two dollars retroactively for those who built without prior permission). Royalties on his lattice bridge made Ithiel Town a wealthy man.

The pattern of forces in the lattice load diagram offers no surprises. Planks rising toward the center of the bridge are compressed, those descending toward midspan are tensed; strut force magnitudes amplify toward the abutments and vice versa. Absent vertical members, the portals of Town Lattice bridges tend to lean outward. At the ends of these bridges, outboard of the foundation, we find a stress reversal, with outermost struts in compression where we would expect tension, and the ends of upper chords switching from compression to tension, because the primary load in these areas comes from the roof, not the road deck.

Town Lattice bridges, lacking verticals and cross-span braces, are prone to buckling failure either in the lattice or the entire truss, which shows up as sidesway or rack. Attempts are often made to combat this by introducing wind braces. But it's curious that almost all Howes, and some other truss types, have few wind braces or none and, according to bridge practitioner Jan Lewandoski, "still do fine." He proposes that the large rack and bow to which lattice bridges are subject results from compression buckling in the top chord, and sometimes the lattice.

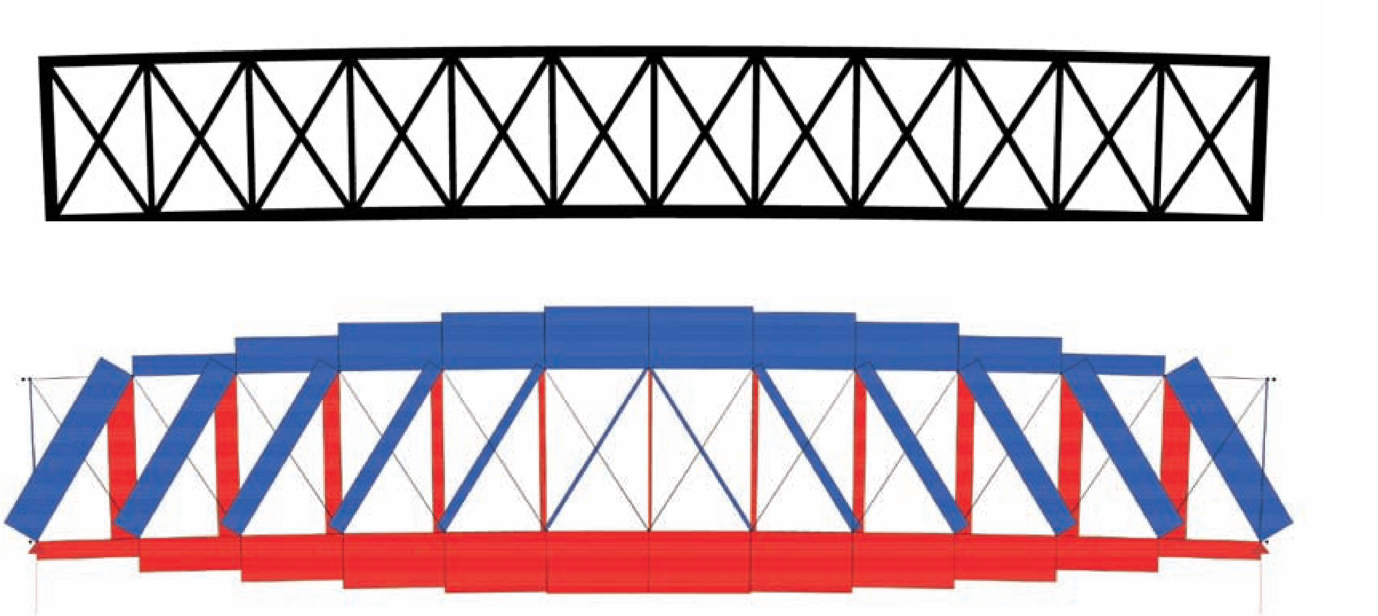
Howe truss The Howe truss represented another move away from timber joinery. William Howe retained the earlier pattern of compressed diagonals rising toward the center plus tensed verticals, but he replaced the timber posts with iron rods and placed hardwood bearing blocks (sometimes steel shod or cast iron) at the panel points along the chords. In addition to the compression struts, typically doubled, Howe added counterbraces running out and down, all kept in place by compression alone due to bridge dead load plus pre-stressing via tightening the nuts on the tension rods. As heavy moving loads travel through the bridge, local stress reversals unload the struts and bring the counterbraces into play. A bolt through the crossing of strut and counter brace prevents unloaded members dropping out.

Ed Levin

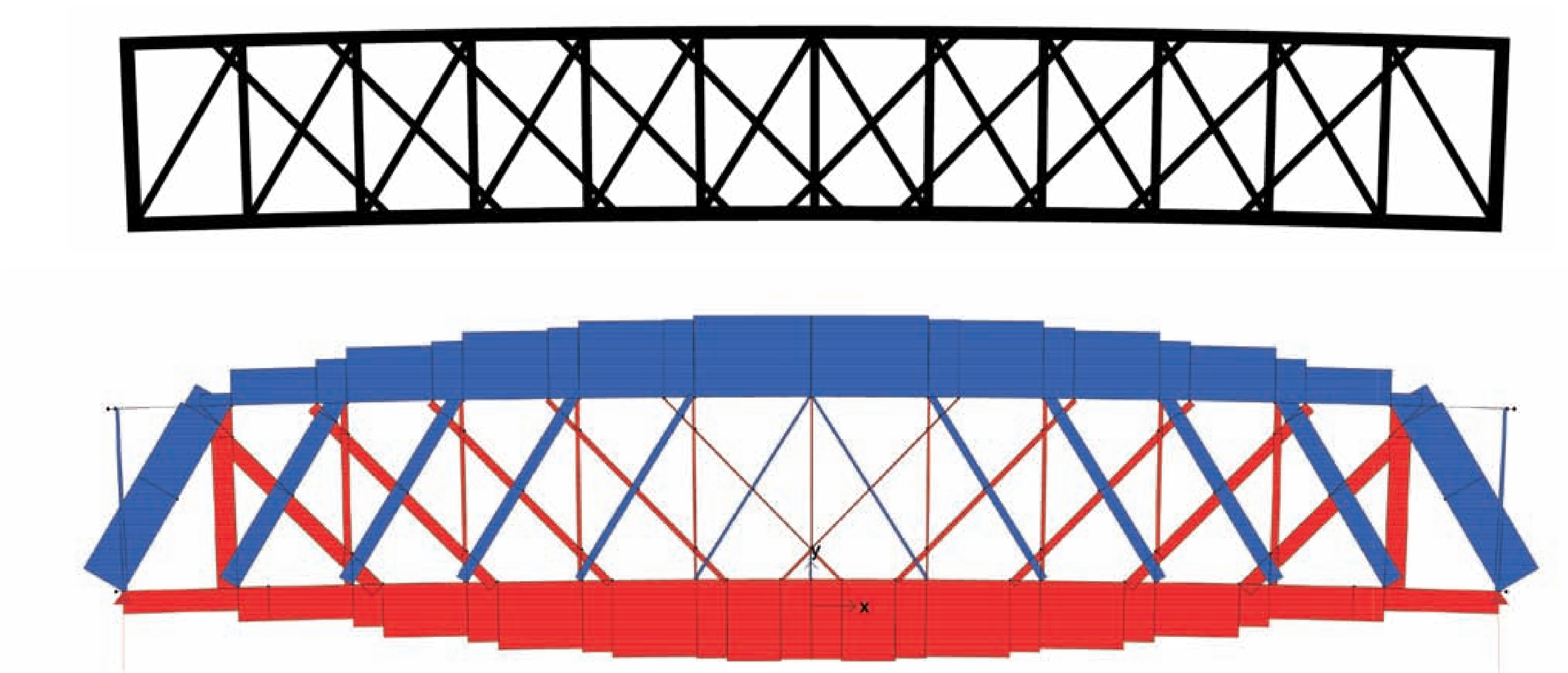
White oak bearing block housed in Howe truss top chord, Packard Hill Bridge, Lebanon, N.H. (1991). Tension rods flanked by counterbrace rising from left, double struts from right. Captive steel shoe on strut side of block.

In the Howe load diagram, since the struts and counterbraces simply lodge against the bearing blocks, neither member can carry tension load, thus the counterbraces are dormant in the uniform load case, and called into action only by asymmetric local live loads. In the second load diagram, uniform live load has been decreased in favor of a significant point load representing a truck with its loaded axle directly over the first post to the right of the bridge centerline. The strut in the panel just to the right of center is now unloaded and the counterbrace in that panel has gone into compression.

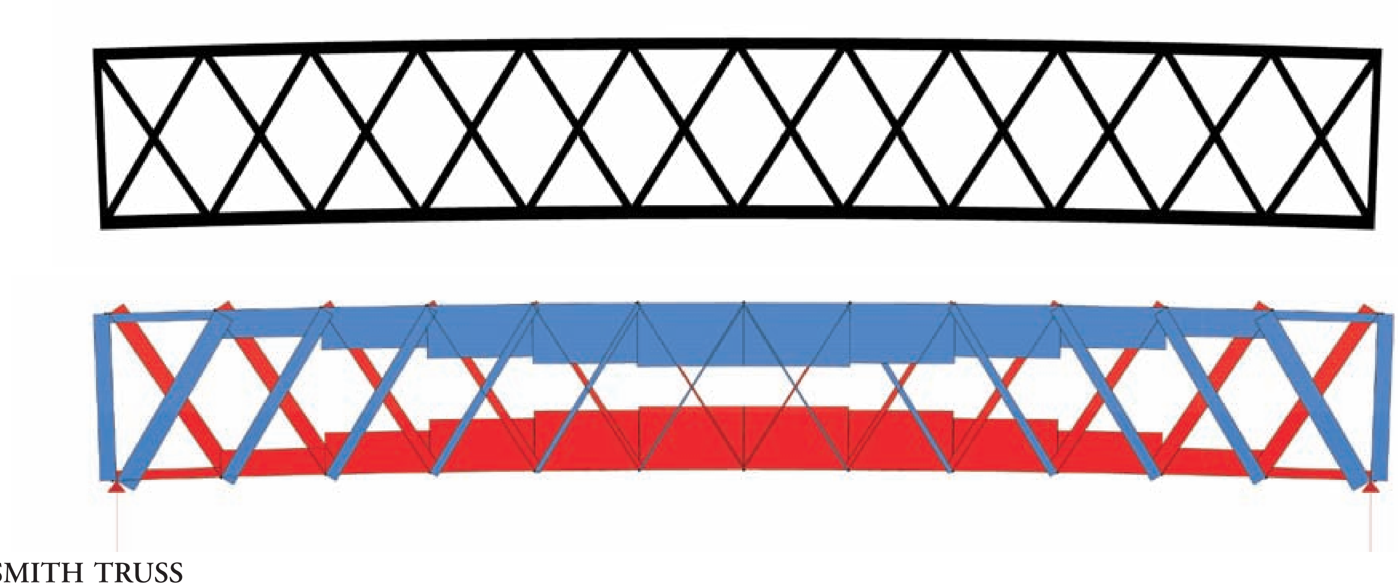
In tall bridges, counterbraces serve yet another function: near the abutments where strut load is greatest, the counters brace the struts at their X-crossing to prevent buckling.



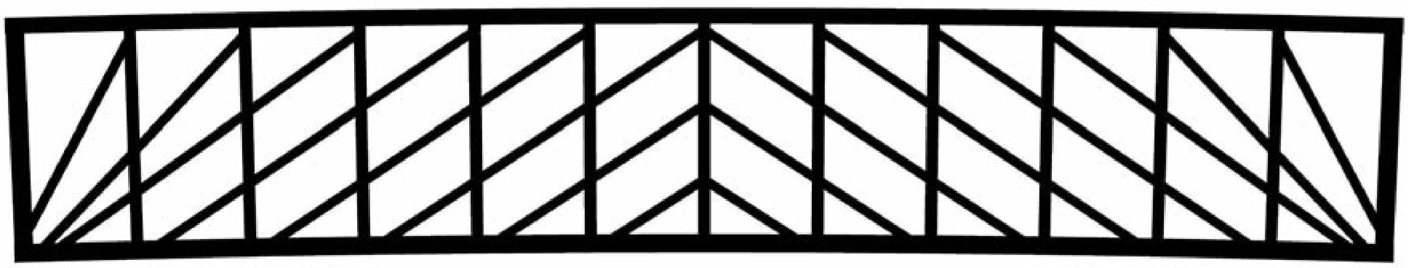
LONG TRUSS

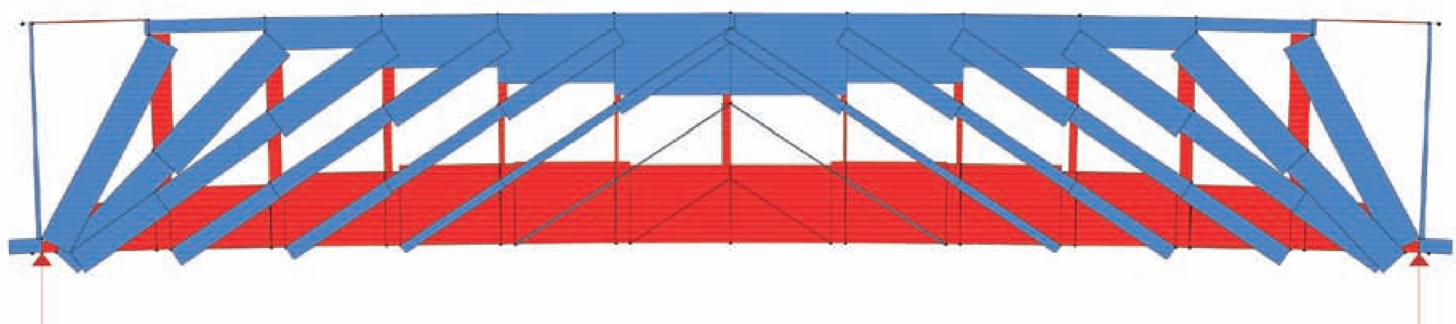


PADDLEFORD TRUSS



SMITH TRUSS





HAUPT TRUSS

Long truss The Long is one of several truss types developed in the middle of the 19th century that enjoyed a local or period vogue. Dartmouth graduate and railroad engineer Stephen Long patented a precursor to the Howe truss in 1830, with the same X-pattern braces, but entirely in timber. Diagonals in the Long truss were prestressed using wedges. A decade after Long, Howe was issued his patent, which rapidly caught on with builders. Load pattern for the Long truss is identical to the Howe. The load diagram shows a uniform load case, so counterbraces are unloaded, but an asymmetric point load could bring them into play as with the Howe.

Contrary to this analysis, Stephen Long was explicit that the purpose of counterbraces in his scheme was to prestress the truss and avoid vibration. But experienced bridge restorers tell us that counterbraces in Long trusses end up functioning like those in Howe bridges. Long's purpose may have held true originally, but the counters work loose eventually and we forget their original function under the Long patent.

Paddleford truss Peter Paddleford's truss is similar to Stephen Long's, posts in tension, compressed struts rising toward midspan, and counterbraces making an X with the struts. Paddleford's innovation was to lengthen the counterbraces to reach beyond their panel into the adjacent panels left and right, so that each counter ran from upper chord down to lower chord, along the way lapping over two posts and three struts, offering multiple opportunities for connection and additional stiffening of the truss. Unlike the Howe and the Long, Paddleford counterbrace ends are secured to the chords and these connections plus the many crossing joints ensure that the counters can both push and pull.

Bridge practitioners report that since Paddleford counters are active tension elements, all their joinery makes them hard to get apart. By contrast, with most Burrs, Howes and Longs, the counterbraces can be removed by hand if the truss is unweighted a bit.

The similarity within the last group of trusses (Long, Paddleford, Howe) occasioned claims of patent infringement, and both Howe and Paddleford faced accusations of stealing from Long.

Smith truss A later entry into the truss sweepstakes, the Smith was distinguished by the complete absence of verticals. The Smith Bridge Company prefabricated trusses for their customers at the factory in Toledo, Ohio, and shipped them around the Midwest. No ambiguity about the load pattern here. Inward rising struts are compressed, their outward rising counterparts in tension, with the usual distribution of chord load.

Haupt truss Civil engineer, author of *General Theory of Bridge Construction* (1851) and "Lincoln's railroad man," Herman Haupt designed and patented the bridge truss that bears his name in 1839, early in a distinguished civilian and military career. Compressive struts in a Haupt truss rise toward the center of the span, but at a low angle so that each strut traverses two or three panels in its trip from lower to upper chord. We don't know certainly where Haupt got his inspiration for this pattern of low-angle struts, but his truss does bear a clear similarity to the 1757 Schaffhausen bridge in Switzerland, built by the Grubenmann brothers (see www.soane.org.uk/images_drawings/642_main.jpg), a bridge that Haupt illustrates and analyzes in his *General Theory*, calling it "a celebrated structure . . . . with many excellencies . . . also serious defects" and "destitute of counter-bracing."

Haupt's own truss is likewise destitute of counterbracing, but the struts are in a pattern that may give the Haupt similar advantages to the Paddleford, with multiple crossings adding stiffness to the bridge and acting to prevent buckling. This is hard to verify historically, since the Haupt did not achieve the popularity of Burr, Town or Howe, and only one Haupt truss bridge survives today.

—Ed Levin

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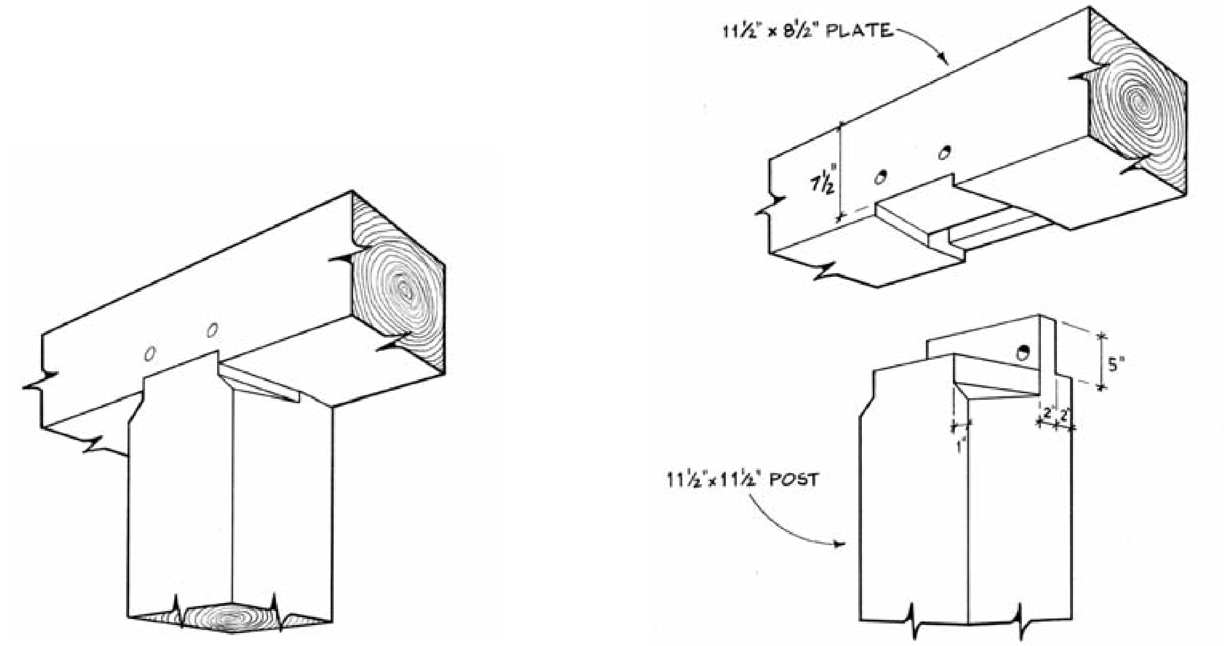
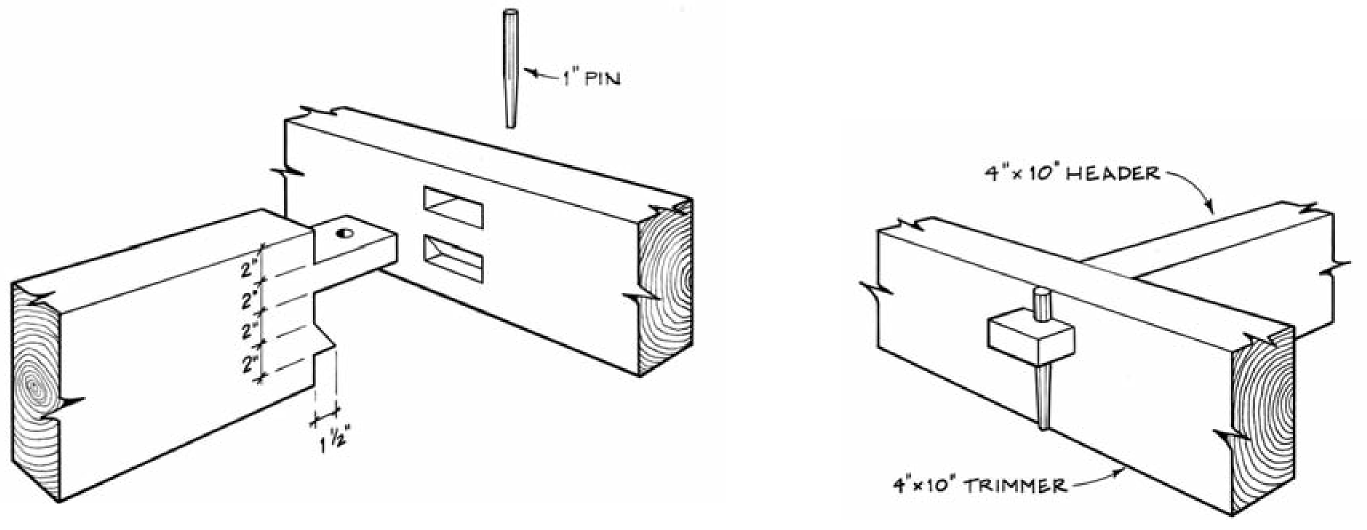
Miscellaneous Joint Addendum

SINCE the publication by the Guild in 2002 of *Historic American Timber Joinery: A Graphic Guide*, additional timber joinery examples continue to surface. Herewith a miscellany of unpublished joints of interest (see also “Tying Joint Addendum,” TF 104 and “Scarf Joint Addendum,” TF 99). —Jack A. Sobon

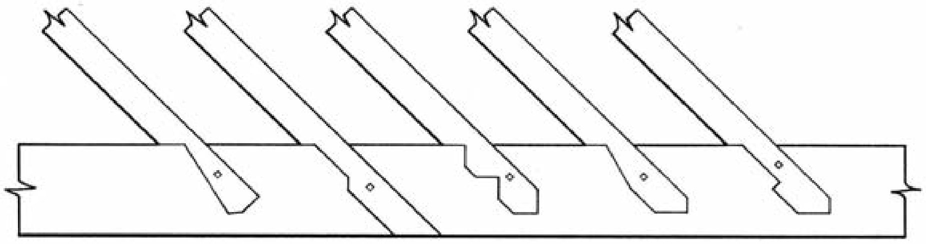


1 At left, assembled and exploded views of plate joint, viewed from inside, in four-bay barn at Caledonia, Ontario, now dismantled for parts. Only one plate survives, shortened, and appears to have been about 60 ft. long originally. The three median posts joined the plate in a curious, ingenious and heretofore unseen housing. Roof thrust in dropped-tie barns commonly causes the post top to split on a plane following the inside cheek of the tenon. The builder of this barn, obviously cognizant of the problem, created a dovetail out of the approximately 1-in.-deep housing. Thus, the whole post top rather than just the tenon can resist the roof thrust, reducing the likelihood of such a failure. Because only the plate survives, the post-top drawing is conjectural.

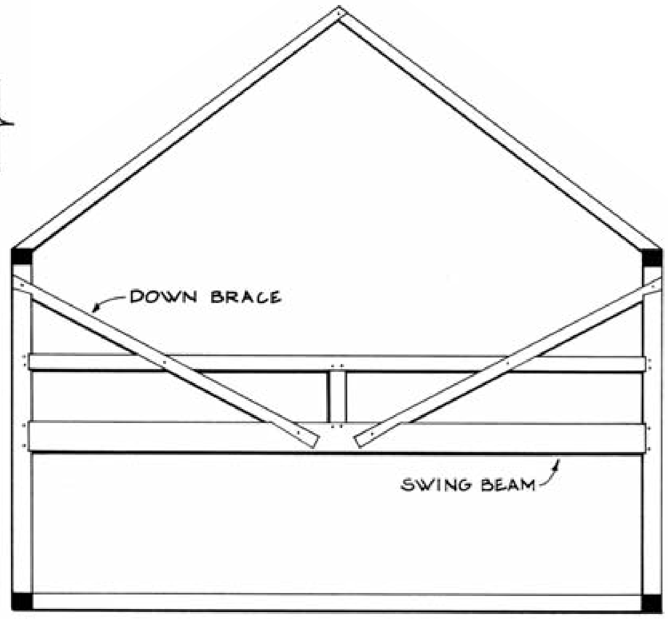
Drawings Jack A. Sobon

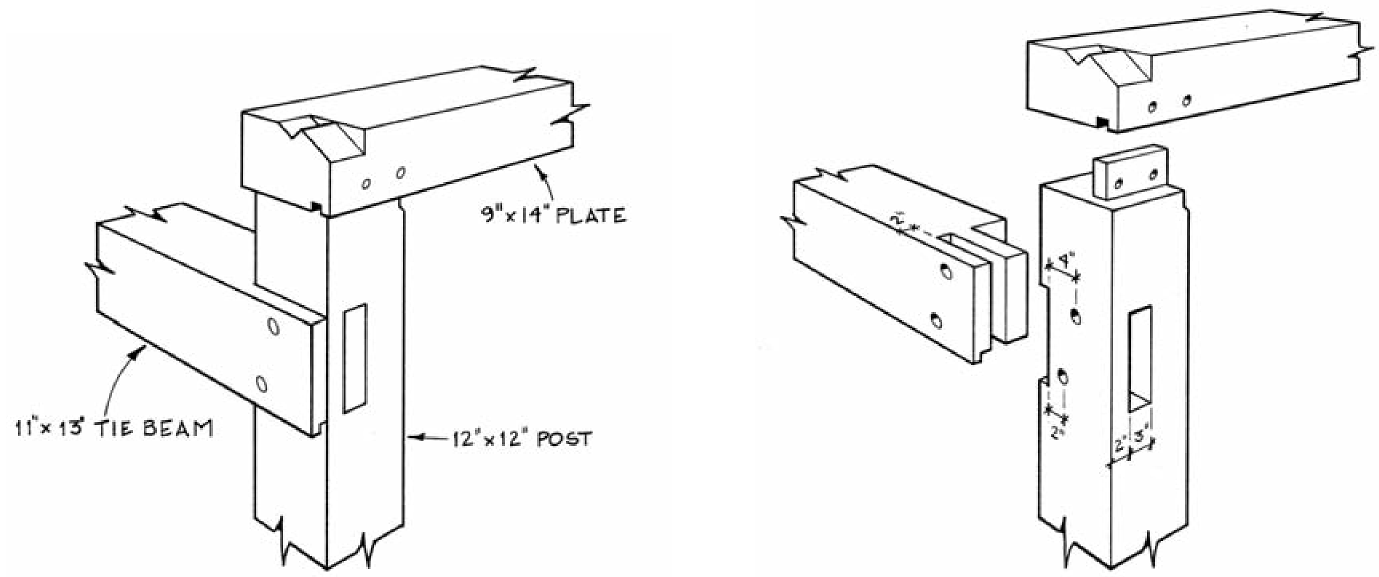


2 Exploded and assembled views of chimney header–joist trimmer joint discovered in the floor framing around the chimneys of the Roosevelt-Dunn house in Johnsburg, New York (1851), which measures 28 ft. 6 in. x 36 ft. 6 in. overall. The carpenter used a form of twin tenons to join the two 4x10 members. The lower tenon is a spurred stub tenon while the upper tenon passes through to be outside-wedged by a tapered pin. Where the 4x10 common joists in the floor frame meet the header, the same joint is used, but without the extended tenon and wedge. The extra work of twin tenons provides resistance to horizontal shear failures in the relatively narrow, deep cross-section joists and header. Original joint information provided by Andy Le Blanc.

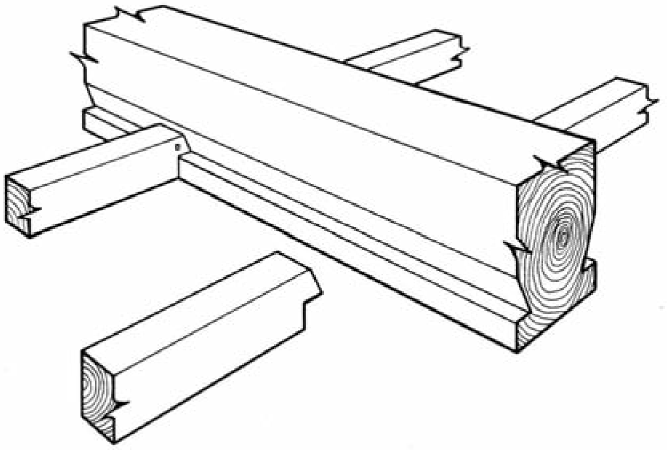


3 Dovetailed and notched joints for swing-beam braces, all secured with a square pin both to hold them fast and to provide additional tension capacity. Left to right, examples from Montgomery, Clinton, Princeton, Millstone, and Port Murray, New Jersey. Swing-beam barns in New Jersey often have long braces at each end descending from the posts, trenched through the upper beam and lapped into the swing beam. (Braces below the swing beam would interfere with the threshing process.) These long braces function not only as transverse wind braces for the barn but also aid in supporting the span of the swing beam, and thus they are tension members, as reflected in the joinery at the swing beam. Joint examples supplied by the New Jersey Barn Company and Jeff Marshall. At right, typical context.





4 Assembled and exploded views of corner tying joint in 30x50-ft., four-bay, swing-beam barn, second quarter of the 19th century, Queensville, Ontario. Square-ruled of large-dimension hewn white pine, with dropped ties, the barn was dismantled, repaired and reerected in West Stockbridge, Massachusetts. Both plates and one end-wall tie beam project 2 in. and have 1x1-in. grooves in their underside to accept vertical boarding. Though such grooves are a common feature in barns, it's unusual for the tie beam projection with board channel to extend to the outside corner of the post, as here, making the tying joint a form of bridle. The connection is secured with two 1½-in.-dia. pins.



5 At left, ceiling joist to tie beam support system, Christ Church, Philadelphia (1754). In sizable trussed-roof structures such as large meetinghouses with plaster ceilings at tie beam level, ceiling joists, typically of small scantling, were inserted between the tie beams and set flush with their bottom edges, preparatory to nailing on of the lath. Traditional carpenters had a variety of ways to allow insertion of the joists after the trusses were set, often fixing one end in a conventional blind mortise and swinging the other end into place via a chase (or overcut) mortise. In the arched ceiling of Christ Church, carpenters used an extreme variation of the horizontal chase mortise to accept at least one end of the joists, hewing a continuous angled rebate in one side of the upcurved tie beams to carry the joists' spurred stub tenons. A nail secured the latter while the lath was applied.

A Week at the Wapsipinicon Mill


1

Photos and drawings Tom Nehil unless otherwise credited

IN June a diverse group of timber frame journeyworkers, apprentices and engineers-carpenters from across the US assembled at the 1870 Wapsipinicon Mill in Independence, Iowa (Fig. 1), for a weeklong workshop organized by Trillium Dell Timberworks, Knoxville, Illinois, in partnership with the Guild, to fulfill elements of the Guild apprenticeship program. The 17 participants came from Washington State, Oregon, New Hampshire, South Carolina, Iowa, Illinois, Michigan and Oklahoma.

The starting point for the workshop was a contract between Trillium Dell and the Buchanan County Historical Society, the owner of the mill, to replace a section of rotted timber plate at the top of the east wall facing the river, and to repair and replace associated rotted rafters and sheathing in preparation for installation of a new metal roof. The work included replacement of missing braces in the timber framing, reattachment and stabilizing of eaves brackets and soffit sheathing on the exterior and painting of the cupola. Trillium Dell also contracted to provide engineering review and repair suggestions and isometric drawings and details.

The six-story height of the mill building, with east and north walls rising directly out of the Wapsipinicon River, provided an excellent opportunity for training in safe work practices at heights and operating a man-lift—in this case a whopping 135-footer. The amount of work for the week was easily managed by our crew of 17, providing ample opportunity for exploring portions of the Guild's apprenticeship curriculum dealing with trade science and conservation techniques.

As no construction drawings remain for the mill, one of the goals for the week was to develop plans, sections and details of the framing. This exercise provided training in how to approach an existing building and in a relatively short time extract the information needed by a structural engineer to analyze framing, identify code issues and develop strengthening recommendations. With its brick and stone exterior, the mill also offered an opportunity to evaluate historic masonry as well as timber framing.

Mill history and description The Wapsipinicon Mill was constructed over a period of several years from 1867 to 1870. Probably because it was one of the largest gristmills in the state (and there are many in Iowa), it has always attracted attention and its history has been well documented.

From the Buchanan County Historical Society's fine collection of photographs, drawings, newspaper articles and artifacts, we learned that the mill was constructed by a group of 33 business people, all residents of Independence. These entrepreneurial residents organized the Independence Mills Company and, according to the historical society, contracted with millwright Samuel

Sherwood to build the mill. Sherwood was born in Fairfield, Vermont, in 1820 and came West in 1845, becoming a resident of Independence from 1846 until his death in 1898 after falling sick following a rainy day's work on the mill's powerhouse foundation.

Located on the west bank of the Wapsipinicon River, the building measures about 62 ft. by 110 ft. and rises nearly 100 ft. from water level to the ridge of the cupola. The shed roof along the east side of the main building is itself over 50 ft. above the water, while the roof of the monitor story, the narrower brick portion atop the main building, gains an additional 22 ft.

The Wapsipinicon River is fairly shallow through this stretch, flowing over limestone. The mill sits ultimately on bedrock, with 4-ft.-thick foundation walls made of granite reportedly split from glacial erratics found in the area. Local Farley limestone 2 ft. thick comprises the walls of the lower level of the mill.

A dam across the Wapsipinicon, originally of wood, raised the water level about 7 ft., sufficient to drive a set of four turbines to power the mill. Above the Farley limestone, the building was clad with brick over a heavy timber frame, with all timbers 12x12 Eastern white pine from the forests of Wisconsin and sawn by Weyerhaeuser's first mills. Rick Collins, who leads Trillium Dell, pointed out raft holes in the timbers left from the rough sapling pegs used to help lash the logs into rafts that were floated down the Mississippi River to mills in Davenport.

The building was initially conceived as a woolen mill but dramatic changes in the wool market even as the building was under construction in the late 1860s caused a change in purpose to a flour and gristmill for wheat. The mill operated until 1942. Over the years, crops raised in the area evolved toward corn, oats, rye and soybeans, and for a while the building was used as a grain elevator and continued to serve as a feed store until the early 1970s before falling into disuse.

The mill was placed on the National Register of Historic Places in 1975 and the Buchanan County Historical Society took ownership in 1976. The society's objective is to use the first two floors of the building as a museum of 1870s grain milling, showing the relationship of farming methods and commodities to the processing of food. The remainder of the building would be devoted to staff use.

Over its 140-year life, the mill has been modified a number of times. By 1915 the turbines had been converted to generate electricity for the mill and other customers. The mill's flywheels were operated by electric motors from that time on.

Recent history A site on a river to obtain water power comes with the perils of periodic flooding, and flooding increased in the Midwest with the advent of field tiling for drainage and waterway straightening at the turn of the last century. The mill has had its lower levels inundated numerous times and the windows of the basement level would on occasion serve to let flood waters out rather than fresh air in.

In 2009 Trillium Dell repaired or replaced most of the lower level floor framing and installed secure attachments to the foundation to keep the floor in place in the event of flooding, providing gaps around columns and adjacent walls to allow flood waters to drain through the floor. A cedar shingle roof installed on the mill in the early 1990s had not held up well, and active leaking had developed in many locations in the shed roofs above the fourth floor and the monitor roof above the fifth floor. Prolonged leaking had led to damage at the east wall, the impetus for the contract that supported this workshop.

Puzzling conditions observed Before any significant carpentry work could begin on the damaged plate rafters and rafter tails over the river on the east side of the mill, a scaffolding system was required that cantilevered out from the second floor windows (Fig. 2).

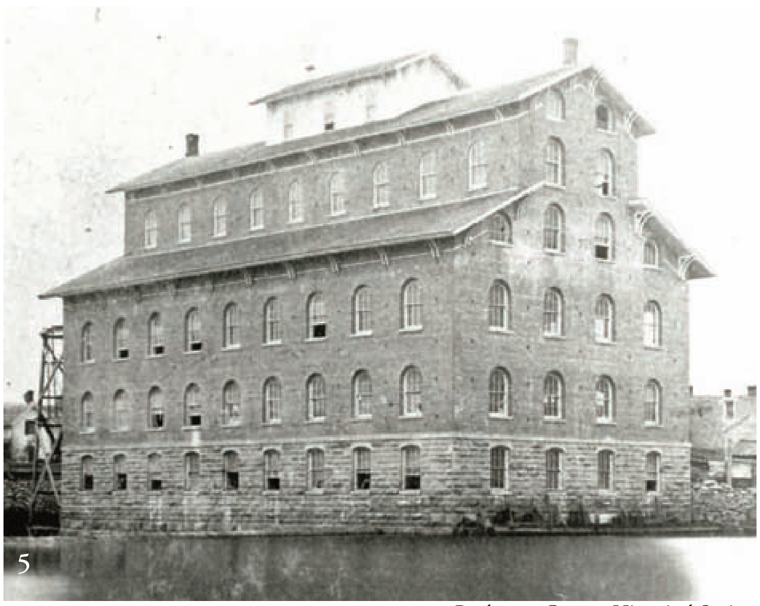
2

3

Facing page, Independence Mills, Independence, Iowa (1870), now called the Wapsipinicon Mill, viewed from the northeast. At top, cantilevered steel scaffolding in place at east shed roof eaves, over the river. Above, Rick Collins (left center in blue jeans) leads the group on a tour of the mill. Much shafting and many pulley wheels remain.

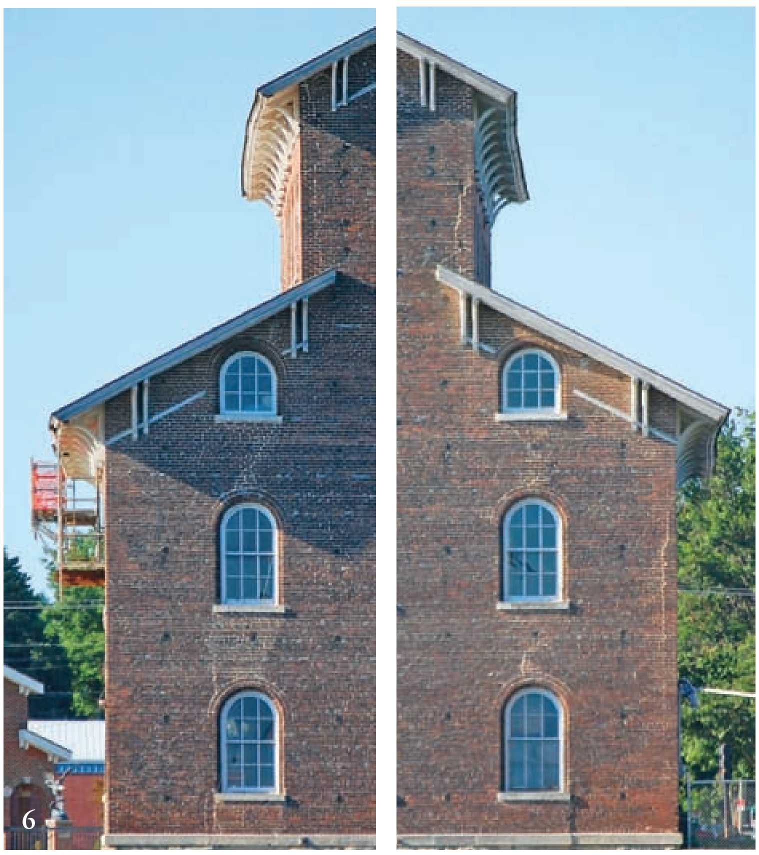
While this system was being installed by a scaffolding subcontractor, our group had an opportunity to assess the mill. Rick Collins guided an attic-to-cellar tour explaining the mill's history and the characteristics of the timber framing (Fig. 3).

During our tour in and around the building, a number of questions arose. While this magnificent building appears quite substantial and solid from a distance, it became apparent upon closer inspection that there was extensive cracking in the brick and numerous repairs were evident—in fact, the entire south gable wall had clearly been rebuilt using modern brick and mortar. What were the causes and conditions that led to these previous repairs?



Buchanan County Historical Society

At top, west elevation detail showing large bearing plates associated with tie rods that run through building at frame lines. Above, east view of the Wapsipinicon Mill, ca. 1874, four years after construction. Below, composite view from north revealing bow to the east of all roof eaves.



Large tie rods with rectangular bearing plates mounted on the exterior of the building at the third, fourth and fifth floors, an obvious feature of the building now (Fig. 4), clearly were not original to the construction, as we could verify in an 1874 stereo view of the mill (Fig. 5).

Standing well back from the building and taking the long view from across the river, we could clearly see sags in the ridgeline between north and south gable ends and the cupola in the center of the building. There was also a pronounced sag in the shed roof over the third floor at the south end of the west wall.

Longitudinal views from north and south made it apparent that the roofs' eaves lines were not straight but rather bowed to the east several inches near the midlength of the building (Fig. 6).

We noticed that the decorative brackets set beneath the eaves and gable end overhangs typically hung well clear of the brick walls (against which we would expect them to bear), sometimes by nearly 2 in. (Fig. 7). Trillium Dell had reattached some of these brackets as part of their work in 2009; determining the cause of detachment and appropriate remedial action to take on the remainder was to be part of this week's work.

A key puzzle to solve was the relationship between the brick on the exterior and the timber framing on the interior. How did these two interact and how was the brick connected to the timber frame, if at all? The many questions identified in the course of a brief tour suggested that perhaps the old mill was not quite so solid as it appeared from a distance. Certainly the building called for a careful look "under the hood."

The frame revealed We broke into teams to accomplish various tasks. One group set about measuring framing member sizes, spacings, spans and floor-to-floor heights, in order to develop frame drawings. Joe Miller, of Fire Tower Engineered Timber, led another group on an inspection tour to identify needed or recommended timber framing repairs. For my part, I reviewed all four elevations of the building to document the condition of the exterior masonry and to address questions raised during the initial review.

Others made preparations for the week's carpentry, bringing in tools and materials. The irony of repeatedly ascending and descending the many flights of stairs from first floor to cupola (with floor-to-floor heights ranging from 12 to 15 ft.) in a building that contained so many (grain) *elevators* was not lost on the group. A pool was established to wager on the total number of steps from lower level to cupola.

Although the main building frame was fairly straightforward and repetitive, developing a good understanding of the three-dimensional relationships in the building was complicated by three large grain bins, each occupying a full bay, penetrating the third, fourth, and fifth floors and independently supported on posts from the foundation to the third floor (Fig. 8).

Supplemental timber beams and posts at the third floor supported the brick walls along the east and west sides of the monitor at the fourth floor. Some original posts had been removed at the first floor and a system of structural steel transfer girders and new supplemental posts had been installed to bridge across a damaged section of floor framing below; this frame modification may have coincided with the turbine changeout and conversion to electric power.

These features, plus a variety of partitions, supplemental bin enclosures and a whole array of historic milling machines stored in the building, ultimately required a full day by the team collecting the data to develop preliminary building plans and full-height sections. Details of the visible framing were sketched in the process. The framing information was passed on to Curtis Milton, of Monolithic Building Services, who on the spot developed a 3D CAD model of the frame minus the bins (Fig. 9).

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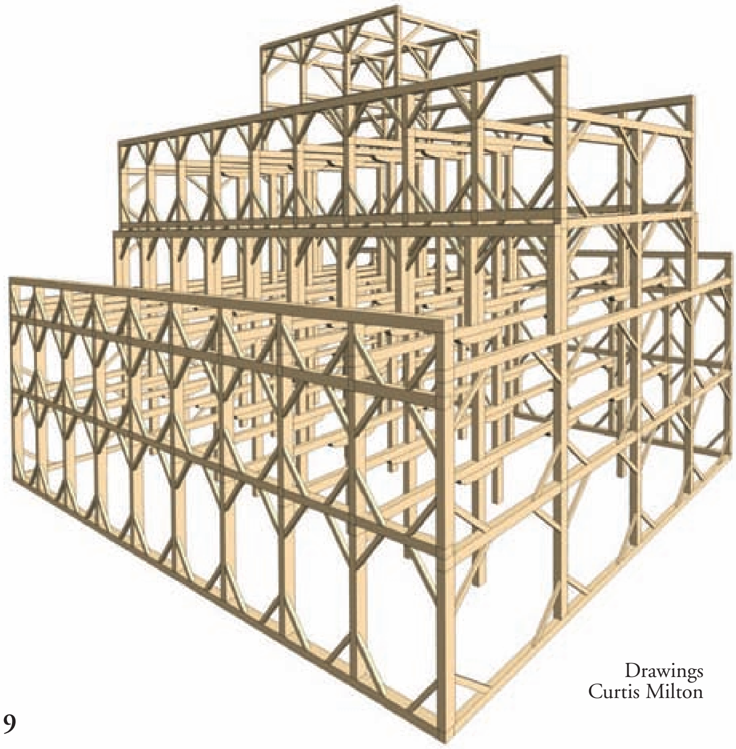


Drawings
Curtis Milton

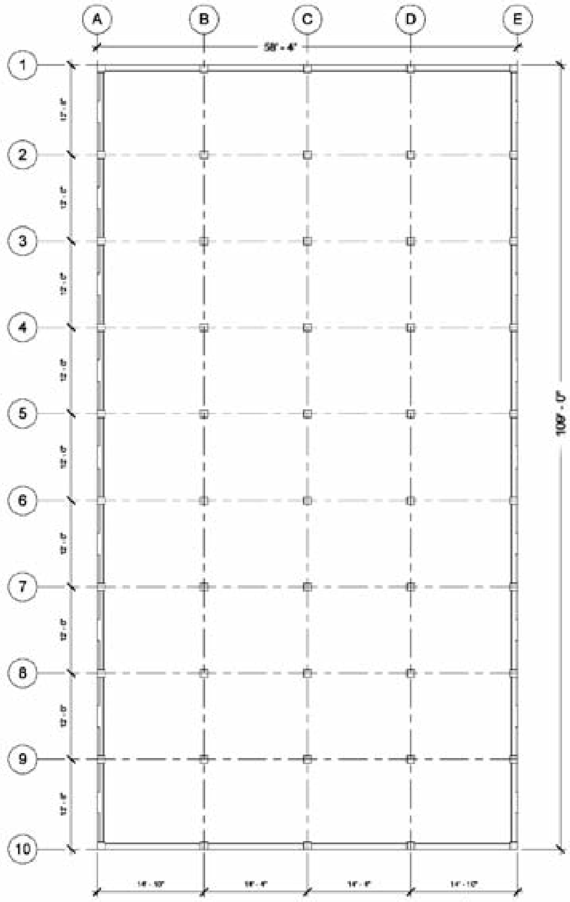
9

Above, decorative bracket separated from wall. Below, multistory grain bins, independently supported down to foundation.

Above, 3D CAD model of the mill's timber frame. Below, post layout for maximum uniformity of joists and girders.

8

Joe Miller



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We found the timber frame to be laid out by centerline square rule (including exterior wall framing) rather than reference face. All bays in the longitudinal direction measured exactly 12 ft. center to center, including the bays at the north and south gable ends. and crosswise post spacing for the four aisles worked out to 14 ft. 3½ in. center to center (Fig. 10). The beauty of such a regular post layout is that framing members become largely interchangeable within groups. Every one of the nearly 1800 2x10 white oak floor joists could be cut the same. Similarly, the scores of 12x12 Eastern white pine beams spanning across the building were mostly interchangeable, the nonconforming ones the result of scarfing and the change at the fourth floor from four aisles wide to two.

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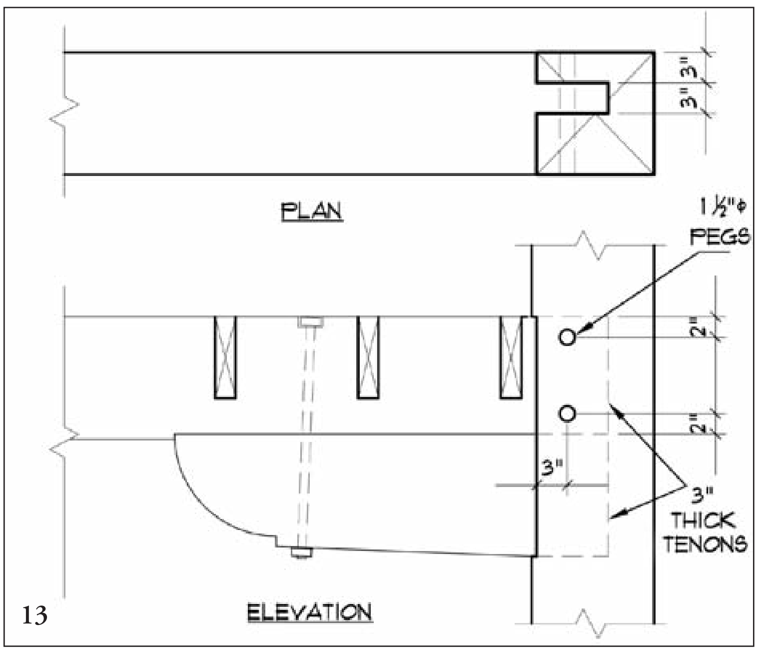
At top, typical interior post with oak bolster. Notch in bolster may reflect clearance for object no longer present. Note reductions on joists, stopped chamfers on beam and post as well as stepped profile of bolster, all signs of conscious craftsmanship. Above, tenoned half-bolster at exterior post, through-bolted to girder. Below, plan and elevation views of bolstered girder joint at post.



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The materials were generally high grade, consistent with old-growth climax forest harvest, their greatest defect occasional excessive slope of grain (spiral grain) that would not be permitted under today's grading rules.

Like many other industrial buildings of the 1800s, the mill's beams passed over the interior posts and were supported on white oak 12x12 bolsters to reduce the effective span somewhat and transfer load to the stacked white pine posts (Fig. 11).

Unlike many industrial buildings of the era, however, this mill featured timber framing in the exterior walls rather than load-bearing masonry. Posts in the exterior walls were framed full-length from foundation to plate, nearly 33 ft., so beams were brought into wall posts with a conventional pegged mortise and tenon joint, supplemented by an oak half-bolster below (really more like a corbel), similarly framed with a tenon that lined up directly below the tenon of the beam, and bolted firmly up to the beam (Figs. 12 and 13).

The benefits of this connection beyond aesthetic balance are subtle, but the oak tenon certainly would have been more resistant to crushing than would a pine tenon bearing in the post mortise, and shear capacity of the beam-to-post connection modestly improved. A nominal ½-in. housing was cut into the post as part of the square rule layout and provided only a small bearing surface for the full width of the bolster.

Exterior 2x5 wall studs were tenoned to the girts and plates. The entire frame was wrapped in 1-in. sheathing boards and brick infill was installed between studs at the inside face of the sheathing at the first, second and third floors, crosswise as well as longwise (Fig. 14).

Why this infill did not continue at the fourth and fifth floors, or the reason for any brick infill at all, was not clear. We speculated on its possible functions as fireproofing, soundproofing, thermal modulator, rodent barrier and bracing for the structure. In any case, diagonal bracing was provided in the exterior walls only. The crossframes had no lateral bracing.

The Wapsie Mill frame was well crafted. The builders paid particular attention to details at the first and second floors, where all posts and beams were heavily chamfered with ogee stops (Fig. 11). It may well be that the fine craftsmanship of the carpenters and stonemasons contributed to the respect for the mill that has led to its preservation for 140 years.

All joists featured a step bearing with 2-in. reduction (Fig. 15). Inspection revealed hand-cut notches at the end of the joists with a bandsawn 12-in.-long taper. Joist spacing, nominally 12 in. between joists but seldom exactly so, would have worked perfectly well with the era's board sheathing not precut to uniform lengths or widths. The pockets were cut in opposed pairs on every beam throughout the building, regardless of the eventual positioning of stairs and other openings. Reportedly the framing was all cut off site at the builder's mill and evidently it was a mass-production effort.

Timber frame engineering issues identified Engineer Joe Miller's team identified two areas on the second floor where severe damage from overloading was evident (Fig. 16). It is not often that one has the opportunity to conduct a load test to near destruction on such a well-crafted structure, but previous mill operators had done that for us. According to history provided by Leanne Harrison of the historical society, grain storage bins in addition to the main bins already described had been constructed on the second floor some time after original construction was complete at the two locations in question. Recall that the main multistory bins were independently supported and rose through penetrations in the floor framing without imparting gravity loads to the timber framing of the mill. The mill was in constant flux during its history, however, as the required types of grains and processing changed, and it was evident from our survey that numerous ad hoc storage bins, mixing

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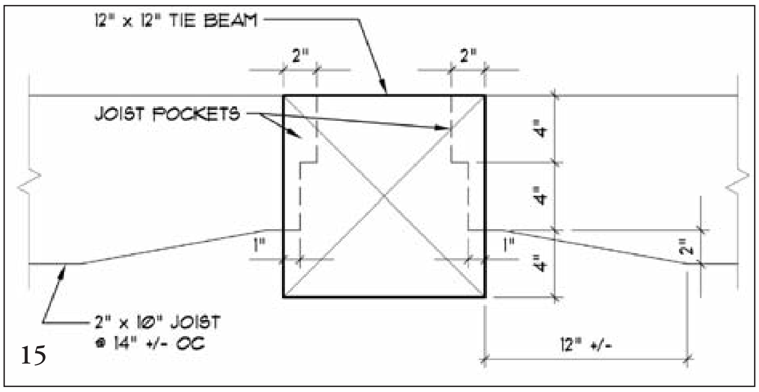

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At top, brick infill at third floor, placed against inside face of sheathing between studs. Above, joists at tie beam, joint detail. Below, representative split white oak joists, a result of double bearing in the joint and loss of support at lower bearing.

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bins, chutes and elevators had been installed, modified and removed at various times over the years. The construction of two large bins directly on the second floor framing appears to have been a move that was not well considered. The added bins were built the full height of the second floor, nearly 15 ft., and conveyors loaded the bins from the third floor. Each of these bins filled an entire bay, an area approximately 12 ft. by 14 ft., or 168 sq. ft. If they had been filled with wheat at 50 lbs. per cu. ft., the load could well have exceeded 110,000 lbs. in each bin, or nearly 700 lbs. per sq. ft. Even if these bins had been used for corn at 45 lbs. per cu. ft., the load could have reached 100,000 lbs. in each bin. No wonder then that damage resulted.

So what happened? As you might expect, a number of the joists cracked at midspan. The notched ends split. The bearing surface in the beam fractured and gave way (Fig. 16). The beam fractured in bending. The beam-and-bolster connection at the exterior column failed and had been supplemented with a bearing block and interior post to replace the failed bolster. Meanwhile, over interior posts we found evidence of crushing, bending and fracture of the oak bolster.

These failures probably did not all occur simultaneously, but rather developed over time as the bin became progressively loaded, leading to a series of reinforcing measures. To put the magnitude of this overload in perspective, a 14-ft.-deep load of kernel corn at 45 lbs. per cu. ft. acting as a fluid would produce bending stresses in the joists of 4500 psi, shear parallel to the grain stresses of 420 psi, and bearing stresses perpendicular to grain at the end of the joists of over 1100 psi.

Compare these stresses to the allowables for No. 1 white oak given in Table 4A of the *National Design Standard (NDS) Supplement*: 875 psi for bending, 220 psi for shear and 800 psi for compression perpendicular to grain.

Similarly, the induced stresses in the 12x12 pine beam supporting half the bin weight acting as a fluid calculate out at over 3000 psi in bending and 245 psi in shear parallel to the grain, with bearing stresses approaching 1000 psi at the exterior column.

Compare these stresses to the allowables taken from Table 4D of the *NDS* for No. 1 Eastern white pine: 875 psi bending (this figure is correct), 125 psi shear parallel to the grain, and 350 psi compression perpendicular to grain. Given the magnitude of these overstresses, it may be that the bins were never successfully filled to the brim. We know we are still looking at most of the original materials of construction, so a disastrous collapse did not occur.

It is instructive to look at how the joist bearing at the beams performed under these heavy loads. The cross-section of the typical beam showing the stepped bearing for the joists is given in Fig. 15. We were able to confirm these dimensions at locations where joists were missing and the joist housings were visible for inspection. We noted that the sides of each housing were initially cut with a hand saw and then the remainder of the housing cut out with chisels.

The exact thinking of the carpenters as they created this stepped bearing rather than a simple housing we can only surmise. According to Rick Collins, this joist housing was the prevalent design across the Upper Midwest from about 1850 to 1910, brought from New England as a standardized method displacing the distinctly different joist housings, more varied in shape and size, in earlier buildings from 1720 to 1840. The labor savings in removing less wood from the beam would have been offset somewhat by the additional labor in preparing the end of the joist. Perhaps the carpenters thought it desirable to remove less wood from the body of the beam. The joint design appears to be a compromise between notching the joist too heavily and notching the beam too heavily, but the resulting double bearing can be problematic. Certainly double-bearing surfaces are common in early light framing, where one often sees an upper and lower tenon at headers inserted into double mortises in beams, or in timber framing where load-bearing beams are housed in girders and also have a horizontal tenon on a separate bearing. But the failures we see at the Wapsipinicon Mill suggest that it is sometimes not possible to have it both ways.

When the lower beam bearing split away, throwing all the load to the upper bearing surface, the joist split parallel to the grain due to the stress concentration at the notch. Once the lower bearing surface failed, joist shear failure likely occurred close behind. The takeaway lesson would be that if the joist (or other entering beam) does not have adequate shear capacity at its upper notched bearing surface to handle the imposed loads, then the lower bearing surface of the entered beam must be sized adequately to support the entire joist or entering-beam load—easier said than done, as the complexity of induced stresses in the receiving beam has so far defied quantification, and timber designers work by rule of thumb. The Guild's Timber Frame Engineering Council is currently at work on this challenge.

The consequences of the overload appeared to have gone beyond just the second-floor framing under the bin, as the interior posts in this area also settled, possibly because of rot in the posts at the foundation level, allowing subsidence on the order of 2 to 3 in. This settlement transferred all the way up through the building, leading to pronounced sagging in the floor at the third, fourth and fifth levels as well. When the posts at these upper levels settled, it caused large compressive loads in the knee braces at the adjacent posts. These brace loads exerted sufficient prying action on the beams to open up scarf joints and push the beams off their bearings. Significantly, when the third floor settled it took with it support for the monitor exterior brick on the west sidewall and the shed rafters. This then was the cause of significant diagonal cracking in the monitor brick walls at the south end of the west elevation, distortion of the window openings in the area, tilting of the windowsills and sagging of the shed roof. It was satisfying for the team to track the cause-and-effect chain here and relate it to those initial observations of distress when walking the perimeter of the building.

While this overload caused some substantial damage to individual members, the structure itself is not in danger of collapse so long as these areas are not heavily loaded again. The primary engineering issue we identified, however, was the lack of lateral bracing for the building in the crosswise (east–west) direction. Apart from the gable ends, there are no braces or internal shear walls to stiffen the building in the east–west direction, and this building certainly presents a large sail area to the prevailing westerly winds. Compounding the effects of wind would have been the load on the main grain storage bins, whose volume was somewhat offset from the supporting framework below, and that could have created a tendency to lean toward the east. We had noted the bow in the eaves lines at midlength of the building in our initial survey of the exterior, and from the interior it was also possible to detect the leaning of the posts, most pronounced in the areas around the grain bins.

The stiffness of the floor diaphragms in this building was minimal to begin with, consisting simply of one layer of parallel board sheathing running east–west, normal to the joists, but even that was compromised by installation of the tall grain bins that punched holes through this diaphragm the full width of the building at the fourth floor (monitor level) and half the width of the building at the third floor. In effect, the diaphragms were hinged or nearly so at around mid-length of the building. The brick on the exterior of the building was a cladding with minimal direct attachment to the timber frame and could not be counted on to function as a shear wall, so bracing of the building to resist lateral loads in the east–west direction would have to come from the timber braces, and the wood stud and brick infill system at the end walls.


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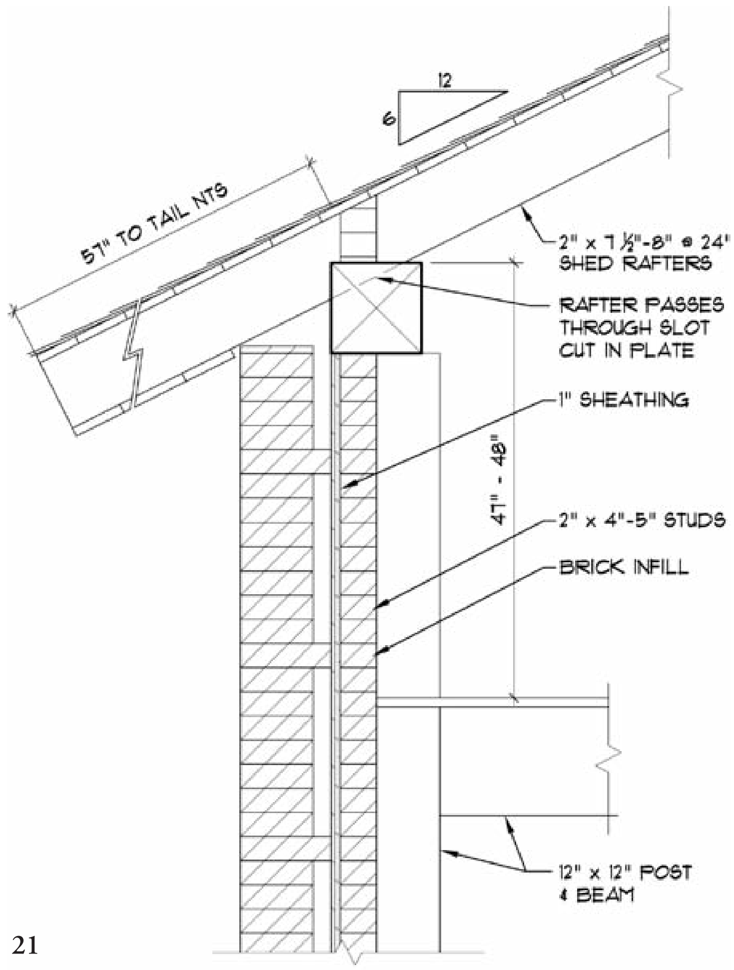

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Above, cracking and distortion at monitor northwest corner, a fault in large brick buildings without expansion joints. Note star brick ties. Facing page, top left, east monitor wall, north end, with large diagonal fractures, previous repairs and distortion of brick coursing lines. Top right, west monitor wall showing rotation and misalignment of stone sills, bowing of wall below windows. Middle left, cast-iron star brick tie that held cladding to wood sheathing, across an air space. Middle right, clinching-head spike used as supplemental tie for the 4-in. brick cladding. Below left, section at top of main wall.

Obviously, the Wapsie Mill has stood for 140 years, although not without developing a noticeable lean. The question remains what if anything should be done about the lack of a competent lateral load resisting system in light of the owner's plans for the building as a museum space open to the public.

Masonry issues The installation of a brick cladding on this building was an unusual decision since most similar mills in the Midwest were clad with wood siding. The interaction between masonry and timber framing at the Wapsie Mill was an intriguing puzzle to solve. Evidence of cracking and previous repairs is readily evident in the north elevations shown (Figs. 1 and 6).

The east and west elevations similarly showed a variety of bulges, diagonal cracks, missing mortar and signs of previous repairs. The masonry of the east and west monitor walls was particularly distressed, with large diagonal cracks at the north end (Fig. 17).

The limestone windowsills at the monitor level were out of alignment in every possible direction and the brick and mortar below the windows was deteriorated and bulging (Fig. 18).

The entire west elevation had been repointed, unfortunately with a mortar that did not match the original in color, texture or finishing detail. Spot repointing was evident all across the east elevation. (From an investigator's point of view, such glaring mismatches in repair make it far easier to track previous damage, but readers unfamiliar with the differences between modern and historic mortars should be aware that the introduction of Portland cement into traditional lime putty mixes, which occurred around the turn of the last century, resulted in increased hardness and reduced permeability of the mortar. These are desirable characteristics in certain situations but potentially disastrous in a soft-mortar historic brick assembly. Portland cement also results in a different binder color that does not match mortars made entirely with lime. For these reasons, it's usually inappropriate to use a modern bag-mix mortar on historic restoration work.)

The walls below the shed roofs were generally in better condition, although with a typical pattern of deterioration below every windowsill. The walls bowed noticeably towards the east at mid-length, following the leaning of the frame.

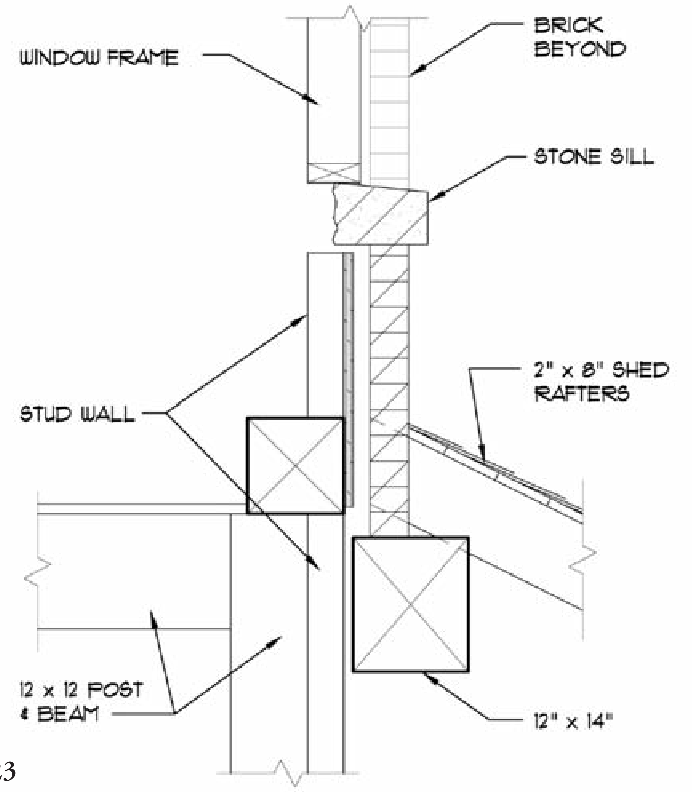
As the week progressed, the picture began to come into focus. The brick cladding on the gable walls and the east and west walls below the shed roofs was constructed 8 in. thick and supported directly on the stone foundations. With the mill building founded on limestone bedrock, there was no evidence of settlement or distress at the foundation level, and those 4-ft.-thick granite walls had withstood repeated flooding. We verified that the decorative cast iron stars were in fact part of the original brick tie system used to hold the cladding against the timber framing, with the average star tie responsible for holding some 30 sq. ft. of masonry. This original system is not to be confused with the tie rods installed (or misinstalled) later, which passed through the building. A complete star tie is shown in Fig. 19.

With shingles and sheathing removed from the east shed roof in preparation for repairs to the rotted timber plate and rafters, we had a rare opportunity to look down into the cavity between the exterior brick and the board sheathing applied to the timber frame. We observed a deliberate gap of 1 to 2 in., maintained by tie bricks spaced roughly 2 ft. apart, which protruded toward the interior and rested against the board sheathing, providing a standoff. There was no building paper applied to the mill's board sheathing in 1870. The gap between brick cladding and board sheathing would be typically provided to break the masonry, a "wet wall," from the wood and keep it dry (Fig. 21).

We determined that the cladding on the east and west faces of the monitor was only 4 in. thick rather than 8 in. as elsewhere, and again with a gap of 1 to 2 in. between the brick and the board sheathing, but here there were no standoff tie bricks installed in this single-wythe running bond layup. In addition to the cast iron star ties holding the brickwork to the wall, we found hand-forged, clinching-head spikes on approximate 2 ft. centers in each direction, with the head of the spikes close to the exterior surface of the mortar joints (Fig. 20).

The single-wythe brick cladding of the monitors was laid up monolithically with the double-wythe gable-end masonry. As is typical of load-bearing brick masonry buildings of this era, no expansion or control joints were provided in the cladding to provide for brick expansion or any other movement. This led to a series of cracks that, from our perspective, were predictable. As brick masonry expands gradually over decades of exposure to moisture, the corners of long, uninterrupted walls, such as above and below the windows here, are gradually pushed away from the building. When this expansion is restrained, for example by the wall being tied to a timber frame (that if anything would shrink slightly after construction), vertical cracks and distortion at the corners typically result. These were especially clear in the late evening's raking light (Fig. 22).

The diagonal cracks we found in the east and west (long) monitor walls at the north end are easily understood in light of the change in support conditions that occurs as the masonry turns the corner from the gable end wall to the sides of the monitor. The gable brick wall was supported rigidly on the stone foundation, and if anything, longterm expansion of the brick would create a slight upward growth of the gable wall. The monitor sidewall masonry, on the other hand, was supported on a 12x14 timber sill devoted to this task (plus carrying the shed rafters), itself supported by posts at 12-ft. centers that in turn were supported by the 12x12



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At top, section through monitor wall showing stone window sills in original position. Above, damaged brickwork resulting from tightening 1¼-in. iron rods against an air space. Below, Jared Wilson prepares for scarfed-in plate repair.

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Joe Miller

floor beams stacked over bolsters at the third floor. Cross-grain shrinkage of all these stacked timbers along with any elastic deflection clearly would cause support for the monitor's sidewall brick to drop, thereby inducing the diagonal cracks. In fact, careful study of the 1874 stereo view (Fig. 5) shows that those diagonal cracks in the monitor were already present after four years. Similar cracking had occurred at the south end, although some of that original distress was corrected when the south gable masonry was rebuilt.

Settlement of these walls was responsible for some of the tilting and misalignment of the monitor's stone window sills, but we found that insufficient support for the interior edge of the sills was likely the cause of many of the sills tilting back in towards the building (Fig. 18; shown in correct position in Fig. 23). Rainwater runoff from the sills into the brickwork caused repeated wetting and drying, combined with freezing in the winter, of the lime mortar joints in the masonry. Loss of integrity of the mortared assembly below the sills combined with minimal or no tying of the brick to the structure likely caused much of the distress.

With our understanding of the construction details of the brick cladding, we were in a better position to understand the impact of the installation of the tie rods that passed through the building and their large bearing plates on the exterior of the brick, and what potential benefit (if any) the tie rods may have provided. We do not know what conditions led to their installation. Without internal bracing or a competent diaphragm and shearwall system, they certainly could not have contributed to lateral stability.

We noted some withdrawal of beam tenons from exterior posts and, given the severe vibration that Curtis Milton assured us the frame of such a large mill building would have been subjected to, restraining the exterior wall posts may have been the goal. Historic photos showed that the tie rods were installed sometime between 1906 and 1930, so the mill may have been in service for as long as 50 years before the rods were deemed necessary. By the time they were to be installed, evidently there was no memory of the gap the original builders had provided between the brick cladding and the timber frame, and damage resulted when these 1¼-in.-dia. rods were tightened (Fig. 24).

It is puzzling that this damage occurred more than once along the monitor walls, and there was some visual evidence that the rods were even able to pull the 8-in. cladding on the lower sidewalls in toward the frame as well. Evidently the cracking of the bricks was not sufficient cause to modify the operation. If the goal had been to tie the exterior posts to the frames, a more direct—and internal—connection to the posts would have been more effective. In the event the exterior masonry is to be repaired or rebuilt, some consideration will have to be given to modifying these tie rods and their external bearing plates.

And what about the complete replacement of the brick cladding on the south gable wall? In response to our inquiries, our hosts at the museum pulled out a newspaper article depicting the collapse of the brick on the south wall in 1991, the proximate cause assigned to winds clocked at 80 mph during a heavy thunderstorm. Given the deterioration and cracking evident on other elevations of the building, we might surmise that the storm was just the last straw. A fire in the mill in the 1950s at this end of the building may have caused some damage that added to the weathering damage that likely was present. Although it would have been preferable from a preservation standpoint to salvage any undamaged bricks, clean them up and reinstall them blended with replacement bricks as needed, the repair contractor elected to rebuild with all new materials. The brick selection was not bad, original detailing at windows was recreated, and the coursing worked out fine. Here again the mortar color and finish did not match the original and provided another case study for the importance of getting the mortar right in every way, including the finishing details, if a good

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At top, left to right, Jake Amadon, Joe Miller, Joseph Ferencik and Tom Haanen coax plate into place over stud tenons. Above, Michael Murphy, left, and Will Fowlkes repair masonry infill. Below left, Tim Whitehouse checking actual needed brace length. Below right, lower end of replacement brace swung into position via overcut mortise and small chiseled relief, then blocked in tightly.

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Joe Miller

match is desired. On the other hand, the repair work does preserve the story of the mill by clearly reminding us that something happened on this elevation.

The work Once the rock-solid cantilevered scaffolding system was in place below the shed roof eaves of the east wall (Fig. 2), work could begin in earnest on repair of the damaged rafters and timber plate. A crew removed rotted fascia boards, debris and nesting materials from the rafter space, pulled back rotted sheathing boards and jacked up the rafters.

The section of damaged plate to be replaced did not coincide with existing scarf joints, and new cuts had to be made. The form of scarf chosen for the replacement section reflected other scarfs found in the original framing of the mill. While many of the plates used an inline tongue-and-fork joint, there were other examples of tabled half-lap scarfs and this form was selected as being most practical and effective for the conditions and location of the replacement piece.

Removal and replacement of the rotted section was made a bit more difficult by the stub tenons that extended from the top of every wall stud into the underside of the plates. As with the joist layout, we found that the stud layout appeared to have been roughly stepped off by the framers. This irregularity required some mapping of the new plate to the studs (Fig. 25).

Rather than remove the existing rafters that had severe rot at the birdsmouth on the eaves plate or at their tail ends, we decided to sister them (after the rotten areas were treated with a heavy dosage of borates). Fortunately, stockpiles of two-by material were stored on the upper levels of the mill, left over from removal of old bins and partitions, so the needed materials came ready with appropriate patina. The Eastern white pine replacement timber for the plate, reclaimed from an old barn, was brought to the site by Trillium Dell and cut outside, then hauled up to the third floor, along with newly sawn Douglas fir replacement sheathing boards.

The plate was eased into position with the aid of well-tuned joinery. The final fit was commendable and the appearance consistent with the original mill construction, what restoration carpenters aspire to (Figs. 26 and 27).

As a final touch, the brick blocking between the rafters and in the stud spaces below the plate was relaid using salvaged original brick from the building in traditional lime putty mortar (Fig. 27). The use of brick rather than wood blocking to fill inter-rafter spaces and close off exterior walls was puzzling to me, even if it was standard practice in the day. Certainly wood blocking would be more compatible with rafters, since it would shrink and swell along with them, whereas brick stands proud of the top surface of rafters as they shrink away, leaving sheathing hung up on the brick.

Over the years, a significant number of the mill's longitudinal knee braces had been cut out to accommodate changes in use of the space. Part of our week's work called for replacement of 14 of the nominal 4x4 braces at the third and fourth floors. All braces in the mill were set at 45 degrees with a 48-in. leg layout. The brace replacement crew considered at some length the available tactics for inserting new braces into existing mortises at posts and girts or plates. In the end, we opted for lengthening the housed mortises at the posts and rotating braces up into position after inserting the upper ends into unaltered mortises in a beam. The lower ends of the braces were then wedged firmly into position with crush blocks driven into the overcut mortises (Figs. 28 and 29).

The intricacies of cutting accurately fitting replacement braces for a frame no longer plumb, level or entirely square, and whose timbers had some degree of twist and irregularity, soon became apparent. The presence of any bow or twist in the replacement brace material only added to the challenge. As a concession to productivity, we did not scribe or map each individual brace.


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At top, Dan Roberts, Tim McGee and Brad Collins on their way up to the eaves in the 135-ft. lift. Above, morning lecture series: Joe Miller, right, discusses damaged floor framing and proposed repairs. Below, our hosts from the Buchanan County Historical Society, from left Wanda Goins, president Leanne Harrison and Judy Scott.


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The weather was hot during the first half of our week in Independence. A 90-degree-plus high-pressure system whipped up some serious wind that definitely added to the thrills for the crew operating the 135-ft. man-lift (Fig. 30).

They were able to reach most of the eaves and gable overhangs on all but the river side of the building, to remove and replace damaged fascia and reattach soffits and decorative brackets. During the work on the rotted plate and rafter repairs at the east wall, we saw clearly that the soffit had pulled away from the underside of the rafter tails, with gaps of as much as an inch, and had taken the decorative brackets with it. Though well-enough made with pegged joinery, the brackets were just spiked into mortar joints at their lower ends and never attached firmly enough to transfer weight from the rafter tails. Additional bracket separation resulted from the tightening of the tie rods that had been run through the building, which simply pulled the brick away from the brackets (Figs. 7 and 24).

Repair of rotted window sills and scraping and repainting of the cupola rounded out the week's high-altitude assignments. Hard hats, harnesses and lifelines were an integral part of all these activities. A small rowboat was tied up to the mill along the riverside each day to serve as a rescue vehicle in the event someone fell, the assumption being apparently that the fall would not kill you. Thanks to the use of safe work practices, no one tested that assumption and no rescue missions were required.

The camaraderie Our last day was set aside for engineering presentations on joist sizing and a review and discussion of our structural assessment of the mill building (Fig. 31).

We debated pros and cons of systems to provide lateral bracing to the timber frame, noting that large interior shear walls or diagonal braces would clearly interfere with the use of the building as a museum, and reviewed methods of creating more substantial shear wall elements in the gable end walls. For these to be effective in stabilizing the whole structure, continuity in the floor diaphragms would be needed while leaving the multistory main storage bins in place. We discussed the findings of the exterior masonry survey, causes and effects of deterioration and implications of the interaction between timber frame and masonry for most effective long-term maintenance and repair. Discussion of the survey methodology and the thinking that led to our conclusions was no less important than discussion of the findings.

Lunch and dinner each day were provided by our hosts from the Buchanan County Historical Society (Fig. 32). They put in more than a 40-hour week, supported us materially and provided valuable historical information that helped put the big picture together.

Our evenings at the campsite north of town, surrounded by cornfields and woodlots, often stretched into the early morning hours with storytelling, fiddle tunes and rowdy singing (and occasional shoptalk). The week provided a privileged experience. Knowledge was freely shared all around. Skilled workers discussed appropriate work methods, Guild apprentices gave engineers direction on carpentry, engineers held forth on joist sizing, lateral stability and structure evaluation. After being fully absorbed in the mill for seven days of exploration and discovery as we worked to unlock its secrets and repair what we could, we came away with a newfound love for this beautiful historical building. The Wapsipinicon Mill preserves an important part of the tradition of heavy timber construction in the Midwest. —Tom Nehil

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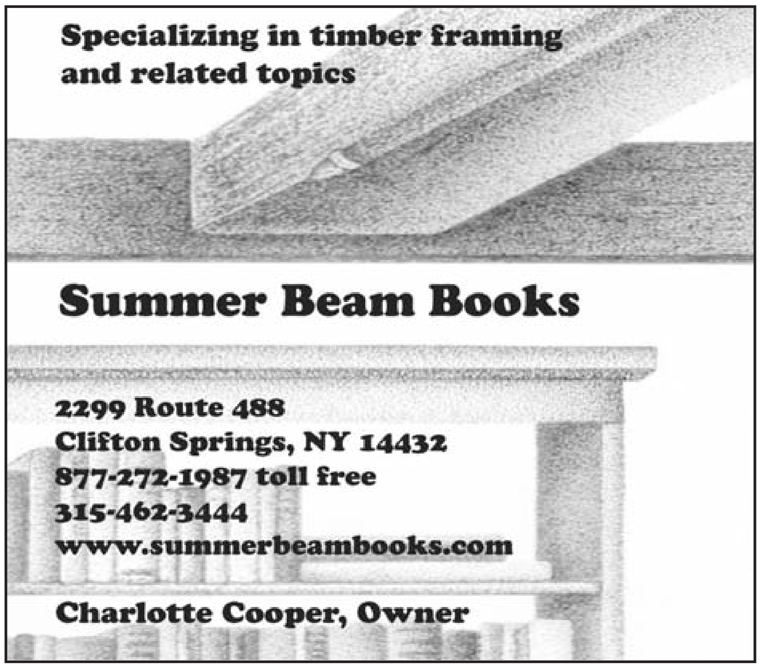
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