TIMBER FRAMING

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Tour charpentier de France 2007

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On the front cover, twisted steeple on village church in Vieil Baugé, in France’s Loire Valley, seen during the Guild’s 2007 Tour de France. Framing inside spire provides flat ribbon-like surfaces for sheathing and slates. On the back cover, the 13th-century Salle des États Généraux, incorporated into the 16th-century Château de Blois. Note slender kingpost trusses and the finely made painted wood ceiling, called charpente lambrissée. *Story page 8. Photos by Will Beemer.*

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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.

Notes & Comment

BILL KEIR, a familiar figure at our conferences, a regular visitor from the UK and a steady supporter of the Guild, had quite a little to say in October at the Montebello ’07 members’ meeting about the social uses of conferences. The Carpenters Fellowship formed in the UK a little later than the Guild in the US and retains the more playful air of youth, with most people camping and most events out of doors (in beautiful places, of course). This year the Fellowship almost didn’t have a meeting. In the end a meeting was pulled together without the usual scholarly and technical offerings. More people than ever came and more than ever expressed their satisfaction with the meeting. I don’t recommend the Guild abandon its educational offerings, but I cite Bill’s information to justify my own use of Montebello ’07 for social purposes.

I had a fine time one afternoon at the Children’s Workshop helping out (mostly as a human clamp) a very determined 10-year-old boy to saw tenon cheeks and shoulders. Of a morning I had breakfast with Bruno Sutter, the accomplished young Frenchman who now teaches timber framing in Charleston (pictures of his students’ work appear on the facing page) and who had previously extended his Tour de France as a *compagnon* to include the US. Last June he led the Guild’s French tour (see page 8). At this conference he gave an advanced workshop in curved roof geometry and helped out continuously at the Children’s Workshop. I asked Bruno whether he would return to France when he was done teaching in Charleston. He said he’d rather move on to someplace different from both France and North America, perhaps the South Pacific, working for a French company building timber structures. When the French speak of *la liberté*, they aren’t kidding.

I spent some time with Patricia Chambers, our *Scantlings* editor, who, well-shepherded by Susan Witter (who moved on this fall), is finding her way humorously though the front and back channels of the Guild enterprise. Patricia takes over a thriving publication whose original purpose in 1991 was to establish a line of communication between the executive director of the day and the membership. Today *Scantlings* is certainly that, but it’s also a crossroads for all Guild activities. No doubt it will evolve further.

The pictures that follow come from the Montebello slide show. We no longer do the conference design contests of old, with prepared submissions, displays, judges (learned or otherwise), as well as a people’s vote, and results published in the journal. But I still like to show a selection of current work that catches my (prejudiced) eye for one reason or another. Log-and-timber work, well represented in the slide show, is absent here. Must it always be so ponderous? We saw at the conference that logs can be made to appear to melt into one another at the connections, or neatly shaved down and housed like timbers. A cylindrical column can be a lovelier thing than a squared post. May we not see buildings framed gracefully of timbers and smooth, slender logs beautifully joined? —KEN ROWER

Tim Diener

Modern-style timber work in select structural Douglas fir by Lancaster County Timber Framers. Above left, 6000-sq.-ft. residence in Lancaster, Pa., with pitched Howe roof trusses; design by Wyant Architecture, engineering by GTA, Inc. Above right, 5000-sq.-ft.residence in Southampton, N.Y.; McDonough & Conroy Architects, engineering by Ruff. Fir timbers are free of heart center. Steel railings appear de rigueur in modern design.

Bruno Sutter

Recent work in Southern yellow pine at the American College of the Building Arts, Charleston, S.C., executed under the direction of Bruno Sutter, a French compagnon *and professor of timber framing at the college. The 24-ft.-wide truss will be part of a timber-framed building to be put up some day at a new campus to serve as showroom and conference room for the college. Each truss will be of a different form and use a different layout system to show the evolution of timber framing through scribe rule, square rule and mill rule. Above right, "easels" built for the stone carving students. Note variations in details.*

Whit Holder

Details of Randolph County, W. Va., residence built by Holder Brothers Timberframes, designed by Patrick Corish (Birmingham, England) and engineered by David R. Simpson. White oak frame, first floor jetty, 50 naturally curved braces, and a traditional English roof system of principal rafters, clasped purlins and common rafters. Cement-board infill panels were scribed to fit and individually installed as frame was raised.

David Kirwin

White oak garden barn in Granville, Ohio, 24 x 32 ft. with an attached solarium 10 x 20 ft., built by David Kirwin and designed in collaboration with the owner. Originally intending to cover it, the client seeing the frame complete decided to leave it exposed.

Kathy Miller

Principal purlin roof frame detail of 4000-sq.-ft. house in Estes Park, Colo., framed by Trailridge Timberframes. Architectural design by Judd Dickey, timber frame design by Mark Miller (Trailridge) and Judd Dickey, engineering by Dave Connolly. Main timbers radio-frequency vacuum-kiln-dried dead salvaged Douglas fir timbers; other elements—corbels, braces, wedges, shear blocks and large curved pieces under the purlins—are cherry, air-dried in the timber yard for a year.

Mike Beganyi

Residence underway in Salina, Kansas. Architectural design by David Exline (Exline Design Architecture) and timber frame design by Mike Beganyi (New Energy Works), timber frame engineering and fabrication by New Energy Works. Frame is a mix of green and radio-frequency vacuum dried free-of-heart-center Douglas fir. Block walls shown will be covered in native Kansas limestone quarried not far from the site. Cluster-columns sit atop stone piers and double-splay a half-degree from top to bottom, making most of the joinery in the frame compound, and will be strapped with forged iron and keyed with white oak. Two-story gallery will be sheathed in glass.

K. Paul Laudenschlager

Leif Calvin

Meditation hall, a hip-roofed tension ring structure framed in Douglas fir by Timber Creations at the Ratna Ling Retreat Center in Cazadero, Calif. Main hall 46 ft. square. Architectural design by Dale Zumfelde, engineering by Steve Pestell; timber frame designed by Leif Calvin (Timber Creations) and engineered by K. Paul Laudenschlager. Platforms suspended from the roof framing will support heavy prayer wheels. Hip nexus is a glue-up.

David Maclay

Douglas fir timber roof by Pine Hill Woodwork over Dykeman Hatch, a trout hatchery built 1871 in Shippensberg, Pa. Ridge was originally to be posted to floor; interrupted lower chord of truss now conceals steel. Reinforced concrete plate consolidates and levels top of rubble infill walls to support new roof evenly. Independent framers Lee Sornson, Nate Campbell and Peter Bugler assisted Pine Hill's David Maclay.

Keith Gunder

Detail of private chapel in Todd, N.C., framed in Douglas fir by Harmony Timberworks. Architectural design Eric Binder (Meyer, Greeson, Paullin), frame design Dan Kiser (Harmony), engineer Rob O'Briant.

Bob Weatherall

Retreat in Ipswich, Mass., 12x18 ft., designed by Weatherall Design and built by Jay Esty of select structural Douglas fir. It sits on a dyed and polished concrete slab on Maine granite plinths.

Dan Fadden

Shop views of curved, laminated and veneered work at Sweet Timberframes in Mt. Desert, Maine, for timber-framed boathouse in East Blue Hill with irregular hip roof and eyebrow eaves dormer. Continuous eyebrow valley is glued up of half-in. pine laminae faced in oak. Dan Fadden worked out the curves and cuts using AutoCAD on drawings by Elliott Elliott Norelius Architecture. Scarf joint (stop-splayed with wedge) at apex will be supported by a purlin at the notches. Eyebrow valley unscarfed would have measured about 18x19 ft., too large for transport.

Owner-built traditional frame in Conway, Mass., by Stephen Thomas, quondam professor of physiology, futuris Three Crows Woodworking (see the near photo), using 5300 bd. ft. of local red oak. New structure replaces a failing barn and yields additional work and living space for the household. Christian & Son designed and engineered the frame and provided shop drawings. Most of the frame went up with gin pole and windlass or A-frame and tackle.

Jeanne Thomas

Owner-designed project near Omaha, framed largely in salvaged pitch pine by Jim Holzknecht (shown here with his handiwork) of Kerrville, Texas, and Randy Churchill of Cambridge, Vermont. Frame was cut in Oklahoma City, stored for some time, then moved to Omaha for the raising. The message is a blessing for all who build and love timber frames.

Randy Churchill

Timber Framer's Tour de France 2007

All photos Will Beemer

Fig. 1. Cathédrale Saint-Julien, Le Mans, with unique split buttresses configured to flank windows in first-story choir below.

THE 2007 Guild timber framer's Tour de France was our second such sojourn into a country rich with tradition in the craft. Our focus in 2003 was the North, as far east as Strasbourg (see TF 69); this time we visited the Anjou and the Touraine, their vital artery the Loire, a major river for transportation and regional defense throughout French history. Towns arose at strategic bridge locations and fortresses (the original *châteaux forts,* such as at Angers) appeared on the high slopes. During the late Middle Ages, the Angevin empire under the Plantagenets beginning with Henry II (born 1133) soon came to encompass the west of modern France and all of England. The Loire Valley's golden age came during the reign of François I, who ruled from 1515–47 and started construction on Chambord, perhaps the most splendid château of them all. Although power shifted to Paris around 1600, luxurious palaces were still erected by the aristocracy in the Loire until the end of the 18th century.

After our rendezvous at Charles de Gaulle Airport near Paris, our group of 16 loaded into two rented Renault vans and headed southwest to the Loire Valley and the old Roman-walled town of Le Mans, Henry II's birthplace. There we were met by Tourangeau Anis, a member of the Compagnons du Devoir. *Compagnons* are part of a centuries-old organization of highly trained tradesmen that gives its members double nicknames to address each other. The first word cites the member's native region or city in France (in this case the Touraine); the second might be the family name (as here), or an admirable or memorable attribute of the person.

The *compagnons* have several Websites. You can visit one at www.compagnons-du-devoir.com; another, www.compagnons.org, gives information on Les Compagnons du Tour de France. There are actually three distinct groups, with timber framers in each. A student craftsman may join only one of the three at the beginning of his career; reasons to choose one over another are personal and varied. One may become a professional timber framer without becoming a *compagnon*; a two-year course with substantial practical experience (apprenticeship) is all that's required at one of the many trade schools around the country. The apprenticeship course and testing at the end of the two years are administered by France's ministry of education, but the *compagnons* also have their own schools. By applying and being accepted into a program, an *apprentis* enters a brotherhood with three major commitments. First is to promise to develop morally and professionally, to agree to strive constantly to improve one's character and craftsmanship. Second, the apprentice agrees to travel during the subsequent *aspirant* stage (usually three years), gaining expertise through a broad range of experience in different shops. Third, the applicant joins a community and thus willingly shares his knowledge with others by teaching and mentoring others, and is always open to aiding those in need, especially *compagnons*. Masculine pronouns apply here because *compagnonnage* (including bakers and pastry chefs) is still an overwhelmingly male activity, although the pattern is beginning to change.

We might equate a *compagnon*'s completion of years of training to a college degree, but *compagnons* themselves are reticent to use this training as a feather in their cap. The qualification will rarely appear as a credential in résumés or company brochures, but instead is viewed as an attitude and lifestyle. *Compagnons* let their work, not their schooling, stand as a testament to their skill.

Our first stop in Le Mans was at the magnificent Cathédrale Saint-Julien, which combines a 12th-century Romanesque nave with a 13th-century Gothic choir and 14th-century transepts. Some of its intricate flying buttresses are unlike those of any other cathedral. Because of the unusual inclusion of first-story windows in the walls between the seven chapels surrounding the choir, each buttress splits into a Y to straddle the windows below (Fig. 1).

The old quarter of Le Mans (Cité Plantagenêt) preserves Gallo-Roman ramparts from the third and fourth centuries, including 11 towers overlooking the Sarthe river. The narrow, cobbled streets are lined by 15th- and 16th-century half-timbered houses interspersed with later masonry mansions, one the local house of the *compagnons*, where we were welcomed with a toast of Le Mans specialty beer. We returned the next morning for a tour of the house, including the library, classrooms and rooftop observation tower. Exams were taking place, so we had to be quiet and some rooms were off limits; a clearly relieved group of students grew larger by the minute in the parking lot as we made our departure around midday.

On our drive to Angers, where we would spend the next three nights, we detoured west into Brittany and the towns of Laval and Vitré, the latter one of the best-preserved towns we visited, with its dark alleyways, tightly packed half-timbered houses and formidable castle, walls and ramparts. Vitré is also noted for one particular street of timber arcades supporting the second floors of shops and houses (Fig. 2).

Raymond Lutellier, owner of a local timber frame company, showed us around the old parts of Vitré and pointed out interesting details and work his company had done. This included an external circular stairway where each step (riser and tread combined) was carved from a single block of wood. M. Lutellier then took us to his office for a look at his woodlot, shop and home, and then on to a church in Maisoncelles du Maine, where he is replacing the vaulted roof framing.

Angers is a bustling city straddling the Main river five miles before it joins the Loire, the longest river in France. The oldest part of town contains a magnificent feudal fortress, a true *château fort,* with huge drum towers built between 1228 and 1240. Some 46 timber frame houses are near the cathedral, the best the Maison d'Adam, unfortunately for us covered in scaffolding for a periodic facelift and painting. We could still glimpse some of the intricate carvings on the 15th-century merchant's house, including sirens, lovers and musicians tucked into every angle. As in all the timbered exteriors we saw, extravagant decoration displayed the owner's wealth. Upper stories that housed servants would show less decoration or might even be undecorated, which could also reflect a reversal of fortune as the house got higher and the owner's bank account lower. Similarly, often just the fronts of houses displayed timbers, while side and rear walls were stone, which also provided fire protection for adjoining buildings.

Fig. 2. Carved arcade in Vitré. Post at left appears a bit gimpy.

In Angers we visited two craft schools and thus learned some aspects of the craft training system in France. Copernic (Fig. 3 overleaf), the first such school, offers two-year programs for students who are mostly commuters and not enrolled in the *compagnon* system. Continuing education courses are also offered here, and students are not required to live in the house (although that option is available). The companies they work for usually sponsor the students, but the latter can also pay their own way (perhaps they aren't employed in their trade yet).

The *compagnon* system has more stringent requirements for admission. In addition to an apprentice's promises to improve his skills continually throughout his career, to be willing to travel and teach and to be a morally upstanding and active member of his community, *compagnons* are also required to complete a masterpiece after extensive travel; all of this makes it much harder to complete the program, and only 13 percent of entrants make it all the way through. One can still work in a trade after completing the two-year apprenticeship, the curriculum for which is the same at Copernic and similar institutions scattered throughout France or at any of the *compagnon* schools such as the one in Angers, called La Baumette (Fig. 4 overleaf).

All the schools share curriculum and tests developed by France's ministry of education. This *formation* includes training in technology, design, assembling and safety. Apprentices generally work six weeks in a company and then study in school for two weeks. One can also attend school full time, but those who

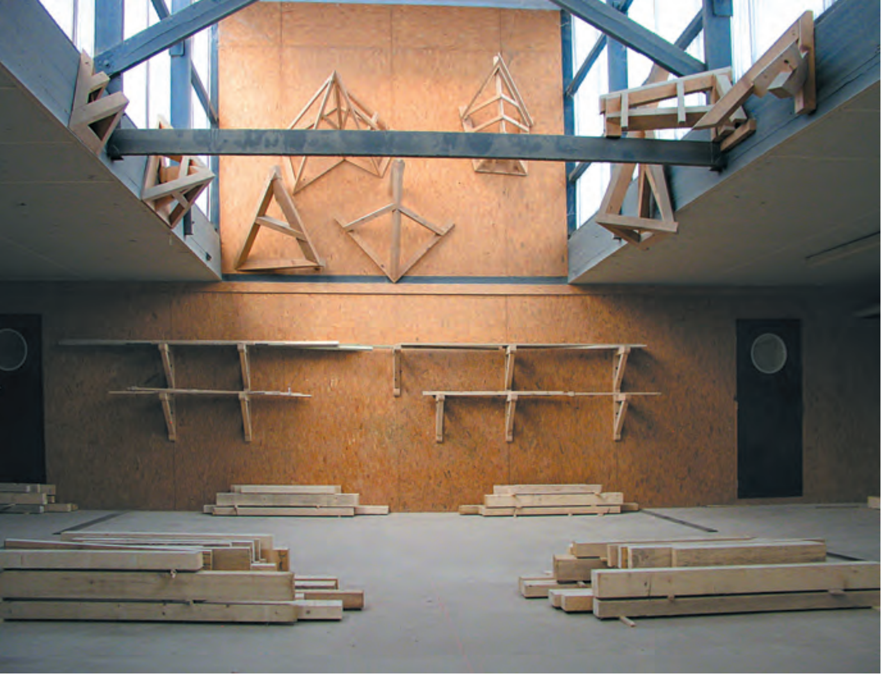

Fig. 3. Carpentry stations ready for final exam at Copernic trade school in Angers. Constructions from previous exams hang on walls above.

Fig. 4. La Baumette, the **compagnon** *house in Angers.*

do are usually people not yet working in the trade. Each participating company in France pays into the system to support the schools, which are also aided financially by continuing education tuitions and regional government grants. Students pay for their tools, materials and books and room and board. Some 140 people a week attend Copernic, most age 25 or under, since after that age the charge to a sponsoring company goes up. One can enter an apprentice program up to the age of 45, although one might have to pay for it oneself. Companies get money back from the region to hire apprentices, and the school might help an apprentice (especially in the *compagnon* schools) find a sponsor company.

At La Baumette and other *compagnon* houses, itinerants in the program can live at the house while they work locally and are even provided a space to work for a year while they build their masterpieces. After a delicious lunch (not like *my* dorm food in college) and a tour of La Baumette, we met with Daniel Coudert, new director of the Institut de la Charpente et de la Construction du Bois. The mission of the institute is to determine the future of the timber-framing trade in France and internationally, and to be prepared to teach what will be required ten years hence, achieving these goals through research, teaching (particularly classes for architects), documentation and meeting other timber framers such as ourselves. The documentation includes recording the evolution of the craft; M. Coudert estimates that a *geste du métier*, or traditional carpentry skill (such as sharpening a handsaw), is being lost every day. It occurred to me that the Guild's mission is similar and that a cooperative publications effort would be fruitful. Our group of American timber framers was given the opportunity to show their work via PowerPoint to the carpentry students, and we then adjourned to the attic studios to view the students' work, mainly their current drawing exercise. Most of us gravitated to an elaborate compound roof model that included sliding, collapsing roof members that demonstrated the transition from plan view to in situ position.

We spent an entire day with Jean Perrault at his company Ateliers Perrault Frères in St.-Laurent-de-la-Plaine, southwest of Angers. Perrault's is one of the most impressive timber framing enterprises I have seen. The company was formed in 1760 and has remained in the family since. With 225 employees (including 15 to 20 *compagnon*s), Ateliers Perrault have worked on castles, manors, cathedrals, the Louvre, Versailles and other buildings dating back to the 12th century. Besides timber frames, they also make their own windows, doors, roofing and hardware. The centerpiece of their woodlot and sawmill complex is le chêne Saint-Jean, a 250-year-old, 42-ft., 56-in.-dia. oak log from Normandy that lies at the sawmill entrance to welcome visitors. Ateliers Perrault maintain 300–400m^3 of reclaimed timber in inventory for their various projects and use a massive bandsaw for resawing or converting. We found the sawmill remarkably dust free (Fig. 5). Perrault's concern with the danger of nasal cancer from working oak is evident: a filtering system keeps the dust at 1mg/m^3 (5mg/m^3 is the safety standard in France). They also frame all their shops in timber rather than steel for superior safety in case of fire.

Ateliers Perrault command most of the real estate in the small village of Saint-Laurent-de-la-Plaine. Besides the sawmill complex and the extensive woodworking shops, there are also blacksmith's shops. In the carpentry yard we found the bell tower of Paris's famous Église Saint-Sulpice undergoing restoration. Perrault will temporarily reerect the tower in their yard, enclosed in a scaffolding with a clear covering for viewing, while the preparation work in Paris is completed (Figs. 6–8).

After the shop tours, M. Perrault took us through the Musée des Métiers, an expansive craft museum his company was instrumental in creating in support of the village. Wooden cranes and massive textile looms provided a backdrop to the many artisans who demonstrated there. We concluded our day with a three-hour private dinner at a restaurant in a restored farmhouse that M. Perrault has been instrumental in developing. He wished us farewell with the advice that we all strive to keep traditions alive while staying abreast of available technology.

Our last tour in Angers was led by archaeologist and author Jean Hunot, who pointed out details of the timber-framed houses in the old part of the city. Although Angers is over 20 centuries old and has evidence of Roman occupation, the oldest remaining wooden house dates from only 1450; many French towns have much older houses. Timber framing died out in favor of stone after the 18th century with changes in architectural tastes, or it was covered over. Houses in Angers are narrow and long, with the narrow eaves wall (and rain gutter) facing the street. Thus only short purlins (but long tie beams) were needed in the roof framing. The highly deco-

Fig. 5. Perrault sawyers prepare large bandsaw blades in immaculate sawmill. Log on carriage will yield a timber about 30 in. square. Figs. 6–8. Below, below left and above left, sophisticated 18th-century timber work from the north tower of the Église Saint-Sulpice in Paris, under repair at Ateliers Perrault near Angers.

rated timber façades often include exposed brick infill (indicating wealth), while the "cheaper" houses have mud infill, often plastered over, and no carvings. While ground-floor stories in many houses are often stone, timber framing in the upper floors made overhangs and openings easier to build.

To date timber frames, M. Hunot explained, archaeologists use a number of techniques and clues including design and joinery. The roof of Église Saint-Martin dates from 1180, the timbers joined by half-lap instead of the later, more advanced mortise and tenon, and lacks wind bracing. Decoration is another clue, with colored timbers indicating Renaissance construction between 1520 and 1530. The biggest and best wood was available in the 1500s. Through dendrochronology, archaeologists can tell that joinery was usually done three to four weeks after felling.

Fig. 9. Twisted steeple over the Église Saint-Denis in Pontigné.

Fig. 10. Masterpiece twisted steeple frame model at Strasbourg.

Leaving Angers, we met timber framer Norman Hardouin at his shop. He led us to three twisted steeples on our way to Saumur. There are seven of these framing oddities in the region (six twist to the right, one to the left), and the most impressive with its new slate roof is the Église Saint-Denis in the village of Pontigné (Fig. 9). Two others are in Mouliherne and Vieil Baugé. A surprising number of people think that these steeples were originally straight and moved on their own, the apparent twist aided by the interruptions of platform framing, as definite breaks in the twist can be seen at ascending plate levels inside. The mystery deepens when we look into the tower framing where rafters meet the plate at each level and see all the shoulders on the rafters open on one side. Timber framers may have a hard time believing steeples could move that much, and numerous examples of masterpieces to be seen at museums and houses suggest that some lucky carpenters were able to turn their fantasies into reality (Fig. 10).

Probably we are seeing the combined effects of purpose and age: a twisted spire model may hold its own in a museum, but under real-world loading a full-scale spire may want to settle and distort. Parishioners' prayers must have been heard, however, as we know of no twisted steeple failing by spiraling into the nave below.

Saumur, where we made a brief overnight visit, is a center of mushroom cultivation and sparkling wines thanks to limestone caves throughout the area. The local chalky tufa stone is very soft, allowing it to be carved into wine cellars, residences, and building blocks for châteaux. (A component of local vineyard soils, it also gives character to the grape varieties Chenin blanc and Cabernet franc.) Some so-called troglodyte cave dwellings cut directly into the tufa date back to the 12th century; these are now improved by stone-fronted houses. Many timber-framed houses in Saumur substitute tufa blocks for brick infill, resulting in a striking contrast (Fig. 11). Though Saumur is the equestrian capital of France and, on our way to a winery housed in a limestone cave, we passed a timber-framed windmill used to process grain, rolling vineyards as far as the eye could see proved that the grape is king (Figs. 12–13). Saumur's *compagnon* house serves as a center for masonry training; the 13th-century house was completely restored by *compagnons* after the city donated it to them 30 years ago (Fig. 14).

We spent two days in Tours, one of the main centers for *compagnonnage* in France, with two houses, one for itinerants only and the other for training in 12 different trades with 430 apprentices and 160 full-time students (Fig. 15). Representatives of the school go out to local high schools regularly to recruit apprentices, for it's estimated that 50 percent of those owning and running carpentry shops in France will retire in the next ten years. After the prospects visit the school with their parents during an open house, they can take an entrance exam given every Wednesday, testing competency in French language and math; a written portion asks how they feel about working in the trades. One-third of those who apply (usually 15 to 18 years old) are invited to attend the school.

Fig. 11. Tufa (soft limestone) infilled timber frame in Saumur.

Figs. 12–13. Gristmill (top), tufa houses and vineyards near Saumur.

Fig. 14. Restored compagnon *house at Saumur.*

Fig. 15. Modern compagnon *house at Tours, one of two.*

Fig. 16. Place Plumereau, Tours, formerly a hat market.

Fig. 17. Flying buttresses at Cathédrale Saint-Gatien, Tours.

Fig. 18. Inside kingposted roof of Saint-Gatien.

The Musée du Compagnonnage, housed in the cloister of a 13th-century abbey, shows masterpieces from all of the trades in all three *compagnon* organizations. Such works include a *château* made of varnished noodles, a tall ship made of spun sugar and pastry (the sails looked particularly yummy) and an Eiffel Tower made of slate. In old Tours, the timber-framed houses were smartly restored after extensive damage in World War II. Place Plumereau, once the town's hat market and now a trendy square of cafés, is lined by a magnificent series of tall half-timbered houses (Fig. 16).

Tours' Cathédrale Saint-Gatien was built 1239–1484. Led by a *compagnon* roofer who had the necessary keys, we took a harrowing tour of its upper reaches. With no lights except our headlamps and no railings on the narrow walkways spanning the roof trusses, we explored the entire roof fearing one of us might go plummeting like a fallen angel through the vaulted masonry ceilings into the crowd attending a confirmation ceremony below (Figs. 17–18).

Our last stop and perhaps the most picturesque town on this tour, Blois shows a harmonious combination of white walls, slate roofs and red brick chimneys. Louis XII moved the court of France here in 1498 and the town remained the center of French political and social life throughout much of the 16th century. Reigning above it all is the Château de Blois, which includes the largest Gothic hall in France. The Salle des États Généraux, used for royal receptions, is a 13th-century room from the original fortress (see back cover). The François I staircase with its ornate carvings is a Renaissance tour de force enclosed in an octagonal well (Fig. 19). From its open balconies the royal family could watch events in the courtyard. Catherine de Medici's room has 237 carved panels, four with secret cupboards. Many of these chambers have intricate ceilings and carved gilt paneling. The close spacing of joists, often the same as the joist width, is indicative of the opulence of the royal French style at the time (Fig. 20). As for the common style, the old quarter contains some marvelous 16th-century timber frames, including a galleried house atop rue Pierre de Blois (Fig. 21).

Chambord, the largest of the Loire *châteaux*, made a fitting final attraction for the 2007 TFG Tour de France. With its forest of chimneys and turrets, it is one of the most extraordinary structures in Europe (Fig. 22). Begun in 1519 as an unfurnished hunting lodge for François I, to a design possibly by Domenico de Corbona or Leonardo da Vinci (the king's good friend), by the time of the death of François in 1547 the keep, with its towers and terraces, had been completed by two master masons and 1800 laborers. Louis XIV later furnished the palace and added a 300-horse stable. The façade is 420 ft. long; the roof boasts 365 chimneys and looks like an overcrowded chessboard. The lantern tower (105 ft. high) is supported by flying buttresses. Two flights of stairs spiral around each other in the innovative double staircase (possibly designed by Leonardo or Pierre Nepveu). People can ascend and descend simultaneously without meeting each other. The grounds of Chambord, originally a 13,000-acre game park for the king, were once surrounded by a wall 20 miles long. Neglected by the second half of the 18th century and stripped during the French Revolution in 1792, the château was purchased by the state in 1930 and restoration began after World War II. Our tour guide, *compagnon* Bruno Sutter, continued his excellent job of organization and got us into the roofs, where the heavily timbered vaults are reminiscent of upside-down boat hulls (Fig. 23). Indeed, shipwrights were hired to do the framing. Rafters, braces and collars, each numbered in the traditional French manner, are so dense in some vaults that they nearly form a continuous wooden ceiling.

A few folks stayed on after the tour to help our 2003 tour guide, *compagnon* Boris Noël, work on his new timber-framed house. *Merci,* Bruno and Boris, for setting the bar high for future timber-framing tours of France. There is so much more to see.

—Will Beemer

Fig. 19. Château de Blois, with its carved François I octagonal staircase opening on the courtyard.
Fig. 20. Above right, the King's bedchamber, with extravagant joist spacing and full polychrome decoration.
Fig. 21. At right, fine 16th-century timber frame in Blois.
Fig. 22. Below, Château de Chambord, largest and most elaborate of the Loire valley châteaux.
Fig. 23. Below right, close-spaced oak roof framing inside one of the many towers at Chambord.

Basic Design Issues in Timber Frame Engineering

WHY do we need structural engineering for design of timber frame buildings? Haven't they stood the test of time? Well, yes, some have, and if every timber frame building we were planning to construct were based on an existing structure whose performance was proven, and whose location and loads matched those of the original building, certainly there would be little need for structural engineering in our designs. However, the scale, complexity and site conditions of many contemporary timber frame projects make traditional frames unreliable for predicting the performance of these new ambitious structures. More and more designs depart from strictly traditional forms to find new ways of defining space (Fig. 1).

The challenge then is to come up with the right timbers, the right joinery and the right structural system to get satisfactory performance from a design that has never been built before. Structural engineering gives us a consistent method for achieving that goal while not relying on the mysterious wisdom sometimes ascribed to traditional heavy timber construction.

Engineering a timber-framed structure is more than just sizing individual joists, beams and rafters. We need an understanding of how the whole timber frame and cladding assembly function as an integrated system to support loads. In this article, the first of two, we will review the structural engineer's methodology for building design and look at some of the basic strategies we use for accommodating loads in timber frame buildings. We will also touch on integrating the design process into construction. We will not get into any higher mathematics here—no equations or number crunching. The emphasis will be on basic design issues.

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Fig. 1. The Herb Nehring Blacksmith Shop at Tillers International, Kalamazoo, Michigan, incorporated large diagonal braces, tension joinery, diagonally sheathed shearwalls and a flexible roof diaphragm to achieve adequate racking resistance for code wind loads. Design by Dick Roosenberg, Tom Nehil, Amy Warren.

The Engineering Method. What then is the structural engineering approach to design? Once the preliminary size and shape of the building have been developed, we then proceed through the following steps:

1. Identify and quantify the loads on the structure.
2. Select the member sizes and materials for the structure.
3. Examine how the building behaves under load.
4. Refine materials and member sizes to achieve satisfactory and effective performance.

So, rather than taking our best guess on an initial sketch and then proceeding with construction, keeping our fingers crossed, we put our initial assumptions through some testing to see if they are valid and make adjustments as necessary while it's still easy—that is, before the timbers have been ordered. Let's look at each of these points briefly and see how the method works.

1. Identify and Quantify the Loads. We have two basic categories: loads that weigh down on our building as a result of gravity, such as the weight of the structure plus occupants, furnishings, fixtures, and snow and ice on the roof; and the loads that push sideways or up and down on our building, that is, wind loads or seismic loads. We have to keep in mind that wind passing over and around a structure can also cause suction on the building and create uplift on roof framing.

For most conventional uses, loads a building must be designed to support are defined by the building codes. The International Building Code (IBC) is now pretty much our national model code in the United States; Canadian building codes of course apply north of the border. The IBC prescribes that the typical living areas of a residence need to support a 40 lbs. per sq. ft. (psf) superimposed live load; sleeping areas can be designed for 30 psf, attic storage areas for 20 psf. The typical office floor loading requirement is 50 psf. Commercial spaces used for retail or restaurant use and lobby areas must be designed for 100 psf—which is like covering the entire floor wall to wall with sacks of cement stood on end, a pretty high demand! For many other applications, such as stadiums, industrial buildings, storage buildings, and the like, the code establishes the required load capacity. Special applications such as agricultural storage (hay) or workshop loads such as lumber or timber storage may require you to make your own rational assessment of the maximum likely loads. By "maximum" here we mean the maximum average loading over the floor area. Stickered hardwood stacked 3 ft. high covering half the floor would represent an average load of about 50 psf (depending how green the wood is and how thick your stickers are). Now, how often might you be stacking that wood 4 ft. high?

The building code also defines snow loads for various geographic areas of the country. We will discuss roof loads in more detail later.

Finally, the code prescribes the lateral loads that our buildings are required to resist. Wind pressures vary considerably with location and exposure—whether, for example, we are on the top of a treeless bluff facing the Atlantic Ocean in a hurricane-prone region or tucked safely in amongst trees and hills in the relatively placid northern Midwest. Seismic loads similarly vary from location to location depending on the likelihood of ground movement. Fortunately for most locations, seismic loads for our relatively lightweight wood structures do not control design. Rather, wind loads are our major challenge for lateral bracing.

The building code, by the way, not only prescribes the loads we must be able to resist but also sets limits on how far we can stress the materials we will be using to build with. A building or structural element can be expected to perform safely and satisfactorily only if under full load it is not stressed right to the edge of breaking. A safety margin is prescribed so that under full loading some reserve capacity remains. This helps prevent not only catastrophic collapse in the event we end up getting that hundred-year snowstorm but also plays a part in controlling the amount of sag and sway we will see in our construction. The code also sets limits on permissible deflections in floors and roofs and on the sway of buildings under lateral loads.

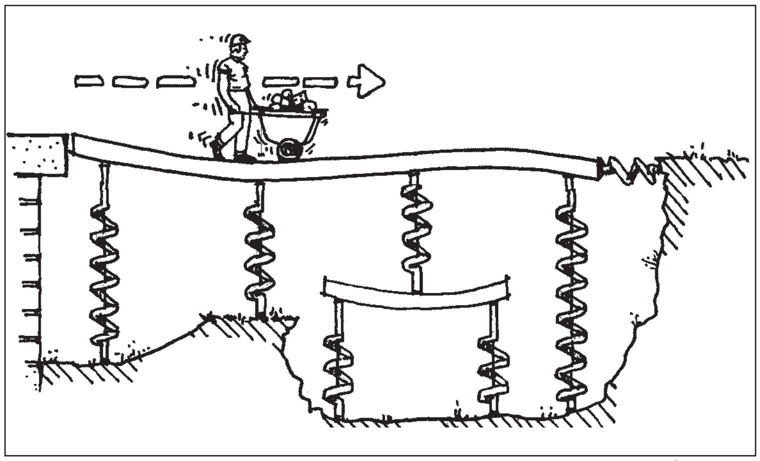
The building code is often maligned by owners, builders and designers alike, and we have done our share of complaining, but we have to appreciate its role in standardizing the rules of design and construction. By eliminating guesswork or personal opinion regarding standards of safety and performance—that is, minimum loads, maximum stresses and maximum deflections—the code helps to ensure safety and dependable performance in construction. This is important, not only if you are building for yourself, but especially if you are the consumer purchasing a home or commercial building from others. We are sure many of you have seen the unhappy results when code requirements are not considered and a combination of bad guesswork, stubborn independence and sometimes downright cheapness produces an unsatisfactory or even unsafe structure.

Following the building code, then, is the first step on the road to taking the guesswork out of the design process. It will generally result in a safe, conservative design, often seeming over-conservative. It helps to remember that the code prescribes for safe performance under fairly severe loading conditions. Following the building code also ensures a legal design, which those of us who are registered architects or engineers are obligated to provide and which you are expected to provide to obtain a building permit.

2. Select Member Sizes and Materials. The initial selections of member size and species for defining a model of a building can be based on some simple rule-of-thumb formulas, or it may be based on appearance considerations such as how massive (or not) you would like the timbers to appear in the finished frame. The selections may be based on what's readily available and affordable. For us in Michigan, white oak and red oak are readily available but, when I proposed using these non-native species to West Coast clients, they were understandably hesitant. We need to make a preliminary guess at not only species but also grade of lumber, since grade affects the allowable stresses we can use in design and also affects the code-prescribed modulus of elasticity (elastic stiffness of the material) we use in modeling the structure's behavior. Unless the timbers are to be graded, it's best to assume the most economical grade reasonable for construction purposes, No. 2, unless you have appearance requirements that will automatically dictate a higher grade. Selecting higher grades may imply needing to have the timbers graded, however, to ensure they meet No. 1 or Select Structural grading rules. Not all mills are able to provide certified grading, so the expense of hiring a grader could be yours.

3. Examine How the Building Behaves Under Load. Once we have established the loads for the building and its basic size and shape, and we have preliminary member sizes and species in place, we are ready to test our ideas. We apply the code loads to a model of the structure to make predictions how the building will behave. In other words, we undertake a structural analysis.

What exactly do we mean by "structural analysis"? Our models are usually mathematical rather than physical. We idealize the structure as essentially a big pile of springs (Fig. 2).



Nelson Nave

Fig. 2. Structural analysis can be likened to applying loads to a pile of springs—an idealized mathematical model of the structure—and then solving a series of equations to determine the load in each spring.

This type of mathematical analysis is usually referred to as stiffness analysis, since the final calculated loads depend on the relative stiffness of the various components of the model. The stiffness of each member is formulated as a series of equations, a function of the member's size, species, and grade of timber, and can be changed by changing any one of these three attributes. It's also important in our modeling to consider the stiffness of the connections (the joinery) that relate these members to one another. The structural analysis then amounts to an accounting problem to keep track of which members are pushing or pulling on which other members, how hard, and how much they have moved as a result of being pushed or pulled. The answers we get from these analyses are the forces that the individual members and the joinery need to resist. The analysis will also predict for us how much the members will sag or sway.

The complexity of the analysis depends upon the complexity of the members and the assembly. Simple elements or frames can be analyzed quickly by hand whereas complex structures may require a computer-aided analysis to crank through all the equations.

4. Refine Materials and Member Sizes. Design is an iterative process and it's certainly easier to make changes to a mathematical model than to a nearly completed frame or building. After the first analysis, we examine the loads and stresses on the members and joinery that have been predicted by the analysis, make changes as necessary to fix those members that appear to be overstressed, and rerun the analysis to examine how the loads redistribute in the model as a result of the changes. This methodology is common to design of structures regardless of the material used for framing.

Now that we've looked at the basic engineering approach to building design, let's next examine some basic strategies for handling loads in timber frame structures.

Strategies for Supporting Floor Loads. Typically, floor load is the beginning point of structural design, and the solution we arrive at will affect our overall building design. We can think of the organization and function of wood framing as being a steady accumulation and concentration of gravity loads, somewhat like rain running down through the upturned branches of an imaginary hollow tree, gradually accumulating from twigs to branches, branches to main limbs and eventually down the trunk to the roots. Similarly our floorboards deliver the floor loads to the joists, then the joists to the beams, then the beams to the posts, and finally the posts to the foundations that rest upon the earth. We can even draw an analogy between the foundations of our building and the roots of a real tree, which not only distribute the weight of the tree to the soil but also help prevent it from overturning. Our foundations must perform both these functions as well.

Basics of Floor Framing. Selection of the floorboards or roof deck usually does not take much effort. We know from experience that nominal 1-in. sheathing boards are satisfactory to span up to 2 ft. and nominal 2-in. tongue-and-groove material can handle spans between joists up to 4 ft. The numbers bear us out on this. The bending stresses in decking materials are low under uniform loads. It's the concentrated loads that put the highest demand on any individual boards. Tongue-and-groove joints help to spread those loads out (provided the tongues actually come into contact with the grooves) so that several boards can participate in resisting a concentrated load such as the leg of a pool table or grand piano.

Our joists are typically simple-span members; for load-bearing purposes, their ends simply rest on a beam at each end. There is always a temptation to space joists farther apart so that we need fewer of them, and to have them span farther, thereby minimizing the number of bents we have to build and reducing the number of posts in our floor plan. Still, we have to keep the bay sizes and spans reasonable to successfully use normally available timber sizes.

As the spacing between joists increases, the load increases proportionately. If we need to span 12 ft. between beams in a residential situation, we can use 2x8s spaced 16 in. on center or 6x8s spaced 48 in. on center. It's the same amount of joist material either way, just distributed differently. On the other hand, as the joist span increases, the bending force on the joists increases in proportion to the square of the span length. In other words, it's no longer a linear relationship and so we are going to need much stronger and stiffer joists if we want to increase the distance between supporting beams.

These same ideas apply to the design of beams. As the spacing between bents increases, the load on the beams carrying the floor joists increases proportionately. So, if an 8x10 beam is satisfactory in bents spaced 12 ft. on center, then we may need to go to a 9x10 or 10x10 beam to space the bents 14 ft. on center. But if we want to make our bents wider and thereby require the beams to span farther from post to post, the bending force in the beams will increase as the square of the span. Beams spanning 16 ft. have almost twice as much bending load as do beams spanning 12 ft.

Fortunately, the geometric section properties that affect the strength and stiffness of our joists and beams are not just proportional to the volume of wood used. The strength of a rectangular timber is directly proportional to its width but proportional to the square of its depth—and the stiffness is proportional to the cube of the depth. In other words, deeper is better than wider. In our joist example above, rather than using 6x8s at 48 in. on center, we could also use 4x10s at that spacing. Less lumber can produce the same strength, and actually better stiffness. By stiffness, here we mean the ability to resist sagging, and since limiting deflections in our floor framing usually controls our design of long-span floor joists (remember, the code sets not only minimum requirements on strength but also maximum limits on sagging), we are especially interested in the increased stiffness that comes with increased depth of the joist or beam. As another example, an 8x12 timber laid on the flat is only 50 percent stronger than an 8x8, but the same 8x12 turned vertically is more than twice as strong as the 8x8 and more than three times stiffer.

Sometimes we need to put openings through our floor framing that will interrupt the span of our joists. This commonly happens at stairways. We must remember that the headers and joists that surround our openings need to be treated like beams: they are collectors of increasing amounts of load, a fact that was often not addressed by old-time carpenters. It's all too common to see the floor around stair openings sagging, sometimes alarmingly so. We have to quantify the amount of load on the header and size it accordingly to handle that load and to span between joists on either end. Similarly, we need to account for the increased shear and bending loads in the joists on either side of an opening. This does not have to be guesswork.

The cutting of notches at the ends of joists and housings in the sides of beams to receive the joists can have significant effects on the strength and stiffness of those members. We will not go into the details here, but clearly if you cut away significant amounts of wood from critical, highly stressed areas of framing members, you are not going to end up with the same strength you started with. Specific limits on notching are imposed by the *National Design Specification for Wood Construction*. Working with, or around, those limitations is a significant part of trying to blend timber framing and all-wood joinery with engineered design and modern code requirements.

Longer Spans for Floor Framing. What solutions are there for achieving longer spans in timber frame construction? Modern solutions include the use of manufactured lumber such as LVL (laminated veneer lumber, those beams and joists that look like long sticks of plywood) or PSL (parallel strand lumber, referred to by a friend of ours not so affectionately as maggot wood) and their related variations. None of these is acceptable for exposed framing.

Glued-laminated beams offer a more visually acceptable solution to achieving greater strength and stiffness in timber construction. Very high quality material can be used at the top and bottom laminae of a beam, where stresses are highest in bending members, and cheaper, lower quality material in the middle of the beam, where stresses are lower. We have used glulam beams in timber frame structures to achieve longer spans and greater load-carrying capacity than could be achieved with solid timbers of greater depth. Not everyone likes the appearance of the glue lines in the timber. With suitable rustication of the exposed surfaces and a dark stain, however, it can be difficult to see the glue lines if the laminae are visually consistent. (You will need to order the appropriate appearance grade glulam.) If the design calls for curved timber, taking a straight timber, sawing it into flexible strips, bending the strips and gluing them back together to form large curved members that look like solid timber achieves results that could not be accomplished by cutting the curve from a single wide stick. (See TF 80, pp. 16–17.)

One traditional approach to achieving longer span capabilities with "normal" sized timbers is the use of so-called keyed beams (Fig. 3).

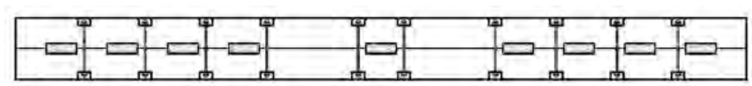


Fig. 3. Schematic drawing of a keyed beam.

If we take two timbers and stack them one on top of the other, clamp them together with bolts and insert mechanical "slip resisters" to prevent the upper and lower members from slipping past one another when loaded in bending, we can make the two timbers behave almost as if we had one solid piece of timber of the combined cross-section. There is some tendency for slip to occur along the mating surfaces and so the keyed beam is not quite as stiff as a solid piece of timber would be. There is also a great deal of work in cutting and assembling keyed beams. They have been used for hundreds of years and provide us with a means of fabricating timber much bigger than could be harvested from readily available trees. So, for example, two 8x10 beams stacked and properly keyed can be nearly as effective as an 8x20 timber, that is, about twice as strong and three times as stiff as the unkeyed 8x10s simply stacked.

Another traditional way to achieve long spans in floor framing with normal timber sizes is by trussing. Timber trusses can readily be built to span 30 to 60 ft., and longer spans are possible. Trusses used for floor framing will typically have both the top and bottom members parallel and horizontal, so the truss outline becomes a rectangle rather than a triangle such as is used for roof framing. They often incorporate some metal, for example steel rods for tension members, or straps and bolts used for reinforcement at highly stressed joinery.

In overall structural behavior, most trusses act like deep beams simply spanning from support to support. Their depth, however, commonly in the range of one-sixth to one-tenth of the span length, is one of their disadvantages. If you plan on spanning 30 ft. across a large room, you will probably need a truss about 5 ft. deep. Design and cutting of the oft-required serious tension joinery can be complicated. Trusses are expensive and labor intensive to design and build, but their appearance can be a significant aesthetic plus to a timber frame building.

If the depth of trusses at intermediate floors within a building is impractical—think of adding 5 ft. to the rise of a set of stairs from first to second floors—then we can always position the trusses up at the roof and then hang the intermediate floors from the trusses by means of hanger rods (Fig. 4).

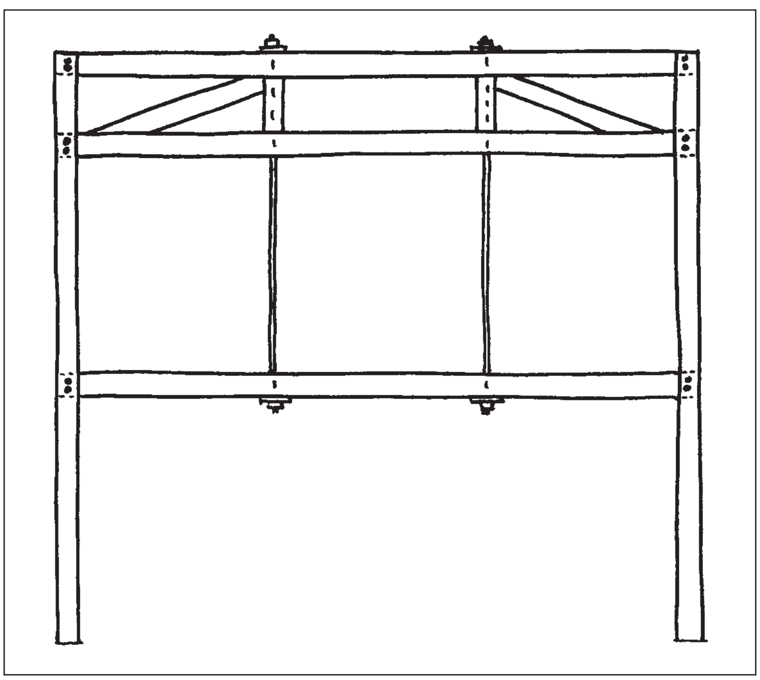


Fig. 4. Hanging the second floor from trusses in the attic or roof can leave the first floor free of posts.

This solution was commonly used during the 1800s in industrial buildings and especially in theaters, where the balconies were hung from large timber trusses in the roof framing. We can also install trusses a full story tall in the interior partition walls of upper- level floors, frame the floor joists to the trusses and leave the floor below clear of posts. This strategy likewise dates back at least to the 1800s.

Interior Supports for Floor Framing. As the width of our timber frame buildings increases, clearspan framing is often impractical. We are more likely to use intermediate supports to reduce the spans of our floor framing and thus avoid the need for excessively large timbers or the more complex solutions discussed above. If the second-floor posts in the design line up over the first-floor posts, then the posts can be continuous from top to bottom, which lets us collect the loads from the beams and direct them immediately to the foundation through the posts. Often, however, differences in layout and function between first and second floors require that interior second-floor posts be offset from those on the first floor. In these cases, we rely on the second-floor beams to collect the loads from the second-floor posts and transmit them to the first-floor posts. Since offset posts can impose large bending and shear loads in the second-floor beams, these beams need to be specifically designed for the amount of load and the spans involved if we are going to avoid excessive sagging of the second-floor beams (Fig. 5).

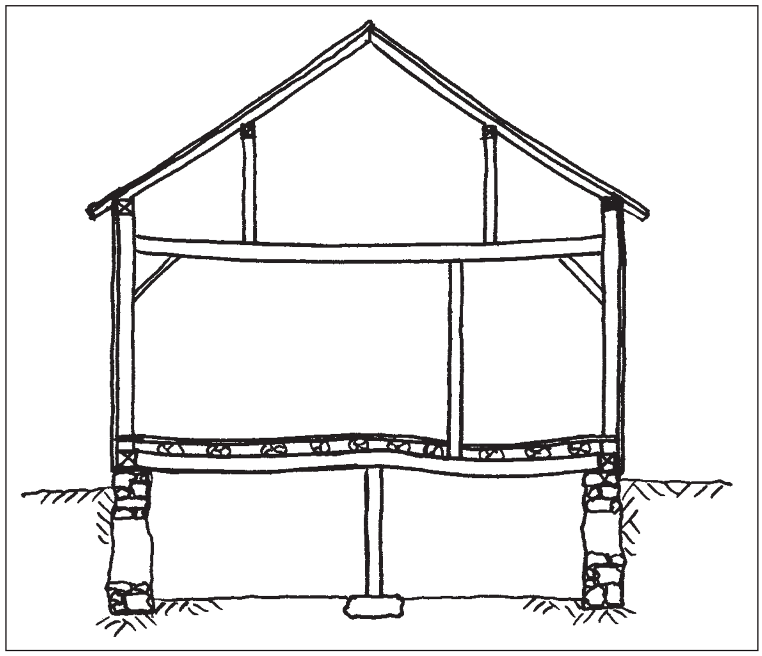


Fig. 5. Cross-section of 100-year-old oak timber frame barn in southern Michigan. Offset posts can cause sagging of supporting beams unless post loads and beam bending stresses are adequately accounted for.

Cantilevering exterior walls beyond first-floor walls as in garrison-style construction is a special example of offset posts. Here again, second-floor beams need to be specifically sized for loads imposed on their outside ends to avoid a sag outside the outer walls and a hump in the interior main span of the cantilevered beam. But cantilevers can thus be used to advantage to reduce maximum bending stress in the main span, with the cantilevered portion acting as a lever relieving main span sag.

Bolsters (capitals) can be used to increase the effective width of posts and thereby decrease the effective span of beams. The bolsters serve then to stiffen the floors and increase the shear capacity of the floor framing in the vicinity of the posts. Since they interrupt the posts at the floor, their use is restricted to buildings with level-by-level construction, such as 19th-century industrial buildings. Bolsters can be useful for support of the first-floor beams in a timber-frame structure, installed over the posts in the lower level.

Knee braces provide us with another means of effectively increasing the width of our support and reducing beam spans.

Fig. 6. Knee braces can effectively widen a support and stiffen beams, helping to transfer loads to posts.

Knee braces can reach out farther than bolsters and provide stiffer support for beams. The longer they are, the better job they can do. They also offer some design flexibility at beam-to-post joints because posts can run through vertically or beams can run through horizontally (Fig. 6).

When a knee brace is loaded by a beam, it transmits that load to the post in a direction parallel to the brace axis. The brace not only pushes downward on the post but also sideways (and with equal force in a 45-degree brace). At an interior post where there may be knee braces on both sides, there is no net sideways thrust on the post when loads are balanced on the spans above. At an exterior post, however, there is no balancing load coming in from the outside, and so the post is subjected to a combination of axial loading from the weight of framing above and bending loads from the sideways thrust of the brace. Knee braces act like wood arches, and there is always outward thrust in an arch. The knee braces are trying to push the posts outward, and that means we need to have both adequate bending strength in our posts and restraint at the top and bottom of the posts to keep them from being forced outward. Thus we need to check the tension capacity of the beam-to-post joinery above the knee brace and the shear resistance at the base of the posts (Fig. 7).

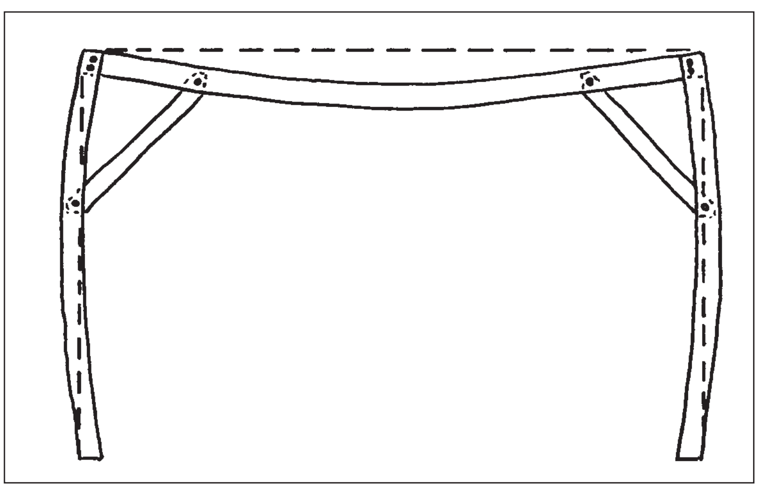


Fig. 7. Behavior of simple knee-braced frame under gravity load.

One last point: how do we make a "nonstructural" knee brace? That is, if we intend to install knee braces in a frame just for appearances, is it possible to prevent them from putting sideways loads on posts when beams above deflect under loading? We come across a lot of nonstructural knee braces in old barns where the braces are rattling around in their housings or have even fallen to the floor below. Shrinkage of the post and beam can introduce some play in a knee brace that originally fit perfectly; the beam has to sag somewhat to close the gap. That is typically an unintentional effect. If we really want knee braces to be nonstructural, we need to provide gaps at the bearing surfaces in housings and use small-diameter flexible pegs. Ignoring the possible inadvertent loading of a nonstructural knee brace on a post may not be of any consequence at short stubby posts and beams, but could produce some undesired effects in tall, more flexible frames. Remember that exterior posts in a building may already have a significant bending load on them from wind suction.

Strategies for Handling Roof Loads. Roof loads consist of the weight of the roof framing and roofing materials plus any superimposed live loads in the form of snow, ice, or maintenance personnel and equipment. Snow loads are highly variable in many regions of the country. In Michigan and upstate New York, for example, lake-effect conditions cause increased snow-load requirements for sites close to the Great Lakes. In mountainous areas, snow load requirements vary with elevation and exposure. For design purposes, it's mandatory that you contact the building official where a new project is to be constructed to obtain the local snow-load ordinance.

It's not that roof loads are different from floor loads; both are gravity loads pulling down on the frame. It's just that we usually choose to frame roofs with some significant slope. If (heaven forbid) all roofs were flat, then our strategies for supporting roof loads would be identical to those for floor loads, but sloping roofs do a much better job of shedding rainwater. If the roof is steep enough and slippery enough, it can shed snow loads as well. Pairs of opposed rafters, however, can produce a significant additional effect: they may generate outward thrust on the walls.

Shed Rafters (Fig. 8). Just because a rafter slopes does not automatically imply that it will generate thrust. A sloping rafter supported at both ends by walls or beams, as in a shed roof, generates no thrust at all. It acts the same as a perfectly flat floor joist. Why is that? Well, both ends are simply supported to prevent the rafter from moving downward, and there are no lateral loads on this rafter, just the weight of snow and gravity drawing it straight down. So, the reaction at each end of the rafter is straight up. It's when we put rafter pairs together opposing one another that interesting things can happen.

Ridge-supported Rafters (Fig. 9). It's possible to have rafter pairs that behave like shed rafters. That's what we get when we incorporate a structural ridge beam into the framing. The ridge beam (posted or otherwise supported) prevents the upper ends of rafters from moving downward under the weight of roof loads. The lower ends of the rafters are similarly supported on either beams or walls and so cannot move downward. The net effect includes no outward thrust. Structural ridge beams do pose some challenges for us. They carry half the rafter span loads on either side and so can support significant areas of roof. They span between distant supports such as trusses, interior king posts or gable end walls, and can very quickly become large heavy timbers or even trusses if the distance between supports becomes large. Structural ridges must be designed just like floor beams to resist bending and shear forces.

Purlin-supported Rafters (Fig. 10). Instead of making the ridge beam do all the work, we can split it up into a pair of supports located at some fraction of the length along the rafter span. We

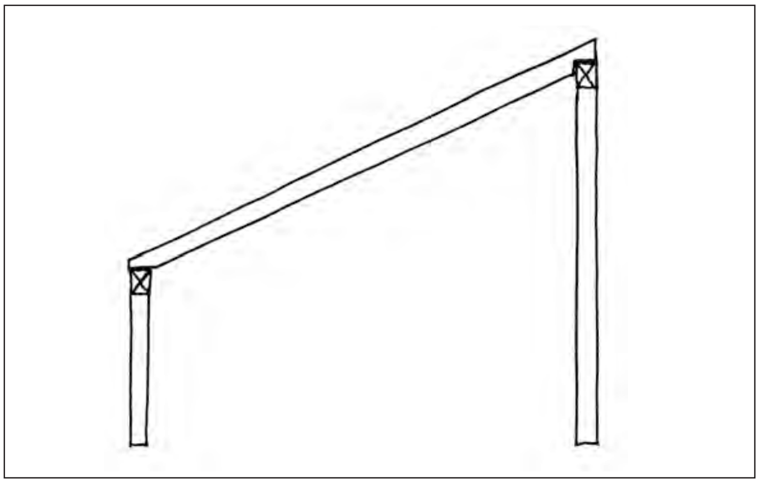


Fig. 8. Shed rafters, supported at each end, produce no thrust.

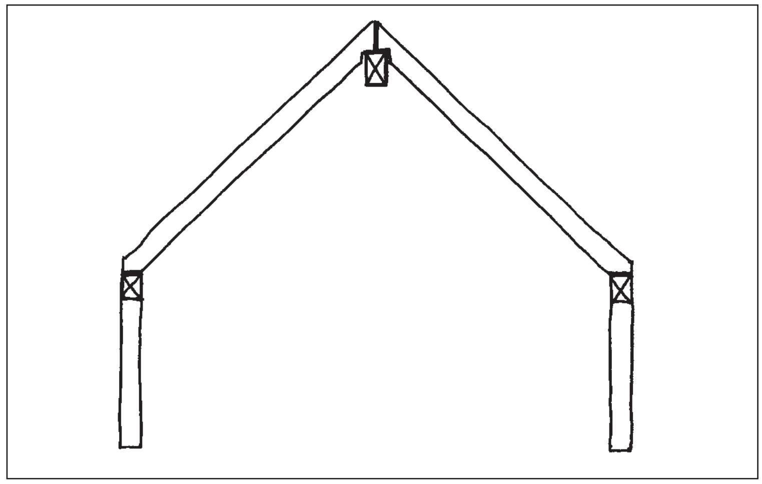


Fig. 9. Ridge-supported rafters act like individual shed rafters.

now have two beams (again, themselves supported) helping to carry the load of the roof instead of just one ridge beam, and so we may be able to span farther or use lighter beams. There is no hard rule where the purlin beams should be located along the rafter span. In practice, because of functional requirements inside the building, we find that purlins lie most often in the range of one-half to two-thirds of the distance from plate to ridge. Provided the purlins are more than halfway up the length of the rafters and the rafters are uninterrupted from plate to ridge, the purlins do a fairly good job of supporting the upper ends of the rafters and reducing thrust from the rafter pairs. In other words, the rafters in a purlin-supported roof can still behave almost like ridge-supported rafter pairs. The farther the purlins are located from the ridge and the lighter and more flexible the rafters, however, the more thrust will be generated by the upper span of the rafters under load.

Let's move on to look at what happens when we remove the ridge beam and the purlin beams completely from an opposing rafter pair. There is nothing to support the upper end of the rafters and, as the ridge line moves downward under load, the geometry of the sloping rafters causes their lower ends to move outward, thereby generating horizontal thrust. If we do not want our ridge to come down, and that is usually the goal, we need to restrain the outer ends of the rafters from moving apart. That can be most directly done by some structural element that "pushes back" to prevent the spreading of the rafter feet. The resisting element could take the form of massive masonry walls, simply too heavy or too well buttressed to be tipped over by the thrust imparted by the rafters. The external restraint does not have to be masonry. It can be provided by the intersecting walls of other portions of the building framed perpendicular to the direction of thrust.

Base-tied rafters (Fig. 11). Rather than external restraint, we often use some form of internal restraint. The most efficient approach is to tie the rafter feet together with an internal tension member. The tie can be timber, it can be a steel rod or it can be dimension lumber. Placing the tension tie right at the foot of the rafters, at the level of the plates at the top of the supporting walls, puts the restraint right at the point of application of the thrust and creates a basic truss. The rafters now act somewhat like an arch: they carry axial load from the ridge down to the plate, but they also have to resist bending between the ridge and plate caused by roof dead load and snow load. Collar struts can help brace the rafters and reduce sagging; we'll get to that in the discussion of trusses that follows shortly.

Base-tied rafters are more complicated than shed rafters or ridge-supported rafters, which sustain no axial loads. Properly designed rafters tied at the plate take into account this combination of axial loads and bending loads. On steep pitches, say 12:12

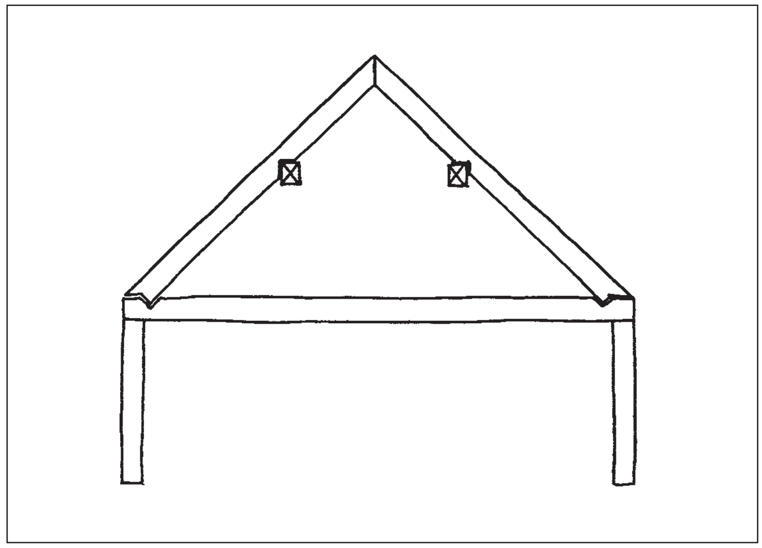


Fig. 10. Purlin-supported rafters produce little thrust at plate.

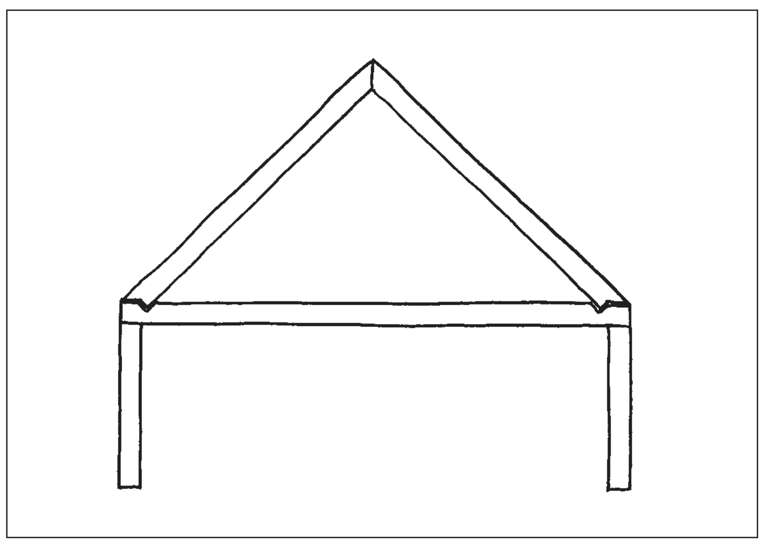


Fig. 11. Base-tied rafters directly solve thrust but sustain axial loads.

or greater, the effect is negligible. As the slope gets low, it can be significant and the rafters may need to be heavier than simple span rafters otherwise would be for the same span and roof loads. For a 6:12 slope, the axial load in the rafter is a little over twice the gravity load reaction at the support, whereas for a 4:12 slope it is over three times the reaction and at a 3:12 slope more than four times the reaction. Put in a summary way, at 12:12 the horizontal reaction is half the gravity load, at 6:12 out-thrust equals vertical load and, at lower pitches, the thrust exceeds the gravity load.

Raised Ties (Fig. 12). It's not uncommon for a designer to want to move that tension tie at the plate up "just a little bit" to gain increased headroom without having to increase the height of the building. Such a move can also allow an interesting vaulted ceiling effect. As we raise the tension tie up along the rafter span, however, some additional challenges begin to develop. This discussion is pertinent not only to simple rafter pairs such as are found in common-rafter roof assemblies, but also to principal rafter pairs or trusses when the bottom chord (tension tie) does not intersect the top chord (rafters) at the supporting beam or wall. The rafter pair still is subjected to bending loads applied between the ridge and outer support under the action of roof loads, but in this case the raised tie adds to the bending loads by pulling inward at its connection to the rafter.

Raised ties are an unsatisfactory way to resist the thrust of rafters because they put such large bending loads into the rafters and also generate large forces to be resisted at the joinery between the tie and the rafters. Furthermore, joinery from tie to rafter weakens the rafter right at its most highly stressed location. The higher the tie is above the plate, the tougher these design challenges become and the heavier the rafters need to be to avoid excessive sag in the roof and outward bulging of the walls.

Dropped Ties (Fig. 13). Instead of raising the tension tie above the level of the plate, 19th-century American framers dropped it below the plate, for example in the high-posted (story-and-a-half) capes of New England and many barns throughout the country. The dropped tie greatly simplified the joinery required by the English tying joint, which it largely displaced, by bringing the tie beam in below the point where post, plate and principal rafter would meet.

There is a trade-off in this system, though. Similar to the raised tie, the dropped tie removes the restraining element from the point of application of the thrust, the feet of the rafters. The result is that we induce bending in the posts rather than in the rafters as was the case with the raised tie. As the distance from plate to tie beam level increases, so do the tension in the tie beam and the bending loads in the posts. Here again, joinery from tie to post weakens the post at a highly stressed location. In barn framing in the Midwest, a common rule was never to drop the tie more than 2 ft. from the top of the plate. Even this guideline was not enough to prevent many tension joinery failures at the joint between tie beam and post. The problem of tension loads at a dropped tie beam-to-post joint is further exacerbated by the presence of knee braces and wind loads.

So, placing the tension tie at the level of the plate is the most efficient way of resisting rafter thrust. That does not mean the other options are not available to use, just that we need to design for the extra bending and joinery forces involved.

Trusses (Figs. 14–18). Similar to the challenges we face with increasing spans in our floor framing, we face limits on what we can do with the simple triangular truss represented by the rafter pair with the tension tie at the plate. As the span between supporting walls or beams gets large, the bending loads and thus the sag in the rafters and in the tension tie increases—particularly when the tie supports a ceiling or attic storage space. This forces us to go to ever larger timber sizes until that simply is no longer a practical or economical solution. But just as we solved this problem in our floor framing by introducing intermediate supports along the length of the span, we can do it in our roof framing as well, not by putting more posts in the buildings to support the roof framing (although that works too), but rather by installing internal supports within the roof framing assembly.

If we place a kingpost in the simple triangular truss (Fig. 14) we can greatly reduce the sag in the tension tie. The kingpost acts as a hanger and essentially pulls the gravity loads up from the tie beam

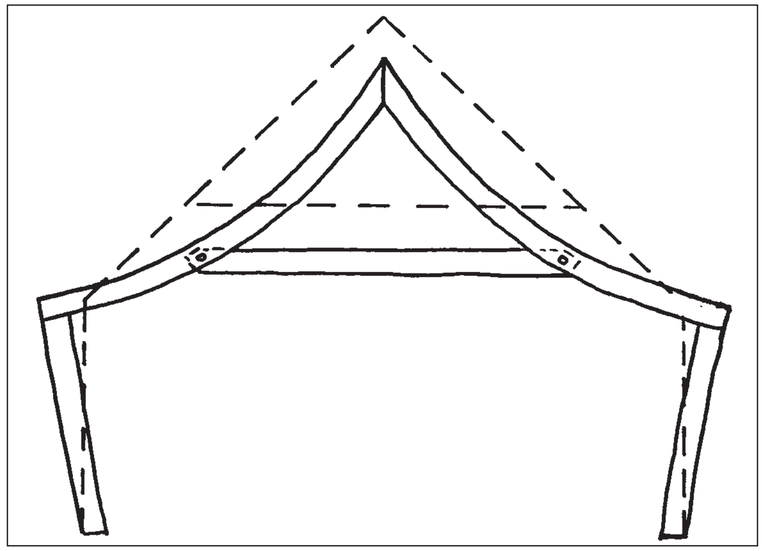


Fig. 12. Raised tie introduces additional bending loads in the rafters and increases tension in the tie.

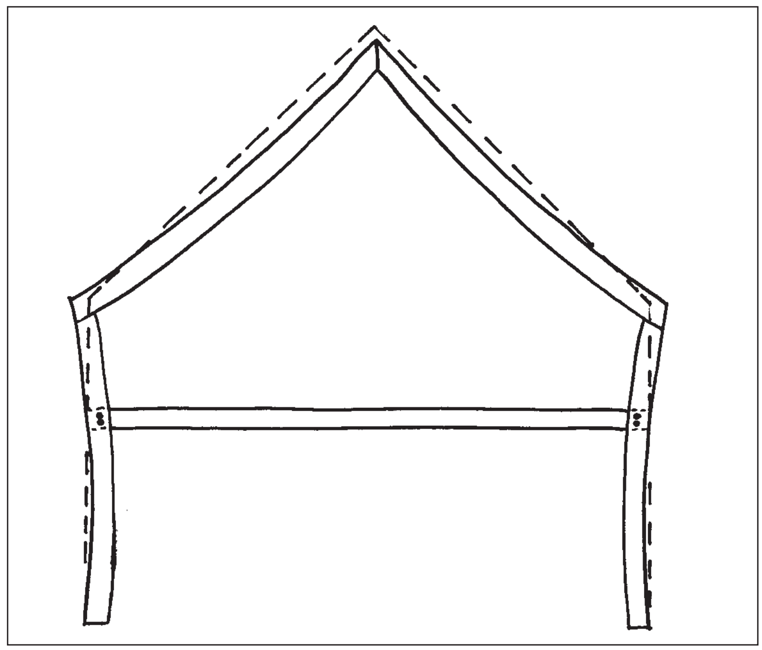


Fig. 13. Dropped tie introduces bending in the posts and increases tension in the tie.

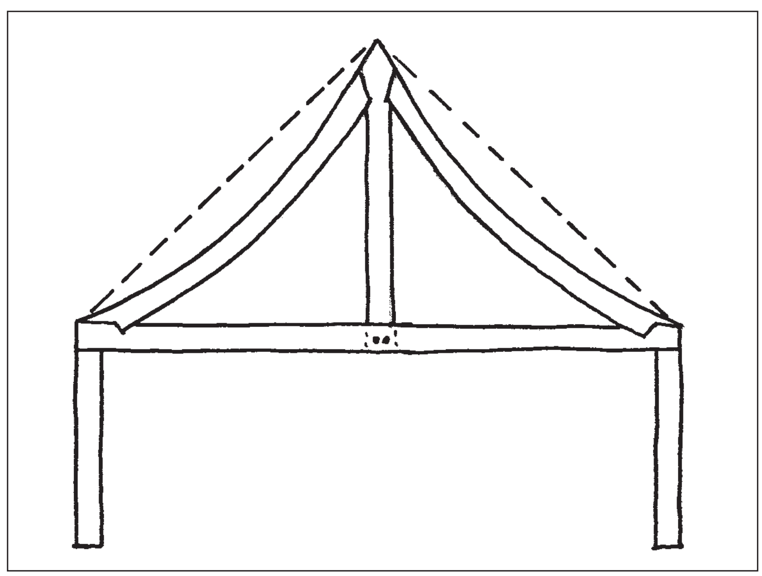


Fig. 14. Kingpost reduces sag (and thus tension) in tie beam of a base-tied truss. Rafter sag can be solved by struts from kingpost to rafters.

into the rafters, thereby increasing the thrust on the rafters and increasing the tension load at the joint between tension tie beam and rafters. That helps the tie beam, but what about the rafters? We can insert an intermediate support there as well in the form of a horizontal collar strut that prevents the rafters from sagging inward at midspan (Fig. 15).

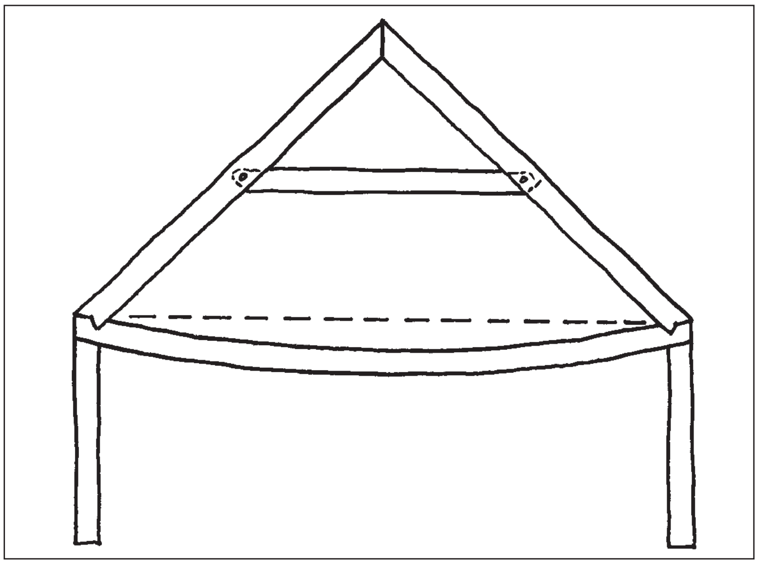


Fig. 15. Introduction of a compression collar between the rafters stiffens them against sag.

This solution also increases tension in the joinery between tie beam and rafter but greatly stiffens the rafters and allows us to reduce their heft. If we put these two ideas together, we have an early form of roof truss found in European churches of the fourth and fifth centuries (Fig. 16). A modern configuration is seen in Fig. 17.

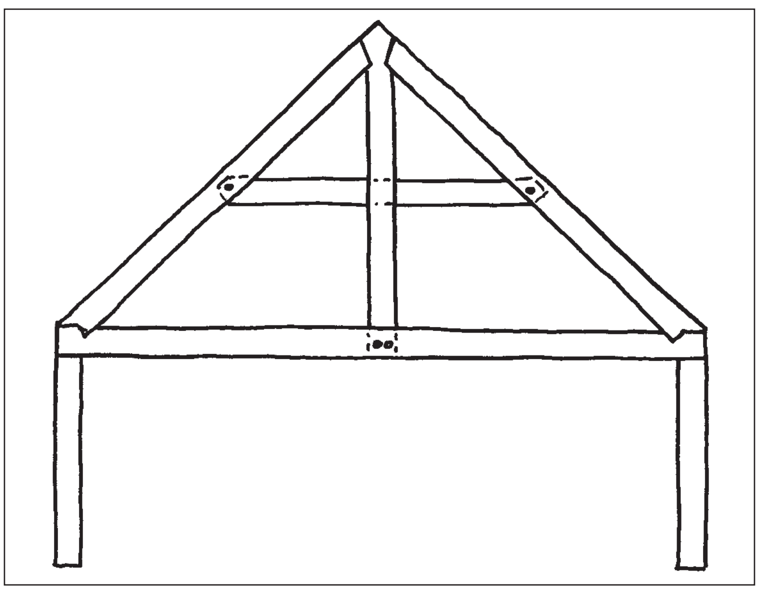


Fig. 16. Together the kingpost and the collar struts form a 4th-century Roman truss.

Hammer Beams. No discussion of roof framing in timber buildings would be complete without at least a brief look at hammer-beam roofs. People often mistakenly look at hammer-beam roof framing as a means of pulling yourself up by your bootstraps—that is, somehow achieving large clear spans without a tension tie and yet avoiding the problem of thrust from the rafters. It just ain't so. Rather, think of the entire hammer-beam assembly as forming simply a large rafter pair with no support at the ridge (Fig. 18).

Fig. 17. Typical modern kingpost truss with diagonal web members to support rafters. White oak 6x12 rafters and tie beams span 30 ft.

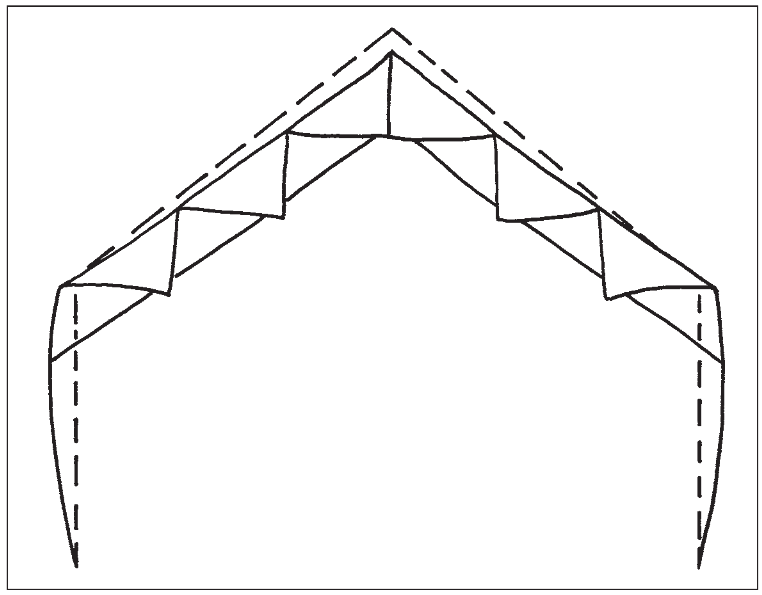


Fig. 18. Hammer-beam trussses can be understood as pairs of trussed rafters thrusting outward against their restraints.

The actual behavior is somewhat more complicated than that, and these structures are properly called hammer-beam trusses. (See TF 48.) Still, roof thrust comes down through the lowest diagonal framing member to the supporting wall or timber post, and that thrust is going to have to be resisted or the ridge will come down and the supporting walls or posts will move outward. If we do not have massive masonry walls with external buttresses or walls from other parts of the building functioning as external restraints, then we will need internal tension ties or hefty posts and some serious tension and compression joinery at the intersection of the post with the lowest diagonal brace and with the rafter. We also will likely need restraint against outward movement at the base of the posts. There is no cookbook formula for these forces and the associated joinery. These depend on the spans, the pitch and spacing of the trusses and the height of the walls, and they must be specifically engineered if satisfactory performance is to be assured.

—Tom Nehil and Amy Warren

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HISTORIC AMERICAN TIMBER-FRAMED STEEPLES

III. Masts and Telescoping

This article is third in a series to discuss the form, function and joinery of selected historic American timber-framed steeples. The series was developed from original research under a grant from the National Park Service and the National Center for Preservation Technology and Training. Its contents are solely the responsibility of the authors and do not represent the official position of the NPS or the NCPTT.

THE Castleton, Vermont, Federated Church (1832) is a brick structure in the idiosyncratic Greek Revival style of its builder, Thomas Dake. The church is 60 ft. wide with walls 28 ft. high. At the full-width portico, four fluted wood columns support a closed pediment and blank tympanum above. The steeple, which terminates 132 ft. above grade, rises from the portico and the front of the church, emerging from the roof first as a square tower, surmounted by a large square belfry. A lantern atop the belfry takes the apparent form of an irregular octagon because of the bold expression of pilasters at the corners. Above the lantern is another drum like stage closer to a regular octagon with large console-like ornament alternating with paneled faces, and atop this a tall, thin, tapering spire terminating in a gold-leafed ball and vane with directional arrow (Fig. 1).

The steeple is finished in white-painted wood except for the spire and the various skirting roofs of each stage, all now covered by lead-coated copper. Originally even the spire was finished in wood, 3-in. to 5-in. tongued and grooved beaded pine and spruce boards applied horizontally. The mitered end joints of this old wooden covering did not have corner beads at the spire arrises but were covered with small overlapping bibs of zinc. This material was still in place under a layer of deteriorating tinned steel when the spire was restored by the author in 1988.

The front steeple posts bear upon the portico plate and the rear posts on a large transverse sleeper. The latter is supported by four lengthwise sleepers that bear via short posts on the front wall plate and then farther back rest on the steeply cambered lower chords of the first and second interior trusses. The first of these trusses, nearest to the rear of the tower and its load, is assisted by two posts rising to its bottom chord and concealed within the walls of the pulpit apse, the half-domed semicircular recess at the front of the audience room (Fig. 2).

The substantial load of the steeple is brought to ground at several points. Timber posts 10x10x28 concealed in the fluted portico columns rise above the columns and receive the lower ends of diagonal braces concealed in the tall portico frieze. These braces rise to the portico plate, into which the two front tower posts, 11x11x40 white pine timbers, are tenoned. The two rear tower posts descend to the 10x16 transverse tower sleeper. The four supporting lengthwise sleepers are large and irregular baulks of timber varying from 9x10 to 11x17, two at 28 ft. long and two at 19 ft., roughly but not exactly parallel to each other. These sleepers begin over the portico plate (but don't bear on it), then cross and bear on short posts over the front wall plate, the load going to ground through the brick walls and stone foundation. The sleepers then

All photos Ken Rower

Fig. 1. Castleton Federated Church, 1832.

pass under the transverse tower sleeper on their way to bearing on the first and second interior truss chords (Fig. 3).

The two inner sleepers cross the first truss bottom chord about 2 ft. inboard of the points where the apse posts rise to lend support, and then continue 10 ft. to cross the second interior truss bottom chord. The two outer sleepers terminate atop the first interior truss, the easterly one crossing it about midway between a suspending princepost and a rising apse post, and the westerly angling inward to arrive right over an apse post. Substantially cambered truss lower chords rising to levels higher than the front wall plate account for the short posts between the plate and the sleepers. Farther back the sleepers sit squarely upon the cambered truss chords.

The stages of the steeple assembly are not tightly framed, but lodged, flexible and dependent upon mass and the deep telescoping of the stages above, a sort of vertical cantilevering, for stability. On the other hand, the steeple's base support condition, whereby the load is brought to ground, is exceptional and substantial compared to many other churches. There is no evidence of any failure or sagging of the interior trusses that carry the rear steeple load. The several inches of rearward lean discernible in the steeple can be attributed to differential shrinkage of the cross-grain material under front and rear tower posts: a 28-in. matrix of horizontal timbers lies below the rear tower posts while the front posts sit on only 12 in. of horizontal timber. Also, some bending occurs in the 10-ft. span of the long sleepers where the transverse rear tower sleeper crosses them.

So far our complex description has merely provided us with the bearing conditions of this sophisticated and well-wrought steeple and how it opportunistically acquires a variety of strong load paths down to the foundation. The stages above the tower are simpler to describe but embody their own ingenious solutions to the problems of building high with timber.

Both the tower where the steeple emerges from the roof and the belfry above it are framed by 11x11x40 white pine posts. Heavily braced girts 12 ft. up from the bottom of the posts carry two 10½x10½ lodged sleepers. Four 9x9 posts 39 ft. long rise from mortises in these sleepers to form the frame of the irregular octagon stage above the belfry. Two levels of girts with braces below the ultimate plate level lend rigidity to this tall and slender (7 ft. 6 in. square) frame. The 9x9 posts are deeply telescoped, 28 ft. within the tower-belfry frame and merely 11 ft. projecting above it. The plate level of this inner group of posts and a ring of 2x14 planks spiked to the posts provide bearing for the eight spire rafters, partially round 4x5 spruce spars 38 ft. long. The rafters are secured to the plate by hand-forged lag screws.

Lending mass to this slender spire frame is a remarkable pendant mast, a 7x7 timber roughly 48 ft. long, suspended from spikes through the long abutments at the top of the eight rafters (Fig. 4 overleaf). The only attachments of this mast to any surrounding frame below are a set of modern, circular-sawn 4x4 timbers spiked to it near its base. These 4x4s are undoubtedly a later addition by carpenters baffled by the sophisticated framing of an earlier period. The original intent was definitely to hang the mast, allowing it to compress the boarded spire, move its center of gravity inward and down and act as a pendulum. The pendant mast telescopes as well, dropping not only below the spire rafters, but entirely through the upper octagon stages and 3 ft. below the plate of the tower and belfry frame (Fig. 3).

The top of the original old-growth chestnut mast served as an anchor for the vane. The 11-ft. wrought-iron vane shaft, 2 in. square at its base, penetrated 2 ft. into the top of the mast. Concealed within the mast, the bottom of the shaft was hammered into the shape of a small hook that carried the slotted upper end of a segment of ½-in. square wrought-iron lightning rod, which exited the side of the mast and eventually ran in many segments to ground. Resulting moisture condensation inside the mast and leakage at the top point of shaft entry served over time to rot even old-growth chestnut. The 7-ft. arrow of the vane was removed in the 1950s and a bucket of concrete (with chicken wire reinforcing) dumped down into the rotted top of the mast. During steeple restoration in 1988, the arrow, fortunately preserved, was reused as well as the original trident from the top. The rotted chestnut mast was replaced with a 48-ft. stick of bitternut hickory, hung from the tops of the original rafters. A downward sloping bib of leaded copper fitted to a ring groove in the vane shaft now resists water penetration, but the problem of condensation on the shaft inside the mast perhaps cannot be solved without heating the shaft.

Fig. 2. Pulpit apse conceals two structural posts that ultimately help support the steeple.

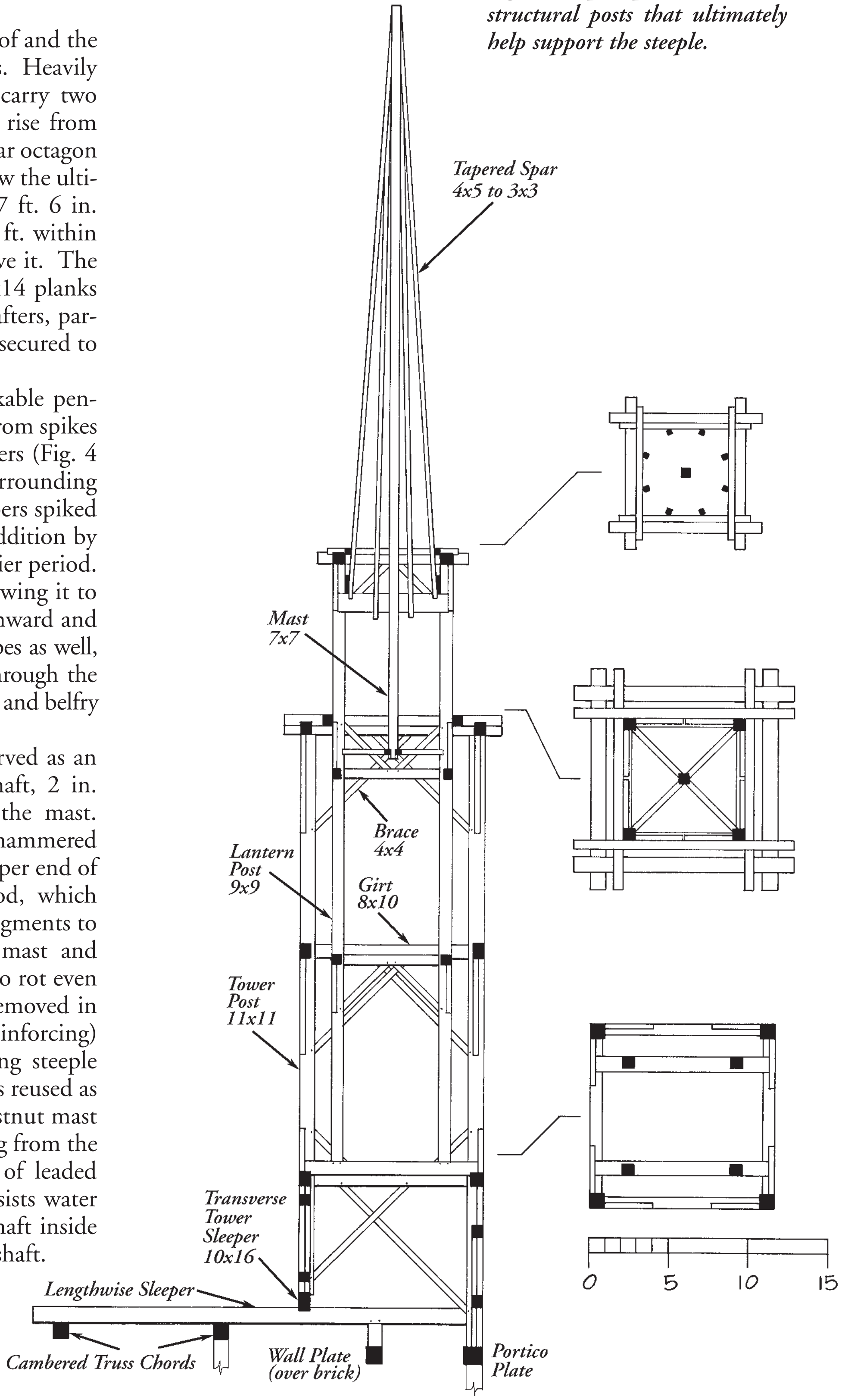

Fig. 3. Section through Castleton steeple, looking toward eaves.

Fig. 4. Castleton's hickory mast since 1988. Original mast had been base-stayed at some point in its history; its replacement followed suit.

Fig. 5. Christ Church, Philadelphia, 1754. Tower stands free of church body, supports two wooden stages and a spire framed platform style.

Telescoping. Telescoping in church steeples indicates ascending stages, diminishing in cross-section, where each stage rises from some distant point within the stage below. (A contrasting method would be to build each stage directly on top of the stage below, platform style.) Without an interior survey of the tens of thousands of tall wooden towers worldwide, it's impossible to identify the origins of the telescoping technique, but suffice it to say that telescoping is used in a modest form in the 17th-century wooden steeples of Wren's parochial churches in London (see plates in Clayton), in some 18th-century Polish steeples (Sadkowski 122–27) and in 18th-century chapels in remote Kenozero in northwestern Russia (Lewandoski 2002).

However, a distinction must be made between telescoping used to provide a concealed space for buttressing or rigidly bracing the stage above to the surrounding one below, and deeply lodged telescoping where the succeeding frames actually do not touch each other above the point of bearing. The latter operate as a sort of vertical series of self-cantilevers; there is not even joinery at the point of bearing. In such systems, the portion of any stage exposed to wind pressure may be no more than 30 to 70 percent of the stage height. The lower remainder, frequently braced and girded within itself and tenoned into its lodged bearing timbers (but not into the framework of the surrounding lower stage) is thus heavy and able to help resist any overturning moment.

In strong contrast to this form of frame engineering stands the steeple of Philadelphia's Christ Church (1754), the tallest structure in the western hemisphere at the time of its construction (Fig. 5). At Christ Church, the steeple's initial brick tower is surmounted by two wooden stages stacked upon each other and bound to those below by various metal and wooden tension members, not by interpenetration of the frames themselves (Fig. 6).

The Middlebury, Vermont, Congregational Church steeple, built 1806–09 (see TF 83), presents an intermediate solution, with both deep telescoping (14 to 16 ft. of penetration) and multiple sets of partners and diagonal braces connecting each stage to the preceding stage surrounding it.

Fig. 6. At Christ Church, forged iron bar and wood corbel buried in stone rubble anchor first wooden stage above to masonry tower.

Castleton is an outstanding and successful example of deep telescoping with little or no mechanical connection between the stages other than roof boarding and flashing. Other historic examples exist in some of the great surviving wooden steeples of the 18th and early 19th centuries. In Rhode Island, the First Baptist Church of Providence (1750) has been previously studied not only for telescoping as an engineering solution but as an aid to assembly as well (Isham 1925 and Lewandoski 1995). Ithiel Town's great Center Church on New Haven Green in Connecticut has four deeply telescoped stages. The roughly 60 ft. of spire are lodged 11 ft. down within the upper octagon stage. The octagon itself is framed by 71-ft. columns (four single sticks and four scarfed) that conceal 37 ft. of their length in the tower below and expose 34 ft. Four levels of horizontal girts with X-bracing between the levels join the octagon posts in their concealed portion. These tall columns tenon into a set of parallel 12x14 timbers not mechanically connected to each other or to the immense square tower. While modern engineers tend to choose rigid tie-down solutions, deep telescoping has been working remarkably well on many of these lightweight, very tall objects for at least 200 years.

The Pendant Mast. Here is a passage from *The Travels of Marco Polo* (ca. 1298), Chapter XXXI, "On the City of Samarcan and the Miraculous Column in the Church of St. John the Baptist":

> The Christian inhabitants of the place . . . proceeded to build a church and dedicated it to St. John the Baptist. It was so constructed that all the weight of the roof (being circular) should rest upon a column in the center, and beneath this, as a base, they fixed a square stone, which, with the permission of the prince, they had taken from a temple belonging to the Mahometans. But upon the death of Zagatai, his son who succeeded him showing no disposition to become a Christian, the Mussulmans had influence enough to obtain from him an order that their opponents should restore to them the stone they had appropriated; and although the latter offered to pay them a compensation in money, they refused to listen to the proposal, because they hoped that its removal would occasion the church to tumble down. . . . When the day arrived on which they were to make restitution of the stone, it came to pass through the intercession of the Saint, the pillar raised itself from its base to the height of three palms, in order to facilitate the removal of the stone, and in that situation, without any kind of support, it remains to the present day.

As we have seen, the steeple of Castleton Federated Church incorporated a pendant mast into its spire that terminated nearly 49 ft. below upon nothing. Several 1-in. boards were casually nailed to it along its length, probably as an assembly aid. At the bottom, much later, 4x4s were spiked between mast and steeple framing in a misunderstanding of the mast's role in the stability of the spire. These were preserved in the 1988 mast replacement.

Many spires, perhaps even the majority built in the 18th and 19th centuries in the New World, have a mast at their centers, but most are rigidly footed or framed tightly to the surrounding timbers of the steeple: the Middlebury mast, for example, has joinery or tight bearing with 57 other framing members over its 53-ft. run. Castleton is designed to have nothing but eight connections clustered at the apex.

The pendant design, however, does not originate in Castleton. Setting aside apocryphal parts of the passage from Marco Polo, we infer that Nestorian Christians in Central Asia sometime between 700–1200 AD built with pendant masts to compress their domes (likely of stone). In 760 AD, Tang Dynasty framers in China constructed the three-stage tower known as the Zhenwu Pavilion, in which the interior columns supporting the penultimate roof system are suspended above the floor by cantilevered eaves (Zhang 157). While not identical to that of a pendant mast, this method is similar, to counterpose a lightweight exterior frame with some suspended weight in the interior, capable of moving slightly rather than rigidly resisting exterior forces.

Closer to home we have the pendant masts of Christopher Wren in England. In Gwilt's *Encyclopaedia* we find the following (962):

> Sir C. Wren, when rebuilding the upper portion of the (former) spire of Chichester Cathedral which had been forced out of the upright, placed [inside it] two intermediate stages connected with a pendant beam of timber about 80 feet in length attached to the finial stone; each stage was about 3 inches in diameter less than the spire at their levels; these restored the spire if it departed from the upright. A similar pendulum, with two stages, to act in like manner, has been introduced by Gibbs in his spire of St. Martin in the Fields, London.

John Clayton includes measured drawings of the steeple framing of Wren's surviving London churches. At least one, St. Mary le Bow (1671), contained a pendant mast with a pair of apparently free-swinging floor frames attached at its bottom (Fig. 7). The spire was unfortunately destroyed in World War II. The numerous examples of telescoping steeple frames illustrated by Clayton show relatively shallow penetration, and as an opportunity for concealed, rigidly connected framing and bracing, not the deep penetration and casual connections so common in eastern North America by the late 18th century.

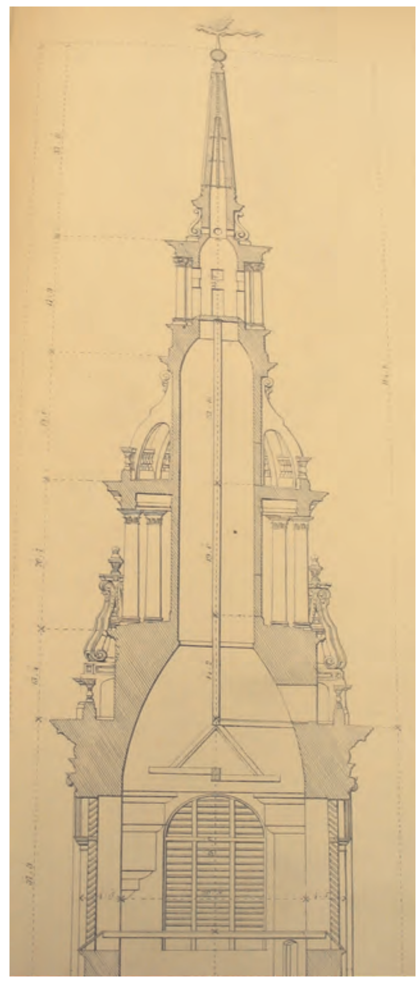

Fig. 7. St. Mary le Bow, London, 1671, designed by Sir Christopher Wren, with pendant floor frames to weight bottom of mast. Horizontal member at mast bifurcation is unexplained.

The steeple of the Stowe, Vermont, Community Church (1861) is remarkable for its height, 165 ft. from the ground to the top of the vane, as well as for an abundance of knowledge about the erection of its slender 90-ft. spire, described in the local newspaper at the time. The frame of the spire is further unusual for its period in being constructed entirely of spiked-together plank, including the central mast that measures 20 in. square at its base. Below the spire, the steeple is timber framed, generally in a very substantial fashion.

The Stowe church is 50 ft. wide with a wall height of 29 ft. sill to plate. The pedimented portico with undecorated tympanum is supported by four fluted columns. The tower or first stage of the steeple, 19 ft. square, crosses the portico, front wall and the first interior roof truss. A belfry stage in the form of an irregular octagon appears next, followed by a clock stage, also an irregular

Fig. 8. Stowe Community Church, 1861.

octagon, and finally the tall, slender spire with a vane on top, composed of a ball, a directional arrow and a golden arrowhead (or leaf) pointing heavenward (Fig. 8). The spire is covered with small galvanized steel panels painted white. The original covering was tin on steel, also in smallish, approximately 2x3-ft. pieces. The tower, belfry and clock stage are white-painted woodwork. Pilasters with inset paneling build out the corners of the octagon, which express the framing, clock faces or louvers fitted in between. The style is Greek Revival with an extremely tall and pointed Gothic element on top, a very popular combination at the time. The 1930 "Brief Historical Sketch" by the Stowe Community Church says of the building, "The lines undoubtedly were copied from the work of England's famous architect, Sir Christopher Wrenn [sic]," a claim that thousands of other small-town churches can make as well.

The tower stage, 22 ft. tall, rises from 8x8 sleepers that sit atop the portico plate, the front wall plate and the first interior truss chord. These sleepers run back to within inches of the second interior truss but inexplicably don't reach it (Fig. 11). Braces descend back from the rear tower posts to the unsupported ends of the sleepers. The only rationale I can summon for this framing, other than error in the length of the sleepers, is the builders' intent to provide a form of spring to absorb rearward movement of the steeple, although at 6 ft. long the 4x4 braces cannot resist much load. The four tower posts, girts, and plates are all 8x8 spruce timber, with 4x4 braces mortised but unpinned, variously hewn or vertically sawn.

The belfry stage rises in telescoping fashion from short sleepers (now sistered with steel channels) that lie diagonally across the corners of the tower sleepers; the belfry framing begins only 8 in. above the tower base. The belfry is framed by the method of partners, borrowed from the nautical practice for securing a mast where it passes through deck levels. From each of the four diagonal belfry sleepers pairs of 35-ft. 8x10 columns rise (these are not the partners), separated by deeply tenoned spacer blocks and carrying tie beams that cross and through-tenon into the opposing pair of posts at two intermediate levels and the top. The half-lapped crossing of these pairs of tie beams, 8x8s at the intermediate levels and 8x10s at the top level, produces a square opening at the center into which the mast can be inserted and wedged. The paired horizontal timbers are the partners.

The partner posts are given architectural expression as the corner posts of the irregular octagonal belfry, the four narrow sides of the octagon bounded by the paired posts and the four wide sides occupying the spaces between sets of partners. Partner posts and tie beams in turn support another level of 10-ft. 8x8 paired posts, producing another partner ensemble to clasp the mast again at a higher point. The architectural expression of this upper partner framing is the irregular octagon of the clock stage above the belfry.

While the belfry stage is telescoped for 22 of its 35 ft., the clock stage is not telescoped at all, but rather deeply tenoned into the top level of horizontal partners of the belfry stage. The 2-in. through-tenons of the posts are 8 in. wide and 10 in. long, each affixed by three 1-in.-dia. pins to make a tension connection. The belfry partners that carry this higher stage are also through-tenoned onto the tops of the belfry partner posts, again with three pins in recognition of the significant uplift or overturning that may occur here (Fig. 9).

Out of these two levels of partners rises the built-up central mast, nearly 90 ft. tall and the attached lightly framed spire it anchors (Figs. 10–11). The rafters of the spire are paired 2x4s, many of them from a 1950s repair, while, in each of the eight spire panels, intermediate long flatwise 2x4s (at least one of which is original and vertically sawn) serve as nailers for the single layer of horizontal boarding lying under the metal. The spire rafters are attached repeatedly to the mast with various plank and board braces, likely installed as the carpenters built upward when the spire stood on the ground next to the church. A set of plank partners clasps the mast directly on top of the highest timber partners. The now-inaccessible nailing of some of the plank partner elements tells us that they were attached to the mast on the ground before it was lifted and inserted.

The entire steeple load, both dead and wind-induced, is successfully brought to the foundation along three parallel lines. First, the 8x8 tower sleepers at the base of the steeple frame bear on a 10x10 portico plate, the latter supported by a cripple wall of 2x8 studs over the 9x10 beam that caps the four portico columns. Each of these very large fluted columns conceals a hewn 9x9 post 25 ft. 2 in. long. The portico frame behind the tympanum is queenpost trussed to the tower posts, unusual for a fully studded gable end supported from below. Inboard 10 ft. the tower sleepers cross the fully studded front wall of the church. The rear of the tower is almost exactly over the first interior roof truss, which sits over the vestibule wall inside.

How did the mast arrive at the top of the steeple? We learn from the nearby Morrisville, Vermont, *Lamoille Newsdealer* of September 27, 1861, that once Mr. Edgerton of Charlotte (about 40 miles distant), together with his horse and a 100-ft. ginpole acquired locally—and undoubtedly a lot of rope, pulleys and a capstan—had lifted the spire above the three in-place stages, it was lowered and affixed at several locations. First, the spire rafters and their sheathing and metal cladding, a rigid eight-sided cone, were brought to bear upon and

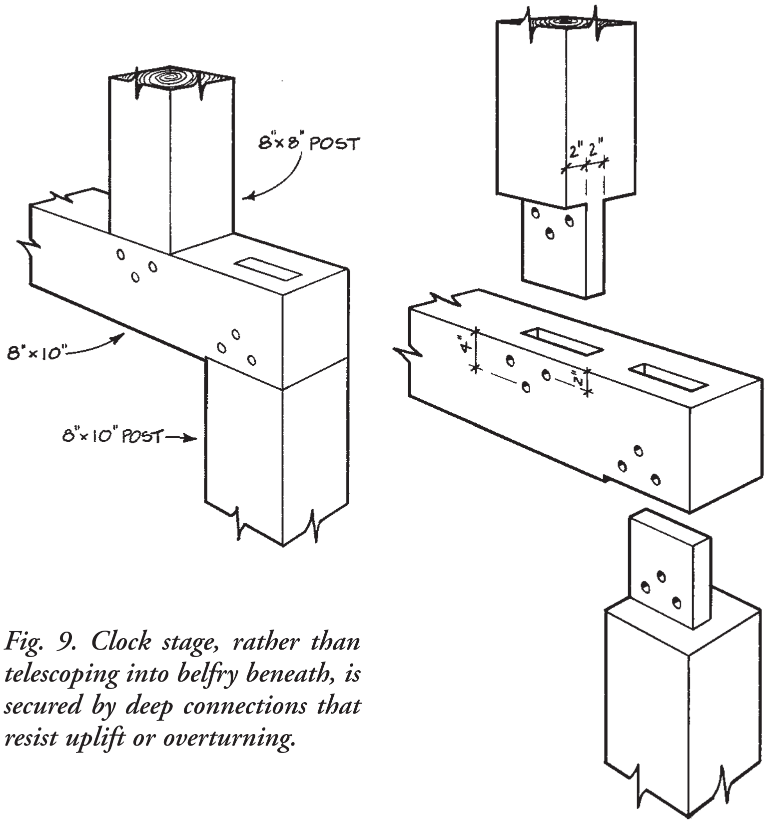

Fig. 9. Clock stage, rather than telescoping into belfry beneath, is secured by deep connections that resist uplift or overturning.

Fig. 10. Spire mast, here notched for some obsolete purpose, is built up of light plank.

spiked to the plate of the topmost stage. (Were this the spire's only connection, it would now be missing.) Second, the mast, 20 in. on a side at this point, extended 11 ft. below the bearing of the rafters and was tightly clasped by two sets of partners: one at the top of the deeply telescoped clock stage and another at the top of the belfry stage. Third, a tension connection was made at the foot of the mast where a captive bolt within the mast dropped some 20 in., attaching to a 3x16 hardwood plank crossing under the partners immediately below the foot of the mast. There are two unexploited opportunities to clasp this mast between partners at lower levels in the belfry frame. Apparently the framers thought it unnecessary to extend the mast down another 23 ft., and they were right.

In our study of steeple framing we have now seen the spire mast designed to operate in three different ways. In the Middlebury Congregational Church in 1806 it was used as the central axis of several deeply telescoped stages and joined rigidly to them at 53 locations. At Castleton in 1832 the mast was originally pendant, attached only at the top and used as a pendulum. At Stowe in 1861 the mast was clasped rigidly only at its base, dependent upon the massive surrounding partner framing to resist uplift and overturning moments from above. These three churches were built within a 55-year period, 30 to 100 miles apart, in a culturally homogenous region. They testify to the diversity and wealth of inventiveness in traditional framing. —Jan Lewandoski

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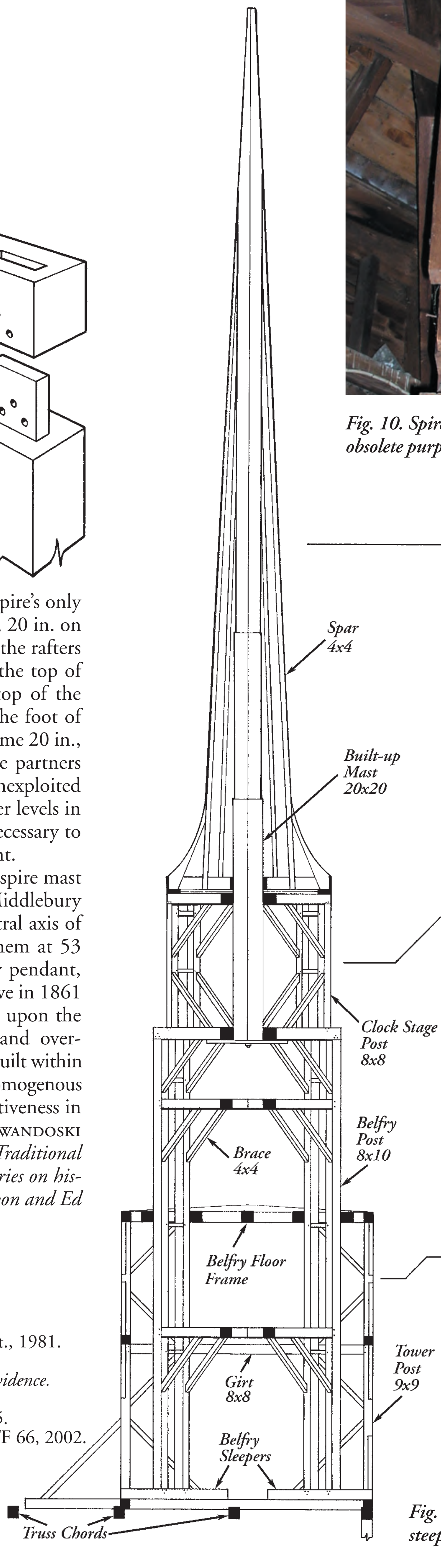
BIBLIOGRAPHY

Clayton, J. *Works of Christopher Wren.* London, 1848–9.
Congdon, H.W. *Dake of Castleton.* Montpelier, Vt., 1949.
Gottlieb, R. et al. *History of the Community Church.* Stowe, Vt., 1981.
Gwilt, J. *The Encyclopaedia of Architecture*. London, 1867.
Isham, N. *The Meetinghouse of the First Baptist Church in Providence.* Providence, 1925.
Lewandoski, J. "The Erection of Church Steeples." TF 36, 1995.
——. "Kenozero and Timber Buildings in Northwest Russia." TF 66, 2002.
Polo, M. *The Travels of Marco Polo*. Beijing, 1989.
Sadkowski, T. *Drewniana Architektura Sakralna Na Pomorzu Gdanskim w XVIII-XX Wieku*. Gdansk, 1997.
Zhang, Y. *History and Development of Ancient Chinese Architecture.* Beijing, 1986.



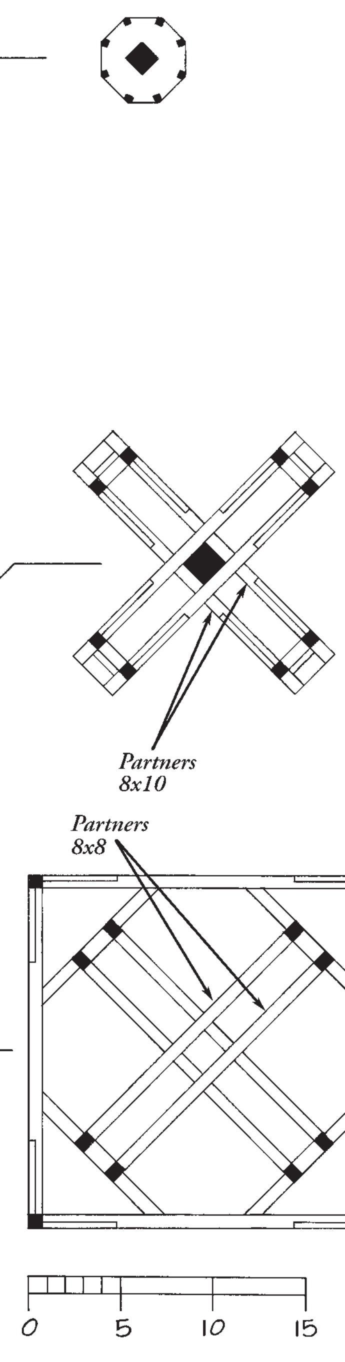
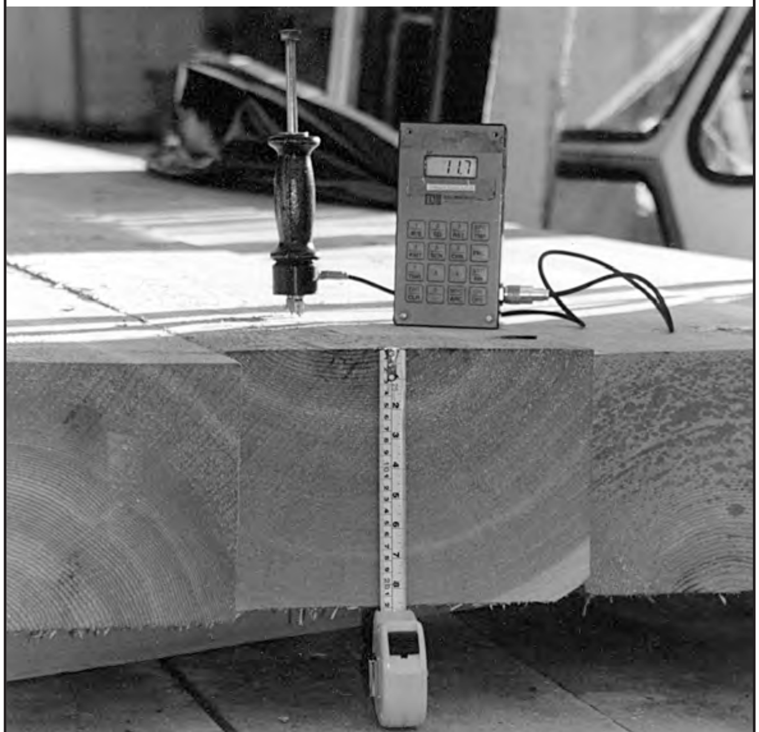


Fig. 11. Section through Stowe steeple looking toward eaves.



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