TIMBER FRAMING

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Number 110D, December 2013

Grindbygg Construction

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On the front and back covers, a grindbygg-framed barn clad in juniper branches on a farm north of Bergen, Norway. Heavy slates pegged to lower parts of walls protect against splash. Photos Peter Henrikson.

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.

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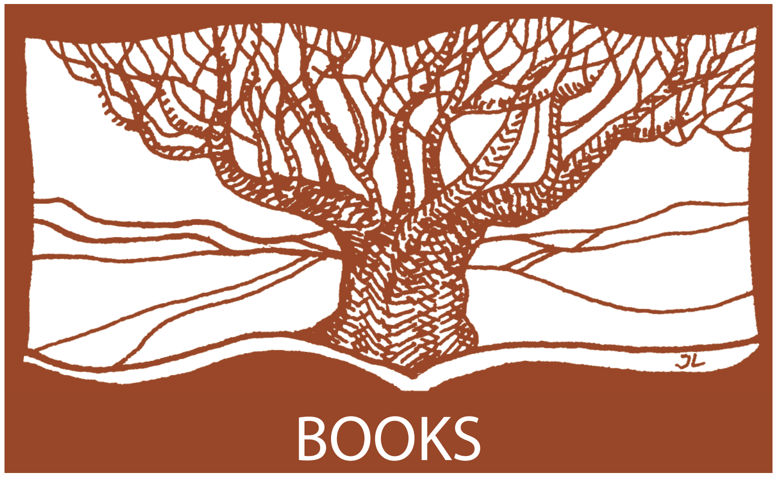
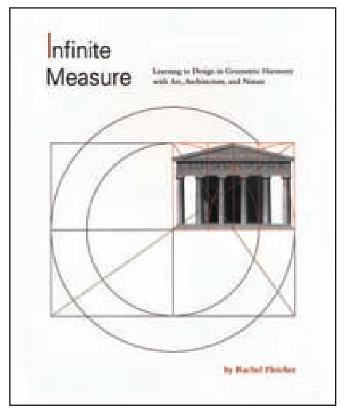


Geometric Design

Infinite Measure: *Learning to Design in Geometric Harmony with Art, Architecture, and Nature,* by Rachel Fletcher. Staunton, Virginia, George F. Thompson Publishing, 2013. 8.2 x10 in., 400 pp., profusely illustrated. ISBN 978-1-938086-02-01. Hardcover, $45.00.



RACHEL FLETCHER'S new publication, *Infinite Measure*, is a wide-ranging book that defines geometry's presence in the natural world, tracks the history and evolution of geometry from before the classical period through to the present day and presents a comprehensive and impressive body of knowledge simultaneously philosophical and practical. It explains the grammar of geometrical construction, from the initial simplicity and unity of the circle, through gradually more complex constructions that lead ultimately to sophisticated geometrical overlays defining proportional relationships in the natural and built environments. The emphasis throughout is on proportion and how the individual elements of a design should relate to one other, and to the whole, in a proportionate and visually harmonious way. It is impossible in a few words to do full justice to the book so the aim here is to give a general sense of its character and content.

First things first. The cover is white, the lettering black, the initial *I* of *Infinite Measure* and the author's name illuminated in red ocher. The cover illustration, drawn in black, red ocher and gold line, presents two parallel circles proportioned by the side and diagonal of a square constructed on the inner circle's radius. Extending the square to the outer circle generates a $\sqrt{2}$ rectangle. The rectangle, in turn, forms the proportional boundary of the eastern facade of the Doric Temple of Theseus, built in Athens ca. 450 BC. The book therefore begins in Greece where geometry began. The cover cards are folded to give the book protection where the pages open, the upper and lower edges are precision guillotined, the spine is bound square and the book has a precise visual character in harmony with its subject matter. The book's 400 pages are gratifyingly substantial in the hand.

The black and red ocher color scheme of the cover is maintained throughout the book, giving the work a sustained sense of order and clarity. The pages, as one would expect, are laid out to a geometrical formula (shown on pages 233–35), the single page geometry mirror-imaged, like a butterfly's wings, on facing pages. The formula generates narrow margins where the pages meet and wide margins, for additional notes and quotes, at their outer edges, with the text and geometrical developments filling the space between, a format similar to the classic Van de Graaf layout derived from medieval books, in which the text block has the same proportion as the page. On the page the constructions are drawn with precision, their fine black lines perfectly defining the intricacy of the geometrical relationships. Crucial alignments are emphasized in thicker, red ocher lines and the letters that indicate specific elements of the construction are carefully placed. Footnotes give the etymon and meaning of words used in the text above them. This is an instantly intelligible and visually satisfying format that is in perfect accord with the book's raison d'être, the comprehension of proportion necessary, as Rachel Fletcher's introduction states, ". . . to provide designers with geometric techniques for composing spaces harmonically."

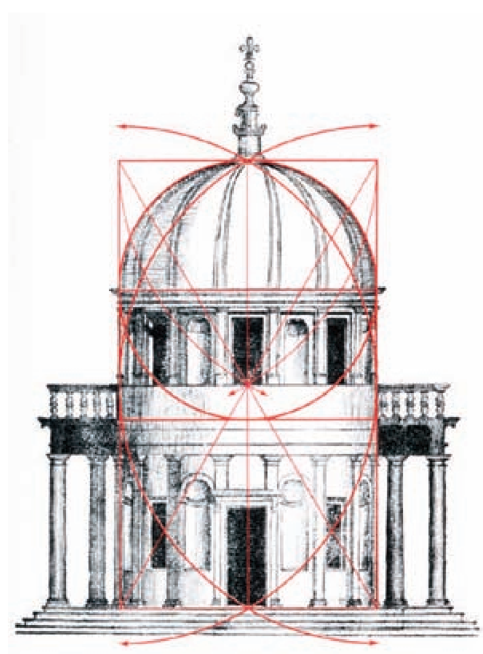
The book is structured in two approximately equal parts, titled *Geometry's Shapes and Symbols* and *Composing Space Plans.* Inevitably, there are elements of overlap, but these act as links between the two parts. The first part begins with the circle and follows the track of spatial logic so that two overlaid circles generate the *vesica piscis* and the vesica generates triangulation, etc. The second part takes up dynamic symmetry and the rectangular ratios arising from the square roots of 2, 3 and 5. Specific drawing instructions for the geometries are given precisely in bold type alongside red ocher bullet points. Occasional quotes appear in the outer margins in red ocher italics: Ralph Waldo Emerson's *The eye is the first circle; the horizon which it forms is the second; and throughout nature this primary figure is repeated without end*, and Wassily Kandinsky's *To harmonize the whole is the task of art*, emphasize the author's philosophical stance.

The book stresses the intricate and intrinsic harmonies of geometrical proportion. The incommensurable ratios, which are found in human and other life forms but do not resolve to whole number dimensions, define those elements of space that have perfect geometrical harmony but far from perfect numerical equivalents. For example, the perfect geometrical relationship between a circle's diameter and circumference yields the incommensurable numerical ratio of 1: 3.14159265359 that extends ad infinitum. While the geometrical proportions have visual clarity, their decimalization is decidedly confusing.

Geometrical examples developed from the Six-Plus-One Circles generate the well-known daisy wheel and relate it, on a scriptural scale, to the construction of the world in six days with a seventh day of rest and, on the visible scale, to the six radials of a snowflake's form. Linking the daisy wheel's petals on the circle's circumference generates a hexagon. Hexagon is printed in bold type in the text and translated from the Greek hexagônon at the foot of the page. Further constructions show patterns of spiraling triangulations, diminishing in scale as they follow the daisy wheel's arcs toward its central axis and then an overlay of the daisy wheel's internal triangulation on the wings of a giant swallowtail butterfly (*Papilio cresphontes*). There is a caveat here in the text, that the subtleties of natural form never conform to idealized geometries precisely, but the overlay demonstrates that natural forms often have a close affinity to pure geometries.

The Square and Tetractys follow. It is a revelation of geometry's intricacy and intimacy that many of the constructions within the square and the tetractys (a pyramidic triangle composed of 10 dots in the format 4-3-2-1 from base to apex) are formed either entirely or partially by compass geometry. The Platonic or Five Regular Solids are next: the dodecahedron, icosahedron, octahedron, tetrahedron and cube, all angular multifaceted three-dimensional forms that, counterintuitively, fit exactly within the encompassing globe of a perfect sphere.

Both parts of the book present architectural analyses of classical and modern buildings. For example, an elevation of Donato Bramante's Tempietto, built in Rome circa 1500 as a small martyr temple to Saint Peter, is proportioned through the harmonic fusion of compass and square geometry, as seen at right: the upper half of a circle inscribed in a square defining the dome, the lower half of the square defining the dome's vertical drum. A vertical vesica piscis defines the full height of the building from ground level to the dome's apex and the floor plan occupies a five-



TEMPIETTO ELEVATION, WITH OVERLAY.
I–10b

Overlay drawing from *Infinite Measure*

circle geometry, the central circle of which defines the interior space. Conversely, Philip Johnson's Glass House (built at New Canaan, Connecticut, in 1949) expresses spatial relationships through approximate use of the Fibonacci series. Born about 1175 at Pisa in Italy, Fibonacci calculated a numerical series, 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, and so on, tabulating the reproductive multiplication of rabbits, a series also found in the number of radiating petals in flower heads. Johnson's Glass House features 3 and 13 in its vertical plane and 8, 8, 5, 8, 8 and 21, 8, 5, 8, 21 in its horizontal planes, the overlapping framework forming a grid of harmonically related rectangles shown by the author's red ocher overlays.

Other examples show geometrical analyses of the sound box of a Stradivarius violin, a Moroccan tile panel, the south rose window of Notre Dame in Paris, a carpet page from the Lindisfarne Gospels and the natural form of a snow iris. The Pythagorean theorem, the vesica piscis, fundamentals of dynamic symmetry, spirals, the Golden Section, Golden Triangle, $\sqrt{2}$, $\sqrt{3}$ and $\sqrt{5}$ rectangles, ad quadratum, the pentagon and octagon, Le Corbusier's Modulor—all are here. Some aspects of geometry are missing, the compass geometry of Romanesque architecture for example, but the omissions are balanced, for this reader, by new revelations. The book concludes with the usual references and index, notes about the essayist who wrote about the author, about the author herself and about the book itself, but by this stage we are on the last page, having undergone a comprehensive geometrical journey under enlightened guidance. This is an impressive book that presents extensive scholarship in a completely reader-friendly way.

Writing this review for *Timber Framing*, some inevitable questions arise. Are timber frames present in the analysis? The answer is no. Does the book show geometrical constructions that a carpenter could lift off the page and use on the framing floor? The answer is again no. So, in the light of these negatives, do the geometrical constructions shown serve any purpose for a carpenter? The answer is yes, because the book introduces the carpenter to the crucial concept of proportion, and control of proportion is a vital tool in the carpenter's kit. While a saw or chisel won't bring good proportions to a frame, geometry will. It follows that, like saw and chisel, geometrical knowledge must be made sharp and kept sharp so that the eye and therefore the mind gain an ever-growing understanding of proportion. Gradually, over time, guesswork will metamorphose into sound aesthetic timber framing judgment.

—Laurie Smith

Laurie Smith (lauriesmith@uku.co.uk) is an artist and graphic designer living in Devon, UK, who has made a specialty of geometric building analysis. His "Useful Geometries for Carpenters" appeared in TF 95 and is collected in Timber Framing Fundamentals.

LETTERS

Covered Bridge Loading

To the editor:
With regard to Phillip Pierce's article "Reflections on Load Capacity of Historic Covered Bridges" (TF 109), I don't think there is any existing documentation on design loads for covered bridges from the 19th century. Builders did much experimentation with scale models, but some, such as Ithiel Town, questioned the validity of these test results. About all we can say is that covered bridges did successfully carry everything that came down the road, until steam tractors and especially threshing machines appeared at the end of the century. At that point we do begin hearing of some bridge failures. The bridge would remain standing with its trusses intact, but since the floor systems were underdesigned, the floor beams would give way.

After the publication in 1847 of Squire Whipple's work, and to some extent earlier with Stephen H. Long, mathematical stress analysis with defined loads began to be used, but mostly for the railroad business. Analysis with defined loads did not become widespread in the covered bridge world until the 20th century, by which time only a few areas were still building them. Oregon commonly used a Cooper's H-15 [15-ton] rating although perhaps only an H-10 depending on the location. Even then they successfully carried more. In the 1970s, I observed loaded log trucks crossing Oregon covered bridges, and they surely exceeded a 15-ton loading,

Phil Pierce makes some valuable comments in his article, and I'm glad it is being published. I agree with him that covered bridges should not be expected to carry immense loads for which they were not designed. To ask them to do so means wholesale replacement of much of the historical structure. The problem, in the larger societal context, is that sufficient funds for repair or restoration are rarely ever available unless the bridge is still carrying modern loads. The solution to this problem is not technical, but rather cultural.

Joseph D. Conwill
Rangeley, Maine

To the editor:
Phil Pierce's article is full of interesting information and conjectures on the difficult question why most old wooden trusses do better than modern engineering analysis thinks they ought to. Many bridge types were patented starting in the first decades of the 19th century and certainly heavily designed, though rarely analyzed quantitatively. Recall bridge builder John Johnson's attempt to use the numbers of Barlow and Emerson [see TF 76, "The Evolution of Roof Trusses"]. By the 1850s Hermann Haupt is doing very good mathematical analysis. The late engineer David Fischetti knew these things, and Ron Anthony spoke about testing and analysis in the 19th century at last year's international building conference at MIT, "Wood in the 21st Century: Design and Preservation of Contemporary & Historic Architecture."

These bridges were designed within a craft tradition and later by engineers much as great and successful frames had been designed for a thousand or more years all over the world. I will agree, however, that the long, single-span American wooden bridges were timber framing's most ambitious structural work ever. Some people have instincts and an eye for structure. This is hard to quantify or codify. The 5 percent exclusion stuff is interesting, although it doesn't apply to E (modulus of elasticity), which is an average, and which I pay more attention to assuming my timber is very good (again, this is hard to put in a code). I also go to tables called "strength properties of wood," which break down groups into single species. At larger sample sizes n you get greater confidence that your results are representative. The more testing that is done, the more confidence you can have in your results.

John Weaver, formerly of the Vermont Agency of Transportation, and now of the Vermont Covered Bridge Society, wrote an article on reserve capacity (vermontbridges.com/reserve.htm) that convincingly located some in the roof deck, not the floor deck. Testing has been done by Dave Fischetti, myself and others on old growth, getting various results, but always as strong as or stronger than current design values. These numerical results can't necessarily be applied to untested members, other than to give you more confidence in your judgment that something is probably good. Phil had trouble with live-load testing (I participated) on a Nichols Powers lattice truss near Rutland, Vermont, getting almost no response to a couple of state trucks, which is why he may doubt its utility. I like it.

A huge amount of work needs to be done on many bridges to determine why a predicted deformation hasn't occurred. Is it the strength of wood or the goodness of the analytic model? I think I understand why Dave Fischetti (who often exercised what he called nonquantitative "engineering judgment"), when we asked him to provide engineering commentary for the Guild's steeple series (see tfguild.org/publications/guild-books), said he couldn't write a general theory of church steeples, he could just present case studies.

Jan Lewandoski (janlewandoski@gmail.com)
Stannard, Vermont

To the editor:

As a professional engineer, I'm legally obligated to follow the governing building codes. Yet I too have encountered many historic timber structures that have performed well for a century or more in spite of being woefully "inadequate" when evaluated by today's code criteria. How is the practicing engineer to reconcile these differences, particularly in today's litigious climate?

Most engineers take the safe route of ignoring the discrepancy, applying a strict interpretation of the *National Design Standard* or state highway timber codes to historic structures. In their defense, there is no established standard of care, and very little published guidance in readily available format, for any other method of evaluating old timber structures. Having done my own homework into the background of various *NDS* provisions, I agree with Phil Pierce that there are areas where the timber code underestimates the real strength of existing older structures, especially those built of high-quality timber. I do use engineering judgment to adjust calculated strengths upward on a case-by-case basis.

This is an admittedly gray area of code compliance, and those engineers who choose to dabble in gray tend to be reluctant to publicly share too many details. But how are we to learn, as a profession, to reconcile the glaring inconsistencies between code ratings and observed performance unless we share our experiences and discoveries with each other? I commend Phil for jump-starting the discussion and encourage other engineers to weigh in on their own approaches to evaluating historic structures.

Katie Hill, PE (structures@gmavt.net)
North Ferrisburgh, Vermont

The Bernese Bauernhaus

By David Bahler

Photos and drawings David Bahler

1 Farmhouse near Gammenthal, Canton Bern, Switzerland. Half-timbered style with side balconies.

AS the Roman era gave way to the Early Middle Ages in the 5th century, Germanic tribes invaded and settled the former Roman territories and brought drastic changes in local cultural systems. The West Germanic tribes such as the Franks, Angles and Saxons carried with them a broad, internally varying tradition of timber building that eventually evolved into the timber framing traditions of Western Europe. One such tribe, the Alemanni, brought their framing techniques into the Swiss Plateau and laid the foundations for the wide variety of Swiss timber building that arose over the course of the next millennium. The Swiss Plateau had been dominated by Gallo-Roman culture during the age of the Empire. The Roman inhabitants, with techniques imported from the Italian peninsula, built large villas of stone, a resource quite abundant in the sub-Alpine and Jurassic regions. The old Roman style of stone building was replaced by Germanic forms of wood framing in the region stretching between the Aar river to the southwest and Lake Constance to the northeast. The Roman style survives to this day in the western, French-speaking portions of the Swiss Plateau settled not by Alemanni but by Romanized Burgundians.

The settlements built by the Alemanni are often portrayed as primitive post and beam structures with earthen floors. Recent archeological evidence suggests that a fairly sophisticated timber framing tradition already existed when the Alemanni pressed into the region starting in the 6th century. Few remains of these early settlements exist, but cross-regional continuity suggests a strong tradition existed at this early stage. Techniques such as sill construction, brace configuration and rudimentary roof framing techniques all suggest that these were known to the early settlers whose descendants would become isolated from each other by distance and geography. Throughout the region where they settled, there continues to be a distinctly Alemannic style.

Across the Swiss Plateau, the more primitive Alemannic farmhouse would evolve into a diverse set of typically Swiss architectural forms. Perhaps the most impressive of these is the classic Bernese *Bauernhaus* (Fig. 1), or farmer's house. This architectural form found throughout the rural regions that fall under the cultural influence of Bern, including the Bernese portion of the Swiss Plateau, the Upper Aargau and portions of the cantons of Basel-Landschaft, Solothurn and Fribourg. Like most of the rural Alemannic forms, the Bernese farmhouse is a multipurpose structure (called *Mehrzweckbau*) housing the agricultural portions of the farm on one end and on the other as many as three or four separate apartments for the farm owners, the families of their sons and hired hands. These buildings are very large, as much as 50 or 60 ft. wide and 100 ft. or more long, with apartment levels as high as three stories below the eaves. They are imposing structures, often elegantly designed and pleasing to the eye, while at the same time thoroughly practical in their construction.

The Bernese farmhouse developed in direct response to changes in agriculture. During the Middle Ages, agriculture in the sub-Alpine regions of the canton of Bern was dominated by subsistence farming of cereal grains. Wheat and barley in particular were the primary crops of much of the region.

The basic form of the modern farmhouse existed at this time, but on a much smaller scale. The animals kept by a farmer would have been only enough to supply his own family with milk and cheese. The 17th century saw the beginning of a drastic shift in farming practices across the canton. Increased trade between cities and cantons brought about a higher demand for specialized farm products, particularly cheese and other dairy products. The rise in power and prominence of the city of Bern opened new markets to its rural subjects. During this time the earlier system of subsistence farming gave way to larger farms producing goods for trade and export. As a consequence, the number of cows a single farmer might keep rose rapidly from one or two up to 15 or 20. The agricultural portions of the farmhouses now needed to be much larger, able to house these larger herds and enough hay to keep them fed during the long winters. This sudden change brought about a great deal of innovation in rural Bernese architecture, as it was impractical simply to scale up the existing frame styles to meet the new needs. Carpenters were faced with the challenge of developing methods to frame large open structures, causing them to abandon the old system of direct-posted ridge beam construction.

2 Residential end of wealthy farmer's house from Ostermundigen, 1797, now in Ballenberg Open Air Museum near Brienz. Gray paint on front façade is intended to imitate sandstone of Ostermundigen townhouse and uppermost "windows" behind balcony are painted on for effect. Note also ornately carved and painted braces under balconies on sides. Multi-story residence with hay stored in gable above is typical as are side and front balconies.

3 Agricultural portion of same 1797 Bernese farmhouse. Note partly covered access ramp to hay mow (on right), broad and complex overhang framing, open slats for crop ventilation along eaves walls, utilitarian wall boarding, masonry construction of lower level.

Framing and plan The Bernese farmhouse is not a standard, cookie-cutter design repeated across the region. Each is built to meet the specific needs of the situation while reflecting the knowledge and skill of the carpenters involved. We will cite what is typical, but the typical is by no means the rule. Of generous size, the Bernese farmhouse is typified by a longitudinal ridge and a large, steep, hipped or hip-ended roof, and it houses the primary farming activities and the residents under that single roof. In contrast to the log-built houses of the Alpine regions of the canton of Bern and the stone architecture of the Bernese Jura, the lowland Bernese farmhouse is a timber-framed structure.

Of the two main parts of the farmhouse, the agricultural and residential, the latter occupies the front section of each structure, almost always located on the downhill side (Fig. 2). The agricultural portion occupies the back two-thirds or more of the structure at ground level, and may take up almost all of the attic space. The ridge beam runs from front to back.

Framing of the residential portion is relatively simple. Direct posts can be used to support the roof purlins in many cases since the space is divided into smaller rooms. The finishing of this section is naturally more refined than that of the agricultural sections, to produce a more comfortable and inviting atmosphere. In some areas the dwelling may be half-timbered and paneled on the inside; other regions favor an all-wood construction with horizontal plank infill between the upright framing timbers. Half-timbered structures rely on long braces extending from sill to plate while plank-filled frames typically rely on the infill to serve the same stiffening purpose. The residential section is typically divided into two or more apartments, which often share a common centrally located kitchen. Interior walls are clad with paneling regardless of infill method. This paneling may be simple or remarkably ornate. Always it reflects the high woodworking skill of Bernese craftsmen.

The agricultural part of a Bernese farmhouse is generally utilitarian in style (Fig. 3). While the residential portion may feature elegantly carved window ledges, ornately profiled timbers or sharply dressed plaster infill, the agricultural portion is built simply, lacking unnecessary adornment and decoration. The lower portion houses the animals on the end of the building farthest from the dwelling, and might be built of masonry rather than wood. If wood-framed, animal quarters infill typically is in the form of wooden planks with gaps left between for air circulation. A granary or utility section might be placed between the animals and dwelling (but typically the granary is a separate structure, reducing the risk that all assets will be lost in case of fire).

An intermediate aisle, opening to both residential and agricultural sides of the building in times past, served as a threshing floor. In modern times, this space is often remodeled to house additional animals or farm equipment since threshing is now a remote process. The space above the agricultural section is divided into areas for the storage of hay, straw and large farm equipment. This upper section is accessed directly by means of a large covered ramp and may extend above the residential section, where the hay and straw once served as insulation during the cold winter months.

The framing of the walls and floors of these buildings is straightforward. Comparatively small posts, perhaps as small as 5 in. square, are placed anywhere from 3 to 8 ft. apart; these are smaller in cross-section and closer together in residential quarters and on newer building, larger in cross-section and farther apart in agricultural quarters and in the oldest surviving examples. As observed, walls may be braced or infilled.

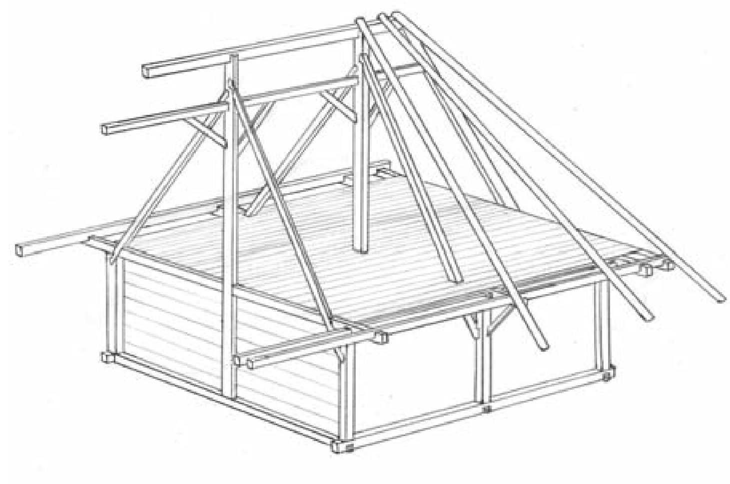
Earlier frames exhibit a medieval tendency toward widely spaced, large-section timbers with heavy joinery, giving way in time to a more typical South Germanic system of small, relatively close timbers with light joinery. Regardless of period, typical Bernese farmhouses employ platform framing, where each level is framed with its own supporting posts, rather than using tall posts stretching up from the foundation to the roof. This, to the Swiss carpenter, is a way of solving the problems of joining floor framing to wall framing and providing interior floor support. Simple joinery in a relatively greater number of small timbers became favored over more complex joinery with fewer timbers, such as in much English or American framing. Over time, joinery reached a point where tenons were rarely longer than 2 in. and pegging of joints was all but nonexistent. Older practices can be observed in structures dating to the 16th and 17th centuries, while modern methods were firmly established by the end of the 18th century. Carpenters accustomed to Anglo-American methods of large pegged tenons and similar heavy timber joinery are often surprised by the simplicity and small size of the joinery in these Swiss structures.

To the northeast of this style's range, infill in the residential portion is most commonly large wooden planks of the same thickness as the framing timbers, producing a flush surface inside and out. The tongued-and grooved planks have stub tenons on their ends to fit grooves in the posts and fit horizontally between the posts. Thus the wall is relatively well sealed against drafts. Where this system is used, braces within the walls are unnecessary. To the southwest, walls are more often framed with braces and infilled with stone, which is then plastered smooth, perhaps owing to an influence from the urban styles of the city of Bern or to the Roman-inspired styles of the French-speaking regions to the west.

Across the region, large balconies (Figs. 1 and 2) are an almost universal feature, extending not merely from the gable end but also from the eaves side of the residential portion and accessed directly by stairways—at times the only access to the upper stories of the structure. Given the platform-framing system, the balconies can rest on extended transverse floor joists reaching several feet past eaves walls, often braced back to the walls for additional support. Decorative designs might be cut into the vertical board cladding on the outside. (The construction and decoration of these balconies along with their balusters and railings could form a topic completely unto itself.)

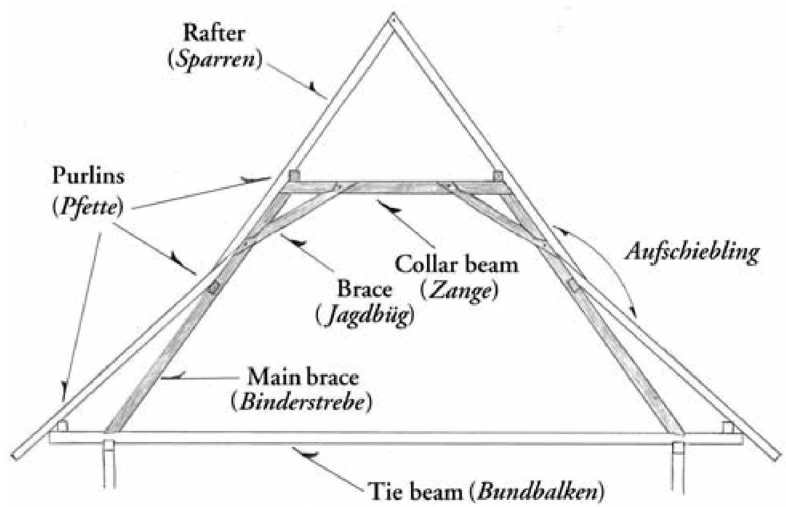
Roof framing While simplicity is generally the rule in Swiss wall and floor framing, when it comes to roof framing configurations can be complex and ingenious. The functional principle of the Bernese roof is that the attic space directly beneath it needs to be accessible and usable for the storage of hay. Buildings were designed so that large hay wagons could be driven up the ramp right into the loft and unloaded directly. This necessitated a large open space without interfering framing members.

4 House from Madiswil now at Ballenberg Museum, late example (1709) of older building form with steep roof pitch and full hips.



5 Older high-posted ridge framing later displaced by Liegender Binder framing. Some braces and rafters omitted for clarity.

6 Liegender Binder framing in haymow of farmhouse on Buechholz farm near Sumiswald.



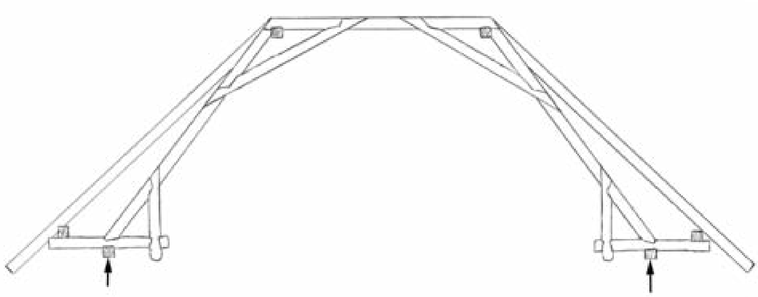
7 Liegender Binder framing anatomy.

The medieval method for roof framing used high posts supporting a ridge beam (Figs. 4 and 5). As buildings grew in size, these posts were no longer stable without a rather complex network of struts and braces. Such a network of course would have greatly reduced the amount of usable space and the ability to move freely within it. To solve this problem, the ridge posts were replaced with two canted posts rising from tie beams near the exterior walls toward the center. At first these canted posts supported a ridge beam with something akin to a high kingpost truss, the kingpost rising from a high collar instead of extending down to the tie beam. As roofs grew larger, ridge framing was abandoned in favor of purlins at midlength under the rafters, and the canted posts stopped there. This system is called the *Liegender Binder*, or the reclining truss, known in other German-speaking regions as the *Liegender Dachstuhl*, or reclining chair, when in an assembly of two or more transverse frames linked by longitudinal plates and purlins (see "The Liegender Stuhl Roof Style," TF 108). The Liegender Binder in its basic form consists of two canted posts joined by a collar at the top and a tie beam below (in Switzerland known respectively as *Binderstrebe, Zange* and *Bundbalken*). Two braces (*Jagdbüge*) connect the canted posts to the collar beam above, preventing any tendency for the assembly to rack to one side or the other under unequal loading (Figs. 6 and 7).

A number of complexities might be added to this structure to suit specific needs of a given situation. Typically the angle of the posts is more nearly upright than the slope of the roof, which is often somewhere in the area of 45 degrees. In many cases, the lower portion of the roof is somewhat flatter while the upper part follows the slope of the posts. This is known as *Aufschiebling* (pushing off).

With the development of this new method of roof framing, carpenters were free to build larger, more open structures. The switch from a primarily ridge-posted roof system to a principal purlin system of roof framing in particular meant that immense structures could be achieved. The former system required excessively long and stout rafters since there was no intermediate support. With the switch to purlin support, shorter sections could be used instead of a single long rafter. Aufschiebling appears to have arisen from this practice, where it was seen as both practical and attractive to place the rafter sets at different angles. (The Bernese actually want snow on their roofs. They often put large hooks on the steep roofs to catch snow so it stays up there. The tile roof is not very air-tight, and snow is seen as a good way to hold off cold winter drafts.) The practicality of the Aufschiebling is the ease with which two rafter lengths can be joined together, since the lower section can be butted and spiked without needing any sort of joinery.

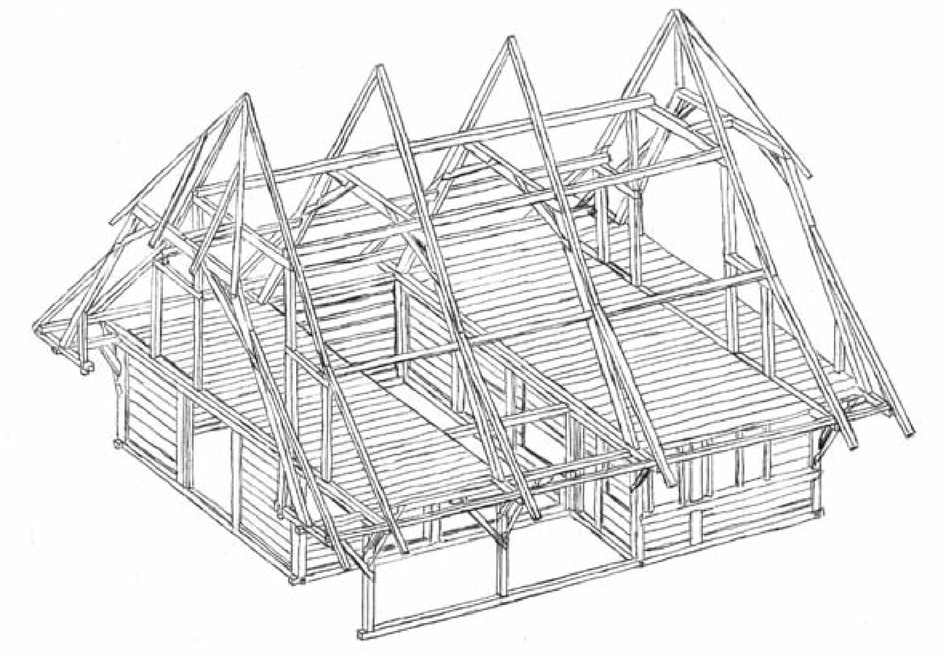
Perhaps the most remarkable aspect of Bernese roof framing is the use of balance and cantilever to transfer loads (Fig. 7). The lowest support purlin is always lodged several feet outboard of the eaves wall. The cantilevered beams supporting the purlins, and which double both as tie beams and floor joists, are forced downward by the rafter load and give an upward flex to the span between the wall supports, thus adding stiffness to the floor. In gable end overhangs, which might be as much as 8 ft., braced supports springing from the wall provide fulcrums for inner and outer rafters to balance their loads (Figs. 8 and 9).



8 Representative overhang framing with outer rafter loads balanced over indicated support points.

9 Complex overhang framing in Affoltern im Emmental.

A century or more ago, thatch was the primary roof covering across much of the Swiss Plateau. Over time, wood shingles split from fir appeared, and later clay tiles, the latter by far the most common roof cladding in the country today. Owing to the requirements of a thatched roof, the roof slopes on these buildings are very steep, 45 degrees or greater. Even modern construction that will never be clad with thatch replicates this older style. In addition to the high peaks, these roofs also have very generous overhang. In the Emmental region it is not uncommon for the roofs of a two-story structure to reach nearly to the ground. These large overhangs provide excellent shelter for the walls, protecting them from the elements. In times past, much of the equipment needed for secondary farm-related activity would be stored along the walls under the shelter of these large roofs. It is still common to see large stacks of firewood all around these buildings, as wood continues to be the most common form of heating in the rural regions.



10 Modified Liegender Binder framing for a quarter-hipped Bernese-style building under construction by author in Indiana.

The oldest structures are often fully hipped (*Walmdach*) as in Fig. 4. Starting around the time of the introduction of the Liegender Binder method of roof framing, end hips gradually became smaller and smaller. Today half-hips are common, and especially in the western regions of the canton of Bern the quarter-hip (*Viertelwalmdach*) is the most common. The full-hipped roof is an ancient Germanic architectural style, with the half-hip or quarter-hip (Figs. 9 and 10) appearing as the desire increased for more usable upper-level space, to be obtained by raising the end wall. It is common for the full hip to be retained on the agricultural end of a building with the smaller hip on the residential end.

The massive roofs that result from the steep slopes, large overhangs and proud hips of these structures are without a doubt the defining characteristic of the architecture of the region. It is the roof that makes the strongest impression on the observer, and its characteristic shape and proportions set this style apart from other related Swiss traditions. The Bernese is one of the most beloved of the many Swiss architectural styles, the massive buildings blending in with the landscape around them rather than rising up to dominate it, as seen in the panorama of Fig. 11.

David Bahler (dlbahler@live.com) is a carpenter near Kokomo, Indiana. He last wrote on houses of the Berner Oberland (TF 106).

11 Countryside in the Emmental region of the Canton of Bern.

Toward Effective Client Relations

By Craig Bridgman

BUSY timber framers immersed in their craft may feel they have little time to dedicate to the nonartisanal needs of their customers. They're craftsmen, after all, not specialists in customer or client relationship management. These days, though, one can scarcely toss a mallet in the air without it being caught by a competitor, and that's a game-changer. It makes client relations and the manner in which the timber framer addresses them a priority.

Building a timber frame is or should be a unique and meaningful experience for the clients, who expect fine craftsmanship, of course, but also assurance that the framer they entrusted with their house or addition will behave sensitively in an emotional, complex and lengthy undertaking. An empathetic relationship cultivated from the first meeting and reinforced by continuing communication influences both the quality of the experience and the level of the clients' satisfaction.

What sets timber frame clients apart from the run-of-the-mill buyer of conventional construction? For one thing, the decision to build a timber frame is a lifestyle choice, an escape from conventional architecture and mass-market housing. For another, heightened sensitivity to craftsmanship and the beauty of timber makes incorporating these elements into their daily life a priority. Perhaps most important, in an age of throw-away products, shifting beliefs and uncertainty about the future, clients desire a structure made to last. They don't wish merely for an impressive roof over their head, but to integrate their life into something traditional and enduring. They're about as close as any of us is going to get to the pharaohs contemplating the raising of their pyramids. Ordinary would not be the word to describe them or their expectations.

In late 2011, my wife Maria Helena and I decided to build a timber-framed house. Although clients differ in the details of design, budget and personality, in most important respects our emotional landscape and practical requirements were typical. We needed a framer who could relate to and counsel us, as well as expertly cut and raise our frame. The experience awaiting us turned out to be as instructive in the unfolding as it was unexpected in its sequel.

Like many, we began in a quandary about the size and configuration of the house we should build, with a hundred details crowding into our minds at once. Where to begin? Web research produced a handful of companies with ready-made plans that helped us focus our thinking. One in particular had a comprehensive, well-designed site that became a primary reference. This was significant. Customers new to the mechanics of timber frame construction need guidance, and a website that includes, as this one did, floor plans, photos, and elevations, along with tips on items like permitting, design, budgeting, finding contractors and suppliers, avoiding common pitfalls, etc., delivers value. It also forges the first link in the customer relationship. A treatise on each bullet point is unnecessary. The site need only provide enough information to demystify the building process for the novice and prompt phone calls that position the timber framer to develop the relationship further.

Maria Helena and I spent several weeks in the evenings over a glass of wine studying plans and budget numbers. Gradually a rough idea of what we wanted and could afford took shape. We arranged to visit the company whose website had been so helpful, and their salesman took us to see an ambitious hybrid project nearby. At that point, though, things began to run off the rails. The project he chose reflected neither their best capabilities nor reinforced their strong Web presence. Moreover, it bore no resemblance to what we wanted to build. We weren't looking for a hybrid but a pure timber frame, and the floor plan we had in mind was a third the size of the one being shown us. Although it's desirable to showcase work with visits to actual projects, the exercise can backfire if these don't correspond to the client's vision for his own. Someone with a rustic 1200-sq.-ft. weekend cottage by a lake in mind may find a 10,000-sq.-ft. mansion built on palisades overlooking the Pacific intimidating, as if he'd mistakenly wandered into the Bentley dealership when what he really wants—and can afford—is a Chevy. If a project of suitable scope is unavailable or impractical to visit, clients can be prepared beforehand to focus on a particular room or joinery details and not the overall structure. This avoids the misstep of making them feel they're out of their league before they've begun. The rule in general is: suit the project to the client's purse and plans.

We resumed our Web research to fill in lingering gaps in our timber frame education—and we began to stray. We decided to visit a small craft shop in eastern Connecticut. Its gorgeous timber-framed office building beside a waterfall in a fragrant pine forest set the scene. It was a hopeful start. Our interview with the owner, however, consisted of ten minutes of pleasantries. When the chit-chat ended, he handed us a brochure prized out of the bottom drawer of a filing cabinet. Perhaps we'd find something in it we liked, he suggested, and returned to his drafting table. We left.

This framer hadn't asked more than a cursory question or two about our project nor offered any information of value. He'd expressed no interest in us. His was a compelling example of how not to initiate a customer relationship, which requires substantial dialogue. Encouraging this dialogue, the timber framer gets a sense of the client's personality and a feel for how the proposed building should go forward. That most of us are ineffective listeners may be taken for granted, but that's a good reason to become a better one, concentrating attention on what the client has to say. Likewise, most of us suffer from the failure of others to hear and understand us, especially in business situations. Being a good listener, while simultaneously satisfying the client's need to be heard, gets things moving in the right direction. In the best of circumstances it can be immensely gratifying.

We were now three months into our thinking and, despite having visited two timber framing companies and studied the websites of a dozen more, we still weren't where we wanted to be. The more design, detail and procedure questions we cleared away, the more they cropped up. It was getting frustrating. One evening, in a chance Web search, we found a small framing company in central Massachusetts, and the next morning we called them. After posing a few qualifying questions, the father-and-son owners said they'd drive down to Connecticut to meet us, discuss our project and help out with ideas. They made no charge for the visit and assured us it implied no obligation. They were polite, professional and, above all, quick off the mark. As we hung up the phone, a light bulb came on, a mental glimmer that perhaps we were about to take the right fork in the path.

A week later, father and son were sitting at our dining room table sketching a floor layout and a rough schematic on a quadrille pad. Theirs was a true timber framing company, they explained, with a track record of 500 unique frames designed, cut and raised. In 45 minutes they resolved several nagging layout questions for us and through a combination of honesty, intelligence and evident competence persuaded us that they and their craftsmen would see us through. If any overt selling took place, we missed it. It wasn't necessary anyway. The chemistry was there.

We drove up to Massachusetts for an initial visit. In contrast to the other timber framers we went to see, this one's world headquarters consisted of a large metal building with a cramped office segregated off in one corner. The operation boasted neither showroom nor conference room. A scale model of a timber frame on a table in the corner and a well-worn portfolio of project photos supplemented by a brochure constituted their non-Web marketing materials. The cants stacked in the yard and the frame being cut in the shop were the only timbers in evidence. It was decidedly bare-bones, classical form following function. But that function was clearly the owners' raison d'être and true passion. The business had the right feel to it.

This was the only company that permitted us to see their craftsmen at work and in fact encouraged us to do so. We watched one man chisel the finishing touches to a dovetail joint while he explained his technique. Another sighted along the crown in a timber and positioned it for the layout of a scarf joint. Know-how, cooperation and enthusiasm pervaded the workers. Yes, the owners had connected with us on the initial phone call, and yes, they'd solidified that connection during their visit to our home. There had been plenty of communication, but being in their shop brought our intentions to life. Inviting clients to see where the magic happens and to meet the craftsmen who conjure it up enhances the romance of timber framing for them, as it did for us. Treading the sawdust and shavings on the shop floor, breathing in the scent of raw wood and watching work in process makes tangible what previously existed solely in imagination and on paper. It's also a proof of more than casual interest. The client has left the virtual world of Web and telephone and joined you the framer in your real world, where human beings work and interact. It's a high-touch phenomenon, and no amount of slick Web marketing or fancy facilities will compensate for the lack of it. Done right it cements the relationship. In our case, it made our project real and filled us with the desire and the courage to move forward. Here was the craftsmanship as well as the counsel and the human connection we'd been seeking. Contracting with the company for our timber frame was a no-brainer.

In the spring of 2012 we bought a five-acre parcel in Cornwall Bridge, Connecticut, and our framers came down to get the lay of the land and make recommendations on the placement and orientation of our future home. Maria Helena and I, in what friends and relatives bluntly characterized as a death wish, had decided to act as general contractors. Our framers supplied us with a checklist and a timetable for the site work we had to complete. They passed along advice to keep us out of trouble, such as having adequate electrical service available for the number of subcontractors, including themselves, who would be working on the site and getting the foundation placed accurately and the deck built well in advance of their arrival. To say that they took up the role of project manager would be overstating it, but their desire to do what they could to assure that things came off smoothly, and not just as it concerned them, went to the heart of the matter. The focus was on us and the overall success of our project.

In late fall, the same men who cut our frame arrived to raise it. During the tour of the shop, I'd asked the founder of the business how he chose his craftsmen. "For their ability to work in a team," he said. "I can teach anyone to make a mortise and tenon, but I can't teach a man how to get along with his co-workers." As we watched the crew work, we got a sense of the wisdom of this approach. To the extent that the employees display friendliness, cooperation and sensitivity to each other and the client, they join in creating satisfaction. Actively

Susana Ughetti

One happy client, mid-raising.

encouraging courtesy, cooperation and client orientation is good business sense. Our crew interacted like the Blue Angels squadron of timber framing. They willingly and cheerfully answered our questions and explained operations of interest. In short, at the tail end of the process they reinforced the professionalism the owners had displayed from the beginning. Concern for the client wove through every step, including this last. It put the capstone on our project and deepened the satisfaction we felt in having chosen to work with this particular company.

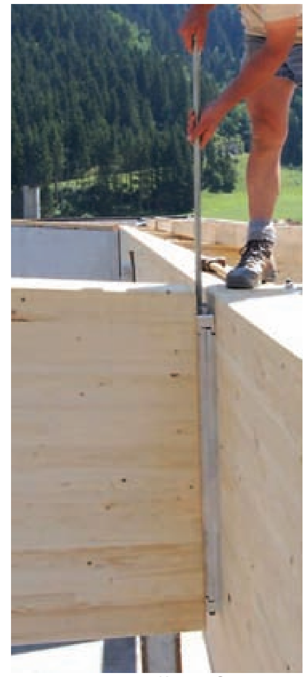
The epilogue to our project affected me personally. Business success lies in placing customers or clients on center stage and striving to understand their needs, as opposed to "selling" them ad nauseam, or up-selling them (adding profitable features or diverting the client to more expensive options). Or treating them with indifference. Tone-deaf companies that relegate us to maddening voice-recognition software or time-wasting "chat" and call it "customer service" put me in a black humor. They fail in the most basic sense—that of acknowledging our common humanity by responding to us personally instead of assigning us to machines. Our favorable experience with our timber framers prompted a second, after-raising thank-you visit to their shop that, in turn, led to a decision on my part to represent the firm. In aligning myself with a company whose business philosophy revolved around genuine interest in the client, and honest engagement, I saw a chance to buck the prevailing, dehumanizing trend. And so began my professional involvement with the timber framing industry.

Call it nostalgia or call it the desire for a link to a faraway past that will carry forward into a distant future—customers, too, want to connect personally with our artisanal tradition. Most timber framing operations, being small and nimble, are ideally suited to develop and sustain such connections. Sensitivity to that possibility makes life richer for the people who come to timber framers to fulfill their dream.

Craig Bridgman (bridgman.craig@gmail.com) managed international sales and marketing for two medical equipment companies and later was vice president of sales and marketing for a Connecticut publisher before representing his timber framers in sales and customer relations.

Engineered Timber Connectors

By Max Closen

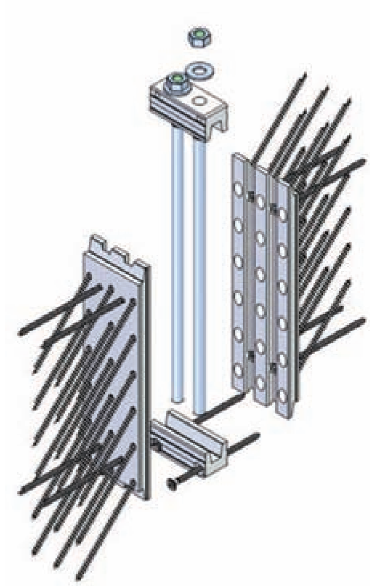



Knapp Connectors

1, 2 Above, glulam joists 8½x39 carried by heavy-duty aluminum connectors, in Grossarl, Austria. Above right, tightening long bolts to clamp mating connectors.

TRADITIONAL timber joints such as mortise and tenon connections have proven their long-term suitability in countless houses, churches, meeting halls and commercial buildings around the world. But in larger engineered commercial or public timber buildings today, their application may be restricted because of limited structural capacity or labor-intensiveness, or both.

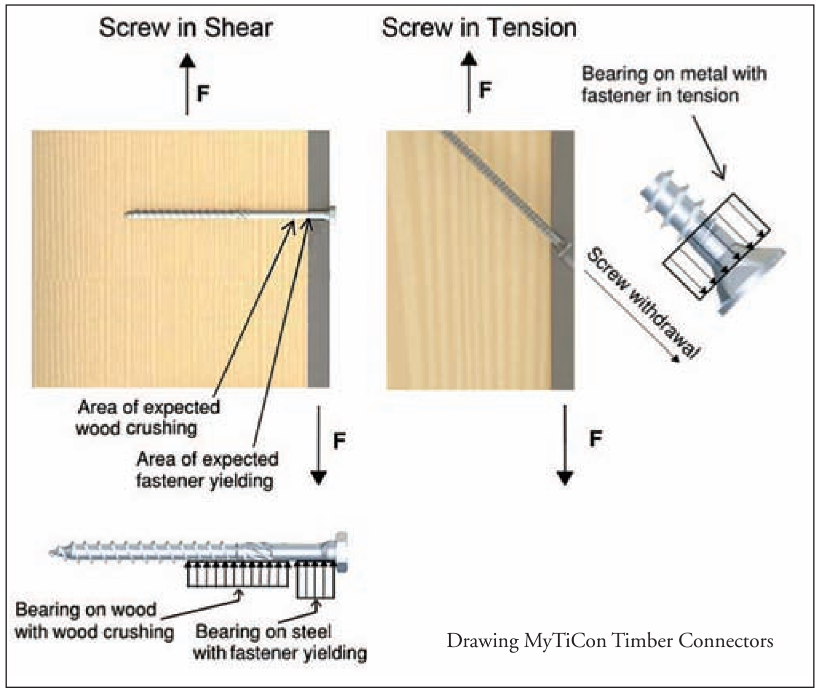
Heavy-duty connectors The appearance of large-scale commercial timber structures initially in Europe and recently in Canada and the US Northwest has pushed the development of heavy-duty engineered metal connections to a new level (Figs. 1 and 2). To obtain large load capacities while maintaining high fabrication efficiency, heavy-duty systems consist of two mating pieces of machined aluminum in various dimensions and shapes. Load-resistance ratings (unadjusted for load duration, timber species, service conditions or wood moisture content) range from 6700 lbs. to 112,000 (Figs. 3 and 4).



4 Exploded view of fastening and clamping elements.

3 Detail of mating connectors and lower clamp jaw.

Full-thread self-tapping screws fasten the aluminum parts to the end grain or side grain of the wooden members. To obtain high load-resistance, the screws enter at an angle to the wood grain, typically 45 degrees, taking advantage of the strongest property of the screws, their withdrawal resistance. In the past, screws in connections were used mainly in shear, with a force component perpendicular to the screw axis, and possible failure modes in bending of the screw or crushing of the wood. This configuration offers high ductility but lower resistance when compared with screws in tension. The newest connectors take advantage of the screws' strongest properties through an inclined installation (Fig. 5).



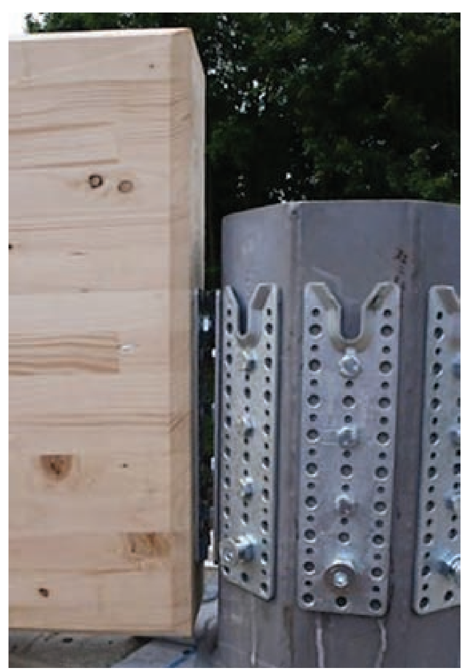
Drawing MyTiCon Timber Connectors

5 Comparison of conventional and withdrawal-plane fastening.

When raising large commercial structures, construction time is of great importance. Premanufactured timber elements including installed connection systems can reduce construction and costly crane time, especially in cold climates where work naturally slows in winter. Requiring only a short assembly distance of ¾ in. for full engagement of heavy-duty connectors (Figs. 2 and 3) contributes to smooth installation and shortens construction time.

Connector manufacturers and distributors may provide end users with setting and routing jigs and other required hand tools for efficient installation, or CNC-machine data, as well as technical support to engineers and designers.

The installation shown in Figs. 1–3 fully exposes the connectors and hence does not allow for fire-resistance rating without additional measures. Alternatively, metal connectors may be concealed or housed, providing sufficient wood cover on three sides and allowing for a fire rating based on the charring rate of the respective timber. Fig. 6 illustrates a medium-duty, concealed, unhoused connector. In a further advantage of the new connection hardware, substituting bolts or concrete anchors for wood screws allows secure connections between wooden elements and steel or concrete elements (Fig. 7).



6 At right, concealed medium-duty V-notch mating connectors.

7 At far right, similar connectors, unconcealed, in a wood-to-steel application.

Medium-duty connectors These provide load resistance (unadjusted) in a range between approximately 4400 and 11,200 lbs., appropriate for common timber frame connections such as post to beam, beam to girder or rafter to ridge beam. Like the heavy-duty connectors, these can be installed hidden or visible. In North America, mating aluminum dovetail plates or mild steel plates with V-notch and collar bolts are the most common forms.

Mild steel plates and collar bolts are mostly adjustable to allow for member-length tolerances of up to ⅛ in. The tolerance helps in beams with large cross-sections since a perfect and plumb end cut is not easy to accomplish. Parallel beam lowering is also eased, with reduced jamming at the connection, through adjustment of the collar bolt, which can be turned in or out. Further, the V-shaped notch allows for a self-centering connection and helps during assembly on site. Aluminum dovetail connectors (not illustrated) may be viewed as tight connectors with little tolerance, but their fit too may be adjusted on site by careful loosening or tightening of fasteners. (Overtightening of fasteners may, however, deform aluminum plates, leading to fitting problems.)

Compared to traditional dovetail joinery or modern dovetail connectors, V-notched connectors may provide an advantage. The distance to be traveled to fully engage male and female parts is only 1⅜ in., whereas dovetailed connections require a greater height or the full height of the dovetail for assembly. In structures with limited space for assembly, or in existing structures, this feature is advantageous.

Light-duty connectors Consisting typically of two mild steel plates with tapered V-shaped notches, or two pieces of milled aluminum with mating dovetail joint, light-duty connectors may be used in heavy stair and window-frame construction, premanufactured wall installation and other applications where design loads are rather small. Typical resistances (unadjusted as before) range from approximately 670 lbs. to 4400 lbs. These connectors can be installed visible or fully concealed, with full-thread self-tapping fasteners. Figs. 8 and 9 show light-duty mating connectors with collar bolt (male) and V-notch (female).

8 Light-duty collar bolt in crosslam member end.

9 Light-duty V-notch connector in crosslam housing

To sum up the advantages of the latest connectors, they are or they may be:

- Preassembled in a controlled environment
- Test-fitted in the shop
- Quickly demountable for use in temporary or movable structures
- Fully concealable if desired for appearance or fire rating
- Available in wide range of load ratings
- Capable of multiple-material connections (wood-to-wood, wood-to-steel, wood-to-concrete)

Encouraging more timber to be used in engineered commercial projects may be good for the trade at both the fabrication and the assembly levels.

Max Closen (max@my-ti-con.com) owns MyTiCon timber connectors in Vancouver, British Columbia. He wrote about threaded steel fasteners in TF 109.

Norwegian Grindbygg Construction

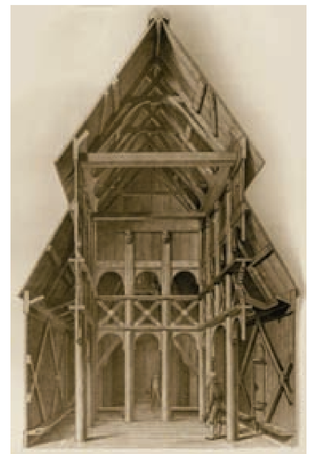
By Peter Henrikson

Peter Henrikson

1 Traditional storehouse, or laft, used for food, treasures, summer sleeping, guests.

Svein Harkestad, Wikimedia Commons

2 Iconic 12th-century stavkirke at Borgund, Norway.

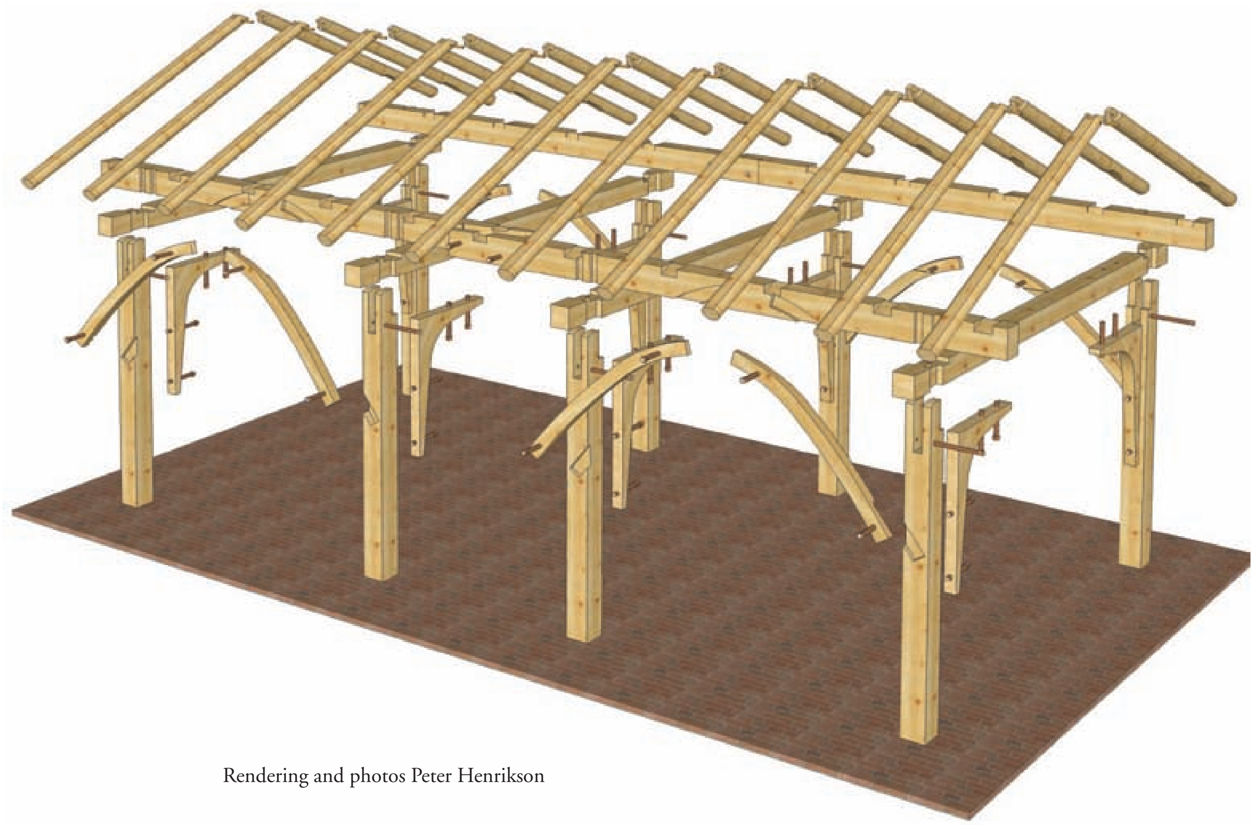


G. A. Bull, Wikimedia Commons

3 Borgund stave church, interior framing.

YEARS ago, I became fascinated with the traditional wooden buildings of Norway. The closest things I knew of to timber framing there were the *laft,* or storehouse, with its overhanging second story of post construction (Fig. 1), and the *stav* churches (Figs. 2 and 3). These were important structures to their owners and parishioners, respectively, and were often ornately carved. Then I came across the booklet *Grindbygningen* at a fundraising auction for North House Folk School in Grand Marais, Minnesota. The work was in Norwegian but had good photos and drawings of what appeared to be an early timber frame building style. It was my first look at *grindbygg* frames. In translation, *bygg* means building and *grind* is most often translated as gate or trestle, but in timber framing terminology the latter is a simple bent of two posts and a tie beam. Thus the basic form looked familiar: posts connected by a tie beam, wall plates and common rafters, knee braces (Fig. 4, a modern example). A closer look revealed no blind mortises. All parts were joined by lap joints, notches and pegs. The braces were often curved natural form pieces and occasionally root knees. These were buildings without the adornment of the laft and stav church, but with great utilitarian appeal.

4 Class-built grindbygg frame, in service as carport, Voss.



5 Exploded rendering of representative grindbygg frame with lapped curved longitudinal braces and pegged root knee transverse braces.

My interest led me to much research, many inquiries and eventually a trip to Norway in fall of 2012. While in Norway, I had arranged to take a class in grindbygg construction taught by Kåre Herfindal (who wrote *Grindbygningen*), to work with a builder using curved braces and root knees, and to visit historic structures.

The grindbygg frame style has a rich historical past. Existing grindbygg frames have been dated to the late 1500s and continued to be constructed into the early 1900s. Archeological evidence from 1100 AD shows similar post locations and the same necked tying joint. Excavations of even older long houses from as early as 500 AD show eaves walls of stone and turf, wood gable walls and two rows of free-standing interior posts which are speculated to have incorporated the same tying joint. This stav (post) construction was the predominant building style until the Vikings brought horizontal log construction techniques home from their travels in Russia. Log construction, with its tight walls, made for more comfortable living in this northern climate and relatively quickly took over as the dominant building technique. But along the coastal and fjord areas of southwestern Norway, grindbygg construction remained the predominant building style for unheated buildings, primarily because of the absence of the extensive pine and spruce forests needed for log construction found farther inland. While pine was, and still is, the wood of choice in grindbygg frames, hardwood species such as birch and aspen are often found where pine is absent.

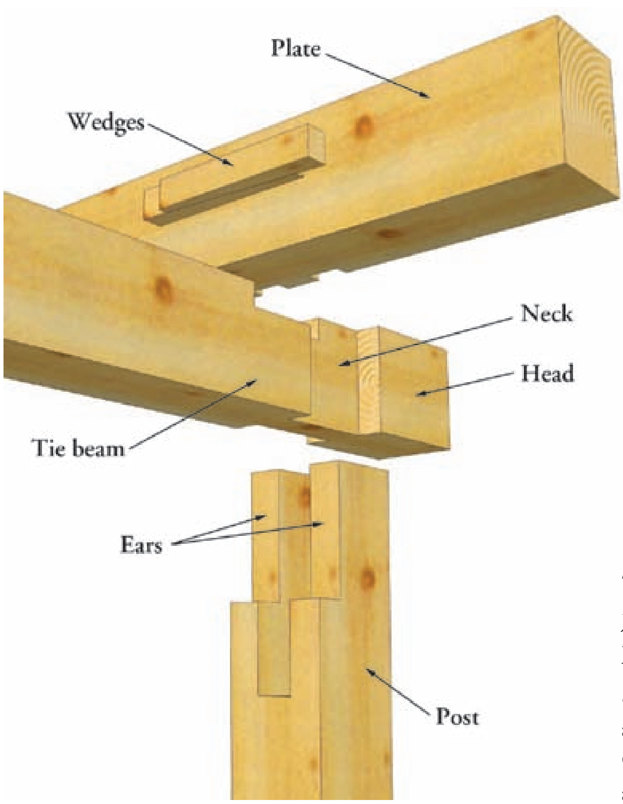
All Grindbygg frames are made up of a series of simple bents, each composed of two posts and a tie beam (*bete*). A wall plate (*stavlægje*) sits on each end of the tie beams and against the post tops. The rafters (*sperre*) are joined to the top of the plate and overhang. Braces (*snedband*) are located in each bent and along most wall sections (Fig. 5).

Roof pitch is commonly 8:12 with some regional variation, viewed in Norway as a 1/3 roof, expressed as height from eaves to ridge over building width, here 8/24. Timbers are generally hewn square, but partially hewn frames and frames hewn only at the joinery exist.

Historical examples often have the post bases displaced outward 5 to 6 in. transversely, with the canted posts sitting directly on a stone pier (Fig. 6), and thus the possibility of side aisles. These were built either with studs attached to the overhanging rafters, or a secondary set of posts and a top plate usually connected back to the main frame only by the rafters. In some southern areas, such as in Rogaland, it was common to extend the aisle around the gable end, forming a Dutch hip roof.

The grindbygg frame is primarily defined by the simple and strong necked tying joint connecting post, tie beam and plate (Figs. 7 and 8). The tie beams are notched both sides, 6 to 8 in. from an end, the notches leaving a neck with the remaining full-section end forming the head of the beam. A slot is cut into the top of the post the same width as the neck of the tie beam, to form what we might call the ears of the post. The neck slides into this slot, cut deep enough that the post ears extend above the tie beam when the latter is slid into place. The plate then sits on the tie beam and rests against the post ears. Generally, the post ears are also cut back on the inner side to form a shoulder so that the plate sits on the post as well as the tie beam. The result is a tying joint that's efficient and straightforward. Everything is in compression as the roof loads push from rafter to plate to post ears to head of the tie beam. "Brutally efficient to the point of being elegant," according to one timber engineer, it provides ample strength to withstand the outward force of the common rafters on the plate even with heavy snow loads, not to mention the dead loads. All the historic grindbygg frames I saw had roofs of either sod or thick slate, some slates measuring 4x5 ft. and 1½ in. thick, weighing over 400 lbs.

6 Canted-post style grindbygg frame from Sunnfjord, 18th century, now at Norsk Folk Museum.



7 At left, exploded view and anatomy of necked tying joint, here with folding wedges to restrain lower part of plate against rafter action that ultimately locks joint.

8 Scots pine necked tying joint with 8-in. head, 2-in. neck and single wedge. Tension testing of similar joint at Guild's 2013 North Central regional meeting was stopped at 22,000 lbs. for safety reasons, well before failure.

9 Plate (at back of photo) notched to tie and post (arrow). Notch for post fairly shallow.

10 Plate notched to tie. Head beveled off to follow roof pitch.

11 Large peg set in tie beam just inside plate helps keeps plate from rolling under rafter action. Note step-lap rafter joint.

12 Unusual unwedged plate, deeply notched in post and tightly fitted to ears.

While the form of grindbygg frames is the same throughout southwestern Norway, there are many differences in the specifics of the joinery as well as the naming of parts. Different fjords, separated by only a few miles of impassable mountains, were isolated enough from one another that differences in language, culture and construction technique developed. During my class in Norway, there were often side discussions about certain regional terms used by Kåre that were unfamiliar to some students. The tying joint varies primarily in how the plate is joined to the post and tie beam. The plate can be notched around the post ears, the tie beam or both (Figs. 9 and 10). The plate is always held against the post ears to prevent any twisting action from the rafter thrust on the top of the plate. For small frames, this can be accomplished with a large peg set in the tie beam (Fig. 11) to hold the plate tight against the post ears, preventing the bottom from rolling inward as the top is pushed out by the rafters. Most often, the plate is set in an over-wide notch in the tie beam and a wedge (or opposing wedges) driven in to hold the plate tight against the post. Many examples had wedges missing but with no apparent movement of the plate. I saw only one example of a tightly fitted, unwedged plate (Fig. 12).

If there isn't enough depth in the tie beam or it's otherwise not desirable to cut a notch, a piece of wood (*brotastykke*) is pegged to the top of the tie beam tight against the plate or with room to drive a wedge (Fig. 13). Traditionally, there was no attachment to prevent uplift of the plate, the weight of sod or slate roofing being more than adequate to anchor it.

13 Piece pegged to top of tie beam serves to keep plate tight to post. Wedge has gone missing with no sign of subsequent plate movement.

Brace style and joinery vary: straight pine, curved birch (some curved up, some curved down), doubled, crossed, long, short—and root knees. When I asked how hard it was to find nicely curved and matching birch for braces, I was told, "It's easy, they all grow that way on the steep hillsides." With the exception of the root knees, braces are scribed and lapped into the main timbers, the majority in simple half-laps, but there are historic examples of half-dovetail and notched or cogged laps as well. The braces are secured with tight joinery as well as a large peg, often octagonal and with a large head. Essential steps in straight brace procedure are shown in the photo sequence (Figs. 14–17). Root knees are primarily found in boathouses, providing additional headroom around a boat (and echoing aesthetically the root knees used for the stem and stern of the traditional wooden boats). No joinery secures the root knees—they are simply attached with four pegs or barbed spikes.

14 Brace located, Kåre Herfindal marks for shoulder.

15 Shoulders cut, tenons to scribe on post and plate.

16 Tenon outline scribed, depth marked with template.

17 Lap housings cut, Kåre hammers home brace.

Rafter joinery resembles certain traditional North American timber framing, with an open mortise and tenon at the peak. The rafters cross the plate with either a steplap (Fig. 11) or a simpler inverted V cut into the top of the plate (Fig. 18). In historic structures, I found the inverted-V joinery only on plates that were tall and rectangular. Scarf joints on the plates are simple half-laps or stop-splayed, usually vertical, and pegged with two pegs. They are located either at a post or between two closely spaced posts (Fig. 19).

The layout of joinery is accomplished with templates and scribing. Here is the traditional construction sequence, just as we followed it in the class, and which I have used subsequently:

1. Scarf plates.
2. Lay out and cut slot in post tops using template.
3. Layup wall to scribe joinery of post-plate connection, disassemble and cut.
4. Layup wall to scribe and fit braces, disassemble.
5. Roll plates and cut rafter seat joinery on plates.
6. Layup bent (*grind*) to scribe tie beam neck location, disassemble, mark neck width with slot template and cut.
7. Assemble bent to scribe and fit braces.
8. Lay out rafter templates using bent layup for width of building.
9. Mark and cut rafters.

Traditionally, grindbygg joinery was cut completely with an axe and a tapered auger called a *navar*. Current technique replaces the axe with a small electric chainsaw (Fig. 20), chisel and mallet. Workmanship on historical grindbygg frames varies from crude to fine, depending on the builder and use. All traditional grindbyggs were utilitarian outbuildings and this general feel is brought to their modern construction. Numerous times during the class and my subsequent work experience, I was told, "Remember, Peter, this is not furniture." This doesn't mean that grindbyggs are constructed shoddily. Where accuracy is structurally important, such as the brace lap joinery, things fit tightly. Most other joinery is purposely cut a tad loose so that as-

18 Inverted-V in plate provides easily cut rafter seat.

19 Antique stop-splayed and pegged scarf.

20 Chainsaw in skilled hands cuts or roughs out joints.

sembly goes easily, but with the knowledge that roof loading will push things to where they need to be.

Most frames were not infilled but enclosed outside the posts. The exception to this is the *sleppvegg* (slip wall) style, where horizontal timbers with short stub tenons are slid down grooves in the posts (Fig. 21). Vertical boards nailed to girts on the exterior of the posts is the most common enclosure seen today, but grindbygg history includes all sorts of unique enclosures, including gravel, bark and sticks packed between a double framework, woven juniper bark, stone and sod. One fascinating technique I saw on a farm north of Bergen was *brakekledning* (juniper cladding). Young juniper branches are woven in overlapping shingle fashion onto horizontal poles spaced 8 in. or so apart (Fig. 22), which sheds water and snow but allows good ventilation—important for a barn in a climate where it rains nearly every day. (See also front and back covers.)

21 Juniper woven on poles (inset) clads grindbygg near Bergen.

Grindbygg frames are the epitome of vernacular outbuildings in western Norway. The most adornment I saw were some nice chamfers and chamfer stops. I find great appeal in the straightforwardness of these frames, especially when combined with aesthetically pleasing curves from natural-form knee braces or root knees. The joinery is relatively easy and fast to cut. Norwegian builders told me grindbygg frames are competitive with stick frame construction for outbuildings. This fact combined with the aesthetic and historic qualities has made it a viable and in-demand construction form in western Norway. From feedback I've received since constructing my first Minnesota grindbygg, that may become true here as well.

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German Code Provisions for Mortises and Tenons Loaded in Shear

By Ben Brungraber, PhD, PE, and Annette Dey, MS, PE

MORTISE and tenon timber frame joinery frequently is loaded in a direction perpendicular to the plane established by the two interconnected members, typically in floor joists in carrying timbers (Fig. 1), and in some roof framing. To some extent, exterior wall (vertical) framing can feel this same out-of-assembly-plane loading from wind pressure. Recent joint testing at Guild conferences has included such loading, and a certain momentum is building in the search for more understanding of traditional joinery loaded in this direction (see "Capacity of Load-Bearing Housings," TF 109). It seems time to introduce North Americans to some longstanding European design provisions that deal with just this topic, a matter nearly completely unaddressed in our codes.

Ken Rower

1 Tenoned oak floor joists and carrying timber, Guilford Ct., 1646.

While there is much in contemporary European technical timber literature to catch our eye, their coverage of mortise and tenon joinery that resists out-of-plane loading (joists and purlins, primarily) includes shear capacities for various soffit tenon configurations, bearing capacities for the associated mortises in the supporting members, and (perhaps of most general use) some helpful general rules on designing traditional joinery to avoid undue member weakening.

Note that all the tenons under discussion are load bearing—no housings are included in their codes, nor in this article, which is derived from Chapters 5 and 7 of the 1991 Edition of DIN (Deutsches Institut für Normung) 1052, the basic timber structures code used in Germany and elsewhere. The words have been translated into English and the units into the US customary system. We have added further commentary in hopes of making the technical terms more user-friendly. No article purporting to offer guidance to designers would be complete without a disclaimer of responsibility by the authors. Make no mistake—you are on your own with the material contained herein. None of it is recognized in any way by any known North American building code. It is offered as information to those interested.

Tenons in general The German code discussion begins with basic statements about load-bearing tenons and soon specifies acceptable size and section of beams in which they may be cut.

Tenons may be used with solid sawn and glue-laminated timbers. Germans upgrade tenon capacity when cut on glulam timber by 33 percent over the same tenon in the same species of sold-sawn timber.

IMPORTANT! Machine-cut timbers shall be visually inspected after cutting. Timbers cut with CNC equipment without first being eyed closely by a craftsman can be seriously compromised by knots and other "growth defects."

Do not use wood with sloping grain. Requiring good wood, especially above and below mortises, is good practice, one we might copy.

Use free-of-heart-center (FOHC) timbers (reduced danger of checking). This specification is perhaps to be understood in the context of frequent German use of stub tenons designed to handle only shear forces. In addition, we recognize practical limits to the FOHC specification.

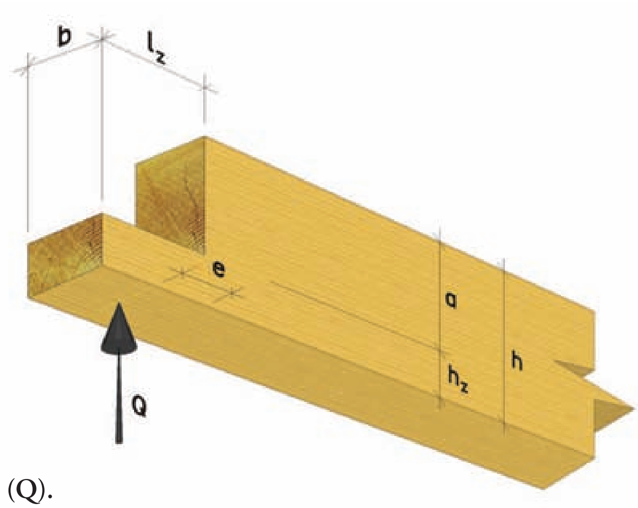
Stub (unpegged) tenons should be at least 1½ in. long, but no more than 2½ in.

Pegged tenons should be at least 2¾ in. long.

If the tenon is not the full width of the tenoned member, use the actual tenon width in the tables.

The tenoned beam may be no deeper than 11⅞ in.

The tenoned beam's aspect ratio h/b, Fig. 2, must be no greater than 5/2 and no smaller than 3/2. (Square timber is excluded.)



2 Soffit tenon loaded in shear (Q).

Soffit tenons We start with perhaps the simplest, and probably the strongest, tenon form—the soffit tenon (Fig. 2). The bottom of the tenon is simply the underside (the soffit) of the tenoned member. The code puts limits on allowable soffit tenon geometry:

$a/h \leq 0.7$ *The soffit tenon depth must be at least 30 percent of the tenoned beam's depth.*

$l_z \leq b/2$ *The soffit tenon must be no longer than half the tenoned beam width.*

Now that we have defined allowable tenons, the equation for allowable shear force V_{all} on those tenons is

$$V_{all} = 2/3 \times b \times h_z \times (1 + 2 \times [a/h]^2)\ F'_v$$

where F'_v is the allowable shear stress in the tenoned beam. In addition, an upper bound on the allowable load is governed by bearing on the bottom of the soffit tenon

$$V_{all} \leq 0.8 \times b \times l_z \times F'_{c\perp}$$

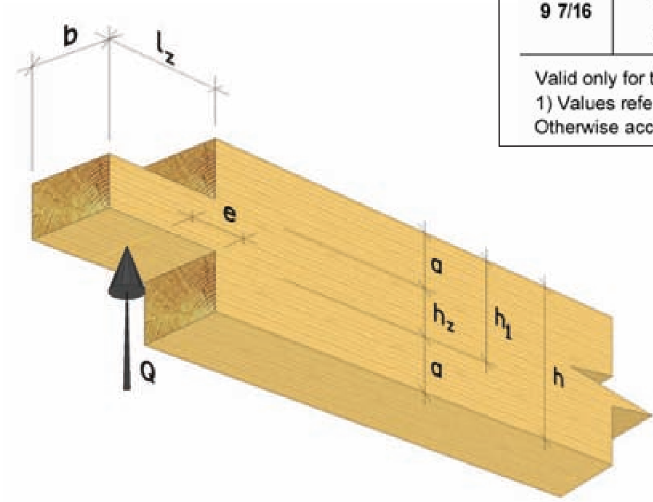
which functionally reduces the bearing area by 20 percent, apparently compensating for uneven bearing under the deflecting tenon. *This upper bound applies to all tenon configurations.*

The code offers a table of allowable loads on apparently standard tenon configurations (Table 1 overleaf). Note that all of the tables in this article are based on 130 psi allowable shear stress, a reasonable value for North American softwoods. At least for engineers, these charts can be fascinating, not least in what we can infer is excluded. Germans following code do not tenon beams that are wider than they are deep, for example. Nor do they tenon timbers that are more than two and half times deeper than they are wide (as repeated in the basic statements). Capacity goes up with tenon thickness—no surprise. On deeper beams, tenons must be at least a minimum thickness. Table 1 reflects a correlation between tenon length and width, and seems further to imply a fixed linear relation between tenon width and tenon thickness, but without saying the latter in any of the code text.

Table 1
Soffit Tenon Admissible Shear Force V_{all} (lbs.)

Tenon length l^*_z (in)		1 9/16	1 15/16	2 3/8	2 3/8	2 3/8
Beam height h (in)	Tenon height h_t (in)	Beam and Tenon width b (in)				
		3 1/8	3 15/16	4 3/4	5 1/2	6 5/16
4 3/4	1 7/16	791	831	809	-	-
	1 9/16	863	953	971	-	-
	1 15/16	993	1146	1263		
5 1/2	1 9/16	872[1)]	-	-	-	-
	1 5/8	1007	1102	1133	1322	-
	1 15/16	1122	1281	1392	1623	-
6 5/16	1 9/16	917[1)]	1146	-	-	-
	1 7/8	1151	1371	1457	1700	1942
	1 15/16	1151	1416	1522	1776	2028
7 1/16	1 9/16	953[1)]	1191[1)]	1430[1)]	-	-
	1 15/16	1102[1]	1378[1)]	1654	-	-
	2 1/8	1151	1641	1780	2077	2374
7 7/8	1 9/16	984[1)]	1230[1)]	1477[1)]	-	-
	1 15/16	1146[1)]	1432[1)]	1720[1)]	-	-
	2 3/8	1151	1798	2104	2455	2805
8 11/16	1 9/16	-	1261[1)]	1515[1)]	1767[1)]	-
	1 15/16	-	1479[1)]	1776[1)]	2072[1)]	-
	2 5/8	-	1798	2428	2832	3237
9 7/16	1 9/16	-	1288[1)]	1546[1)]	1805[1)]	2061[1)]
	1 15/16	-	1519[1)]	1823[1)]	2126[1)]	2432[1)]
	2 13/16	-	1798	2589	3021	3453

Valid only for tenon length $l_{t,act} = l^*_z$!
1) Values refer to figure 2.
Otherwise according to DIN 1052 part 1, section 8.2.2.1



3 Centered tenon loaded in shear (Q).

Centered tenons According to DIN 1052, centered tenons (Fig. 3) may be calculated analogously with notched beam ends, so long as the tenoned beam height does not exceed 11⅞ in (the joist tables in fact stop at 9⁷⁄₁₆ in.). *The National Design Specification for Wood Construction*, the bible for US designers in structural wood, treats shear stresses at supports for notched beams in similar fashion. We are not sure why Germans limit beam depths to about 12 in. Perhaps they simply do not design tenons on deeper beams. Strange things do start to happen at that depth—our own *NDS* corrects (reduces) allowable bending stresses in beams deeper than 12 in.

When the tenon is centered in the depth of the tenoned member, in additon to conforming to the general tenon limitations, as compared with the soffit tenon the depth limit changes and the length limit has an additional limitation:

$h/3 \geq hz \geq h/6$ *The centered tenon depth must be at least a third of the beam's depth but no more than five-sixths.*

$l_z \leq b/2$ *The centered tenon must be no longer than half the tenoned beam width.*

$lz \leq 2\frac{3}{8}$ in. *The tenon may not be too long, lest it fail in bending.*

The equation for shear capacity is

$$V_{all} = 2/3 \times b \times h_z \times k_t \times F'_v$$

where F'_v is the allowable shear stress in the tenoned beam, and

$$k_t = 0.4 + 0.8 \times (a/h_1)^2$$

The upper bound on the allowable load is again governed by the 20 percent reduction in bearing area:

$$V_{all} < 0.8 \times b \times l_z \times F'_{c\perp}$$

Again, the code offers a table for use with the most common tenon dimensions (Table 2).

Table 2
Centered Tenon Admissible Shear Force V_{all} (lbs.)

Tenon length l^*_t (in)		1 9/16	1 15/16	2 3/8	2 3/8	2 3/8
Beam height h (in)	Tenon height h_t (in)	Beam and Tenon width b (in)				
		3 1/8	3 15/16	4 3/4	5 1/2	6 5/16
4 3/4	1 3/8	243[1]	-	-	-	-
	1 9/16	259	324	389	-	-
	1 15/16	274	344	414	-	-
5 1/2	1 9/16	279[1]	-	-	-	-
	1 13/16	301	378	454	528	-
	1 15/16	308	384	461	537	-
6 5/16	1 9/16	297[1]	371[1]	-	-	-
	1 15/16	335[1]	418[1]	-	-	-
	2 1/8	346	432	517	605	690
7 1/16	1 9/16	313[1]	391[1]	470[1]	-	-
	1 15/16	353[1]	443[1]	531[1]	-	-
	2 3/8	389	486	582	679	778
7 7/8	1 9/16	326[1]	407[1]	490[1]	-	-
	1 15/16	371[1]	463[1]	558[1]	-	-
	2 5/8	432	540	648	755	863
8 11/16	1 9/16	-	423[1]	508[1]	591[1]	-
	1 15/16	-	483[1]	580[1]	677[1]	-
	2 7/8	-	594	713	832	948
9 7/16	1 9/16	-	436[1]	524[1]	611[1]	697[1]
	1 15/16	-	501[1]	603[1]	701[1]	802[1]
	3 1/8	-	648	778	906	1036

Valid only for tenon length act $l_t = l^*_t$!
1) Values refer to figure 3.
Otherwise calculate according to DIN 1052 part 1, section 8.2.2.1

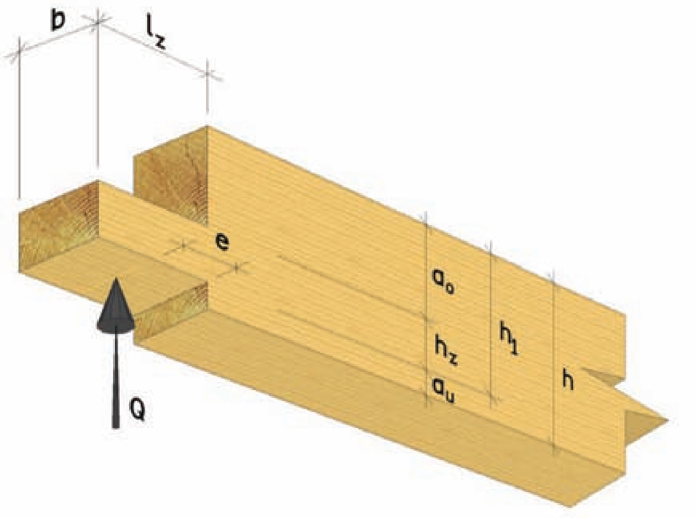
Noncentered, nonsoffit tenons We have covered soffit and centered tenons. How much more complicated can things get? The code does indeed allow for tenons other than soffit and centered tenons (Fig. 4 overleaf). In additon to the general tenon limitations on page 20, we have the same limits on the length of the tenon as for the centered tenon but a different one for the depth, as well as a limitation on height of tenon on the beam:

$l_z \leq b/2$ *The noncentered tenon must be no longer than half the tenoned beam width.*

$lz \leq 2⅜$ in. *The noncentered tenon may not be too long, lest it fail in bending.*

$h_z \geq h/6$ *The noncentered tenon depth has to be at least a sixth of the beam's depth.*

$a_o \geq a_u$ *The tenon, if not centered, must lie toward the lower part of the tenoned member.*



4 Noncentered tenon loaded in shear (Q).

The equation for shear capacity is

$$V_{all} = 2/3 \times b \times h_z \times k_v \times F'_v$$

where F'_v is the allowable shear stress in the tenoned beam, and

$$k_v = k_z + k_a + k_u$$

Engineers love it when a single coefficient is made from three others:

$$k_z = 1 + 2 \times (a_o \div h_1)^2$$
$$k_a = 1 - 2.8 \times a_u \div h \geq 0.3$$
$$k_u = 1 + a_u \div h \leq 4/3$$

There is still that upper bound on the allowable load, governed by bearing on the bottom of the soffit tenon:

$$V_{all} < 0.8 \times b \times l_z \times F'_{c\perp}$$

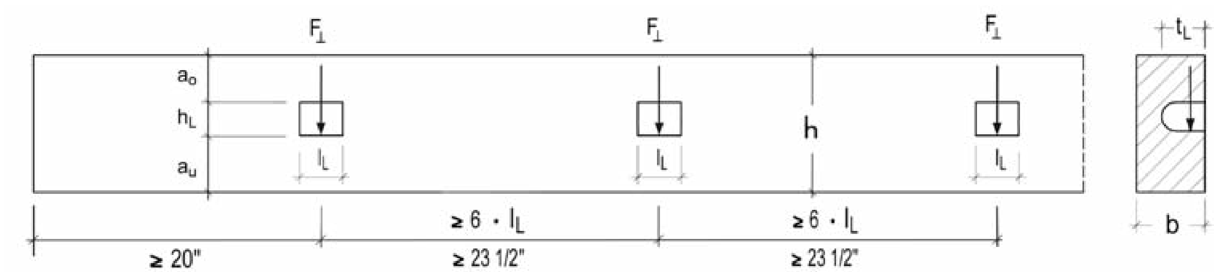
And, once again, the code is good enough to offer a table of the more common tenon capacities, though not directly. Rather, the compiled coefficients are given (Table 3). This especially helpful chart offers a shortcut to that compiled k_v factor. The vertical axis covers the under-tenon depth ratios for tenons placed *other than* flush with the soffit of the tenoned member. The maximum height of tenon bottom surface is 0.4 of the way up the tenoned member.

The horizontal axis is the over-tenon depth ratios. The top line lists ratios for soffit tenons (flush with bottom of tenoned member). The closest any tenon top surface can get to the top of the tenoned member is a third of the member depth. At the other extreme, the tenon top can be 80 percent of the way down the tenoned member depth, so long as the tenon bottom is flush with its member bottom. (The large missing area of the chart would describe overly thin, even impossibly thin, tenons.)

Table 3
Values k_v for assessment of allowable loads V_{all} in softwood tenons (130 psi allowable shear stress)

a_u/h	a_o/h									
	0.333	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
0.00	1.222	1.320	1.405	1.500	1.605	1.720	1.845	1.980	2.125	2.280
0.01	1.204	1.302	1.387	1.483	1.588	1.703	1.828	1.963	2.109	
0.02	1.186	1.284	1.369	1.464	1.569	1.685	1.810	1.945	2.091	
0.03	1.166	1.264	1.350	1.445	1.550	1.665	1.791	1.926	2.072	
0.04	1.146	1.244	1.329	1.425	1.530	1.645	1.770	1.906	2.051	
0.05	1.125	1.223	1.308	1.403	1.508	1.623	1.748	1.884	2.029	
0.06	1.104	1.201	1.286	1.381	1.486	1.601	1.725	1.860		
0.07	1.081	1.179	1.263	1.358	1.462	1.576	1.701	1.835		
0.08	1.058	1.155	1.239	1.333	1.437	1.551	1.675	1.808		
0.09	1.034	1.130	1.214	1.308	1.411	1.524	1.647	1.780		
0.10	1.009	1.105	1.188	1.281	1.384	1.496	1.618	1.750		
0.11	0.984	1.078	1.161	1.253	1.355	1.466	1.588			
0.12	0.957	1.051	1.133	1.224	1.325	1.435	1.555			
0.13	0.930	1.023	1.103	1.193	1.293	1.402	1.521			
0.14	0.901	0.993	1.073	1.162	1.260	1.368	1.485			
0.15	0.872	0.962	1.041	1.129	1.226	1.332	1.447			
0.16	0.842	0.931	1.008	1.094	1.189	1.294				
0.17	0.811	0.898	0.974	1.058	1.151	1.254				
0.18	0.779	0.864	0.938	1.020	1.112	1.212				
0.19	0.746	0.829	0.901	0.981	1.070	1.168				
0.20	0.711	0.792	0.862	0.941	1.027	1.122				
0.21	0.676	0.754	0.822	0.898	0.982					
0.22	0.640	0.715	0.780	0.853	0.934					
0.23	0.602	0.674	0.737	0.807	0.885					
0.24	0.563	0.632	0.692	0.759	0.833					
0.25	0.523	0.588	0.645	0.708	0.778					
0.26	0.531	0.599	0.658	0.723						
0.27	0.540	0.610	0.671	0.738						
0.28	0.549	0.621	0.684	0.754						
0.29	0.558	0.633	0.698	0.771						
0.30	0.567	0.645	0.712	0.788						
0.31	0.576	0.657	0.727							
0.32	0.586	0.670	0.743							
0.33	0.596	0.683	0.759							
0.34	0.604	0.694	0.772							
0.35	0.610	0.703	0.783							
0.36	0.617	0.712								
0.37	0.624	0.722								
0.38	0.631	0.733								
0.39	0.639	0.744								
0.40	0.647	0.756								

Note that tenons get stronger as they move down the end of the tenoned member. Correspondingly, they weaken when they sit higher on the end of the tenoned member.
Because this table is all ratios, it can handle any practical-size tenon. This means thicknesses that fall between values on earlier tables, as well as really huge (and wee) versions.



5 Mortise array showing minimum spacing derived from width of mortise I_L ; relation of mortise height h_L to height of material above (a_o) and below (a_u) mortise; tenon length (t_L); and relish (≥20 in.).

Mortises And now we get to the juicy other half of tenoned connections—the mortises. Note that we say mortises in the plural because the code treats mortise capacities in the context of adjoining mortises along the supporting timber (Fig. 5). The code offers general rules for cutting load-bearing mortises:

Wood subject to mortise and tenon joinery is to be chosen with care.

The grade requirements must be fulfilled by the wood fiber material above and below the mortise.

Bending stress calculations for mortised members shall consider the net section at the mortise. Here, we have explicit instructions to use beam net cross-section after mortising to calculate the stresses.

Mortised members shall be secured against torsion (especially if mortised on only one side). Mortised members might want to spin on their axes (torsion) because of eccentric or unequal loads from the bearing surfaces, especially true for timbers loaded from only one side.
As ever, there are restraints (some familiar, some new) on mortise geometry. Using the factors labeled in Fig. 5 plus the tenon length-to-breadth limitation:

$a_u \geq a_o$
$a_u \geq h/3$
$h_l \leq h/3$
$I_L \leq b$
$h \leq 12$ in.
$3/2 \leq h/b \leq 5/2$

We launch right into the capacity equation:

$$F_{\perp,all} = 4/3 \times b \times a_u \times k_{z\perp} \times F'_v$$

And there it is, the allowable shear force on a mortise. This capacity is a multiple of the cross-sectional area beneath the mortise, times the allowable shear stress, and a seemingly simple "correction factor," $k_{z\perp}$. The mortise capacity is also a function of how much shear there is in the mortised member on either side of the mortise. The beam might already be feeling enough shear stress to have an impact on the more local shear stresses induced by the mortise and tenon loading.

$$Vall \leq 0.8 \times bz \times lz \times F'_{c\perp}$$

We are still restrained by bearing stress on the bottom of the mortise, where

l_z = tenon length
b_z = tenon width = b

Now, back to that "correction factor":

$$k_{z\perp} = k_{\perp} \times (1 - (a_u \div a_o)^3 \times k_t) \geq 0$$

It seems that $k_{z\perp}$ is based itself in more sweet factors, $k_{\perp}$ and k_t :

$$k_{\perp} = 0.6 \text{ for } t_{\perp} \leq 2/3 \times b$$
$$k_{\perp} = 0.5 \text{ for } t_{\perp} > 2/3 \times b$$

So $k_{\perp}$ allows for how deep the mortise penetrates, relative to the width of the mortised member. No surprise, shallower mortises give higher capacity but lower bearing capacity.
And what about that other component of the correction factor?

$$k_t = (F'_{v,a} \div (F'_v \times k_{\perp})) - 1 \geq 0$$

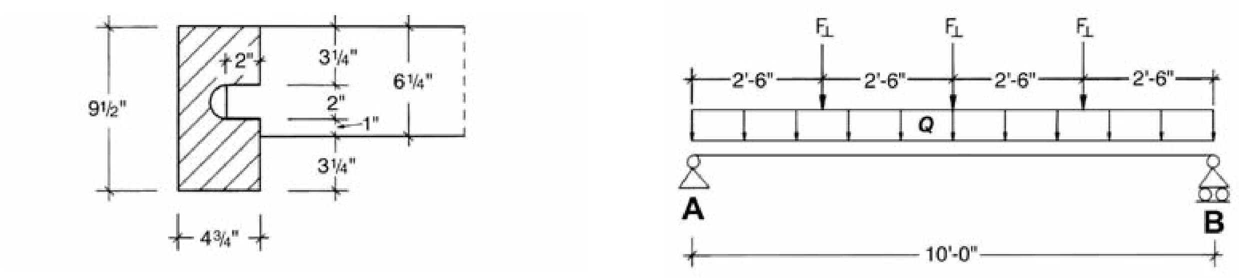
Here we have one of those factors that delight engineers while keeping them in work. For starters, k_t is in fact a function of yet more factors. The $F'_{v,a}$ or shear stress is described as the apparent shear stress under the mortise. And to calculate that apparent shear stress along the mortise, we are offered this:

$$F'_{v,a} = 1.5 \times (h \div a_u) \times V_o \div (b \times h) = 1.5 \times V_o \div (b \times a_u)$$

where V_o is the largest shear force immediately to the left or right of the mortise. (With coefficients both compiled and nested, engineers might be in bliss.) This represents a lot of coefficient manipulation. Thankfully, the code offers yet another table, the finest table of all (Table 4). Note that this table applies *only* to mortises that go no farther than two-thirds of the way through the mortised member. (No through-mortises for opposing joists allowed, not here anyway.) This table combines all those factors into that single, most crucial one $k_{z\perp}$. The first column specifies the mortise height on the face of the mortised member. Note that the possibilities go from centered to within a third of the member depth from the top. The top row is the shear stress in psi the mortised member is feeling, as measured in the member cross-section along the mortises.

Table 4
Values k_v for assessment of allowable loads F_{all} in softwood mortises (130 psi allowable shear stress)

a_o/a_u	$F_{v,a}' = 3/2 * V_a / (b * a_u)$ in psi												
	78.3	81.2	84.1	87.0	89.9	92.8	95.7	98.6	101.5	104.4	107.3	110.2	
1.00	0.6	0.578	0.556	0.533	0.511	0.489	0.467	0.444	0.422	0.4	0.378	0.356	
0.98	0.6	0.576	0.553	0.529	0.506	0.482	0.458	0.435	0.411	0.388	0.364	0.34	
0.96	0.6	0.575	0.55	0.525	0.5	0.474	0.449	0.424	0.399	0.374	0.349	0.324	
0.94	0.6	0.573	0.546	0.52	0.493	0.466	0.439	0.413	0.386	0.359	0.332	0.306	
0.92	0.6	0.571	0.543	0.514	0.486	0.457	0.429	0.4	0.372	0.343	0.315	0.286	
0.90	0.6	0.57	0.539	0.509	0.478	0.448	0.417	0.487	0.356	0.326	0.295	0.265	
0.88	0.6	0.567	0.535	0.502	0.47	0.437	0.404	0.472	0.339	0.307	0.274	0.241	
0.86	0.6	0.565	0.53	0.495	0.46	0.425	0.39	0.355	0.32	0.286	0.251	0.216	
0.84	0.6	0.563	0.525	0.488	0.45	0.413	0.375	0.338	0.3	0.263	0.225	0.188	
0.82	0.6	0.56	0.519	0.479	0.439	0.398	0.358	0.318	0.278	0.237	0.197	0.157	
0.80	0.6	0.557	0.513	0.47	0.426	0.383	0.34	0.296	0.253	0.209	0.166	0.123	
0.78	0.6	0.553	0.506	0.46	0.413	0.366	0.319	0.272	0.225	0.179	0.132	0.085	
0.76	0.6	0.549	0.499	0.448	0.398	0.347	0.296	0.246	0.195	0.144	0.094	0.043	
0.74	0.6	0.545	0.49	0.435	0.381	0.326	0.217	0.216	0.161	0.106	0.052		
0.72	0.6	0.54	0.481	0.412	0.362	0.302	0.243	0.183	0.124	0.064	0.005		
0.70	0.6	0.535	0.47	0.406	0.341	0.276	0.211	0.146	0.082	0.017			
0.68	0.6	0.529	0.459	0.388	0.317	0.247	0.176	0.105	0.035				
0.66	0.6	0.523	0.445	0.368	0.291	0.214	0.136	0.059					
0.64	0.6	0.515	0.43	0.346	0.261	0.176	0.091	0.007					
0.62	0.6	0.507	0.414	0.32	0.227	0.134	0.41						
0.60	0.6	0.497	0.394	0.291	0.188	0.086							
0.58	0.6	0.486	0.372	0.258	0.144	0.031							
0.56	0.6	0.473	0.347	0.22	0.094								
0.54	0.6	0.459	0.318	0.177	0.035								
0.52	0.6	0.442	0.284	0.126									
0.50	0.6	0.442	0.244	0.067			Table is only valid for $t_v \leq 2/3$ b						
0.48	0.6	0.399	0.198										
0.46	0.6	0.372	0.143										
0.44	0.6	0.339	0.078										
0.42	0.6	0.3										0.038	0.78
0.40	0.6	0.253									0.036	0.079	0.8
0.38	0.6	0.195								0.036	0.076	0.116	0.82
0.36	0.6	0.124							0.038	0.075	0.113	0.15	0.84
0.34	0.6	0.035					0.006	0.041	0.076	0.111	0.146	0.181	0.86
≥0.32	0.6					0.13	0.046	0.078	0.111	0.143	0.176	0.209	0.88
					0.021	0.051	0.082	0.112	0.143	0.173	0.204	0.234	0.9
			0.001	0.029	0.058	0.086	0.115	0.143	0.172	0.2	0.229	0.258	0.92
		0.011	0.038	0.065	0.092	0.118	0.145	0.172	0.199	0.225	0.252	0.279	0.94
	0.022	0.047	0.073	0.098	0.123	0.148	0.173	0.198	0.223	0.248	0.273	0.299	0.96
	0.057	0.081	0.104	0.128	0.151	0.175	0.199	0.222	0.246	0.269	0.293	0.317	0.98
	0.089	0.111	0.133	0.156	0.178	0.2	0.222	0.244	0.262	0.289	0.311	0.333	1
	145.0	142.1	139.2	136.3	133.4	130.5	127.6	124.7	121.8	118.9	116.0	113.1	a_o/a_u
	$F_{v,a}' = 3/2 * V_a / (b * a_u)$												



6 Example of mortises and noncentered, nonsoffit tenons in shear, with load reactions.

Example Calculation Given, 4x6¼ joists on 32-in. centers mortised into a 4¾x9½ in. carrying beam (Fig. 6). The support reaction (or shear) at the joist ends is

$F_{\perp} = 782\text{lb}$

The carrying (mortised) beam is also sustaining a distributed load in lbs. per lineal foot

$q = 58\text{plf}$

Design the tenon and mortise dimensions and calculate their capacities.

TENONS

$h_z = 2$ in.

$b_z = 4$ in.

$l_z = 2$ in.

$V_{all} = 2/3 \times b \times h_z \times k_v \times F'_v$ when $\leq 0.8 \times b \times l_z \times F'_{c\perp}$

where $k_v = k_z \times k_a \times k_u$.

$k_z = 1 + 2 \times (a_o \div h_1)^2 = 1 + 2 \times (3.25\text{in} \div 5.25\text{in})^2 = 1.77$
$k_a = 1 - 2.8 \times a_u \div h = 1 - 2.8 \times 1\text{in} \div 6.25\text{in} = 0.552$ [> 0.3, so okay]
$k_u = 1 + a_u \div h = 1 + 1\text{in} \div 6.25\text{in} = 1.16$ [< 1.33, so okay]

$k_v = 1.77 \times 0.55 \times 1.16 = 1.133$

$V_{all} = 2/3 \times 4 \text{ in.} \times 2 \text{ in.} \times 1.133 \times 130 \text{ psi} = 786\text{lb}$

MORTISES

$A = B = 58\text{plf} \times 10.5\text{ft} \div 2 + 3 \times 782\text{lb} \div 2 = 1478\text{lb}$

$V_a = 1478\text{lb} - 58\text{plf} \times 2.5\text{ft} = 1333\text{lb}$

$F_{va} = 1.5 \times 1333\text{lb} \div (4.75\text{in} \times 4.25\text{in}) = 99\text{psi}$

$k_t = 99 \text{ psi} \div (130 \text{ psi} \times 0.6) - 1 = 0.27$

$k_{z\perp} = 0.6.\ (1 - 4.25\text{in} \div 3.25\text{in})^3 \times 0.27 = 0.24$

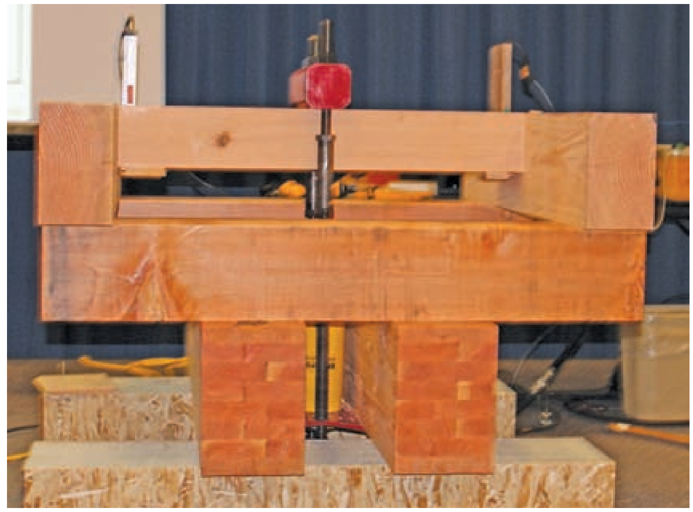
$F_{\perp,all} = 4/3 \times 4.75\text{in} \times 4.125\text{in} \times 0.24 \times 130 \text{ psi} = 840\text{lb}$

$F_{\perp,act} \div F_{\perp,all} = 782\text{lb} \div 840\text{lb} = 0.93 < 1.0$

At right, test rig.

Below, tenon after test.

Below right, mortised member after failure at 29,000 lbs.



Mack Magee

7 Soffit-tenoned 6x6 joist with entrant shoulder, loaded to failure in central mortise of 6x10. Douglas fir yielded at about 23,000 lbs.

Conclusions This article provides an example of the technical support to be found in current (and past) German codes and references. The allowable mortise and tenon shear forces described are just one of the topical issues for which we might seek more guidance in writings abroad. At the 2013 Timber Framers Guild conference in August, we load-tested specimens crafted with the handcut lap dovetail (long derided by modern timber engineers), machine-cut versions of the dovetail, several of the myriad metallic joist hangers now available in Europe and America, and soffit tenons, machine and hand crafted (Fig. 7). We hope still to compare them on pounds of capacity per unit cost of material and labor.

Ben Brungraber (ben@ftet.com) is a structural engineer at Fire Tower Engineered Timber in Providence, Rhode Island. Annette Dey (www.annettedeyengineering.com) is a structural engineer in Alstead, New Hampshire. A native German-speaker, she translated the entire DIN 1052 code section discussed in the article. In addition, Helmut Stoll (helmut.stoll@spax.com), an engineer with Spax International (fasteners) in Ennepetal, Germany, contributed early and significantly to the work. Joe Miller, PhD and PE, of Fire Tower reviewed the article. Example problems and elaborations on this edition of the code will appear on Fire Tower's website (www.ftet.com).

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