TIMBER FRAMING

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Building the Norwell Crane

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On the cover, Jim Kricker and Rick Brown join forces aloft to pull together the upper beam of the Norwell Crane, a reproduction built near Boston of an 18th-century French builder's crane. Photo by Laura Brown.

Timber Framers Guild, PO Box 60, Becket, MA 01223
www.tfguild.org
888-453-0879

Editorial Correspondence
PO Box 275, Newbury, VT 05051
802-866-5684 journal@tfguild.org

Editor Kenneth Rower

Contributing Editors
History Jack Sobon
Timber Frame Design Ed Levin

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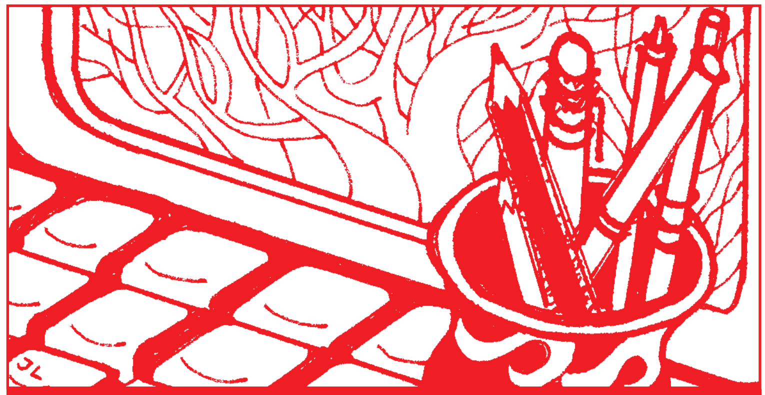


LETTERS

And *More* on Purlin Plates

Re Jack Sobon's TF62 letter "More on Purlin Plates": It's the behavior of frame members that are connected at three or more joints in the frame that I think is behind the observations. He noted correctly that "A rafter continuous across a purlin plate must bend before it can exert thrust on the opposite rafter." My statement, "the thrust on the purlin is a function of the clear span between purlins," is strictly correct only when there is no continuity in the rafters, that is, [when] they are separate members from ridge to purlin and from purlin to plate. My statement is still essentially correct when the center clear span is large compared to the side aisles, and is [the principle] we would use for design purposes.

If we look at some different configurations of a Dutch barn frame, we can see how the continuity of the rafters and their stiffness can change the amount of thrust a frame feels. In Fig. 1, we have a fairly normal arrangement, whereas in Figs. 2 and 3 I have exaggerated the position of the purlins either toward the ridge or towards the outside plates to make it easier to see the behavior. In Fig. 2, it's fairly obvious that with a rafter that is continuous over the purlin from plate to ridge there will be no thrust on the purlin or the plate, and that the rafters on one side of the roof could be completely removed without causing the rafters on the other side to collapse or break over the top of the purlin.

In Fig. 3, it is clear that unless the rafters are very stiff, and the connection of the rafter to the plate is really put together to take a lot of uplift, the rafters in this frame are going to lean against each other and generate thrust that will have to be taken out by the purlins or plates or both, depending on the joinery, the relative stiffness of the members and the geometry of the frame.

Returning back to Fig. 1, where the rafter spans on either side of the purlins are more balanced, provided the rafters are strong enough and there is some type of framing connection at the ridge and at the plate to handle some tension, these rafters could remain standing if either the rafters on one side of the roof were removed, or if the plate on one side were to settle. Even with a fairly deep notch in the rafter at the purlin, the rafter will still behave as continuous if bearing at the seat cut is solid.

So, how much thrust is there on the purlins and/or plates in the roof shown in Fig. 1? Theoretically, it is possible to figure that out by performing a structural analysis that takes into account all the various stiffnesses of the members and the joints. In a real building, we probably can't tell. The framing may not be precisely put together, so that some joints give more than others. The stiffness of the joints, particularly where tension is involved, is tough to figure, and for both tension and compression depends on how tightly the joints were assembled in the first place and how they respond to subsequent shrinkage. Since these frames are part of a three-dimensional grid of frames, with the purlins being continuous, any misalignment between one bent and the next can change reactions in the frame. The roof sheathing acts to some extent as a diaphragm and can transfer some of the thrust from mid-bay rafters to the rafters near the bents. Then there are the kinds of changes that occur after construction is complete, such as rotting of sills and posts and the settling or collapse of foundations.

For all of these reasons, I would offer a reminder to all of us to take the results of computer-aided structural analysis programs with a grain of salt when applied to timber frames. The analysis that Ed Levin presented in his remarks in TF61 and illustrated in the moment and shear diagrams published in that issue are really only correct for an ideal structure, something like a steel frame with welded connections on rigid foundations.

TOM NEHIL Nehil • Sivak Consulting Structural Engineers
414 South Burdick St., Kalamazoo, Michigan
March 25, 2002

Fig. 1

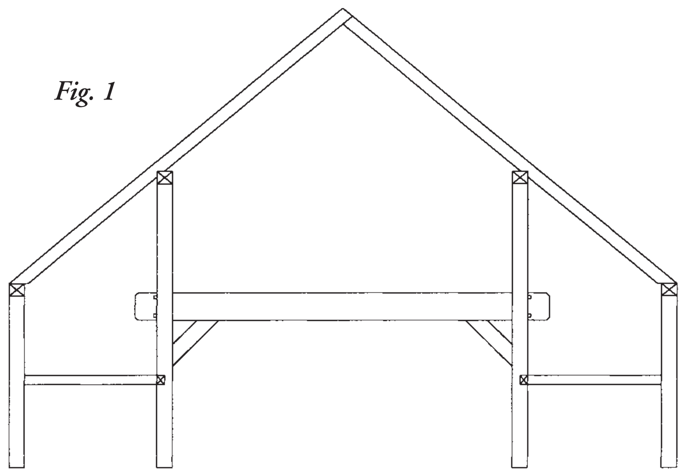


Fig. 2

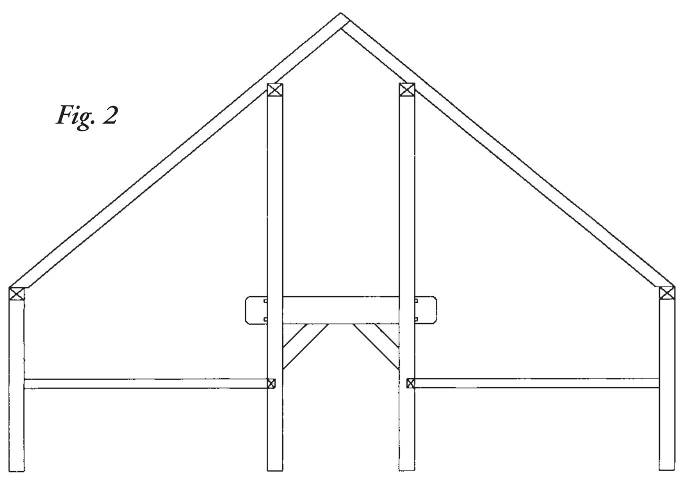
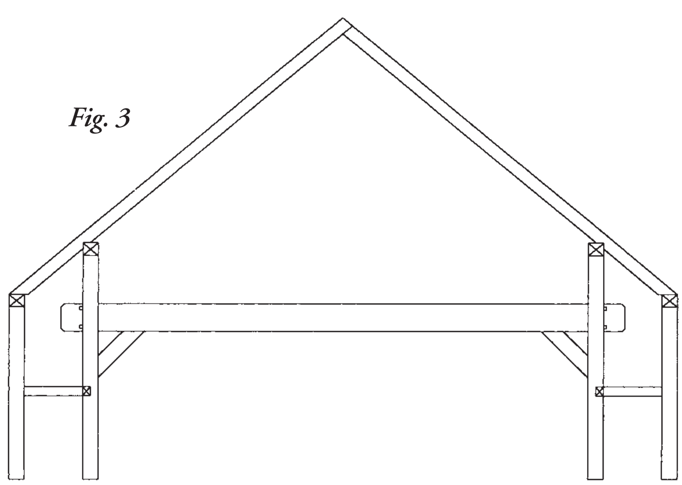


Fig. 3



Why Timber-Framed Walls?

Like Mark Witter (see TF62, "Why Do We Build Timber-Framed Walls?"), I love timber framing but also find myself questioning the use of prodigious amounts [of it] to construct a large building. I started with our studio first (see TF58), which has earthen walls supporting a series of roof trusses. The net effect is to drastically reduce the amount of timber used and to have walls far more thermally efficient than those awful insulated panels that you seem to love over there.

The more I study the older vernacular ways of building, the more respect I have for the economy of materials used (I am talking of small domestic structures here) and also the natural economy of the times—they did not have all our modern contrivances to alter our immediate climate and so they adapted as best they could: they could put up with more cold or heat. They consumed far, far less in the building than we do now, and where possible they used only local materials to do so.

For my part I have tried to reflect this in my building practices here. For example, in the workshop (timber framed) that I am constructing, I have got nearly all the timber (90 percent) for either nothing or a minimal fee as the trees were all either windfalls or removals. [For] any trees that I have to cut down to use, I replant two to three to replace them. Infill for the panels will be wattle and daub using only clay and lime plaster.

Of course, taken to its logical conclusion, perhaps we could all build houses with Nubian vault roofs and use no timber at all! This is of course a silly assumption but your story does indeed raise some uncomfortable questions for timber framers, especially given the shrinking amount of timber resources we have at our disposal. (Where does this leave the Hundegger with its ability to mass produce frames faster and faster and use more and more timber faster and faster?)

While we're thinking along these lines, perhaps we should also address the problem of designing smaller homes. I am constantly amazed (appalled) at the sizes of some of the timber frames I see. They so often are all the same: standardized, huge, cavernous spaces with the obligatory hammer beam roof and large double-story Palladian windows in the gable end. Masses of timber all sanded slickly to look like plastic beams. These homes must be a pain to heat and cool no matter how many insulated panels are put in. Surely the use of timber here represents a disregard for the economy of use.

It is interesting to note the change of style in timber framing in Europe and the UK in response to shrinking timber availability over the centuries. There was a very discernable altering of consciousness in the way they used the wood. They went from an ostentatious to a very sparing use of timber both in dimension and quantity. A very close study of vernacular traditions can teach us immeasurable amounts about the use of timber in a building. In Devon and South Wales, where a large proportion of mud houses still exists, the timber tradition is mainly concerned with the roof and internal walls. This is obviously in direct proportion to the timber available to work with, and they have responded magnificently to the challenge. The carpentry is very different (even quite crude at times) but is nonetheless of its time and place. It would do well for people to study other methods and see what solutions they could come up with for timber framing, using less and using it in a different and challenging manner.

ROB HADDEN PO Box 582, Castlemaine
Victoria, Australia 3450
marmalade@castlemaine.net
October 12, 2001

These letters have been edited for length and style.

A Framer's First Glimpse of Japan

I NEVER had a strong desire to go to Japan. Perhaps it was fear of the unknown; the culture and language seem so different compared to Europe, where at least the alphabet is pretty much the same. Although I own a few nokogiri (saws), I haven't felt ready to make the leap into Japanese edge tools and sharpening, where the subtleties of the system require one to surrender fully in order to truly understand it and get its full benefits.

Then, just after the Western Conference this year in Banff, I was reminded that Hida Tool and Hardware was sponsoring a ten-day tour of Japan at the end of March. Hida, in Berkeley, California, is one of the leading Japanese tool retailers in this country. Its owner, Osamu Hiroyama, was instrumental in bringing four daiku (carpenters) to our 2001 Conference at Asilomar in Monterey. These four were part of a larger contingent that has come over to the US in the past few years to participate in Kezurou-Kai USA, a demonstration of planing and carpentry techniques sponsored by Hida. In Japan, the Kezurou-Kai group has met twice a year since 1997 in order to exchange and preserve traditional techniques. This year's meeting in Nagahama would be the centerpiece of the tour, which would also include visits to temples and toolmakers. I looked up at my calendar and was amazed to find the dates open.

As an executive director of the Guild, I would reinforce our connections to the Kezurou-Kai carpenters, make new contacts, confirm arrangements to increase their participation in Guild events here in North America and explore other ways to exchange information and personnel in the future. So I had some great excuses to go, and once I bought my plane ticket my excitement mounted. I was about to enter a woodworker's paradise and, despite previous misgivings, I had always known Japan to be such.

I called around to a few fellow timber framers who had visited or worked in Japan and got some recommendations, and I loaded up with plenty of small gifts for our hosts (mostly maple syrup). In San Francisco I joined Chris Feddersohn and Phil Goetsch of Palomar College near San Diego, where periodically I help teach a timber framing course; altogether ten people from Palomar came on the trip. As a matter of fact, I would be only one of two persons out of 25 on the trip not from California.

In the morning we met the rest of our traveling partners at the airport and recognized many faces from the Asilomar Conference. Most were experienced woodworkers and some were employed on elaborate Japanese-influenced residential projects in the Bay Area. On the 11-hour All Nippon Air flight to Tokyo we were treated to glimpses of the volcanic cones of the Aleutian Islands as we lost a day crossing the International Date Line. Arriving at Narita Airport outside of Tokyo, we caught a flight to Osaka, where we boarded a bus for the one-hour evening ride to Nara, home to many of the finest examples of Japanese temple architecture.

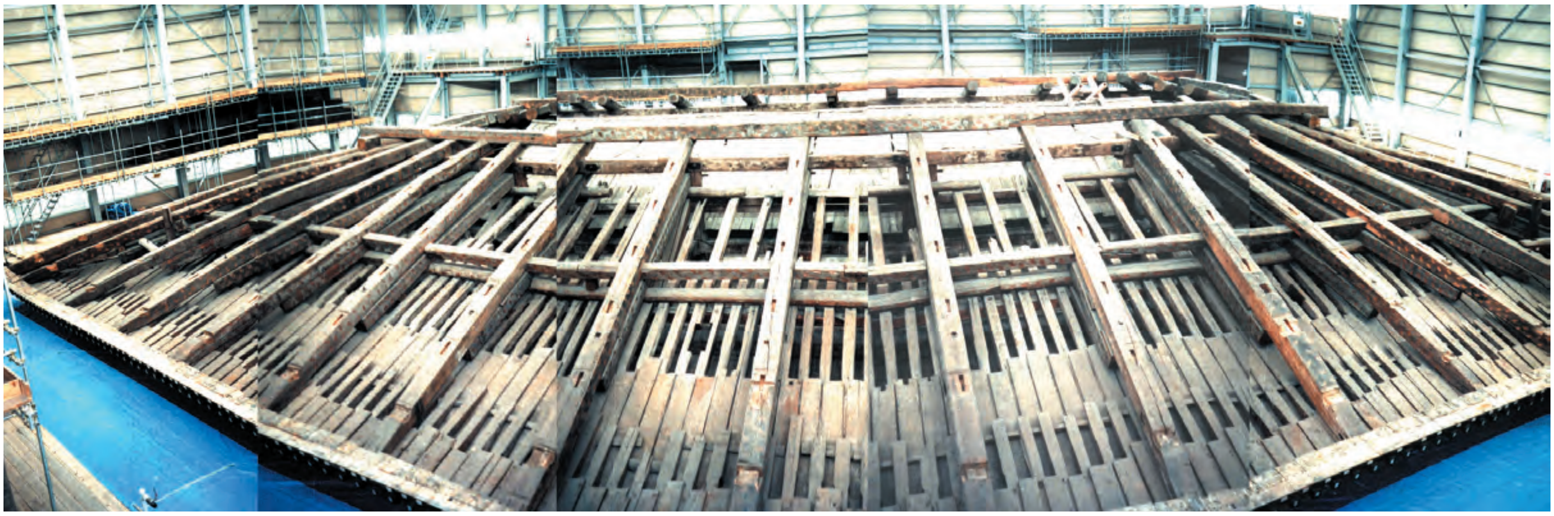
After checking into our Western-style hotel in Nara, a few of us went out for our first meal in Japan and found a noodle shop that provided basic fare—filling, delicious and affordable. And the shop had beer, of course. I found most things in Japan surprisingly affordable, perhaps because the yen had become weaker recently compared to the dollar. The most expensive item would turn out to be coffee bought in "coffee shops."

In the morning I got my first look at urban Japan in the daylight. Walking around the neighborhood, I found shrines, gardens and temples tucked away among stores and residences, all within a few blocks. Intricate and weathered woodwork, much of it at eye level, provided a preview of the details we would later see on a much grander scale. I didn't have a clue what most of the plaques on the buildings said, but I could decipher the dates, which had only *three* digits. And these buildings weren't even in the guidebook.

After a traditional Japanese breakfast of smoked salmon, miso soup, umeboshi plums, pickled vegetables, rice, tea and nori (seaweed), we gathered for the first major event of the tour: a visit to three of the most famous temple sites of Nara. First was Yakushiji, originally built in 718, a complex of numerous buildings, most notably twin pagodas. The east pagoda is original from the 8th century while the west pagoda, destroyed by fire following a lightning strike, was rebuilt in 1981. Mitsuo Naoi, the elder of the group who visited us at Asilomar, and who donated the 20-ft.-long drawing of the west pagoda at Yakushiji to the conference auction, had participated in the west pagoda's reconstruction and proudly posed on the steps for photos, but grew embarrassed by all the Westerners snapping photos on their knees in front of him. He related a story about trying to match the faded look of the 1300-year-old pagoda in the paint scheme of the new one. Once the builders found it impossible to do so, they reproduced the original colors so that the new pagoda appears as it might have in the early 700s. The new west pagoda was deliberately built taller than the surviving east pagoda; by now it has settled to match perfectly.

We were given a behind-the-scenes opportunity rarely afforded visitors—personal tours of the temples being dismantled and reconstructed, led by the foremen and carpenters actually doing the work. Luckily, we had at least three translators with us at any time who could not only vault the language barrier but also understood Japanese woodworking terms. This is critical if one wants to understand what one is looking at. The terms are so esoteric that not any translator would do. Even so, it was sometimes hard to keep up; the details that follow I believe to be accurate but may stand correction.

AT Yakushiji we visited the Lecture Hall, under reconstruction. The large posts and other structural timbers we saw here and in other temples being rebuilt were of a variety of hinoki, the Japanese cypress used in the original construction, but which now comes from Taiwan. Alaskan yellow cedar *(Chamaecyparis nootkatensis)* and Port Orford cedar *(C. lawsonia)* were also in use, especially for trim and details. While power tools could be seen on site, there was also evidence of traditional technique. Most of the surfaces we saw were hand planed, some showing the beautiful texture left by the yarikanna, or spear plane, a pure edge tool unjigged by any enclosing block. The Lecture Hall displayed painted ceilings; red hues on the timbers were produced with an iron oxide paint. The foreman explained how the posts on the perimeter of the structure (which reminded me of the Parthenon) were all tilted inward slightly to resist the outward thrust of the roof. We got our first good look at the bracketing and cantilevered rafter systems that would become so familiar throughout the tour, and we learned how the



Photos Will Beemer

Author's photomontage giving fish-eye view of lower roof system at Toshodaiji, originally built 759, last modified around 1800.

double rafter planes (ceiling below, steeper weather roof above) work together to strengthen the cantilever and allow the use of shorter pieces. (For more details on Yakushiji, see *The Genius of Japanese Carpentry*, by S. Azby Brown, 1989, ISBN 0-877011-897-8.)

It would be hard to imagine how things could get better on the tour, but they did, and they also became more traditional as we went on. We walked to lunch at a restaurant where we sat on tatami mats and were offered tempura, sushi, sashimi, noodles, miso soup and, of course, tea and beer. Our translators Osamu-san and his assistant Maru-san shepherded us well and set up the meals, transportation and hotels, all included in the price of the tour. Although the menu always included the basic dishes, each was prepared differently and artistically presented. Various preparations of sesame and tofu were also regular fare. (While I never got tired of the food, when I returned home I did take a few days off from the steady diet of fish.)

We next visited Toshodaiji, built by the "illustrious Chinese priest Ganjin" in 759. Here we had the chance to see a temple being completely dismantled for replacement of posts that had had new bases scarfed on during the last regularly scheduled maintenance job around 1800. This time, entirely new 50-ft. posts were to be installed, but first the building was being thoroughly documented as it came down. A steel building had been erected around the temple for the duration of the ten-year project (the usual procedure). We were led by the foreman up to the eave-level scaffolding, where we saw the entire lower roof exposed and how the rafter system worked. All the major pieces were regularly patterned with light marks; these, we

Views of the Lecture Hall at Yakushiji. A colonnade of painted exterior posts, all on a slight batter to counter the thrust of the roof, surrounds the exterior. Inside, some timbers and other surfaces are decorated with iron oxide paint. Most timber is hinoki cypress imported from Taiwan.

Kezourou-Kai, a group devoted to woodworking skills, above all hand planing, gathers semi-annually for a best-shaving competition and exposition of tools and techniques. Shaving at right mikes at 17 microns.

were told, were adzed during the last job to allow ink lines to be seen on the ancient timbers. A few workers perched atop the structure with sashigane (squares) and note pads, carefully measuring, labeling and drawing pieces before they were removed. Five kingpost roof trusses, which formed the major upper roof slope, were still assembled and leaning against the wall. They startled me a bit until we learned that they were built during the 1800 restoration and represented the third change to the roof structure. The builders had been influenced by recent contact with Westerners and had adopted some of their engineering designs.

Nara flourished as the ancient capital of Japan, with many more temples and palaces than we could possibly see. We missed what's known as the world's oldest wooden structure, Hiroyuji Temple, built originally in 607 and rebuilt after a fire in the early 8th century. We did, however, end our tour of Nara with a visit to the world's largest wooden building, the 8th-century Todaiji Temple. Fire destroyed this awesome edifice twice, and the present structure was built in 1692 at two-thirds of the original size. Nevertheless, the Japanese consider reconstructed temples to have the same spirit within as the original building. Todaiji houses a remarkable bronze Buddha, at 50 ft. the tallest in the world. It's said that half the then-population of Japan worked on the original construction of Todaiji.

AFTER another fabulous dinner (the fish and beer kept on coming. . . .and did I forget to mention the sake?), we departed Nara the next morning. Nara and Kyoto (where we stopped only briefly) and the area between could take up an entire week of sightseeing for anyone interested in wooden buildings. We picked up the Bullet Train in Kyoto and headed north for Nagahama on Lake Biwa for the two-day Kezurou-Kai meeting. About 200 attended, mostly woodworkers in Japan who enjoy preserving planing skills through learning, practicing and teaching. The group included carpenters, hobbyists, schoolteachers, young craftworkers and about 25 gaijin (us). Kezourou-Kai is headed by Kojiro Sugimura (another of the visiting carpenters at Asilomar), representative director of Asakusaya Co., Inc., which specializes in the design and construction of Japanese temples and shrines. Japanese planing skills have become less frequently used in recent times, and the Kezurou-Kai group is dedicated to passing the skills on to the next generation—and to us in the West, it appears. They meet semiannually in Japan and compete to achieve a plane shaving as long, thin and wide as possible. Shavings as thin as 6 microns (.006 mm or .00024 in.) were being produced at the meeting, with the world record being 3 microns. To produce such a shaving requires highly skilled blacksmiths to make the plane's blade (we would visit their shops later), precise sharpening of the blade, careful fitting of the blade and the chip-breaker into the wooden plane body (the die) and, not least, delicate adjustment of the body.

The first day of the meeting offered presentations by masters to the entire group on adjusting the die (by scraping the sole in various locations), fitting the blade and sharpening. By late afternoon everyone was practicing on Alaskan yellow cedar 3x3s at over two dozen stations set up around the exhibition hall. Those not planing could be found squatting over their sharpening stones in any available floor space, often in groups of six or more. The competition would begin in earnest the next day, but not until after a welcoming party at a local hotel, which included a raffle of numerous tools in which most Americans seemed to win something. We were treated as honored guests, yet I could tell the competitive spirit was in full swing as I tried to get to the buffet line. (It's survival of the fittest when it comes to eating or getting on a train in Japan.) Posters around the streets of Nagahama advertised the Kezurou-Kai event, and included in bold type the phrase "The Americans are coming to try to win!" or something to that effect.

The next morning progressed rapidly with demonstrations of sawing, adzing, tatami-making and saw-sharpening, displays by tool and stone vendors and book dealers, and opportunities for one to try out various tools. The most remarkable plane I saw was a 12-in. (wide) unit that would retail for over $5000. William Richter from Berkeley brought a collection of Western tools that intrigued and sometimes amused the Japanese, and his long two-man crosscut saw was tried out and duly sharpened by a master. While it was faster than the large one-man Japanese oga saw, it left a rougher finish. The oga was a much-sought-after item during our forays into antique tool stores later in the trip.

I took a break to poke around the neighborhood and found some more astonishing shrines and temple complexes, mostly deserted at that time of day. I also needed a respite from tobacco smoke. (I was

Above, floorboards in a preserved merchant's house in Takayama, showing the kind of work done by the planes displayed on the previous page. Above right, Saab enthusiast prepares to attack a small log with an oga.

generally dismayed, if not surprised, to see the quantity of cigarettes smoked indoors in Japan, especially in restaurants. Small coffee shops were the worst.) In the exhibition hall, I thought of the wood dust and shavings, combined with the kerosene some of the contestants used to prepare the wood for planing, and how, if this mix ever connected with the nearby smokers, we could lose centuries of woodworking knowledge in one catastrophic fire. By mid-afternoon people were beginning to submit their best shavings to the micrometer, after which the shavings were delicately draped over a display line. Russ Filbeck from Palomar College assembled and finished a beautiful ladderback rocking chair (his specialty as instructor at the school) that he had precut, and presented it to the organizers of the event as a memento of our visit. I re-established contact with architect Kimihiro Miyasaka, whom some may recall from the 1993 Rindge conference, where he led a carpentry demonstration. One of two Japanese members of the Guild, Miyasaka-san is firmly committed to the exchange of information about wooden construction between East and West and is always researching funding possibilities. He has already sponsored one trip to Japan by Guild lights Jack Sobon, Joel McCarty and Tedd Benson as part of the Wood in Architecture Forum.

WE departed Nagahama the next morning for Uji-City, just south of Kyoto. Here we dropped our bags off at the vast Zen monastery complex of Mampukuji, where we would stay the night. But first we were able to spend the afternoon in Uji, a beautiful river city famous for the tea we saw growing on the hillsides. Its centerpiece is the Byodoin Temple and Phoenix Hall, built in 1053 as a villa. Its light, complex design resembles a bird spreading its wings and, with the surrounding pond and cherry blossoms we were lucky to catch in early bloom, it was stunning.

Our return to the monastery began what was to be the most intimidating part of the trip. Sugimura-san set up our visit, meant to show us (as "temple builders") how the "clients" (the monks) lived, worked, prayed and ate. It was an inspired idea; we would meditate and dine as the monks did, and they were gracious enough to open their doors, something rarely if ever done for outsiders other than trainees. I was just afraid that I would be so boorish, clumsy, loud and generally offensive that I would set relations back to a time before Admiral Perry, and shut the door on any more such visits in the future. But the young monk who was our trainer turned out to be good humored and patient, and he cut us loads of slack. The rules were laid out as we sat in the tatami room where we would all sleep: no shoes on tatamis (as usual), but also slippers-only on the wooden pathways; no talking except in our room, and then only at a low level; bath (traditional style) between 8 and 9 pm; walk just this way with the hands just so—and no walking down the center of any path or porch (that was for the head monk only). I could see that we had already broken most of the rules, and we had only just arrived.

We filed down to *another* 1000-year-old building for a light dinner of miso soup, rice and a few vegetables, and were gently told the ritual we were expected to repeat the next morning. Then we adjourned to the meditation room and received instructions for the two one-hour *zazen* sessions we were to endure the next day. I was really looking forward to them but not sure I was up to sitting still for an hour at a stretch.

At 4:30 the next morning began the most other-worldly experience of my life. We were awakened in the dark by the soft sounds of gongs being struck somewhere in the woods and a single monk chanting. Silently and quickly we filed into the monastery's Buddha Hall amid candlelight and incense, and watched as the two dozen monks entered and began their morning routine. This consisted of non-stop chanting while the head monk in full regalia dispersed prayers among the various statues of (among other figures) warriors and gardeners, called *arahats,* looming in the darkness. The head monk and his assistant moved constantly; the others were motionless except for occasionally striking a wooden chime or drum and chanting. All too soon it was over, and they were gone; we only caught glimpses of them during the rest of our stay.

Our meditation sessions were mercifully abbreviated to a half-hour each, as these old bones weren't used to such sitting, and I was one of the youngsters in the group. In *zazen* one is supposed to empty the mind; I found that hard enough without the wonders of an ancient temple around me. In the dark it was easier, but as dawn broke and the birds started singing, the distractions increased. Before leaving, we were able to tour the grounds informally. We visited another temple under reconstruction, this one getting its first major maintenance since being built around 1800. It had the usual

Large wooden fish at Mampukuji is struck with the baton hanging on the wall at right to summon the monks to their meals. Above right, temple repair underway at the monastery. Some beam numbers are visible.

temporary building around it, but was being repaired in situ and not dismantled, so it had its exposed skeleton (of some of the crookedest timber imaginable) surrounded by a five-story bamboo scaffolding, unlike the high-tech scaffolding we had seen in Nara, the latter affordable, apparently, only for buildings deemed National Treasures.

We finished our visit to Mampukuji with a lavish meal served by a few of the monks in the temple restaurant, and a far cry it was from our previous meals. I had some time since run out of superlatives to describe the food; nevertheless, each meal seemed to get more creative and generous. I should say here that I saw only one overweight person in Japan, a Sumo wrestler glimpsed on television. However, I had begun to notice a distinct lack of fruit and green vegetables in the diet, and I picked up some tangerines in a market on the way to the train.

WE were halfway through the tour as we headed northeast to Nagoya and then changed trains for Takayama. This small town in the Hida region is the traditional home of carpenters in Japan, and some of the most famous temple builders hail from there. Located in the mountains amidst forests and hot springs, it is also the area of the minka folk villages and merchant houses described in Norman F. Carver, Jr.'s excellent 1984 book *Japanese Folkhouses* (ISBN 0-932076-05-X). We settled into the most traditional of our lodgings in Japan, a minshuku guesthouse. These are the most affordable versions of the ryokan (Japanese inn), where three to six people sleep in a room furnished with futons on tatamis. Baths are shared down the hall, and one showers before entering the tub. We took advantage of the rather luxuriously developed onsen (hot springs) across the street on both nights we spent there.

The following morning we were welcomed by the mayor's staff at the city hall (a great place to check e-mail, I discovered, with free computer access in the lobby). Some people then departed on a hastily arranged bus tour over the snowy mountain passes to the traditional farming village of Shirakawa, while the rest of us walked in the Old Town of Takayama. Here we found the houses of tradesmen and merchants from the 19th century, which contain what many consider to be the apex of Japanese woodworking and interior detailing. Standards of preservation for the historic district have resulted in remarkably coherent architectural neighborhoods. The gentle roofs have long and low eaves set at a uniform height, such that the front of each house lines up with the next. Grilled openings *(koshi)* at street elevation include inventive detailing. Inside, the irregular sizes and spacing of the framing timbers complement the asymmetrical planes of the movable walls *(tategu)*. The walls hang from the beams, some shoji open, some closed, but the beams define the spaces.

Here, as elsewhere, we saw the stress-relief grooves *(sebiki)* cut on normally unseen faces of timbers to control the effects of shrinkage on visible faces. Domestic woods were the rule: chestnut, hinoki (cypress) and hiba (arborvitae) are used for foundations where rot and great pressures are likely. Hinoki, cedar and a variety of pine are used for *kozozai* (structural timbers), and hinoki and pine, which have fine color, grain and fragrance, are selected for *zosazai* (interior fittings or trim). Most material scaling is based on the ken (roughly 6 ft.), a standard column-to-column distance, or the size of a tatami mat, which, though somewhat variable, itself derives from conventional column-to-column distances. Tucked among these residences

Funahiro-san prepares to forge-weld the harder steel that will form the working edge of a chisel to the milder steel that will make up the body.

of sake brewers and merchants were a number of antique shops, and it didn't take long for the tool sleuths to make the connection. Around the charcoal fire in the middle of the floor back at the minshuku the lucky ones spread their loot: chisels, adzes, planes (kanna), axes, and three oga, the huge saws that were soon recognized to be a liability when it came to packing for the airplane trip home. Not to worry: Osamu-san volunteered to ship them with his next Hida order and even offered to have them sharpened in Japan.

Before leaving the next day, some went back to make sure they didn't miss any tool bargains while I visited the local Hida folk village museum to see over 30 of the famous *gassho* farmhouses with their steep thatched roofs and lashed pole construction. Few minka—a generic term for folkhouse that might cover poorer farmhouses to middle-class tradesmen's houses—more than 200 or 300 years old exist today; temples are much more enduring and cared for. Fire and warring clans destroyed many country villages until recent, more stable, times. With its folk village on the western edge of town, the merchant houses in the center and a series of a dozen temples and shrines arrayed on the hillside to the east, Takayama presented a capsule of the best in Japanese architecture, all within a 30-minute walk from one end to the other. But Japan has its contrasts. It was odd to see all this beautiful architectural detailing obscured by utility wires draped everywhere, even if there may be a shortage of space to bury the lines.

AFTER two days in Takayama we headed farther north by train. We had Japan Rail passes for most legs of our journey—and God help you if you're late and can't read the timetable. You don't have the time to ask! I would say that no more than one out of 25 people spoke any English where we were. We hit the Sea of Japan at Toyama and turned right up the coast to Nagaoka and blacksmith country. Here we visited the toolmakers who make the irons for many of the finest chisels and planes sent to the States. The best-quality irons are signed by their makers with stamps, and we watched as two such blacksmiths, Funahiro-san and Yokosaka-san, plied their craft. We saw the layering process in which the harder higane steel is forge-welded to the softer jigane, using a flux, at a temperature of 1000-1070 degrees C. In use, the jigane serves as a shock absorber for the cutting edge of the working tool. We were shown the different types of steel (white, blue, sword, super blue), how they are used for different tools and how they are sharpened with different stones. The blacksmith's skills lie in understanding heat treatment, flux applications and the significance of flame color in the forge as a temperature monitor. We did not witness any tools being quench hardened (said to take place in water when the steel is at 760-800 C., at least for chisels). Funahiro-san used a microscope in his office to show us how the crystalline structure of the steel is rearranged during toolmaking. If I felt ignorant about Japanese edge tools before I arrived, I came away from this leg of the tour knowing lots more but feeling even more ignorant. There's a lifetime of learning here.

We had one more treat that day in the village of Yoita, where the blacksmiths lived. The Daiken Tool distributor gave us free run of his warehouse for a few hours, and we took advantage. And there were more feasts of fish! Now we were really in seafood country, and I took an early morning walk up the beach to a little fishing village where the residents looked at me as if I were from Mars. (Not many tourists get up here.) On our last full day in the country, we took a short bus ride up to Niigata to visit another blacksmith, as well as a die-maker producing the wooden bodies that hold the plane iron. Here we saw some heavy-duty stationary power tools unlike any seen before—multiple skewed chisels in presses to rough out the cavity for the iron (final fitting is still done by hand), and a super surfacer with a stationary knife and a power feed to move the stock under the knife and return it for successive cuts. Such surfacers are made for timbers as well, and it must be quite a sight to see a large stick flying back and forth. With its fixed knife, the surfacer can produce a much finer finish than the rotary head planers we're used to.

In most of our visits to these small shops in Yoita and Niigata we were treated to tea ceremonies by the ladies of the house (including mothers-in-law, daughters, aunts and any other women who might want to get a giggle). They were all extremely gracious, although sometimes the tea ceremony became a beer bash if the work day was almost over. In one of these houses we had noticed some very elaborate shoji screens with intricate fretwork. When we visited the shop where these *tategu* (partitions) were made, we were greeted by a freshly caught octopus hanging in a side doorway, which Mother immediately began to prepare for us by slicing off bits of tentacle and offering them up on a platter. They went well with the beer.

And next to this was the Hundegger of shoji makers, a phalanx of computer-driven saws, carving heads and drill presses to make screen frames and the delicate latticework that goes over the rice paper. Such intricacy as we saw in the houses would be unaffordable as handwork, and the ganged cutters and blades we thought unique. Meanwhile, a former-boatbuilder relative, who could have been 50 or 80 years old, was in the other room proudly unwrapping his old saws from their oilcloths and showing us how he had used them to spline and join hull planks.

We spent our last night in the hot-springs and ski-resort town of Yuzawa, and had our last dinner (the best so far, of course) amid small gifts, large amounts of sake and beer, long good-byes and too-long karaoke. Then a midnight dip in the seventh-floor outdoor hot pool overlooking the moonlit town in the valley below.

I know I'll see some of my new friends at upcoming Guild conferences, but I will have to return to Japan to see many others and get to those tool shops no one would talk about until we were safely out of range. Hida plans to return with another tour in September and for every Kezurou-Kai thereafter in Japan, and I strongly encourage you all to go. It's the only way you would be able to see most of the things we did, impossible for the casual tourist. *Sayonara Nippon, arigato.*

—Will Beemer

Will Beemer (will@tfguild.org) is co-executive director of the Guild in charge of education and administration.

LATERALLY LOADED TIMBER FRAMES

III. Sheathed Frame Behavior

This article is third in a series to discuss the results of research conducted at the University of Wyoming on the behavior of sheathed and unsheathed timber frames subjected to an applied lateral load. Primary funding for this research was provided by the US Department of Agriculture National Research Initiative Competitive Grants Program, with additional support from the Timber Frame Business Council, the Timber Framers Guild and individual timber framing companies who contributed the test frames. Subsequent articles will review the behavior of structural insulated panel-to-timber connections and modeling of unsheathed and sheathed frames.

INTRODUCTION. The objective of this part of the research was to characterize the response of sheathed full-scale timber frames subjected to lateral load. Traditional timber frames provide gravity and lateral load resistance, but the term "timber frame" does not imply any particular form of building envelope. There are many methods of enclosing timber frames, but the most common modern North American technique is to apply structural insulated panels (SIPs) to the exterior of the structure. As demonstrated in previous articles (see Parts I and II in TF62 and TF63), unsheathed timber frames may not have adequate stiffness to resist lateral loads, and the addition of SIPs is herein shown to significantly increase the resistance to lateral loads.

Test Assemblies. Two 1-story, 1-bay (1S1B) and two 2-story, 2-bay (2S2B) frames (see Figs. 2-4 facing page, for dimensions) were sheathed with SIPs either 4-in. or 6-in. thick (nominal). A photo of a sheathed 2S2B frame is shown in Fig.1. All panels were installed with screws of shank diameter 0.180 in. Screw length was 6 in. for the 4-in. panels and 8 in. for the 6-in. panels unless noted otherwise.

1S1B Douglas Fir. Two 6-in. panels oriented as shown in Fig. 2 were attached to a 1S1B Douglas fir frame. The panels were joined by a continuous 7⁄16-in. x 4-in. oriented strand board (OSB) spline attached to each OSB skin with 8d nails 6 in. apart (nails had clipped heads and were driven with a pneumatic nail gun). This frame was not tested in the unsheathed condition and is not the same unsheathed 1S1B Douglas fir frame as described in Part I of this series. The sheathed 1S1B Douglas fir frame was tested with the SIPs attached by screws spaced at both 8 in. and 12 in.

1S1B White Oak. A continuous 4-in. panel, 12 ft. wide by 8 ft. high, was applied to the 1S1B white oak frame, which was also tested in the unsheathed condition as described in Part I of the series (see TF62). The panel was attached by 6-in. screws located at 16 in. on center. Pilot holes (1⁄8-in. diameter) were predrilled through the panel and into the timber to facilitate screw penetration into the frame. Washers were installed under the heads of all screws, and a ½-in. plywood shim was installed between the frame and panel, resulting in a screw penetration of 1 in. into the frame timbers. The shim was installed to simulate a field practice that eases insertion of finish wall material between the frame and the panels.

Rob Erikson

FIGURE 1. SHEATHED 2S2B FRAME IN THE LABORATORY.

2S2B Douglas Fir. The 2S2B Douglas fir frame was sheathed with four 6-in. panels of size and orientation as shown in Fig. 3 (facing page). The panels were joined by a continuous 7⁄16-in. x 4-in. OSB spline attached to each OSB skin of the SIP with pneumatically driven 8d clipped-head nails 4 in. apart. This frame was tested with the SIPs attached by screws spaced at both 12 in. and 24 in. The sectional width of the beams was less than that of the posts and, to provide a flush surface for installation of SIPs, shims were installed along the entire length of all beams. A double layer of 7⁄16-in. OSB shims provided a total shim depth of 7⁄8 in. Given the screw length of 8 in., panel thickness of 6½ in. and a shim thickness of 7⁄8 in., the penetration of the screws into the beams was only 5⁄8 in.

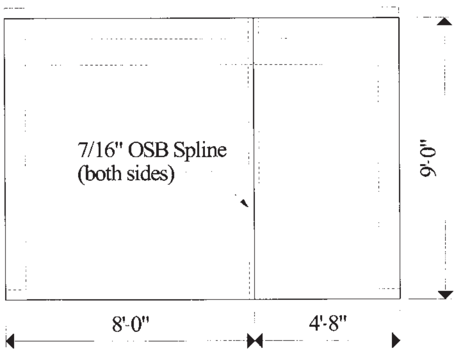
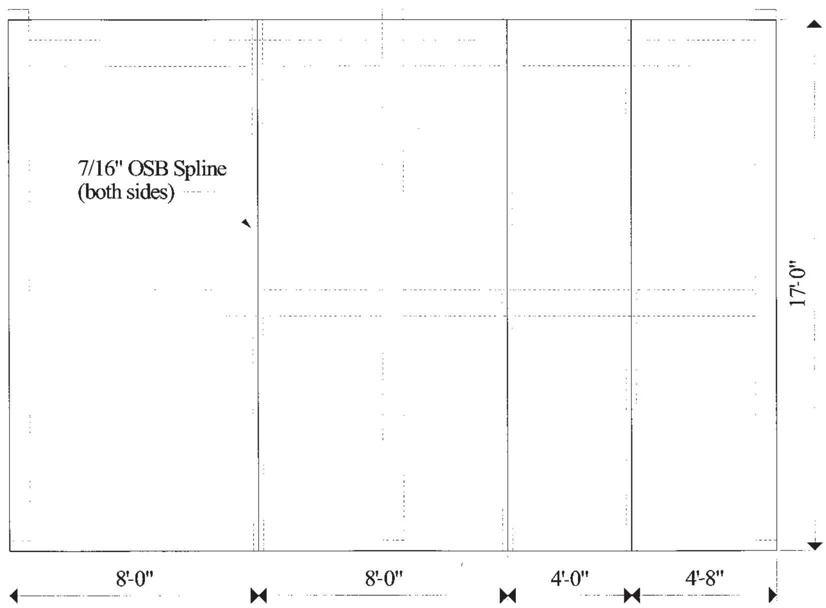
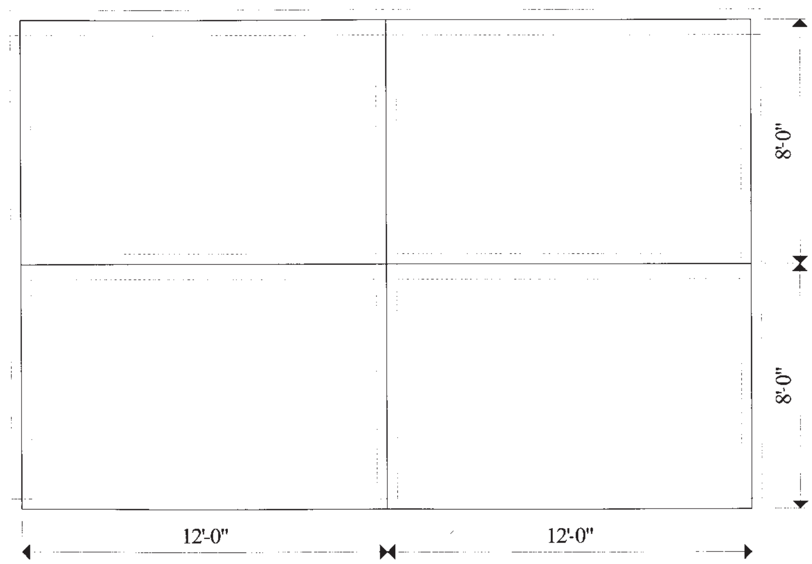


Figure 2. 1S1B Douglas fir sheathed

Figures 3 and 4. At right, Fig. 3, 2S2B Douglas fir sheathed. At right below, Fig. 4, 2S2B Eastern white pine

Drawings Rob Erikson





2S2B Eastern White Pine. The 2S2B Eastern white pine frame was sheathed with four 4-in. panels each 12 ft. wide by 8 ft. high as shown in Fig. 4. All panel joints coincided with frame members, and no splines were used. This frame was initially tested without a sill timber, and then a sill was installed to permit full perimeter attachment of the SIPs. All tests were conducted with 4-in. screws located 12 in. apart.

RESULTS. In order to simplify comparison of frame stiffness, the stiffness of each frame load cycle discussed in this chapter was determined by the slope of a line connecting the points of maximum load and displacement (pull stroke to push stroke). The resulting stiffness based on this line is labeled $k_{G'}$.

Comparison of Unsheathed and Sheathed Frame Stiffness. The addition of SIPs resulted in a significant increase in stiffness for all three frames that were also tested in the unsheathed condition. As shown in Table 1, the increase in stiffness ranged from a modest 71 percent for the 1S1B white oak frame to a dramatic 920 percent for the 2S2B Douglas fir frame. Load-deflection traces for the unsheathed and sheathed 2S2B Douglas fir frame are shown in Fig. 5.

Frame	Unsheathed Stiffness (lb/in)	Sheathed Stiffness (lb/in)	Increase
1S1B White Oak	4040	6890	71 %
2S2B Douglas Fir	1050	10710	920 %
2S2B Eastern White Pine	1950	16540	748 %

Table 1. Increase in Frame Stiffness.

Effect of Adding a Sill Timber. All but one of the sheathed frames were tested without the benefit of full perimeter attachment of the SIPs. A sill timber was added to the 2S2B Eastern white pine frame, and the results are shown in Fig. 6. This frame had the highest stiffness at 16,540 lb/in, and the stiffness more than doubled to 37,560 lb/in with the attachment of the SIPs to the sill timber. Fig. 6 also demonstrates the 748 percent increase in stiffness from the unsheathed to the sheathed condition as listed in Table 1.

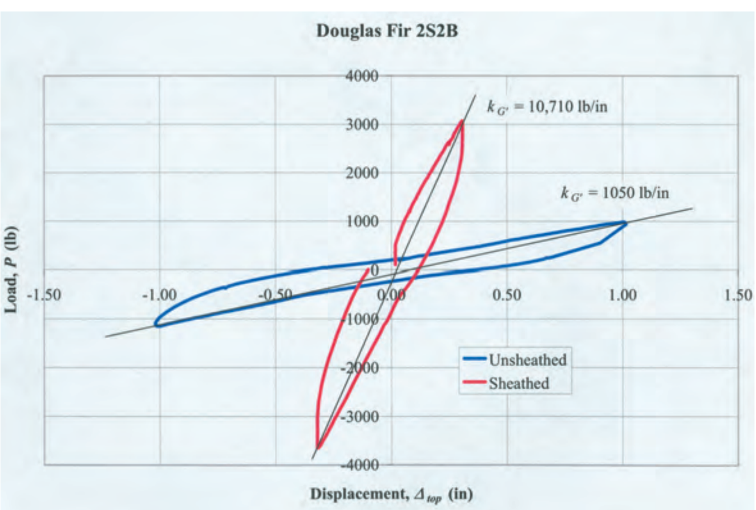


Figure 5. Unsheathed vs. sheathed frame stiffness.

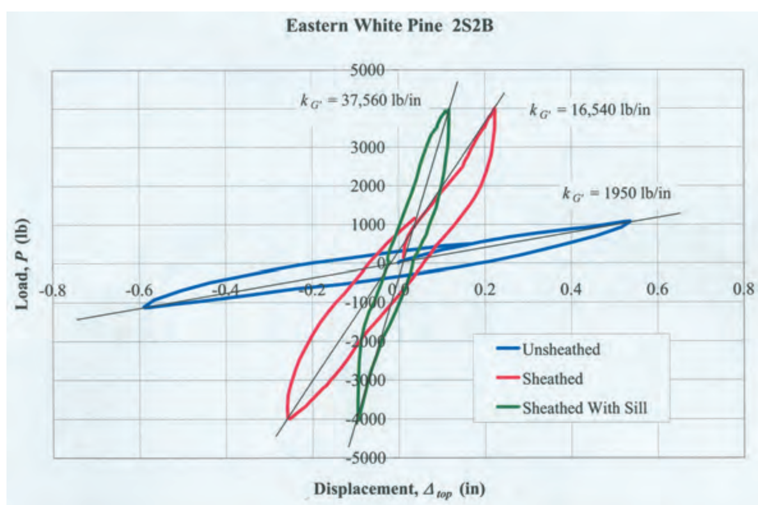


Figure 6. Effect of full perimeter sheathing attachment.

Effects of Screw Spacing. The effects of varied screw spacing were investigated on two frames. As shown in Fig. 7 (facing page), decreasing screw spacing from 12 in. on center (o.c.) to 8 in. o.c. on the 1S1B Douglas fir frame resulted in a 41 percent increase in frame stiffness (2930 lb/in to 4140 lb/in). Decreasing the screw spacing on the 2S2B Douglas fir frame from 24 in. to 12 in. resulted in a 56 percent increase in frame stiffness (6850 lb/in to 10,710 lb/in).

Maximum Load. Maximum load values for each frame are listed in Table 2. For each loaded direction, the column titled "Limiting Failure?" indicates if the frame was loaded to screw failure and the frame was no longer able to carry additional load. As shown in the table, the two Douglas fir frames had lower stiffnesses than the other two frames. This was primarily because the splined joints in the panels did not fall over frame members. Hence the sheathing itself was naturally less stiff for these two frames.

A maximum load of 4370 pounds was applied on the push stroke to the 1S1B Douglas fir frame with screws installed 12 in. apart. Screw failure occurred at the base of the posts with two shear failures at the west post and one failure at the east post. With screws installed 8 in. apart, the frame was able to carry increasing load throughout the full available displacement in the push direction, but screw failure occurred in the pull cycle at an ultimate applied load of 7210 pounds. Screw failure occurred at the base of the posts with two shear failures at the west post and, as shown in Fig. 8 (facing page), three failures at the east post. Significant deformation occurred in several screws located in the lower region of each post. Examples of screw failures and deformations are shown in Fig. 9.

The maximum load cycle for the 1S1B white oak sheathed frame is shown in Fig. 10. As the load approached the ultimate load of 5080 pounds, the screws began to fail, resulting in increased displacement without increased load. Reversal of the load caused the same result at maximum load of 5020 pounds. Removal of the SIPs revealed three screws had failed in double shear. Two of the failures were at the base of the west post and one was at the base of the east post.

There was no significant difference in the performance of the 2S2B Douglas fir frame at maximum load with screws installed 12 in. apart compared to a 24-in. spacing. The only limiting failure occurred with screws installed 12 in. o.c. at a pushing load of 9020 pounds and a displacement of 1.88 in. In both conditions, several screw failures occurred at the base of all three posts.

The 2S2B eastern white pine frame was not subjected to large load without the sill installed. With a sill timber installed, the frame withstood a load of approximately 10,000 lbs. on both the push and pull strokes without incurring any apparent damage. Removal of the screws revealed only minor damage to any of the fasteners.

Effect of Openings. Openings of progressively larger area were cut in the center of each of the four panels installed on the 2S2B Eastern white pine frame. The first test was conducted with 6-ft.-wide by 4-ft.-high openings cut in each panel. All openings were then enlarged to 6 ft. wide by 6 ft. high as shown in Fig. 11. Finally, to simulate an opening for a two-section sliding glass door, the openings on the lower story were enlarged to 6 ft. wide by 7 ft. high.

The results of these tests are shown in Fig. 12. With the 6-ft. x 4-ft. openings, the stiffness was 62 percent less than the fully sheathed frame stiffness of 37,560 lb/in. As expected, the stiffness decreased further as the opening was enlarged, but even with the largest openings, the frame stiffness of 8930 lb/in was still much greater than the assumed required design stiffness of 3070 lb/in (see Part II of this series in TF63).

Damage to the OSB skins did not occur until the frame was subjected to a load of 10,000 pounds on a subsequent cycle. As shown in Fig. 13 (facing page), failure was exhibited by cracking at the upper corners of the lower openings. The cracks propagated diagonally upward and outward from the opening to the edge of the panel. Removal of the fasteners revealed significant screw deformation at several locations around the perimeter of the lower panels.

Rob Erikson

FIGURE 11. 2S2B EASTERN WHITE PINE FRAME WITH OPENINGS.

Frame	Push Stroke			Pull Stroke			Stiffness at Max. Load (lb/in)
	Load (lb)	Disp. (in)	Limiting Failure?	Load (lb)	Disp. (in)	Limiting Failure?	
1S1B Douglas Fir (screws 8" o.c.)	5810	3.01	No	7210	3.37	Yes	2040
1S1B White Oak	5080	0.88	Yes	5020	0.72	Yes	6310
2S2B Douglas Fir (screws 12" o.c.)	9020	1.88	Yes	8940	1.90	No	4750
2S2B Eastern White Pine (with sill)	9990	0.42	No	10,100	0.62	No	19,320

TABLE 2. MAXIMUM LOAD.

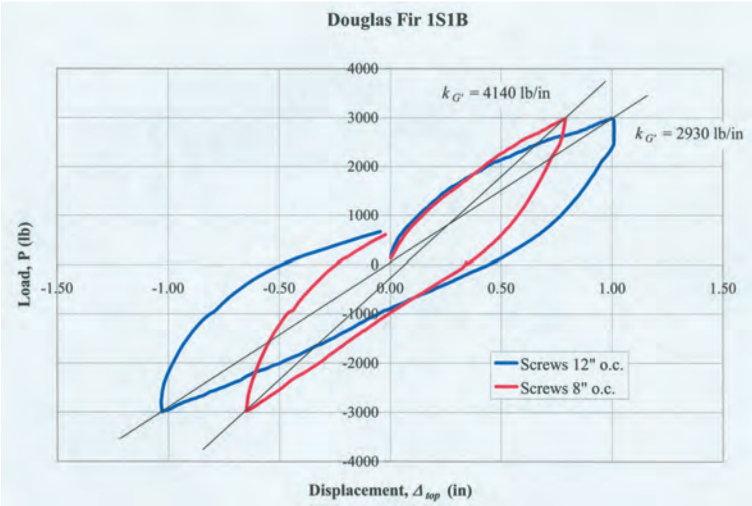


Figure 7. Effect of Screw Spacing

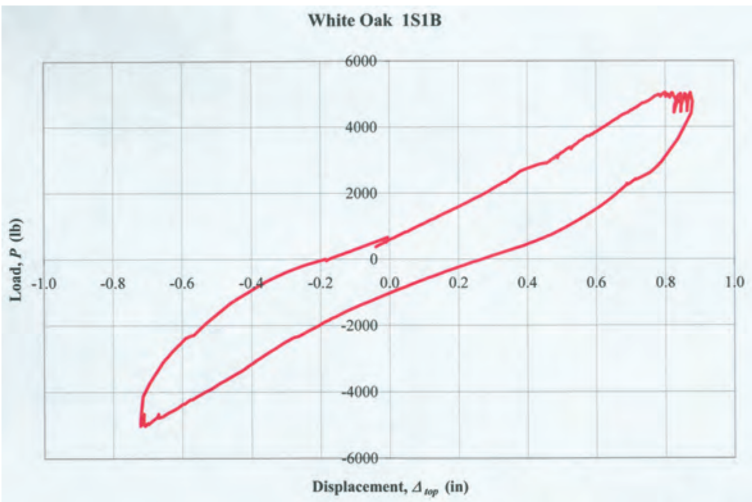


Figure 10. Maximum load cycle.

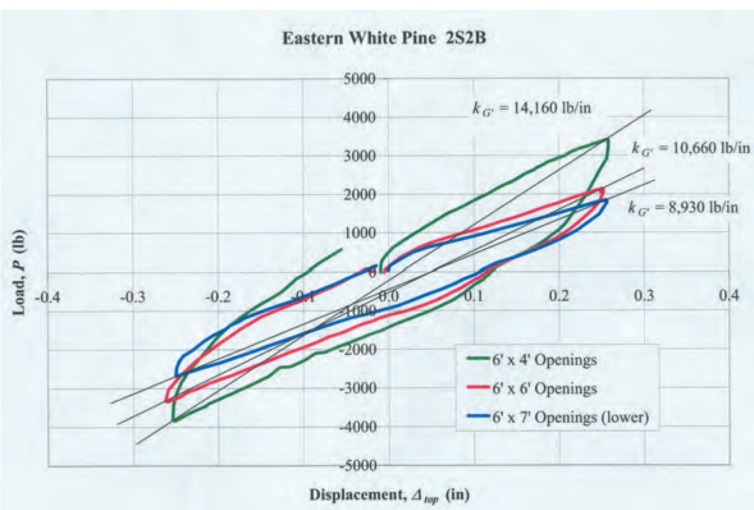


Figure 12. Effect of openings.

Summary. As expected, the addition of SIP sheathing increased frame stiffness to levels required for strength and serviceability. Attachment of the panels around the full perimeter resulted in a significant increase in frame stiffness; therefore, attachment of the SIP to a sill is recommended to obtain maximum performance. Without the use of a sill, significant screw damage was confined to the lower portions of the posts, indicating that the load was not equally distributed to all fasteners.

The frames that had 6-in. SIPs installed with panel joints not coincident with frame members exhibited relatively lower stiffness.


Figures 8, 9 and 13. Above left, Fig. 8, Douglas fir post with broken screws. Above right, Fig. 9, broken and deformed screws. Below, Fig. 13, Failure of OSB at opening corner.

Rob Erikson

This finding indicates a benefit from attaching SIPs at frame timbers whenever possible.

When a sill timber was installed and large openings were cut in the panels, the Eastern white pine frame exhibited acceptable performance levels. This finding indicates the potential benefits of SIP panels on walls with many openings. It is important to note that the tests on the frame with openings were conducted with panels having all joints located over frame timbers. In many instances, window walls are sheathed with smaller pieces of SIPs, resulting in many joints not coincident with a frame timber. In such a case, the SIPs may not provide the required contribution to frame stiffness.

—Rob Erikson and Dick Schmidt

Rob Erikson (erikson@uwyo.edu) is a graduate student and part-time instructor at the University of Wyoming and the owner of WyoBuild, Inc. in Laramie. Dick Schmidt (schmidt@uwyo.edu) is a professor in the Department of Civil and Architectural Engineering at the University. *Structural insulated panels were provided by Insulspan, Blissfield, Michigan, and Premier Building Systems, Fife, Washington. Experimental frame materials were provided by The Cascade Joinery, Everson, Washington (Douglas fir frame); Benson Woodworking, Walpole, New Hampshire (Eastern white pine frame); Earthwood Homes, Sisters, Oregon (Port Orford cedar frame, not used in Part III); and Riverbend Timber Framing, Blissfield, Michigan (white oak frame).*

Building the Norwell Crane

WHEN the lure came in from the Guild's Joel McCarty, that genial fisher of souls, the e-mail message read: "Lesser Crane of Norwell desperately seeking solution. . . . Who will tell us how large the arm should be in red oak? In Eastern white pine?" The proposed "Lesser Crane" would be a reproduction of an 18th-century French wood-framed portable builder's crane, perhaps 50 ft. tall. The rendezvous would take place at Handshouse, sculptors Rick and Laura Brown's riverside studio in Norwell, Massachusetts, with volunteer timber framers leading art and architecture students from Massachusetts College of Art and Wentworth Institute. Here was another opportunity to leave affectionate families and congenial day jobs to spend a week camping in the cold, working into the night at arcane tasks for no pay. But where else could one have such great times in such good company? I took the hook.

The life of architect and civil engineer Jean-Rodolphe Perronet spanned most of the 18th century, and his *oeuvre* featured stone arch bridges still spanning the rivers of France two and a half centuries later. Perronet documented his work in *Description des projets et de la construction des ponts de Neuilly, de Mantes, d'Orléans, etc.; du projet du canal de Bourgogne, pour la communication des deux mers par Dijon; et de celui de la conduite des eaux de l'Yvette et de Bièvre à Paris*.

Originally published in 1783, the work is in two bound volumes: one of 634 pages of text and the other an atlas with 75 engraved plates measuring as large as 2 ft. by 3 ft. These breathtaking drawings show not only the finished bridges but also works in progress, plus the tools, staging, falsework and machinery used in their construction. The author was both illustrator and designer of many of the latter devices. The portable builder's crane that we were to reproduce was used to lift stone for the Pont d'Orléans, built across the Loire in the 1750s. Bearing a distinct resemblance to its avian namesake, the crane's rotating superstructure pivoted on a fixed base and boasted a 27-ft. central mast carrying a 50-ft. boom, with the entire apparatus standing over 50 ft. tall, reputedly capable of lifting and placing a long ton anywhere along a 40-ft.-dia. circle.

CONSTRUCTION. We took many of our dimensions from Perronet's bill of materials (see page 20), ignoring the 1 percent difference between our inches and feet and, respectively, Perronet's *pouces* (thumbs) and *pieds* (feet).

Base. The massive 16x16x27 central mast is stepped into the cavity formed by four 10x10 sills lapped into a double-cross, and stabilized at midpost by eight paired 6x6 struts that spring from the ends of the cross. These struts rise at 60 degrees, converging on center both in elevation and plan as they climb, thus requiring compound joinery at the connections. The strut feet tenons are pinned into mortises in the sills. Otherwise the base is kept together by gravity.

Superstructure. Principal elements of the superstructure are the long 11x11 boom footed on the main beam, itself a 30x8x22 built up of two 15x8s bolted together, clasping boom, mast and great wheel hangers. A secondary 28x6x14 upper beam (double 14x6) clasps the inner wheel hanger, mast and lower strut. Other secondary members include the 8x8 hangers for the great wheel and the lower and upper struts supporting the boom.

Tertiary members complete the assembly. On the wheel side, diagonal braces to the main beam stabilize the wheel assembly and, along the upper boom, four 28x6 (double 14x6) clasps bind together booms and struts. The entire superstructure pivots on the tip of the mast, bearing laterally and vertically on the turned-down mast where it passes through the main beam just above the base strut connections.

As is typical of ancient lifting engines, the boom on the Perronet crane does not rise or fall, so its point of lift remains a fixed distance from the main pivot (all the points making up the 40-ft. circle). Since crane technology remained essentially unchanged from the late Middle Ages through the Enlightenment, we can infer that this characteristic was not a significant limitation.

Post windmills, similar to our crane in scale and form, feature a tail pole, an extended lever used to turn the entire mill so that its sails face into the wind (see TF44). But there is no evidence of any such lever in the Perronet drawing, implying that the crane must have been both sufficiently well balanced and easily enough rotated on its bearings so that the entire boom assembly could be turned by simply pushing on the wheel (the only reachable portion of the superstructure) or pulling on a tag line.

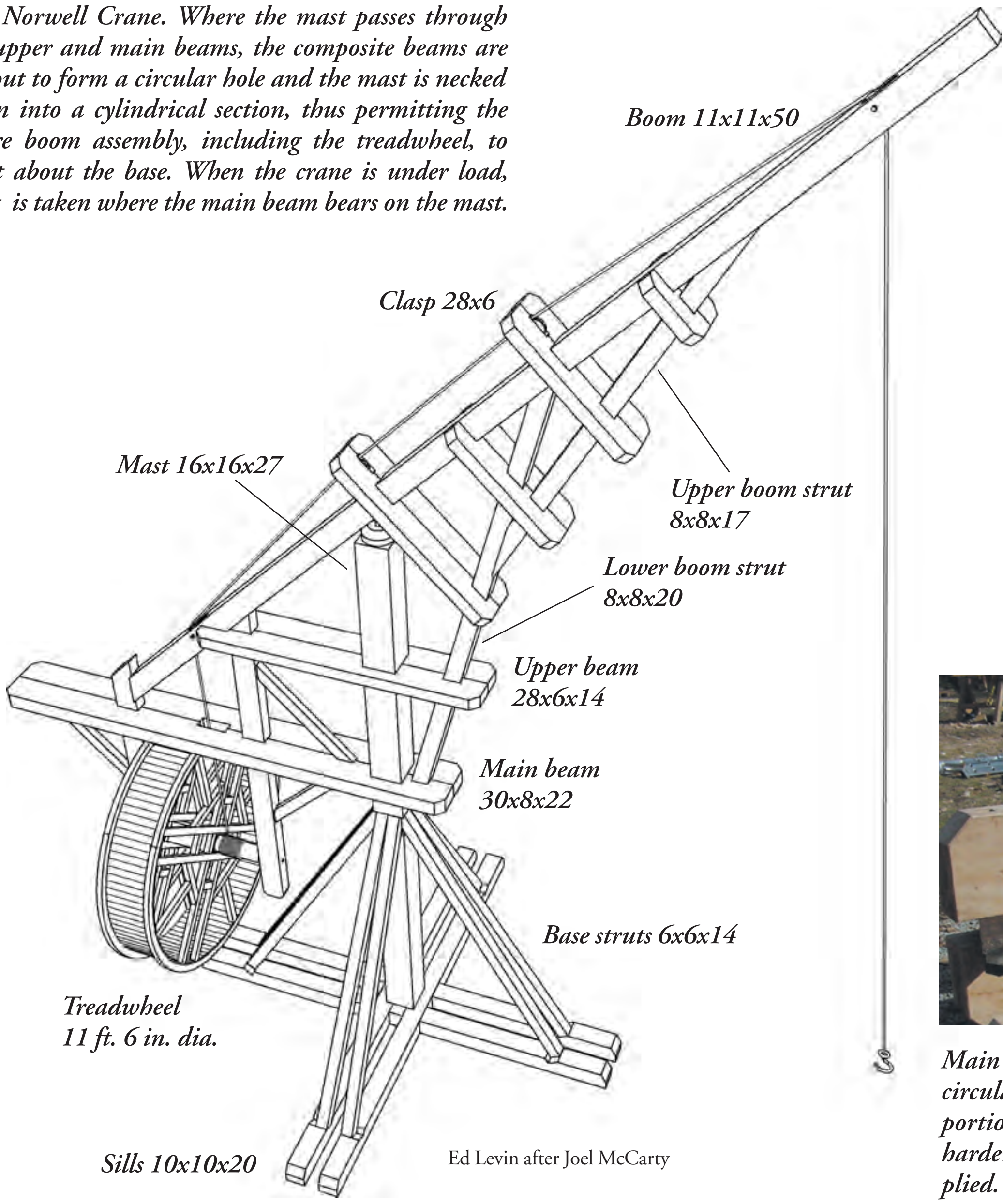
Hardware. The plans and elevations (see page 19) in the Perronet atlas indicate the iron hardware used in the crane, and the bill of materials in the text lists the pieces by weight. The two-part beams and clasps are clearly bolted together and, judging from the pictures, the bolts are unthreaded, with a head on one end and a slot through the rod at the other through which a thin wedge is driven to tighten the bolt. Such draw-wedged bolts are quickly detachable, a convenience for a knock-down portable device. In the bill of materials, nutted bolts are listed for the wheel, which presumably did not get knocked down for transport. The drawing shows the main beam halves bolted together through its joints with boom, hangers and boom struts; the upper beam is bolted through the boom, but adjacent to the strut crossing. (The pivot joints at the mast are, of course, unbolted.) An iron strap reinforces the connection of the inner wheel hanger to the boom.

The drawing does not show bolt locations for the clasps. We concluded that these may have been bolted through the boom crossings, but that no bolts pass through struts so that they can shift axially relative to the clasps (more about this below). The drawing does show iron bearings at the two principal pivot joints, where the mast passes through the main beam and where it terminates at the boom. For the mast tip, our ironcasters produced a 3-in.-dia. gudgeon pin, broached into the wood (itself double-hooped to prevent splitting). This pin engages a bearing welded to a plate fastened to the underside of the boom. Our lower bearing was speculative. Two plates were forged in halves, so that they could be installed around the mast journal and into the half-circles of the two-part main beam. The upper elements, with downward projecting cylindrical rims, were screwed into the underside of the main beam. The lower elements were flanged and fastened to diametrically opposed flat surfaces on the mast. The assembly, which enjoys lubrication, provides bearing against side thrust as well as down pressure.

Wheel. The final element of the crane, the great wheel that serves as the windlass to raise and lower the load, is really two wheels hung on the same axle, joined together by sheathing nailed to the inside surfaces of the rims and used as a runway. To actuate the windlass, the operator or operators climb into the wheel between the spokes and walk around inside, treadmill fashion.

The ratio between the 11-ft. inside diameter of the wheel and the 9-in. outside diameter of the wheel arbor gives a mechanical advantage of 14.7:1. Without indulging in hamster heroics—running as high as possible up the wheel to increase leverage—it should be easy for a wheel-walker to exert leverage equal to half of one's weight. Neglecting friction, a 150-lb. person should be able to lift over half a ton, and two walkers would be able easily to lift the rated long ton of 2200 lbs.

The Norwell Crane. Where the mast passes through the upper and main beams, the composite beams are cut out to form a circular hole and the mast is necked down into a cylindrical section, thus permitting the entire boom assembly, including the treadwheel, to pivot about the base. When the crane is under load, most is taken where the main beam bears on the mast.



Ed Levin after Joel McCarty

Joel McCarty

Main beam before assembly around mast. The circular aperture closes around a necked-down portion of the mast to form a pivoting joint, hardened by steel bearing surfaces not yet applied. See also photos on page 16.

ENGINEERING. The issue of mechanical advantage led us naturally to structural design questions as we chose the timber and had to work out joinery sufficient to resist the resultant loads and stresses. Even without reference to loading, specifying white oak for the sills (to resist ground decay) and for the wheel arbor (to resist wear) seemed obvious calls. Beyond that, the mast, the main beam and the boom stood out as large and critical pieces calling for close attention.

The structural model was loaded with the dead weight of the crane timber frame, plus the mass of the lift (maximum pick 2,200 lbs). The wheel was not modeled; rather its load was accounted for by 500-lb. point loads for the two wheel rims and their shares of sheathing, plus an additional 400 lbs. for wheel operators. Results of interest included member axial and shear forces (which give bearing and tension forces at connections) and member bending stresses. Because of the relatively large stick sizes, shear stresses were not a significant factor.

Apart from the oak sills and arbor, which we could have, it turned out that for everything else we could have any species and grade we wanted as long as it was No. 2 Eastern white pine. (Restricted timber availability may not be a new problem for crane builders. The Perronet drawing shows a scarf joint in the boom in the vicinity of the uppermost clasp, a configuration confirmed by the timber list. Most likely, the builders were unable to find a single tree long enough for their needs, though it's also possible that such an outsize piece would be a nuisance to transport when the crane was knocked down to go to the next job.)

Since our boom could not be made of oak, it was fortunate that FEA model results indicated that Joel's original concern about boom strength was misplaced. The pine boom looked quite comfortable under load. Alas, the same could not be said for the main beam or mast. The problem lay with the first law of structure: Load Goes to Stiffness. In the model, from the top sheave where the lift line transferred pick weight to the boom, the load path of choice followed the boom and forked down the upper boom strut through the lower boom strut, where it delivered a considerable compressive punch to the inner end of the main beam. It chose this route because the struts are positioned to take the load in direct compression, whereas the boom is forced into bending. And, like all framing materials, wood is much stiffer when loaded axially than it is in bending.

Unfortunately, the down thrust of the lower strut imparts a moment to the main beam right at the point where the mast punches through it, greatly reducing the net section of the beam and proportionately increasing the resulting bending stress. Worse, the lean of the strut delivers a hefty side thrust to the even-smaller net section of the mast right where it necks down to pass through the main beam, yielding bending stress on the mast more than double the allowable. Nothing that couldn't be handled by a stout piece of clear oak, the first choice of our English and French forebears, but well beyond the capacity of the available soft pine. What to do?

Virginian and fly fisherman Al Anderson, henceforth to be known as Professor Lift, explains to the crew what's going to happen now that the base and mast have been made ready to receive the rotating assembly.

Photos Ed Levin

Boom with upper and lower boom struts clasped together and offered to masthead, Rick Brown aloft assembling the upper beam, Matt Hincman beneath with bolts. Main beam to complete assembly is yet to come.

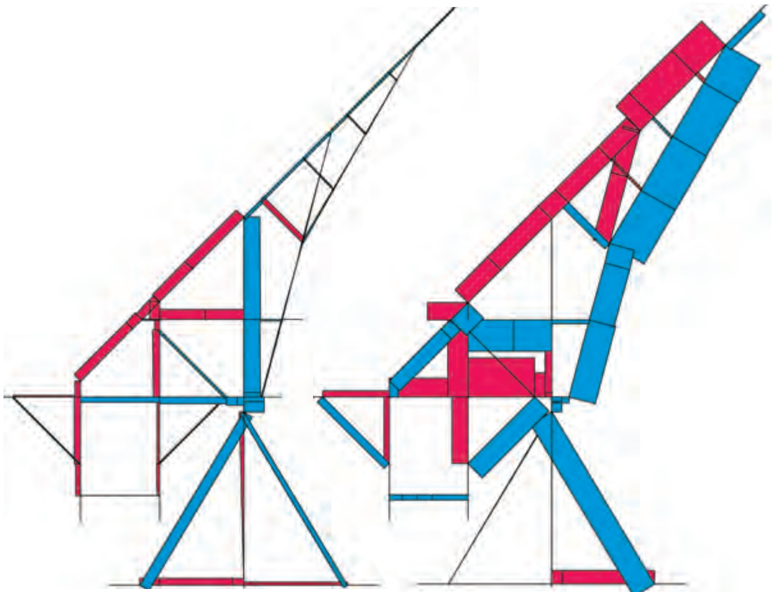
ENTER the Virginian. Helicopter pilot, heavy equipment operator, experienced rigger of church steeples, windmills and trébuchets, framer Al Anderson of Blue Ridge Timberwrights, Christiansburg, Virginia, was our professor of lift. Al had anticipated the crane load distribution problem and had a solution ready to hand. There was plenty of carrying capacity in the crane, he reasoned. It was just that we weren't utilizing the full structure. If there were a way to split the load path between the struts and the mast, we might overcome our material limitations. It was a question of imagination. Where I saw a rigid truss frame structure, fisherman Anderson pictured a flexible giant fly rod supported by a couple of props. What would happen if we pulled out the props and let the rod work on its own? Doubtful, I went back to the computer model and disconnected the struts from the boom. Under full load of 2200 lbs., the unassisted boom tip deflected a foot, and bending stress in the boom soared well beyond acceptable oak values.

Al suggested we reduce the load in steps until we were back in allowable territory. It turned out that the boom on its own could pick 500 lbs. without exceeding bending limits. We checked boom deflection under that load at its points of intersection with the incoming struts. Looking at travel along the lines of the two struts, we measured 5/8 in. of boom deflection at the tip of the lower strut and nearly an inch at the tip of the upper strut. What if we shortened the struts by these amounts? Then the crane should handle dead load plus the first 500 pounds of lift via boom bending and mast compression. Put on additional load and the strut shoulders would come home against their housings and mortises, bringing the struts into play, and the balance of the load should travel down the strut pathway.

So how would this load sharing affect crane performance? The FEA software could not account for the threshold phase shift in a single model, so the answer would have to come from the algebraic sum of two separate models. Looking at the comparative axial force diagrams (facing page), where blue is compression and red is tension, the alternate load paths are clear. In the Stage 1 drawing, the light lift load flows to ground via boom, mast and base struts. In Stage 2, the heavier pick is carried via boom, boom struts, mast and base struts. Note that in many of the areas of significant axial load, the forces are of opposite sign in the two diagrams (by convention, compression is negative and tension positive). That is, where you find compression on the right, you see tension on the left, and vice versa, and in the algebraic sum of the two conditions, they cancel one another out. Meanwhile, in the lightly loaded Stage 1, the center of gravity of the crane superstructure is to the left of the pivot, and thus the rear struts are more heavily loaded. Conversely, Stage 2 overbalances to the pick side (right), with almost all the load channeled via the front struts.

Turning to the paired bending stress diagrams (facing page), look at the most heavily loaded areas in the mast and main beam adjacent to the pivot point. As with the axial forces, you will note that once again bending is of opposite sign in the two diagrams—in Stage 1, the pre-load of the crane's rotating weight plus 500 lbs, the mast bends to the left; in Stage 2, the load represented by adding 1700 lbs., it turns to the right, so once again you get cancellation. The same effect is found in the wheel hangers and parts of the boom.

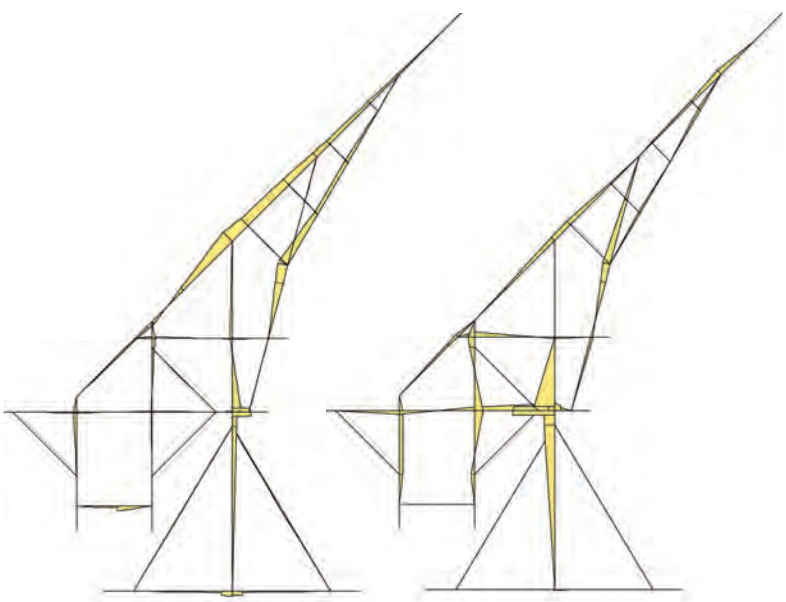
The force of Al's two-stage-load reasoning was relentless. We issued the necessary revisions to the strut shop drawings and put the fly rod scheme into effect.



STAGE 1 AXIAL FORCE   STAGE 2 AXIAL FORCE

The Clasps. Now what was the role of the clasps, as Al called them, in this scheme? Axial forces in the struts were insufficient to cause buckling. The long lower strut was already sufficiently reinforced by the upper beam. Remove the clasps from the FEA model and there was no discernible effect. On the other hand, if—as we proposed to do—you unlaced the strut upper ends from their mortises, what would keep the struts in place before the joints came home under heavy load? Could the primary function of the clasps be to act as strut retainers while the crane was unloaded or lightly loaded? Was it possible that we had discovered the hidden logic of Perronet's crane?

In addition to shortening the top ends of the upper struts to accommodate the load-sharing scheme, we made one other significant alteration to the apparent crane design, based on our reasoning about how the load should affect the structure. Observe that in both loadcase drawings, the final branch of the load path follows struts rather than the mast. That is the case because we cut short the shoulders of the mast to prevent its bearing on the sills, insuring that the struts (unpegged, remember, in their upper mortises) remained perpetually in compression, lest vibration or motion of the crane cause them to depart their housings. While in our design the mast foot floats above the base, it is restrained from sideways movement by the ample engagement of the mast base tenon into the deep square pocket formed by the sill crossings.



STAGE 1 BENDING STRESS   STAGE 2 BENDING STRESS

RAISING and Rollout. The erection of a 50-ft.-tall lifting machine incorporating 15,000 lbs. of timber and iron presented a certain chicken-and-egg problem, which rigger-in-chief Al Anderson puzzled over at length. When not evoking Rodin's *Thinker*, Professor Lift could be found in the impromptu project engineering office, huddling with me over a glowing laptop as we sorted out alternate lifts, loads, centers of gravity, shear leg and tackle configurations.

We resolved to assemble, block up and level the base cross, then pick the mast, using tackle descending from a pair of shear legs, and lower it into the base socket while inserting the eight supporting struts Iwo Jima style. Then we would assemble and raise the boom, struts and clasps, engaging the mast peak bearing. We would leave the rigging in place while adding the wheel hangers, upper beam and main beam and braces. The wheel would go on last.

Our lifting engine (the chicken) would be shear legs harvested from the Brown's woodlot. Like a pair of dividers, shear legs are stable once secured fore and aft in a straight line perpendicular to the spread of the legs. In our case, two stout trees provided tie-offs for the stays, and block and tackle in both stays would enable us to erect the shear legs and then incrementally adjust their lean to relocate the point of lift. We needed 50-ft. poles with 8-in. midspan diameters. A pair of candidate trees was quickly located right across the road from the site. Darryl Weiser felled and limbed them, and reeving and rigging began. For our major lift—the 2-ton boom assembly—we used two sets of tackle, giving us a pair of lift lines. For all but the simplest picks, the procedure was to locate the load's center of gravity and rig to two points roughly equidistant from it on either side. Our ability to adjust the lean of the shear legs put the point of lift just where we needed it. And the double-line lift enabled perfect adjustment of the hang of the incoming load.

Picking the wheel was a breeze; it was moving it to the crane site that was the problem. The finished wheel was assembled vertically, hanging from chainfalls inside the workshop. We had the bodies, and it seemed a simple matter to lay the wheel flat and carry it out through the shop's large double doors. Unfortunately, the wheel's Achilles heel turned out to be its 3x4 white pine spokes, which were halved in thickness at their crossings. The wheel builders assured me that if we tried to lift the 1600-lb. assembly flatwise, the spokes would fracture at these weak points.

There was a puzzled silence while everyone pondered Plan B. The solution proved irresistible. What is it that a wheel does best? The path to the site was fairly level and the surface smooth. Okay, so the wheel was nearly 12 ft. high and a bit unstable, but we had the numbers to handle the load and tipping forces should be easily restrained (as long as we didn't let it lean *too* far). So we took her out for a spin.

When the crane was finished and it was time to strip the rigging and lower the shear legs, we were briefly puzzled again. The legs couldn't simply go back down the way they had come up since the crane was in the way. So, naturally, we used the crane to lower them.

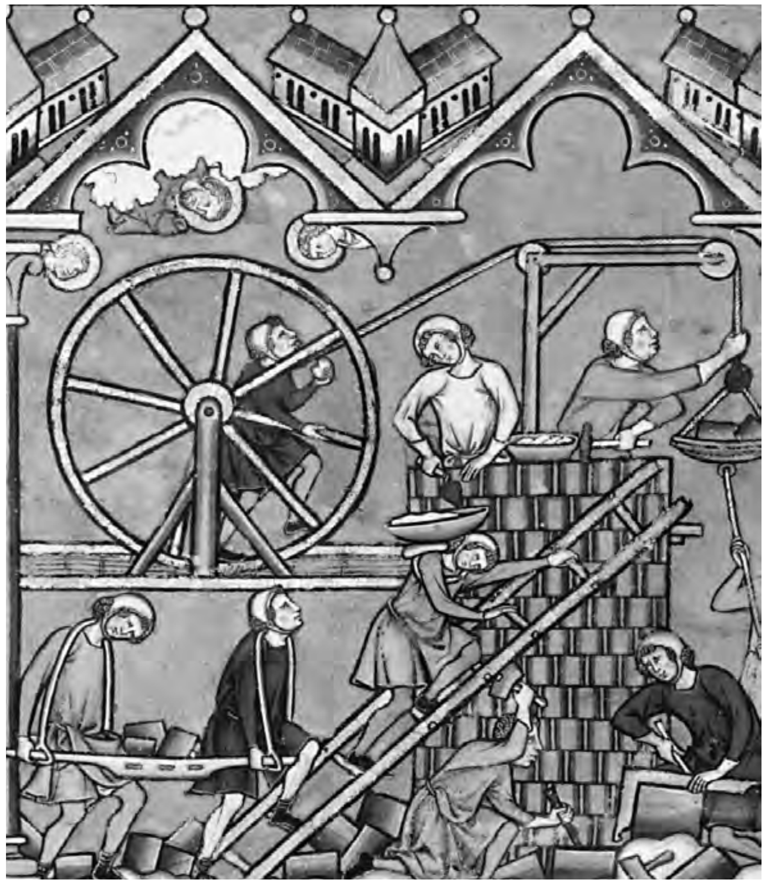
WITH the crane free of rigging and able to rotate freely, it was time to put it through its paces. The builders took turns riding the hook and running the wheel. Then we lifted some dunnage to clear it from the site. I pushed on the wheel and the crane rotated easily. Here was a wooden machine with almost no moving parts, using no fossil fuel and making no noise, that could be run easily by one person. Add a pulley to the lift line and, with 2:1 mechanical advantage, a single operator could pick and move a ton, perhaps even more. My last view as I headed out was of four-year-old Silas Russell hoisting his father Henry into the sky, to the accompaniment of much giggling. I started to think about building a crane model with my seven-year-old Nate. But why make a model when, with just a bit more work, you could have a full-size working crane? —ED LEVIN

A Little Crane History

IN order to add the perspective of an art historian to their expertise in experimental archaeology, architectural design and woodworking, and to include students from another of the group known as the Colleges of the Fenway in Boston, Don Oster of Wentworth Institute of Technology and Rick Brown of Massachusetts College of Art invited me to join their interdisciplinary crane-building project funded by the Davis Foundation.

We began by taking the Great Crane of Bruges as a possible subject of this year's study, inspired by a detail from a painting by Pierre Pourbus published in Mark Girouard's *Cities and People*.[1] The painting is a 1551 portrait of Bruges merchant Jean van Eyewerve, seated before an open window through which we see the Kraanplaats, or Crane Plaza, of Bruges.[2] One can but think that the crane, as tall as a three-story house, made a big impression on the citizens of Bruges because of its size and important contribution to the city's economy.

Bruges was not alone in its respect for massive cranes of this type. A similar large crane that worked the docks in Antwerp appears in the background of at least two paintings, including an *Adoration of the Magi* now in the Philadelphia Museum of Art, and is prominently displayed in numerous city views and plans.[3] More than 40 other cities, from London to Seville, possessed cranes similar to the Bruges example in size and construction in the late 15th century.[4]



The Pierpont Morgan Library, New York. M.638, f.3

Fig. 1. Detail of manuscript (Paris,1250) illustrated by miniatures depicting Old Testament scenes. The fellow working the treadwheel keeps up his energy by eating fruit, but the hod carrier and the other laborers about to climb the ladder have an uncertain future.

However, last December we learned that students in the technical high school in Bruges intended to reconstruct the crane, or a version of it, in its original location, so the search began for other possible examples for our own project. In addition to their use on the docks of European cities in the late medieval and early modern periods, large human-powered cranes were employed in construction, most notably on the great cathedrals. An enormous wooden treadwheel still rests above the vaulting of Salisbury Cathedral today, and numerous manuscript illuminations depict such machines in use, especially in illustrations of the construction of the Tower of Babel (Fig. 1).[5] Such lifting devices continued to be used on construction sites through the 18th century, only replaced by iron and steel cranes powered by steam in the 19th century.

A number of illustrations of cranes are extant from the 18th century, including one made for Diderot's *Encyclopédie* (Fig. 2).[6] French architect Jean-Rodolph Perronet wrote and illustrated a series of volumes detailing his various bridge and canal projects, including the building of a stone bridge over the Loire River at Orléans 1750-1760.[7] For this project, Perronet designed a wooden crane similar to the one shown in Diderot's encyclopedia. It was

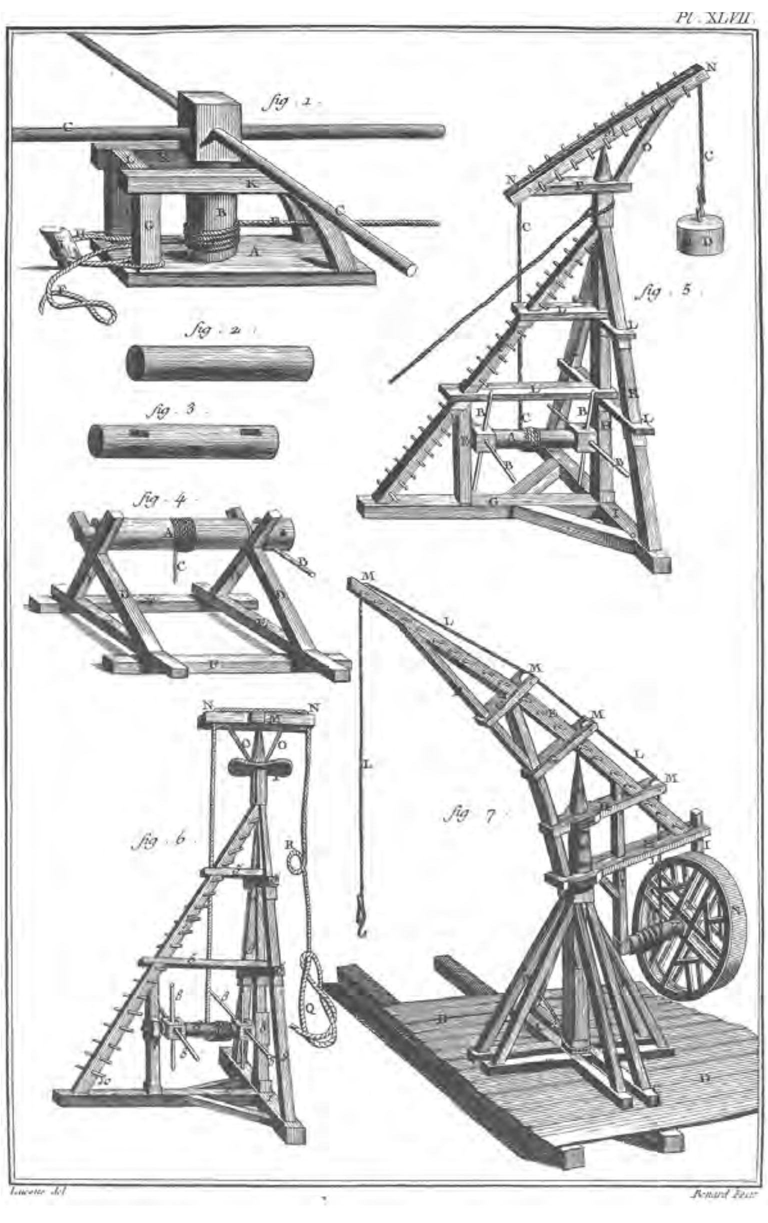


Fig. 2. Plate 47 from Diderot's* Encyclopédie *(1751-1772), showing a builder's crane, two hoists and two windlasses. The sharply pointed mast of the crane suggests that no load is taken there, and it is a mystery how, given the fixed location of their windlasses, the hoists could pivot on their pointed masts. (Plate used by permission of Dover Publications, Inc.)

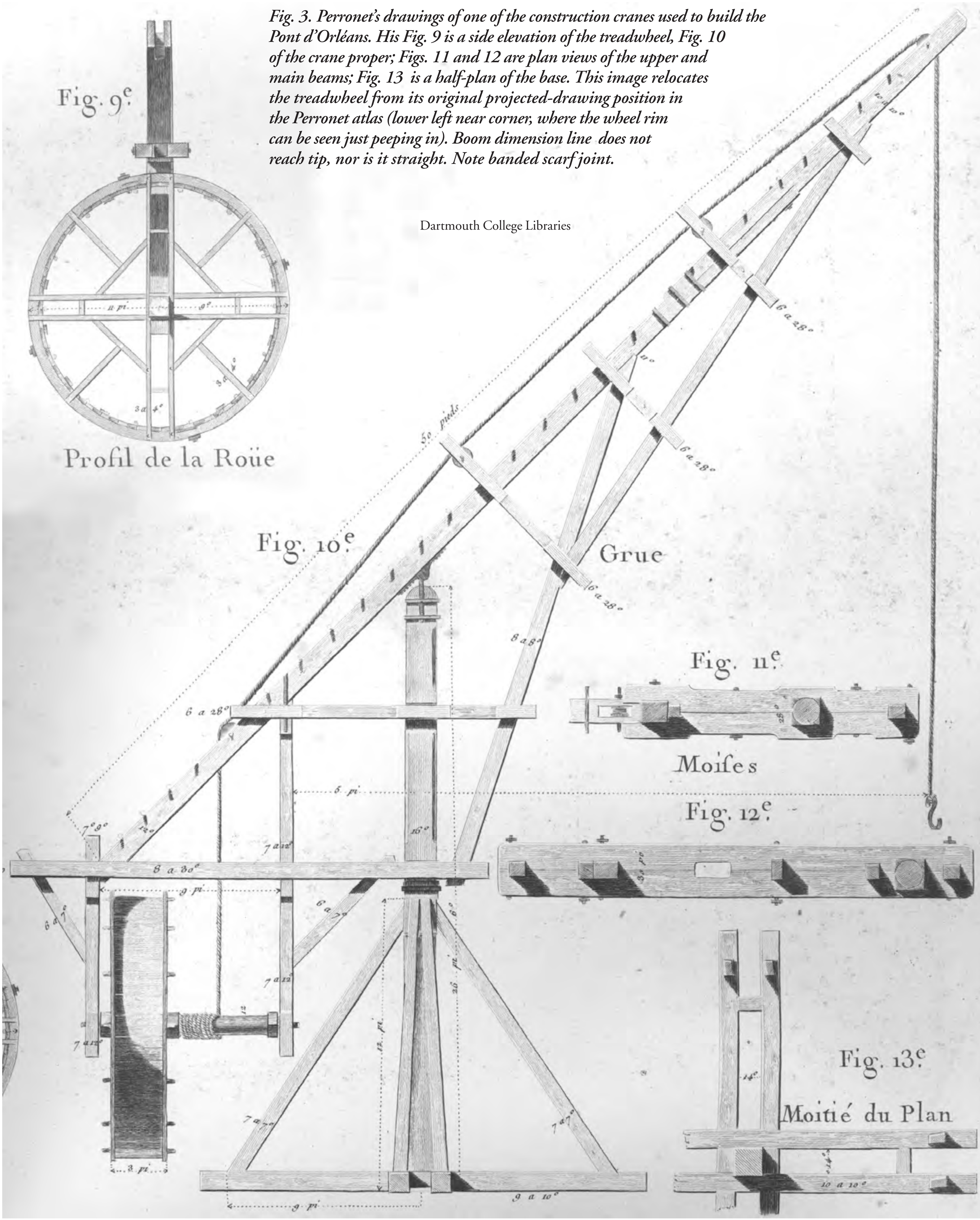


Fig. 3. Perronet's drawings of one of the construction cranes used to build the Pont d'Orléans. His Fig. 9 is a side elevation of the treadwheel, Fig. 10 of the crane proper; Figs. 11 and 12 are plan views of the upper and main beams; Fig. 13 is a half-plan of the base. This image relocates the treadwheel from its original projected-drawing position in the Perronet atlas (lower left near corner, where the wheel rim can be seen just peeping in). Boom dimension line does not reach tip, nor is it straight. Note banded scarf joint.

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powered by a single treadwheel and used to lift the large stones into place on the bridge. Perronet included a detailed drawing of the crane (Fig. 3) in his book, with dimensions indicated, as well as a bill of materials (both wood and iron) used in the structure, indicating lengths and sections or weights (Fig. 4 overleaf).[8] The drawing provided the information for the crane built this spring.

Information about the construction of wooden wind and water mills, more readily available, and about historical timber framing

John Fenske

Fig. 6. Pont de la Concorde in Paris, designed by Perronet, constructed 1787-1791 and widened in 1930. Perronet introduced daring proportions to the ratio of arch span to pier thickness. Upriver is to the left.

PONT D'ORLÉANS. 231

Détail des bois et fers employés à la construction de cette grue.

BOIS.

NOMS DES PIÈCES.	LONGUEUR.			GROSSEUR.					SOLIVES.			
	pieds.	po.	lig.	po.	lig.		po.	lig.	soliv.	pieds.	po.	lig.
Quatre racinaux ou croisillons d'empatement.....	20	3		10		à	10		18	4	6	
Quatre entretoises, chacune de.................	1	8		9		à	10		1	2	2	
Un poinçon....................................	26	6		16		à	16		15	4	2	8
Huit liens du pied, chacun de..................	15			7		à	7		13	3	8	
Une grande moise..............................	21	6		8		à	30		11	5	8	
Une seconde moise.............................	13	6		6		à	28		5	1	6	
Une grande aiguille pendante..................	15	9		7		à	12		3		4	6
Une petite aiguille, *idem*.....................	9	6		7		à	12		1	5	1	
Un lien de la grande aiguille..................	6	9		6		à	7			3	11	3
Un lien pour la petite aiguille................	5	8		6		à	7			3	3	8
Le treuil......................................	9	6		11		à	11		2	3	11	7
Circonférence réduite de la roue à tympans, le diamètre 11 pieds 9 pouces..............	36	11	2	3		à	4		1		1	10
Quatre grands bras de la roue, chacun de........	12			3		à	4		1	2		
Quatre petits bras de la roue, chacun de.........	3	4		3		à	4			2	2	8
Quatre goussets de la roue, chacun de...........	3	7		3		à	4			2	4	6
Quatre entretoises, chacune de.................	1	2		3		à	4				9	6
Première partie de la volée....................	43	4		11		à	11		12		9	11
Deuxième partie, ante de la volée..............	18	3		10	6	à	10	6	4	3	11	4
Premier lien de la volée......................	24	6		8		à	8		3	3	9	4
Petit lien de la volée.........................	24	6		7		à	7		2	4	8	1
Troisième moise...............................	9			6		à	28		3	3		
Quatrième moise...............................	5	10		6		à	28		2	1	7	4
Cinquième moise...............................	5	10		6		à	28		2	1	7	4
Sixième moise.................................	2	6		6		à	28			5	10	
TOTAL des bois................................									110	5	2	6

FERS.

Une écharpe de tête pesant avec son boulon et crochet...........	36 liv.
Une autre écharpe portant l'S, et son boulon, pesant............	110
Six crochets à la volée pour soutenir l'écharpe, une bride pour la volée, deux plate-bandes pour l'empatement, ensemble...............	141
La frette du treuil, et quatre pour les entretoises; un pivot et sa crapaudine; trois frettes de poinçon..........................	159
Quarante-un boulons pour les moises et poulies...............	379
Vingt-huit boulons à écrous pour la roue......................	32
Huit clavettes pour les tasseaux..............................	9 ¾
TOTAL des fers..................	866 ¾

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Fig. 4. Perronet's bill of materials. The wooden pieces* (Bois) *are listed by length, section and volume, the ironware* (Fers) *by weight. Modern English inches and feet differ by about one percent from French* pouces *and* pieds *of the day. A* solive *is defined as a volume measuring 6 by 6* pouces *by 12* pieds *long. Reasonably enough, the word also means joist.

and carpentry techniques, guided the fabrication of several small-scale working models by Wentworth and Mass Art students (Fig. 5 opposite). Knowledge of such sources was also available on the construction site, as many experienced timber framers participated. Joel McCarty (of Alstead, N.H.), an executive director of the Timber Framers Guild, Jim Kricker (Saugerties, New York), a millwright responsible for the reconstruction of a number of historical mills and waterwheels, and Henry Russell (Bristol, England), a timber frame preservationist, were among them. All of the experts taught students from Mass Art, Wentworth, and Wheelock as they worked on various parts of the crane during construction in Norwell.

Perronet is an interesting figure, as his career marked the beginning of professional engineering education in France. Before the 18th century, most formal education was provided by the Church. Craftsmen and skilled workers were typically trained through apprenticeships with an appropriate guild. By the 1700s that system had begun to break down, and the French government created new professional schools meant to educate and train a corps of technicians to meet its requirements.[9] The École des ponts et chaussées was formed in Paris in 1747, with Perronet as its first director, a post in which he served until his death in 1794.[10] He was particularly well known for his refined stone bridges, whose sophisticated arches minimized obstruction to the flow of the rivers they spanned. In some cases he employed very long, flat arches on narrow piers, as was the case with the Pont de la Concorde in Paris, built 1787-1791, under which 65 percent of the waterway is open (Fig. 6).[11] In his 1768 bridge at Neuilly (destroyed in 1939), he used piers 12 ft. wide to carry 120-ft. arches, a ratio of 1 to 10, when prior practice had dictated a ratio of no more than 1 to 5.[12] It is not entirely clear how much of Perronet's ability to construct daring but durable bridges derived from his knowledge of recent developments in mathematical techniques and how much is attributable to his varied experience and keen observational skills.[13]

It is somewhat ironic that Perronet's institution, the École des ponts et chaussées, along with other technical schools and societies established at the same time, was in part responsible for bringing about the Industrial Revolution. Of course it was the Industrial Revolution that made timber frame techniques, such as those used to construct this replica of Perronet's crane, obsolete. —MARJORIE HALL

Marjorie Hall is Associate Professor of Art History at Wheelock College.

Notes

1 M. Girouard, *Cities and People: A Social and Architectural History* (New Haven: Yale University Press, 1985), p. 95.

2 For a view of the full painting see: P. Huvenne, *Pierre Pourbus peintre brugeois 1524-1584* (Bruges: Musée Memling, 1984), pp.210-214; and see M.P.J.Martens, ed., *Bruges and the Renaissance: Memling to Pourbus* (Bruges, 1998) for this and many other images of the Bruges crane.

3 J. Van der Stock, ed., *Antwerp: Story of a Metropolis 16th-17th Century* (Antwerp: Hessenhuis, 1993), p. 52, and *passim.*

4 Many of the cranes are depicted in some detail in the popular city views of the era. See F. Bachmann, *Die alte deutsche Stadt, ein Bilderatlas der Stadteansichten bis zum ende des 30 jahrigen Krieges,* 3 vols. (Leipzig: K.W. Hiersemann, 1941) and G. Braun and F. Hogenberg, *Beschreibung und Contrafactur der vornembster Stät der Welt,* 6 vols. (Plochinger: Müller und Schindler, 1965-70, facs. reprt. of Cologne ed., 1572-1618) for reproductions. A more accessible but abbreviated version of the latter can be found in J. Goss, *The City Maps of Europe: 16th-Century Town Plans from Braun and Hogenberg* (Chicago: Rand McNally, 1992). Forty-two of the city views in Braun and Hogenberg show cranes.

5 A. Erlande-Brandenburg, *Cathedrals and Castles: Building in the Middle Ages* (New York: Harry N. Abrams, Inc.,1995) illustrates many images from manuscripts that include cranes, and includes a photograph of the Salisbury wheel.

6 D. Diderot, *The Architectural Plates from the "Encyclopédie"* (New York:

Joel McCarty

Fig. 5. Working models of the Perronet crane constructed by students in Boston at Wentworth Institute and Massachusetts College of Art. In the background is the scene from the 1551 Pourbus painting showing the Kraanplaats and the Great Crane of Bruges, the original project model.

Dover Publications, Inc., 1995), p. 108. This modern selection of plates is taken from Diderot's *l'Encyclopédie, ou Dictionnaire Raisonnée des Sciences, des Arts, et des Métiers*, 28 vols. (Paris, 1751-72).

[7] J.-R. Perronet, *Description des projets et de la construction des ponts de Neuilly, de Mantes, d'Orléans & autres; du projet du canal de Bourgogne, pour la communication des deux mers par Dijon; et de celui de la conduite des eaux de l'Yvette et de Bièvre à Paris, en soixante-sept planches* (Paris, L'Imprimerie royale, 1782-83).

[8] *Ibid.*, Pl. XLII, figs 9-13.

[9] C. R. Day, *Education for the Industrial World: The Écoles d'Arts et Métiers and the Rise of French Industrial Engineering* (Cambridge, Mass.: MIT Press, 1987), p. 7. For a more complete discussion of technical training in the context of educational movements in the age of the Enlightenment, see F.B. Artz, *The Development of Technical Education in France, 1500-1850* (Cambridge, Mass., and London: The Society for the History of Technology and the M.I.T. Press, 1966), pp. 60-86.

[10] B. Marrey, ed., *Écrits D'Ingénieurs* (Paris, Editions du Linteau, 1997), p.10.

[11] E. Garrison, *A History of Engineering and Technology: Artful Methods* (Boca Raton: CRC Press, 1991), p.133. Although its roadway was widened in 1930, Perronet's bridge is still in use, as is one he built at Nemours.

[12] S.B. Hamilton, "The French Civil Engineers of the Eighteenth Century," *Transactions* of the Newcomen Society 22 (1941-42), p. 153. The Neuilly bridge served until it was demolished in 1939.

[13] R.S. Kirby et al., *Engineering in History* (New York: McGraw Hill Book Co., Inc., 1956), pp. 220-222.

A Time Machine for Learning

IN June 1969, less than 24 hours before the liftoff of Apollo 11 from Cape Canaveral, I rushed to my hometown airport in Roanoke, catching the last seat on the last flight to Atlanta, hoping to snag a seat on the last plane to Orlando. I sweated every minute as the plane filled, and by luck landed the last seat on the last flight to Florida. I arrived in Orlando during the night, caught a limousine to Melbourne and flagged a taxi full of half-crazed space-flight kooks like myself. Coming upon a beach meadow filled with cars and people, all radios tuned to the countdown that echoed across the water—*3, 2, 1, liftoff!*—everyone stood in awe as the three commanders rushed into the unknown. What would become of them? Why was I here?

I have always enjoyed learning, but the conventional educational process feels to me like a suit that does not fit. Like Mark Twain, I never let my schooling get in the way of my education. I am part of a very large group of curious and eager learners who do not take the direct path to knowing. It is safe to say that many Guild members fall into this category of trailblazing, self-taught, high-risk adventurer learners. Individual vision has its place. In learning and in life it is important to follow your curiosity and to trust your instincts.

When the Apollo 11 spacecraft took off, it was actually pointed in the opposite direction from the moon. The moon was on the other side of the Earth, completely out of view. The known orbits of the moon around the Earth and the Earth's around the sun and the known speeds of the spacecraft and of the Earth's rotation made possible the final perfect alignment. Often the path to a goal is not linear or direct but a sequence toward a constantly moving target.

A year later, while attending college and trying to come to grips with what was important in my life, I came to the conclusion that I would avoid any profession where I could not wear blue jeans to work. Shortly after that decision, I met Laura Smith (she was wearing a pair of blue jeans) and, inspired by my profound denim vision, she convinced me to go to art school. Shortly after that, we got married, we both became sculptors and then educators, and after 31 years we both still wear blue jeans to work.

As teachers, the best thing we can hope for is to prepare young (and not so young) people for a lifetime of learning on their own. Our time is best spent nurturing curiosity and stimulating imagination—which, as Einstein correctly observed, is more important than knowledge. With the right conditions, all we have to do is point toward the window in the wall. The students will do the rest.

Over the last 30 years, I have decided that the creative maker-thinker-doer will be best equipped for problem-solving after developing a sense of history, an understanding of oneself and a craft to forever perfect. The hand, said philosopher Jacob Bronowski, is the cutting edge of the mind.

SO how did we decide to build a 50-ft.-high wood-framed human-powered construction crane? At an exhibition of our Massachusetts College of Art faculty work in Boston a couple of years ago, my friend Don Oster, who teaches architecture at Wentworth Institute, asked me if I thought we could build a wood-

Photos Joel McCarty

The treadwheel, put together in the author's sculpture studio and here suspended by chainfalls, required a subcontract of its own. Below, there was plenty of night work: here the 27-ft. mast is carried to the base where it will be erected by means of shear legs the following day.

framed dockside crane similar to the 16th-century Great Crane of Bruges (Belgium), which he had seen depicted in a painting. This device is a three-story crane, enclosed with siding and a roof, that rotates like a post windmill. Having been to Virginia and to Scotland on trébuchet-building expeditions with the Guild, I answered

that I knew a group of people who could make it happen! Putting our heads together, and inviting Wheelock College art historian Marjorie Hall to join us, we composed a proposal to the Davis Foundation of Boston for a grant administered by the Colleges of the Fenway to encourage innovative teaching projects among faculty members of participating institutions. To our amazement, the proposal was fully funded. We then enrolled three individual but related classes centered on the Great Crane of Bruges of 1650. Don Oster's architectural model-making class would produce architectural drawings and models based on information gleaned from northern European paintings of the period. Marjorie Hall's architectural history class would scour paintings, prints and drawings that depicted cranes and research the history of the crane in the social and economic history of the time. My course, Culture and Technology, was to research the technology of the crane and make a 12-ft. working model during an intensive week-long workshop.

A few months later, I presented the idea to Jim Kricker, millwright extraordinaire and perpetual student of historic timber frame technology, whom I had worked with before in Virginia, Scotland and Massachusetts (see TF44, 50, 54). Jim said, "Count me in!" At that moment, the indomitable Henry Russell was en route from England, on his way to New York via Boston, and had independently conceived an interest in building this very crane. Henry showed us his collection of crane pictures and information and enthusiastically joined the team. Soon after, Henry and Jim left for a meeting of traditional timber framers in Virginia. At the conference they found themselves looking at slides shown by Kristen Brennan, a historic preservation graduate student at Cornell University who had recently spent a year in Belgium (see TF60-62). To their surprise, the slides included views of none other than the Great Crane of Bruges. Small world.

Several months into the project we discovered that the City of Bruges had been designated the Cultural Capital of Europe for Summer 2002, a prestigious designation accompanied by funding that provided local historians, educators and builders the means to build their own reproduction of the crane. We were surprised but happy enough for them—after all, it made perfect sense for the crane to be built in Belgium. However, in order not to be doing repetitive research, Henry suggested that we change plans and build a different device, this time a builder's crane used to erect cathedrals, other large buildings and bridges, and designed by the 18th-century French engineer Jean-Rodolphe Perronet. Such a crane could be erected on site and then disassembled and moved to another location. In the case of a bridge, it could be moved across the bridge as construction proceeded. Perronet published a relatively clear drawing and a written description of this crane, several of which he used to build a stone bridge over the Loire at Orléans, France, in the 1750s. Henry Russell and Jim Kricker quickly agreed that this change of plans would give us the opportunity to build the crane *full size*. How did they deduce that? Probably in a telephone conversation with Joel Whynot? McCarty, who by this time had agreed to provide a full set of detail drawings to boot.

WHEN the time came for class recruitment, if I had asked my students, "How would you like to study the history of France circa 1750?" many, if not most, of them would have jumped out the window to avoid answering the question. But when I asked, "How would you like to build a human-powered crane of wood?" their heads popped up like gophers on the first day of spring. They stood in line to enroll. Still interested by the Bruges crane, we started by studying a fragment of a painting by Pierre Pourbus from 1551. Using this image alone as our point of departure, the students' genuine curiosity and desire to build fueled the discovery and learning process. Research and inquiry produced piles of images of cranes, painted by significant artists throughout northern Europe. Information and answers led to more questions. What is technology? What is the relationship between technology and culture? How big is this big crane? Can we build it? In class, architecture student Alexa Riner translated Perronet's French text accompanying his drawings of the crane we would actually build. In disbelief, Alexa had translated a passage describing how it took the French 108 (carpenter-) days to build the crane. "How are we going to build it in a six-day workshop?" she cried. I explained that in 1750 carpenters cut the trees down by hand, fashioned them into finished pieces with axes and hauled them to the building site with draft horses or oxen. I should also have quoted Samuel Johnson, that "Few things are impossible to diligence and skill." And little did Alexa know who would be coming to help us.

Through their research, drawings and many models, the students began to gain an insight into the history surrounding the crane. Issues of patronage, economic systems, the formation of trade guilds and social organization became prominent. The crane was revealed as a symbol of civic pride and economic dominance. Details appeared of process, materials and complementary technologies. The students developed an understanding of the history of lifting engines and the people and societies who built them. The process of learning-by-doing provided a way to get a little closer to what it might have been like to live and build in a particular society at a particular time.

Joel McCarty

Jane Eisensmith, Mass Art sculpture student (at left), and timber framer Donna Williams put the finishing touches on the treadwheel axle. Sized surfaces will be enclosed by passing spokes of the double-rimmed wheel; cylindrical portion will wind and dispense the lift line. Axle journals are cast iron with square shafts fitted to broached holes.

SO in the early days of April our studio and work yard overlooking the North River in Norwell, an old shipbuilding town near the south shore of Massachusetts Bay, took on the feeling of a historic village. Here, Matt Hincman, Mass Art alumnus, directed several students and alumni forging large numbers of bolts and clamps, using coal-fires, anvils, hammers and tongs. There, sculpture student Matt Stone built an iron cupola, and, with George Greenamyer of the Mass Art sculpture faculty, directed a crew of sculpture students who cast iron gudgeons for the axle ends of the large human-powered treadwheel. A team of students and alumni worked with timber framer Chris Madigan and furniture maker and sculptor Ellen Gibson to build this elaborate wooden wheel, almost 12 ft. in diameter, that serves as both counterweight and engine. Timber framer Donna Williams produced the axle while permanently influencing one lucky student with her knowledge of layout and craft. Our two-acre work yard was filled with volunteer timber framers who had traveled from several corners of the country, bringing not only truckloads of the tools of their trade and years of expertise, but also a remarkable willingness to share their knowledge and engage in "discovering" with each and every student.

Henry Russell's determination to hand-hew the 45-ft. boom and the 27-ft. mast worried me, given the limited duration of the workshop. I mentioned the idea of a portable sawmill to West Virginian Darryl Weiser, but he calmly assured me there was no problem. Have you ever seen the West Virginia chain saw method? I had heard of Darryl Weiser but had never seen chain saw performances

Diane Muliero

Iron parts make up little of the bulk of the crane but play a vital role in its operation. Above, Matt Stone's gudgeon pin-casting operation. At right, smiths Erica Moody (thinking), David Cronin (hand in fire) and Ted Hinman (on bellows), heating the iron rings to band the mast and axle.

as elegant as Nureyev dancing. Darryl cut and brushed the end of the mast into a perfect circle, and then, at the request of the structural designers, cut it off and politely made the new end perfectly round again. Peter Bull then cut a second equally perfect mortise to house the cast-iron gudgeon on which the lifting arm would pivot.

Kristen Brennan organized a conference call with our crane building counterparts in Belgium, who had just completed their project the day we started our crane, giving us a sense of international collegiality. Wentworth students Jay Jenhurst and Nat Crosby were delighted to hear the new Bruges crane was not built full scale, thus holding onto their dream of doing it themselves one day. A real sense of community, cooperation and education glowed through the six days of production. The non-hierarchical organization provided students with the opportunity to work with many different experts in many different processes. All the while, timber framer Bob Smith gently (and often unnoticed) coordinated all the operations and saw that every detail was in place and on time for the final installation of parts, the latter patiently choreographed by Al Anderson in his gentlemanly fashion. His focused comrades Will Truax, Leon Buckwalter and Al Thomas took on each task as it came up. This generosity, of time, labor and expertise, was the fundamental ingredient for the success of our endeavor.

This crane will not put anyone or anything on the moon. It has served as a process to feed the imagination. It has inspired students of many ages and walks of life. And it has demonstrated the possibilities of creating a large, intricate object through intelligent research, keen observation, collaboration and hard work. The project gave a picture window view into history, but the process of the learning exceeded the importance of the object produced. In the end, it's ourselves that we make. —Rick Brown

Rick Brown (handshouse@attbi.net) is professor of sculpture at Massachusetts College of Art, Boston. He has previously worked with Guild members moving obelisks (his idea) and building trébuchets.

Laura Brown

All passion spent, Rick Brown takes the completed Perronet for a spin.

Rendezvous '02

THE Lesser Crane of Norwell (misnamed after all that) had several flaws as a Guild project; there was not nearly enough time or money in hand to produce that kind of professional teaching event at which we have become so adept. As a rendezvous, it further suffered from a very short lead time, ambiguous goals and iffy logistics throughout. But, somehow, there were 25 Guild members on the scene alongside the 60 or so art and architecture students (why don't we do a project with law students?) from the Boston area. Somehow a third of the Guild Directorate (Williams, Madigan and Mullen) managed to insinuate itself into the proceedings to good effect.

There were historical plans, sort of. Certainly we had more to work with than the fragment of parchment that initiated the first trébuchet at VMI in 1997. A single sheet from Jean-Rodolph Perronet (Paris, 1783), with enchanting details, scantlings in French, and even some dimensions! It soon became clear that the draftsmen may have seen the machine, but they could not have been the ones who built it. Fitchen's *Building Construction Before Mechanization* (MIT Press, 1986), included a couple of fascinating images from Diderot and D'Alembert very close to what we wanted to build, reproduced from Antoine Moles' *Histoire des charpentiers*. I incautiously volunteered to generate an electronic model (how difficult could that be?). While the students made beautifully detailed studio-sized models in Boston, I pecked away at electronic ephemera, wildly speculating on joinery methods and raising sequence. I arrived on site with 30-plus pages of shop drawings and threw myself upon the mercy of my colleagues—who immediately began to supply me with an almost endless stream of improvements, interpretations, corroborations and, ultimately, solutions to the ancient vagaries. It is unlikely that the as-built will ever catch up with the object of our desire.

Three colleges made this happen. Massachusetts College of Art (the only state-supported arts college in the nation) took the lead, under the relentless direction of Rick Brown, seconded by the no-less-determined Laura Brown. (None of this would have been necessary without them.) Wentworth Institute of Technology, via Don Oster, the conceiver of the whole project in the first place, went so far as to bring tools, timbers and me down to Boston for one of my favorite indoor sports—the merciless abuse of architecture students. Wheelock College contributed the amazing Marjorie Hall, art historian, who did all the legwork on the old paintings and drawings, and provided academic legitimacy to an event that otherwise would have looked like a complete circus. All your tired jokes about art majors aside ("Did you want fries with that?"), we would do well to include an art historian on subsequent adventures.

Three trades made this happen. I may have to deny this later, but it was an unreserved delight to work with these students—the first constituency I've encountered whose enthusiasm may exceed even our own. We were blessed with the company of material artists whose minds were open to anything, who wanted just a bit of direction, and then jumped in with both feet. We made our own cast iron (how cool is that?) in a dramatic night-time pour, and at any moment we could count three forges and anvils, attended by men and women, ringing to the ancient song of Haephestus. The iron-casters made us some very cool axle bits (gudgeons), and the smiths supplied a steady stream of hand-wrought bolts, wedges, washers and such, accompanied by appropriate clouds of smoke.

Photos Diane Muliero

The boom was assembled to its struts and carefully double-rigged (two pull lines) to keep the required force under 50 lbs. per person and the better to control a truly awkward object. Clockwise from left, pick is readied and slack taken up; load is raised and inclined toward its eventual pitch; load is raised higher and further inclined, ready to lift onto the waiting gudgeon pin and be captured by the upper and lower beams.

Photos: Chris Madigan above, at right Joel McCarty

Peter Bull (at left) and Darryl Weiser ponder the latest instructions from Design and, in the photo at right, Darryl takes the plunge.

Joel McCarty

More than three people made this happen. Principal actors in the drama include, but can hardly be limited to, millwright Jim Kricker, laconic as Marcel Marceau, who brought considerable equipment, expertise and leverage to the event and also brought his own fiddler (daughter Susannah, 14); Henry Russell of the UK, direct comedic descendent of Harpo Marx, who insisted on hewing and scribing every part (and was immediately overruled by The Authority), who came with much ancient technology experience and who also brought his own fiddler (son Silas, 4); Laura and Rick Brown, neither laconic nor comical, and *sans* fiddler, whose remarkable home (in part *ca*. 1640) and well-equipped studio (entirely *ca*. 1998) and generous spirits provided ample infrastructure and ambience; Peter Bull, Darryl Weiser, Curtis Milton and Al Thomas, who took on the down and dirty timber framing work with good humor and high style, and then did it again when the numbers changed; Ellen Gibson, Chris Madigan and Donna Williams who overran the studio and made all that fussy round, rolling, bolted, tapered, revised, again-revised (and again-revised), carved, decorated and heavy work come to fruition in a timely and cheerful fashion; Leon Buckwalter and students, who worked, out of the limelight, taking the huge white oak sleepers from raw timber to interlocking fruition, while Will Truax, several students, and various Mullens plugged away on the two complex hanging posts that ultimately cradled the big wheel; Grigg Mullen II, Pete Cz and Ed Levin who, as the engineering peer review team, provided colorful load diagrams and multiple suggestions for upgrading something that may merely have worked, into a stylish mobile that casually resolves loads of a long ton. Dr. Brungraber deserves honorable mention for a drive-by consultation.

Head and shoulders above us all in the *pantektikon* must stand Bob Smith, Al Anderson and Laurie Macrae. Their contributions cannot be overstated. Bob emerged from hospital to take on the role of Information Czar and Revision Manager—somehow carrying it all in his head and rolling with the frequent punches from both the revisors and the revised. Al drank coffee and smoked for three days, staring at the raising "situation" until it resolved in his mind, with a little help from the computer jockies, and none whatsoever from the historical documents. He ran us through the paces with great patience and a usually calm demeanor. No raising has gone smoother. Laurie kept our bodies and souls together with 17 consecutive meals of surpassing variety and increasing quality (finishing with the smoked Brie and revisionist shrimp), delivered with a memorable mix of insouciant grace and charm. *Don't* forget to wash your own dishes, and *don't* come back for seconds until everyone has been through. Thank you very much.

I must speak, finally, of the crane *per se*. A 30-ft. pine 16x16 felled 100 yards from the job site was to hold the entire rotating assembly aloft, floating serenely above the four crossed 10x10x20 white oak sleepers by virtue of eight slightly compound struts (is

Diane Muliero

Treadwheel was rolled to position under its hangers and raised into place. Above left, cast axle ends (to fit broached and wedged square holes) with pouring cups and vents (sprues) still attached.

"slightly compound" like "slightly pregnant"?). Hewn almost square, with generous areas of Nature's chamfer, then worked into a complex timber with two journal bearings (to receive the horizontal clasps), an octet of compound mortises, and a bizarre cap embracing the cast-iron spindle at the peak with forged rings. The boom, likewise a very nice piece of pine from the site, finished at 55 ft., 11x11, hewn and mortised by a mixed crew of Guild members and sculpture students. The more-is-better crowd lobbied for using the entire length, disrupting the elegant proportions of the original drawing and alarming the engineers. Good sense and finite element analysis prevailed. This boom was bound into a complex assemblage of clasps, braces and struts in a horizontal assembly that was ultimately rotated 270 degrees axially and contorted another 170 degrees in azimuth about its elusive and shifting center of gravity, by the gentle deployment of legacy rigging from the 1991 Guelph Bridge job.

The treadwheel, 11 ft.-6 in. dia., with comfortable accommodation for one adult, elegant carving about the shaft, treadway sarking (that's older English for sheathing) fastened with cut nails from the old Tremont Nail factory a bit down the road in Wareham, nice old bolts about the perimeter, and an impossible-to-assemble basketweave joinery pattern at the hub (just because it can be drawn doesn't mean it should be built). This elegant object, when suspended by its axle bits from the overhead cranes in the sculpture studio where it was built, provided much raucous and irresponsible late-night amusement for the gerbil-inclined of our group. Its eventual emergence from the studio was a moment of considerable drama and fanfare. It rides now upon a pair of locust bearings, secured by wedges and backed up by forged iron bands, wedged in their turn to take up for inevitable shrinkage. —Joel C. McCarty

Joel McCarty is co-executive director of the Guild in charge of membership, publications and development.

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SILAS Russell gives his dad Henry a lift on the brand-new Norwell Crane, built in the Massachusetts town of that name by students from three colleges in Boston, aided and abetted by their teachers and numerous members of the Timber Framers Guild. Henry flew with Silas from Bristol (UK) to Boston, intending to hew as much as possible of the timber for the lifting engine, a close reproduction of an 18th-century French builder's crane. A full-grown walker on the treadwheel can be expected to lift about a half-ton. The crane pivots easily enough on its base to be drawn around by a tag line. Its original was used in the construction of the Pont d'Orléans across the Loire in the mid-18th century.

Rick Brown