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Raising an Obelisk

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SINCE early times, obelisks, some of them huge, have been removed from Egypt to cities such as Constantinople, Paris, Rome, London and New York, but always re-erected using the most recent technology of the time. In 1994 and 1995, Public Broadcasting System's educational science series NOVA produced a film of an attempt to raise an obelisk using probable Egyptian New Kingdom technology. This attempt provided vital information, but the film crew departed Aswan, Egypt, leaving their obelisk resting on the ramp at a 35-degree angle to the ground. The producers geared up for another attempt in 1999. I agreed to make a replica of an ancient tool (a bronze core drill for stone, shown below) in exchange for an invitation to travel with the film crew to Egypt. Shortly before departing, the film director Julia Cort asked if I would, in addition, construct a timber-framed device to help raise the obelisk. I agreed in exchange for another invitation, this one for my anthropologist, timber-framing, jack-of-all-trades son. Next thing we knew, Wyly Brown and I were on our way to Egypt, proudly carrying our reproductions of Middle Kingdom stone cutting tools and an abundance of woodworking tools that would be vigorously checked by every baggage inspector from Boston to Cairo. It is right that inspectors should be a little unnerved by suitcases laden with bronze cylinders, 21-in. chisels and a chain saw.

Arriving at the Aswan quarry 440 miles south of Cairo, we discovered the film crew and extras reenacting the overland transport of a 25-ton block of granite lashed to a wooden sledge sitting on lard-lubricated timbers set in the sand, seen at right. Teams of laborers levered on the sides and behind the sledge while 170 people pulled on two sets of ropes under the direction of structural engineer and project designer Mark Whitby (London), nautical archaeologist and ancient rigging expert Owain Roberts (Wales) and stonemason Roger Hopkins (Massachusetts). The air was filled with dust, shouting and frustration.

By the end of the day, the stone had been moved all of 20 ft. Wyly and I met with Mark Whitby to discuss the timber device we would soon construct, and he anxiously presented us with a schematic sketch and the sense that time was a-wasting. We were concerned about the basic theory and that several details were not fully understood.

Photos Rick Brown

Roger Hopkins cheering 170 pullers in their contest with 25 tons.

Wyly and I fast-track designed with engineers Henry Woodlock (England) and Iolo Roberts (Owain's son). We rounded up a substantial pile of 20-ft. 10x10 Southern yellow pine timbers left over from the 1994 raising attempt. Additional materials were delivered (for cash) via the local donkey cart. Abdul Alim, proud of his participation in the construction of the modern Aswan Dam and now our construction manager, led a team of Egyptian workers hired to assist in the raising of the stone. This group, which Henry named the "Happy Gang" because of their enthusiasm, quickly built a temporary woodshop with a grass roof to protect us from the hot desert sun. We began cutting timbers for the levering apparatus, which we entitled *The Hand of God.*

The drill, with instructions.

We inscribed names on all the wooden parts: Dave, Ed, Joel, Grigg, Al, Jim, Mikey, Ellen, Laura, Donna, Bob. If people inquired, we told them, "These are the names of the timber framers who should be here with us." Of course, these were the names of our trébuchet-building mates in Virginia and Scotland. On several occasions, we telephoned home to mechanical engineer Grigg Mullen of the Virginia Military Institute, at that time working on the Guild's Project Horizon Workshop in Lexington. He would pull his calculator out of his pocket (we presume) and verify the load capacities of our late-night designs. Thus shooting from the hip, Grigg played an important role in our contribution to the project. For the next five days, the building was fast and hard, dusty and dry under a constant hot desert sun. The Egyptian bystanders fell completely under a spell when I cranked up my orange Husqvarna chainsaw. For a few days I was Mikey Goldberg on the upper Nile.

Raising an obelisk was not an official Timber Framers Guild project, but it's no accident that, in the end, a good number of Guild members became directly involved. The Guild constantly defines and redefines itself. Craft, history and public service certainly are its concerns. But as an artist, educator and part-time

The raising derrick lashed to the obelisk waiting on the ramp.

project, but I believed that if we gave it more time and paid attention to some critical details, this method would succeed. Mark Lehner, the Egyptologist on the scene, frequently emphasized the importance of historical accuracy in method. His vigilance and genuine interest heightened my own. My first thought was that rigorous organization must have been the rule in ancient Egypt, given the vast numbers of people needed to build. Our experience in Aswan showed the importance of carefully chosen persons for every specific task. With this in mind, I eagerly began to develop my own ideas on how to proceed.

Wyly and I visited several historic sites on our journey home. In Karnak (below) and Luxor we saw obelisks still standing on their original pedestals. In the hall at Karnak we walked between hypostyle stone colonnades of a scale beyond belief (overleaf). To build these halls, the Egyptians would literally fill the

timber framer, I am very interested in the creative problem-solving skills of many Guild members, and in their undertakings. When given a problem, many of these maker-thinker-doers can find a solution using hand tools, hard work, principles of physics—and cooperation.

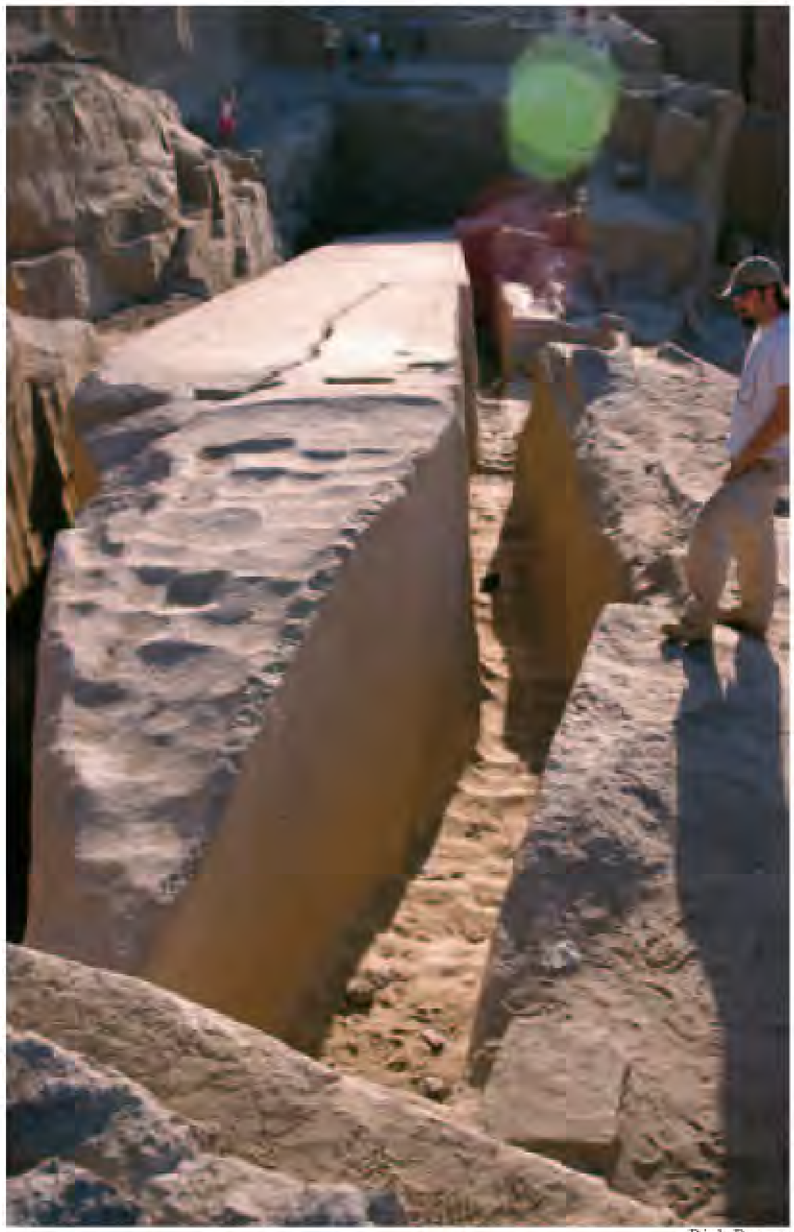
Our raising apparatus was a derrick of sorts, designed to reduce the pulling load required to rotate the obelisk cartwheel-fashion into its final position. Opposed, canted sets of X-braced 10x10s were tenoned at 45 degrees into a 20-ft. timber sledge framed with dovetailed ties to hold the runners parallel. Trapezoidal blocks installed between the canted arm sets increased the compressive strength of the system.

IOLO Roberts and Wyly lashed the entire structure onto the obelisk waiting on the ramp (above). Ropes encircled the belly of the 33-ton beast, then passed over the outstretched arms of our frame and to the ground. When pulled down, the obelisk would drop onto a pivot log on the lower bearing wall. Continuing the pull would bring the obelisk, rotating in its own length, down to the pedestal stone sitting on grade. In preparation, Wyly gathered the group together to pay respects to the ancient builders who had come before us. Now our hard work would be put to the test.

Mark Whitby first tried to pull the obelisk with four 2-in. ropes stretched over the derrick and down to snatch blocks attached to telephone poles lashed to two granite deadmen. Later in the day, a 3½-ton granite counterweight was added to the system to assist the pull. Later still, a front-end loader (probable Middle Kingdom technology?) entered the picture. Ropes regularly stretched and finally broke. The obelisk persistently turned out of its intended line of rotation. Nearing the end of the day, 170 enthusiastic pullers lined up in a final attempt to rotate the stone. As the pullers tugged, inspired by traditional chants, the obelisk would rhythmically raise its head but the pivot log on which it rested continued to slide closer and closer to the edge of the bearing wall, too close to continue safely. The order was given to call it a day. That night, back at the New Cataract Hotel, the engineers decided to abort the mission. Once again the mystery of the ancient obelisk builders remained veiled. Wyly and I stood in amazement. How could we give up so easily?

At the time, I could not speak for the historical accuracy of the

An ancient obelisk in its native habitat, at Karnak Temple.



Rick Brown

Above, the hypostyle colonnade at Karnak. Above right, Wyly Brown considers the unfinished obelisk still in the quarry at Aswan. Tool marks from the dolerite balls used by the quarrymen to pulverize the stone are discernible at the bottom of the man-sized channel.

temple with earth and pull in the large stones on man-made ramps. The inclined plane and a unified workforce seem to have provided them with a sufficient method.

For several thousand years, granite was extracted from the Aswan quarry for ancient monuments and statuary. In the quarry lies an unfinished obelisk (above right) weighing over 1,000 tons, apparently abandoned when a crack in the stone was discovered. This ruin reveals the ancient method used to remove granite from the quarry. Egyptians cut the stones out of the ground using a dolerite ball, harder than the granite. Quarrymen would line up shoulder to shoulder and with the balls pulverize the stone, creating channels around the perimeter of the desired block. This painstaking process would continue until they reached the required depth. Then, by the same means, they would undercut the block until it could be levered off a narrow remaining spine.

The Egyptians produced a multitude of structures, some of the largest and most precise in history. They used natural resources: soil, stone, wood, fibers (for rope), unlimited amounts of sand and large numbers of people. Through keen observation and experience they came to know and understand how these materials would behave under certain conditions. There is no evidence of pulleys, capstans or the knowledge of iron at this time. As far as we know, they used only simple mechanical aids such as wedges, levers and rollers. And so should we.

WE are all familiar with the center of gravity of the seesaw at the school playground. The apparent weightlessness of an object resting on a fulcrum is a captivating perception. In ancient times, the discovery of this physical phenomenon may have conferred near magical powers and generated sacred interpretations. Dieter Arnold's *Building In Egypt* (Oxford University Press, 1991) refers to evidence found in several cities and temples that workers pivoted large pillars at their center of gravity as early as the Fourth Dynasty (ca. 2600 B.C.). Once supported at its center of gravity, a large object can easily be moved by a single person. This technique will work with a seesaw at the playground, a 250-lb. timber post or a 500-ton obelisk. We chose to work with this technique as the first element in our proposed simple system.

R. Englebach in *The Problem of the Obelisks* (T. Fisher Unwin, 1923) suggests sliding the obelisk down a funneled earthen chamber to the top surface of the pedestal stone below, using sand somehow to stand the pillar upright. But this is the equivalent of driving an automobile through a tunnel without a steering wheel. It may be possible to get through the tunnel, but much is left to chance, and at best the obelisk would suffer some bouncing and bashing of outer surfaces on tunnel walls. This seems a crude way of handling a polished stone. Further, every obelisk in Egypt was erected on a pedestal with a pronounced radiused groove, the so-called "turning groove," carved quite near one edge across its top surface (seen at the back edge of the pedestal in the drawing at right). This groove would seem to have been designed to receive the heel of the obelisk at a fairly steep angle and locate it securely while it was pulled over, or "turned," into its final upright position. Using a funneled chamber would not be a likely procedure for arriving at the precise target of the turning groove.

Nonetheless, Julia Cort believed that Englebach's sand method, adapted by Roger Hopkins in NOVA's 1994 and early 1999 efforts with a 2-ton representative obelisk, provided vital information and was worth pursuing.

Dry sand flows freely. When a hole is placed low in the side of a box of dry sand, the sand will flow downward through the opening until the remaining pile reaches an angle of repose, the maximum slope at which the pile will stand without flowing and bear a load. In addition, smooth downward movement is a natural characteristic of sand-flow. Evidence in the papyrus Anastasi I, as translated by Dieter Arnold, suggests the possibility of lowering a monument into position by progressively removing the sand from the sides of a supporting pile in a chamber below: "Empty the space which has been filled with sand under the monument of thy lord."

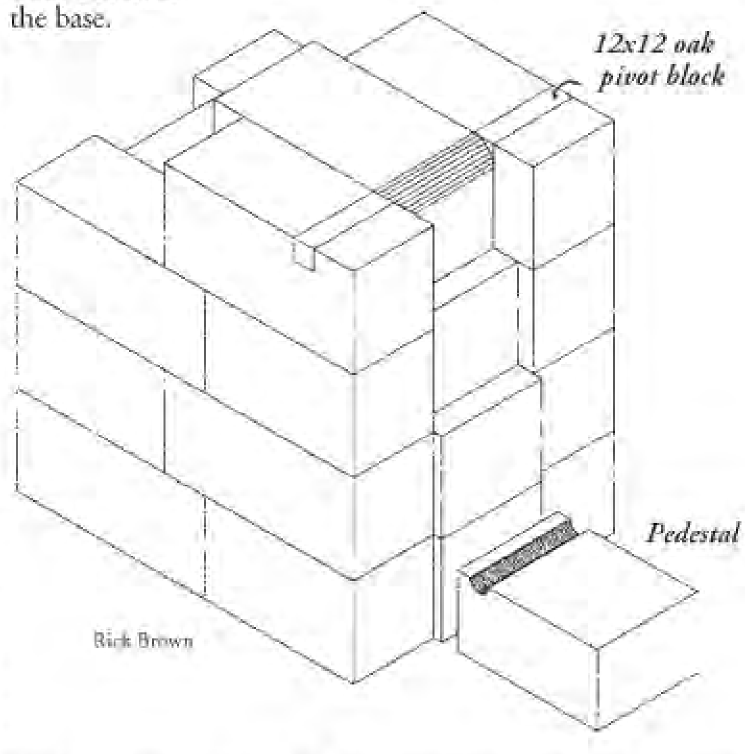
I was determined to stick with this problem and to get an obelisk upright. My sculptor, builder, timber-framing wife Laura now became engulfed in my obsession. Laura and I made drawings and constructed and tested two concrete models. Mark Lehner and Julia Cort visited our studio for a demonstration. Surprising me, Mark enthusiastically supported the method. "This is Egyptian, archaic and simple," he said, "an idea I believe will work."

Shortly afterward, Julia Cort approved our construction calendar and offered funding to conduct a design development workshop inviting VMI's Grigg Mullen, the ever-ready traveling engineer with calculator, Jim Kricker, the New York millwright and rope and rigging expert with *his* 7,000-lb. dynamometer, as well as VMI cadet-on-leave Andy Smith and our own Wyly Brown armed with long-handled hoes. Laura and I were delighted with the new problem-solving firepower on our obelisk-raising team. Jim Kricker suggested a single rope sling around the obelisk, notably simplifying our thinking about stabilizing the tall, slender granite shaft during the raising. During a four-day workshop at our studio in Norwell, Massachusetts, we poured a 6-ft. concrete obelisk and built a 3x4x8-ft. sand pit and ramp holding a ton of sand to test and refine our idea.

The Aswan experience had alerted us to the importance of *knowing the ropes*. Jim Kricker inquired at The Cordage Institute in nearby Hingham and found suppliers for large quantities of Manila rope similar to that used by the Egyptians. Manila's natural fibers align with use, increasing its strength and diminishing its stretch. Using Kricker's dynamometer, we tested inch-and-a-half and 2-in. rope using the known load requirements for our raising. The amount of stretch in the rope under working loads was a factor in setting the height of the bearing wall so that the obelisk would land on or above the turning groove in the pedestal.

Reminding ourselves of the frustration when 170 pullers were unable to raise the stone from a 35-degree position on the ramp, we decided to find out what angle we needed for the final pull, when most of the sand would be out of the box. Grigg Mullen calculated pulling requirements for our proposed 25-ton stone at a number of different angles. He proposed a 75-degree angle, which would (for example) require a 37-lb. pull from each of 135 pullers. Such a light load would insure an easily controllable final pull. One Egyptian temple relief shown by Dieter Arnold depicts a symbolic erection of an obelisk with ropes by Ptolemaios XII Neos Dionysos. The angle of the obelisk in the relief is—you guessed it—75 degrees.

The scene now moved to Milford, New Hampshire, where Dave McCormick, Fletcher Granite's yard supervisor, used two cranes to pull a 65,000-lb. (175 lbs. per cu. ft.) chunk of Kitledge gray granite out of Fletcher's quarry there. Then the scene moved to Fletcher's headquarters in Chelmsford, Massachusetts, where the inspired quarrymen took great pride in skillfully shaping the block into an obelisk measuring 36 ft. overall, including the 42-in. pyramidium, the topmost portion where the four sides taper sharply up to a point. The finished stone, 42 in. square at its base, tapered to 30 in. square at the base of the pyramidium and weighed 49,500 lbs., with its center of gravity equidistant from its four surfaces and 14 ft. 1 in. from the base.

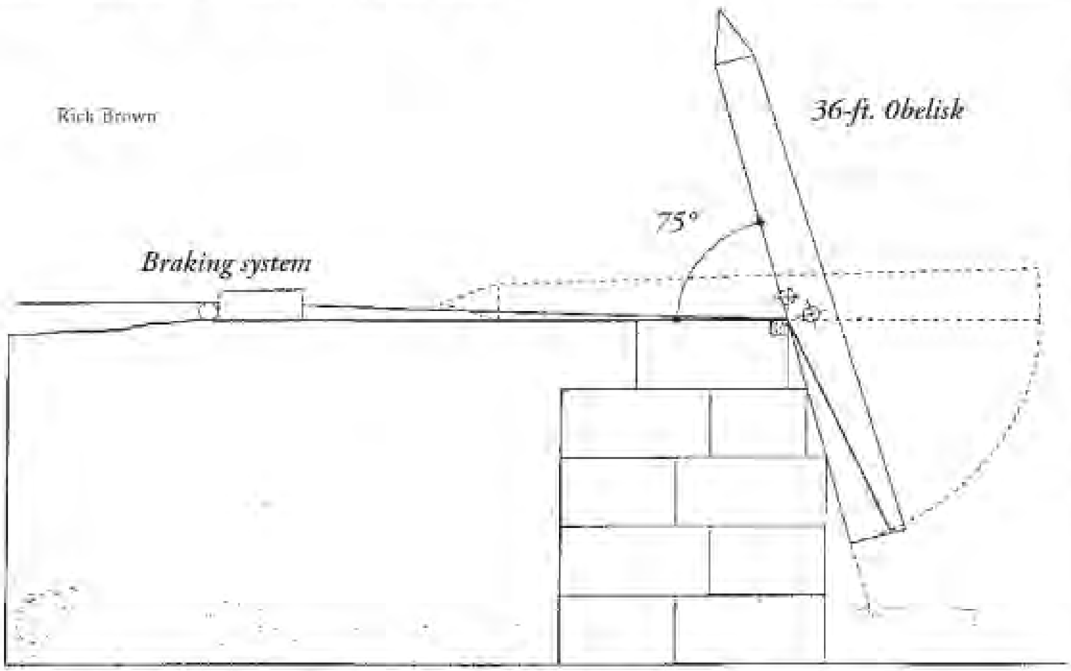


Orthogonal drawing of 18-ft. granite bearing wall with stepped center section and plumb flankers. Shading lines indicate radiused portion of the pivot block above and 13-in.-wide turning groove in the pedestal below.

On August 24, 1999, Al Anderson of Blue Ridge Timber Framing arrived and hit the ground running (though he brought his fishing pole). Over the next three days he supervised the construction of the bearing wall, ramp and sand box. The bearing wall comprised large granite blocks in a three-bay system (drawing above), with the central bay offering a stair-stepped 75-degree face and the outer bays plumb to restrain the obelisk if necessary. Our ramp of crusher-run gravel ran in a gradual slope up to the rear of the bearing wall. Fletcher provided precast concrete blocks tenoned together to make up the walls of the box.

Around noon that same day, Jim Kricker drove up in his one-ton flatbed truck, riding low on the axles with a spectacular load of hemp, some of it 3-in. Smiling from ear to ear, Jim had never in his life imagined a project that would require so much cordage. Using a simple lever, Jim and Grigg pre-stretched the rope to the load limits required to raise the obelisk. We developed a controlled brake-release method. Three 3-in. lines, each wrapped three times around the 12-in. oak brake logs at each end, provided six points of controlled release which would allow us to lower the obelisk slowly into position.

Was any timber framing involved in this project? It's a fair question. After leaving our dusty derrick dead in the desert, we hadn't used much wood to speak of. We did have a beautiful veneer-grade white oak pivot block (labeled in the drawing above), made by Wyly and my colleague Ellen Gibson, which provided a soft bearing surface for the obelisk to rotate around from horizontal to the 75-degree position against the bearing wall. Laura made the saddle, a tenoned structure with carved housings to hold the ropes wrapped around the butt of the obelisk. Wyly made a plumb square, based on the ancient Egyptian pattern shown in W. M. Flinders Petrie's *Tools and Weapons* (Constable & Co., 1917). We strapped this device to the side of the obelisk to observe its angle of rotation (facing page, lower right). Andy carved hardwood long-handled hoes (facing page, top), similar to those used by ancient Egyptians, to pull the sand through the sandbox portals. Our pedestal stone allowed for a 16-in. margin around the base of the obelisk. The turning groove was 5 in. deep, 13 in. wide.



General scheme of raising. The challenge is to bring the shaft over to land in the turning groove, while managing its tendency to slide forward as it rotates about the pivot block. Sand not shown.

On Sunday, August 29, we filled the box with sand and finished the ramp. Granite blocks and gravel buttressed the sand box. Late in the day the obelisk was laid with its center of gravity over the pivot block on the bearing wall. Next day, we rigged the obelisk, tensioned the 3-in. steering ropes and began to lower the stone. Portal captains Wyly and Andy directed two teams made up of students from the Massachusetts College of Art and National Guardsmen from Hanscom Air Force Base. Through the 4x5-ft. portals on either side, the sand was symmetrically removed with hoes to a line of workers who carried the sand away in baskets.

The sand had been preheated to 160 degrees and delivered (still hot) absolutely dry to assure free flow. As sand was removed, the sand remaining inside the box flowed downward toward the portal consistently maintaining an angle of repose of 35 degrees. We used this natural slope to support the weight of the obelisk, and the fluid quality of the flowing sand to gently rotate the obelisk to the turning groove. As the sand flowed out of the sand box, two symmetrical slopes formed a ridge down the center of the box in line with the obelisk, and as the ridge descended, the base of the obelisk came down with it, and the pillar gradually rotated around the pivot block above. We had learned from our models that when sand is removed even one scoop at a time, the obelisk moves in turn. This provided very precise control of the process.

After every five degrees of rotation, Jim Kricker measured the profile of the sand to record the relationship between the angle of repose and the position of the obelisk. By the end of the day we had reached 45 degrees. Mark Lehner observed that this was already greater than any of the previous attempts and things seemed completely under control. Looked like a good time to stop for the day.

On Tuesday, we continued lowering the obelisk, knowing that rotation beyond 45 degrees would entrain rope stretch. The distance from the pivot block above to the turning groove on the pedestal below had been calculated by taking the distance from the base of the obelisk to its center of gravity (14 ft., 1 in.) and then adding an allowance for rope stretch based on our testing plus a generous safety factor. (Overshooting the turning groove cannot be corrected and therefore was not an option.) The workers on the hoes maintained tremendous control on the symmetry and the sand flow. Every scoop had an effect on how the obelisk moved. The actual placement of the symmetrical hoes in relation to the toe or heel of the obelisk was critical in controlling rotation versus forward slippage as the stone moved closer to the final 75-degree angle. Casual removal of sand could result in disaster. Our obelisk team remained focused and slowly piloted the stone onto the stair-stepped bearing wall at 75 degrees, resting on 20 in. of sand directly above and in line with the turning groove. Coming in 20 in. high meant that we had had far less rope stretch than we anticipated. The sand had carried a greater load than we had expected. Hurrah! We did not overshoot the target.

Now the brake-release method would be put to use. The two brake release teams were led by Al Anderson and Jim Kricker, while Grigg Mullen and I went inside the sand pit (facing page) to remove the final 20-in. cushion of sand between the obelisk and the pedestal stone. Simultaneously, the two ends of each rope were released in small increments, repeated by the next pair of ends until all three sets of ropes had been equally released. This cycle of release was repeated again and again as the sand was removed and the obelisk slid down the 75-degree pitch of the bearing wall until it came to rest in the turning groove. The brake release method was very safe and verified our guided rotation theory.

The next morning, we removed the saddle and the steering ropes from the obelisk and the brake logs. We packed up our tools and went home until our return 10 days later for the final pull. During that period, the sandbox and remaining sand were removed. The obelisk rested safely in the turning groove and against the bearing wall, fully rigged and ready to be raised the last 15 degrees. When we returned, on a beautiful, crisp, clear fall day, nearly 200 eager pullers from The Massachusetts College of Art, Fletcher Quarry, Hanscom Air Force Base and the film company joined the obelisk team to complete our task. We spent the morning on final layout of pulling ropes. Two opposed lateral brake lines led from a central harness at the pyramidium to deadmen at the sides, and two brake lines led aft to the brake logs. Four forward pulling lines gathered into a single braid at the harness. The braid would avoid any twisting caused by unequal line pull.

Our experience in Aswan demonstrated the importance of having a unified pulling force. The creation of such a team reenacts a significant feature of Egyptian building history. Pulling the obelisk to 90 degrees is a delicate operation. At 75 degrees, the obelisk has a high and forward center of gravity. After the initial pull towards upright, the load diminishes rapidly. At 86.5 degrees, the obelisk develops a forward motion. Lack of attention might result in the ultimate disaster. We invited the Guild's Joel McCarty, an expert in on-the-spot group management, to bring his hand-raising experience to direct an on-site pulling school. Using our 6-ft., 300-lb. concrete obelisk, the pullers learned fingertip control and experienced firsthand the physical principles necessary for the job.

The pull would be divided into two parts. The first would bring the obelisk from 75 to 86.5 degrees, to be held there with a propping wedge dropped down between the shaft and the bearing

Laura Brown

Grigg Mullen (silver hardhat) and Rick Brown hoeing sand out through portals, allowing obelisk to descend to turning groove. Below, Grigg relaxes on the brake logs wrapped with 3-in. line, which served as release winches. Below right, the shaft is ready for the final pull.

wall. The second pull would bring the obelisk to 90 degrees. Joel organized his trained pullers into four teams of 28 people, each team on one rope, standing (for safety) about 100 feet ahead of the obelisk. Grigg Mullen was nominated Single Voice to direct the 112 pullers. Al Anderson and Jim Kricker, our brake and alignment team, released tension on the rear brake lines simultaneously as the 112 pullers tugged the obelisk off the bearing wall. Laura and I lowered the propping wedge between the bearing wall and the back of the obelisk to hold the space we gained as the obelisk moved higher and higher to the crucial 86.5-degree angle. Single Voice gave the word to release the lines to give the pullers a rest before bringing the stone to vertical. Grigg then surveyed the site, refocused the troops and called the final pull. All 112 pullers pulled as one while the brakemen eased off tension on the rear brake ropes. The obelisk moved with the grace of a magnificent bird and without a single sound gently came to rest on its solid base. Our hand-raising Egyptian-style was now complete. —Rick Brown

Rick Brown teaches at the Massachusetts College of Art in Boston. His last adventure with NOVA and the Timber Framers Guild unfolded last year at Castle Urquhart in Scotland (see TF 50), where he organized the precision casting of 14,000 pounds of lead to be mounted on the throwing arm of a fixed-counterweight trébuchet. PBS's "Medieval Siege" will air February 1, 2000, and "Pharaoh's Obelisk" will air February 8.

Photos Rick Brown