CONCRETE CANOES

Henry Petroski

The idea of a boat made of concrete is often greeted with skepticism, if not derision, by the uninitiated, who are as likely as not to call up the gangster-movie cliché of concrete shoes fitted to murder victims. Concrete, no matter how configured, is not supposed to float. But stereotypes and false assumptions can get in the way of common sense, for who would doubt that vessels made of steel, a material with three times the specific gravity of concrete, can float? Indeed, a kind of reinforced concrete was introduced as a boat-building material more than a century and a half ago, long before steel-hulled ships became commonplace.

The terms *concrete* and *cement* are often confused—they are not synonyms—and their usage can serve as a shibboleth. The most common type of cement, portland cement, is a powdery substance made by heating a slurry of crushed chalk or limestone and clay until fused and then grinding the resulting clinkers into a powder. When mixed with water, the cement undergoes a chemical reaction and develops strength and rigidity against being compressed. (The reaction continues for months, if not years, at an ever-decreasing rate, but the strength of concrete typically is measured 28 days after it is mixed and placed—that is, poured into the shape in which it is to harden.)

A process for making portland cement was patented by the English inventor Joseph Aspdin in 1824 and named after the Isle of Portland, whose limestone the set cement resembled. Mixing sand and water with the dry powder forms a mortar that is used in laying bricks and assembling stonework. But when broken stone, gravel and the like—known as coarse aggregates, as distinguished from sand, or fine aggregate—are also added to the mixture, concrete is formed. What in some parts of America is commonly called a cement sidewalk or driveway is in fact made of concrete, the rock-like mass that most of us, as children, fell on and skinned our knees, or worse.

Because heat is generated during the curing or setting process, concrete tends to occupy its greatest volume shortly after it is placed and thereafter wants to shrink as moisture is lost and the temperature drops to ambient. This shrinking, when constrained, may induce within the concrete mass considerable pulling forces, causing the concrete to crack. At the least, such cracks blemish the work, and in the worst cases they can weaken the structure and threaten its integrity. When workers score a freshly placed sidewalk or driveway with a finishing tool, any shrinkage cracks will tend to develop at the base of the grooves, which are known as control joints or contraction joints, and will for all practical purposes be disguised.

Positive Reinforcement

Because concrete cannot effectively resist being pulled apart, whether by shrinkage or by the loads imposed on a structure, it must be reinforced. This is most commonly done by embedding various shapes of ribbed steel rods in the concrete to create what is known as reinforced concrete. Most concrete, sidewalks being an exception, is in fact reinforced. As the concrete cures, the reinforcing bars (known as rebar) and concrete bond together, so when the concrete is pulled, the tensile force is transferred to the rebar. In those parts of a concrete structure that are not expected to experience tensile forces, little if any rebar is included, because the concrete itself is ideally suited to resisting compressive forces.

Reinforced concrete is a familiar construction material, and preparations for its use are often carried out in plain view of sidewalk superintendents. The rebar, these days commonly coated with a green epoxy to prevent corrosion, is often arranged according to size and type in a way reminiscent of the Erector set parts laid out on the floor by a child embarking on an ambitious building project. The rebar is bent, shaped and fastened together with wire to form cage- or skeleton-like assemblies that prefigure the finished structure. When the rebar has been fully assembled according to plans within a wooden or steel form, the concrete is placed and allowed to cure. Within a few days the concrete has usually set enough to be self-supporting, so the formwork can be removed, often to be reused to frame another section of the structure being built.

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Figure 1. Concrete-canoe competitions got their start in the early 1970s between engineering students at the University of Illinois and Purdue University. On June 7th of this year, Clemson University's team was victorious over 25 other entrants. (All photographs courtesy of the American Society of Civil Engineers.)

The earliest use of reinforced concrete is commonly credited to the Frenchman Joseph Monier, who was a gardener at the palace at Versailles. In the 1850s he made concrete garden tubs and flowerpots by forming them around wire mesh, which inhibited crack growth and breakage. The process was patented in 1867, but it was not without its precedents. Tom F. Peters, who has written about the nature of building in the 19th century, traces to ancient times "the idea for improving the structural behavior of concrete by combining it with other materials." He points out that two millennia ago Vitruvius wrote about "ceilings suspended from iron or brass bars" and that Pompeian builders "cast concrete floors on timber beams." Although strictly speaking not reinforced concrete, such practices were not unheard of in the Middle Ages, according to Peters. True reinforced concrete was anticipated in the 1830s when Marc Brunel experimented with embedding iron and other materials in mortar as an inexpensive way to line his Thames Tunnel.

The Etymology of Ferro-Cement

In fact, Monier's process was also anticipated by another Frenchman, a Monsieur Lambot, who lived on his family estate at Miraval, in Provence. (Lambot's given names are variously reported as Joseph Louis and Jean-Louis. Given the French practice of identifying authors of patents and other documents by their surname only, which name is correct remains to be confirmed.) As early as 1845 Lambot is said to have made reinforced-concrete planters and also to have suggested the use of such a concept for structural beams and columns. Most relevant for the history of concrete boats, however, is his use of reinforced mortar, which is called *ferciment* in French, to build boats for use at Miraval. The first such boat appears to date from 1848, and a second was built the following year. A prototype of Lambot's *bateau-ciment* was shown at the Paris Exhibition of 1855, at which time he stated advantages of his *bateau* that could be advanced still today: saving in initial cost of construction; saving in maintenance; speed of construction; immediate repairs in case of damage; impermeability; incombustibility; and soundness under test. He also pointed out, based on tests conducted over a five-year period, that his novel material was suitable for making "water cisterns, cellar doors, tubs for orange trees [and] all structures which tend to deteriorate where they stand whether in or out of water." Lambot took out French and Belgian patents on his invention and expressed the intention of filing for a British patent for "An Improved Building Material to be used as a Substitute for Wood in Naval and Architectural Constructions and also for Domestic Purposes where Dampness is to be Avoided." He described the material as consisting of "a network or parallel set of wires or metallic bars or rods imbedded or cemented together with hydraulic or other cementing material so as to form beams or planks of any suitable size," but he did not follow up on the British patenting process.

Lambot's boats, which were made with wire mesh rather than iron rods and used mortar rather than concrete, were thus by the strict definition of the term not truly reinforced-concrete structures. Nevertheless, they certainly deserve recognition as significant achievements in the use of reinforcement in a novel application of a concrete-like material. By the end of the century, however, the boats appear to have been largely forgotten as the history of reinforced concrete began to focus on Francois Coignet's work on true reinforced-concrete conduits, lighthouses and buildings of the 1860s, and Francois Hennebique's wide-ranging applications of the material in the 1880s and 1890s. By the turn of the century, reinforced concrete was a fashionable material, and the idea of making complete houses out of the "artificial stone" attracted no less an inventor than Thomas Edison.

Whatever Floats the Boat

The centennial of modern reinforced concrete was celebrated in Paris in 1949, giving due recognition to Lambot, Coignet and Monier—considered the French fathers of the material. At one of the sessions, it was remarked that one of Lambot's boats might still be floating at Miraval, and some years later two concrete row boats, in reasonably good condition, were extracted from the mud and silt at the bottom of a pond. Lambot's boats were known to have been afloat at Miraval as late as 1902. There have been many other concrete boats. The scow *Zeemeeuw* was built in 1887 and as late as 1968 was still in regular use at the Amsterdam Zoo. The Norwegian ship *Namsenfjord* was launched in 1917 to become the first self-propelled reinforced-concrete ocean-going vessel. Ten concrete cargo vessels were registered by the U.S. Bureau of Shipping and launched between 1919 and 1921.

The great Italian structural designer Pier Luigi Nervi, who wrote that "reinforced concrete is the best structural material yet devised by mankind," began in 1942 to experiment with what he called "the new reinforced concrete material *Ferro-cemento*," which he believed could be used to make fishing boats. His company, Ingg. Nervi & Bartoli, constructed for the Italian navy three 150-ton transport vessels out of ferro-cement; a 400-ton ship was begun in 1943, but construction was halted because of the war. In 1946 Nervi's firm resumed concrete-ship building and produced the 146-ton sailboat *Irene*. The 1.4-inch-thick hull was reinforced with three layers of ¼-inch steel bars and eight layers of wire mesh. No forms were required, and the pozzuolanic cement, made from the volcanic dust from Pozzuoli (for which fly ash is often substituted outside Italy), "was applied by hand from inside of the hull, forced through the mesh, and smoothed out from the outside." The finished hull weighed 5 percent less than a comparable wooden hull, and the cost was 40 percent less. The savings over a steel hull were believed to be even more. Nervi also designed and built a 40-foot ketch, the *Nanelle*, whose hull had a predominant thickness of only ½ to ⅝ inch. He went on to design larger-scale land-based structures, most notably the elegantly domed sports palaces in Rome for which he is best known.

In the 1960s, boats made of ferro-cement, defined as "a thin section of cement mortar with a relatively high proportion of steel reinforcement in the form of multiple layers of wire mesh," began increasingly to be built, most notably in Australia and New Zealand but also in England and Canada. I first heard about concrete boats in the late-1960s, when one of my Canadian colleagues from graduate school announced that he was returning to the north country to work on concrete boats. It was also at our alma mater, the University of Illinois at Urbana, where some of the first concrete canoes were built.

Figure 2. The University of Alabama at Huntsville's second-place 2000 entry was 22¾ feet long and weighed 79 pounds.

Concrete-Canoe Races

Although concrete canoes may have been built in the late 1960s and possibly even raced intramurally at that time, the concept was brought to national attention in the spring of 1970 by a project carried out in an honors class in concrete taught at Illinois by Clyde Kesler, a professor of civil engineering and of theoretical and applied mechanics and a former president of the American Concrete Institute (ACI). The Illinois canoe was christened *Mis-Led*, probably because in spite of its ½-inch average thickness it tipped the scales at 365 pounds. The canoe was made without forms by troweling a stiff mortar containing four parts cement, one part fly ash, and five parts sand over chicken-wire mesh and a few number 3 reinforcing bars—steel rods of ⅜-inch diameter. The structure was cured under wet burlap and painted white on the inside and rose on the out, a curious combination for a school whose colors are blue and orange. According to Kesler, the canoe was not only "seaworthy" but easy to build, and, given the class's experience, another one could be made possibly in as little time as a single day. The concrete in such a canoe might take a bit more time to cure, however.

According to the most common version of the sparsely documented history of concrete canoes, when civil engineering students at Purdue University heard about the boat built at Illinois, the Boilermakers decided to build a concrete canoe of their own and challenge the Illini to a race. According to an Illinois version of the history, it was Professor Kesler who challenged Purdue to take part in the contest. In any case, the project was taken on by the Purdue student chapter of the American Society of Civil Engineers (ASCE), who adapted the plans for a conventional racing canoe and used a foamed-plastic mold for the inside of the craft. The resulting canoe was on average only ⅜-inch thick and employed foamed polystyrene plastic blocks encased in each end to provide positive buoyancy should the canoe fill with water. The finished canoe weighed only 125 pounds, and Purdue was strongly favored to win the competition.

What was billed as the world's first concrete-canoe race was held on May 16, 1971 on a small lake known as the Inland Sea at Kickapoo State Park, near Danville, Illinois. The race took place over a 1,240-foot course and consisted of five heats. According to a report in the *ACI Journal* by one of the judges:

> Illinois won the first heat; the second heat went to Purdue in a near photo-finish when Illinois suffered a man overboard. Purdue easily won the third heat also, but Illinois came back to win the fourth when half of the Purdue team fell into the water. Illinois emerged the victor by taking the fifth and final heat.
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> Fastest time for the course was 2 min and 46 sec. The two schools were about evenly matched as to number of students dunked in the lake, but the Illinois win was attributed to greater expertise with the paddles. Both canoes were made of ferro-cement.

The student competitors carried out the concrete theme in the trophies they designed and made. The first-prize trophy consisted of "a slender shaft of exposed aggregate concrete, mounted on a sawed concrete base, and topped by a plaster of paris canoe model." It had come from Illinois and went back home with them. Purdue students had created a "life preserver" made of normal-weight concrete that was "so heavy that two men were required to comfortably support it." A great time appears to have been had by all, who expressed the hope that a concrete-canoe race might be held annually and be participated in by other student groups "within canoe hauling distance." (It would later be said that 2,000 miles away students at the University of California at Berkeley were also holding a regional competition in the early 1970s, but the contemporary civil engineering and concrete magazines reported the Illinois-Purdue contest as the first.)

Concrete-canoe races did become an annual event, with 17 midwestern schools competing at Eagle Creek Park in Indianapolis in 1972. The rules were set by the sponsoring group, the Purdue ASCE student chapter, and limited the size of the canoes to 14 feet long and 3 feet wide. They were to be built entirely by students and were to cost no more than $50. Purdue used the same canoe that had raced against Illinois the previous year, and this time Purdue was victorious. Second place went to the University of Missouri, and Illinois tied for third place with the Indiana Institute of Technology.

Figure 3. All canoes entered in the races must float during a prerace "swamp" test, which these North Carolina State University students are about to appreciate.

By 1973, the Midwestern competition was no longer billed as a world event, suggesting that other regional contests were becoming equally popular. The Third Midwest Concrete Canoe Race was held at Eagle Creek Park on April 28, a day so windy that the choppy waters threatened to swamp the canoes, causing the race to be moved from the main reservoir to calmer Lily Lake. There were 27 entries, with canoes ranging in weight from 115 to over 500 pounds. The same size limits applied, but the cost of materials allowed was raised to $100. The Purdue student chapter of ASCE again sponsored the event, which was won by a team of naval architecture students from the University of Michigan. Notre Dame took second place, and Purdue and the University of Toronto tied for third.

The early Midwestern races were reported on by ACI staff member Mary K. Hurd, thus preserving a bit of their history. In her report on the third Midwestern race, she also mentioned the Second Annual West Coast Ferro Cement Canoe Race, held at San Luis Obispo, California and won by a team of construction engineering students from Stanford University, as well as an eastern competition sponsored by students at the University of Pennsylvania and a race in Oklahoma. She acknowledged that there were "perhaps even others we haven't heard about." Indeed, by 1988 the regional events had led to a national competition, under the sponsorship and coordination of the ASCE and Master Builders, a Cleveland-based manufacturer of construction chemicals.

The races have evolved into the National Concrete Canoe Competition, participated in by the winners of 20 ASCE Student Regional Conferences. These conferences and the national competition are more than just a canoe race. In addition to the extensive technical rules about what concrete mixtures and structural details are allowed in a qualifying canoe, there are academic requirements spelling out what constitutes a design paper, in which the student team must describe its canoe's hull design, concrete mix, reinforcement, construction, project management, cost and innovative features. There is a length limit to the paper, which must be submitted for judging four weeks prior to the national competition, but technical appendixes can be extensive in providing elaborations on costs, research and development, and the construction process, including engineering calculations, computer work and plans.

At the competition, each student team must make an oral presentation, which is strictly timed at five minutes, with another five minutes reserved for responses to judges' questions. The students must also mount a display, akin to what they might encounter at a trade show. The report, oral presentation and display all contribute to the overall scoring of the competition, which culminates in the canoe race.

Two engineering schools have dominated the national competition since its inception. The University of California at Berkeley took first place four of the first five years, and that school finished in the top three in nine of the first 10 competitions. The University of Alabama at Huntsville has also been a powerhouse, taking first place four times and finishing in the top three in seven out of the last eight competitions.

Building Engineers

In addition to the considerable bragging rights that go to a championship team, there are many other reasons why engineering educators and the event's sponsors have encouraged the annual races, foremost among them being the officially stated objective of the competition, which is "to challenge civil engineering students to apply engineering principles in designing and racing a concrete canoe" and thereby learn to be better engineers. But to some the exercise is frivolous, and thus the concrete-canoe race does have its detractors. One dissenter, who asserted that the concept of concrete boats "has not worked, it does not work and it will not work," had this to say:

> It is a disservice to our youth to waste their educational opportunities on irrelevant trivia such as concrete canoes, which are a Saturday-afternoon-at-the-fairgrounds stunt, an academic abstract, a distraction from legitimate pursuits. Why don't we have a concrete automobile contest, or a concrete airplane contest? Why don't we develop a concrete pole-vaulter's pole?

Why not indeed, some might counter, for the purpose of the exercise is to get engineering students to appreciate the limitations of the real world outside the classroom. Rather than being "an academic abstract," having to confront the real world of concrete mixes, reinforcements and molds, and of weight and cost limitations, and to have to defend one's choices in written and oral reports and put them to the test of paddling a concrete canoe against one's competitors, is no mere stunt. Students who have participated in the "distraction" have said as much. "The real benefits of this project are the public speaking and research skills and teamwork. We're building engineers, not canoes," was one student's response to the critics.

The future of concrete-canoe design, construction and racing appears to be as solid as the material at its core. Although the rules and regulations have evolved quite a bit since the first intercollegiate concrete-canoe race, the central objective has remained to teach students about a construction material through a concrete example.

There can be little doubt that the rules of the game will continue to evolve, perhaps until they reach the ideal that Professor Kesler, the "father of the concrete canoe," articulated in 1973:

> I believe the ultimate concrete canoe race would be to place the crews on a sandy beach with a sack of cement, a roll of chicken wire, and some tools and see who could get to the other side of the lake quickest in a concrete canoe. A trained crew might do this in one hour's time!

Although in his enthusiasm Professor Kesler may have been a bit optimistic about how fast the concrete might cure, he did capture the imagination of students everywhere.

The concrete boat has come a long way since Lambot's pioneering efforts of more than 150 years ago, and there is every reason to believe that it will continue to inspire further creative applications of reinforced concrete and related materials. Indeed, ferro-cement has been promoted as a most promising construction material for developing nations, and those engineering students building concrete canoes today will be the experts in such appropriate technology in the future.

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