"A Race to Innovate"

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The Concrete Canoe Competition fosters many breakthroughs, but most of them go down with the ship. The 1996 winner, UAH, showcased a design for lightweight, thin-walled sections that could go on to make waves.

Take an impossible-sounding challenge, add determined groups of students and top it off with inter-university rivalries, and you have a sure recipe for creativity. The annual Concrete Canoe Competition, sponsored by ASCE and Master Builders, Cleveland, is a case in point, with the winning boats exhibiting a variety of unique designs. Unfortunately, many of those innovations are lost to a wider audience since the students who developed them move on to other assignments and their technical reports go ignored by engineering professionals.

This is unfortunate, but in at least one case at the University of Alabama in Huntsville, we students and professors who won the 1996 competition may yet see our ideas taken to the next level. In building our boat, we discovered a unique approach for designing and producing efficient, light-weight thin-walled composite sections of reinforced concrete. These sections, which we used to produce a strong, fast craft may one day be used to repair infrastructure, construct affordable housing and even build shelters in space.

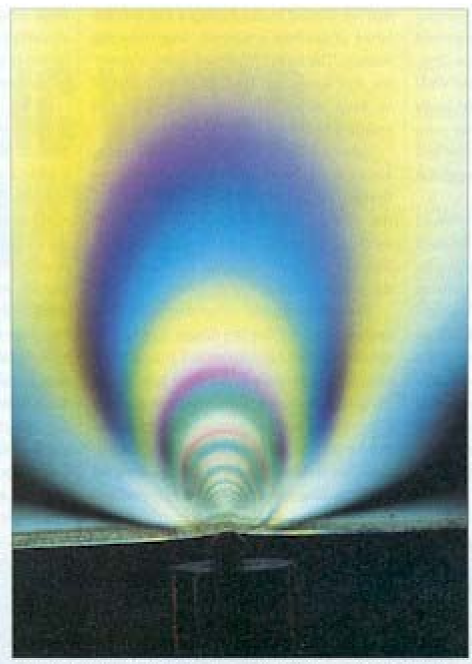
The 0.2 in. thick panels sandwich flexible, lightweight concrete between two layers of steel mesh and a geotechnical grid. The concrete provides form and solidity to the structure, but under a load the concrete flexes slightly, causing the steel mesh to carry most of the imposed stress. The geotechnical grid keeps the layers of mesh separated for optimal panel strength. Given this geometry, the panel acts like corrugated cardboard or a very broad I-beam.

We arrived at this design after a long period of research because, unlike many schools, we had to start completely from scratch. The graphite reinforcement that we had introduced in 1993 had been outlawed, and the transition to traditional materials posed a formidable challenge.

We began with a series of experiments to determine stress distribution in the hull. We characterized this through finite-element analysis and by studying cracks that had developed in our older, steel-reinforced canoes. These reviews were supplemented by data obtained from strain gauges mounted at critical locations on the boats. These data helped us quantify the dynamic loads and stress reversals that occur during paddling. We determined that the peak strain was equivalent to a 14.47 in. lb moment applied to a plate that was 0.2 in. thick and 1 in. wide.

Armed with this information, we performed a comprehensive study to select the geometry and materials for the cross section and establish the minimum required compressive strength for the concrete. We began by producing photoelastic models for several different reinforcement schemes. The models were made of birefringent material that, when viewed through a polariscope, revealed isochromatic fringe patterns proportional to the applied stress. After testing a variety of configurations, it was clear that an extremely efficient section could be produced by placing two layers of reinforcement as far apart as possible.

Studies using the transformed-section method and the elastic flexure formula revealed that concrete's stiffness was much more important than its strength for carrying a load. By selecting a concrete with a low elastic modulus compared with its reinforcement, the transformed section became, in effect an I-beam.


The isochromatic fringe pattern obtained by photoelasticity was used to establish stress distributions at critical locations in the design.

Since the concrete and the reinforcement were located at the same distance from the neutral axis of the section, the ratio of the maximum stresses in them was the same as the ratio of their elastic moduli. Thus, the required concrete strengths for our steel-reinforced sections were very low (100-250 psi) compared with those of other universities, which relied on stiffer concretes (1 million-6 million psi) and less efficient designs.

To eliminate any controversy over our choice of materials, we selected steel as the primary reinforcement even though it is relatively heavy. Comparable performances were obtained for all steel meshes considered, but we chose 0.125 in. square-welded steel mesh constructed with 0.017 in. diameter wires. This mesh was less stiff than any of the others, making it easier to place over the mold. It also better conformed to one of the contest's objectives, namely that "reinforcement materials must be flexile materials that provide stiffness by forming a composite system with the concrete."

Our numerical analysis predicted that, with proper design, the composite would be under-reinforced. When the stress in the concrete reached a mere 264 psi, the stress in the reinforcement would be 72,000 psi, so high that failure would actually occur in the steel and not the concrete. While this is a typical practice on large concrete structures, it is not typical for the contest.

The final design employed two layers of steel mesh spatially separated by a coarse, weak geotechnical grid. All of this was held together in the mold by monofilament fishing line. By taking the maximum expected moment into account and incorporating a safety factor of 1.5, we calculated that a minimum concrete compressive strength of 250 psi was required.

One way to achieve this strength and low stiffness within our design envelope was to use polymer-modified concrete. Tne National Concrete Canoe Rules Committee had approved latex as a concrete additive in 1995, so we tested the material properties of 27 different mixes.

We relied primarily on the ASTM third-point flexural beam test, since it produced the same type of stress conditions that occur in the critical sections directly beneath the paddlers. After rejecting several mixes, we evaluated 19 reinforced sections that had been cured for seven days. In every case, failure occurred in the steel strands directly beneath the applied loads where both the moment and the shear were greatest. Despite deflections that reached 1.7 in. over a 15 in. span, the concrete did not delaminate or spall.

To determine which concrete we would use, we created an efficiency index for each mix under consideration. The efficiency index is the ratio of the maximum moment supported by a given section to the weight of the resulting canoe. Our final mix had an average 28-day strength of 510 psi and a weight of only 35 lb/cu ft, which actually makes the concrete light enough to float. At 510 psi, the strength is significantly higher than we had planned, but it gives the boat a margin of safety that will protect it from accidents and other hazards.

The canoe was fabricated out of sections that we formed to exact shapes and was finished to produce a smooth, drag-reducing surface. The boat christened Spirit of America, was about 21 ft long, 34 in. wide and 10 in. deep, with a hull thickness of 0.2 in. It weighed 78 lb.

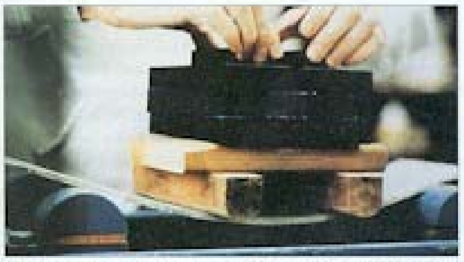
After taking the regional competition, we went to the national contest and won first place for technical presentation. On the water, Spirit of America set a new men's sprint record, making it the longest, lightest and fastest canoe ever raced until now on the national level.

More importantly, as we worked on the boat we realized that the design strategy we developed may have important practical applications, especially if the steel is replaced with lighter, corrosion-resistant carbon fiber. These sorts of panels could easily be used in construction or to repair infrastructure. The technology might even be adopted by the military to design easily assembled mobile shelters or by NASA to make low-mass structures in space. Currently, a construction firm is considering using our methods to build low-cost housing for developing countries.

If any of these possibilities bears fruit, it will show that the Concrete Canoe Competition is more than a stunt. In fact, from a technical standpoint the races have promoted a technology transfer that has led to rapid advancements in hull design, materials analysis, construction methods, performance evaluation and managerial techniques among engineering students. A similar technology transfer could be taking place from the students' designs to the civil engineering world, and if engineers start to take the results of this contest seriously, it will.

Strain gauges mounted on older steel-reinforced canoes determined the concrete compressive strength required for the new design.

Concrete was placed over two layers of steel mesh separated by a geotechnical grid to create a sandwich panel.



Bending tests conducted on composite plates confirmed that concrete remained in place until failure occurred in the steel.

The mesh reinforcement was held in position during the placement of the concrete using polystyrene bearing blocks and fishing line.

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Jeff Lindner (stern) and Kirk Smith establish a new men's sprint record at the 1996 National Concrete Canoe Competition, making UAH's *Spirit of America* the longest, lightest and fastest concrete canoe in history.

Students have been trying to outdo one another at the odd task of building a concrete canoe since the early 1970s, but it wasn't until 1988, when 20 boats competed at the University of Michigan, that the first official National Concrete Canoe Competition was sponsored by ASCE and Master Builders, Cleveland, a manufacturer of concrete-reinforcing chemicals.

The competition has been held every year since, and it has many goals, only one of which is to actually win the race. Winners may get bragging rights, but every student who participates learns more about applying engineering principles to real designs, the various properties of concrete and the value of teamwork. The contest also helps strengthen cooperation among the local chapters of ASCE and their affiliated student clubs.

Teams compete in sprint and endurance races, but the winning canoe isn't always the fastest. Teams can gain or lose points based on their oral and written presentations, where they must sell the canoe's design, construction and materials properties to a panel of judges. Finally, in the swamp test, a canoe must pop up and float after being submerged.

Designs have evolved considerably since the competition's early days. Today's concrete canoes are faster than commercially available aluminum ones and could challenge the fastest Olympic sprint boats, provided the latter also had to make the 180 deg turn that is part of the competition's course.

The rules on materials have also evolved over time, but generally schools are expected to use commonly available materials, so as not to allow one school an advantage over the others. In 1995, for example, the University of Alabama in Huntsville (UAH) boat won both races, but was penalized for using an exotic carbon-fiber-reinforced frame that had been baked solid at a local NASA test center. The UAH team lost so many points that the South Dakota School of Mines and Technology, which used standard materials, was able to claim first prize.

A total of 30 teams from the U.S. and Canada participated in the 1996 race, which was held by the University of Wisconsin on nearby Lake Mendota. UAH won, for the third time in four years, followed by Michigan State University. Four-time winner University of California, Berkeley, came in third, and the defending champion, South Dakota School of Mines and Technology, placed fourth. Next year will mark the 10th anniversary of the contest, and to celebrate, the race will be held at Master Builder's headquarters in Cleveland and feature international teams. Interested students should contact the Office of Student Services at ASCE.