ENHANCING ENGINEERING EDUCATION THROUGH THE CONCRETE CANOE COMPETITION

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ABSTRACT

Concrete Canoe – will it float? With the correct mix of cement, water, aggregate, and admixtures in addition to "Stamina, Teamwork, Strength, Imagination and Commitment," yes, it will!

The use of concrete to make a canoe is an unusual application of a common building material. In the 1970's when some civil engineering college students decided to build a canoe using reinforced concrete, concrete boats were not an entirely new idea. In 1848, Joseph Louis Labot of France built the first concrete dingy. The first ocean-going concrete ship was an 84-foot long boat constructed in Norway and launched in 1917. Concrete boats were built during WWII and yachts are still being manufactured from concrete in several countries. American Society of Civil Engineering (ASCE) student chapters have been building and racing concrete canoes in regional competitions since the early 1970's. The first national competition was held in 1988 at Michigan State University where 18 teams competed to be national champion.

Because reinforced concrete is an unlikely material from which to construct a canoe, it forces innovation and creativity in the engineering design phase. Every year students strive to formulate concrete mixtures that are both strong and workable enough to apply to a hull form that will result in a more efficient, faster, more maneuverable and aesthetic concrete canoe. The design/build process required to create a competitive concrete canoe provides civil engineering students with an opportunity to gain hands-on practical experience and leadership skills that will enhance their engineering education. They learn the importance of effective project management and teamwork, including communication, organization, quality and cost control and safety. The technical challenges of the project are quite similar to those encountered in a high-quality undergraduate research project.

Students who participate on a concrete canoe team gain valuable skills that they would not necessarily learn in a standard engineering undergraduate curriculum. The concrete canoe competition is a program that allows civil engineering students to work on a project from start to finish. It is an excellent design/build project requiring an engineering design based on rigorous specifications. Classes, even Senior Design classes, are usually limited as the final product is often conceptual, at most.

Since 1988, up to 250 schools design and build concrete canoes and compete at the regional level every year, hoping to advance to the national competition. If each team has 15 members, this represents 3,750 students who participate on a yearly basis, or 71,250 students since 1988. Building a competitive concrete canoe enhances a civil engineering student's educational

experience and produces an atmosphere of school pride among the hard-working, and competitive group of students.

Introduction

This paper is intended discuss the importance of student participation in engineering design competitions. Student design competitions closely mirror real-life engineering and provide the students with experiences in project management, design, analysis and testing, and collaboration with professionals in the field of engineering that they would probably not experience in the classroom. This is very beneficial to them as they begin their professional engineering careers. Student participation in the National Concrete Canoe Competition will be used to illustrate how a design-build competition of this type can enhance their engineering education. This national competition has been sponsored since 1988 by the American Society of Civil Engineers and BASF Admixtures, Inc. - originally Master Builders, and other corporate sponsors.

First some history; the use of concrete to make a canoe is an unusual application of a common building material. In the 1970's, when some civil engineering college students decided to build a canoe using reinforced concrete, concrete boats were not an entirely new idea. In 1848, Joseph Louis Labot of France built the first concrete dingy. The first ocean-going concrete ship was an 84-foot long boat constructed in Norway and launched in 1917. Concrete boats were built during WWII and yachts are still being manufactured from concrete in several countries. In 1970, ACI Past President, Clyde Kesler inspired his students at the University of Illinois to build the first concrete canoe. The first regional concrete canoe competition was held between Purdue University and the University of Illinois in 1971. Word of this competition spread in the Midwest and the following year 16 schools competed in a regional concrete canoe competition hosted by Purdue University. The first national competition was held in 1988 at Michigan State University where 18 teams competed to determine a national champion. The University of California – Berkeley was the winner at this first national competition.

I attended my first concrete canoe competition in 1980 at CU while I was a junior at Mines. Mines was not competing, but I had heard about the races and wanted to see what it was all about. My first exposure to the Concrete Canoe competition, other than watching the races at CU, was when some CSM students decided to build the "USS Uncle Karl", named after Dr. Karl Nelson, Professor Emeritus, in 1994. The students participated in the competition, but unfortunately, the "USS Uncle Karl" now lies at the bottom of Cherry Creek Reservoir. The use of styrofoam beads as an aggregate, intended to lighten the canoe, soaked up water and made the canoe so heavy it sank during the first sprint race. The CSM ASCE student members have been participating in the Concrete Canoe competition ever since this incident, have represented the Rocky Mountain region at the National Concrete Canoe competition twice, placing 10th in 2001 and 13th in 2003 out of 28 or so entries. The CSM ASCE student chapter submitted a proposal and was chosen as host of the 13th annual National Concrete Canoe Competition in June of 2000.

Personally, I have been the ASCE Student Chapter faculty advisor for 13 years and have worked with the concrete canoe team since the days of the "USS Uncle Karl". I was a National competition judge in 1998 and returning head judge in 1999; I have served on the rules committee for the National Concrete Canoe Competition (NCCC) since fall 2003 and recently rotated off of this committee.

In my experience, the teams that are most successful are those that learn from past years' experiences and bring this knowledge forward. Success in this competition is based on a combination of factors; the ability to combine recent advances in concrete technology with the concepts of naval architecture; the use of effective project management; and the motivation, creativity and spirit of a team of young men and women who take extreme pride in their work.[4]

At the concrete canoe competition, there are four main areas that are judged; finished product, oral presentation, written technical report and the races, each part now worth 25% of the total competition points. To successfully address the project of designing and building a concrete canoe, students must plan the structure of their engineering design team. Initially, the teams must focus on designing a fast and maneuverable hull, a light-weight concrete mix and a method by which to form the canoe, all in accordance with the National Concrete Canoe Competition (NCCC) rules and specifications, published each year in early September. Typically, under the leadership of a project manager, team leaders (project engineers) are appointed for each focus area of the canoe design.

In order to determine whether or not civil engineering departments in major universities across the country endorse the value of the concrete canoe competition, a message was sent through the NCCC list serve asking if "there are concrete canoe teams who receive engineering credit toward their degree for participating in this competition?". Sixteen responses were received over the course of 3 days; of those 16 responses, 14 universities do allot engineering credit for the concrete canoe project, while 2 do not. This credit varies from Senior Design/Capstone Engineering credit to Independent Study credit. The U. S. Naval Academy was one of the respondents and instructors Dr. Jennifer Waters and LCDR David Robinson provided the following information: The course for which they give credit to students participating in the concrete canoe project is the Capstone Design course, "Ocean Engineering Systems Design II" (3 semester hours). The course description is "The conceptual design of an ocean engineering system is accomplished by midshipmen teams. Projects are selected to match student interest and vary each semester, but normally include such areas as coastal shore protection, marinas, offshore structures, tidal wetlands, artificial reefs, ocean energy systems, underwater vehicles, diving and life support systems. Design teams work independently and integrate detailed engineering design along with other project elements such as proposal writing, project management, cost estimating, report preparation and oral presentation". The last sentence of the course description encompasses all that students must do to be successful in the concrete canoe competition.

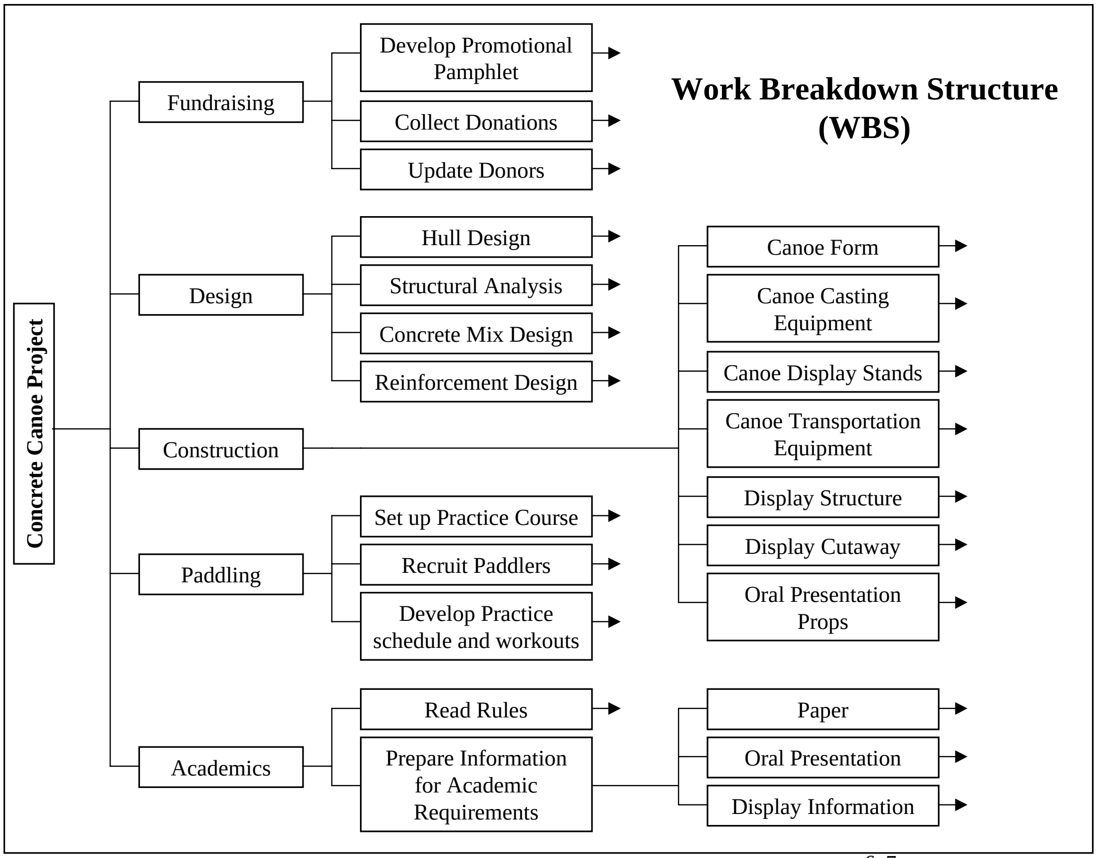
Capt. Peter Crispell, a faculty member at the United States Air Force Academy, stated that their students who are interested in participating in the concrete canoe competition take a 3 credit hour course called "Lightweight Concrete Design and Construction". The course is counted as one of the cadets' basic engineering option classes and includes lectures, labs and homework projects including Archimedes' principle (buoyancy), concrete mix design, AutoCAD, hull design and modeling, scheduling and the use of MS Project, composite materials, and the overall engineering process.

These two course descriptions are mirrored by other respondents, including the University of California – Berkeley, University of S. Illinois – Edwardsville, Vanderbilt University, Colorado School of Mines and many others. This is an endorsement of the value of the engineering process required to be successful in the concrete canoe competition.

Project Management

Project management can be defined as the process of coordinating people, organizing and communicating with them to complete a specified project on time, within the required specifications, and on or under budget. Effective project management includes the development of a budget and project schedule, organization of labor and material resources, quality assurance and quality control, fundraising, conflict management and safety. Of these requirements, civil engineering students may be exposed to project scheduling and cost estimating and budgeting in a senior design capstone course, but they are rarely afforded the opportunity to experience the other aspects of effective project management. The concrete canoe competition is a project that requires effective project management to be successful and gives the students experience from which they can learn as they organize a team of students to design and build a concrete canoe over the span of an academic year.

For the concrete canoe project, the organizational structure of the project management and the team members varies from school to school, but many have a similar format based on the specific tasks required to design and build a concrete canoe for competition. The most successful schools set their project management structure based on a breakdown of the work required to complete the project. Oklahoma State University has used a “Work Breakdown Structure” shown below to outline all of the basic tasks associated with the concrete canoe project, including structural analysis, hull design, concrete mix design, reinforcement design of the composite section, form construction, preparation for the technical paper and oral presentation, paddling practice, etc.



Example of Work Breakdown Structure[6, 7]

Once a "Work Breakdown Structure" has been created, it can be used to model the project management of the entire team to cover the required tasks. For example, a Project Manager, preferably someone with a year or two of previous experience with the project, would be selected to manage and coordinate the entire project. A lead engineer might be assigned to oversee the engineering aspects of the project, including hull design, form construction, structural design, concrete mix and reinforcement design, as well as preparation for the technical paper and oral presentation at the competition. The next level of management could be the formation of major committees, with a committee chairman, dedicated to one of the primary aspects of the project, all working under the Lead Engineer and the Project Manager. If this is the structure of the concrete canoe team, the primary leadership team for the project would include the Project Manager, Lead Engineer and each committee chair. Even the process of deciding on an effective project management structure provides a learning experience for the students that they will probably use during their engineering careers.

One of the first tasks for the management team, once their structure for the project has been determined, will be to create a detailed project schedule with the critical path identified. As they create this schedule, they will set deadlines for the completion of major tasks and track the overall progress of the entire project. In past experience, students create a schedule, but don't understand the importance of constantly using and updating the schedule as the project progresses. The concrete canoe project should reinforce the importance of a critical path project schedule, because if it is not followed, their team may not be prepared for competition.

Once the schedule has been created, each team can begin their tasks. As each team works, the project management team will be required to develop and implement quality assurance and quality control methods that apply to each process. The development of these methods could be based on previous experience with the project in past years.

Fundraising is an important part of a successful concrete canoe project. Many concrete canoe teams work with their university during this period, contacting potential corporate donors and alumni who are interested in supporting students in their civil engineering program. Some concrete canoe teams publish a brochure outlining the canoe project, past success and future goals to inform potential donors of the project and current financial needs. The publication of such a document, combined with a letter of introduction, and possibly meeting company representatives and alumni is invaluable experience for the civil engineering students. In addition to the importance of writing and publishing a newsletter, students gain the opportunity to meet and network with potential future employers. This opportunity is typically not available to a student in the standard civil engineering curriculum. Once donations are received, the students will be required to account for the monies received and balance their project costs, which is also an important exercise.

Two other very important aspects of successful project management include effective communication and the ability to employ conflict resolution, if required. A student can successfully complete a civil engineering curriculum without ever having to employ either effective communication and/or conflict resolution, both very important tools for the success of anyone in their professional development. With the “top down” management style that has been described, typically with teams of 20 -30 students, that is used by many concrete canoe teams, both of these tools will be used at sometime during the process of designing and building a concrete canoe for competition. Project management teams that employ effective communication will be much more successful during the concrete canoe project than those who do not. Effective communication methods vary and are constantly changing with the use of electronic methods. Additionally, with so many people working on a project, there will probably be some conflict; students who learn how to address and mitigate conflict in a timely manner without alienating part of the team will ultimately be more successful. The students who gain experience in conflict resolution will learn effective methods and will take this knowledge with them as they begin their careers upon graduation. Effectively working with people is a very important skill to have in the workplace, no matter what the profession, and working on a concrete canoe team is a very good place for students to learn some of these skills.

Another important part of the concrete canoe competition is the awareness of the importance of a safe workplace. The students will be working with toxic materials as they develop a concrete mix design and should wear appropriate safety gear, such as safety glasses, masks, gloves, and boots. As the students construct the form for their canoe, they will use various power tools and should also wear appropriate safety gear. In the engineering profession, safety is of the utmost importance, and students participating in the concrete canoe competition learn about safety and gain an awareness of the importance on avoiding an accident.

Students who participate in the concrete canoe project gain many skills in effective project management including the development of a budget and project schedule, organization of labor and material resources, quality assurance and quality control, fundraising, conflict management and safety. Very few of these skills are learned during a typical civil engineering undergraduate experience and will be invaluable to those students who have participated in the concrete canoe competition as they begin their civil engineering careers.

Hull Design

One of the key aspects of the competition is the development of a hull design in compliance with the specifications that are outlined in the rules and regulations and performs well under various race configurations (200 meter sprint race and 600 meter endurance and slalom race). Over the course of the last two decades of the national competition, changes such as dimensional (width and length) restrictions and loading conditions (2-, 3-, and 4-person races) have been made to the rules in an effort to challenge the engineering students.

Outside of understanding Archimedes' principle - the buoyant force on a submerged object is equal to the weight of the fluid displaced – most engineering students have little knowledge about hydrodynamic performance of various hull designs. As a result, students conduct extensive research using the volumes of published literature and design software on hull design and conduct small-scale, and sometimes full–scale, prototype testing in order to develop a design. This is typically following by a structural analysis to determine the critical stresses that result for various loading conditions, including racing with 2, 3 and 4 paddlers and transportation loads. The concrete mix and composite section of the canoe will be designed to withstand these critical stresses. Over the long term, teams will make refinements and adjustments to subsequent canoes based on the performance of their concrete canoe and others on race day of the competition.

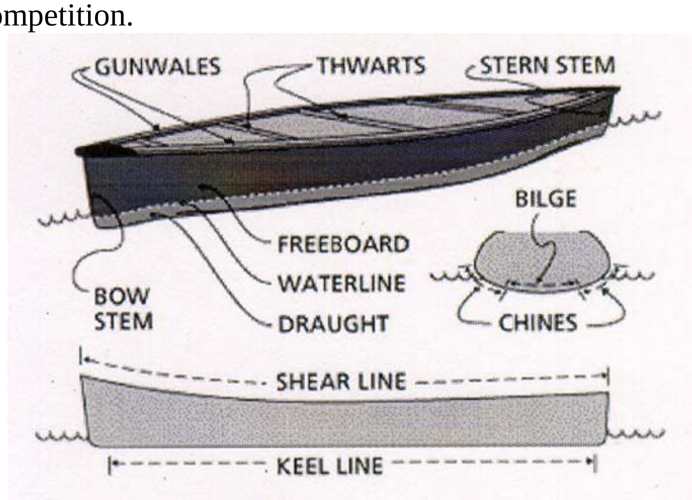


Figure 1: Canoe Nomenclature

There are four (4) main characteristics of hydrodynamic performance that concrete canoe designers attempt to optimize in their designs - speed, tracking, maneuverability, and stability. The race configurations include a combination of straight-aways and 180° hairpin turns in the sprints and a slalom course in the long-distance race. These races are run under various paddler loading conditions, so designers are tasked with developing a design that meets conflicting objectives – a canoe that has adequate speed and tracking, but yet is maneuverable and stable as well. In order to achieve this balance, hull designers start the design process by applying the fundamental basic concepts of naval architecture to understand the basic terminology of boat building (Figure 1) and determining the effects of hull characteristics such as length, beam or width, depth, longitudinal and cross-sectional shape (Figure 2a), and rocker (Figure 2b) on the overall performance of the canoe in the water, in respect to attaining adequate straight-line speed, the maneuverability to negotiate race buoys, and the capacity to hold up to four people with sufficient freeboard. During this process, the students develop a basic understanding that variances in the individual parameters can have either a significant or negligible effect on the performance of the canoe and that compromises need to be made to achieve the desired goal. For example, as the length of the canoe increases, the theoretical hull speed of the canoe increases and it will tend to track straighter requiring less adjustment by the paddlers to keep it on course. However, this means that the canoe is less maneuverable and would generally be harder to turn. As a result, rocker (the curvature of the canoe along the keel line) may be incorporated to compensate for this.

Other examples of hull characteristics and choices are "tumblehome vs. flare" and "chines" of a canoe.[2] Tumblehome is a descriptive term for canoe sides that angle in toward the paddlers. A large amount of tumblehome, or sides angled heavily inward as shown in Figure 2c, allow easier access to the water for the paddlers but reduces stability. The opposite of tumblehome is flare, when the sides of the canoe angle out away from the paddlers. Excessive flare adds to the stability of the canoe by increasing underwater volume. While flare adds to the stability of the canoe, it makes it harder for the paddlers to reach the water with their paddles.

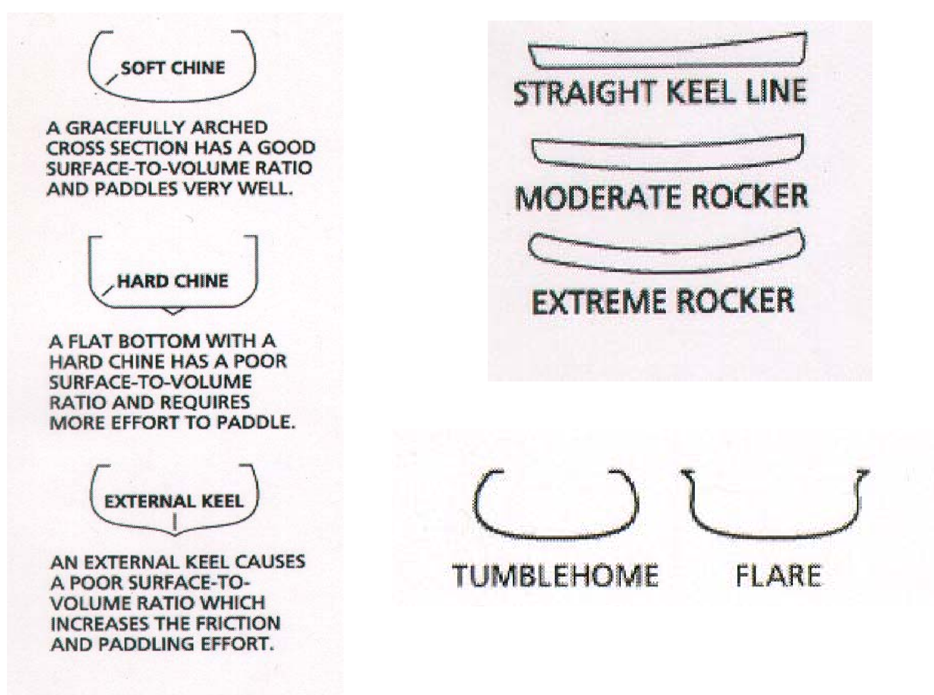


Figure 2: (a) Cross-Section Shape, (b) Forms of Rocker, and (c) Tumblehome and Flare

Although the hydrodynamic attributes are considered the most critical aspects of the hull design, additional consideration is given to the overall aesthetics of the canoe, as well as how difficult the construction of the recommended hull form will be.

Some teams may rely solely on empirical knowledge obtained from the published literature in order to develop their hull design, while others, depending on time constraints and team capabilities, conduct more advanced analyses may be conducted in order to verify assumptions, refine designs or to obtain a more thorough understanding of the overall process. Computer programs such as naval architectural software design programs (Nautilur®, Vacanti®) are common tools used by the students in the development of their hull designs. In addition, computer simulation can be used to evaluate the expected performance of each prototype in the water. The simulation shown in Figure 3 shows pressure on the canoe as it flows through the water. The higher pressure is indicated by the yellow and green color at the bow of the canoe.

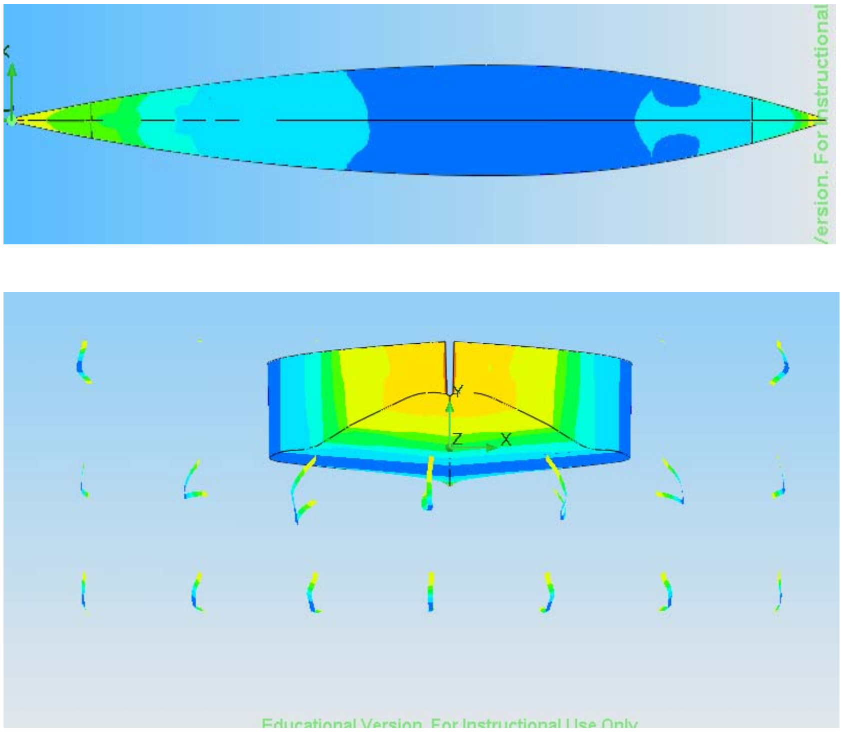


Figure 3: Flow simulation on canoe profile

In addition to the computer simulation, many students also create scale models of their top performing hull designs to be tested in a flume. See Figure 4. Conditions approximating those to which the full size canoe will be exposed to can be simulated in the flume test. The models are tested in this physical simulation for speed, mobility and stability. Based on the results of the computer and physical simulations, analysis and testing, the best hull design can be chosen by the design team.

Figure 4: Flume Test simulation [2]

Reinforced Concrete Design

A primary design requirement is the development of a reinforced concrete composite that can withstand the rigors of racing as well as the transportation to and from the competition(s). Using the results obtained from the structural analysis, minimum acceptable values of compressive, tensile and flexural strength are determined. The structural analyses used to determine these values vary from performing simple bending equations based on mechanics of materials theory to more advanced methodologies using finite element analysis. Students usually use allowable stress design as they analyze the stresses, but lately there has been a trend to incorporate load and resistance factor design instead. In addition to the strength parameters, other objectives are typically set. Students achieve target concrete unit weights through the incorporation of lightweight aggregates, improved properties of fresh concrete such as workability with the use of various admixtures, and enhanced aesthetic appeal by using pigments, stains and sealers.

One of the objectives of the competition is to provide civil engineering students an opportunity to gain hands-on, practical experience by working with concrete mix designs (NCCC Rules, 2006). However, in most undergraduate civil engineering curriculums, students are generally introduced only to the textbook basics of concrete mixture design and testing methodologies with very limited hands-on experience in actual batching and proportioning of concrete mixtures. The competition affords the opportunity for students to actually develop, test and refine concrete mixtures in order to achieve their desired properties. Because of the limited exposure to mixture design in the classroom, the continuity of knowledge and experience for the development of concrete for the competition is critical. Most teams use members from the previous years' to educate new members, which provides continuity each year. The knowledge that is gained by the students is further augmented by their contact with various manufacturers, suppliers, engineers and researchers who provide materials and technical support.

In the early stages of the concrete design process, team members research various cementitious materials, aggregates, admixtures and fibers and determine their compliance with the specifications outlined in the rules and regulations. Current rules require that fly ash and/or slag cement must account for a portion of the cementitious materials used in the concrete mixture designs; however, various other materials such as metakaolin, rice hull ash, silica fume and epoxies have also been allowed. One of the most common mix design goals is to achieve a buoyant concrete with a unit weight less than water. To do this teams must investigate numerous lightweight aggregates both naturally occurring and commercially made, including pumice; expanded shales, slates and clays; glass beads; and ceramic microspheres. Various admixtures to improve workability, permeability, and setting time as well as fibers that are used as secondary reinforcement are also considered by the teams.

Once the ingredients have been thoroughly researched, concrete mixtures are formulated and an extensive laboratory testing program is implemented. For many undergraduate students, this is the first time they have been introduced to the preparation of test cylinders, cubes and beams, and conducting slump cone, unit weight, and strength (compression, split-tensile and flexural) testing. Students are encouraged to conduct testing in accordance with the applicable industry standards such as ASTM and ACI.

Once the optimum design(s) is formulated, the focus of the team shifts towards the development of the reinforcement that will be used in the concrete composite. In the early years of the competition, the primary reinforcement considered was steel welded wire mesh, however, in recent years the shift has been made to the use of more pliable and lighter materials such as carbon fiber, polypropylene, Kevlar and fiberglass mesh. Composite plates constructed using concrete and multiple layers of reinforcement which mimic the proposed section of the canoe are tested in three-point bending according to ASTM C78.3 Another type of primary reinforcement regularly considered by concrete canoe teams is the placement of pre-tensioned cables or tendons where tensile stresses will occur in the canoe cross section. To test the effectiveness of pre-tensioned tendons, beams are constructed of the concrete and pre-tensioned tendons in accordance with ASTM C293.3

Form Construction

Concrete Canoe construction design teams begin their work on the form by researching different types of forms and investigating time and cost effective methods of constructing the form.

There are three basic types of forms that teams usually consider; male, female and a combination of the two (Figure 5):

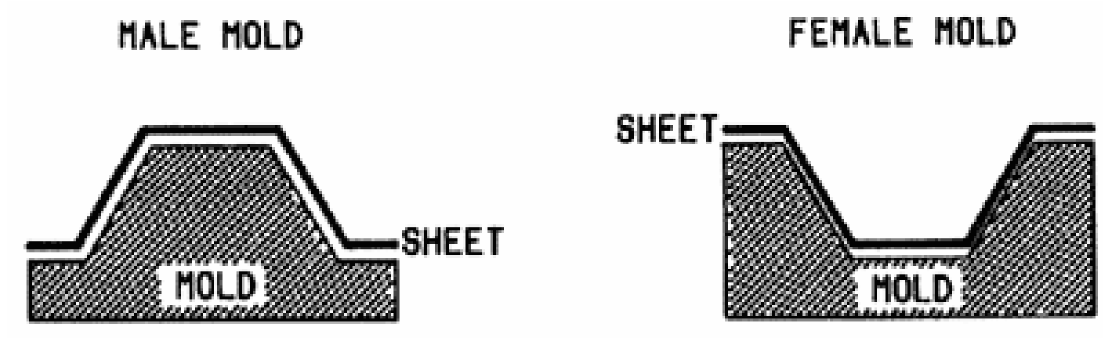


Figure 5: Male and Female form-types [2]

All three types of forms have advantages and disadvantages that the team must evaluate when deciding on the type that will work best with their hull design.

Typically, the process of construction begins by taking the recommended hull design and creating AutoCAD drawings. These drawings can then be used on a milling machine to cut wooden cross sections of the canoe at regular intervals of 12 to 18 inches. The wooden sections are then be attached to a strong back and high density construction foam can be cut using the wooden cross sections as a guide for a hot wire cutter. The foam will then be placed between the wooden ribs and the entire form sanded to a smooth finish. Usually, the form is coated with paint or a drywall compound to ensure a smooth finish. Then, the finalized form can be coated with baby oil, shrink wrap, or a wax to insure release of the concrete canoe after it has been placed on the form and cured. Some concrete canoe teams will use the same form to construct a fiberglass, full-size prototype of their canoe in which to practice paddling. [3]

Summary

The following quotes have been obtained from past and current students who have participated in the concrete canoe competition:

<u>From Adam Koester, Colorado School of Mines, graduating in May 2007:</u>

"The concrete canoe project has made me reconsider the possibilities of graduate school in civil engineering. The opportunity I have had to do research in the field of lightweight concrete mix design has given me a knowledge base and skill set that few others in the world can say they have. This is a project that gives students an early opportunity to see what the research field is all about."

<u>From Scott Rutledge, Oklahoma State University, graduated in May 2000:</u>

"Teamwork, leadership (not just management), loyalty, camaraderie, writing skills, public speaking, creative thinking, and problem solving – no grades attached. That is the engineering student I want to hire."

This paper has illustrated how student design competitions, such as the concrete canoe competition, closely mirror real-life engineering, enhance the education of engineering students and provide them with experiences in project management, design, analysis and testing, construction, as well as collaboration with professionals in the field of engineering that they would probably not experience in the classroom. Students who participate in the concrete canoe competition build a project management structure and work within that structure to design and build a concrete canoe to compete in a regional competition and possibly a national competition. The canoe must be built to national specifications provided by the Committee on National Concrete Canoe Competition. At the regional competition, teams must present a technical paper describing their design/build process, give an oral presentation and answer judges' questions, paddle their canoe in sprint and endurance races and present a finished product (their canoe). These four major parts of the concrete canoe competition are judged by a slate of five professional engineers, all trained and practicing in the field of civil engineering. Participation in the concrete canoe competition enhances the education of engineering students and provides them with opportunities to learn that are not otherwise a part of their undergraduate education. These experiences will better prepare these students to begin their professional civil engineering careers.

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