NORTHERN
ARIZONA
UNIVERSITY

American Society of Civil Engineers
National Concrete Canoe Competition
Background Research Document
CENE 476: Capstone Prep

To: Mark Lamer, P.E., Grading Instructor

Cc: Bridget N. Bero, Ph.D., P.E. and Wilbert Odem, Ph.D., P.E.

From: Evan Kaichi, Chelsie Kekaula, Brent Lipar,
Colton McConnell and Emily Melkesian
Undergraduate Civil Engineering Students
College of Engineering, Forestry and Natural Sciences
Northern Arizona University

Date: September 25, 2015

Fall 2015

Table of Contents

List of Abbreviations

ASCE	American Society of Civil Engineers
Cal Poly SLO	California Polytechnic University, San Luis Obispo
NAU	Northern Arizona University
NCCC	National Concrete Canoe Competition
PSWC	Pacific Southwest Conference
UF	University of Florida
in.	inches
ft.	feet
mm	millimeter
psi	pounds per square inch

1.0 Description of Technical Aspect

The American Society of Civil Engineers (ASCE) annually hosts a National Concrete Canoe Competition (NCCC) in which engineering students have the opportunity to design, construct and race a concrete canoe. This report will provide the technical background information necessary for the design and analysis of the canoe; this includes hull design and analysis, concrete mix design, reinforcement use and construction methods. The hull design governs the canoe's ability to accelerate, maneuver, and provide stability. In addition, the canoe requires a concrete mix that is lightweight and provides high strength to carry various loads and to remain buoyant. Concrete inherently has high strength in compression, however it lacks tensile strength. To provide tensile strength to the canoe, the team will include reinforcement and a pre- or post-tensioning system. Lastly, to allow for a successful final product, construction methods must be researched to assure that the hull design, concrete pouring and curing, and reinforcement placement are feasible.

2.0 Hull Design

The hull design consists of, but is not limited to, three primary aspects: length, width and shape. The length affects the hull speed and overall maneuverability of the canoe. A longer canoe provides greater speed and tracking, while a shorter canoe provides greater pivoting and mobility (Johnson Outdoors Watercraft Inc., 2015). There are two widths that take part when designing a canoe: the width at the 4 inch (in.) waterline and at the gunwale. The 4 in. waterline represents the displacement when fully loaded and has a strong influence on the performance of the canoe. A narrow 4 in. waterline width will provide greater speed but lack stability, and a wide width at this point will be slower but more stable. The gunwale width is measured across the top of the canoe and is determined by the walls' cross-sectional design. Lastly, the hull shape is related to the rocker, bottom cross-section and wall cross-section. A rocker is the canoe's bottom arch from front to back and it affects the canoe's ability to track and maneuver. Straight-line rockers sit predominantly in the water, which increases tracking, while heavy rockers have a steeper arch providing greater maneuverability. The bottom and wall cross-sections sections will create drag based on the canoe's wetted area, or area below the waterline. Therefore, these two cross-sections will vary based on the designer's desire for stability, speed and maneuverability (Fine Wood Water Craft, 2014). The 2016 ASCE NCCC Rules and Regulations state that the length of the canoe cannot exceed 22 feet (ft.), however the width and other dimensions have no restraints (ASCE, 2016).

The University of Florida (UF) won place at the 2015 ASCE NCCC. UF's objective was to optimize straight-line speed by constructing the canoe at the maximum allowable length, 22 ft., and using a straight-line rocker to create minimal lateral resistance (University of Florida, 2015). The 2015 NAU concrete canoe, Dreadnoughtus, was designed at 21 ft. in length and 27 in. in width. The dimensions were chosen to increase speed and sacrifice some stability for the paddlers.

3.0 Hull Analysis

The hull design requires hydraulic and structural analysis. Hydraulic analysis is performed using the software, Prolines, to design a canoe hull that meets the desired speed, maneuverability and stability. These three attributes are defined by the drag, optimal speed, righting arm and waterline. In addition, structural analysis accounts for various loading cases that the canoe may experience, such as applied loads from the two and four person races, transportation of the canoe and the reaction forces from the display to the canoe. These loads are simulated in RISA 2D to understand the longitudinal and transverse bending. Similar to 2015, the 2016 ASCE PCCC Rules and Regulations limit analysis to 2D methods.

To measure strength, California Polytechnic University San Luis Obispo (Cal Poly SLO) applied strain gages to the canoe during paddling practices to simulate various stresses that may occur while in use (Cal Poly SLO, 2015). Therefore Cal Poly SLO was able to compare hand calculations with test data. The University of Florida, on the other hand, applied a transom stern analysis to maximize the waterline length and decrease tracking resistance. Both Cal Poly SLO and UF analyzed the canoe’s cross-section as parabolas, however, the 2015 NAU concrete canoe team used a simplified rectangular cross-section. This simplified analysis is over-designed, while a parabolic analysis will result in a more accurate, cost-effective design.

4.0 Concrete

Concrete canoes are made using a lightweight concrete mixture which consists of cementitious material, admixtures, aggregates, and water. The overall winner for the 2015 ASCE NCCC, UF, constructed the canoe in three layers and each with a different concrete mixture. The mixture used for the middle layer achieved a high compressive strength of 2148 pounds per square inch (psi), while the inner and outer layer achieved lower compressive strengths of 1512 and 1350 psi (University of Florida, 2015). The variance in strength is due to the use of different sized Poraver® and Glass Microspheres aggregates, which are commonly used in concrete canoes due to the strength to weight ratio of glass. The middle layer contained the largest aggregates ranging from .25-2.0 millimeters (mm) in diameter, while the outer layer had the smallest diameter aggregates ranging from .25-.5 mm in diameter. The larger aggregates used in the middle layer provides a higher strength however forms a rough concrete surface. Therefore UF uses smaller aggregates on the inner and outer layer to increase the smoothness on the final product.

The second place finisher in the 2015 ASCE NCCC, Cal Poly SLO, focused on adjusting admixtures. Admixtures are known to increase strength, durability, and workability in concrete. Cal Poly SLO included the following admixtures to the concrete mix: Styrene butadiene (latex), Eclipse® 4500 (shrinkage reducer), Darex® II (air entrainer), Darapel® (water repellent), ADVA® Cast 555 (high-range water reducer), and Daraset® (set accelerator). Styrene butadiene was added to increase the flexural strength and air content. Darex® II was used to “increase the amount of microscopic air voids to decrease the total unit weight of the concrete” (Cal Poly SLO, 2015). Eclipse® helped minimize the shrinkage in the concrete which reduced the amount of cracking during the curing phase. ADVA® Cast 555 reduced the water to cement ratio, while still producing the desired slump. The last admixture added was Daraset® which allowed the concrete to achieve a compressive strength of 1200 psi in just 12 hours. (Cal Poly, 2015).

Last year's NAU concrete canoe team used Poraver®, Glass Bubbles and the admixture, MasterAir AE 90 (Northern Arizona University, 2015). The cementitious material used, Ekkomaxx™, was a fairly new product donated by CeraTech. Ekkomaxx™ is known to have low permeability, reduced heat (compared to Portland cement), minimal cracking, early strength development, low retained moisture levels, and the lowest carbon footprint in the world (USA CeraTech). In addition, Ekkomaxx™ is beneficial for a concrete canoe due to its high strength to weight ratio.

In previous years, the ASCE Concrete Canoe Rules and Regulations only allowed the use of Portland cement as the primary cementitious material. Currently, cementitious material such as Hydraulic Cement, Fly Ash, Metakaolin, Slag Cement, and Silica Fume may be used as long as it meets the proper ASTM code requirements. The 2016 ASCE Rules and Regulations state that specialty admixtures such as epoxy resins, acrylic, phenolic, and polystyrene resins are strictly prohibited. In addition, aggregates must make up a minimum of 25% of the total volume in all concrete mixtures (ASCE, 2016).

5.0 Reinforcement

Reinforcement is placed within the canoe to provide tensile strength. Determining the most appropriate material for the concrete canoe requires research of reinforcement materials, workability of the materials and testing procedures. As stated by Stephen Schmitt from Vanderbilt University, "The static and dynamic loads under each paddler create the need for reinforcement to resist the tension forces from flexure" (Schmitt, 2006). To counteract the forces, Vanderbilt University's concrete canoe team tested carbon fiber, polypropylene, Kevlar, and fiberglass mesh to utilize as reinforcement. To test the composite flexural strength of the reinforcement, custom 12'' x 12'' x 0.5'' plates were constructed to simulate the bottom of the canoe. The plates were then supported at the corners and loaded in the middle until failure. Based on the carbon fiber's strength and workability, this material was used within the canoe and placed in two separate layers.

For the 2015 concrete canoe, NAU tested four reinforcement options for tensile strength and elongation, using an Instron 3885 H screw driven machine. The materials tested were Glasgrid Pavement Reinforcement System, TriAx Geogrid, Parex Glass Fiber Reinforcing, and Dryvit reinforcing mesh. Through testing, it was determined that the Glasgrid had the highest strength and smallest amount of elongation at 181 lb-f/in and .04 in, followed by the Parex at 135 lb-f/in and .08 in, Dryvit at 102 lb-f/in and .07 in, and the TriAx Geogrid with a tensile strength of 72 lb-f/in and elongation of .62 in. Due to its overall strength, minimal elongation, bonding behavior and workability, the Parex Glass Fiber Reinforcing was implemented into the canoe (Northern Arizona University, 2015).

To resist the tensile forces placed on the canoe through various loading situations, pre-tensioning and post-tensioning systems are placed within the canoes. In 2014, University of Nevada, Reno, implemented a pre-stressing system, consisting of 18 steel tendons into their concrete canoe, Alluvium. To implement the system, “Four stations were drilled into the form to hold steel ribs. Springs were used to anchor tendons after determining the stiffness coefficients to establish the length change requirements associated with desired jacking forces” (University of Nevada, Reno, 2014). This pretensioning system allowed UNR’s concrete canoe to have a controlled pretensioned force of 250 pounds. The NAU concrete canoe team implemented post-tensioning as a form of reinforcement in 2015 with their concrete canoe, Dreadnoughtus. NAU’s Dreadnoughtus utilized six steel wires encased in nylon to form a net, which was draped over the canoe mold at set locations. Seven days following the construction of the canoe, the six pots-tensioning tendons were tensioned, providing a final force of approximately 115 pounds of tension in each cable (Northern Arizona University, 2015).

The ASCE NCCC installs rules and regulations which the reinforcement used in the canoes must follow. Per the ASCE NCCC Rules,” All of the materials serving as the primary reinforcement in the canoe shall have sufficient open space to allow for the mechanical bonding of the concrete composite.” (ASCE NCCC, 2016). The sufficient open space refers to the percent open area of the material, which must be greater than or equal to 40%. The reinforcement used must be in its original state, and cannot have any post-manufacturing perforations or bonding agents added. The material used must also have an overall thickness of less than 50% of the canoe’s overall thickness.

6.0 Construction

Construction of a concrete canoe requires study of mold types, concrete pouring and proper placement of reinforcement. Choice of mold type, whether it be a female, male or duel, requires coordination with the hull design, concrete mixture and reinforcement requirements. A female mold design requires concrete to be placed on the inside of the mold, while a male mold requires the concrete mixture to be placed on the outside of the mold. A duel mold system combines the male and female systems to form a shell that requires injection of the concrete mixture. Once a mold selected, the pour method must be determined. Pouring techniques include trowelling and hand placement with a female mold, shotcrete with a male mold, and injection or pumping with a duel mold system. In addition, concrete pouring must allow for reinforcement to be placed and for the pre- or post-tensioning system to be added.

From 2011-2014, NAU had consistently used a female mold; however, the 2015 concrete canoe team decided to change the trend and use a male mold to accommodate the post-tensioning system. The mold was made by cutting the four-section foam mold with a hot wire cutter, then shrink-wrapped it to create a smooth interior for easy pouring and removal.

8.0 References

Alvarez, Cynthia, Aguilar, Ramon, DeGeyter, Jeremy, Schneider, Matt, and Kristin Van Sciver. "2015 Northern Arizona University Concrete Canoe." *2015 NAU Concrete Canoe*. N.p., 5 May 2015. Web. 21 Sept. 2015.

American Society of Civil Engineers. "2016 American Society of Civil Engineers National Concrete Canoe Competition Rules and Regulations." *Rules and Regulations*. American Society of Civil Engineers, 2015. Web. 21 Sept. 2015.

Fine Wood Water Craft. *Essentials of Hull Design*. (2014). Retrieved September 22, 2015, from http://www.finewoodwatercraft.com/Essentials-of-Hull-Design-1.htm

Johnson Outdoors Watercraft Inc. *Size & Cross Section*. (2015). Retrieved September 22, 2015, from http://www.oldtowncanoe.com/canoes/canoe_anatomy/size_cross_section/

Kennedy, Danielle, Tyler Mokris, Kevin Carabeo, Teresa Lewis, Michael Ferguson, and Zach Prytula. University of Florida. N.p.: n.p., n.d. PDF.

Leyva, Jessica, Brett Diener, Tim Forrest, Dayna Scott, Joshua Core, Julie Hendrick, and Brandon McCormick. California Polytechnical San Luis Obispo. N.p.: n.p., n.d. PDF.

Schmitt, Steven. "The Vanderbilt Concrete Canoe Design Project: The Little Engine That Canoed." *The Vanderbilt Concrete Canoe Design Project: The Little Engine That Canoed*. School of Engineering of Vanderbilt University, 2006. Web. 20 Sept. 2015.

University Of Nevada, Reno. *Alluvium* (2014): n. pag. *Wisconsin Concrete Canoe Team*. 2014. Web. 19 Sept. 2015.

USA CeraTech. "High Strength Concrete. Sustainable Concrete." Web. 19 Sept. 2015. <http://www.ceratechinc.com/products/ekkomaxx>.