2011

SEALION

The College of New Jersey

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Executive Summary

The College of New Jersey (TCNJ) is a highly selective institution that has earned national recognition for its commitment to excellence. Founded in 1855, TCNJ has become an exemplar of the best public higher education has to offer, and is consistently acknowledged as one of the top comprehensive colleges in the nation. TCNJ currently is ranked as one of the 75 "Most Competitive" schools in the nation by Barron's Profiles of American Colleges and is rated the No. 1 public institution in the northern region of the country by U.S. News & World Report. The current enrollment is approximately 6,135 students, with 132 students enrolled in Civil Engineering. This year's competition will mark the first time that TCNJ will be represented at the Metropolitan Regional Competition with a concrete canoe team. It is our hope to be competitive and start a strong tradition at TCNJ with the goal of becoming a top competitor in the future.

Canoe Name: **SEA LION**	
Canoe Physical Properties	**Primary Reinforcement - Polypropylene Mesh**
Canoe Mass (Weight): 120.3 kg (265 lb)	Unit Weight: 909 kg/m3 (56.8 lb/ft3)
Canoe Length: 6.1 m (20 ft)	Tensile Strength: 170 Mpa (25 ksi)
Canoe Width (Max): 79.2 cm (31.2 in)	Modulus of Elasticity: 2.07 Gpa (300 ksi)
Canoe Depth (Max) 46.0 cm (16 in)	Percent Open Area: 70%
Avg. Thickness: 20.3 mm (0.8 in)	**Secondary Reinforcement Free Fibers**
Colors: Gray w/ Navy and Gold Letters	3/4" Polypropylene (PP) Fibers (Core Mix)

The team entered this competition as an opportunity to design and build something which required a substantial amount of research into the use of innovative materials, techniques, and ways of thinking and constructing. This competition was also seen as a way to establish TCNJ on a larger stage as a competitive engineering school, comparable with any given school across the country. Furthermore, in an attempt to display TCNJ pride, our canoe utilizes our college's colors, blue and gold. The school's mascot, Roscoe the Lion, was modified and used as the team's logo, and to formulate the canoe's name, the **SEA LION**.

Construction of the canoe was performed with a focus on sustainability. The canoe was casted in a female mold, reducing the amount of wasted concrete and allowing finer control of the exterior surface of the canoe. The mold was held together longitudinally by four ½" bolts, and can be disassembled to fit in the bed of a pickup truck with a safe amount of overhang. These features were added to accommodate refurbishing of the mold. With the exception of Portland cement, all materials in our concrete were recycled or produced sustainably.

From a management standpoint, electronic communication and document review, combined with measures such as carpooling, reduced our team's carbon footprint. The small team allowed for a constant exchange of information and a clear understanding of assigned tasks and overall project goals.

Concrete Mix	**Unit Weight**	**28-day Comp. Strength**
Core (free fibers)	977 kg/m^3 (61.7 lb/ft^3)	16.7 Mpa (2450 psi)
Exterior Surface (no free fibers)	979 kg/m^3 (61.8 lb/ft^3)	20.3 Mpa (2945 psi)

Analysis

Overview: Being our first year, this competition was an opportunity to design, setup, and construct an intricate product using desired engineering cues. With that in mind, our main goal was to achieve a respectable design adhering to all rules and regulations stipulated by the National Concrete Canoe Competition (NCCC).

Critical Parameters: Although the cross-sectional data for the canoe had been predetermined, many parameters of the canoe could be changed which would alter the performance while in the water. Some parameters such as the center of gravity, combined weight of the canoe and paddlers, and location of paddlers play a pivotal role in achieving and sustaining high velocities while in water. In addition, these parameters are necessary to ensure the canoe performs the way in which it was intended.

Using the ship design analysis program FreeShip (www.freeship.org), the center of gravity was determined by entering the cross-sectional data provided by the NCCC. The main dimension from the center of gravity is in the z direction which is taken from the bottom of the canoe and extends upwards. This value of 141.43 mm (5.568 in) is the minimum depth the waterline can be to prevent significant rocking of the canoe. After obtaining this value it was determined that a slightly higher waterline was preferred to account for any slight discrepancies in the thickness or consistency of the concrete and to provide more stability.

Furthermore, knowing the specific weight of the concrete mix design, the canoe's total mass (weight) was determined to be 120.20 kg (265 lb). This mass in addition to a generalized mass of 258.55 kg (570 lb) (2, 72.57 kg (160 lb) males and 2, 56.70 kg (125 lb.) females) produced a maximum racing mass of 378.75 kg (835 lb). Utilizing the program Hullform (www.hullform.com), the racing weight produced a draft of 168.86 mm (6.648 in). This mass provides a reasonable amount of stability while not allowing water to enter the canoe during the race.

Additionally, through watching several videos of other competitors who participated in past competitions as well as training with an experienced canoeist, we were able to hone in on the skills and style necessary to maximize our speed and acceleration while not compromising the stability of the canoe. The knowledge obtained from the canoeist has allowed us to learn the correct stroke method, how to reduce the splashing of water from entering the interior, and reducing our point load effect at entry.

Stress Analysis: To allow for analysis and minimal use of materials, 7:1 scale models were created. This was necessary to analyze stresses being applied on the canoe under transportation and racing conditions. It was determined through interpolation that maximum strain would occur toward the bow between sections 6 and 8. Under the critical loading, the maximum tensile stress in our concrete mix was calculated to be 0.096 MPa (14 psi). The ultimate tensile strength of polypropylene can be considered 34.5 MPa (25 ksi); therefore it is highly unlikely that a fracture will occur.

Impact testing was also performed at the critical section producing a maximum resistance to a force of 40.67 N-m (30 ft-lbs). This is critical in ensuring the integrity of the canoe through all forms of stresses acting on it.

Composite Outline: During the construction of the concrete canoe tensile strength rather than compressive strength was the most influential on the design. Furthermore, we determined that two different mixes should be used to allow for adequate compressive strength and the necessary tensile strength. Both layers were placed at a thickness of 10.16 mm (0.40 in) with layers of polypropylene mesh reinforcement sandwiched in between.

Supported by our initial research and testing it was determined that the interior concrete mix should be designed to have a unit weight of 977 kg/m^3 (61.7 lb/ft^3) and the exterior mix should have 979 kg/m^3 (61.8 lb/ft^3). The interior layer provided added tensile strength due to the fiber reinforcement used. Also, to greatly increase the tensile strength of the canoe the polypropylene was layered. The exterior concrete layer provided good finishability due to its lack of fiber reinforcement which tends to pull at the concrete during the finishing process.

Development and Testing

Mix Design: Designing a mix was a daunting task for a school that had never built a concrete canoe. We knew that we needed a canoe that was lightweight, yet strong enough to support the forces it would be subjected to during a race. We also knew that it was important to follow the theme of sustainable engineering.

We spent many hours researching materials used to create strong, lightweight concrete mixtures. After considering several materials we felt would optimize our canoe's strength-to-weight ratio, we addressed the issue of physically obtaining these materials. We were fortunate to have several contacts in the engineering profession assist us in securing the materials we needed, as well as providing us with a facility where we could fabricate the canoe.

Our benchmark design was based off of advice from engineers who had experience in concrete canoe competitions. We tested a total of 6 distinct concrete mixtures. Our baseline mix consisted of all our final materials minus the silica fume. After initial testing, it was determined that this baseline mix had a 28 day compressive strength of 14.12 MPa (2048 psi), and a unit weight of (65 pcf). Through analysis we discovered the mix contained too much air. This baseline mix was good, but needed to be improved. Major deviations from our baseline mixture included the addition of silica fume to the mix to add strength and greatly increase our workability, and testing of mixes with and without polypropylene fibers to experiment with finishability. The most time consuming obstacle we faced was obtaining the correct blend of the water/cementitious ratio, as many of our preliminary mixes were dry. Appendix B lists the final proportions used in the two concrete mixtures in the **SEA LION**.

Cementitious Materials: As per the design requirements, we used type I Portland cement (ASTM C 150). In keeping with sustainable engineering principles, we supplemented the Portland cement with blast-furnace slag (ASTM C 989) to help with the overall strength and durability of the concrete, as well as silica fume (ASTM C 1240) to increase strength and workability. The mass of cementitious material was proportioned according to section 3.3.1 (NCCC Rules 2011).

Aggregates: We knew that the aggregates chosen would be vital to achieving the unit weight requirements for our concrete design. The specific gravity and absorption of our aggregates were calculated in compliance with ASTM C 128. Poraver which is a form of expanded recycled glass (Poraver 2011), as well as cenospheres, hollow ceramic spheres recycled from coal burning (Cenostar 2011) were chosen as our aggregates because they would provide us with all of the properties needed for a quality mix. Aggregates were proportioned according to section 3.3.2 (NCCC Rules 2011).

Admixtures: Two admixtures were selected for our mix designs. The first was an air-entraining admixture (ASTM C260), at 720 mL/45.4 kg (24 fl oz/100 lbs), used to reduce the weight and improve the durability of the concrete. An overdose of 8 times the manufacturer's suggested ratio (Grace Concrete Products 2011), of 90 mL/45.4 kg (3 fl oz/100 lbs), was determined not to be detrimental to the canoe. The second was a superplasticizer (ASTM C 494), used to improve the workability of the concrete and reduce the amount of water required for hydration. The amount of 1034 mL/45.4 kg (35 fl oz/ 100 lbs) was used which is an overdose of 1.94 times the manufacturer's suggested dosage (BASF 2011) of 532 mL/ 45.4 kg (18 fl oz/100 lbs). This allowed the acquisition of the right amount of workability.

Reinforcement: We decided to use one layer of polypropylene molded mesh reinforcement with a strand thickness of 2.41 mm (0.095 in) and strand width of 1.19 mm (0.047 in). The ultimate tensile strength of polypropylene can be considered 25 ksi (Spaniol, Rulander, Jack 2011). As per section 4.3.2 (NCCC Rules

2011), percent open area was determined to be 70 percent. The procedure for that is included in the Engineer's Notebook.

Secondary Reinforcement: One of the two mixes used in the **SEA LION** incorporates polypropylene fibers for reinforcement. Polypropylene increases the flexural strength of our concrete while decreasing the permeability of the canoe (Brown, Shukla, Natarajan 2002).

Testing: To test the compressive strength of the concrete as per ASTM C39, 101.6 mm x 203.2 (4 in x 8 in) concrete cylinders were cast. As shown on page *i*, our 28 day compressive strength was calculated as 20.31 MPa (2945 psi). A concrete beam was cast to test flexural strength using the 3 point method as per ASTM C78. Unit weight and air content were computed following ASTM C138.

Project Management & Construction

Team: In stark contrast with many of the competitors in years past, our canoe design and construction team did not consist of an abundance of members from The College of New Jersey's ASCE student chapter. Rather, the project was undertaken as a design project of interest, with the entire team consisting of only four ASCE members. This simplistic arrangement produced several advantages as well as numerous disadvantages when compared to other teams.

Communication within the team was a relatively simple task, where one person would simply call the other three if they needed to get a message out. A team email account was created and all project related emails were forwarded to this address to enable all members to access communications from faculty, sponsors, and other parties. The small team guaranteed 100% attendance to necessary team meetings or discussion sessions, reducing possible confusion surrounding crucial topics related to the project and a quality delivery. Roles for team members were allocated based on their areas of interest and previous experience. Team meetings were reduced from scheduled ordeals to simple discussions after class sessions.

While there were advantages to this setup, several complications arose due to the inexperience and small size of the design team. Individual members were required to perform multiple tasks in various areas of the project. The concrete mix design team worked extensively on the mix design and construction, while the group members involved with stress and hydraulic analysis worked extensively their portions as well as the mold construction. While there were instances of overlapping causing an imbalance of work, the majority of work performed involved every team member to a certain degree.

Project Management: The project planning process was broken down into two main categories; mix design and mold construction. With the 2011 competition being the inaugural entry for The College of New Jersey, both of these categories were major unknowns upon commencement of the project. To deal with the various unfamiliar aspects, these categories were broken down into two distinct components: focusing on selection and testing of materials and the development of construction methods. Each component had two individuals responsible for the overall quality.

Headed by the Project Manager, the mix design team handled the responsibility of ensuring the quality of the mix design, results and analysis of components. The individuals responsible for the construction method focused primarily on design, efficiency, and stresses on the canoe's overall form while in the water and in transit.

All man-hours were compiled for each major activity based on the critical path compiled prior to the conference competition: 300 hours for structural analysis, 800 hours for mix design and structural testing, and 700 hours for canoe construction. There was an additional 300 hours spent on non-design assignments including business proposals, presentations, application for grants and documentation.

Team Building: Upon reviewing all rules and regulations stipulated by the National Concrete Canoe Competition (NCCC) it was realized that there would be a need for female members to assist in the racing portions of the competition. After active recruiting we found female members and other individuals who were interested in partaking in this year’s events and continuing the competition next year. This now required us to place an emphasis on educating those who had no initial role in the design and construction phases.

Fundraising: Entering a competition of this magnitude requires a substantial financial investment in the project. The College of New Jersey assigns every engineering design project a budget of $100 per student to assist the project. Any funding beyond this requires special approval and typically takes several weeks before the money becomes available.

Cognizant of the relative cost of the project, the design team aggressively pursued options to reduce total project cost. Very early in the project process, a bill of materials was developed in conjunction with a business plan which was sent to companies that had expressed interest in donating materials and services to the canoe construction. Several materials, such as blast furnace slag, Portland cement, silica fume, and polypropylene fibers were donated to the team.

Total cost of materials for the mold construction and mix design (listed in the Bill of Materials on page C-1) came to approximately $1,391.73. Monetary contributions to the project accounted for the majority of these costs.

Critical Path: With this being the first year entering the competition, our project schedule was based mainly on our engineering judgment. We broke down the project into key components and established several major milestones. The critical path was determined by following the activities containing no float. The critical path along with the key milestones can be seen on the project schedule (see page 8) of the design report.

With the relatively small size of our team it was sometimes difficult to meet the deadlines established. However, by having a smaller group it enabled us to communicate ideas quicker and more efficiently without causing confusion.

Each milestone marked a necessary step required to creating our finished product. Without completing these significant processes, efficiency would be diminished and construction would be delayed or halted. Table 1 lists the major milestones.

Table 1. Major Project Milestones

Milestone	Delays
Mix Design	--
Structural/ Hydrostatic Analysis	--
Canoe Construction	3 days
Documentation	--

All milestones, with the exception of the canoe construction, were completed on time. Canoe construction was delayed due to a deficiency with a cement mixer. The mixer did not have the proper cycle rate needed to adequately mix the concrete and needed to be replaced with a grout mixer with a higher speed.

Safety: We strictly enforced our safety policy by requiring at least two members to be present at all times during mixing, construction, and any use machinery, and had members working on equipment take a machine shop safety course. We highly regard the responsibility of working safely, using protective equipment, and following OSHA guidelines (OSHA 2011) as critical steps to safely reaching our goal. The MSDS for each material was used to ensure proper use and safety.

Mold Construction: Since our team has no formal knowledge in forming unique shapes like a canoe, we decided to use a female mold in the casting process. As compared a male mold, the female allows for a uniform outer surface that requires modest sanding and gives the ability to replicate the given dimensions while adjusting the thickness. Female molds generally reduce the exterior finishing time because the concrete is placed within the cavity and has a smooth outer surface as compared to the extensive detailing required for male molds. The female mold was also determined to be easier and more cost effective. Considerations had to be taken for the interior of the canoe to make it comfortable for individuals within.

Using the excel sheet provided of the cross sections, 22 AutoCAD drawings were produced. These were then offset to account for the thickness of the materials that were used to form the interior of the mold. They produced design drawings at cross sections located at 309.88 mm (12.2 in.) intervals along the length and used them to create 12.70 mm (0.5 in.) thick plywood templates that were mounted and aligned on a wooden strongback. Plywood was used because of its strength aspect and its ease of finishing. Tempered Hardboard, with a thickness of 3.175 mm (0.125 in.), was cut into 25.4 mm (1.0 in.) and 38.1 mm (1.5 in.) width strips and nailed to the inner surface of the plywood templates. The strips allowed greater definition of the cross section due to the flexibility. The shapes were refined using drywall which assisted in identifying and resolving the discontinuities within the interior. Once the mold was finalized it was clear coated with petroleum jelly and ready for casting.

Canoe Construction: A handheld grout mixer was used to produce our concrete mixtures. This allowed a greater efficiency of quality mixes since we were dealing with very fine aggregates. Four, 0.014 m^3 (0.5 ft^3) batches of our fiber-free mix were created and placed within the mold using trowels. Once the first layer of concrete had been completely placed to

Figure 1: Reinforcement mesh

a thickness of 10.16 mm (0.40 in), the interior was laced with a layer of polypropylene molded reinforcement, placing them in 5.08 cm (2 in.) wide strip sections while aligning them with the axis of the canoe. Prior to the second layer being placed, QUIKRETE® Concrete Bonding Adhesive was brushed onto the reinforcement and first layer to increase the efficiently of the bond between both concrete layers and the mesh. Once the bonding agent was set, four 0.014 m^3 (0.5 ft^3) batches of the second and final layer of concrete, consisting of our fiber mix at the thickness of 10.16 mm (0.40 in), was placed carefully over the mesh to avoid detrimental movement.

During the uncasing phase, some cracking was seen and was filled will additional concrete. Overhanging reinforcement that was still protruding from the gunwale was cut to an appropriate length and covered. Both the interior and exteriors were sanded at this time and filled voids when necessary.

Quality Control: It was essential that we attempted to develop processes for each activity within the project to relate to similar procedures coherent to industry standards. To produce a quality product we had to create an institution of quality assurance to insure minimal waste of materials, a feature rich design and an effective construction process. Our quality relied on planning and extensive communication between members. Extensive scrutinizing of processes such as proportioning materials and mold construction ensure efficiency throughout the casting process.

Innovation & Sustainability

Innovation: Our innovations began the instant the project commenced. No team from The College of New Jersey had ever been involved with this competition prior to this year. Due to this initial fact, every decision made, every batch of concrete mixed, every construction technique was an innovation in and of itself. As far as the canoe is concerned, the first major innovation was creating a concrete light enough to allow the fully loaded canoe to float, and strong enough to hold up to four racers.

Throughout the project, recycled materials and materials produced sustainably were the focus of our mix design.

An additional facet of this year’s project was to lay the groundwork for a team from TCNJ to compete next year. To that end, management and construction skills developed have been passed along to those who have expressed interest, along with skills related to fundraising, recruitment, and quality assurance and control. In addition, previously unknown facts about mold construction and concrete placement techniques have been relayed to potential future team members. The first innovation in our project was the selection of our materials. Blast furnace slag is a cementitious material with reduced density when compared to Portland cement. In addition, a slower setting time meant greater workability when placing the canoe (SCA 2002). The next innovation was the use of free fibers as a secondary reinforcement, which would complement our primary reinforcing layer. The use of polyvinyl alcohol fibers reduced the unit weight of our concrete and improved the behavior of the hardened concrete in flexure. The final major innovation in the mix design was the use of silica fume as a supplementary cementitious material.

Silica fume changes the microstructure of the concrete. Due to the incredibly fine particles, a phenomenon known as particle packing or micro-filling occurs. This reduces the permeability of the mix substantially, even in small portions. In addition, as Portland cement in concrete reacts chemically, calcium hydroxide is released. The fume reacts with this to form additional binder material called calcium silicate hydrate, which is very similar to the binder formed by Portland cement. In addition the silica fume enhances the cohesion of the concrete mix (Silica Fume User's Manual 2011).

The uniqueness of our mold design using four ½” bolts to longitudinally join our strongback which could be disassembled to fit in the bed of a pickup truck with a safe amount of overhang. This feature was added to accommodate refurbishing of the mold.

Sustainability: The idea of sustainability was a major factor in this project. Nearly every aspect of our design, from start to finish, incorporated some degree of sustainability. The concrete mix designed is exemplary of this dedication to sustainability. Apart from Portland cement and our reinforcing materials, every material was recycled or produced sustainably; our two aggregates showcase this excellently. Poraver is made from recycled glass while cenospheres are harvested from the ash ponds produced by coal burning. Also, blast furnace slag is a nonmetallic co-product in the production of iron and steel (NSA 2009). Silica fume is a captured by-product of producing silicon metal using electric-arc furnaces. Our canoe was also placed in a female mold, and concrete that did not hydrate properly was recycled and used in patchwork. These processes nearly eliminated all waste associated with concrete placement.

The design team participated in TCNJ’s commitment to sustainability. TCNJ has signed on to the American College & University Presidents Climate Commitment and is listed in “Guide to 286 Green Colleges” (Princeton Review 2011). To that end, all papers were submitted electronically for review and were only printed when finished, meetings were held on campus and members walked or rode bicycles to attend, and carpooling was used whenever possible. All reports were printed on recycled paper and all communications were through electronic means such as Gmail and Facebook.

Organization Chart

Keith O’Sullivan

Project Manager
Concrete Mix Proportioning
Mold Design
Mold Construction
Concrete Placement
Design Paper

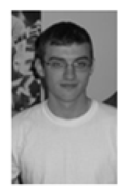
Kevin Morgan

Concrete Mix Materials
Concrete Laboratory Testing
Mold Construction
Concrete Placement
Paddling technique
T-shirts
Design Paper

Oluwaseye Akele

Structural Analysis
Mold Design
Mold Construction
Concrete Placement
Canoe Finishing
Website
Design Paper

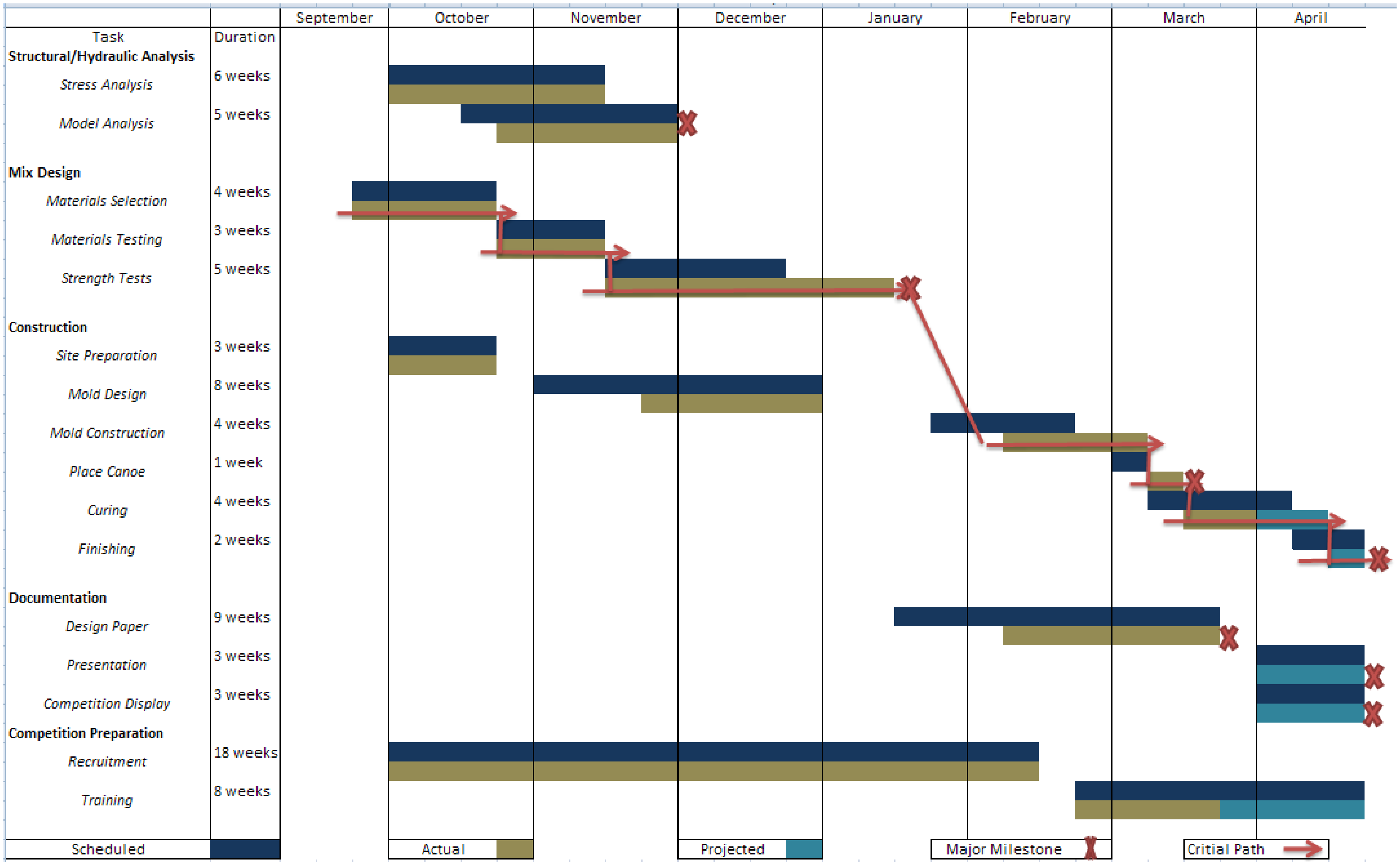
Ryan Havey



Hydraulic Analysis
Mold Construction
Concrete Placement
Canoe transport
Design Paper
Canoe display

Paddling Team: Kevin Morgan, Keith O’Sullivan, Ryan Havey, Oluwaseye Akele, Jackie Ferrara, Nicole Brown, Amanda Hess

Project Schedule



Design Drawing with Bill of Materials

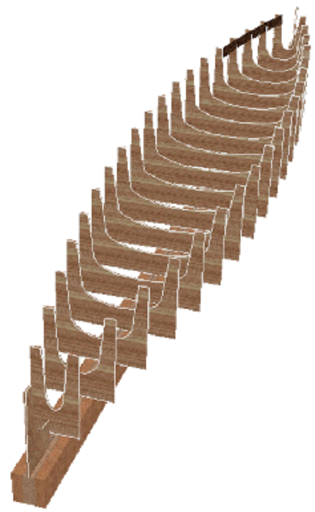
A) The blue line represents the length and width as required by NCCC.

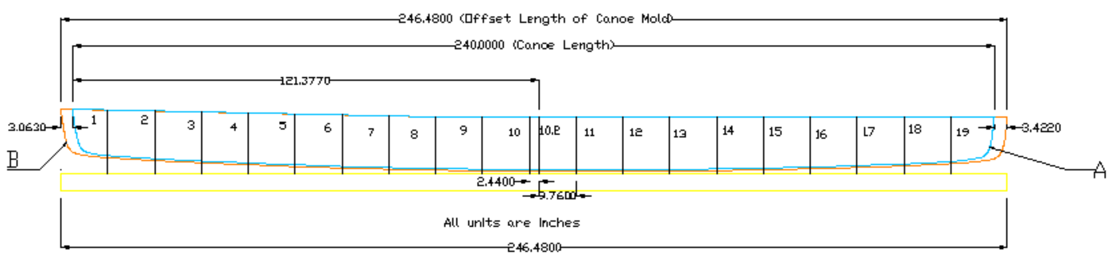
B) The orange line represents the offset dimensions of the mold used to create the correct length and width as specified by NCCC.

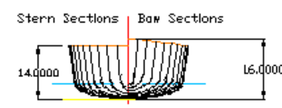
C) The provided sections were enlarged by a scale of 1.016375. This added enough space for the additional thickness of the tempered hardboard strips and drywall leading to a satisfactory requirements based on the NCCC provided dimensions of the canoe.

Material List

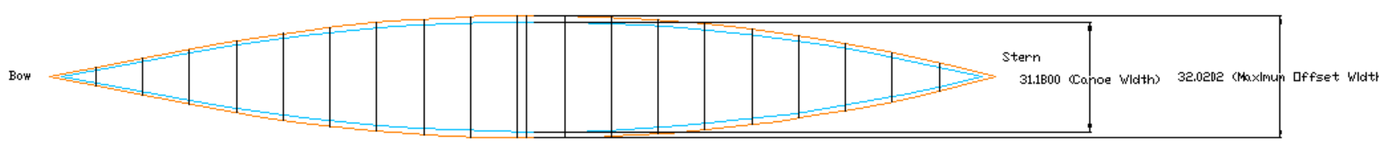
Item	Quanity	Description	Part
1	6	2' x 6' x 10' Lumber	Strongback
2	4	4' x 8' x 1/2" Plywood	Cross Sections
3	4	4' x 8' x 1/8" Tempered Hardboard	Strips
4	1	5 Gallon Bucket of Drywall	Filler
5	4	1/2" x 6" Lag Bolt	Bolt
6	4	1/2" Washer	Washer
7	4	1/2" Nut	Nut
8	1	10-lb Box o 3" Drywall Screws	Screw
9	3	Petroleum Jelly	Clear Coat







Sections Provided by NCCC



TCNJ Concrete Canoe
Canoe Design Sketch

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Appendix B: Mixture Proportions

Table B.1 – Summary of Mix Proportions

Mixture ID: No Fibers (Exterior Surface)				Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3):		1.00						
Cementitious Materials			SG	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Type 1 Portland Cement		3.15	352.66	1.79	14.13	0.07	350.95	1.79
CM2	Granulated Blast Furnace Slag		2.89	445.00	2.47	17.83	0.10	442.85	2.46
CM3	Silica Fume		2.20	41.93	0.31	1.68	0.01	41.73	0.30
	Total Cementitious Materials:			839.59	4.57	33.64	0.18	835.53	4.55
Aggregates									
A1	HG75/400 Cenospheres	Abs: 5.84%	0.58	327.45	9.05	13.12	0.36	325.87	9.00
A2	Poraver (0.5mm - 1.0mm)	Abs: 10.04%	0.47	176.28	6.01	7.06	0.24	175.43	5.98
	Total Aggregates:			503.73	15.06	20.18	0.60	501.29	14.99
Water									
W1	Water for CM Hydration (W1a + W1b)		1.00	293.86	4.71	11.77	0.19	292.44	4.69
	W1a. Water from Admixtures			28.09		1.13		27.96	
	W1b. Additional Water			265.77		10.65		264.48	
W2	Water for Aggregates, SSD		1.00	36.82		1.48		36.64	
	Total Water *(W1 + W2)*:			330.68	4.71	13.25	0.19	329.08	4.69
Solids Content of Latex Admixtures and Dyes									
S1	N/A								
	Total Solids of Admixtures:			0.00	0.00	0.00	0.00	0.00	0.00
Admixtures (including Pigments in Liquid Form)			% Solids	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)	Amount (fl oz)	Water in Admixture (lb)	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)
Ad1	Daravair 1000 (AEA)	*8.34 lb/gal*	5.00	24.00	12.47	8.07	0.50	24.00	12.41
Ad2	Glenium 3030 (HRWR)	*8.51 lb/gal*	20.00	35.00	15.62	11.77	0.63	35.00	15.55
	Water from Admixtures *(W1a)*:				28.09		1.13		27.96
Cement-Cementitious Materials Ratio				0.42		0.42		0.42	
Water-Cementitious Materials Ratio				0.35		0.35		0.35	
Slump, Slump Flow, *in.*				1.50		1.50		1.50	
M	Mass of Concrete. *lbs*			1674.00		67.07		1665.90	
V	Absolute Volume of Concrete, ft^3			24.33		0.98		24.22	
T	Theoretical Density, lb/ft^3 = *(M / V)*			68.79		68.79		68.79	
D	Design Density, lb/ft^3 = *(M / 27)*			62.00					
D	Measured Density, lb/ft^3					61.70		61.70	
A	Air Content, % = *[(T - D) / T x 100%]*			10.95		11.49		11.49	
Y	Yield, ft^3 = *(M / D)*			**27**		1.09		**27**	
Ry	Relative Yield = (Y / Y_D)					0.0403			

Table B.1 – Summary of Mix Proportions

Mixture ID: Free Fibers (Core)					Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3):			1.00						
Cementitious Materials				SG	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Type 1 Portland Cement			3.15	352.34	1.79	14.13	0.07	350.64	1.78
CM2	Granulated Blast Furnace Slag			2.89	444.61	2.47	17.83	0.10	442.45	2.45
CM3	Silica Fume			2.20	41.89	0.31	1.68	0.01	41.69	0.30
	Total Cementitious Materials:				838.84	4.56	33.64	0.18	834.78	4.54
Fibers										
F1	3/4" Polypropylene Fibers			0.91	1.50	0.03	0.06	0.00	1.49	0.03
	Total Fibers:				1.50	0.03	0.06	0.00	1.49	0.03
Aggregates										
A1	HG75/400 Cenospheres	Abs:	5.84%	0.58	327.16	9.04	13.12	0.36	325.57	9.00
A2	Poraver (0.5mm - 1.0mm)	Abs:	10.04%	0.47	176.12	6.01	7.06	0.24	175.27	5.98
	Total Aggregates:				503.28	15.04	20.18	0.60	500.84	14.97
Water										
W1	Water for CM Hydration (W1a + W1b)			1.00	293.59	4.71	11.77	0.19	292.17	4.68
	W1a. Water from Admixtures				28.07		1.13		27.93	
	W1b. Additional Water				265.53		10.65		264.24	
W2	Water for Aggregates, SSD			1.00	36.79		1.48		36.61	
	Total Water *(W1 + W2)*:				330.38	4.71	13.25	0.19	328.78	4.68
Solids Content of Latex Admixtures and Dyes										
S1	N/A									
	Total Solids of Admixtures:				0.00	0.00	0.00	0.00	0.00	0.00
Admixtures (including Pigments in Liquid Form)				% Solids	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)	Amount (fl oz)	Water in Admixture (lb)	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)
Ad1	Daravair 1000 (AEA)	*8.34*	*lb/gal*	5.00	24.00	12.46	8.07	0.50	24.00	12.40
Ad2	Glenium 3030 (HRWR)	*8.51*	*lb/gal*	20.00	35.00	15.61	11.77	0.63	35.00	15.53
	Water from Admixtures *(W1a)*:					28.07		1.13		27.93
	Cement-Cementitious Materials Ratio				0.42		0.42		0.42	
	Water-Cementitious Materials Ratio				0.35		0.35		0.35	
	Slump, Slump Flow, *in*.				1.50		1.50		1.50	
M	Mass of Concrete. *lbs*				1674.00		67.13		1665.90	
V	Absolute Volume of Concrete, *ft^3*				24.34		0.98		24.22	
T	Theoretical Density, *lb/ft^3* = *(M / V)*				68.78		68.78		68.78	
D	Design Density, *lb/ft^3* = *(M / 27)*				62.00					
D	Measured Density, *lb/ft^3*						61.70		61.70	
A	Air Content, *%* = *[(T - D) / T x 100%]*				10.93		11.47		11.47	
Y	Yield, *ft^3* = *(M / D)*				**27**		1.09		**27**	
Ry	Relative Yield = *(Y / Y_D)*						0.0403			

Appendix C: Bill of Materials

	Concrete Canoe Budget Plan					
Item #	Category	Unit	Quantity	Cost per Unit	Subtotal	
	Concrete Materials					
	Cement					
1	Portland Cement - Type 1	lb	75	$0.12	$9.00	ok
2	Blast Furnace Slag	lb	150	$0.01	$1.50	ok
3	Silica Fume	lb	10	$1.32	$13.20	ok
	Aggregates					
4	HG75/400W Cenospheres	lb	150	$2.00	$300.00	ok
5	Poraver 0.5mm - 1.0mm	lb		$0.70	$46.20	ok
6	M70 ¾" Cut Monofilament Fibers		1	$20.00	$20.00	
	Admixture		Per 16 oz.			
7	Daracem 65 (HRWR)	16 oz.	5	$30.00	$150.00	
8	Daravair 1000 (AEA)	16 0z.	5	$35.00	$175.00	
9	Polypropylene Free Fibers					
10	Polypropylene Molded mesh	ft	8*40	6.15 per sq. ft	$246.00	ok
11	Quickcrete Bonding Adhesive	1 gallon bottle	1	$15.00	$15.00	
	Concrete Materials Subtotal				**$975.90**	
	Mold Construction					
	Mold Construction Cost Total				**$291.83**	ok
	Canoe Finishing					
30	paints	gallon	2	$50.00	$100.00	ok
31	Sikagard Penetrating Sealer	gallon	1	$24.00	$24.00	
	Total				**$1,391.73**	