1 Introduction ............................................................................................................................... 2
2 Rules for Materials .................................................................................................................. 3
  2.1 Materials in Concrete Mixtures ......................................................................................... 3
  2.2 Canoe Reinforcing Materials ............................................................................................ 5
3 Materials Used ........................................................................................................................ 7
  3.1 Cementitious Materials ..................................................................................................... 7
  3.2 Aggregate Materials .......................................................................................................... 8
  3.3 Admixtures .......................................................................................................................... 9
  3.4 Stains & Sealers .................................................................................................................. 9
4 Mixture Development ............................................................................................................. 10
5 Tests Performed ..................................................................................................................... 11
  5.1 Cubes ................................................................................................................................ 11
  5.2 Wet Concrete ...................................................................................................................... 11
  5.3 Panels ................................................................................................................................ 11
  5.4 Expansive Beams .............................................................................................................. 13
6 Mixture Results ....................................................................................................................... 14
  6.1 Outer Mixture ................................................................................................................... 14
  6.2 Middle Mixture ................................................................................................................ 15
  6.3 Inner Mixture ................................................................................................................... 16
  6.4 Patching Mixture ............................................................................................................. 17
  6.5 Inlay Mixture ................................................................................................................... 18
7 Panel Testing Results (Wall thickness) .................................................................................. 19
8 Drying and Sealer Testing Results ........................................................................................ 21
9 Beam and Reinforcement Results ......................................................................................... 22
10 Conclusion ............................................................................................................................. 23

List of Tables
Table 1. Summary of Outer Mixture Designs and Test Results...................................................... 14
Table 2. Summary of Middle Mixture Designs and Test Results..................................................... 15
Table 3. Summary of Inner Mixture Designs and Test Results. ...................................................... 16
Table 4. Summary of Patching Mixture Design and Test Results................................................... 17
Table 5. Summary of Inlay Mixture Designs and Test Results......................................................... 18
Table 6. Summary of Load-Deflection Panel Testing Results.......................................................... 19
Table 7. Material Selections and Key Properties. ........................................................................ 23

Table of Figures
Figure 1. Ideal Load-deflection Curve for Single-Point Loading Panel Test. ..................................... 13
Figure 2. Results for Load-Deflection Panel Testing with Mixtures U, V, and AA. ............................ 19
Figure 3. Results for Load-Deflection Panel Testing with Mixtures U, W, and AB. ........................... 19
Figure 4. Results for Load-Deflection Panel Testing with Mixtures AD, AE, and AG in Form Up Configuration. ............................................................................................................. 20
Figure 5. Results for Load-Deflection Panel Testing with Mixtures AD, AE, and AG in Form Down Configuration. ............................................................................................................. 20
Figure 6. Results of Sealer Testing: Weight vs Time Submerged .................................................... 21
Figure 7. Results of Beam Testing: Microstrain vs Time. .............................................................. 22
1 INTRODUCTION

Class Summary

CEE 428 created a space for developing and testing lightweight concrete mixtures, reinforcement, sealers, and placing techniques for use in the 2014 ASCE concrete canoe competition. The goal of this class was to create quality concrete mixtures and select materials and procedures that optimized canoe performance. We primarily focused on development of the concrete mixtures. This involved altering the mixtures’ ingredients and proportions in order to adjust the concrete’s physical properties, including buoyancy, strength (compressive and flexural), workability, and aesthetics, while still following the competition rules.

The two primary mixtures used in last year’s competition served as baselines for the 2014 mixture designs. Major changes implemented this year included refining the aggregate gradations, altering the paste content and water/cement ratio, and incorporating an additional mixture in the cross-section. The third structural mixture was added in the hopes of lowering the specific gravity of the boat by creating a lighter-weight mixture for the interior surface of the canoe.

The time-limited nature of this course represented the most significant constraint on the scope of work performed. With a start date of September 25th and a placing day set at November 23rd, we worked for nine weeks to reach our goals for the mixtures. Each week, we met for a total of four hours: one hour discussing the mixture changes for that week and three hours mixing and testing the concrete. In addition, each person spent approximately 1-2 hours outside class each week individually analyzing data, performing extra testing, or preparing information for the following week’s mixtures.

In total, we created 32 concrete mixtures. We measured and tested each mixture to determine relevant data about the concrete, including its specific gravity, compressive strength, flexural strength, and shrinkage. We also tested the strength of the reinforcing material that we used between the layers of concrete. This data allowed us to extrapolate performance of a concrete canoe constructed from such materials, based on the typical stresses developed in a canoe with two to four paddlers. From the extrapolated performance, we determined which mixtures to include in the final design of this year’s concrete canoe.

Student Contributions

Each student in the class contributed significantly to the project. Everyone assisted with the weekly mixing, placing, and testing, but also took individual leadership roles in the following ways:

- **Stuart Kretzschmar** directed the mixture development and analyzed overall testing results.
- **Fabia Fu** researched competition rules and regulations and organized student roles.
- **Abbey Trautman** tested stains and sealers and selected which ones to use for the canoe.
- **Samuel Dougherty** measured shrinkage and tested reinforcing materials.
- **Connor Lester** performed flexural testing and analyzed the data.
- **Stetson Shearer** led compressive strength testing and analysis of related data.
- **Daniel Ullom** organized weekly testing data into clear and useful tables.
- **Jamie Shinsato** oversaw data acquisition and organization of the lab notebook.
- **Laura Moser** managed compilation of the technical report.
2 Rules for Materials

The following rules are copied from the 2014 ASCE Concrete Canoe Competition Rules and Regulations

2.1 Materials in Concrete Mixtures

I. Applicable general ASTM references are as listed below:
   - Terminology (C125)
   - Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete (C309)
   - Performance Specification for Hydraulic Cement (C1157)
   - Liquid Membrane-Forming Compounds Having Special Properties for Curing and sealing concrete (C1315)

II. Cement Materials. Included are the applicable ASTM references and limiting material properties of various cementitious materials.
   - 3.1: ASTM References
     - Portland Cement (C150)
     - Blended Hydraulic Cements (C595)
     - Coal Fly Ash and Raw or Calcined Natural Pozzolan (C618)
     - Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars (C989)
     - Silica Fume as a Mineral Admixture in Hydraulic Cement Concrete, Mortar, and Grout (C1240)
   - 3.1.1.1: Hydraulic Cement Shall meet the requirements of ASTM C 150, ASTM C 595 and/or ASTM C 1157, and shall react with water to form a binder.
   - 3.1.1.2: Fly Ash shall meet the requirements of ASTM C 618, Class C or Class F, except the loss-on-ignition should not to exceed 3%.
   - 3.1.1.3 Metakaolin shall meet the requirements of ASTM C 618, Class N.
   - 3.1.1.4 Slag Cement shall meet the requirements of ASTM C 989, Grade 100 minimum.
   - 3.1.1.5 Silica Fume shall meet the requirements of ASTM C 1240.
   - 3.1.1.6 Other Cementitious Materials
     - Other secondary cementitious materials and pozzolans, such as but not limited to vitreous calcium aluminosilicate (VCAS™) are permitted. Teams wishing to incorporate a given material as a cementitious material/pozzolan and having questions or concerns of whether it is an acceptable material shall contact the CNCC via e-mail for a determination of its applicability.

III. Fibers: Includes the required compliance with ASTM C 1116.
   - 3.1.2 Fibers shall meet the requirements of ASTM C 1116 and shall be dispersed within the concrete matrix.

IV. Admixtures: Includes applicable ASTM references and required properties and limiting admixtures that can be used. Also specified are coloring additives for aesthetic purposes.
   - 3.1 ASTM References
     - Air-Entraining Admixtures (C260)
     - Chemical Admixtures for Concrete (C494/C494M)
     - Pigments for Integrally Colored concrete (C979)
Latex and Powder Polymer Modifiers for Hydraulic Cement Concrete and Mortar

3.1.3.1 Water—Reducing (Normal, Mid-Range, and High-Range) and Set-Controlling Admixtures shall meet the requirements of ASTM C 494.

3.1.3.2 Air-Entrained Admixtures shall meet the requirements of ASTM C 260.

3.1.3.3 Coloring Admixtures/Agents and Concrete Pigments shall meet the requirements of ASTM C 979.

3.1.3.4 Polymer Modifier shall be a latex or re-dispersible powder formulated for use with hydraulic cements that meets the requirements of ASTM C 1438, Type II and, if warranted, shall be accounted for in the mass and volume calculations during mixture proportioning to ensure proper yielding of the concrete mixtures.

3.1.3.5 Specialty Admixtures, such as but not limited to, shrinkage reducers, integral capillary waterproofers (see Section 3.1.3.5.1) and viscosity-modifying admixtures, currently do not have ASTM standards. The use of these admixtures is not prohibited. Teams may use commercially-available specialty admixtures specifically formulated for concrete in their mixtures and do not need to receive pre-approval from the CNCCC. Epoxy resins (such as acrylic, phenolic, and polystyrene resins), their curing agents, asphalt emulsions, or similar materials shall not be considered as specialty admixtures and are strictly prohibited. Teams wishing to incorporate a material as a specialty admixture that is not commercially-available or specifically made for use in concrete and have questions or concerns of whether it is an acceptable material shall contact the CNCCC via e-mail for a determination of its applicability.

3.1.3.5.1 Integral Capillary (Waterproofing) Admixtures are typically comprised of materials including cement and sand and are used in low dosages. Although they are considered admixtures in the concrete industry, teams shall consider them as part of the cementitious materials content (Section 3.1.1) for the purpose of completing the Concrete Mixture Design Table (Table 3.1). These waterproofers are not considered pre-packaged cement, mortar or grout. They shall be considered as an admixture in the report and oral presentation.

V. Other Requirements: These requirements involve the mass of cementitious materials, volume limits for aggregate proportioning, water-cementitious ratio and solids content, determination of unit weight, and curing.

3.2.1 Mass of Cementitious Materials: All concrete mixtures must contain hydraulic cement meeting the requirements of Section 3.1.1.1. The minimum amount of hydraulic cement (c) is 30% (by mass) of the total cementitious materials (cm) content in any given concrete mixture (e.g., c/cm ratios shall be 0.30 or greater for any given concrete mixture). Any one type (or mixture of various types) of hydraulic cement(s) may be used but each type has to be in compliance with the requirements of Section 3.1.1.1.

3.2.2 Aggregate Proportioning: the aggregate(s) selected shall constitute a minimum of 25% of the total volume of any concrete mixture (based on yielded proportions). This volume percentage is to be calculated based on aggregates in the oven-dry condition. The total amount of aggregate used in concrete mixtures may vary from one mix to another; however, each mixture must contain minimum 25% of aggregate by volume.

3.2.3 Water/Cementitious Material (w/cm) Ratio and Solids Content: There is no limit on the w/cm ratio. The water content of the all admixtures shall be taken into account for the w/cm ratio using the following equation:

\[
\text{Water in admixture} = \text{dosage} \times \text{cwt of cm} \times \text{water content} \times (\text{1gal/128fl oz}) \times (\text{lbs/gal of admixture})
\]

where cwt of cm = hundred weight of cementitious material (example, 800 pcy of cm is equal to 8 cwt)
For the competition, latex, dyes solids, and admixtures in powder form are to be accounted for in the determination of solids content. Disregard the contribution of solids from other admixtures such as air-entrainers, water reducers, shrinkage reducers and viscosity-modifiers. The solids content are to be computed using the following equation:

$$\text{Solids in admixture} = \text{dosage} \times \text{cwt of cm} \times \text{solid content} \times \left(1 \text{ gal/128 fl oz}\right) \times \left(\frac{\text{lbs/gal of admixture}}{\text{lbs/gal of admixture}}\right)$$

- **3.2.4.1 Wet (Plastic) Unit Weight:** The unit weight of the concrete mixtures(s) is based on the reported unit weight under the Yielded Proportions of Table 3.1. Refer to ASTM C 138 for the determination of the fresh unit weight of concrete. Each concrete mixture must meet this requirement. It is understood that the concrete placed on the canoe may be denser than the unit weight determined per ASTM C 138 due to method of placement. Report the value obtained per ASTM C 138.

- **3.2.4.2 Dry Unit Weight:** The dry unit weight of the concrete mixtures(s) is to be based on oven-dried conditions. Once concrete cylinders have been properly set and cured (times to be determined by the teams), representative samples should be oven-dried to remove all moisture from the sample. It is recommended that the samples be dried for a period of no less than 24 hours at a temperature not to exceed 250 degrees F. Once dried, the samples must be protected in order to prevent from absorbing any moisture (plastic wrap).

- **3.2.5 Curing Concrete** shall be cured after placement and finishing using an appropriate curing method. Liquid membrane-forming compounds for curing concrete that are certified to meet the requirements of either ASTM C 309 or ASTM C 1315, with a volatile organic content (VOC) less than or equal to 350 g/L and stated as such on the product data sheet, may be applied to any portion of the canoe at the discretion of the team. Equivalent products may be submitted to the CNCCC for consideration as an approved equal. The application of either a curing compound or curing and sealing compound to any portion of the canoe shall be limited to a maximum of two (2) coats following the manufacturer’s recommended procedure for application and thickness.

### 2.2 Canoe Reinforcing Materials

I. **3.1 ASTM References:** Fiber-Reinforced Concrete and Shotcrete (C1116)

II. **Reinforcement Requirements**

- **CNCCC Intent** - The intent of this section is to provide the specifications for the various materials that teams may use to serve as the primary reinforcement in their concrete canoe. In general, teams are permitted to develop a reinforcement scheme that (a) uses materials that contain sufficient open space measured in terms of percent open are (POA), (b) the total thickness of the reinforcing layers is equal to or less than 50% of the total thickness of the reinforced concrete composite, and (c) the reinforcing materials do not have post–manufacturer applied coatings that enhance the properties of the reinforcement.

- **General:** All reinforcement shall be covered in concrete. All material not part of a concrete mixture shall be classified as reinforcing material and shall comply with all of the specifications outlined below. This does not apply to materials that are used for flotation purposes.

- **4.1 References:** The publications listed below form part of this specification to the extent referenced. The latest version of each standard shall govern wherever referenced. The publications are referred to in the text by basic designation only.

  ASTM C 1116 Standard Specification for Fiber–Reinforced Concrete and Shotcrete
4.2 Materials: 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. The determination of sufficient open space of the reinforcement is measured by percent open area (POA) as defined in Section 4.3.2. Solid mats or plates for reinforcing are not permitted. Solid mats and plates are described as reinforcing materials that require additional bonding agents or post–manufacturer perforations to keep the reinforcement from delaminating from the concrete composite (i.e., there is a lack of open space between the reinforcement sufficient for mechanical bonding to the concrete composite). Fibers that are dispersed within the concrete matrix to improve the tensile and flexural characteristics of the concrete (ASTM C 1116) are considered as serving as secondary reinforcement and therefore are not subject to the measurements listed in Section 4.3. Fibers shall not be considered an aggregate in any concrete mixture.

4.3.1 Thickness: The thickness of a layer of reinforcing is defined as follows: a single layer of the reinforcing is to be placed on a flat surface, a piece of plate glass, 6 mm (1/4") or thinner, is to be placed on the reinforcing, the distance from the bottom of the plate to the top of the supporting flat surface is the thickness of a single layer. When subjected to the weight of the glass alone, the sum of all such measured thickness divided by the total thickness of the canoe wall or structural element (prior to staining or sealing) at any point in the canoe shall not exceed 50%. All canoe elements, including but not limited to, walls, ribs, gunwales, thwarts, bulkheads, etc., and the connections of structural elements to the canoe wall are subject to this rule. If individual rods or reinforcing bars are used in such a way that they cross each other, this use constitutes at least two (2) layers of reinforcing.

4.3.2 Percent Open Area: The minimum percent open area (POA) of any layer of reinforcing material is 40%. The determination of the POA of a particular reinforcement is obtained by using the following equation:

\[
POA = \frac{\sum Area_{open}}{Area_{total}} \times 100\%
\]

where: \( Area_{open} \) is the total open area (i.e., the area of the apertures)\n\( Area_{total} \) is the total area of the reinforcement specimen

Depending on the size of the reinforcing material and apertures, magnification of the sample may be required. Magnification could be accomplished with the use of a photocopier, projecting it onto a wall with the use of an overhead projector, or digitizing an image of the sample. Values of areas, thicknesses and any other measurements needed to compute the POA may be obtained from direct measurements (using applicable methods and tools), values provided by manufacturer, or combination of the two. Figure 4.1 provides a sample calculation of POA.

Teams are permitted to modify a given mesh by removing strands as needed in order to achieve the required POA. However, once fabricated, teams are not permitted to treat the material (e.g., apply coatings or heat).
3 MATERIALS USED

3.1 CEMENTITIOUS MATERIALS

Gray Portland Cement
Portland cement is the essential component of the cement paste that provides the strength of concrete, as well as holds the concrete together. The purpose of using gray-colored Portland cement was to distinguish the middle layer from the outer and inner layers during placing day. Iron and other metal oxides produce the gray color in gray Portland cement. Initially, gray Portland cement was a component of the tested middle mixture. However, due to a batching error while placing the canoe, white Portland cement was used instead.

White Portland Cement
Besides the metal oxides, white Portland cement contains the same properties and contents as gray Portland cement. White cement was used cosmetically to enhance the colors of the stains and pigmented concrete on the canoe. The inner, outer, middle, inlay, and patching mixtures all contain white Portland cement.

Metakaolin
Metakaolin is a by-product of clay processes. It is a pozzolan with an off-white color, and is a relatively fine material (10μm or less in size). The fineness of metakaolin allows for more particle packing (by extending the particle gradation curve in the finer direction), which helps increase the final concrete strength. It is usually used as a replacement for silica fume, because it is cheaper and whiter, improving aesthetic quality. For these aesthetic and economic reasons, as well as improvement to the particle gradation curve, metakaolin was included in the outer, inner, middle, inlay, and patching mixtures.

Slag Cement
Ground blast furnace slag, or slag cement, is a by-product form iron manufacture process. It is considered a replacement for cement, and is known for slowing the early rate of hydration, which enhances the long-term concrete strength. For the 2014 mixture designs, slag was combined with Portland cement for enhanced strength. Use of slag is also environmentally conservative as it is a by-product of manufacturing processes, and would otherwise be wasted. Slag is used in the outer, middle, inner, inlay, and patching mixes.

CTS Komponent (Expansive K)
CTS Komponent additive serves a fairly unique purpose in the mix design. CTS Komponent consists of Portland cement clinker as well as expansive clinker. Because of its expansive properties, this additive acts as a pre-stressing agent in the concrete. It aids in reducing the tension stress and improving crack resistance in concrete, and also establishes a better bond with the reinforcement. CTS Komponent is used in the outer, middle, inner, inlay, and patching mixtures.

Fly Ash
Fly ash is a pozzolan collected from solidified exhaust gasses from manufacture processes. It is a tannish-brown color, and was not used for the mix design. It was considered because of improved workability, and ease of finishing, as well as strength increase. Fly ash is very similar to metakaolin except for the brownish color. For the aesthetic purposes, metakaolin was used instead.
3.2 Aggregate Materials

Elemix
ELEMIX is a concrete additive made up of lightweight synthetic particles. With a particle diameter of 1-2mm, ELEMIX can replace a significant volume and weight of traditional aggregate with extremely low-density material. It also reduces price of the mixture, because it costs far less volumetrically than alternatives such as Poraver. However, ELEMIX also has low strength properties, contributing very little to the structural integrity of the canoe. ELEMIX was therefore only included in the middle mixture, which required both the lowest specific gravity and lowest strength.

Poraver
Poraver expanded glass granulate is a lightweight aggregate that consist of recycled glass. To form Poraver, broken glass is crushed then expanded to create glass spheres of specific sizes. The availability of different sizes allows for greater control over aggregate gradation, while the glass shell provides a stronger aggregate than ELEMIX. The 2014 mixture designs used three Poraver diameter ranges: 0.5-1 mm, 0.1-0.3 mm, and 0.5-0.25 mm. Because of its wide variety of sizes, relatively high strength, and light weight, Poraver is the main component of the aggregate for all mixture designs.

Fiber
Chopped fiberglass fiber is used to help reduce the cracks in the concrete. With a length of approximately one inch, these fibers help prevent minor cracking by increasing the concrete’s ability to resist tension at a small scale. This material was only added to the middle mix, so that fibers would not be exposed on the outside of the canoe and cause unpleasant aesthetics and difficulties in stain and sealer application.

Aggregate Blending
This year’s mixtures were all designed to be dense and well-graded concrete mixtures, in order to maximize the strength properties for a given combination of aggregate. For each mixture, aggregate proportions were iterated until they approached the following gradation equation:

\[
% \text{Passing} = \left( \frac{d - d_o}{D - d_o} \right)^{0.45}
\]

(where \(d\) is minimum aggregate diameter, \(D\) is maximum aggregate diameter, and \(d_o\) is the diameter of the aggregate size being examined). This equation is derived from the Federal Highway Administration’s 0.45 power curve for maximum density.
3.3 Admixtures

Latex
Polymer based latex was used to create a sealed and impervious concrete. Polymer based latex is also known to increase bond strength between the aggregate within the mixture, which results in an increase in flexural strength and tensile strength. Latex was included in the outer, inner, middle, inlay, and patching mixtures.

Daravair
Daravair is a liquid air-entraining admixture that increases the amount of air voids in the concrete. This results in a lower density concrete, increasing the buoyancy of the canoe. The air that is entrained into the concrete during the mixing process additionally acts as flexible ball bearings, thereby increasing the plasticity and workability of the concrete. This increased workability allows for a lower water content, which can further lower density of the mixture. Daravair also reduces bleeding, plastic shrinkage and segregation. Daravair was used only in our inner mixture design.

Rheocell
Rheocell is a foaming agent that produces stable air voids for a low-density concrete mixture. It essentially acts similar to the Daravair, but Rheocell creates a higher void ratio and therefore a lighter-weight concrete. Like Daravair, Rheocell also reduces bleeding and segregation while increasing workability. Rheocell is a highly concentrated product was only used in the middle mixture.

Pigments
Pigments were added to concrete mixes to give color to the finished concrete. Rather than just painting the exterior of the concrete, the pigment would give a different feel of the color. During Testing with the pigments, different colors absorbed different amounts of water. Workability became an issue as well as the compressive strength due to desegregation.

3.4 Stains & Sealers

Stains
Lithochrome Tintura Stain is a penetrating, water based system designed specifically to stain concrete. The stains contain low VOC and is claimed by the maker to be a green building material which may earn LEED credits. Five shades of the stain were donated and used: Black, Mustard Yellow, Pink Dawn, Vivid Violet, and Zenith Blue.

Sealers
The sealer used is ProtéShield Elastomeric Waterproof Sealer, a water-based modified polymer coating designed to penetrate and seal concrete surfaces. This product was chosen because there was an abundance of it left over from last year, allowing the team to obtain it at no cost.
4 Mixture Development

Mixture development focused primarily on decreasing the specific gravity and increasing reliability of the concrete while maintaining adequate strength and good workability. Through refining the aggregate gradations, altering the paste content and water/cement ratio, and incorporating an additional mixture to the cross-section, the team improved upon last year’s mixtures to optimize the concrete’s engineering properties.

Last year, the cross-section of the canoe incorporated only two primary concrete mixtures. This year we designed a cross-section with three layers in the hopes of imparting more targeted stress resistance throughout the canoe. This involved first increasing the strength of the middle mixture. However, by making the middle mixture stronger, it also became denser, creating the need for a new inner mixture to make up for this increase in weight. The inner mixture was designed to have similar engineering properties as the outer mixture, but with a lower specific gravity.

The two primary mixtures used in 2013 served as baselines for the development of the three structural mixtures designed this year. Due to the similar strength and weight requirements for the inner and outer mixtures, the 2013 outer mixture provided an adequate baseline for both the outer and inner mixtures this year. But with a 28-day compressive strength of 2975psi, the 2013 outer mixture exhibited excess strength, indicating an opportunity for increasing efficiency in the 2014 mixtures. Since the 2013 middle mixture behaved satisfactorily in competition, it served as the baseline for this year’s middle mixture. However, internal cracking exhibited by last year’s canoe indicated an opportunity for increasing strength in the middle mixture in order to create a more structurally robust boat.

Each week, the team isolated properties of each mixture to alter and test. The first step was to create a more accurate aggregate gradation for the mixtures by changing proportions until the mixtures had the desired gradation (as described in “Aggregate Blending”, pg 8). The next iterations involved changing the water-cement ratios and paste percent in order to create mixtures that were workable while still as strong as possible. Finally, changes to latex were made to improve bonding between the different layers when placed in the canoe. All selected batches were then made mixed and tested twice more to check for consistency, once before placing day and once after placing day.
5 Tests Performed

5.1 Cubes

Cubes were made to evaluate numerous characteristics of the finished concrete. With the 2” x 2” x 2” cubes we were able to accurately measure the weight, exact measurements and finding the resulting dry density. After finding the density we were able to compare these cubes with other mixtures on a common dimension. These cubes also allowed for different testing procedures such as compressive strength at different time intervals. 12 cube samples were made from each mix with varying curing conditions, wet curing, oven curing, and varying curing times (7, 14, and 28 days). After testing the compressive strength using the Tinius Olsen machine, we were able to quantify the compressive strength results by following the procedures described in ASTM C 109.

5.2 Wet Concrete

It was imperative that we controlled our mixing procedure to allow for the most consistent results possible. The mixing procedure had a specific ingredient order as well as timed durations for two different mixing speeds. These Procedures are described in ASTM 305. Following the mixing procedure we visually noted the concrete’s physical properties.

We then quantified these characteristics by following the procedures described in ASTM C 1437-13. This procedure allowed us to analyze the fluidity of the mix and quantify the flow characteristics. This test was computed at different time intervals (1 minute, 15 minutes and 30 minutes) to relate the flow properties and the speed of curing. Comparing these values when ultimately choosing the final mix designs gave us the ability to choose a mix that will stay workable long enough to be placed into the foam canoe mold.

We also calculated the Density of the wet concrete following the procedures described in ASTM C 188-1. This was a very important aspect of the testing procedures, because the contest rates each canoe by weight. The lighter the mixture design, the more advantageous that mixture would be to use in our ultimate design.

5.3 Panels

Purpose

The compressive strengths found through cube tests only show how the canoe will fail in compression, but the largest stresses in the canoe during the competition will most likely be due to applied moments (both from the distributed load of the water and point load of the racers inside). The panel testing allowed for better analysis of these moments. We tested sixteen panels during design, and used data from these tests to choose the preferred wall thickness and mixture selections for the canoe. Each test yielded a load-deflection curve that allowed us to determine the elastic modulus of an uncracked section, the flexural strength (first crack stress), the flexural stiffness after cracking had occurred, and the residual strength remaining in a the member. The tests also provided a visual of the behavior of the panel, from initial cracking to yielding of the tension steel to ultimate failure of the panel, allowing us to make assumptions about how the member would fail in the field.
The elastic modulus will help us perform a thorough analysis of the canoe’s response to loading conditions placed upon it during the competition. The flexural strength is important in determining if the canoe will be able to sustain competition conditions without cracking. The flexural stiffness will act as a section modulus, giving us insight into the behavior of the member after cracking, when we can no longer reliably calculate the moment of inertia. The residual stress will help quantify the additional load a panel can support after the initial cracking. It will also help to compare the long term loading effects of panels with different compositions and thicknesses.

Understanding the behavior of the panel leading up to failure is integral in determining the durability of the canoe (Will the canoe fail because of delamination between layers and can this issue be solved during construction? Will the canoe fail suddenly after the first crack or remain structurally sound until the reinforcing ruptures?). This will aid in determining the best course of action when making repairs during the competition. The panels were created during the last stages of design in order to test how the final mixtures would act together when placed in their intended order (outer, middle and then inner mix) and properly reinforced. The sixteen panels tested included eight varying designs (thickness and composition) and allowed to test each panel type in a form up and form down configuration to see flexural response of both the inner and outer mix being in tension and compression.

Making the panels
The panels were made using 245 by 100 mm molds at varying thicknesses of 12, 15 and 18 mm. The panels were layered in the same process intended for the canoe. First a thin layer of outer mix was poured and smoothed into the mold. A rectangular cut of reinforcing was gently pressed into the outer mixture; the dimensions of the reinforcing allowed for approximately 1/8th of an inch cover on each end of the panel. The outer mix was placed as flat as possible to improve uniformity. Next, a layer of middle mix was placed over the outer mix. After the panel was allowed to cure for 2 hours a second piece of reinforcing was added and a final layer of inner mix was placed to match the approximate thickness of the outer layer. The entire panel was a demolded after approximately 24 hours and placed in a moisture room where it cured for 6 days before testing. Reference: ASTM C192/192M-07

Testing
In order to test each panel we took a modified approach to the ASTM C1018-97, utilizing a single-point loading method instead of third-point loading. The testing apparatus included a linear variable differential transformer or LVDT, which was capable of recording a change in deflection as a reading of millivolts or mV. It also included a load-spring which recorded a mV reading in place of the applied load. Before and after each test each device was calibrated by performing controlled tests of the LVDT and load-spring, recording the results and using the data to form linear curves whose slopes allowed a conversion between mV and the respective value (inches for linear deflection and pounds for applied load). This test was performed before and after so that any changes in the recording devices during tested would be accounted for. The testing of each panel consisted of placing the panel on two pin-like supports (to ensure near-zero moments) spaced 3 inches from the center of panel. The load was applied to the center of the panel at a constant rate until complete failure in the tension reinforcement occurred. Measurements were then taken of the depth of the tension reinforcement to allow for calculation of tensile strength. Lastly, each panel was examined for the type of failure, be it delamination of layers or rupture of the tensile reinforcing.
Figure 1 represents an ideal load-deflection curve. Deflection is located on the x-axis while the applied load is located on the y-axis, despite load being the independent variable during testing. This is to show how stress builds up in a member during deflection. The first crack area before the first crack load represents the elastic region of the curve where the moment of inertia is calculable and the elastic modulus is constant. The region afterwards is where the panel begins cracking in tension and the tension reinforcement yields and eventually fails. Also labeled are the deflection points associated with the toughness indices, intermediate values necessary for calculation of residual strength. Reference: 
ASTM C1018 – 97

5.4 EXPANSIVE BEAMS

Concrete invariably shrinks as moisture evaporates out during the curing process, a process called drying shrinkage. To test the magnitude of drying shrinkage for our mixtures, we made beams and tested them periodically to measure the change in length. Testing the shrinkage also allowed us to determine any strain imposed on the reinforcement due to expansion. Understanding the amount the reinforcement will strain before its full strength is mobilized is critical for knowing whether or not there will be any prestressing in the concrete from the expansive K and the reinforcement. We made two beams, one with expansive K (R) and one without (Q). A third set of beams was made out of mixture AD at a later date to ensure that we had not made an error in the previous beams. Only three beam sets were needed, since there is little variability in the behavior of concrete.

The beams are 10 3/8"x1 1/16"x1 1/16". The concrete is made from the respective mixtures and is placed in the beam form in two lifts. In between the two lifts, the reinforcement is placed into the concrete. The concrete is consolidated each lift by vibration. The beams are then left to dry for 24 hours, then they are placed in a moisture room at room temperature and kept there for a little over two weeks. They are then taken out and let to dry again at room temperature. Periodically, the length and mass of the beams are measured. Reference ASTM: C878
6 Mixture Results

6.1 Outer Mixture

Table 1. Summary of Outer Mixture Designs and Test Results.

<table>
<thead>
<tr>
<th>Batch</th>
<th>Layer</th>
<th>Description</th>
<th>Specific Gravity (Batch)</th>
<th>Specific Gravity (1 day)</th>
<th>Specific Gravity (7 day)</th>
<th>Strength (7 day psi)</th>
<th>Strength (28 day psi)</th>
<th>Water-Cementitious Ratio</th>
<th>Paste Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Outer</td>
<td>Outer Mix 2012</td>
<td>1.20</td>
<td>1.26</td>
<td>1.33</td>
<td>2512.50</td>
<td>2975.00</td>
<td>0.46</td>
<td>42.57</td>
</tr>
<tr>
<td>D</td>
<td>Outer</td>
<td>A + Lower Paste Content</td>
<td>0.98</td>
<td>1.09</td>
<td>1.05</td>
<td>2300.00</td>
<td>2606.25</td>
<td>0.45</td>
<td>40.93</td>
</tr>
<tr>
<td>E</td>
<td>Outer</td>
<td>A + Lower Paste Content</td>
<td>0.94</td>
<td>1.02</td>
<td>1.06</td>
<td>1812.50</td>
<td>1775.00</td>
<td>0.43</td>
<td>38.20</td>
</tr>
<tr>
<td>H</td>
<td>Outer</td>
<td>D w/ Refined Aggregate</td>
<td>0.89</td>
<td>0.95</td>
<td>1.00</td>
<td>975.00</td>
<td>1600.00</td>
<td>0.45</td>
<td>40.93</td>
</tr>
<tr>
<td>J</td>
<td>Outer</td>
<td>G w/ More Paste Content</td>
<td>0.89</td>
<td>0.95</td>
<td>1.02</td>
<td>950.00</td>
<td>1562.50</td>
<td>0.47</td>
<td>43.66</td>
</tr>
<tr>
<td>M</td>
<td>Outer</td>
<td>J Retry</td>
<td>0.94</td>
<td>1.07</td>
<td>1.15</td>
<td>N/A</td>
<td>2637.5</td>
<td>0.41</td>
<td>43.66</td>
</tr>
<tr>
<td>N</td>
<td>Outer</td>
<td>M w/ Higher w/c ratio</td>
<td>0.90</td>
<td>1.06</td>
<td>1.14</td>
<td>1875.00</td>
<td>2387.5</td>
<td>0.45</td>
<td>43.63</td>
</tr>
<tr>
<td>O</td>
<td>Outer</td>
<td>N w/o Expansive K</td>
<td>0.89</td>
<td>1.03</td>
<td>1.10</td>
<td>1650.00</td>
<td>2443.75</td>
<td>0.46</td>
<td>43.61</td>
</tr>
<tr>
<td>Q</td>
<td>Outer</td>
<td>Batch N for beams</td>
<td>0.90</td>
<td>0.94</td>
<td>1.04</td>
<td>1537.50</td>
<td>2462.5</td>
<td>0.45</td>
<td>43.63</td>
</tr>
<tr>
<td>U</td>
<td>Outer</td>
<td>N</td>
<td>0.90</td>
<td>1.11</td>
<td>1.18</td>
<td>2137.5</td>
<td>3075</td>
<td>0.45</td>
<td>43.63</td>
</tr>
<tr>
<td>AD</td>
<td>Outer</td>
<td>N</td>
<td>0.88</td>
<td>1.06</td>
<td>1.15</td>
<td>2487.5</td>
<td>3062.5</td>
<td>0.45</td>
<td>43.63</td>
</tr>
</tbody>
</table>

Development

After evaluating last year’s outer mixture, it was apparent that the aggregate gradation was far from optimal; however, several weeks were spent creating a suitable method for determining the proper aggregate proportions for this year. During this time, the paste percent and water cement ratio were adjusted to make the mixture more workable while maintaining its strength. The aggregate gradation was then optimized over a few weeks, resulting in a mixture with similar strength and lower density compared to last year. Tests were performed to ensure the CTS Komponent decreased the drying shrinkage as desired. This was confirmed, and mixture N was selected for use.

Mixture Chosen

The outer mixture needed to withstand possible impacts that could occur during the competition without increasing the weight of the canoe too much. Even though this mixture could theoretically have a specific gravity above one and still create a floating composite concrete when layered with the other mixtures, the team kept the specific gravity near one in order to mitigate placing day concerns. This is because mixture compaction during placing day is greater than compaction of the testing cubes, which creates a lower air content and thus a higher specific gravity for the canoe. It was also important that the mixture not harden too quickly, since a quick hardening could result in the formation of lifts during placing. Mixture N was chosen due to its low water-cement ratio, high paste percent, good workability, long hardening time, and specific gravity near one.
6.2 **Middle Mixture**

Table 2. Summary of Middle Mixture Designs and Test Results.

<table>
<thead>
<tr>
<th>Batch</th>
<th>Layer</th>
<th>Description</th>
<th>Specific Gravity (Batch)</th>
<th>Specific Gravity (1 day)</th>
<th>Specific Gravity (7 day)</th>
<th>Strength (7 day) psi</th>
<th>Strength (28 day) psi</th>
<th>Water-Cementitous Ratio</th>
<th>Paste Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Middle</td>
<td>Middle Mix 2012</td>
<td>0.40</td>
<td>0.52</td>
<td>0.64</td>
<td>245.00</td>
<td>350.00</td>
<td>0.56</td>
<td>42.57</td>
</tr>
<tr>
<td>I</td>
<td>Middle</td>
<td>C w/ Refined Agg.</td>
<td>0.35</td>
<td>0.40</td>
<td>0.48</td>
<td>425.00</td>
<td>43.75</td>
<td>0.46</td>
<td>42.02</td>
</tr>
<tr>
<td>P</td>
<td>Middle</td>
<td>I w/ Corrected Agg.</td>
<td>0.35</td>
<td>0.66</td>
<td>0.73</td>
<td>137.50</td>
<td>237.5</td>
<td>0.53</td>
<td>42.02</td>
</tr>
<tr>
<td>V</td>
<td>Middle</td>
<td>P</td>
<td>0.35</td>
<td>0.66</td>
<td>0.73</td>
<td>137.50</td>
<td>373.75</td>
<td>0.53</td>
<td>42.02</td>
</tr>
<tr>
<td>W</td>
<td>Middle</td>
<td>I w/ Corrected Agg.</td>
<td>0.35</td>
<td>0.64</td>
<td>0.76</td>
<td>148.13</td>
<td>222.5</td>
<td>0.59</td>
<td>42.02</td>
</tr>
<tr>
<td>AE</td>
<td>Middle</td>
<td>I w/ Corrected Agg.</td>
<td>0.35</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.59</td>
<td>42.02</td>
</tr>
</tbody>
</table>

**Development**

Because cracking was observed in last year’s canoe, the team wanted to develop a higher strength middle mixture this year to better support the paddlers. To increase strength, the water cement ratio was increased and aggregate gradation refined for maximum density, similar to the outer mixture development. Due to a lack of Elemix, only one iteration with refined aggregate was batched and tested. Minor changes were then made to Latex volume, and Batch V was selected for use in the canoe.

**Mixture Chosen**

The primary goal for the middle mixture was to be as light as possible, to keep the overall specific gravity of the boat below one (despite the inclusion of heavy materials such as the patching mixture and reinforcement). The secondary goal was to increase the strength enough to prevent cracking in the canoe. Though it had a higher density than last year’s middle mixture, the specific gravity of Batch V was still well below one, and it retained a higher compressive strength at 28 days. These properties should both allow the canoe to float and prevent internal cracking.
### 6.3 Inner Mixture

Table 3. Summary of Inner Mixture Designs and Test Results.

<table>
<thead>
<tr>
<th>Batch</th>
<th>Layer</th>
<th>Description</th>
<th>Specific Gravity (Batch)</th>
<th>Specific Gravity (1 day)</th>
<th>Specific Gravity (7 day)</th>
<th>Strength (7 day) psi</th>
<th>Strength (28 day) psi</th>
<th>Water-Cementitious Ratio</th>
<th>Paste Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Inner</td>
<td>B + Higher W/C</td>
<td>0.64</td>
<td>0.69</td>
<td>0.77</td>
<td>367.50</td>
<td>442.50</td>
<td>0.48</td>
<td>45.30</td>
</tr>
<tr>
<td>F</td>
<td>Inner</td>
<td>D w/ Daravair</td>
<td>0.90</td>
<td>0.96</td>
<td>1.01</td>
<td>1425.00</td>
<td>1737.50</td>
<td>0.45</td>
<td>40.93</td>
</tr>
<tr>
<td>G</td>
<td>Inner</td>
<td>F w/ Daravair</td>
<td>0.87</td>
<td>0.96</td>
<td>1.02</td>
<td>1287.50</td>
<td>2000.00</td>
<td>0.43</td>
<td>38.20</td>
</tr>
<tr>
<td>K</td>
<td>Inner</td>
<td>J + Daravair</td>
<td>0.86</td>
<td>0.94</td>
<td>1.01</td>
<td>118.75</td>
<td>1412.50</td>
<td>0.41</td>
<td>42.02</td>
</tr>
<tr>
<td>L</td>
<td>Inner</td>
<td>M w/ 1.5 daravair</td>
<td>0.88</td>
<td>0.92</td>
<td>0.99</td>
<td>1150.00</td>
<td>2050.00</td>
<td>0.40</td>
<td>42.02</td>
</tr>
<tr>
<td>R</td>
<td>Inner</td>
<td>Batch O for beams</td>
<td>0.89</td>
<td>0.98</td>
<td>1.04</td>
<td>1375.00</td>
<td>2012.5</td>
<td>0.46</td>
<td>43.61</td>
</tr>
<tr>
<td>S</td>
<td>Inner</td>
<td>L w/ color pigments</td>
<td>0.88</td>
<td>1.12</td>
<td>1.19</td>
<td>3150.00</td>
<td>3562.5</td>
<td>0.40</td>
<td>42.02</td>
</tr>
<tr>
<td>T</td>
<td>Inner</td>
<td>L w/ Color Pigments</td>
<td>0.88</td>
<td>1.00</td>
<td>1.07</td>
<td>1812.50</td>
<td>2000.00</td>
<td>0.40</td>
<td>42.02</td>
</tr>
<tr>
<td>X</td>
<td>Inner</td>
<td>M w/ 1.5 daravair</td>
<td>0.88</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.40</td>
<td>42.02</td>
</tr>
<tr>
<td>Y</td>
<td>Inner</td>
<td>M w/ 1.5 daravair</td>
<td>0.88</td>
<td>1.00</td>
<td>1.07</td>
<td>2193.75</td>
<td>3012.50</td>
<td>0.40</td>
<td>42.02</td>
</tr>
<tr>
<td>AA</td>
<td>Inner</td>
<td>M w/ 1.5 daravair</td>
<td>0.88</td>
<td>1.07</td>
<td>1.13</td>
<td>1312.50</td>
<td>2012.50</td>
<td>0.40</td>
<td>42.02</td>
</tr>
<tr>
<td>AB</td>
<td>Inner</td>
<td>M w/ 1.5 daravair</td>
<td>0.88</td>
<td>1.06</td>
<td>1.16</td>
<td>1737.50</td>
<td>1893.2</td>
<td>0.40</td>
<td>42.02</td>
</tr>
<tr>
<td>AC</td>
<td>Inner</td>
<td>M w/ 1.5 daravair &amp; Black pigments</td>
<td>0.88</td>
<td>1.09</td>
<td>1.12</td>
<td>2318.75</td>
<td>3000.00</td>
<td>0.40</td>
<td>43.11</td>
</tr>
</tbody>
</table>

**Development**

Because the density of the middle mixture this year was higher than last year, the team was concerned about maintaining a canoe with a specific gravity below one. In order to mitigate this concern, it was determined that a third mixture, an inner mixture, could be created with a lower density than last year’s inner layer. Using Outer Batch D as a baseline, Daravair was added to increase air content of the concrete. The next tests involved refining the aggregate gradation, which in turn necessitated a higher paste percent. In the end, Batch L was selected for use as the inner mixture.

**Mixture Chosen**

The goal of this mixture was to have a strength close to that of the outer mixture with a lower specific gravity. In previous years, identical mixtures were used on both sides of the middle mixture, but this year, it was decided that some of the strength on the inside of the canoe could be forfeited for a decrease in weight, since the only compressive stresses imposed on the inner mixture are the weight of paddlers and the associated impacts caused during paddling. Even though cracks formed during paddling last year, it was assumed that these cracks primarily formed due to the weakness of the middle mixture. Batch L was significantly lighter than the outer mixture while retaining a high strength, providing the desired properties for the inside layer of the canoe.
### 6.4 Patching Mixture

Table 4. Summary of Patching Mixture Design and Test Results.

<table>
<thead>
<tr>
<th>Batch</th>
<th>Layer</th>
<th>Description</th>
<th>Specific Gravity (Batch)</th>
<th>Specific Gravity (1 day)</th>
<th>Specific Gravity (7 day)</th>
<th>Strength (7 day) psi</th>
<th>Strength (28 day) psi</th>
<th>Water-Cementitious Ratio</th>
<th>Paste Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF</td>
<td>Patching</td>
<td>N</td>
<td>0.90</td>
<td>1.52</td>
<td>1.60</td>
<td>5300.00</td>
<td>7575.00</td>
<td>0.21</td>
<td>61.03</td>
</tr>
</tbody>
</table>

**Development**

The exclusive purpose of this mixture was to easily fill any small gaps that may form during placing day, as well as any cracks that appeared during drying and demolding. At first, we attempted to create a mixture with the lowest legal water/cement ratio allowed, while keeping a paste percentage matching that of the outer mixture. However, the paste percent of this mixture was too low, forming concrete too wet for use in the canoe. No cubes were made or tested for this mixture. Corrections were made to the water-cement ratio, resulting in a mixture that was easy to work and had an aesthetically desirable texture.

**Mixture Chosen**

Mixture AF was the final mixture that was created and was chosen for the canoe. The low water-cement ratio and paste content of this mixture, which fall just within the legal requirements of the competition, make it an extremely high strength mixture. However, since this mixture would not be a structural mixture, strength was not a priority. Instead, the biggest concerns were workability and texture. The mixture needed to easily fill any holes and cracks on the outside of the canoe, and also needed a texture that would create a smooth surface for detailing the canoe. Bonding was also of concern, but after testing the other mixtures with additional latex, this concern was alleviated. Because mixture AF met the minimum mixture proportions as well as the desired mixture properties of patching concrete, no additional iterations were performed and this mixture was accepted as the final patching mixture.
6.5 Inlay Mixture

Table 5. Summary of Inlay Mixture Designs and Test Results.

<table>
<thead>
<tr>
<th>Batch</th>
<th>Layer</th>
<th>Description</th>
<th>Specific Gravity (Batch)</th>
<th>Specific Gravity (1 day)</th>
<th>Specific Gravity (7 day)</th>
<th>Strength (7 day) psi</th>
<th>Strength (28 day) psi</th>
<th>Water-Cementitious Ratio</th>
<th>Paste Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Inner L w/ color pigments</td>
<td>0.88</td>
<td>1.12</td>
<td>1.19</td>
<td>3150.00</td>
<td>3562.50</td>
<td>0.40</td>
<td>42.02</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Inner L w/ Color Pigments</td>
<td>0.88</td>
<td>1.00</td>
<td>1.07</td>
<td>1812.50</td>
<td>2000</td>
<td>0.40</td>
<td>42.02</td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>Outer (final) M w/ 1.5 Daravair &amp; Black Pig.</td>
<td>0.88</td>
<td>1.09</td>
<td>1.12</td>
<td>2318.75</td>
<td>3000</td>
<td>0.45</td>
<td>43.63</td>
<td></td>
</tr>
</tbody>
</table>

Development

Initially, the team intended to create inlays on the interior surface of the canoe, so pigmented mixtures were designed using the inner mixture as a baseline. However, due to concerns regarding the structural integrity of inlays on the inside bottom surface of the canoe, the team decided to implement inlays only on the exterior of the boat. For exterior inlays, the outer mixture formed the baseline for testing. Because adding pigment affected the concrete consistency in unpredictable ways, each pigment color required different adjustments to paste content and water cement ratio to achieve reasonable workability. The purple pigment drastically increased fluidity, requiring lower water/cement ratio. The yellow pigment formed a dry mixture, necessitating increases in paste content. The black pigment had little influence on workability, and no changes were needed.

Mixture Chosen

The team selected the outer mixture as a baseline for the inlays in order to create a consistent outside surface on the canoe. Additionally, the inlay mixtures required high enough viscosity to not run down the sides of the canoe during placing, but sufficient workability to be placed into small places with precision. Another potential concern was that the increased paste content of the yellow mixture added some density to the mixture, but the increase in weight should not be significant enough to cause any problems. The pigments were chosen from supplies we already had in the lab from previous years, and therefore were available at no additional cost.
7 Panel Testing Results (Wall Thickness)

The results of the panel testing are summarized below in Table 6 and Figures 2, 3, 4, and 5.

Table 6. Summary of Load-Deflection Panel Testing Results.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>13.79</td>
<td>358.8871689</td>
<td>376.37</td>
<td>4.75%</td>
<td>46000000</td>
<td>46000000</td>
<td>2.46E+03</td>
<td>38.80</td>
<td>20.89</td>
<td>102.8737491</td>
</tr>
<tr>
<td>1.2</td>
<td>13.57</td>
<td>443.6214803</td>
<td>332.89</td>
<td>-28.52%</td>
<td>24800000</td>
<td>24800000</td>
<td>1.25E+04</td>
<td>64.00</td>
<td>80.39</td>
<td>2012.249491</td>
</tr>
<tr>
<td>2.1</td>
<td>13.92</td>
<td>348.1379037</td>
<td>512.66</td>
<td>38.23%</td>
<td>29900000</td>
<td>29900000</td>
<td>1.64E+04</td>
<td>93.78</td>
<td>104.47</td>
<td>310.536566</td>
</tr>
<tr>
<td>2.2</td>
<td>14.78</td>
<td>443.6214803</td>
<td>301.02</td>
<td>-38.34%</td>
<td>53800000</td>
<td>53800000</td>
<td>1.68E+04</td>
<td>91.66</td>
<td>91.72</td>
<td>1998.415966</td>
</tr>
<tr>
<td>3.1</td>
<td>9.97</td>
<td>430.8131846</td>
<td>442.07</td>
<td>2.58%</td>
<td>45300000</td>
<td>45300000</td>
<td>9.20E+04</td>
<td>100.00</td>
<td>100.00</td>
<td>20969.24401</td>
</tr>
<tr>
<td>3.2</td>
<td>10.45</td>
<td>442.7188724</td>
<td>401.32</td>
<td>-9.81%</td>
<td>99600000</td>
<td>99600000</td>
<td>7.01E+04</td>
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Figure 2. Results for Load-Deflection Panel Testing with Mixtures U, V, and AA.

Figure 3. Results for Load-Deflection Panel Testing with Mixtures U, W, and AB.
Interpretation
The preceding values were entered into an analysis program, which compares the maximum stresses in the canoe against the maximum stress that a panel can support using several different loading conditions. By varying both the thickness and composition we could determine the effectiveness of adding more weight to the canoe and compare how much more strength we would gain from creating a thicker body. The analysis also found the stresses in the tensile reinforcement at failure. This indicated whether the failure was caused by tensile rupture or delamination between the concrete layers and the tension reinforcement. There are a few cases where the test yielded poor results such as 3.1 and 7.1 where elastic portion of the curve is extremely short. This could be due to poor construction causing cracking to happen almost instantly or due to an improper setup that kept the LVDT from being depressed until cracking had already occurred in the member.

After the initial few tests and seeing how the panels reacted to bending we determined the composition of the canoe to be Outer – AD, Middle – AE and Inner – AG. The next set of tests 3.1 through 8.2 were used to determine which thickness would yield the best result and if making the canoe thicker would be worth the additional weight. The results show that a thickness less than 12 mm has strength significantly less than 15 mm or 18 mm thick panels. However, the difference between 15 mm and 18 mm was less dramatic. In some cases, the form down tests, the 15 mm thick panels actually performed better. We decided that the strength gain from a thicker section was not worth the additional weight and opted for the 15 mm canoe. After further analysis we found that the residual strength in the 15 mm panels was greater than that of the 18 mm, meaning that the 15 mm panels had similar strength capabilities and performed better during post cracked loading than 18 mm.
8 DRYING AND SEALER TESTING RESULTS

The sealer was tested on panels to determine its waterproofing capabilities. Three test panels of different thicknesses left over from flexural testing were used to test the sealer. The exposed edges were coated with epoxy to simulate the actual canoe in which those sides are not exposed in any places. Then two coats of ProtéShield were applied with a roller. After the sealer was allowed to dry for several days, the panels were weighed, then sunk completely under water and weighed again at five, ten, fifteen, thirty, and sixty minutes of being submerged. These tests showed that the sealer is effective in preventing the concrete from absorbing a significant amount of water. The following results were obtained:

Figure 6. Results of Sealer Testing: Weight vs Time Submerged.
9 BEAM AND REINFORCMENT RESULTS

Shown below is a graph of the strain versus time. The lines show the average of the pairs of beams tested. The graph clearly shows that the concrete first expands, then contracts which is expected. Unfortunately, it can also be seen that there is no residual expansion in any of the mixtures so we are unable to get any prestressing from the reinforcement.

Figure 7. Results of Beam Testing: Microstrain vs Time.
10 Conclusion

During the nine weeks of class, the students in CEE 428 designed and tested 32 mixtures, selected the six to be used for the final canoe, chose reinforcement, stain, and sealer materials, and determined thickness of each layer in the cross-section. These selections are summarized in Table 7.

<table>
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<th>Table 7. Material Selections and Key Properties.</th>
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<td>Canoe Component</td>
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<td>Wall Thickness</td>
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Based on the test results from this class, the canoe constructed this year is expected to perform adequately, but several aspects of mixture development and placing could be improved. In future years, reinforcement testing is recommended in order to quantify the stresses resisted by the reinforcing that was incorporated into the canoe. More Expansive K (CTS Komponent) could potentially be incorporated into future mixtures to create a post-tensioning effect on the reinforcement. Further sealer testing might also be performed, to create a data set from which to select a sealer with more long-lasting waterproofing capabilities. In construction, better Quality Assurance measures could be implemented to ensure that the thickness and compaction of the canoe better matches the thickness and compaction of the lab-tested panels.