PADDLEGONIA

NORTHERN ARIZONA UNIVERSITY - DESIGN REPORT 2017

PADDLEGONIA

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EXECUTIVE SUMMARY

From almost any point in the city, the residents of Flagstaff can see the majestic beauty of the mountain peaks. Flagstaff Arizona is located at seven thousand feet above sea level, which allows the residents close views of the mountain peaks and endless opportunities for exploration. The sights of towering mountains and potential for adventure inspired this year's concrete canoe theme. With the theme of mountains and adventure in mind, attention was quickly directed to the South American region of Patagonia. Using a play on words the team was motivated to call the canoe *Paddlegonia*.

The Northern Arizona University (NAU) Concrete Canoe team's five members will participate in the Pacific Southwest Conference (PSWC) by completing all conference tasks, and entering quality deliverables in the competition. In the past three years NAU has placed 6th with *Polaris* in 2016, 3rd with *Dreadnoughtus* in 2015, and 13th with *Spirit* in 2014 in the PSWC. To remain competitive in PWSC, the team decided to begin their design from scratch.

A significant design change from *Polaris* and *Dreadnoughtus* is the hull design. The team redesigned the hull to accentuate many natural capabilities of the canoe with regards to speed, tracking, stability, and maneuverability. The new hull uses a hybrid of several different shapes that transition from better speed and tracking in the front, to better stability and maneuverability in the back. A new structural analysis had to be run because of the team's decision for a new hull shape. The canoe was idealized as a rectangular shaped cross-section for the compressive and tensile stress calculations instead of parabolic like *Polaris*. This switch gave an accurate analysis, based on the new hull design that has a flat, long, almost rectangular component along half the canoe length.

This year, all aspects of construction had a focus on sustainability and reusable components. This not only reduced waste for this year's design, but for future designs at NAU. Items such as wood cross sections, canoe-building table, and curing chamber are all designed to be reusable and easily reassembled by future teams. The new canoe-building table was lowered by 6 inches to allow for easier access to the canoe during casting. Additionally, the table was designed to deconstruct when not in use. The curing chamber dimensions were reduced from a 24' by 8' by 8' structure to 22' by 28" by 20" chamber that was constructed on the canoe-building table for ease of access and reusability. This new curing chamber covers the canoe in close proximity with a new, reusable tarp, and allows for humidifiers at both the bow and stern avoiding the inefficiency of a large chamber.

A new mix design method was used to optimize the materials used versus amount of mix yielded. The new method used is a saturated surface dry (SSD) method in comparison to using a large concrete mixer like *Polaris*. This method allowed the mix to be more uniform, workable, and have manageable batch sizes for testing to avoid material losses.

Project management was more critical than years past because *Paddlegonia* has a newly designed hull, structure, and concrete mix design. These changes required that project management find new donors for various materials, finances for construction, and fabricators for new construction methods.

Table 1: Concrete Canoe Properties

Concrete Canoe Name: *Paddlegonia*	
Hull Dimensions	
Maximum Length	252 in.
Maximum Width	28 in.
Maximum Depth	16 in.
Average Thickness	0.5 in.
Estimated Weight:	200 lb
Reinforcement	
Primary	SpiderLath Fiberglass Galvanized Steel Post-Tensioning Cable
Secondary	MasterFiber® M 100
Color	
BASF MasterColor	Medium Red
	Black

Table 2: Concrete Properties

Finishing Mix	
Wet Unit Weight	77.8 lb/ft^3
Oven-Dry Unit Weight	64.8 lb/ft^3
28-Day Compressive Strength	3547 psi
28-Day Tensile Strength	321.9 psi
Concrete Air Content	19%
Structural Mix	
Wet Unit Weight	60.3 lb/ft^3
Oven-Dry Unit Weight	53.9 lb/ft^3
28-Day Compressive Strength	1939 psi
28-Day Tensile Strength	218.1 psi
28-Day Flexural Strength	827.4 psi
Concrete Air Content	11%

PADDLEGONIA

PROJECT MANAGEMENT

The project management of *Paddlegonia* began with acquisition of material and monetary donations. Material donations came from Badische Anilin und Soda Fabrik (BASF), Cemex, and Trinity lightweight for our admixtures, cement, fly ash, and aggregate. These donations were then supplemented through monetary donations from family members and local engineering companies to a GoFundMe page for convenience. These funds were spent on the cutting of our mold cross-sections, additional raw materials, travel, and tools.

Figure 1: Critical Path

The critical path in Figure 1 consists of defining the main tasks and combining them into logical groups. The first three tasks were raising money for material, designing a hull to identify the amount needed, and acquiring the material for testing and construction. The fourth task incorporates the testing of materials for the final concrete mix and reinforcement materials. With final design selected the construction phase initiated, followed by the finishing phase. This process culminated in a finalized canoe and met deliverables required by the National Concrete Canoe Competition (NCCC).

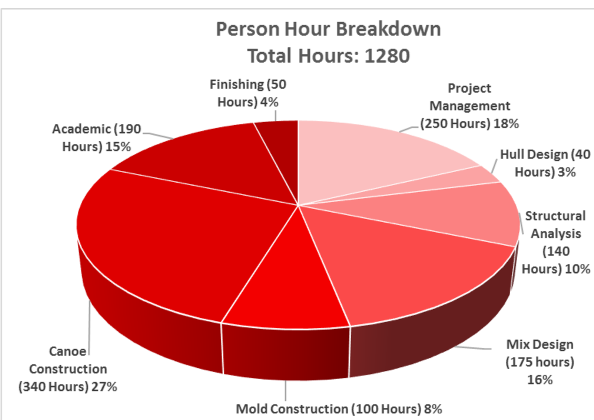


Figure 2: Person Hour Breakdown

Table 3: Milestone Tasks To Complete In Competition

Task	Determined	Achieved
Canoe Shape Selection	Needed to proceed with design.	Through research.
Concrete Mix Design/ Reinforcement Selection	Needed to ensure it worked for practice casting and pour day.	Through testing.
Practice Canoe Casting	Needed to ensure the mix and reinforcement materials work.	Through procuring material and scheduling.
Canoe Pour	Needed to have a final product.	Through being prepared from the practice casting, and the labor.
Canoe Finishing	Needed to have canoe be aesthetically and physically ready for PSWC.	Through adding aesthesis required by the NCCC and patching the canoe.
Attend PSWC	Given in NCCC Rules.	By attending in April.

All people involved including the canoe team and mentees were required to complete a safety training before working on the concrete canoe construction process, running any testing machines, and equipment. Once the safety training has been completed the members can proceed to the following steps in Figure 3.

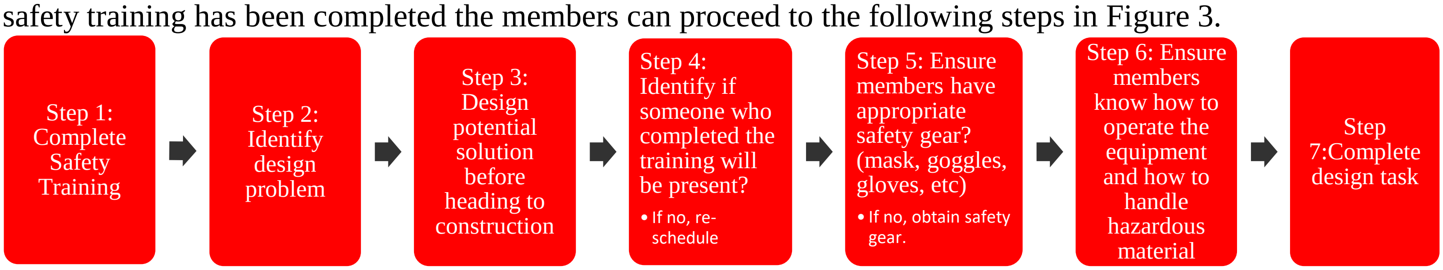


Figure 3: Safety Flow Chart

The final mix design and material testing was pushed back accordingly due to a lack in material procurement. Delays were further exacerbated by difficulty creating an EPS mold, which pushed our pour day back from January to February, and everything else following. Another change to the schedule was a removal of the class submittals associated with our project, as they were not relevant to the NCCC.

QUALITY ASSURANCE/QUALITY CONTROL

Paddlegonia implemented a quality assurance and quality control program very early in the stages of development. Team members met for a complete rule review as soon as the 2017 NCCC Rules were released. The goal was to have every team member familiarize themselves with all the rules for their tacks and expose them to unique rule changes from the 2016 NCCC Rules. Frequent rule review sessions were conducted as request for information (RFI) documents became available to help interpret certain rules.

Both *Polaris* and *Dreadnoughtus* used a 100% fly ash cement produced at an out of state batch plant. *Paddlegonia* opted for a local plant to ensure easier access to cementitious materials in large volumes. Having a local batch plant ensured material was readily available for the team and the risk of having no means to procure additional material out of state was eliminated. Every batch utilized contained the same material from the same source providing quality control in the mix.

The local batch plant offered cement and fly ash in 5-gallon buckets. To safeguard potential mix-ups or the misplacement of materials, each team member was instructed on the difference in material properties, and any material procured was identified and labeled appropriately for batch trials. This was important because the batch mixes called for various ratios of fly ash to cement and a mix up of materials could have cause a potentially good mix to be rejected. In addition to the labeling of cementitious materials, each trial batch mix was carefully labeled with material type and actual weight shown in Figure 4.

Figure 4: Quality Control Labeled Material Bags

A technical data sheet is required for each material used in mix design along with the confirmation of material compliance. Due to previously limited availability of material, it was important to optimize what material *Paddlegonia* had on hand. Upon completion of the data sheet the batch was reduced to a quarter of a cubic foot to pour three cylinders according to American Society for Testing and Materials (ASTM) standards. Three cylinders of material allowed for one 7-day compressive test, one 14 day split tensile test, and an oven dried unit weight test. Batches with favorable initial results at the 7-day compressive test were duplicated for further testing and the unfavorable batches were discarded. This method allowed quality assurance of batch mix material as it proved the mix could be reproduced and undesirable mixes were not pursued avoiding material waste. Material that was not accompanied by a technical data sheet due to the manufacturing process required a letter from a Professional Engineer (PE) assuring the material is ASTM compliant.

A large component of *Paddlegonia's* quality assurance and control efforts were created in a mentee training program. A certified American Concrete Institute (ACI) concrete field tester taught proper testing procedures and cylinder fabrication methods to all members of the team to ensure samples were adequate for testing. All team members were instructed to verify the weights of each material against the mix design table when preparing trial mixes to establish accuracy.

Pour day quality assurance and control consisted of a strict process of hand mixing pre-batched concrete from clearly labeled mix bags. Concrete was placed in molds that were $64in^2$ shown in Figure 5. They were then struck off to 1/8in thick using a trowel. Sticking to a 1/8in lift ensured material placement according to design volume. Two *Paddlegonia* members were selected for this task due to their ability to consistently strike off the correct amount of concrete from the molds.

Figure 5: Standardized Square Concrete Mold

ORGANIZATION CHART

Project Manager

Matthew Vigil
Senior

Leader in team scheduling, task, management, finances, and fundraising. Additional responsibilities included procurement, construction, graphic design, and paddling program. Assisted other tasks as needed.

Project Engineer

Katrina Shurley
Senior

Managed construction tasks including mold, curing chamber, and pour table.

Materials Engineer

Michael Schubert
Senior

Researched and tested concrete mix designs, while leading quality control on materials.

Reinforcement Engineer

Cristopher Aguilar
Senior

Tested and selected reinforcement materials, designed post-tensioning, and determined reinforcement placement.

Structural Engineer

Stephanie Croker
Senior

Selected final hull design shape, calculated target concrete strengths, and modeled the canoe in AutoCAD.

Mentees

Name	Year
Branden Peterson	JR
Joshua Leon	JR
Zachary Radovich	JR
Gina Boschetto	JR
Katy Adams	JR
Virgilio Bareng	SO
Kylie Dykstra	SO
Ernesto Mauricio	SO
Ally Marnocha	SO
Logan Grijalva	FR

Paddlers

Name	Year
Matthew Vigil	SR
Katrina Shurley	SR
Sabrina Ballard	SR
Branden Peterson	JR
Joshua Leon	JR
Gina Boschetto	JR
Virgilio Bareng	SO
Kylie Dykstra	SO
Ernesto Mauricio	SO
Ally Marnocha	SO

Volunteers

Name	Year
Robert Hoppe	SR
Robert Dyck	SR
Ryan Morofsky	SR
Holly Hanson	JR
Yusef Aldawood	SO

HULL DESIGN AND STRUCTURAL ANALYSIS

Previous years designs, competition experiences, and paddlers' feedback have provided this year's team with knowledge on what canoe shapes and dimensions were most effective. The previous year's hull design and structural analysis was considered, but the team went with a new approach to create *Paddlegonia*. The new design will maximize speed and the ability to track in a straight line through water. The goals for structural analysis include illustrating various loading scenarios to determine the shear and moment, and perform calculations to obtain the tensile and compressive stress.

Hull Design

The collaboration between the team and paddlers in designing *Paddlegonia* resulted in a balance amongst speed, tracking, and stability. The characteristics of the canoes shape were researched based on the desired performance. The research entailed using previous years' canoe documentation and outside sources. A variety of design features were found that met the team's performance needs. These were utilized and converged into an innovative shape, reminiscent of some high-end racing canoes.

The dimensions of the canoe were selected based on the preferred performance of the canoe and the 2017 NCCC Rules. To meet the design parameters and preferences, the length, width, height, and thickness are 21 ft, 28 in, 16 in, and 0.5 in respectively. These dimensions provide a long, narrow canoe for increased tracking performance, while still allowing enough capacity for four paddlers (Figure 6).

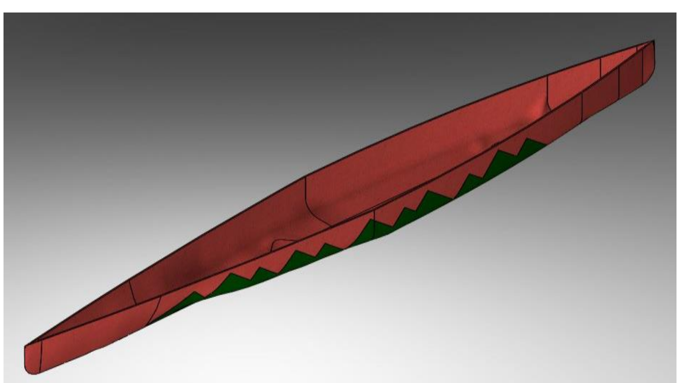


Figure 6: 3D Render of Canoe

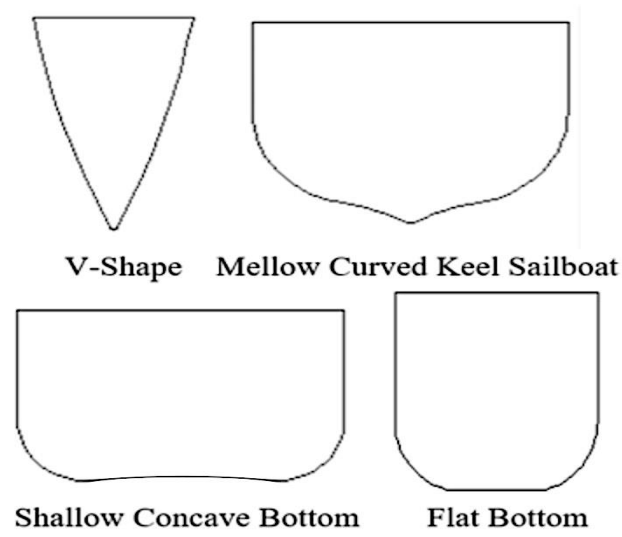


Figure 7: Hull Design Shapes

Paddlegonia was streamlined by changing the cross-sectional shape from anything that had been built in the past at NAU. Previously the shape of the hull has always been a V-shape at the bow that converges into a flat bottom in the mid-section and back to a V-shape at the stern of the canoe. The shape's appearance this year is distinct due to the new hull shape described below and shown in Figure 7. The selected design maximizes the tracking while still maintaining a smooth transition to a stable middle and back.

A square stem was selected for the bow and stern of the canoe providing improved tracking performance in the water, while sacrificing some maneuverability. The bow of the canoe begins as a single chine V-Shape and gradually transitions into a mellow curved Keel Sailboat profile. These shapes are designed to cut through water quickly and in a straight line to maximize performance in sprint races. The midsection has a shallow concave bottom to keep the water flow moving longitudinally down the canoe. This creates an uplifting force providing an increase in speed while still creating stability for the paddlers. The midsection transforms into a flat bottom and tapers off to the end of the stern. The flat bottom provides additional stability to ensure the paddlers do not overturn the canoe when moving in the water.

Ribs were designed into the canoe for extra strength in the midsection of the canoe. The ribs are placed in locations where the paddlers will be sitting. They will help support the loads and prevent cracking. The locations of the paddlers and ribs were predicted qualitatively from the most natural sitting positions in the canoe.

Structural Analysis

The volume of the concrete used to create the canoe is approximately 3.5ft^3. The total weight of the canoe can be approximated at 200lb by using this volume and the average unit weights of the concretes. All the calculations, such as the longitudinal moments, tensile stress, and compressive stress were completed using an Excel spreadsheet.

There were 42 cross sections created 6in apart, with dimensions implemented into an Excel spreadsheet. The cross sections were analyzed as a U-shape to be conservative with the complex design. This was conservative because the analysis used the most extreme widths at each cross section, which resulted in a more severe force. The centroid and moment of inertia was determined for each cross section so that the longitudinal shear and moment could be calculated.

The longitudinal shear and moment were calculated for different loading situations. The loading cases were selected based on the races happening at conference and where the paddlers sit in the canoe. There are 2-men races, 2-women races, and a 4-person coed race. The canoes longitudinal shear and moment was analyzed as a simply supported beam with various loads applied to it. The self-weight of the canoe and buoyancy are linearly distributed loads whereas the paddlers act as point loads on the beam. The paddlers are assumed to all be 175lb, which is conservative for the team selected. The moment for each scenario is modeled in Excel and can be seen in Figure 7. The maximum moment for the loads being the closest to the bow and stern, 2-person, and 4-person is respectively -5260lb in, 2164lb in, and 6447lb in.

The maximum tensile and compressive stress longitudinally on the canoe was calculated using the maximum moment applied on the beam. Using the maximum moment, cross sections centroid and moment of inertia the tensile and compression stress can be calculated. Out of all the scenarios the 4-person had a maximum tensile stress of 102.5 psi and the paddlers closest to the bow and stern had a maximum compressive stress of 83.6 psi.

The maximum stresses are taken from different scenarios to compare the testing results to the calculation results. The testing results would need to be greater than the calculated results to ensure the selected concrete could withstand the stresses applied to it.

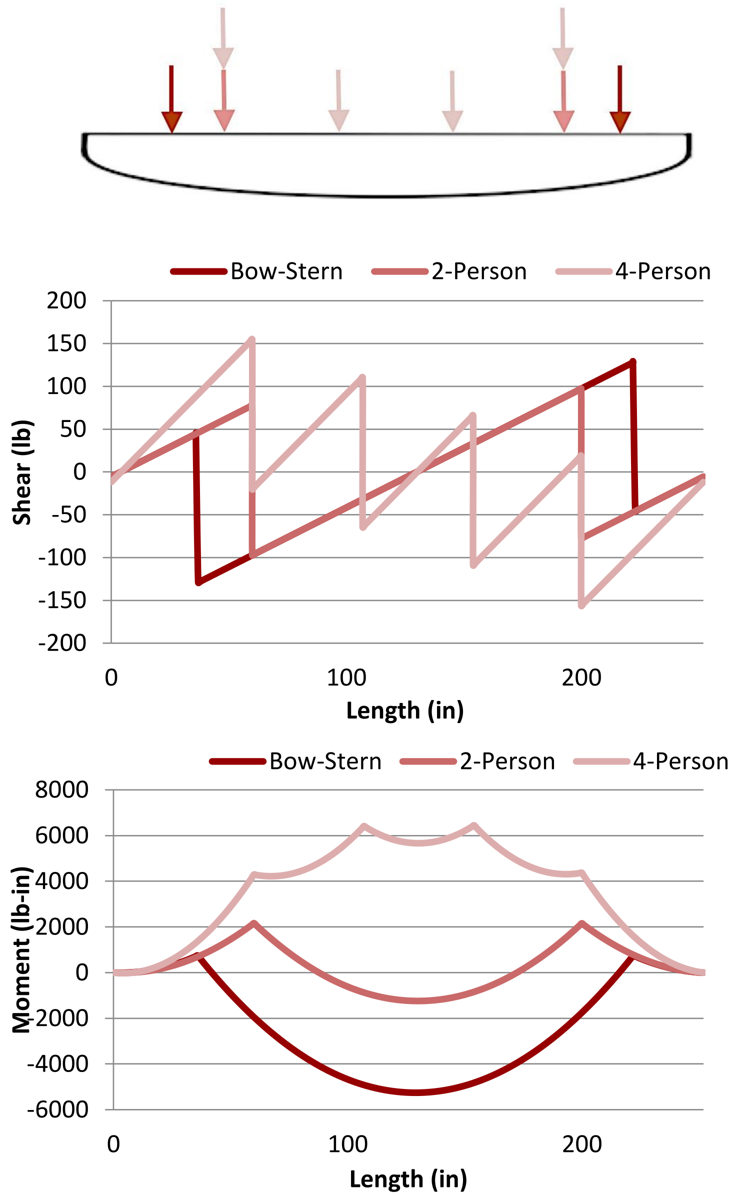


Figure 8: Longitudinal Shear and Moment

The NCCC Rules state that the canoe will be fully submerged and the rims of the canoe will have to float back up to break the surface of the water. This was calculated by finding equilibrium between the foam and the displacement of water. The displacement of water was 3ft^3, requiring 1.5ft^3

To be placed in the bow and stern of the canoe.

DEVELOPMENT AND TESTING

The primary objectives of *Paddlegonia*'s mix designs were to move away from a 100% fly ash based cement and to focus on a Portland cement and Class F Fly Ash design. This new mix design was a result of readily available material in the area and an improvement in strength, unit weight, and workability of the mixes. Procurement troubles and limited availability for previously used materials aided in the decision to switch to gray Portland Type I cement and Class F Fly Ash. These cementitious materials were selected based on availability and desirable properties for strength and durability. A secondary objective of the mix was to improve the canoe's aesthetics through the use of liquid color admixtures, as stains were strictly prohibited in this year's rules.

The concrete mix for *Paddlegonia* aimed for a decrease in slump compared to *Polaris* and *Dreadnoughtus*. Less slump was desirable as the team opted for a controlled hand placement method onto a male mold using tile molds that are 64 square inch and 1/8 in thick. Minimal slump was designed to avoid thicker sidewalls during construction.

Establishing a mix method was vital to determining a baseline mix for the canoe. A large concrete mixer was initially utilized; however the batch mixes were too small and the material was too fine, causing inconsistencies due to numerous dry areas with unmixed material. Paddle mixing in a 5-gallon bucket in half batches proved to be a time-consuming process resulting in an increase in loss of material. When the mix became thick the drill could no longer spin through the dry unmixed material. The captains ultimately decided to hand mix in large 5 gallon concrete tubs due to the large surface area available. Hand mixing in large tubs allowed dry spots to be noticed and worked into the mix effectively to provide a uniform mix.

Another fundamental change to the mix design program came in the form of calculating proper saturated surface dry (SSD) weight from the absorption of the various aggregates in the mix. Initially the cementitious materials and aggregates in an oven dry condition were added together into the mix. The introduction of the batch water simultaneously began the hydration process while the aggregate absorbed water. The result was very difficult-to-control water amount for the batch mix. Once the aggregate reached an SSD condition and significantly upped the free water in the mix, it went from what felt to be a near workable mix to a soupy mess. Calculating the SSD weight of the aggregate demonstrated the water needed to achieve an SSD condition to be batched separately. The set retarder was added into the SSD batch water and applied to the hand mixed aggregate in the tub. The result of this was the aggregate looking like wet beach sand. In this wet beach sand condition, the hand mixed dry cementitious materials could be added to the SSD, aggregated and dispersed throughout by hand in the tub but, have no free water in the mix. Once dispersed uniformly in this dry condition, the batch water could be introduced, providing a more uniform mix as hydration had been delayed. All the batch water introduced became free water in the mix and contributed to hydration as the aggregate was no longer in a dry state that would absorb free water.

Figure 9: Compression Test

Figure 10: Split Tensile Test

Paddlegonia produced low volume mixes that made approximately a ¼ cubic foot of material where the 7-day compressive strength, oven dry unit weight, and 14-day tensile strength could be tested. A backup cylinder was made for any failed test methods due to unforeseen issues. All favorable testing results caused more cylinders to be made to verify results. The main considerations in the initial mixes were the cement to fly ash ratios.

It was projected that 28 batch trial mixes would be tested, but it became clear as testing commenced that *Paddlegonia* did not have enough material on hand. However, once the baseline was established off a 50% fly ash to cement ratio, tweaks could be made to improve functionality of the mixes. The baseline 50% fly ash mix called for a straight 50/50 blend of Portland type I cement to Class F fly ash and used small grain sizes of expanded glass aggregate. A #1 sand graded expanded clay shale was used at the ASTM C330 compliant material at 25% by volume. Set retarder, high range water reducer, shrinkage reducer, and air entrainer were added to the mix with favorable results. However, the mix was very wet and did not have the workability the team was looking for. A simple workability test, in addition to a quick slump test, was to take some material and place it on a shrink-wrapped piece of foam that mimicked our male mold. The slump eventually flowed down on the mock mold and was not easily placed. Another downfall of this mix was that it exceeded our target unit weight of 62.4 pcf. Cutting the cement with fly ash to a 70% fly ash with 30% cement by weight allowed for a very light mix at 60 pcf wet weight. However, the mix was completely unworkable and had no desirable finishing characteristics due to lack of cementitious material. However, this mix allowed us to see where we could cut unit weight down. Switching to a 70% cement with 30% fly ash blend by weight and keeping all aggregate and admixtures constant provided a very good workable mix. Wet unit weights of 70 pcf were constantly recorded during batch testing and the mix had no trouble being placed on our mock mold. However, we felt we could cut the unit weight down. The decision was made to keep the 70% cement by weight but increase the aggregate amount. The result was a larger air content of 11% in the mix but, required less free water and more SSD water to be absorbed. Entrained air was added to help further reduce unit weight. The mix measured a wet density of 60 pcf and oven dried to 54 pcf. Workability for the mix was desirable. This mix finished well but, due to the entrained air and large 1.0-2.0 mm aggregate size, it had a very grainy look. However, it bonded well to the fiberglass mesh and was chosen as a structural/composite mix to cut unit weight in the canoe in the unexposed layer.

Our colored finishing mix was designed and selected a week after determining the final structural mix. Due to the large grain sizes in the structural mix, the finished product did not look very aesthetic. A colored overlay mix using smaller aggregate sizes and incorporating BASF coloring admixtures was engineered. The choice was made to use the colored mix. The workability and ease of placement far exceeded that of the structural mix. The coloring admixture gave it a very plastic form that held shape, had almost no slump, and could be placed in any area with ease. Test results for the mix were highly favorable, along with unit weight. Because of the high air content in the mix by nature, the choice was made to not use entrained air in the mix.

Following the success of *Polaris*' reinforcement selection, which avoided causing any visible cracks on their canoe, the team decided to re-use the SpiderLath Fiberglass Lath System. This mesh material was re-used for its tensile strength, large percent open area (63.24%), and its bonding properties with the mix design. This helped prevent cracking in tension, and made placing concrete on the mold very easy. Excess SpiderLath from the build of *Polaris* was used during construction to save cost, as the mesh is approximately \$0.60/ft2. New SpiderLath was ordered to have a baseline to compare the results to and supplement the current supply. The tensile strength of the old mesh and the new were compared by bracing a strand of the mesh on a 2x4 piece of wood, tying the other side to a 5-gallon bucket, and gradually filling the bucket with water until failure of the strand. The results of the testing showed that there was only a difference of 1.33 pounds per 1 strand of mesh as displayed in Table 4. As the result difference was minimal, the team considered it negligible and decided to use a mix of last year's material and new material on *Paddlegonia*.

Table 4: Single Strand Reinforcement Test Results

SpiderLath Material	Strength (lb)
Last Year's Material	28.80
New Material	30.13

Figure 11: Single Strand Reinforcement Test

Sample beams were created by bonding the mesh at different overlap placement of the reinforcement mesh within Paddlegonia. The lengths of overlaps that were tested were 2, 4, and 6 inches. The sample beams showed that the structural mix bonded well with the SpiderLath at all three overlap lengths. For the placement on the canoe, the 6in overlap was chosen to account for an additional factor of safety and improved quality control due to easy measurements and calculations.

The major mesh placement was divided into three sections: an angled placement to help avoid transverse cracking, three long strips placed horizontally across the bottom of the canoe, and 4 inch strips along the gunwales for additional support. With this placement, only two locations would overlap at one time. The angled placement section was divided into 5 sections and placed across the whole canoe at a 45-degree angle. The 5 sections were cut by taking the whole roll of mesh over the mold, and cutting the mesh when both sides of the canoe were properly covered. The three horizontal strips went along the bottom of the canoe from end to end covering only 6 inches of the canoe to add additional reinforcing and minimize potential for cracking. The reinforcing mesh was also placed along the four ribs.

Post-tensioning was selected despite the potential for slightly higher strength from pre-stressing due to its ease to construct and reduced potential for error. The system was created with six symmetrically placed strands and of a 1/16 inch galvanized steel wire cable encased in 1/8 inch nylon tubing. The six strands were systematically placed and consisted of placing two wires on each of the sidewalls, and two wires along the bottom of the canoe. It was decided that the sidewalls would require higher additional strength because they are considered to along the weakest points of the canoe. The two wires placed along the bottom are for an additional factor of safety. While the wire placement was systematic, it was also symmetrically placed along both sides to avoid creating a bending moment that would cause the canoe to crack. Although the wires were not placed based on the geometric center, which is suggested to avoid cracking, the placement was intentionally offset to account for an eccentric moment. To apply tension to the canoe with both ends of canoe with the wire exposed, one side will be fully braced and the other side will be pulled after a 14-day curing data. This will be possible using a turnbuckle and a strain gauge on the side of interest.

Figure 12: Wire Placement

This design was chosen for ease of constructability and less potential for error in smaller workspaces. The team's post tensioning design differed from *Polaris* because they had their post tensioning wires engraved into foam pieces that required them to cut out larger chunks of their mold to place. The team decided to change the design, and have the wires placed into the concrete mix with just enough wire exposed to post tension to avoid potentially structurally weak points along the canoe after the tensioning. A projected 100 pounds of force will be applied to the canoe after the 14-day cure, after accounting for losses 70 pounds of force per wire is expected.

CONSTRUCTION

Paddlegonia's followed the example of both *Dreadnoughtus* and *Polaris*, who opted for hot wire cut molds. Rigid foam housing insulation was chosen as the substitute for the EPS foam blocks due to a cheaper unit cost and a known width of two inches per each block. Six blocks of insulating foam were bonded together using a spray adhesive to form a one-foot section. These sections were combined for the length of the canoe to form the entire canoe mold.

Figure 13: 1 Foot Section

Figure 14: Canoe Mold

The complicated cross sections for the canoe were fabricated using high-pressure water jet services. Detailed cross sectional drawings were used to cut precise cross sections with a high pressure water stream and laser guidance system. The benefit of having the cross sections cut via water jet technology allowed the sections to be cut quicker, and with more precision. After the pieces were cut with cross sections, they were wrapped in plastic to prevent the concrete from bonding to the mold.

Figure 15: Plastic Wrap

The mix process and placement method for pour day was determined based on the limited resources on hand. Hand tubs were placed on a table slightly below chest level. All cementitious materials, aggregates, and fibers for both the structural, and finishing mixes were pre-batched in 1 gallon freezer bags and placed on a shelf in organized rows. The mix process called for grabbing pre-batched kits described in QA/QC and following the hand method described in the testing and development section.

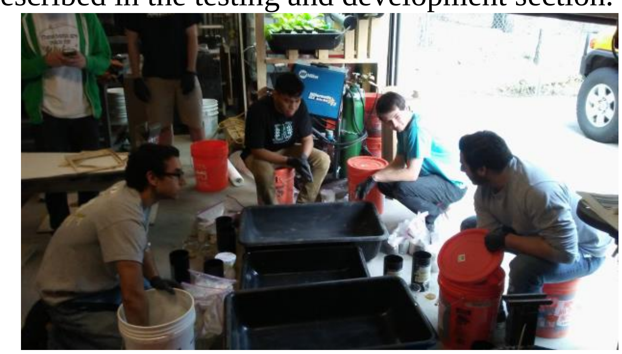


Figure 16: Hand Mix

Upon completion of the mixes, two separate methods for placing concrete on the mold were developed depending on mix type. The finishing was placed in an 8" x 8" x ⅛" wood mold and the excess concrete was immediately struck off to mold thickness using a damp trowel. This method was limited to two tile makers at a single time. A uniform thickness was achieved throughout the entire pour day because only two out of three total tilemakers were tasked with striking off to the planned thickness at a time. Strike off occurred while the molds were placed over a sheet of wax paper. Once the excess material was struck off and the tile was the appropriate lift thickness, the wax paper was transported to the canoe mold.

Figure 17: Tile Placement

The finishing team placed the tiles on the canoe and removed the wax paper. The middle structural mix was placed by hand in one layer and the mesh was then overlaid on it. With the mesh laid to the appropriate design plan, additional structural mix was placed by hand and rubbed in the open area on the mesh until the composite of the mesh was bonded between the two structural lifts and covered until no mesh was exposed.

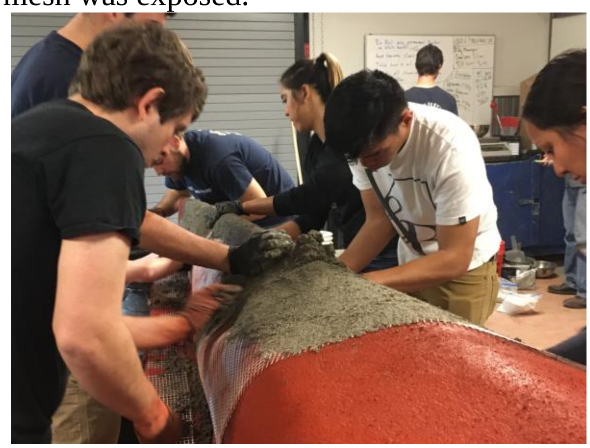


Figure 18: Structural Mix Placement

From here the 1/16” steel reinforcement was placed atop the structural mix and overlaid to finish with two color tones of finishing mix tiles using the same method as the first layer applied.

Upon final tile casting, a curing chamber was erected over the 22 foot long canoe stand that the casting was performed on. Utilizing simple wood pieces that attached to connected pegs on the construction stand, plastic was erected around the entire canoe. Velcro strips were added to the base of the stand and onto the plastic tarp so the entire plastic cover could be attached and detached from the stand with ease. Two small room humidifiers were placed at opposite ends of the stand and set to achieve a target relative humidity of 95% for 28 days. The target goal of 95% relative humidity gave the advantage of having an effective moist cure which would yield the maximum compressive, tensile, and flexural strengths in the canoe.

Figure 19: Curing Chamber

The rib sections were removed first which provided ample space to carefully remove the other sections.

Finishing for *Paddlegonia* utilized a wet sanding method to achieve a polished look. Two coats of clear sealer were applied to Paddlegonia over the placed stickers to protect them from the salt water during racing.

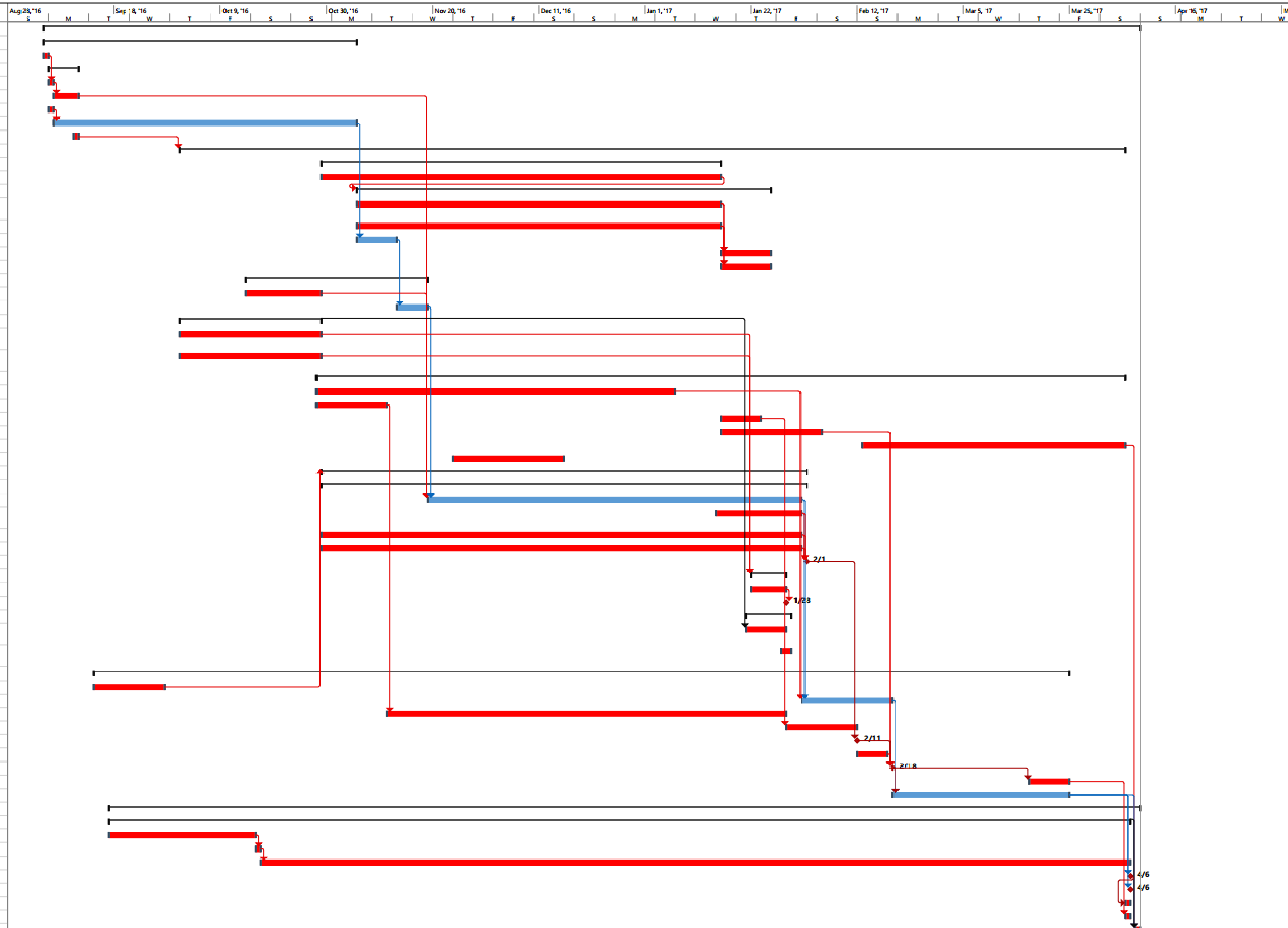
The aforementioned methods had definite effects on budget, schedule, and the safety of the construction process. Hand cutting the form molds required significantly more time than planned for mold construction, but the tradeoff was $3000 saved for materials and construction for CNC cuts. Purchasing dust masks was paramount to the pre-batching process as those who were batching out 3+ cubic feet of material into Ziploc bags were exposed to high levels of dust. Additionally, those hand cutting and sanding the form molds were exposed to high level of EPS foam particles and also required dust masks to avoid respiratory problems.

Large dollar amounts of the budget were needed for a new construction stand, curing chamber, and new cross sections to accommodate the new hull design. Because of this, construction of these elements was undertaken with a focus on sustainability for future canoe teams. Construction methods allowed each to be preserved from year to year to allow more focus for other technical elements of the mix design and structural analysis.

PADDLEGONIA

PROJECT SCHEDULE

ID	Task Name	Duration	Start
1	**NAU ASCE 2016-2017 Concrete Canoe**	**217 days**	**Sun 9/4/16**
2	**1.0 Project Management**	**62 days**	**Sun 9/4/16**
3	1.1 Concrete Canoe Team Set	1 day	Sun 9/4/16
4	**1.2 Project Preparation**	**6 days**	**Mon 9/5/16**
5	1.2.1 Safety Training	1 day	Mon 9/5/16
6	1.2.2 Building Access	5 days	Tue 9/6/16
7	1.3 Budgeting	1 day	Mon 9/5/16
8	1.4 Fundraising	60 days	Tue 9/6/16
9	1.5 ASCE Conference Rule Review	1 day	Sat 9/10/16
10	**2.0 Analysis and Design**	**187 days**	**Sat 10/1/16**
11	**2.1 Hull Analysis**	**79 days**	**Sat 10/29/16**
12	2.1.1 Buoyant Force	79 days	Sat 10/29/16
13	**2.2 Structural Analysis**	**82 days**	**Sat 11/5/16**
14	2.2.1 Shear and Moment Analysis, Cross Sectional Analysis	72 days	Sat 11/5/16
15	2.2.2 Flexural Capacity	72 days	Sat 11/5/16
16	2.2.3 2D/3D Analysis	8 days	Sat 11/5/16
17	2.2.4 Bulkhead Design	10 days	Mon 1/16/17
18	2.2.5 Rib Design	10 days	Mon 1/16/17
19	**2.3 Concrete Mix Design**	**36 days**	**Fri 10/14/16**
20	2.3.1 Material Research	15 days	Fri 10/14/16
21	2.3.2 Acquire Materials	6 days	Sun 11/13/16
22	**2.4 Reinforcement**	**28 days**	**Sat 10/1/16**
23	2.4.1 Research Reinforcement Materials	28 days	Sat 10/1/16
24	2.4.2 Research Post-tensioning Materials	28 days	Sat 10/1/16
25	**2.5 Construction Management**	**160 days**	**Fri 10/28/16**
26	2.5.1 Mold Re-design	71 days	Fri 10/28/16
27	2.5.2 Table Re-design	14 days	Fri 10/28/16
28	2.5.3 Incubator System Design	8 days	Mon 1/16/17
29	2.5.4 Pour Day Requirements	20 days	Mon 1/16/17
30	2.5.5 Canoe Transport Design	52 days	Mon 2/13/17
31	2.5.6 Post-tensioning Design	22 days	Thu 11/24/16
32	**3.0 Testing**	**96 days**	**Sat 10/29/16**
33	**3.1 Concrete Mix Design**	**96 days**	**Sat 10/29/16**
34	3.1.1 Concrete Mixing and Testing	74 days	Sat 11/19/16
35	3.1.2 Concrete Stain and Pigmentation	17 days	Sun 1/15/17
36	3.1.3 Flexural Testing	95 days	Sat 10/29/16
37	3.1.4 Tensile Testing	95 days	Sat 10/29/16
38	3.1.5 Mix Design Selection	1 day	Wed 2/1/17
39	**3.2 Reinforcement**	**7 days**	**Sun 1/22/17**
40	3.2.1 Reinforcement Testing	7 days	Sun 1/22/17
41	3.2.2 Reinforcement Selection	1 day	Sat 1/28/17
42	**3.3 Composite Testing and Design**	**9 days**	**Sat 1/21/17**
43	3.3.1 Concrete with Reinforcement Testing	8 days	Sat 1/21/17
44	3.3.2 Post-tensioning Anchorage System Testing	2 days	Sat 1/28/17
45	**4.0 Construction**	**193 days**	**Wed 9/14/16**
46	4.1 Inventory and Farm Clean-up	14 days	Wed 9/14/16
47	4.2 Mold Fabrication	18 days	Wed 2/1/17
48	4.3 Table Renovation	79 days	Fri 11/11/16
49	4.4 Incubator Construction	14 days	Sun 1/29/17
50	4.5 Test Pouring	1 day	Sat 2/11/17
51	4.6 Final Mix/Batch Preparation	6 days	Sun 2/12/17
52	4.7 Canoe Pour	1 day	Sat 2/18/17
53	4.8 Canoe Artwork and Design	8 days	Sat 3/18/17
54	4.9 Canoe Finishing	35 days	Sun 2/19/17
55	**5.0 ASCE PSWC Conference**	**204 days**	**Sat 9/17/16**
56	**5.1 Paddling**	**202 days**	**Sat 9/17/16**
57	5.1.1 Start Paddling Practice	29 days	Sat 9/17/16
58	5.1.2 Select Teams and Positions	1 day	Sun 10/16/16
59	5.1.3 Continue Paddling Practice	172 days	Mon 10/17/16
60	5.2 Design Report	1 day	Thu 4/6/17
61	5.3 Engineer's Notebook	1 day	Thu 4/6/17
62	5.4 Presentation Day	1 day	Thu 4/6/17
63	5.5 Final Product Display	1 day	Thu 4/6/17
64	5.6 Canoe Races	1 day	Sat 4/8/17

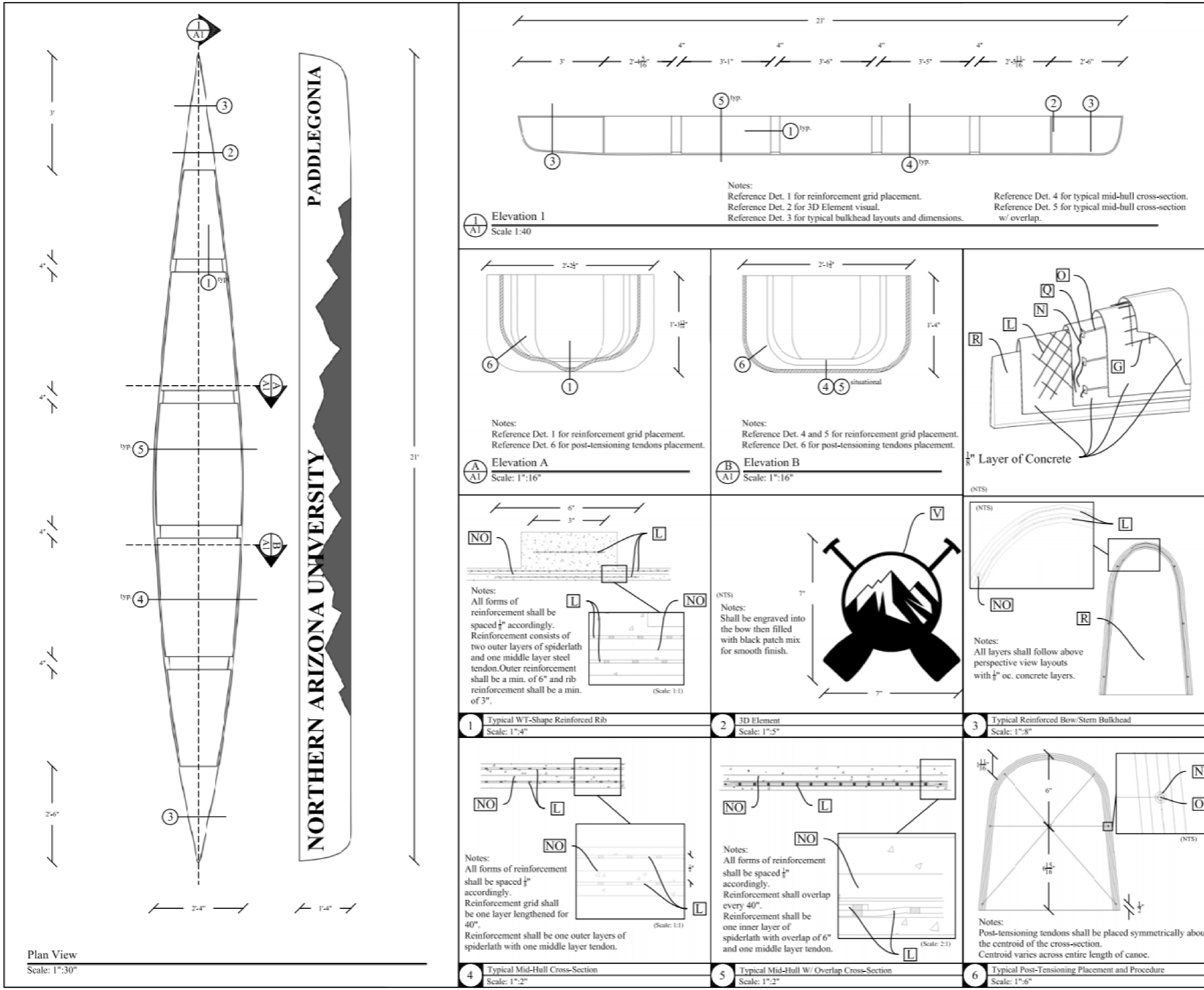


Project: Paddlegonia 2016-2017
Date: Thu 3/2/17

Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Progress, Manual Progress

PADDLEGONIA

CONSTRUCTION DRAWING



Bill of Materials:

Item No.	Item Description	Quantity	Unit
	Concrete Constituents		
A	CalPortland Gray Portland Type I Cement	57	LB
B	Boral Class F Fly Ash	26	LB
C	Trinity Lightweight Aggrigate #1 Sand	41	LB
D	Poraver 0.1-0.5mm	20	LB
E	Poraver 0.5-1.0mm	24	LB
F	Poraver 1.0-2.0mm	20	LB
G	BASF MasterGlenium 7500	1.3	LB
H	Master Set Delvo	0.3	LB
I	Master Life SRA 20	0.1	LB
J	MasterAir AE 90	0.01	LB
K	BASF MasterColor (Medium Red and Black)	11	LB
	Reinforcement/ Post Tensioning		
L	SpiderLath Fiberglass Mesh	110	FT^2
M	3/4" BASF MasterFiber M 100 Fibers	0	LB
N	1/16" Galvanized Steel Cable	150	LF
O	1/8" Parflex Nylon Tubing	150	LF
P	13/64" Zinc-plated Copper Button Stops	12	EA
Q	1/8" x 1/8" x 1" Steel Bearing Plates	12	EA
	Floatation		
R	2" x 4" x 8" R-Tech Foam Sheet	2	EA
	Mold		
S	2" x 4" R-Tech Foam Sheets	15	EA
T	BASF Spray Adheive	1/2	GAL
U	Uline Plastic Shrink Wrap	100	FT^2
V	Bulk Head Element	1	EA
	Strongback		
W	Wooden Alignment	1	EA
X	Rotating Steel Plate	4	EA
Y	1/2" Bolt	2	EA
Z	3/8" Bolt	2	EA
a	Wood 2x4	120	LF
b	Wood 2x6	64	LF
	Finishing		
c	Pro-Release Sealer	2	GAL

General Notes:

Canoe Parameters:
- Max length shall be 252"
- Max hull thickness shall be 0.5"
- Max width shall be 28"

Reinforcement:
- Reinforcement shall be a combination of Spiderlath Fiberglass Mesh and (6) 1/16" galvanized steel cables
- Reinforcement shall be spaced 1/8" oc. from each other
- Reinforcement mesh shall have a min. percent opening of 40%
- Total reinforcement thickness shall not exceed half the hull thickness

Concrete:
- Concrete shall have a slump of 1" to 2"
- Concrete shall have a 28-day compression strength of 1750 psi
- Layers of concrete shall be sprayed at 1/8" layers
- Clear cover shall be at minimum 1/8" to maintain sufficient bonding

Post-Tensioning System:
- Shall be able to hold tensioning each tendon to 85 *lbs* without buckling.
- Order to tension each tendon is as follows:
  - top-left tendon
  - bottom-right tendon
  - top-right tendon
  - bottom-left tendon
  - middle-right tendon
  - middle-left tendon

Revised By: | Rev. No. | Date | Rev. Details

PADDLEGONIA

Address: Engineering Bldg, 2112 S Huffer Ln, Flagstaff, AZ 86011

Northern Arizona University

Concrete Canoe: Construction Plan

Drawn By: SMC
Date Drawn: 2/26/17
Reviewed By:
Date Reviewed:

Sheet: A1
Of: A1

APPENDIX A- REFERENCES

American Concrete Institute. (2014). *Building Code Requirements for Structural Concrete and Commentary*. Farmington Hill, MI: American Concrete Institute.

ASTM. (2004). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. *ASTM C496 / C496M-11*. West Conshohocken, PA: ASTM International.

ASTM. (2011). Standard Performance Specification for Hydraulic Cement. *ASTM C1157 / C1157M-11*. West Conshohocken, PA: ASTM International.

ASTM. (2014). Standard Specification for Lightweight Aggregates for Structural Concrete. *ASTM C330 / C330M-14*. West Conshohocken, PA: ASTM International.

ASTM. (2015). Standard Practice for Making and Curing Concrete Test Specimens in the Field. *ASTM C31 / C31M-15ae1*. West Conshohocken, PA: ASTM International.

ASTM. (2015). Standard Specification for Fiber-Reinforced Concrete. *ASTM C1116 / C1116M-10a*. West Conshohocken, PA: ASTM International.

ASTM. (2015). Standard Test Method for Slump of Hydraulic-Cement Concrete. *ASTM C143 / C143M-15a*. West Conshohocken, PA: ASTM International.

ASTM. (2016). Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. *ASTM C39 / C39M-16b*. West Conshohocken, PA: ASTM International.

ASTM. (2016). Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete. *ASTM C138 / C138M-16a*. West Conshohocken, PA: ASTM International.

ASTM. (2016). Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). *ASTM C78 / C78M-16*. West Conshohocken, PA: ASTM International.

Canoe Design. (2013). Retrieved from Canoe Guide: http://www.canoeing.com/canoes/choosing/design.htm

Northern Arizona University. (2015). *Dreadnoughtus.* NCCC Design Paper. Flagstaff: Northern Arizona University.

Northern Arizona University. (2016). *Polaris.* NCCC Design Paper. Flagstaff: Northern Arizona University.

Post-Tensioning Friction & Anchor Set Losses. (n.d.). Retrieved from Ut Tensio, Sic Vis: http://utsv.net/prestressed-concrete/5-post-tensioning-friction-anchor-set-losses

SpiderLath Testing and Documents. (2007). Retrieved from SpiderLath: http://spiderlath.com/test.html

Steve Kosmatka et al. (2002). Design and Control of Concrete Mixtures,. *15*. Skokie, IL: Portland cement Association.

PADDLEGONIA

APPENDIX B- MIXTURE PROPORTIONS

MIXTURE DESIGNATION: STRUCTURAL/COMPOSITE

CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Gray Portland Cement, Type I	3.15	2.04	400.00	Total Amount of cementitious materials 600.0 lb/yd^3 c/cm ratio 0.67
Fly Ash, Class F	2.30	1.39	200.00	

FIBERS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of Fibers (mass/volume) (lb/yd^3)*	
MasterFiber M 100 Microfibers	1.80	0.004	0.50	Total Amount of Fibers 0.50 lb/yd^3

AGGREGATES

Aggregates	*ASTM C330**	*Abs (%)*	*MC_{stk} (%)*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*$Volume_{SSD}$, (ft^3)*	*Batch Quantity (at MC_{stk}) (lb/yd^3)*
					OD	*SSD*		
Trinity Lightweight #1 Sand	Y	8	10	1.30	400	432	4.93	401
Poraver 1mm – 2mm		20	50	0.40	100	120	4.01	101
Poraver 0.5mm – 1mm		20	50	0.50	100	120	3.21	101
Poraver 0.1mm – 0.5mm		32	50	0.70	200	264	4.58	201

ADMIXTURES

Admixture	*lb/gal*	*Dosage (fl.oz/cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
Set Retarder	9.9	4	14	1.60	Total Water from Admixtures, $\sum w_{admx}$ 4.70 lb/yd^3
High Range Water Reducer	9.1	8	26	2.51	
Shrinkage Reducer	7.6	3	80	0.21	
Air Entraining Admixture	8.5	1	6	0.37	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
N/A	N/A	N/A	N/A	Total Solids from Admixtures N/A lb/yd^3

WATER

	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		w: 240.0	3.85
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: 135.0	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: 4.7	
Batch Water, lb/yd^3		w_{batch}: 235.3	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	600.0	0.5	800.0	6.7	370.0	$\sum$M: 1777.5
Absolute Volume of Concrete, V, (ft^3)	3.430	0.004	16.720	0.100	5.934	$\sum$V: 26.12
Theoretical Density, T, *(=∑M / ∑V)*	73.96	lb/ft^3	***Air Content*** *[= (T – D)/T x 100%]*			11.0 %
Measured Density, D	65.83	lb/ft^3	***Slump, Slump flow***			1.0 in.
water/cement ratio, w/c:	0.93		***water/cementitious material ratio, w/cm:***			0.61

PADDLEGONIA

MIXTURE DESIGNATION: FINISHING MIX (RED AND BLACK COLORING)

CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (ft³)*	*Amount of CM (mass/volume) (lb/yd³)*	
Gray Portland Cement, Type I	3.15	2.04	450.00	Total Amount of cementitious materials 650.0 lb/yd³ c/cm ratio 0.67
Fly Ash, Class F	2.30	1.39	200.00	

FIBERS

Component	*Specific Gravity*	*Volume (ft³)*	*Amount of Fibers (mass/volume) (lb/yd³)*	
MasterFiber M 100 Microfibers	1.80	0.004	0.50	Total Amount of Fibers 0.50 lb/yd³

AGGREGATES

Aggregates	*ASTM C330**	*Abs (%)*	*MC_{stk} (%)*	*SG_{SSD}*	*Base Quantity (lb/yd³)*		*$Volume_{SSD}$, (ft³)*	*Batch Quantity (at MC_{stk}) (lb/yd³)*
					OD	*SSD*		
Trinity Lightweight #1 Sand	Y	8	10	1.30	300	324	3.70	400
Poraver 0.5mm – 1mm		20	50	0.50	200	240	6.41	201
Poraver 0.1mm – 0.5mm		32	50	0.70	150	180	3.43	151

ADMIXTURES

Admixture	*lb/gal*	*Dosage (fl.oz/cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd³)*	
Set Retarder	9.9	4	14	1.73	Total Water from Admixtures, $\sum w_{admx}$ 54.05 lb/yd³
High Range Water Reducer	9.1	8	26	2.72	
Shrinkage Reducer	7.6	3	80	0.23	
Liquid Coloring Admixture	16.7	112	48	49.36	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)

Component	*Specific Gravity*	*Volume (ft³)*	*Amount (mass/volume) (lb/yd³)*	
N/A	N/A	N/A	N/A	Total Solids from Admixtures N/A lb/yd³

WATER

		Amount (mass/volume) (lb/yd³)	*Volume (ft³)*
Water, lb/yd³		w: 260.0	4.17
Total Free Water from All Aggregates, lb/yd³		$\sum w_{free}$: 111.3	
Total Water from All Admixtures, lb/yd³		$\sum w_{admx}$: 54.1	
Batch Water, lb/yd³		w_{batch}: 206.0	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	650.0	0.5	650.0	101.8	317.2	∑M: 1709.5
Absolute Volume of Concrete, V, (ft³)	16.22	0.02	59.63	1.76	22.38	∑V: 100.0
***Theoretical Density, T,** (=∑M / ∑V)*	78.89	lb/ft³	***Air Content** [= (T – D)/T x 100%]*			19.3 %
Measured Density, D	63.68	lb/ft³	***Slump, Slump flow***			1.0 in.
water/cement ratio, w/c:	0.70		***water/cementitious material ratio, w/cm:***			0.49

APPENDIX C- EXAMPLE STRUCTURAL CALCULATION

Assumptions:

1. The canoe is analyzed as a 252in simply supported beam with paddlers (175lb each) as point loads.
2. The paddlers are located as close to the bow and stern as realistic possible.
3. The self-weight (200lb) of the canoe and the buoyant force are linearly distributed loads across the beam.
4. Cross section 11 (129in from the bow) will be analyzed because it is the location of the max moment determined in the teams excels for this scenario.

Cross Section

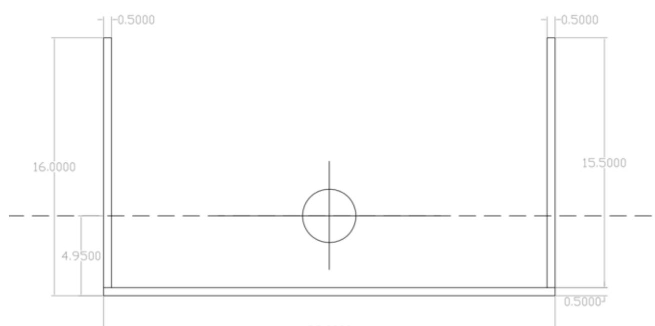
Centroid ($\bar{y}_{11}$)

$$\bar{y}_{11} = \frac{\sum_{i=1}^{N} yA}{\sum_{i=1}^{N} \mathrm{A}} = \frac{\left(0.5\text{in}*28in*\left(\frac{0.5}{2}\right)\right)+2\left(0.5in*15.5in*\left(\left(\frac{15.5in}{2}\right)+0.5in\right)\right)}{(0.5in*28in)+2(0.5in*15.5in)} = 4.45in$$

Moment Of Inertia (I_{x_11})

$$I_{x\_11} = \sum_{i=1}^{N} I + \sum_{i=1}^{N} \mathrm{A}dy^2 \qquad I = \frac{bh^3}{12}$$

$$= \frac{(0.5in)^3*28in}{12} + \left(0.5in*28in*\left(4.45in - \left(\frac{0.5in}{2}\right)\right)^2\right) + 2*\left(\frac{(15.5in)^3*0.5in}{12} + \left(0.5in*15.5in*\left(4.45in - \left(\frac{15.5in}{2}\right)\right)^2\right)\right) = 726.37in^4$$



Loads

Canoe Self-Weight (W_c)=Area Of Concrete (A_c)*Unit Weight Concrete (Υ_C)

$$W_c = 200lb \qquad W_c = \frac{200lb}{252in} = 0.79lb/in$$

Weight Of The System (W_{sys})= $\sum_{i=1}^{N} All\ Forces$

$$W_{sys} = 200lb + 175lb + 175lb = 550\ lb$$

Buoyant Force (W_B)= Weight Of The System (W_{sys})/Length Of Beam

$$W_B = \frac{550lb}{252in} = 2.18lb/in$$

Reaction R_A and R_B

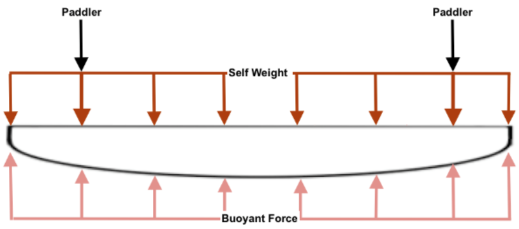
$$+\uparrow \sum_{i=1}^{N} M_A = 0 = \left(550lb*\frac{252in}{2}\right) - (175lb*36in) - (175lb*222in) - \left(200lb*\frac{252in}{2}\right) + (R_B*252in)$$

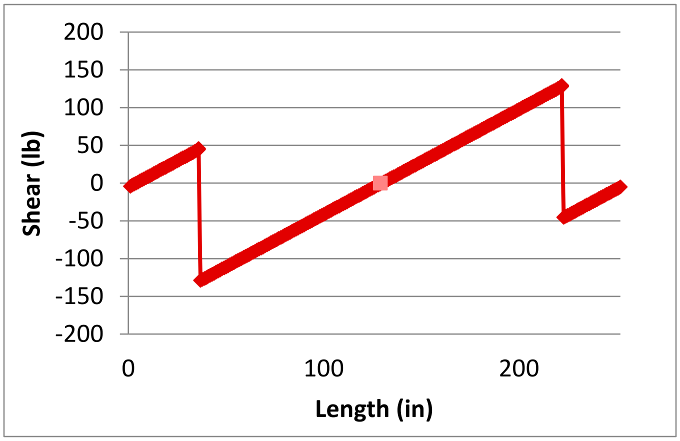
$$R_B = 4.17\ \mathrm{lb}$$

$$+\uparrow \sum_{i=1}^{N} M_B = 0 = \left(550lb * \frac{252in}{2}\right) - (175lb * 216in) - (175lb * 30in) - \left(200lb * \frac{252in}{2}\right) + (R_A * 252in)$$

$$R_A = -4.17 \text{ lb}$$

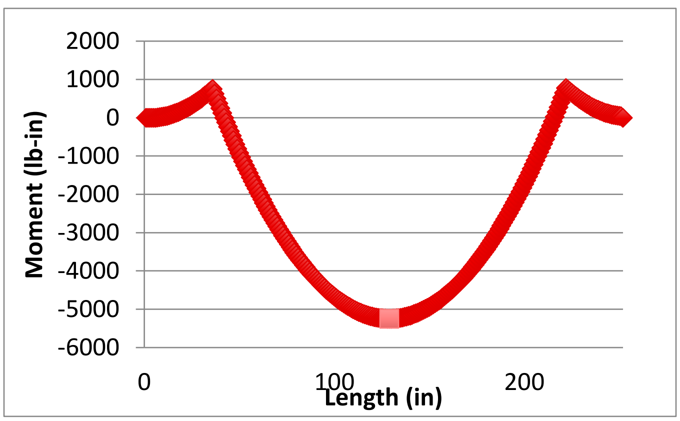
Shear and Moment





Shear (V_{11})= $\sum_{i=1}^{N} All\ Forces$

$$V_{11} = -4.17lb - 175lb - \left(\frac{200lb}{252in}\right) * 129in + \left(\frac{550lb}{252in}\right) * 129in = \mathbf{-0.07\ lb}$$



Moment (M_{11})= $\sum_{i=1}^{N}(All\ Forces * Distance)$

$$M_{11} = -4.17lb * 129in - 175lb * 93in - \left(\frac{200lb}{252in}\right) * 129in * 64.5 + \left(\frac{550lb}{252in}\right) * 129in * 64.5 = \mathbf{-5260lb\ in}$$

Shear Stress (τ_{11})

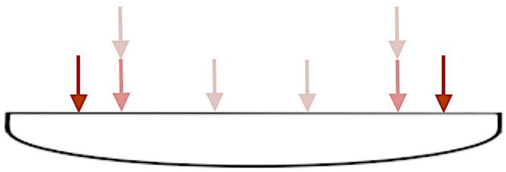
$$\tau_{11} = \frac{V_{129in}}{A_c} = \frac{0.14lb}{29in^2} = 0.002\ psi$$

Longitudinal Stress (σ_{11})

$$\sigma_{T\_11} = \frac{M_{11} * \bar{y}_{bot}}{I_x} = \frac{-5260lb\ in * (4.45in - 16in)}{726.37in^4} = \mathbf{83.6psi}\ \text{(83.6psi in T)}$$

$$\sigma_{C\_11} = \frac{M_{11} * \bar{y}_{top}}{I_x} = \frac{-5260lb\ in * 4.45in}{726.37in^4} = \mathbf{-32.2psi}\ \text{(32.2 in C)}$$

Scenario Result Comparison



Moment Results

Scenario	Moment (lb in)
Bow-Stern	-5260
2-Person	2164
4-Person	6447

Stress Results

Scenario	Tensile Stress (σ_T) psi	Compression Stress (σ_C) psi
Bow-Stern	32.2	83.6
2-Person	34.4	13.3
4-Person	102.5	39.5

APPENDIX D- HULL THICKNESS/ REINFORCEMENT AND PERCENT OPEN AREA CALCULATIONS

Given: Reinforcement thickness
T_{mesh}= .032 inches (per the glass test found in the Concrete Canoe Rules and Regulations)
$T_{post\text{-}tensioning}$= .125 inches (.0625 steel wire enclosed in .125 nylon tube)
Find: all Hull locations to be less than 50%
1.) Canoe Walls (Red and Blue lines on Figure)
Hull Thickness = .5 inches
Reinforcement Thickness (1 layer) = .032 inches x 1 layer = .032 inches
Post Tensioning= .125 inches
Reinforcement %= $\frac{.032+.125}{.5}\ x\ 100\% = 31.4\% < 50\%, okay$
2.) Keel including 6 in overlaps (Includes the Yellow and Red on Figure)
Hull Thickness = .5 inches
Reinforcement Thickness (2 layer) = .032 inches x 3 layer = .096 inches
Post Tensioning= .125 inches
Reinforcement %= $\frac{.096+.125}{.5}\ x\ 100\% = 44.2\% < 50\%, okay$
3.) Gunwale including overlaps (includes the Red and Green in the Figure)
Hull Thickness = .5 inches
Reinforcement Thickness (2 layers) = .032 inches x layer = .064 inches
Post Tensioning Not present in Gunwale
Reinforcement %= $\frac{.064+.125}{.5}\ x\ 100\% = 37.8\% < 50\%, okay$
4.) Ribs (Section inside canoe, not on Figure)
Hull Thickness = .5 inches
Rib Thickness at all sides= 3 inches
Reinforcement Thickness= .032 inches x 1 layer = .032 inches
Post Tensioning= .125 inches
Reinforcement %= $\frac{.032+.125}{3+.5}\ x\ 100\% = 4.4\% < 50\%, okay$
5.) Bulkhead (includes Red on Figure)
Hull Thickness = .5 inches
Reinforcement Thickness (1 layer) = .032 inches x 1 layer = .032 inches
No Post Tensioning in bulkhead
Reinforcement %= $\frac{.032}{.5}\ x\ 100\% = 6.4\% < 50\%, okay$
6.) Post Tensioning System (Blue lines on Figure)
Hull Thickness = 2 inches
Flat Washer = .5 inches
Post Tensioning= .125 inches
Reinforcement %= $\frac{.5+.125}{2}\ x\ 100\% = 31.25\% < 50\%, okay$

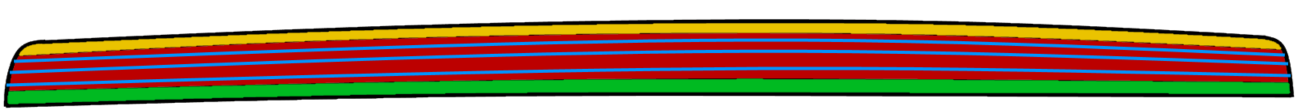


Figure 1: Schematic of Mesh Placement: (yellow - keel) (blue - post-tensioning wires) (red - wall of canoe) (green - gunwale)

PADDLEGONIA

Percent Open Area Calculations

Given: $POA = \frac{\sum Area_{open}}{Area_{Total}}\ x\ 100\%$

n_1=number of apertures along sample length d_1=spacing of reinforcing along length (center to center)
n_2= number of apertures along sample width d_1=spacing of reinforcing along width (center to center)
t_1=thickness along length t_2=thickness along width
Aperture dimensions= .25 inches (from technical data sheet)

Find: POA to be greater than 40%

t_1=.045 inches t_2= 0.085 inches
n_1=n_2= 12
d_1= aperture dimensions + $2(\frac{t_1}{2})$ = .25in+ $2(\frac{.045}{2})$ = 0.295 inches
d_2= aperture dimensions + $2(\frac{t_2}{2})$ = .25in+ $2(\frac{.085}{2})$ = 0.335 inches

$Length_{sample}$= $n_1 d_1$ = 12 x .0295 inches= <u>3.54 inches</u>

$Width_{sample}$= $n_2 d_2$= 12 x .335 inches= <u>4.02 inches</u>

$\sum Area_{open} = n_1 n_2 Area_{open}$= 12 x 12 x (.25 in x .25 in) = 9 $inches^2$

$Area_{total} = Length_{sample} Width_{Sample}$ =4.02 in x 3.54 in= 14.23 $inches^2$

$POA = \frac{\sum Area_{open}}{Area_{Total}} x100\% = \frac{9}{14.23}$= 63.24%

<u>POA = 63.24% > 40% so okay</u>