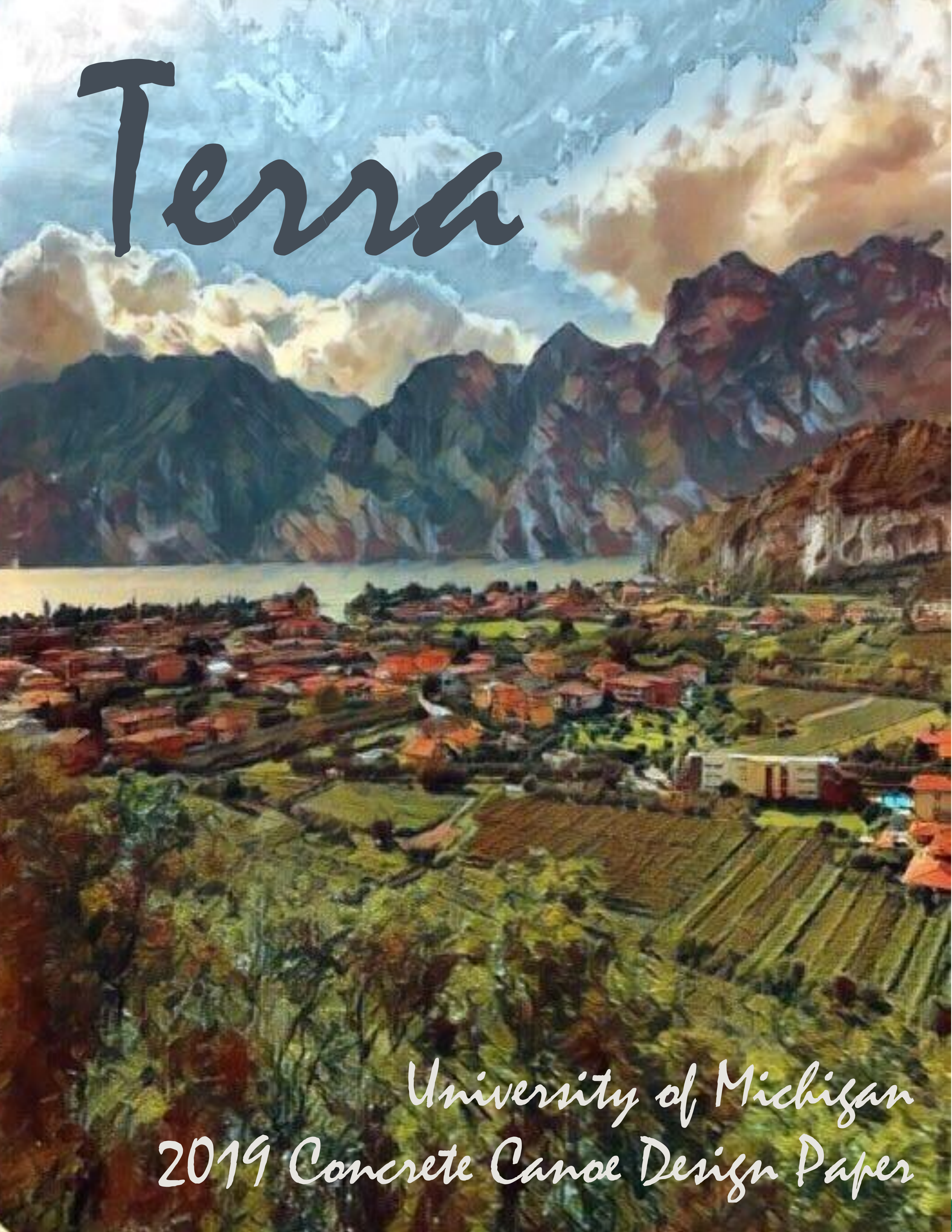
Terra



University of Michigan
2019 Concrete Canoe Design Paper

Table of Contents

List of Appendices

List of Tables

List of Figures

Executive Summary

For centuries the Italian Peninsula has been a cradle for advancements in science and engineering. Visionaries throughout history left their mark on many academic disciplines, among the most important being civil engineering. From the Roman Empire's use of aqueducts to the construction of *Il Duomo*, various mathematicians, architects, and engineers alike advanced the field of civil engineering to new boundaries. Following in their footsteps, the Michigan Concrete Canoe Team (MCCT) strives to reach new heights as the Leaders and Best in all challenges we face. As a tribute to the land that cultivated such great minds as Vitruvius, Brunelleschi, and Da Vinci, the 2019 canoe, *TERRA*, emulates the environment that fostered great discoveries and advancements in engineering. Inspired by art and architectural works of the University's Kelsey Archeological Museum, MCCT hopes to celebrate the rich history and culture of the Italian countryside whose beliefs of innovation and excellence have fostered generations of continued progress in engineering to the benefit of all.

The University of Michigan was founded in 1817 and is located in Ann Arbor, Michigan. The University is well known for its exceptional engineering programs and research institutions (National Science Foundation, 2017). As part of the College of Engineering, MCCT embodies the strategic mission of the college through all aspects of our work, empowering our members to "challenge the present and enrich the future" (Michigan Engineering, Strategic Vision). The Michigan Concrete Canoe Team competes annually in the ASCE North Central Regional Conference. The past three years have been by far the team's best and have seen increasing improvement with the 2018 canoe, *MAJESTY*, placing first in the regional competition, the 2017 canoe, *VALIANT*, placing second, and the 2016 canoe, *EXTINCTION*, placing third. The considerable upward trend can be attributed to the dedication of all members of MCCT and the excellent knowledge transfer from experienced members to those who are the future of the team.

After the departure of much of the team's past leadership, project management for 2019 focused on training our new leaders and iterating on past year's progress to create a high-quality final project. Technical leads, trained under leadership from 2018, set goals to improve upon the 2018 canoe, *MAJESTY*, while maintaining compliance with the 2019 NCCC Rules and Regulations. Project management maintained strict adherence to the project schedule, guided technical leads through the design phase, and ensured quality control was maintained during construction.

To achieve a lightweight, ASTM C330 compliant concrete, the mix design team modified the design process to streamline the testing process, and incorporated new, locally sourced materials to decrease the team's environmental impact. Hull leads used paddler feedback to increase paddler comfort and decrease the tipping angle. To increase paddler familiarity with the parameters of *TERRA*, hull leads also created the team's first fiberglass practice canoe to mimic race day conditions. Additionally, aesthetics and construction subteams worked more diligently throughout the year to create MCCT's best display to date. Much like the architectural and engineering achievements of Italy, the Michigan Concrete Canoe Team has worked diligently yet efficiently to present its 2019 canoe, *TERRA*.

Table 1. Canoe Specifications

TERRA				
			Structural Mix	*Finishing Mix*
Weight	214 lb	Compressive Strength	1025 psi	N/A
Length	248 inches	Split Tensile Strength	243 psi	N/A
Width	28.85 inches	Flexural Strength	240 psi	N/A
Depth	13 inches	Concrete Colors	Grey	Green, Brown, Purple, Pink
Average Hull Thickness	0.82 inches	Concrete Unit Weight	55.34 lb/ft^3 (dry) 58.44 lb/ft^3 (wet)	88.50 lb/ft^3 (dry) 90.86 lb/ft^3 (wet)
Reinforcement	Fiberglass Mesh 6mm, 8mm, 12mm PVA Fibers	Air Content	12.0 %	28.2 %

Hull Design and Structural Analysis

With *MAJESTY*'s successful performance in 2018, MCCT's Hull Design team used multiple approaches to modify last year's canoe in order to improve at the 2019 competition, including data driven design and qualitative feedback approaches.

Hull design project goals included the recruitment of new talent, teaching the principles of design and useful software tools, and improving this year's canoe. New members became familiarized with the process of designing the hull and had a direct impact on the final design. The goals for the canoe design this year were to improve tracking and minimize rolling while maintaining the freeboard, turning, and amount of pitching.

During the 2017 season, the team began relying on computer aided two-dimensional hydrostatics calculations for hull analysis through Maxsurf Stability Suite (Maxsurf 2017). Since the team was more than satisfied with *MAJESTY*'s performance, the hull design team incorporated significantly more feedback from the paddlers which gave insight into potential focus areas for design. The team then implemented these changes on Rhinoceros 5.0 (Rhinoceros, 2017). *MAJESTY* was applauded for its tracking, turning, and ergonomics by the paddlers. It suffered because it had a high amount of rolling for two reasons: *MAJESTY*'s small beam length and the inexperience of the paddlers.

From paddler feedback, it was determined that the balance of turning and tracking on *MAJESTY* was a great advantage over previous hulls. However, the opportunity cost to this design feature was more rolling and a smaller maximum angle of heel. To achieve the desired design modifications and make sure experienced paddlers were still familiar with the hull shape, the overall cross sectional profile was retained while the beam and length were modified from *MAJESTY*.

Team members made hull modifications to *MAJESTY* in Rhinoceros 5.0 and used its hydrostatics features to extract values for various parameters. For example, volume of displacement and wetted surface area were found for each Rhinoceros model. The team iterated by length every two (2) inches from negative four (4) to positive four (4) from *MAJESTY*'s length and iterated by width every inch from negative two to positive three inches from *MAJESTY*'s width. These iterated models were transferred into Maxsurf Stability Suite to find values for other parameters, such as maximum bending moment and righting lever using two-dimensional analysis. These values were compared to find the best balance to accomplish this year's goals for the hull.

The team kept the center of gravity low, but maintained a similar Block Coefficient, C_B (MCCT, 2018). To maintain the speed of the vessel, the team augmented the length to maintain a similar Length-to-Beam Ratio. The increase in length and beam length resulted in an increase in stability without sacrificing the top speed of the canoe.

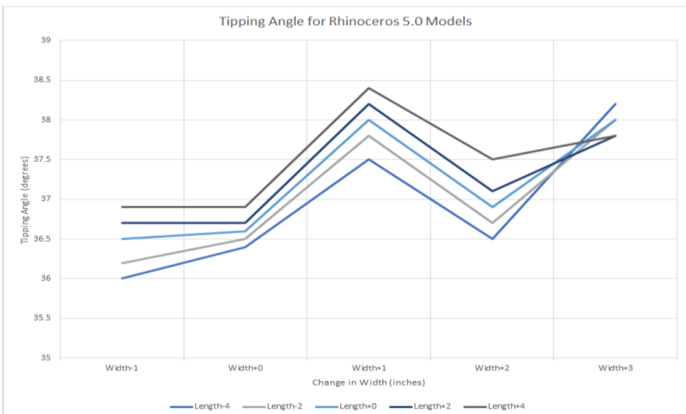
Figure 1. Paddling at national competition

TERRA featured similar geometry to *MAJESTY* with a U-shaped hull for stability and a sharp, square bow to pierce through the water. In the final design, the maximum beam of the vessel was increased by one (1) inch to 28.85 inches while the length was increased by four (4) inches to 20 feet 8 inches. TERRA's depth was retained from *MAJESTY*'s hull because it provided a desirable freeboard that did not produce a noticeable wind heel arm and provided sufficient paddler comfort (MCCT, 2018).

MCCT used G_{MT} and GZ curves to identify the stability of the canoe. This year's iterations were compared to values from previous years. Metacentric height, G_{MT}, is a measure of the distance from the center of gravity to the intersection of the vertical line of gravity and the line of buoyancy. Righting Lever, GZ, is the perpendicular distance from the line of buoyancy to the center of gravity. G_{MT} is used for small angles of roll, and GZ is used for large angles of roll. As G_{MT} and GZ grow, the righting lever increases. This is because the distance between the center of buoyancy and the center of gravity grows larger. This means that the buoyant force produces a greater moment that acts on the center of gravity. This righting lever acts in the opposite direction as the roll and serves to keep the canoe in an upright position.

The Hull design team found that increasing the length produced a slightly greater righting lever. Increasing the length also improves tracking ability, but can produce the drawback of larger bending moments inside the canoe, which could result in cracking (MCCT, 2018). However, the team did more analysis using Maxsurf Stability Suite and discovered that the maximum bending moment changed from 504.5 ft lb to 500.1 ft lb and was therefore negligible.

Table 2. Tipping Angle



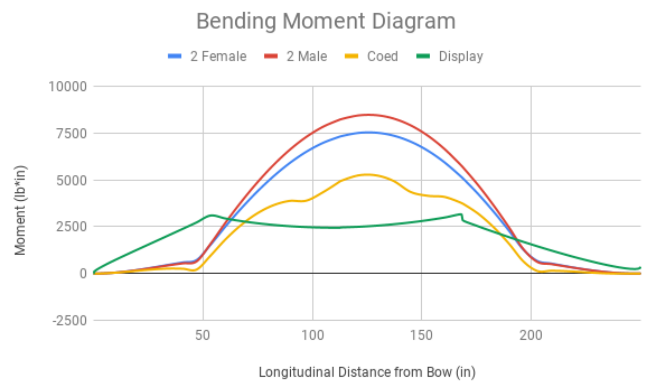
Five load cases were used to analyze the structural integrity of the canoe. The load cases consisted of two males, two females, four coed paddlers, two display stands, and transportation. The transportation load case was assumed to have a moment of zero throughout the entirety of the canoe, because of the support from the form fitting mold pieces.

Table 3. Male Paddler Load Case

Male Paddler Load Case	2018	2019
Maximum Bending Moment (ft*lb)	504.50	500.10
Tipping Angle (degree)	36.60	38.40
Righting Lever at Tipping Angle (in)	2.94	3.40
Prismatic Coefficient	0.580	0.552
Block Coefficient	0.44	0.45

MCCT approximated Frictional Resistance Coefficient by employing the skin friction line developed by the International Towing Tank Conference with the assumption that the hull would be smooth after sealing (ITTC 1978).

Table 4. Bending Moment Diagram



This year, hull design created a fiberglass version of the canoe. It was formed from layers of fiberglass and epoxy that were reinforced with wooden ribbing. The fiberglass canoe was formed on top of *VALIANT*, the 2017 canoe. *VALIANT* and *TERRA* have the same cross sectional shape with slightly different dimensions. This innovation helps MCCT because paddlers can bring the fiberglass canoe to pools and tanks to practice in a canoe similar to the one which they will race at competitions. This helped the team train more experienced paddlers that would already be familiar with how *TERRA* moves in the water.

Figure 2. Hull design leads test practice canoe for leaks

Development and Testing

The structural mix for this year's canoe was based on the 2018 mix used in *MAJESTY* as it demonstrated desirable strengths and buoyancy with newly incorporated materials (MCCT, 2018). Although the 2018 mix used an ASTM C330 compliant natural aggregate, the reported specific gravity for the Haydite expanded shale was determined to be incorrect. This resulted in the mix not satisfying the minimum natural aggregate requirement. The main goals of the concrete design team this year, therefore, were to increase the amount of natural aggregate and fulfill the mineral filler rule while adjusting various characteristics and materials to optimize the resulting strength and buoyancy.

To accomplish these goals, different aspects of the mix were iteratively adjusted until the concrete demonstrated the desired qualities. New materials were tested and used in the concrete including Fly Ash Class C and Tylac 4191 Liquid Latex Modifier. These were chosen by considering sustainability, specific gravity, compliance with the rules, and reported effectiveness.

The structural mix for *TERRA* retained many of the same components from *MAJESTY*'s concrete mix. Portland cement was the main cementitious material used while VCAS 160 was retained as an environmentally sustainable substitute for the cement. Komponent was also used as a substitute to prevent shrinkage cracking during the curing process. Fly Ash Class C was newly incorporated as a replacement to the Ground Granulated Blast Furnace Slag (GGBFS) that was used for *MAJESTY*.

The 2019 concrete mix incorporated the same aggregates that were used for *MAJESTY* as these components demonstrated desirable low specific gravities and were favorable due to the team's familiarity of the materials (Table 5). Three different sizes of Poraver were chosen to create a smooth gradation and to increase workability and strength. SG-300 and K20 were incorporated as both aggregates and mineral fillers, chosen for their small particle sizes that could contribute to the steady gradation of aggregates. Haydite shale was retained as the natural aggregate and was chosen in 2018 after comparing various natural aggregates and determining that Haydite contributed to an increase in tensile strength (MCCT, 2018).

Table 5. Aggregate properties.

Aggregate/ Composition		Specific Gravity	Abs (%)	Particle size (mm)
Haydite Shale	Expanded Shale	1.67	10	2.4-0.6
Poraver	Glass Microsphere	0.40	19	1.0-2.0
Poraver	Glass Microsphere	0.50	18	0.5-1.0
Poraver	Glass Microsphere	0.70	21	0.25-0.5
SG-300	Cenosphere	0.72	1	0.01-0.3
K20	Cenosphere	0.20	1	0.03-0.09

Each material was added individually to the 2018 baseline mix to analyze its effect on the concrete. Once it was determined how the materials impacted the baseline mix, they were all combined into a single mix and the proportions and design parameters were varied iteratively. These parameters included aggregate ratio, component weight fractions, admixture dosages, and designed air content. Haydite shale was then incorporated into the mix at a much higher amount in order to adjust for a more than doubled measured specific gravity compared to the value used in 2018 (MCCT, 2018). This data was determined by the team through a specific gravity test according to ASTM C127-12. Mineral fillers were also considered when proportioning the aggregates and solids of each mix to ensure volume requirements were still met. Once each rule was fulfilled, the dosage of air entrainer was increased incrementally until a desired density and air content were reached that allowed the concrete to float.

The final mix was determined in December of 2018 after testing 19 mixes and is compliant with the 25 percent natural aggregate by volume and mineral filler rules. This mix was able to demonstrate improved buoyancy relative to last year's concrete with minimal sacrifice in strength despite having more than double of the ASTM C330 compliant Haydite shale by mass. This was achieved by increasing the total aggregate ratio from 0.40 to 0.52 and adjusting the admixture dosages.

Table 6. Summary of constituents used in all concrete mixes.

Component	Intended Use	Designation
CEMENTITIOUS MATERIALS		
Federal White Portland Cement Type I (Federal White Cement)	Concrete Binder	ASTM C150
CTS Komponent ® (CTS Cement)	Additive for Low-Shrinkage Concrete	ASTM C150
VCAS™-160 White Pozzolans (Vitro Minerals)	Supplementary Cementitious Material	ASTM C618
Phoenix Fly Ash Class C Pozzolan (Salt River Materials Group)	Supplementary Cementitious Material	ASTM C618
NewCem® Brand Slag Cement (Lafarge)	Slurry Cementitious Material	ASTM C989
FIBERS		
NYCON-PVA RMS702 6mm	Reinforced Concrete	ASTM C1116
NYCON-PVA RECS15 8mm	Reinforced Concrete	ASTM C1116
NYCON-PVA RECS100 12mm	Reinforced Concrete	ASTM C1116
AGGREGATES		
Poraver® 1.0-2.0mm, 0.5-1.0mm, 0.25-0.5mm (Poraver North America)	Lightweight Aggregate	ASTM C330
Extendospheres® SG-300 Hollow Microspheres (Sphere One)	Lightweight Aggregate, Mineral Filler	ASTM C33/C33M-18
3M ™ Glass Bubbles K20	Lightweight Aggregate, Mineral Filler	ASTM C33/C33M-18
Haydite Expanded Shale 4.75mm (DiGeronimo Aggregates)	Lightweight Aggregate	ASTM C330
Hess Grade 7 Pumice (Hess Pumice)	Slurry Lightweight Aggregate	ASTM C330
ADMIXTURES		
Tylac® 4191 Styrene-Butadiene Emulsion (Mallard Creek Polymers)	Polymer Modifier (Admixture/Solid)	ASTM C1438
ADVA® Cast 555 (Grace Construction Products)	Superplasticizer	ASTM C494
Darex® II AEA (Grace Construction Products)	Air Entrainer	ASTM C260

The final structural mix used Fly Ash Class C as a replacement for the GGBFS. Fly Ash was chosen for its low specific gravity and environmentally sustainable qualities since it is a byproduct of coal combustion. This natural pozzolan can increase strength, reduce shrinkage, lower water demand, improve workability, and reduce permeability and absorption. However, the carbon content in Fly Ash can also cause an increase in the dosage of air entrainer required to achieve a desired air content.

Admixtures in the final mix were changed to meet the competition rules as well as to improve aspects of the mix. Tylac 4191 Liquid Latex Modifier was used as a replacement to the Sika Liquid Latex Modifier which was incorporated in past canoes (MCCT, 2018). This latex was selected from the list of acceptable latex modifiers in the rules due to its comparable density and solids content to the Sika Latex. The dosage of latex was increased from 200 to 250 fl oz/cwt to improve workability. After reviewing national winning designs, the dosage of the water reducer was increased from 8 to 10 fl oz/cwt to decrease water usage. Due to the addition of Fly Ash as well as an increase in the amount of Haydite shale in the mix, the dosage of the Darex II air entraining admixture (AEA) used in past years was not sufficient to achieve a density that allowed the concrete to float. The additional Haydite shale, which has an absorption capacity of 10 percent, caused an increase in the amount of AEA absorbed by the aggregate. Therefore, after incrementally increasing the dosage in subsequent tested mixes, the final dosage of AEA was raised from 2 fl oz/cwt to 20 fl oz/cwt, which allowed the concrete to float.

The concrete design team tested the effect of adding the admixtures separately and in different sequential orders to achieve the maximum possible air content. Through both research and mix testing, the optimal batch order was obtained. The AEA was first added onto the cementitious and aggregate materials before mixing. After mixing began, the water reducer was added about 20 seconds into the process. Right before the last of the water was added, the latex was dispensed and allowed to incorporate into the concrete for a few seconds before mixing was stopped. This procedure allowed for the AEA to react in the concrete before coming into contact with the latex's de-foaming components.

In order to decrease the likelihood of plastic shrinkage cracking, past years' advancements were retained while adding new innovations. Each tested mix had the same amount of PVA fibers at 6.5 lb/yd³ which was determined to be optimal from the 2018 design process. This resulted in an increase in the compressive and tensile strengths of the 2018 mix and was desired for the 2019 concrete design (MCCT, 2018). To further prevent shrinkage cracking, based on recommendations from expert advisors, Haydite shale was soaked for 24 hours before being used in a mix in order to achieve a saturated, surface-dry condition. This would prevent the shale from absorbing additional water during the curing process of the concrete which would, over time, cause excessive shrinkage cracking.

The combination of the adjusted parameters and newly incorporated materials resulted in a final concrete density of 58.44 lb/ft³ and air content of 12.0 percent. These values vary from last year's mix which had a density of 59.0 lb/ft³ and air content of 1.5 percent. The large increase in the amount of AEA used, as well as the incorporation of the mineral fillers and Fly Ash, helped to increase the air content while maintaining a low density.

Throughout the design process, the compressive and tensile strengths of the concrete were tested to ensure a mix's structural durability. The compressive and tensile strengths of the final mix were tested according to ASTM C39 and ASTM C496. The resulting concrete strengths are slightly lower than last year's strengths which could be explained by the increase in the air content (Table 7).

Table 7. Comparison of strength values.

	Baseline (2018)	Final mix (2019)
Unit Weight (lb/ft³)	59.0	58.44
Compressive Strength (psi)	1168	1025
Tensile Strength (psi)	273	243

The slump of the final concrete mix was determined to be 1.5 inches and was tested according to ASTM C143. Although the concrete had a low slump, it was able to provide the necessary workability to properly form the canoe mold without being too stiff to place. By utilizing a lower slump, water usage was ultimately reduced in the concrete mixing process.

The canoe was constructed from the selected mix and then cured in a climate-controlled room for 28 days. The canoe was reinforced with Spiderlath Fiberglass Mesh between 1.5" of concrete at the gunwales and 3/8" layers of concrete for the rest of the canoe. This layering scheme was chosen as it allowed the strength requirements determined using structural analysis calculations to be fulfilled. The fiberglass mesh was chosen due to its contribution to composite flexural strength and its being more lightweight than similar materials tested in the past (MCCT, 2015).

After the canoe was constructed, the mix design team worked to develop a finishing mix for the exterior of *TERRA*. Due to the success of the team's aesthetic slurry in 2018, only minor aspects of the finishing mix were adjusted (MCCT, 2018). The mix contained similar components as in 2018 including GGBFS, Poraver size 0.25-0.5 mm, Pumice, and pigment, though Tylac 4191 Latex was incorporated to accommodate the rules. To further increase workability and adherence to the previously cast concrete, the amount of latex was increased in the mix and a small amount of water was added. This combination of materials resulted in a light gray baseline mix that could be used with varying colors and amounts of pigments to achieve the desired aesthetic appearance. Each color was applied to a test section of concrete to determine the proportion of pigment necessary and to ensure ease of placement.

The mix design team was able to achieve the original goals to create a concrete mix with the desired properties of adequate strength and buoyancy while considering the effect on sustainability, budget, and schedule. Over 50 percent of materials were donated from local vendors to negate the environmental effects from shipping. An emphasis was also placed on sustaining knowledge by educating new members about the mix design process with a focus on safety. With these improvements and considerable planning, the team was able to stay below budget and on schedule to achieve an improved design process that built on the success of the mix team in past years (MCCT, 2018).

Construction

TERRA's construction benefited greatly from the innovations pioneered from previous years, and in 2019 MCCT made further improvements to streamline the overall construction process. The team set out several goals for the construction process including improving quality assurance during the casting of *TERRA* through updated quality control devices, and to create an elegant final product through a revised sanding process.

MCCT started the construction process with an overhauled hull design. The hull design subteam used Rhinoceros 5.0 (Rhinoceros, 2017) to model the mold for the canoe and prepare it for Computer Numerical Control (CNC) routing. After the completion of the design and modeling phase, the hull design team divided the model into 80, 3-inch thick cross sections and cut the cross sections into several sheets of expanded polystyrene foam (EPS) using a CNC machine. Additional EPS was cut to create the base of the cross section for display purposes. Hull design leads chose EPS as the primary foam material because it is lightweight, inexpensive, and available from local distributors in large quantities. Like previous years, the team used four alignment pieces with gunwale forms to act as the base of the mold and the cross sectional pieces were carefully placed in sequential order on top of the base to reduce time spent sanding and to ensure the keel line was maintained.

Hull design leads embraced a positive canoe mold since it minimizes the amount of EPS used and it allows for greater precision in gunwale formation. Before casting day, the team realized that choosing a positive mold could sacrifice exterior precision and in anticipation, several members were selected to implement quality assurance measures including troweling the exterior of the canoe after the application of concrete layers and employing a string along the keel line to allow members to keep the line pronounced. Another disadvantage of using a positive mold was the possible stress caused from the plastic shrinkage during curing. Therefore, the Mix Design Team used a Type K shrinkage compensating cement, as well as PVA fibers to alleviate some of the stresses from the positive mold which prevented cracking significantly.

Before casting day the team sanded the individual mold pieces to remove imperfections, glued the pieces together, and aligned the pieces using the wooden alignment guides. The team then applied a layer of spackling paste to the exterior of the mold to fill any voids and smooth the surface. Once the spackle dried, the team sanded the entire mold and applied three coats of Chem-Trend® CR-19568 release agent to ease the demolding process.

Figure 3. Assembly of form used to cast *TERRA*

In preparation for casting day, several efforts were made to assure the construction of the canoe was streamlined and an excellent final product was created. After the success of the practice section used last year, the team again created one-foot test sections to teach new members the process of applying concrete and primary reinforcement on the canoe to prepare them for casting day. Project management decided to use leftover EPS from previous years as the mold for the test sections to negate the need for additional foam and save cost in the process.

To improve the efficiency of casting day, the mix design team premixed cementitious materials and aggregates into individual 0.35 ft^3 batches the day before. Dividing the mixes allowed the team to mix batches faster during casting. When casting started, designated team members measured fibers and liquids for each mix as needed and concrete was mixed using a Hobart D300 mixer. The Quality Control Team and the Mix Design Team kept in close communication to determine when the next mix should be made for the next section of the canoe.

Additionally, several novel quality control devices were created in preparation for casting day. First was the use of ⅜-inch thick foam tape that quality control leads placed along a cross section of the canoe in one-foot intervals. Since the thickness of the tape was the same as the thickness of each layer of the canoe, the team was able to use the tape as a guide to make sure the thickness along the canoe was uniform. Additionally, quality control leads used several sets of nails placed along the outer edge of the gunwale forms to ensure that members placing concrete did not apply extraneous concrete near the gunwales.

Figure 4. Foam tape used to maintain uniform thickness in each layer of *TERRA*

During casting day, the team made use of the chasing scheme used in previous years to great effect. The chasing scheme involves placing the first layer of concrete, the fiberglass reinforcement, the second layer of concrete, and finally finishing in quick succession so the concrete never hardens. For the purposes of the chasing method, the fiberglass mesh was cut into 3 ft sections and placed on the first layer of concrete, and the second layer of concrete lagged behind by an average of 3 ft. with finishing work following closely. Using the chasing method greatly improved casting day efficiency because several team members were selected to focus on one aspect of the method along the length of the canoe, allowing greater attention to detail in their work.

Once casting was complete, the curing process started immediately. The canoe was kept in a paint booth in the team's workspace for 28 days. The paint booth was kept at 70°F for the duration of curing and twice a day damp sheets were replaced to maintain ideal hydrated conditions and allow the concrete to achieve high strength.

After the winter recess, *TERRA* was removed from the curing location, and was prepared for form removal. *TERRA* was flipped over and fitted into negative mold pieces saved from previous years. The team carefully removed one EPS piece in its entirety and used the newly created space to apply leverage and remove the remainder of the pieces. In addition to the manual removal of the form, the release agent applied prior to casting day led to an easy form removal process.

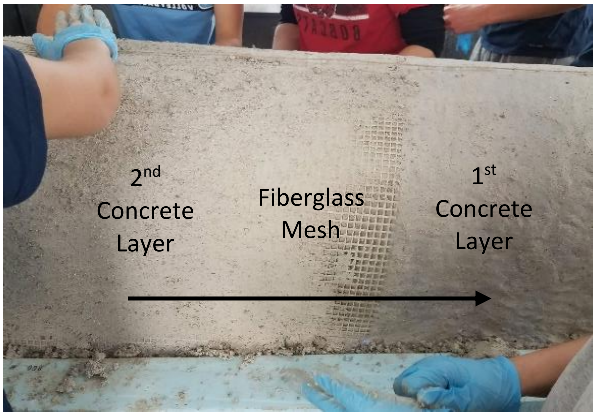


Figure 5. Chasing method adopted by team to streamline casting process

Like previous years, the team turned its attention to sanding both the interior and exterior of the canoe after form removal. With the leadership of several experienced members, new sanding techniques were introduced and the members focused on removing imperfections in the concrete through careful sanding and careful application of slurry designed to blend to the natural color of the canoe. Sanding started with 40 grit paper and was increased to 220 grit paper for the final touches. Due to the efforts of dedicated members, MCCT produced a final product that is smoother and more uniform in color than in previous years.

To maintain consistency with the 2019 theme, relevant aesthetic finishing mixes were applied to the surface of the canoe. Aesthetic leads applied several mixes of different colors in intricate designs to create a fresco-like painting on the interior, and a roman style border on the exterior of the canoe. Aesthetic leads applied finishing mixes to the designated areas of the canoe and used cardstock held in place with double sided tape to ensure that clean lines between the aesthetic slurry and the canoe surface were maintained.

Project and Quality Management

Following the departure of several experienced members of MCCT, project management focused on developing younger members of the team and improving on past iterations of the project. After the release of CNCC 2019 competition rules, technical design leads determined individual goals which were verified by the Captain and then communicated to the rest of the team for effective coordination. Major project management improvements include the further expansion of subteams implemented in 2018 to help facilitate knowledge transfer between members in addition to a change in project schedule that allowed multiple technical leads to further their research, testing, and construction outside of the previously scheduled timeline. Project management also facilitated successful recruitment from multiple engineering departments to attract new talent and allow more manpower to yield a more refined final product compared to previous years.

Through the use of transition documents, the advice of past team project management was used to develop a project schedule. From the developed project schedule, two major milestone were created, from which it was critical that the team did not deviate. The first milestone was the casting day for *TERRA* which was chosen for early December so curing could take place over the winter recess and work could continue immediately after members returned. The second milestone was the regional competition, as all project tasks must be completed by the start of the competition. Several more flexible deadlines were set for critical project components to ensure steady progress of final product, and to reduce the chances of bottlenecks in the construction process. After each of the deadlines was decided, buffer time was added to safeguard timely completion of all tasks. Critical project deadlines included the recruitment mass meeting, theme selection, final hull selection, structural mix selection, mold construction, canoe construction, application of finishing mix, display construction, technical report submission, and technical presentation finalization. While most tasks set by project management were completed on or close to the planned completion date, some tasks took much longer than expected or had to be pushed back in the project schedule. At the beginning phases on the project, aesthetics, construction, and project management leads set a goal to have the display stands for *TERRA* done by December of 2018. However, due to delays in the design and construction of a new carrier for *TERRA*, the team decided to push the construction of stands back to January 2019 and update the project schedule accordingly given the buffer time allocated earlier in the schedule.

After the project schedule was determined, subteams were assigned certain aspects of the project to optimize manpower allocation. Due to the hard work of experienced and new members alike, the project was finished in approximately 3025 hours.

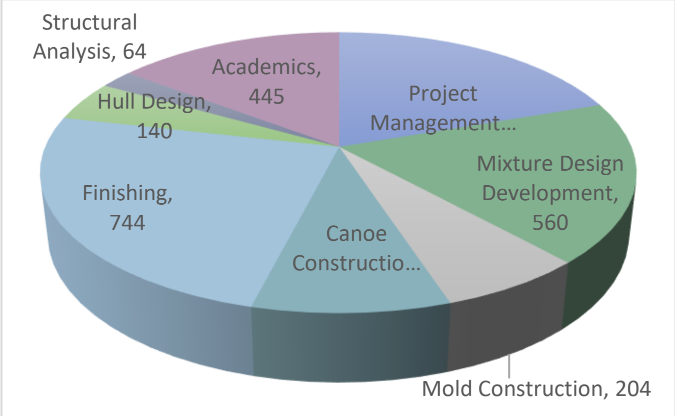


Figure 6: Person-hour breakdown of 2019 canoe

As always, safety was a high priority for the team throughout the construction process. A dedicated safety officer verified that all MSDS, OSHA, and University safety standards were met throughout design and construction phases, and ensured that all members received necessary trainings and adhered to safety guidelines when working in the team's workspace. All members of the mix design subteam were required to receive both university sponsored mixer and respirator training, and construction subteams were required to take machine shop training before beginning the construction of display. All materials used by MCCT were labeled according to OSHA standards, and necessary PPE was worn when members used these materials.

Using past MCCT project budgets for reference, the 2019 budget was created and distributed to all required sectors. The total budget for 2019 was $10,750, up from $8,750 in 2018. Project management decided that a budget increase was necessary to procure higher quality materials for construction and to fund the construction of an easily de-constructible carrier. Despite the overall increase in budget, significant cost saving measures included the use of locally sourced, donated materials to help the team become more sustainable economically, socially, and environmentally. Due to the University of Michigan hosting the regional competition, MCCT was able to allocate funds from hotels to help improve the quality of display materials as well as create a fiberglass practice canoe to help improve paddler experience.

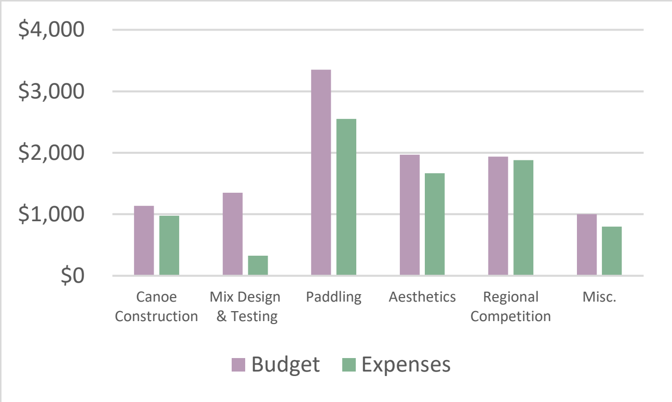


Figure 7: Budget and expenses for 2019 project

MCCT strives to achieve the highest level of sustainability possible for the project. In 2019 project management focused on developing the knowledge and engagement level of younger members, specifically the first year members of leadership. Since a majority of leadership has sophomore standing, project management found the best way to sustain the gains achieved by MCCT was to develop these members to their greatest potential. The team achieved higher economic sustainability from previous years through the continued support of sponsors who have reaffirmed their engagement to support the team, fostering valuable relationships for the coming years. Project management initiated several measures to help the team cut its carbon footprint. To this end, when the team designed the form for TERRA, the amount of EPS foam and time and energy spent CNC routing was considerably cut down from previous years by choosing not to taper certain cross sections. Instead, the team spent time sanding and applying spackling paste to ensure the final product wasn't compromised.

The main goal this semester for quality control was to improve the methods used during pour day to achieve a more consistent and thus higher quality final product. Rather than simply using nails painted with guides for the correct thickness of each layer, foam tape of the correct height was used as the thickness guides for the first layer. This method resulted in a more consistent and even thickness across the entirety of the canoe. Originally it was planned to use the same method for the top layer however the reinforcement mesh in between caused issues with placing the thickness guides. Thus, nails painted to the correct thickness were used to measure the second layer as has been done in previous years. Next year we hope to resolve this issue to achieve an even, consistent thickness in both layers of the canoe.

Quality control started at the beginning of the year when the rules came out from ASCE. The team leads promptly read the section of the rules that pertains to their role on the team so all team members had a good idea of what is expected of them. The quality control lead read through RFIs as well as the entire rules and regulations and started to make check lists of the most important things that the design leads must consider so that the team can be successful this year. In addition to this quality control leads submitted RFIs for any questions where the team cannot come to a consensus. These lists became incredibly convenient to come back to throughout the year. When designs were ready to be finalized, the quality control lead met with the design leads of hull design and mix design to make sure the rules were being properly considered and met. Additionally, for concrete design a list of materials used in the design was given to the quality control lead, who worked with a selected group of people to ensure that the materials used met the correct standards.

New members were put through several standardized trainings before being permitted to help with pour day. These trainings included a mix training, respirator training, and basic training of how to use the facilities where the canoe is built. New members were also given more targeted instruction while working on a test section prior to pour day where specific procedures and questions were addressed.

Organization Chart

Alec Distel (Sr)
Captain

Kristin Lewis (Jr)
Mix Design

Jackie Clemons (So)
Construction

Megan Shibley (Jr)
Quality Control

Jacob Cieply (So)
Hull Design

Maria Khalaf (So)
Aesthetics

Jackie Nisbet (Sr)
Treasurer

Rachel Kass (So)
Secretary

Ben Kaufman (So)
Public Relations

Estelle Feider-Blazer (Sr)
Paddling Lead

Julia Healy (So)
Safety Officer

Mix Design
Tiana Gillis (Jr)
Nicholas Keller (Jr)
Christina Brietske (So)
Ben Cader-Beutel (So)
Claire O'Donnel (So)
Deborah Reisner (So)
Nathan Jarski (Fr)

Hull Design
Hannah Deloney (Jr)
Noah Robbins (Jr)
Max Chapman (So)
Michael Kadian (So)
Connor Michaelson (So)
Nicholas Monson (So)
Connor Arrigan (Fr)

Aesthetics Design
Jessica Ma (Sr)
Skylar Carlson (Jr)
Danielle Sternberg (Jr)
Erik Rehkopf (So)
Robin Albert (Fr)
Koby Khoo (Fr)
Cindy Stuch (Fr)

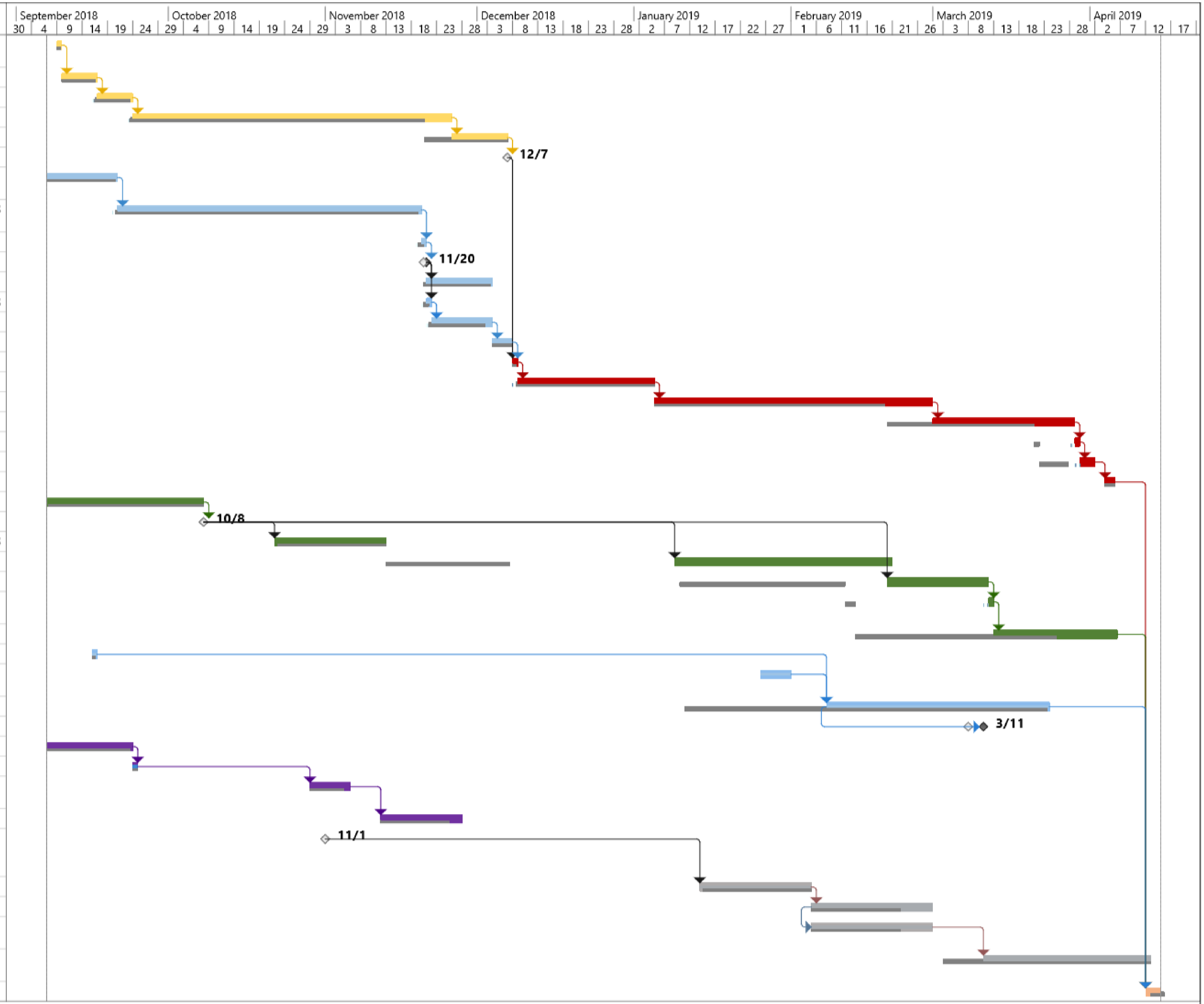
Construction Design
Hannah Bashore (Grad)
Madison Carlson (Jr)
Rachel Low (Jr)
Ashton Doyle (So)
Eric Montrief (So)
Seth Stump (So)
Emma Anielak (Fr)

Team Captain:

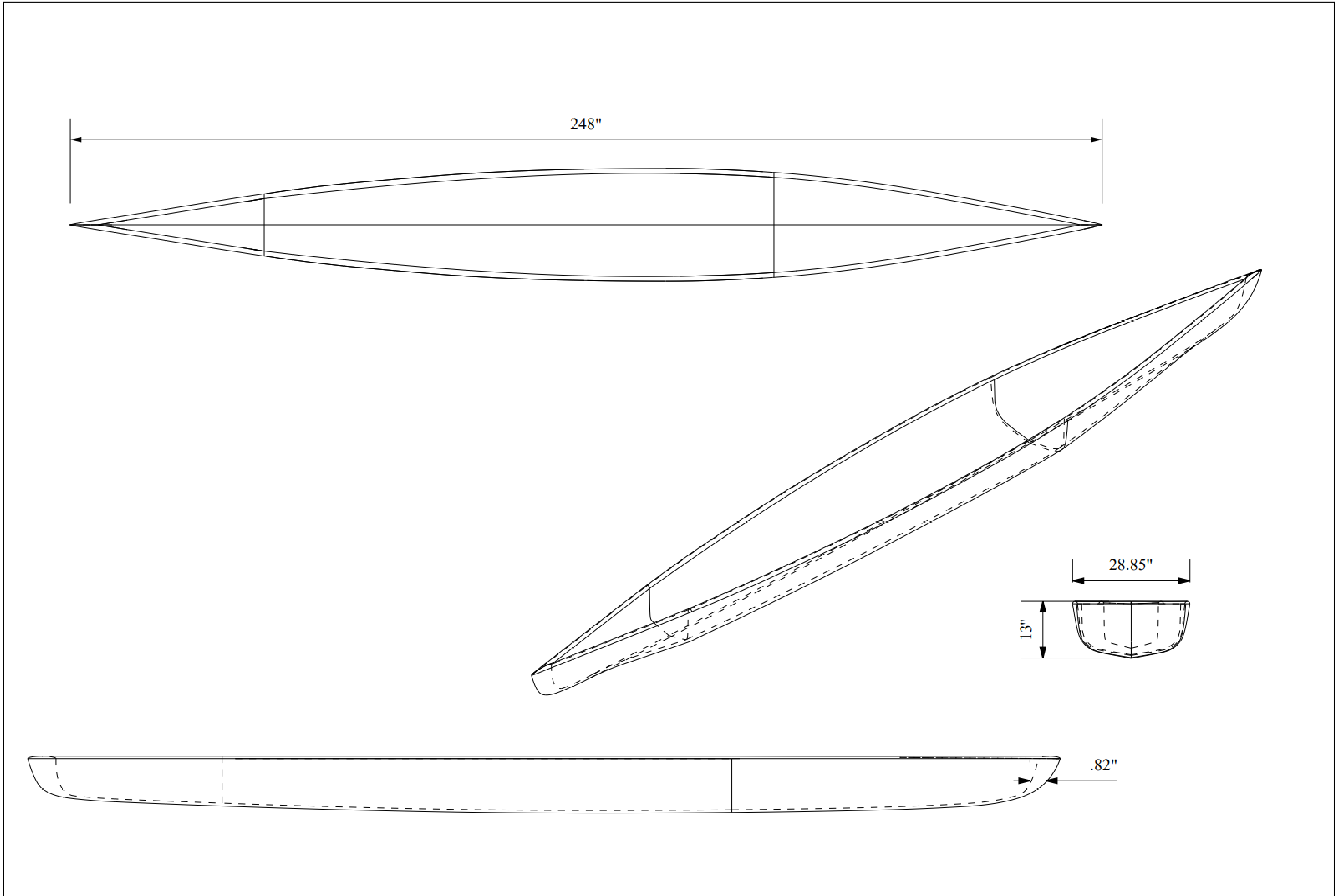
Faculty Advisor: Will Hansen

Project Schedule:

ID	Task Name	Act. Start	Act. Finish	Baseline Start	Baseline Finish
1	Clean and Organize Space	Sun 9/9/18	Sun 9/9/18	Sun 9/9/18	Sun 9/9/18
2	Order Materials	Mon 9/10/18	Sun 9/16/18	Mon 9/10/18	Sun 9/16/18
3	Material Testing	Sun 9/16/18	Sun 9/23/18	Sun 9/16/18	Sun 9/23/18
4	Mix Testing	Sun 9/23/18	Sun 11/25/18	Sun 9/23/18	Tue 11/20/18
5	Data Analysis	Mon 11/26/18	Thu 12/6/18	Tue 11/20/18	Thu 12/6/18
6	Mix Design Chosen	Fri 12/7/18	NA	Fri 12/7/18	Fri 12/7/18
7	Paddler Feedback Analysis	Fri 9/7/18	Thu 9/20/18	Fri 9/7/18	Thu 9/20/18
8	Design and Prototyping	Thu 9/20/18	Mon 11/19/18	Thu 9/20/18	Mon 11/19/18
9	Design Review	Mon 11/19/18	Tue 11/20/18	Mon 11/19/18	Tue 11/20/18
10	Hull Design Chosen	Tue 11/20/18	Tue 11/20/18	Tue 11/20/18	Tue 11/20/18
11	Structural Calculations	Wed 11/21/18	Mon 12/3/18	Tue 11/20/18	Mon 12/3/18
12	Purchase Foam	Tue 11/20/18	Wed 11/21/18	Tue 11/20/18	Wed 11/21/18
13	CNC Cut Mold	Wed 11/21/18	Mon 12/3/18	Wed 11/21/18	Sun 12/2/18
14	Assemble Mold	Tue 12/4/18	Fri 12/7/18	Tue 12/4/18	Fri 12/7/18
15	Casting Day	Sat 12/8/18	Sat 12/8/18	Sat 12/8/18	Sat 12/8/18
16	Canoe Curing	Sat 12/8/18	Fri 1/4/19	Sat 12/8/18	Fri 1/4/19
17	Sanding	Sat 1/5/19	Thu 2/28/19	Sat 1/5/19	Tue 2/19/19
18	Apply Slurry	Fri 3/1/19	Thu 3/28/19	Wed 2/20/19	Wed 3/20/19
19	Apply Lettering	Thu 3/28/19	Fri 3/29/19	Thu 3/21/19	Thu 3/21/19
20	Seal Canoe	Fri 3/29/19	Mon 4/1/19	Fri 3/22/19	Wed 3/27/19
21	Swamp Test	Thu 4/4/19	Fri 4/5/19	Thu 4/4/19	Fri 4/5/19
22	Theme Brainstorming	Fri 9/7/18	Sun 10/7/18	Fri 9/7/18	Sun 10/7/18
23	Theme Chosen	Mon 10/8/18	NA	Mon 10/8/18	Mon 10/8/18
24	Construct Carrier	Mon 10/22/18	Mon 11/12/18	Mon 10/22/18	Mon 11/12/18
25	Stand Construction	Wed 1/9/19	Wed 2/20/19	Tue 11/13/18	Fri 12/7/18
26	Prepare Poster	Wed 2/20/19	Mon 3/11/19	Thu 1/10/19	Mon 2/11/19
27	Complete Cross Section	Mon 3/11/19	Tue 3/12/19	Mon 2/11/19	Wed 2/13/19
28	Display Construction	Tue 3/12/19	Sat 4/6/19	Wed 2/13/19	Mon 3/25/19
29	Paddling Introduction	Sun 9/16/18	Sun 9/16/18	Sun 9/16/18	Sun 9/16/18
30	Practice Canoe Construction	Sat 1/26/19	Thu 1/31/19	NA	NA
31	Paddling Practice	Fri 2/8/19	Sat 3/23/19	Fri 1/11/19	Sat 3/23/19
32	Teams Selected	Mon 3/11/19	NA	Fri 3/8/19	Fri 3/8/19
33	Recruiting	Fri 9/7/18	Sun 9/23/18	Fri 9/7/18	Sun 9/23/18
34	Mass Meeting	Mon 9/24/18	Mon 9/24/18	Mon 9/24/18	Mon 9/24/18
35	Draft and Send Sponsor Letters	Mon 10/29/18	Mon 11/5/18	Mon 10/29/18	Sun 11/4/18
36	Funding Applications	Mon 11/12/18	Tue 11/27/18	Mon 11/12/18	Sun 11/25/18
37	Project Schedule and Acknowledgement Form	Thu 11/1/18	NA	Thu 11/1/18	Thu 11/1/18
38	Write Design Paper	Mon 1/14/19	Mon 2/4/19	Mon 1/14/19	Mon 2/4/19
39	Finalize Design Paper	Tue 2/5/19	Thu 2/28/19	Tue 2/5/19	Fri 2/22/19
40	Complete Project Overview	Tue 2/5/19	Thu 2/28/19	Tue 2/5/19	Fri 2/22/19
41	Make and Practice Presentation	Mon 3/11/19	Fri 4/12/19	Sun 3/3/19	Fri 4/12/19
42	Regional Conference	Fri 4/12/19	Sun 4/14/19	Sat 4/13/19	Mon 4/15/19



Construction Drawing



2603 Draper Dr. Ann Arbor, Michigan, 48109

Terra

PREPARED BY:

Deirdre Howard

Bill of Construction Materials:

- White Portland Cement 36 lb
- Komponent 9.24 lb
- VCAS 25.8 lb
- Fly Ash Class C 21.24 lb
- PVA Fiber 6mm .332 lb
- PVA Fiber 8mm .332 lb
- PVA Fiber 12mm .322 lb
- Poraver® 1.0 - 2.0mm 14.04lb
- Poraver® .5- 1.0mm 6.96 lb
- Poraver® 0.25-0.5mm 2.04 lb
- SG-300 3.24 lb
- K20 12.72 lb
- Haydite Shale 64.08 lb
- ADVA Cast555 273.12 mL
- Darex II 546.24 mL
- Tylac 4191 Latex 15.24 lb
- Fiberglass Mesh 45 sq.ft
- Increte Crystal Clear VOC 2 gal
- Chem-Trend Release Agent CR-19568 0.33 gal
- Foam Mold, 1 mold
- Sand Paper 1 pack
- Vinyl Letters (School Name) 2 Units
- Vinyl Letters (Canoe Name) 2 Units

Concrete Canoe Team

University of Michigan College of Engineering

DATE:	03/12/2019
SCALE:	1/24

Construction Drawing

Appendix A – References

ASCE (American Society of Civil Engineers). (2018). "2019 ASCE National Concrete Canoe Competition Rules and Regulations". American Society of Civil Engineers National Concrete Canoe Competition. <https://www.asce.org/rules-and-regulations/> (Sept. 5, 2018).

National Science Foundation (2017). "Rankings by total R&D expenditures" Academic Institution Profiles, <https://ncsesdata.nsf.gov/profiles/site?method=rankingBySource&ds=herd> (Feb 2, 2019)

The Regents of the University of Michigan (2017). "Michigan Engineering 2020 Strategic Vision" Michigan College of Engineering, <http://strategicvision.engin.umich.edu/> (Feb 2, 2019).

Michigan Concrete Canoe Team (2018). "Majesty." NCCC Design Paper, University of Michigan, Ann Arbor, Michigan.

Michigan Concrete Canoe Team (2017). "Valiant." NCCC Design Paper, University of Michigan, Ann Arbor, Michigan.

Michigan Concrete Canoe Team (2016). "Extinction." NCCC Design Paper, University of Michigan, Ann Arbor, Michigan.

(Maxsurf, 2017) and Maxsurf (2016). Computer Software. Bentley Systems, Exton, PA.

Rhinoceros 5.0 (2017). Computer Software. Robert McNeel & Associates, Seattle, WA.

ITTC (International Towing Tank Conference). (2008). "1978 ITTC Performance Prediction Method." International Towing Tank Conference, Society of Naval Architects and Marine Engineers, Alexandria, Virginia, 1-31.

Michigan Concrete Canoe Team (2015). "Allegro." NCCC Design Paper, University of Michigan, Ann Arbor, Michigan.

ASTM (American Society for Testing Materials). (2017). "Standard Specification for Lightweight Aggregates for Structural Concrete" C330/C330M, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2014). "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete." C138/C138M-14, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2014). "Standard Specification for Slag Cement for Use in Concrete and Mortars." C989/C989M-14, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2014). "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." C39/C39M-14a, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2013). "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars." C109/C109M-13, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2013). "Standard Specification for Chemical Admixtures for Concrete." C494/C494M-13, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2013). “Standard Specification for Concrete Aggregates.” C33/C33M-13, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2012). “Standard Practice for Making and Curing Concrete Test Specimens in the Field.” C31/C31M-12, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2012). “Standard Specification for Portland Cement.” C150/C150M, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2012). “Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate.” C127-12, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2012). “Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate.” C128-12, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2010). “Standard Specification for Air-Entraining Admixtures for Concrete.” C260/C260M-10a, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2010). “Standard Specification for Fiber-Reinforced Concrete.” C1116/C1116M-10a, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2019). “Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.” C618-19, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing Materials). (2017). “Standard Specification for Latex and Powder Polymer Modifiers for use in Hydraulic Cement Concrete and Mortar.” C1438-13, West Conshohocken, Pennsylvania.

Expanded Shale, Clay & Slate Institute (ESCSI). (2007). "Chapter 6 Physical Properties of Structural Lightweight Concrete." Salt Lake City, Utah

Appendix B – Mixture Proportions and Primary Mixture Calculation

MIXTURE DESIGNATION: STRUCTURAL MIX

CEMENTITIOUS MATERIALS

Component	Specific Gravity	Volume (ft³)	Amount of CM (mass/volume) (lb/yd³)	
Federal White Portland Cement Type I	3.15	1.18	231.54	Total Amount of cementitious materials **593.68** lb/yd³ c/cm ratio **0.39**
CTS Komponent ®	3.10	0.31	59.37	
VCAS™-160 White Pozzolans	2.60	1.03	166.23	
Phoenix Fly Ash Class C Pozzolan	2.64	0.83	136.55	

FIBERS

Component	Specific Gravity	Volume (ft³)	Amount of Fibers (mass/volume) (lb/yd³)	
NYCON-PVA RMS702 6mm	1.30	0.03	2.13	Total Amount of Fibers **6.39** lb/yd³
NYCON-PVA RECS15 8mm	1.30	0.03	2.13	
NYCON-PVA RECS100 12mm	1.30	0.03	2.13	

AGGREGATES

Aggregates	ASTM C330*	Abs (%)	SG_{OD}	SG_{SSD}	Base Quantity (lb/yd³)		Volume (ft³)
					OD	SSD	
Poraver® 1.0-2.0mm	No	19.0	0.40	0.48	90.04	107.15	3.61
Poraver® 0.5-1.0mm	No	18.0	0.50	0.59	45.02	53.12	1.44
Poraver® 0.25-0.5mm	No	21.0	0.70	0.85	12.86	15.56	0.29
Extendospheres® SG-300	No	1.0	0.72	0.73	19.29	19.48	0.43
3M™ Glass Bubbles K20	No	1.0	0.20	0.20	64.32	64.96	5.15
Haydite Expanded Shale 4.75 mm	Yes	10.0	1.67	1.84	411.62	452.78	3.95

ADMIXTURES

Admixture	lb/gal	Dosage (fl. oz / cwt)	% Solids	Amount of Water in Admixture (lb/yd³)	
Tylac 4191 Liquid Latex Modifier	8.45	250.0	47.0	51.93	Total Water from Admixtures, $\sum w_{admx}$ **63.52** lb/yd³
Water Reducer ADVA® Cast 555	8.90	10.0	5.0	3.92	
Darex® II Air Entrainer	8.70	20.0	5.0	7.67	

SOLIDS (LATEX, DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)

Component	Specific Gravity	Volume (ft³)	Amount (mass/volume) (lb/yd³)	
Tylac 4191 Liquid Latex Modifier	1.01	0.73	46.05	Total Solids from Admixtures **65.13** lb/yd³
SG 300 (mineral filler)	0.72	0.03	1.36	
K20 (mineral filler)	0.20	1.42	17.72	

WATER

	Amount (mass/volume) (lb/yd³)		Volume (ft³)
Water, lb/yd³		w: 296.84	4.76
Total Free Water from All Aggregates, lb/yd³		$\sum w_{free}$: 33.00	
Total Water from All Admixtures, lb/yd³		$\sum w_{admx}$: 63.52	
Batch Water, lb/yd³		w_{batch}: 200.32	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	fibers	aggregates	solids	water	Total
Mass of Concrete, M, (lb)	593.68	6.39	713.05	65.13	296.84	∑M: 1675.09
Absolute Volume of Concrete, V, (ft³)	3.35	0.08	14.88	2.18	4.76	∑V: 25.23
Theoretical Density, T, (=∑M / ∑V)	66.39 lb/ft³		**Air Content [= (T – D)/T x 100%]**			12.0 %
Measured Density, D	58.44 lb/ft³		**Slump, Slump flow**			1.5 in.
water/cement ratio, w/c:	1.28		**water/cementitious material ratio, w/cm:**			0.50

MIXTURE DESIGNATION: FINISHING MIX

CEMENTITIOUS MATERIALS

Component	Specific Gravity	Volume (ft^3)	Amount of CM (mass/volume) (lb/yd^3)	
Ground Granulated Blast Furnace Slag	2.90	5.30	959.87	Total Amount of cementitious materials **959.87** lb/yd^3 c/cm ratio **0.00**

FIBERS

Component	Specific Gravity	Volume (ft^3)	Amount of Fibers (mass/volume) (lb/yd^3)	
				Total Amount of Fibers **0.00** lb/yd^3

AGGREGATES

Aggregates	ASTM C330*	Abs (%)	SG_{OD}	SG_{SSD}	Base Quantity (lb/yd^3)		Volume (ft^3)
					OD	SSD	
Poraver® 0.25-0.5mm	No	21.0	0.70	0.85	132.16	159.91	3.02
Pumice	Yes	30.0	2.72	3.53	1029.43	1338.25	6.08

ADMIXTURES

Admixture	lb/gal	Dosage (fl. oz / cwt)	% Solids	Amount of Water in Admixture (lb/yd^3)	
Tylac 4191 Liquid Latex Modifier	8.45	1427.17	47.0	479.30	Total Water from Admixtures, $\sum w_{admx}$ **479.30** lb/yd^3

SOLIDS (LATEX, DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)

Component	Specific Gravity	Volume (ft^3)	Amount (mass/volume) (lb/yd^3)	
Tylac 4191 Liquid Latex Modifier	1.01	6.74	425.04	Total Solids from Admixtures **441.04** lb/yd^3
Pigment (color proportions vary)	5.24	0.05	16.00	

WATER

	Amount (mass/volume) (lb/yd^3)		Volume (ft^3)
Water, lb/yd^3		w: 212.28	3.40
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -336.58	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: 479.30	
Batch Water, lb/yd^3		w_{batch}: 69.56	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	fibers	aggregates	solids	water	Total
Mass of Concrete, M, (lb)	959.87	0.00	1498.16	441.04	212.28	$\sum M$: 3111.35
Absolute Volume of Concrete, V, (ft^3)	5.30	0.00	9.10	6.79	3.40	$\sum V$: 24.59
Theoretical Density, T, ($=\sum M / \sum V$)	126.52 lb/ft^3		Air Content [= (T – D)/T x 100%]			28.2 %
Measured Density, D	90.86 lb/ft^3		Slump, Slump flow			10.0 in.
water/cement ratio, w/c:	N/A		water/cementitious material ratio, w/cm:			0.22

Detailed Step by Step Calculation

Design parameters:

Cementitious Material	Mass (lb)	SG
Portland Type I Cement	231.54	3.15
Komponent	59.37	3.10
VCAS 160	166.23	2.60
Fly Ash Class C	136.55	2.64

Fibers	Mass (lb)	SG
PVA (6mm)	2.13 lb,	1.30
PVA (8mm)	2.13 lb,	1.30
PVA (12mm)	2.13 lb,	1.30

w/cm ratio	0.50

Aggregate	SG_{OD}	SG_{SSD}	W_{OD} (lb)	W_{SSD} (lb)	W_{stk} (lb)	Abs (%)	MC_{stk} (%)
Expanded Shale (meets C330)	1.67	1.84	411.62	452.78	514.53	10.0	25.0
Poraver (1-2mm)	0.40	0.48	90.04	107.15	90.04	19.0	<1.0
Poraver (0.5-1mm)	0.50	0.59	45.02	53.12	45.02	18.0	<1.0
Poraver (0.25-0.5mm)	0.70	0.85	12.86	15.56	12.86	21.0	<1.0
SG 300	0.72	0.73	19.29	19.48	19.29	1.0	<1.0
K20	0.20	0.20	64.32	64.96	64.32	1.0	<1.0

Admixture	Dosage	Solids (%)
HRWR (8.9 lb/gal)	8 fl oz/cwt	5
Air Entrainer (8.7 lb/gal)	3 fl oz/cwt	5
Latex (8.45 lb/gal)	200 fl oz/cwt	47

Cementitious Materials/Fibers:

$$\text{Absolute Volume} = \frac{mass\ (lb)}{SG*62.4\left(\frac{lb}{ft^3}\right)}$$

$$V_{portland} = \frac{231.54}{3.15*62.4} = \mathbf{1.18\ ft^3}$$

$$V_{komponent} = \frac{59.37}{3.10*62.4} = \mathbf{0.31\ ft^3}$$

$$V_{VCAS} = \frac{166.23}{2.60*62.4} = \mathbf{1.03\ ft^3}$$

$$V_{fly\ ash} = \frac{136.55}{2.64*62.4} = \mathbf{0.83\ ft^3}$$

$$V_{fibers\ 6mm} = \frac{2.13}{1.30*62.4} = \mathbf{0.03\ ft^3}$$

$$V_{fibers\ 8mm} = \frac{2.13}{1.30*62.4} = \mathbf{0.03\ ft^3}$$

$$V_{fibers\ 12mm} = \frac{2.13}{1.30*62.4} = \mathbf{0.03\ ft^3}$$

Aggregates:

$$\text{Absorption} = \text{Abs} = \frac{W_{SSD}(lb) - W_{OD}\ (lb)}{W_{OD}\ (lb)} * 100\%$$

$$\text{Expanded Shale} = \frac{452.78 - 411.62}{411.62} * 100\% = \mathbf{10.0\%}$$

$$\text{Poraver 1-2mm} = \frac{107.15 - 90.04}{90.04} * 100\% = \mathbf{19.0\%}$$

$$\text{Poraver 0.5-1.0mm} = \frac{53.12 - 45.02}{45.02} * 100\ \% \% = \mathbf{18.0\%}$$

$$\text{Poraver 0.25-0.5mm} = \frac{15.56 - 12.86}{12.86} * 100\% = \mathbf{21.0\%}$$

$$\text{SG 300} = \frac{19.48 - 19.29}{19.29} * 100\% = \mathbf{1.0\%}$$

$$\text{K20} = \frac{64.96 - 64.32}{64.32} * 100\% = \mathbf{1.0\%}$$

$$\text{Aggregate Absolute Volume}(ft^3) = \frac{W_{SSD}(lb)}{SG_{SSD}*62.4\left(\frac{lb}{ft^3}\right)}$$

$$V_{shale} = \frac{452.78}{1.84*62.4} = \mathbf{3.95\ ft^3}$$

$$V_{poraver\ 1\text{-}2} = \frac{107.15}{0.48*62.4} = \mathbf{3.61\ ft^3}$$

$$V_{poraver\ 0.5\text{-}1} = \frac{53.12}{0.59*62.4} = \mathbf{1.44\ ft^3}$$

$$V_{poraver\ 0.25\text{-}0.5} = \frac{15.56}{0.85*62.4} = \mathbf{0.29\ ft^3}$$

$$V_{SG300} = \frac{19.48}{0.73*62.4} = \mathbf{0.43\ ft^3}$$

$$V_{K20} = \frac{64.96}{0.20*62.4} = \mathbf{5.15\ ft^3}$$

Water: As all aggregates except Haydite are stored at approximately their oven dried condition, it is assumed that the total moisture content is 0. In the equation below $(0)/W_{OD}$ x 100% = 0.

Water = w/cm * cm
w = 0.5 * 593.68 lb = **296.84 lb**
$MC_{total} = \frac{W_{stk} - W_{OD}}{W_{OD}} * 100\%$
$MC_{free} = MC_{total} - Abs$
For all aggregates except Haydite:
MC_{total} = **0** MC_{free} = **-Abs**
For Haydite: (Abs = 10.0)
MC_{total} = **25.0** MC_{free} = **15.0**

$w_{free} = W_{OD}(lb) * \frac{MC_{free}}{100\%}$
$w_{free,\ haydite} = 411.62 * \frac{15.0}{100\%} =$ **61.74 lb**
$w_{free,\ poraver\ 1\text{-}2} = 90.04 * \frac{-19.0}{100\%} =$ **-17.11 lb**
$w_{free,\ poraver\ 0.5\text{-}1} = 45.02 * \frac{-18.0}{100\%} =$ **-8.10 lb**
$w_{free,\ poraver\ 0.25\text{-}0.5} = 12.86 * \frac{-21.0}{100\%} =$ **-2.70 lb**
$w_{free,\ SG300} = 19.29 * \frac{-1.0}{100\%} =$ **-0.19 lb**
$w_{free,\ K20} = 64.32 * \frac{-1.0}{100\%} =$ **-0.64 lb**
Combined free water = $\sum(w_{free})$ = **33.00 lb**

Water in admixture $= dosage\left(\frac{fl\ oz}{cwt}\right) * cwt\ of\ cm\left(\frac{lb}{yd^3}\right) * \frac{\%\ water}{100} * \frac{1\ gal}{128\ fl\ oz} * \left(\frac{lb}{gal}\right) of\ admixture$
$w_{HRWR} = 10.0 * \frac{593.68}{100} * \frac{100-5}{100} * \frac{1\ gal}{128\ fl\ oz} * 8.90\frac{lb}{gal} =$ **3.92 lb**
$w_{AEA} = 20.0 * \frac{593.68}{100} * \frac{100-5}{100} * \frac{1\ gal}{128\ fl\ oz} * 8.70\frac{lb}{gal} =$ **7.67 lb**
$w_{Latex} = 250.0 * \frac{593.68}{100} * \frac{100-47}{100} * \frac{1\ gal}{128\ fl\ oz} * 8.45\frac{lb}{gal} =$ **51.93 lb**
Total Water from admixtures = 3.92 + 7.67 + 51.93 = **63.52 lb**

$w_{batch} = w - (w_{free} + \Sigma w_{admx})$
w_{batch} = 296.84 lb – (33 lb + 63.52 lb) = **200.32 lb**
$V_{water} = \frac{Mass_{water}\ (lb)}{62.4\left(\frac{lb}{ft^3}\right)}$
$V_{water} = \frac{296.84}{62.4} =$ **4.76 ft³**

Solids: Neglecting all admixtures except for latex and mineral fillers.

Solids in admixtures $= dosage\left(\frac{fl\ oz}{cwt}\right) * cwt\ of\ cm\left(\frac{lb}{yd^3}\right) * solids\ content * \frac{1\ gal}{128\ fl\ oz} * \left(\frac{lb}{gal}\right) of\ admixture$
From Latex $= 250.0 * \frac{593.68}{100} * \frac{47}{100} * \frac{1\ gal}{128\ fl\ oz} * 8.45\frac{lb}{gal} =$ **46.05 lb**
Total Amount of Solids = 46.05 + 1.36 + 17.72 = **65.13 lb**
$V_{Solids} = \frac{Mass_{solids}\ (lb)}{SG*62.4\left(\frac{lb}{ft^3}\right)}$
$V_{Solids\ Latex} = \frac{46.05}{1.01*62.4} =$ **0.73 ft³**
$V_{SG300\ mineral\ filler} = \frac{1.36}{0.72*62.4} =$ **0.03 ft³**
$V_{K20\ mineral\ filler} = \frac{17.72}{0.20*62.4} =$ **1.42 ft³**
Total Volume of Solids = 0.73 + 0.03 + 1.42 = **2.18 ft³**

Densities, Air Content, Slump, and Ratios:

Mass of Concrete = $Amount_{cm}$ + $Amount_{fibers}$ + $Amount_{aggregate}$ + $Amount_{water}$ + $Amount_{solids}$
M = 593.68 lb + 6.39 lb + 713.05 lb + 296.84 lb + 65.13 lb = **1675.09 lb**
Volume of Concrete = $Volume_{cm}$ + $Volume_{fibers}$ + $Volume_{aggregate}$ + $Volume_{water}$ + $Volume_{solids}$
V = 3.35 ft^3 + 0.08 ft^3 + 14.87 ft^3 + 4.76 ft^3 + 2.18 ft^3 = **25.23 ft^3**
Theoretical Density T = M/V
T = 1675.09 lb / 25.23 ft^3 = **66.39 lb/ft^3**
Measured Density D
D = **58.44 lb/ft^3** (Measured in the plastic state)
Air Content = $\frac{T\left(\frac{lb}{ft^3}\right)-D\left(\frac{lb}{ft^3}\right)}{T\left(\frac{lb}{ft^3}\right)} * 100\%$
Air Content = $\frac{66.39-58.44}{66.39} * 100\%$= 11.97**%**
Cement to Cementitious Materials Ratio, c/cm = 231.54 lb / 593.68 lb = **0.39**
Water to Cementitious ratio, w/cm = 296.84 lb / 593.68 lb = **0.50**
Water to Cement ratio, w/c = 296.84 lb / 231.54 lb = **1.28**
Slump (Measured) = **1.5 in**

Concrete Ratios:

Aggregate Ratio (%) = $\frac{V_{aggregate}(ft^3)}{27}$ *100%
Aggregate Ratio (%) = $\frac{14.88}{27}$ *100%= **55.11 %** > 25% **Compliant!**
ASTM C330 Aggregate Ratio (Volumetric) (%) = $\frac{V_{aggregate\ C330}(ft^3)}{V_{aggregates}(ft^3)} * 100\%$
ASTM C330 Ratio = $\frac{3.95}{14.88}$ *100% = **26.54 %** > 25% **Compliant!**

Appendix C – Example Structural Calculations

Assumptions

Fiberglass mesh provides negligible flexural reinforcement

Male paddlers weigh 170lb, female paddlers weigh 145lb and 170lb

$f_c' = 1025psi$

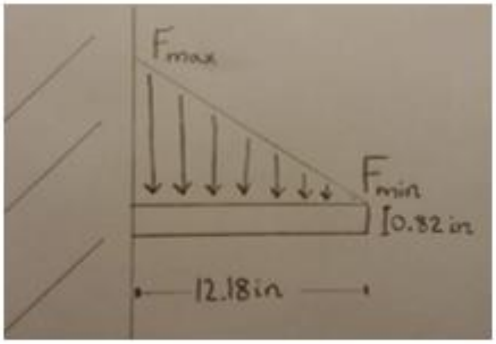
$E = Young's\ Modulus\ of\ lightweight\ concrete = 4.3 * 10^3 ksi$

Unless stated otherwise, x is the longitudinal distance from the bow in inches

Chine Shear and Gunnel Deflection

All forces will act on square inches, so all forces will be pressures force min is water pressure, force max is water pressure plus weight of water times depth

X is in inches where x=12.18 is the gunwale and x=0 is the chine



$$F(x) = F_{max} - \frac{F_{max}}{depth_{max}} * x \qquad \frac{63pcf}{1} * \frac{1ft^3}{12^3 in^3} = 0.0365\frac{lb}{in^3}$$

$$F_{min} = (wave\ action\ factor)(unit\ weight)(depth) = (1.3)\left(0.0365\frac{lb}{in^3}\right)(0in) = 0\frac{lb}{in^2}$$

$$F_{max} = (wave\ action\ factor)(unit\ weight)(depth) = (1.3)\left(0.0365\frac{lb}{in^3}\right)(12.18in) = 0.578\frac{lb}{in^2}$$

$$F(x) = 0.578\frac{lb}{in^2} - \frac{0.578\frac{lb}{in^2}}{12.18in} * x = 0.578\frac{lb}{in^2} - 0.0475\frac{lb}{in} * x$$

$$V(x) = \int_0^{12.18} F(x)dx = (.5)(F_{max})(12.18in - 0in) = 3.52\frac{lb}{in}$$

$$V(x) = -\int F(x)dx = -0.578x + 0.0238x^2 + 3.52$$

$$M(x) = \int V(x) = -.289x^2 + .0079x^3 + 3.52x$$

$$I = \frac{b * h^3}{12} = \frac{1 * (.82)^3}{12} = .046in^4$$

$$deflection\ at\ gunwale = d = \int_0^{12.18} \frac{M(x)}{EI} = 0.0094in$$

Punching Stress

$$Weight = W = (.75)(200lb) = 150lb$$

$$Perimeter = p = 2(base) * 2(height) = 2(4) + 2(4) = 16in$$

$$required\ strength = V_n = \frac{W}{p * depth} = \frac{150lb}{(16in)(.82in)} = 11.43psi$$

Shear and Bending Moment Diagram

$$W_C = Canoe\ Weight = 235lb = \int_0^L W(x)dx$$

$$F_B = Bouyant\ Force = \int_0^L F_B(x)dx = 145lb + 3(170lb) + 235lb = 890lb$$

$$W_C = (.5)(L)(W_{max}) = .5 * 248in * W_{max} \quad W_{max} = 1.90\frac{lb}{in}$$

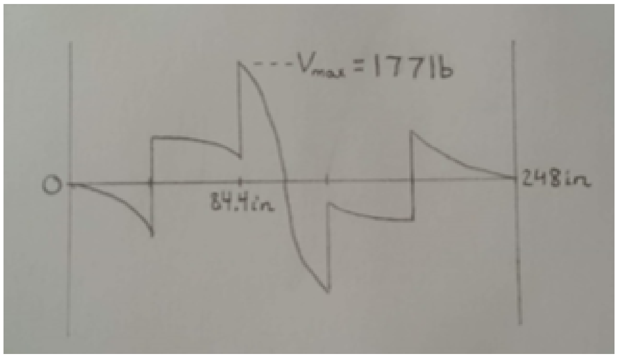
$$F_B = (.5)(L)(F_{max}) = .5 * 248in * F_{max} \quad F_{max} = 7.18\frac{lb}{in}$$

$$W_{female\ avg} = \frac{170lb + 145lb}{2} = 157.5lb$$

$$\sum F_y = F_y(0) = 0 = -(.5)\left(1.90\frac{lb}{in}\right)(124in) - 170lb - 157.5lb + (.5)\left(7.18\frac{lb}{in}\right)(124in) - V(124in)$$
$$= -118lb - 170lb - 158lb + 445lb - V(124) = -1lb - V(124in)$$

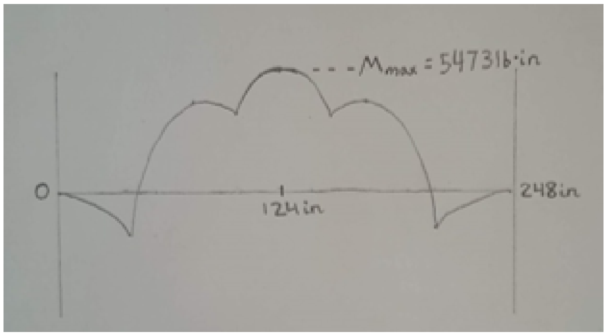
$$V(124in) = -1lb$$

$$V_{max} = V(84.4in) = 170lb + 157.5lb + \left(\frac{84.4in}{124in}\right)\left(1.90\frac{lb}{in}\right)(.5)(84.4in) - \left(\frac{84.4in}{124in}\right)\left(7.18\frac{lb}{in}\right)(.5)(84.4in)$$
$$= 170lb + 158lb + 55lb - 206lb = 177lb$$

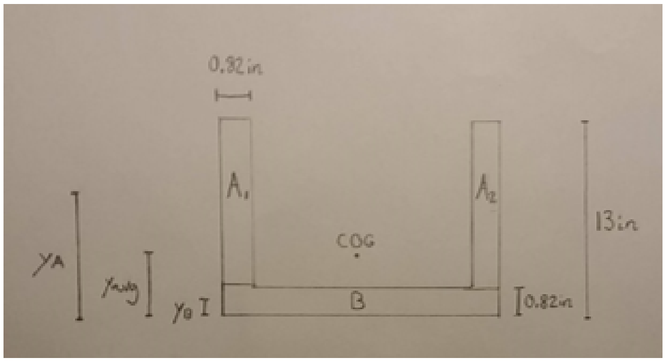


$$\sum M = M(0) = 0 = -(170lb)(48.8in) - (157.5lb)(84.4in) - (.5)(124in)(124in)\left(\frac{2}{3}\right)\left(1.90\frac{lb}{in}\right) + (.5)(124in)(124in)\left(\frac{2}{3}\right)\left(7.18\frac{lb}{in}\right)$$
$$+ M(124in) = -8296lb * in - 13293lb * in - 9738lb * in + 36800lb * in + M(124in) = 5473lb * in + M(124in)$$

$$M_{max} = M(124in) = -5473lb * in$$



Cross Section Bending



$y_{avg} = \frac{\sum y_i A_i}{\sum A_i}$ $\quad$ $y_A = \frac{13in - .82in}{2} = 6.09in$ $\quad$ $y_B = \frac{.82in}{2} = .41in$

$A_A = (13in - .82in)(.82in) = 10.00in^2 \quad A_B = (28.85in)(.82in) = 23.66in^2$

$$y_{avg} = \frac{(y_{A1})(A_{A1}) + (y_{A2})(A_{A2}) + (y_B)(A_B)}{A_{A1} + A_{A2} + A_B} = \frac{(6.09in)(10.00in^2) + (6.09in)(10.00in^2) + (.41in)(23.66in^2)}{10.00in^2 + 10.00in^2 + 23.66in^2} = 3.01in$$

$I_{rectangle} = \frac{bh^3}{12}$ $\quad$ $I_{Ax} = \frac{(.82in)(13in - .82in)^3}{12} = 123.47in^4$ $\quad$ $I_{Bx} = \frac{(28.85in)(.82)^3}{12} = 1.33in^4$

$I = I_x + Ad^2$ $\quad$ $I_A = I_{Ax} + A_A(y_{avg} - y_A)^2 = 123.47in^4 + (10.00in^2)(3.01in - 6.09in)^2 = 218.33in^4$

$$I_B = I_{Bx} + A_B(y_{avg} - y_B)^2 = 1.33in^4 + (23.66in^2)(3.01in - .41in)^2 = 161.27in^4$$

$$I_x = \sum I_{xi} = I_{A1} + I_{A2} + I_B = (218.33in^4) + (218.33in^4) + (161.27in^4) = 597.94in^4$$

$$\sigma = \frac{-M_{maxsurf} * y}{I}$$

$\sigma_{comp} = \frac{-(-5473lb*in)(13in - 3.01in)}{(597.94in^4)} = 91.4psi\ compression\ at\ gunwales$ $\quad$ $\sigma_{tens} = \frac{-(-5473lb*in)(3.01in)}{(597.94in^4)} = 27.6psi\ tension\ at\ bilge$

Appendix D – Hull Thickness/Reinforcement and Percent Open Area Calculations

Hull Thickness:

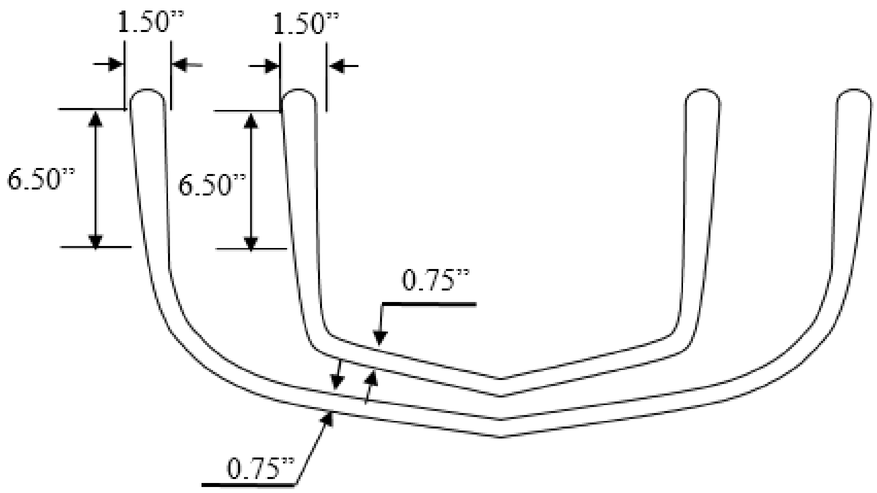


Figure D- 1. Representative cross sections for *TERRA* located 25% and 75% from the bow.

MCCT used a gradient similar to the 2017 gradient to strengthen the area below the gunwales which was determined to be the area experiencing the most stress. The width and height of the gradient is maintained throughout the entire length of the canoe. The ThicknessAnalysis() function was used in Rhinoceros 5.0 to find the average thickness between the outer and inner polysurfaces of the canoe design. Representative cross sections are shown above in Figure D-1. The gunwale thickness was 1.5" and the thinnest part of the canoe was 0.75" with the gradient between the two thicknesses spanning 6.5". The ThicknessAnalysis() function provided an average thickness of 0.82".

The Spiderlath fiberglass reinforcement used in the canoe has a thickness of 1/16". Only one layer of reinforcement was used through the entire canoe. The example calculation below confirms that the reinforcement is less than 50% of the total thickness of the canoe. The reinforcement is incorporated into the concrete so that the final hull thickness is 0.75 inches.

1^{st} Layer of concrete:	0.375 inches
Reinforcement:	0.0625 inches
2^{nd} Layer of concrete:	0.3125 inches

Total Thickness = 0.375" + 0.3125" + 0.0625" = 0.75 inches

% of Thickness that is reinforcement = 0.0625"/0.75" = 8.3%

Percent Open Area:

One layer of fiberglass mesh was used in the layering scheme chosen for *TERRA.* Calculations are presented below.

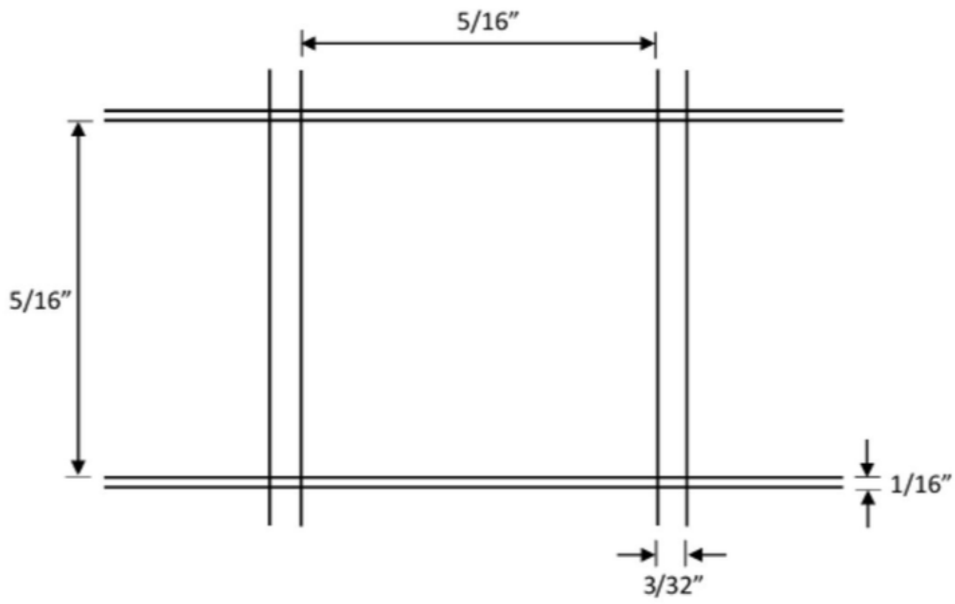


Figure D- 2. Schematic of the fiberglass mesh used as reinforcement.

Number of apertures along sample width = 20

Number of apertures along sample length = 20

$$\text{Open Area} = 20 \times 20 \times {}^{5}/_{16} \times {}^{5}/_{16} = 39.06\ \text{in.}^2$$

$$\text{Aperture Area}\ \left(\text{consider}\ {}^{1}/_{2}\ \text{of strand thickness}\right)$$

$$W = {}^{5}/_{16}" + {}^{1}/_{2}\,(2 \times {}^{3}/_{32}") = {}^{13}/_{32}"$$

$$L = {}^{5}/_{16}" + {}^{1}/_{2}\,(2 \times {}^{1}/_{16}") = {}^{6}/_{16}"$$

$$\text{Width of Sample} = 20 \times {}^{13}/_{32}" = 8.13\ \text{in.}$$

$$\text{Length of Sample} = 20 \times {}^{6}/_{16}" = 7.50\ \text{in.}$$

$$\text{Total Sample Area} = 8.13" \times 7.50" = 60.98\ \text{in}^2$$

$$\text{Percent Open Area} = \frac{39.06\ \text{in.}^2}{60.98\ \text{in.}^2} \times 100 = \mathbf{49.3}\%$$