Vitruvius

University of Massachusetts Lowell

2019 Concrete Canoe Design Paper

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EXECUTIVE SUMMARY

The University of Massachusetts Lowell (UMass Lowell) campus officially became an educational institute in 1895, founded as the Lowell Textile School, serving students by training students for the textile industry. In 1975, the Lowell Technological Institute and Lowell State College merged and became known as the University of Lowell. In 1991, it was integrated into the UMass system and became known as the University of Massachusetts Lowell.

The university has almost 18,000 students, offers 122 bachelors', 43 masters' and 36 doctoral degrees within its six colleges (About UMass Lowell 2019). The Francis College of Engineering has a prominent reputation for its hands-on education. The college's students are known for being hardworking, dedicated, and well-prepared for their future careers (Francis College of Engineering 2019).

UMass Lowell competes in the New England Regional Competition (NERC). In the last three years, the Concrete Canoe Team at UMass Lowell has had a mix of triumphs and defeats in the NERC - placing 8th in 2016 with *Sockeye*, 2nd in 2017 with *Jester* and 3rd in 2018 with *Flintlock*.

Table 1. *Vitruvius* Specifications

Weight	200 lbs (Estimated)
Length	20 ft
Width	26.92 in
Depth	13.05 in
Average Thickness	1/2 in
Reinforcement	Basalt Mesh, Fiberglass Mesh
Colors	Red, White, Gold, Grey

For the 2019 competition, UMass Lowell planned to improve designs of previous canoes using the CNC. The team analyzed the pros and cons of utilizing CNC milling against hand construction. Ultimately, it was determined that the mold would not be milled due to time constraints (Construction, 11).

In addition to improving the overall design, the process of designing ***Vitruvius*** and all subsequent Umass Lowell canoes stressed additional input from the paddling captain to ensure that the paddling team was able to handle and control the canoe on the water.

Further research into the behavior of expanded shale as a lightweight aggregate resulted in a final mix design capable of withstanding the stress of competition (Table 2). Ultrasonic Sonar B testing was also used as a form of nondestructive testing in order to take a look at internal cracking and spaces in the layers of concrete.

Table 2. Concrete Properties

Plastic Unit Weight	65.92 lb/ft^3
Oven-Dried Unit Weight	56 lb/ft^3
Compressive Strength	1440 psi
Tensile Strength	250 psi
Flexural Strength	310 psi
Slump	¼ in
Air Content	0.6 %

In addition to the improvements and innovations made to the mix development and design process, Lowell focused on a new mission of lowering the environmental footprint left by construction team. This new mission included the purchasing of recycled foam for mold construction and creating a can/bottle drive for the 2018 – 2019 school wide fundraiser.

Inspired by the architecture and civil engineering feats achieved by the Roman Empire, the 2019 UMass Lowell Concrete Canoe Team is honored to present ***Vitruvius***.

HULL DESIGN AND STRUCTURAL ANALYSIS

Hull performance was broken down into three basic categories: maneuverability, stability and comfort. The design and analysis team approached the initial hull design with a smaller hull in mind, allowing for a smaller wetted hull area in order to decrease lateral water flow and wave drag. This advantage would create a hull that would have similar tracking and maneuverability as canoes from previous years. The design team then consulted with the paddling captain and his team members to ensure that paddler comfortability and ergonomics would not be jeopardized with a smaller, narrower hull design. Both the design and paddling captain concluded that stability was the team's next area of focus. Understanding the limited experience of new paddlers, the canoe was designed for stability and necessary adjustments were made to the hull design of *Moswetuset* from 2015.

The paddlers from Jester's entry mentioned that they had felt more secure within a tumblehome canoe and requested that feature be reinstated within ***Vitruvius'*** hull design. The tumblehome sidewalls allow for more efficient paddling due to their close proximity to the hull, which increases the paddler's control of the canoe. Canoe stability is a characteristic of the canoe that is directly affected by the shape of the hull bottom and sidewalls. Stability of a canoe can be broken down into an initial phase, which refers to stability of a canoe when upright in calm water, and a final phase, which is how resistant the canoe is to capsize when rolled on its edge. (Randall 2010). A shallow arch bottom not only provides good initial and final stability but is also predictable and responsive when leaned. The arched bottom along with the tumblehome allows the hull to become more stable as it is loaded to capacity by positioning the widest part of the hull below the waterline. The arch bottom allows the hull to remain in the water when leaning and rocks less due to less resistivity to waves; easing paddler's ability to maintain balance when paddling.

Table 3. Design Parameters for Two-Male Loading

Canoe Name	*Sockeye*	*Jester*	*Flintlock*	*Vitruvius*
Overall Length	238 in	246 in	245 in	240 in
Maximum Depth	13.96 in	13.78 in	13.8 in	13.55 in
Freeboard	8.62 in	8.29 in	8.91 in	8.25 in
Bow Rocker	6.7 in	3.7 in	3.8 in	6.56 in
Stern Rocker	4.6 in	3.9 in	4.3 in	4.49 in
Wetted Hull Surface Area	30.79 ft^2	32.13 ft^2	30.23 ft^2	30.56 ft^2
Prismatic Coefficient, C_P	0.468	0.446	0.417	0.438

The free surface affect, discovered by *Flintlock's* design team, was also taken into consideration this year. Throughout the duration of races, paddlers continually splash water into the canoe, resulting in continuously increasing moment applied to the canoe as the water moves further from the center of gravity (Gudmundsson 2009). This creates problems with listing and slows down maneuverability.

To combat this issue of onboard water hindering maneuverability, the design team reinstated the concept of longitudinal ribs within ***Vitruvius.*** The tumblehome sidewalls also decrease the open area in which water can pass over the gunwale line and into the canoe during paddling. Intricate 3D aesthetic elements placed within the canoe provide additional small voids where water can be trapped. The combination of these two design elements work in conjunction to combat this free surface effect. A final design was chosen with the longitudinal ribs splitting the hull into even thirds between each bulkhead face, being spaced 64 in apart.

When analyzing the canoe, UMass Lowell considered five different loading scenarios on ***Vitruvius.*** These scenarios being: two-male race conditions, two-female race conditions, four-paddler race conditions, two-person carry, and static display. UMass Lowell developed structural analysis spreadsheets using Microsoft Excel and applied said spreadsheets to ***Vitruvius*** for the five scenarios. Transportation was not considered with respect to structural analysis, as the canoe will be fully supported and therefore is not subject to any loading.

Table 4. Strength Demand for *Vitruvius*

Parameter	Demand (psi)
Tensile	33.62
Compression	61.32

When creating the structural analysis spreadsheets, ***Vitruvius*** was assumed to behave as a simply supported beam with bending occurring about the longitudinal axis and was modeled as such. Research into previous submissions has led to the conclusion that inclusion of ribs, gunwales, and similar features can reduce critical stress by as much as 43% when compared to a featureless canoe (Moswetuset, 2013). As ribs and gunwales were within the technical experience of the design and placement team, the decision to include them in the design of Vitruvius was made in order to reduce stress in the canoe by increasing the moment of inertia about the longitudinal axis.

Point loads representing paddler weights and locations were then applied to all race conditions. A two-person male loading was represented by a conservative estimate of 170 pounds for each load. For females a point load of 140 pounds was used for each paddler. These loads were modelled by placing the one male loads at 52 inches and the second male load 188 inches from the bow and the female loads one each at 86 and 154 inches from the bow. The dead load of the canoe was represented by a triangular distributed load at an estimated 190 total pounds. Then, based on the principles of mechanics of materials, the maximum tensile and compressive bending stress at critical locations were calculated.

The largest bending moment (M_{max}) was found during co-ed loading and was located at 120 inches aft of bow. The extreme fiber distances were $Ct = 8.58\ inches$ and $Cc = 4.72$ inches. The Moment of Inertial about the X-Axis (I_x) was hand calculated using Parallel Axis Theorem. UMass Lowell's design and analysis team calculated maximum tensile and compressive bending stresses (σ_b) using Equation 1.

$$\sigma_b = \frac{M_{Max} C}{I_x} \qquad Eq. 1$$

A dynamic loading amplification factor of 1.25 and a mix design factor of 2.5 was then applied to all bending stresses to account for factors outside the scope of simple 2D analysis. The magnified stresses were then plotted alongside ***Vitruvius'*** failure envelope and Lowell determined the canoe would be strong enough to withstand a combination of tension, compression, and shear. The results of the analysis team's structural analysis are shown in Table 4. A simplified analysis showing Lowell's ability to calculate these requirements is shown in Appendix C.

DEVELOPMENT AND TESTING

To reduce the errors made in previous years, a practice placement was used to test mix properties, like workability, that fell outside of the standard strength testing. Practice placement took place in early November and served as a learning experience for both construction team members and mix design team members. The mix design team made a small volume mix to determine the amount of pigment needed to produce the colors that the aesthetics captain had approved. On the practice placement day, however, the team struggled to produce a workable mix to place on the mold. The concrete mix was much drier than expected and was not usable for the placement because the concrete would not adhere properly to the practice mold. Upon this discovery, the mix design team mechanically agitated the concrete and worked with different admixtures to try to restore workability. The remaining mix inadvertently bled out water and pigment, rather than adhering to the mold. Based on this practice placement, the mix design team modified the mix for the placement day of ***Vitruvius***. The Project Manager, Operations Manager and Mix Design captain unanimously agreed that the practice placement was successful because the discovery that the mix was not useable allowed changes to be made before the 2019 canoe was placed. Moving forward, the mix team was tasked with determining the appropriate water to cement ratio in order to achieve the target workability and strength.

Development of the ***Vitruvius***' mix involved the most intensive changes since 2012. These changes were largely driven by two new rules created for the 2019 NCCC: 3.2.3.4, Polymer Modifiers, Bonding Adhesives, and Waste Latex Paints (NCCC 2019) and 3.3.3 Aggregate proportioning, Subsection B (NCCC 2019). Along with these rules, the team also sought to reduce the density of the concrete. Recent mixes had been increasing in density, and the mix team felt that although factors of safety were still being applied during all aspects of design to ensure the canoe would be buoyant, focusing on a less dense mix was vital to creating the best canoe possible. These changes resulted in a concrete mix vastly different from *Flintlock*. To meet this requirement, Lowell used *Revolution*'s mix as a baseline (0.50 w/cm, 520 psi tensile strength, and 2980 psi compressive strength) to begin the design process as shown in Figure 3.

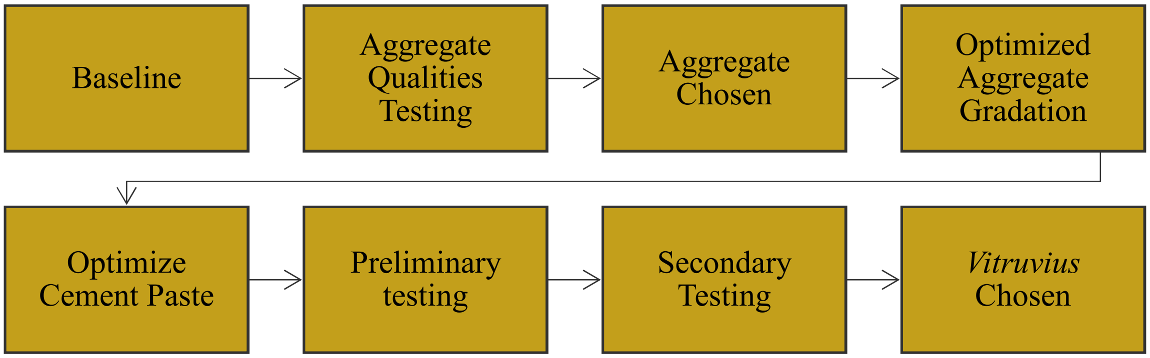


Figure 1: Iterative Design Process

After selecting a baseline mix to work from, UMass Lowell began investigating different particle sizes for the aggregate to be sieved out to, in accordance to the rule that stated any aggregate that passes through a No. 200 (75 µm) sieve shall be logged as a mineral filler, therefore excluded from the calculation of the volume of the aggregate. (NCCC 2019) This ruled out using 3M's K15 Glass Bubbles, a staple in Umass Lowell's mixes throughout the years, as an aggregate. Umass Lowell's solution was to pass the shale through a No. 16 sieve and remove the particles that were retained, making all the shale an aggregate, rather than a mineral filler. Examples showing the expanded shale in concrete sections are shown in Figure 2.

Next, UMass Lowell determined important material properties of the sieved expanded shale before preliminary mixes could be made. The mix development and testing team calculated the oven-dry specific gravity, saturated surface-dry specific gravity, and absorption in accordance with ASTM C128. Aggregates being tested by the mix development team were also wet-sieved in compliance with ASTM C117 in order to produce the data needed to complete the mix.

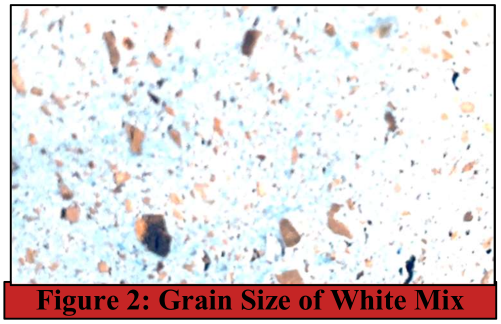


Figure 2: Grain Size of White Mix

Bond strength of Portland cement-based concrete is related to the hydration of Portland cement. During the hydration reactions of belite (C_2S) and alite (C_3S) produces calcium-silicate-hydrate (C-S-H) and hydrated lime (CH). This is shown in Table 5, Equations 1 and 2. Hydrated lime is hydrophilic and weakens concrete over time. In a poor concrete matrix, hexagonal hydrated lime crystals stack up on each other and cause weak zones in concrete. However, if colloidal C-S-H gels fill these voids instead of hydrated lime, the overall strength in these zones is increased. Lowell was able to eliminate the impact of hydrated lime by taking the new CH created and using it as the limiting reagent in the pozzolanic reaction shown in Table 6, Equation 3. A comparison of a high lime content cement matrix against an ideal one shown in Figure 5. By decreasing hydrated lime content in the cement matrix, stresses were decreased within the interfacial transition zone (ITZ) – concrete's tensile failure zone – by allowing more bonding potential due to increased C-S-H content (Kosmtaka et al. 2011).

Table 5. Chemistry of Hydration Reaction	
Belite	$2C_2S + 7H_20 \rightarrow C - S - H + CH$ (EQ 1)
Alite	$2C_3S + 750 \rightarrow C - S - H + 3CH$ (EQ 2)
Pozzolanic Reaction	
Pozzolanic Reaction	$Pozzolanic + CH \rightarrow C - S - H$ (EQ 3)

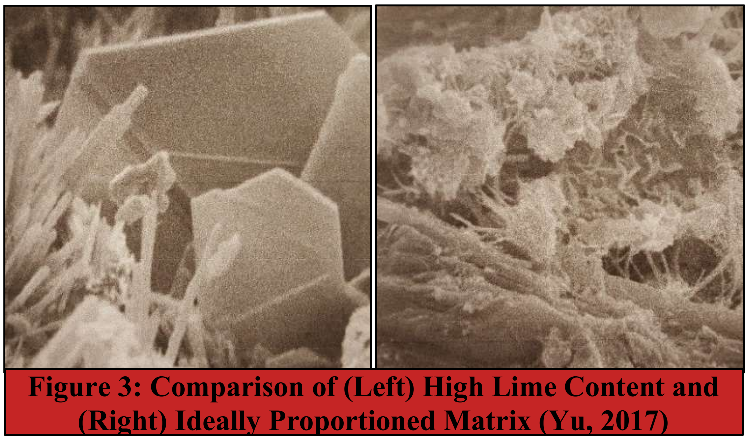


Figure 3: Comparison of (Left) High Lime Content and (Right) Ideally Proportioned Matrix (Yu, 2017)

Moisture in ***Vitruvius'*** mix was a large factor in the design changes for this year. Silpro C21 All Acrylic had been previously used either as an addition to, or as a replacement for water. The latex added to the strength of the concrete by creating a better bond between particles at the interfacial transition zone (Kosmatka et al. 2011).

Due to rule 3.2.3.4, Polymer Modifiers, Bonding Adhesives, and Waste Latex Paints (NCCC 2019), Silpro was no longer allowed as a source of moisture in the Concrete. Mallard Creek Tylac 4190 was chosen as the source of moisture after extensive testing of several different alternatives. Tylac 4190 provided the highest strength in both Compressive and Tensile stress, along with an air content of 13.46%. Tylac 4190 also proved to have a mild water reducing effect, allowing the mix team to use a lower W/CM ratio. As Tylac 4190 contains 50% solids by weight, a mixture of both Tylac 4190 and water was used to bring the solids content to 22.02%, comparable to that of Silpro at 20%. This mixture gave the concrete the desired workability, along with a very low slump.

AVDA Cast 575 superplasticizer was originally chosen to help increase workability, but due to a shipping error, ADVA Cast 555 was instead used in the concrete mix. ADVA Cast 555, used in other concrete canoes such as California Polytechnic State University; San Luis Obispo, was shown to have a better effect on workability than ADVA Cast 575, requiring less superplasticizer to achieve the same slump. At the same time, the amount of Eclipse Floor 200 shrinkage reducer was reduced to less than half the manufacturer recommended maximum amount of 2.5 gal/yd3 (amount used was 1.01 gal/yd3). This was done to maintain a higher air content, as shrinkage reducer has an air detaining quality, but as the aggregates in the canoe contained a more uniform gradation than in past canoes, shrinkage was no longer as big of a concern as before, meaning less shrinkage reducer could be used

Before preliminary testing began, ***Vitruvius'*** Safety Officer performed an inspection of UMass Lowell's Concrete Research Laboratory to ensure all equipment was safe for use. This inspection consisted of posting material safety data sheets (MSDS) and ensuring that personal protective equipment (PPE) was available for all members of the team.

For preliminary testing, UMass Lowell chose to reduce material costs and limit its environmental footprint by using 2x4 cylinders in place of 3x6 cylinders for tension testing (ASTM C496) and compression testing in accordance with ASTM C39. Only 1/5 of the material was required to make cylinders of this size, which meant a decrease in material waste.

In the past, a 0.45 w/cm ratio was used due to its workability and high tensile strength. Revolution's 0.50 w/cm mix was used as a baseline because originally, non-water admixtures could not reduce the ratio any lower. Based on the further mix research done by the team, a 0.45 w/cm ratio was selected. The final engineering properties of ***Vitruvius'*** mix were determined from 3x6 cylinders and flexural beams, all of which were cast on placement day. Lowell determined the mix was adequate for all types of stresses. A comparison of this mix with four of Lowell's previous canoes can be found below in Table 6.

Table 6. Comparison of Lowell Mixes

Canoe	w/cm	%CP	Unit Weight (pcf)	Tensile Strength (psi)	Compressive Strength (psi)
Vitruvius	0.45	45%	65.55	520	1440
Flintlock	0.45	40%	59.4	526	1998
Jester	0.45	40%	61.9	310	1990
Sockeye	0.65	40%	44.3	330	940

CONSTRUCTION

After the success of the 2018 season, UMass Lowell’s construction and design teams focused on improvements on mold construction with a CNC milling machine. With a team short on design experience, the software and programming used to create the mold took much longer than expected. This delayed progress on the mold and pushed back other dates on the critical path. Umass Lowell’s Project Manager, Operations Manager and Design Captain made the executive decision to continue working on the mold throughout the winter recess. Upon returning to Lowell, management concluded that the mold would not be able to be completed by being milled in a CNC machine. The decision was made to produce the mold by hand in an attempt to not push other dates on the critical path back further.

Following the release of the 2019 NCCC Rules and Regulations and the completed hull design, the construction team began work on the mold. Two-inch rigid XPS foam was chosen for its ability to support the construction process, ease of shaping, and availability. To cut down on cost and lower the amount of waste created by using new material, recycled foam was used. The recycled foam had to be cleaned and sanded before construction of the mold could begin.

The construction team immediately began work on the new male mold and female bulkhead forms. Using two-inch interval paper cross sections provided by the design team, ***Vitruvius***’ computer model was then transferred to sections of foam that had been cut down to the approximate size of the canoe section, as shown in Figure 4.

This method gave the team high accuracy and a short turn over time for the mold. Using the transferred outlines, the foam sections were cut on a bandsaw. Two ribs (1 in x 2 in) were routed in specified sections. The sections were laid together using a centerline, then glued together. The mold was then sanded down to the finished shape.

Figure 4: Recycled Foam Section for Male Mold

Gunwales were cut using a track system that provided a smooth and consistent shape that spanned the length of the canoe. Imperfections in the recycled foam were filled with drywall compound and sanded smooth. Aesthetic elements were also projected onto the mold and routed in, avoiding areas that would cause major paddler interference. Finally, two coats of release agent were then applied, and the mold was ready for placement.

Placement of ***Vitruvius*** took place in mid-February. The week of placement day, the mix design time hand-sieved dry materials to ensure a more consistent mix. Dry materials were batched out after they were hand sieved to reduce the workload before placement. The day before placement took place, all dry liquid materials were batched out so that placement day would run smoothly. All materials were accurately measured by weight, using multiple identical scales that read values beyond the required tolerance.

Placement of the concrete travelled from bow to stern, starting with a 1/4-inch first layer, integrally colored with bright white pigment. Wooden depth checkers were used to maintain a constant thickness throughout each concrete layer. Depth checkers were cleaned after each layer in order to reduce unwanted color transfer in between layers. Once the first layer was underway, placement of the bow bulkhead began using a new innovative female form that helped develop the stem shape without placing unnecessary amounts of concrete. Before the second layer, reinforcing mesh was placed followed by a smear of concrete so that basalt mesh could also be placed immediately before the second concrete layer. As each mesh layer had the same size openings, the mesh was placed so the grids aligned with each other to ensure maximum bonding between first and second concrete layers. Each rib received two strips of basalt mesh, and gunwales received two strips of basalt mesh. This created the skeletal reinforcement structure for the canoe. During the placement of the canoe, the layer of basalt mesh was forgotten before second layer placement commenced on the last foam section near the stern. The decision was made to fit the mesh onto the section in order to have as much reinforcement possible. Based on the placement, there were concerns that the second layer of mesh was not properly adhered to the first layer, leaving a gap between the two under the second layer of concrete. Both construction and design teams will be running Ultrasonic B-Scan Imaging on the section, in order to use ultrasound waves to determine how large of a gap is between the first and second layers of mesh.

Just before the first concrete layer reached the 3D elements, the routed areas, shown in Figure 5, received concrete layers of varying thicknesses, covered by the first layer. The routed areas contained three different concrete colors, whereas the first and second layers of concrete only had one. At the completion of the second layer, the total hull thickness was 1/2 inch, providing a buffer to account for irregularities that will be sanded down to complete the average thickness of 1/2 inch. ***Vitruvius*** was kept in a moist environment for the first seven days of its curing cycle. Team members often checked whether the canoe was receiving sufficient moisture; if concrete dries during the moist curing cycle, the maximum strength of the concrete may not be achieved even if moisture is resupplied (Neville and Brooks 2010). At the 21st day, ***Vitruvius*** will be removed from the hydration tent.

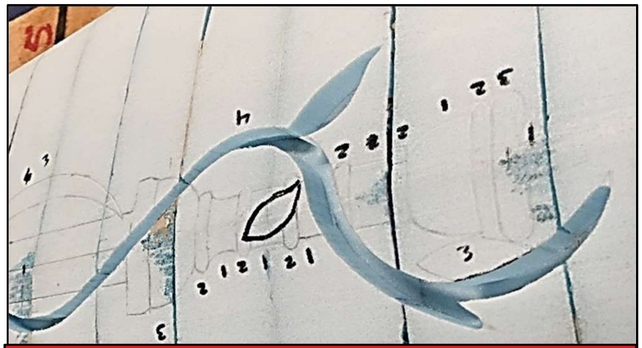


Figure 5: Inlay (Routed Area) Design on Male Mold

Beginning with wet sanding using 60-grit sandpaper, Lowell's construction team will work for two weeks to shape the exterior of the hull. The mold and canoe will then be removed from the table and the canoe will be flipped onto stands. The mold will then carefully be removed by cutting out each foam section, saving usable pieces for stand construction. Residual drywall compound on the interior of the canoe will be removed afterwards. Team members will dry sand with up to 1500-grit sandpaper. Following the competition of sanding, vinyl lettering will be adhered followed by two layers of sealer, resulting in a smooth and glossy finish.

PROJECT AND QUALITY MANAGEMENT

The new management of Umass Lowell's concrete canoe team made large changes to optimize the existing management and role system. With a predominantly younger team at the helm, roles were switched and updated to fit the new style of management. The 2019 Core Team was composed of one Project Manager, one Operations Manager, five team captains, and two officers were selected. With the departure of team members due to graduation, most core team members were new to their role. This led to difficulties in regard to areas such as design, with the appointed design captain struggling to keep up with the software. The Project Manager worked with the other team members and faculty to schedule team meetings, promote team activities, recruit new members, and manage fiscal matters.

Five team captains directed the five subdivisions within the team: Design and Analysis team, Mix Design team, Construction team, Aesthetics team and Paddling team. Team captains were responsible for keeping their members informed on daily tasks and innovating in their specific field. Captains were also responsible for ensuring the milestone deadlines along the critical path were still met (Table 3). The critical path was calculated using Microsoft Project by determining tasks that had no slack. A Google calendar was set up and managed by each team captain. This calendar served to keep each captain aware of what other teams were doing in an effort to avoid scheduling conflicts. The calendar also served as another way for the Operations Manager to stay updated on weekly events held by each team. The Project Manager conducted Core Team meetings to air any concerns or address deviations from the project schedule.

Table 7. Major Project Milestones

Milestone	Planned Date	Actual Date	Reasons for Variance
Vitruvius* Hull Design	11/25/2018	12/17/2018	Team Inexperience
Mold Cut	11/9/2018	NA	CNC Machine Unavailable
Practice Placement Day	11/17/2018	11/17/2018	-
Placement Day for *Vitruvius**	02/02/2019	02/18/2019	Time Constraints
***Vitruvius* Finishing Design Paper Submission**	03/15/2019	3/08/2018	Deadline not known During Planning

*Denotes Critical Path

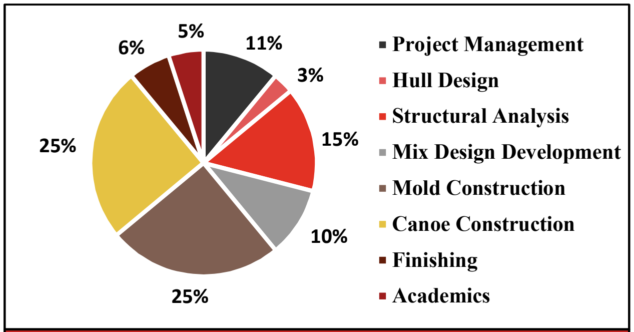


Figure 6: Person - Hour Allocation

Vitruvius' team was composed of 18 members, accumulating a total of 3,780 person-hours (Figure 6). This represents a decrease in the amount of time worked on Flintlock by 27%. This decrease in person-hours can be attributed to the placement of only one canoe, rather than the two canoes that were placed in 2018 due to structural deficiencies. ***Vitruvius'*** financial plan was based upon prior experiences, including issues that incurred cost during the 2017 – 2018 season. The operating budget was set at $15, 510 to include average costs from previous years and miscellaneous costs not limited to canoe materials, canoe placement and moving to the new laboratory costs.

Umass Lowell's Safety Officer organized safety training for all team members, ensuring that construction and mix meetings were only held with members who completed Lab Safety Training. Additionally, the Safety Officer coordinated with the Environmental Health and Safety Department and Umass Lowell Facilities and Maintenance. Upon arrival at the new lab, the Safety Officer made sure all MSDS were placed in a notebook that was kept where every member of the mix development, construction and aesthetics teams could easily find it.

Umass Lowell's management team planned and conducted Core Team meetings beginning in early September. Upon release of the NCCC 2019 Rules and Regulations, all core team members were assigned official roles based upon tasks that needed to be completed. During meetings, team captains provided updates on conducted research, materials that had been tested, techniques that were being used and calculations that had to be performed. These meetings served as a method for reviewing each other's work, making sure every team was acting in accordance to the rules and keeping on similar schedules. The implementation of a group calendar also allowed for captains and officers to schedule meetings without overlapping with another team. The Operations Manager was appointed to oversee all aspects of the project to ensure that standards placed by the management team were met and all teams stayed compliant with the rules.

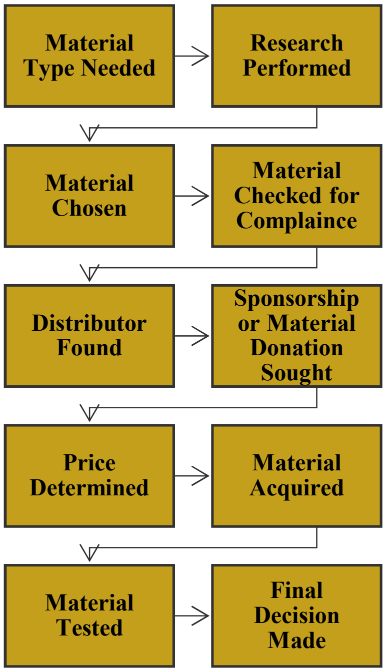


Figure 7: Quality Control Process for all Materials

The majority of materials used for ***Vitruvius*** had to be purchased at the beginning of the academic year. With the construction of two canoes during the 2018 season, material supply and funding coming into the 2019 competition year were much lower than expected. Lowell took care to locate, review, and understand the MTDS and MSDS of all materials used. MTDS were compiled electronically to be reported in the Project Overview and Technical Addendum. MSDS were compiled in a notebook, which was located where all team members could easily access it at any point during the construction or mixing process.

Team members received operation and safety training on all machinery in Lowell's Lab, as well as training on handling of relevant materials. The Environmental Health and Safety Department at Umass Lowell held a remote safety meeting that included video instructions and a post-presentation quiz. With the move into our new laboratory space, entry was only allowed through the locked door if you had participated in the safety training. Certification of completion was kept with the MSDS Binder. Lowell's Safety Officer dictated that individuals who did not complete this training could not participate in the construction or mixing processes.

As soon as the NCCC 2019 Rules and Regulations were released, core team members read the rules to ensure compliance in all aspects of the project. With the NCCC providing a Facebook page where all Requests for Information (RFI) were answered publicly, all questions and answers could be analyzed by team members on their own time as questions occurred.

ORGANIZATION CHART

Management Team

Project Manager: Kat Evasius
Responsible for all scheduling, communications, processing documentation, and overseeing daily operations in relation to critical path.

Operations Manager: Joshua Gittings
Responsible for managing overall construction and design, ensuring quality control of all teams and weekly safety checklist coordination.

Design Leads

Design: Yushai Canteenwala
Responsible for designing the hull, computer modeling, classical two-dimensional analysis, and structural elements design.

Construction: Maurico Reyes
Responsible for construction and finishing of the mold, canoe, and structural elements of the stand, sectional, and display.

Mix Design: Dylan Shaffer
Responsible for mix research and innovations, material selection, initial and final testing, and sample placement.

Officers

Budgeting Chair: Conor Geary
Responsible for managing fundraising, sponsorship letters and securing funding/ grants from various organizations.

Safety Officer: Grace Federiconi
Responsible for ensuring student lab safety by working with the Environmental Health and Safety Board.

Captains

Paddling: Frank Feltes
Responsible for coordinating practices, conditioning paddlers, and coaching proper paddling technique.

Aesthetics: Steven Fallon
Responsible for theme coordination, display board design, logos, final paper imaging and stand design.

Team Members
Josh Gittings (Sr)
Kat Evasius (Jr)
Dylan Shaffer (Sr)
Steven Fallon (Jr)
Yushai Canteenwala (So)
Grace Federiconi (Jr)
Conor West Geary (Sr)
Frank Feltes (So)
Mauricio Reyes (Jr)
Omar Gomez (Jr)
Michael Ward (Jr)
Jamie Trimper (Jr)
Zakaria Attioui (Jr)
Fernando Aguiluz (Jr)
Eoin Stack (Fr)
Gabe Barragan (So)
Hayat Azoui (So)
Mike Kane (Sr)
Molly Houlihan (Fr)

Paddlers
Kat Evasius
Grace Federiconi
Frank Feltes
Eoin Stack
Gabe Barragan
Molly Houlihan

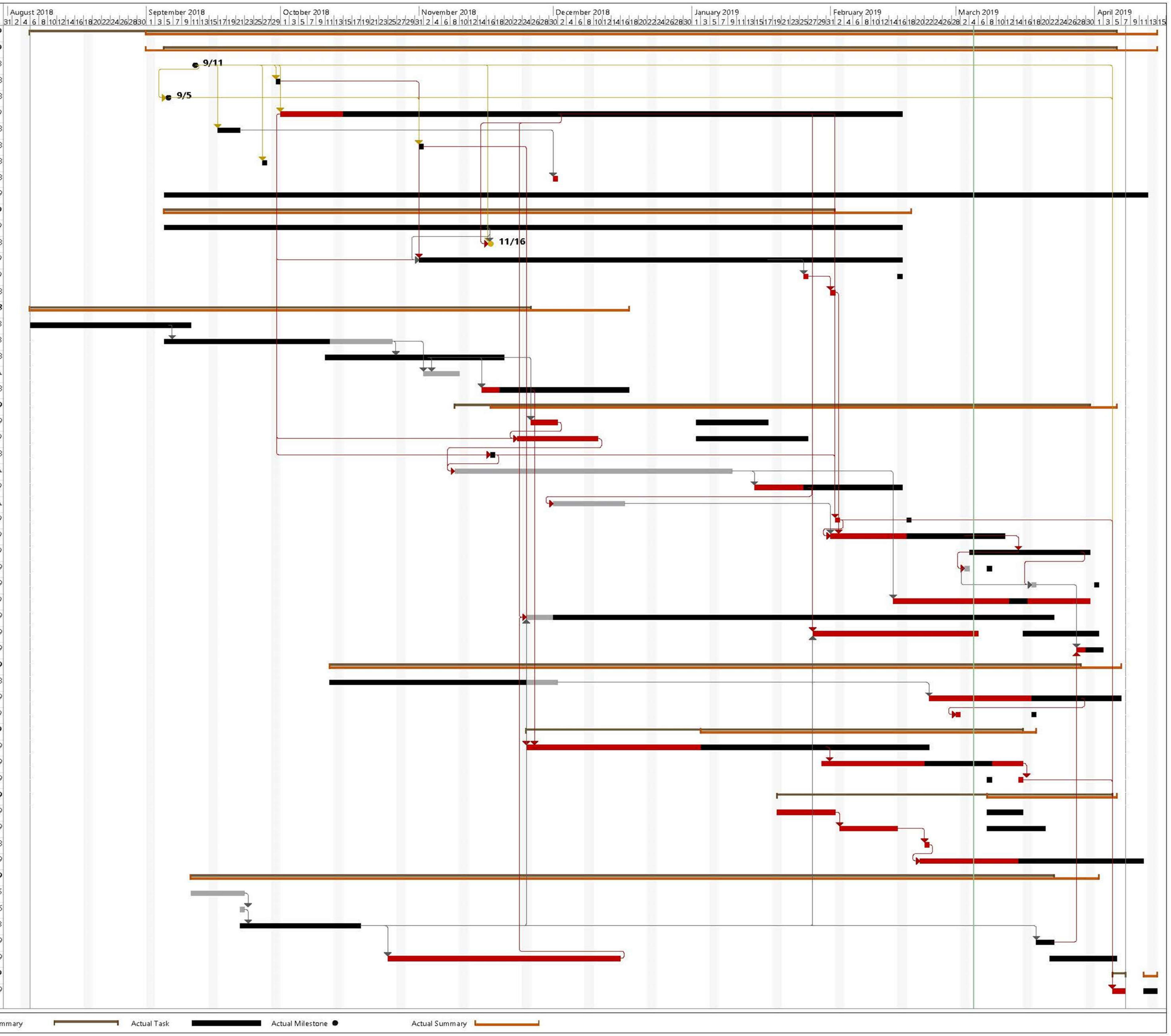
Mix Development
Dylan Shaffer
Jamie Trimper
Hayat Azoui
Mike Kane
Omar Gomez
Michael Ward

Analysis Team
Yushai Canteenwala
Conor West Geary
Josh Gittings
Steven Fallon

Faculty and Staff Advisors: Raj Gondle and Gary Howe

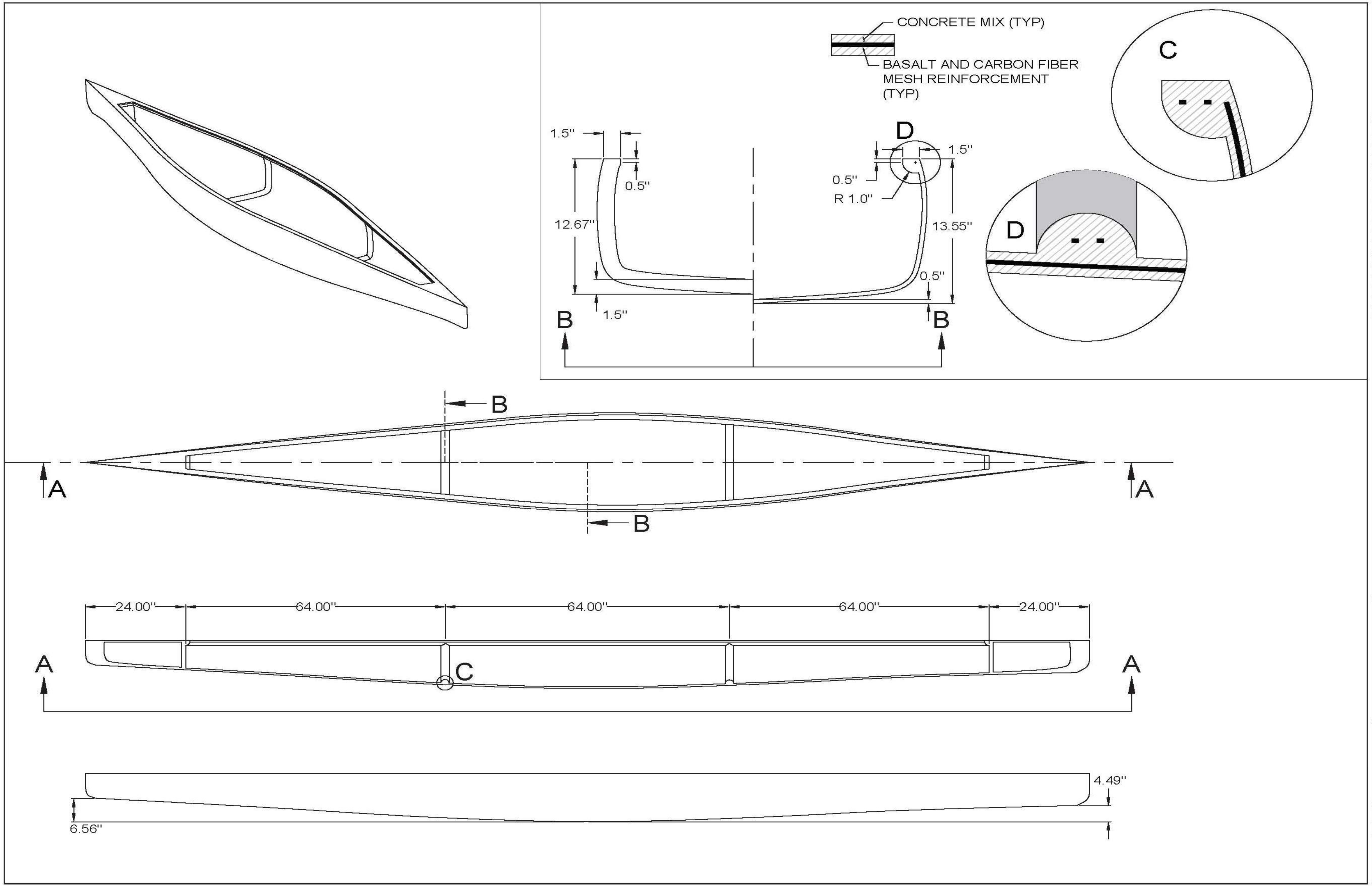
PROJECT SCHEDULE

ID	Task Name	Duration	Planned Start	Planned Finish	Actual Start	Actual Finish
1	**Umass Lowell Concrete Canoe Project**	**175 days**	**Mon 8/6/18**	**Fri 4/5/19**	**Sat 9/1/18**	**Sun 4/14/19**
2	**Project Management**	**153 days**	**Wed 9/5/18**	**Fri 4/5/19**	**Sat 9/1/18**	**Sun 4/14/19**
3	Role Establishment Meeting	1 day	Tue 9/11/18	Tue 9/11/18	Tue 9/11/18	Tue 9/11/18
4	Safety Inspection of Laboratory Facilities	1 day	Sun 9/30/18	Sun 9/30/18	Sun 9/30/18	Sun 9/30/18
5	Rules Released	1 day	Wed 9/5/18	Wed 9/5/18	Wed 9/5/18	Wed 9/5/18
6	Material Procurement	46 days	Mon 10/1/18	Sat 12/1/18	Mon 10/15/18	Sat 2/16/19
7	Freshman Presentations and Recruitment	5 days	Mon 9/17/18	Fri 9/21/18	Mon 9/17/18	Fri 9/21/18
8	Preliminary Project Schedule Submitted	1 day	Thu 11/1/18	Thu 11/1/18	Thu 11/1/18	Thu 11/1/18
9	First General Meeting	1 day	Thu 9/27/18	Thu 9/27/18	Thu 9/27/18	Thu 9/27/18
10	Register Team for Comeption	1 day	Sat 12/1/18	Sat 12/1/18	Sun 3/11/18	Sun 3/11/18
11	Fundraising	153 days	Wed 9/5/18	Fri 4/5/19	Wed 9/5/18	Fri 4/12/19
12	**Mix Design**	**108 days**	**Wed 9/5/18**	**Fri 2/1/19**	**Wed 9/5/18**	**Mon 2/18/19**
13	Mix Design Material Research	52 days	Wed 9/5/18	Thu 11/15/18	Wed 9/5/18	Sat 2/16/19
14	Practice Placement Day Prebatching	0 days	Fri 11/16/18	Fri 11/16/18	Sat 11/16/19	Fri 11/16/18
15	Mix Design Testing	56 days	Thu 11/1/18	Thu 1/17/19	Thu 11/1/18	Sat 2/16/19
16	Canoe Mix Selected	1 day	Sat 1/26/19	Sat 1/26/19	Sat 2/16/19	Sat 2/16/19
17	Placement Day Prebatching	1 day	Fri 2/1/19	Fri 2/1/19	Sun 2/17/19	Mon 12/17/18
18	**Hull Design**	**80 days**	**Mon 8/6/18**	**Sun 11/25/18**	**Mon 8/6/18**	**Mon 12/17/18**
19	Hull Design Research	23 days	Mon 8/6/18	Wed 9/5/18	Mon 8/6/18	Mon 9/10/18
20	Hull Design (Prolines)	37 days	Wed 9/5/18	Thu 10/25/18	Wed 9/5/18	Thu 10/11/18
21	Hull Modeling (SolidWorks)	7 days	Thu 10/25/18	Fri 11/2/18	Thu 10/11/18	Mon 11/19/18
22	Convert Mold to Mastercam (DID NOT OCCUR)	6 days	Fri 11/2/18	Fri 11/9/18	NA	NA
23	Structural Analysis	8 days	Thu 11/15/18	Sun 11/25/18	Mon 11/19/18	Mon 12/17/18
24	**Construction**	**102 days**	**Fri 11/9/18**	**Sat 3/30/19**	**Sat 11/17/18**	**Fri 4/5/19**
25	Move to New Concrete Lab	6 days	Mon 11/26/18	Sat 12/1/18	Wed 1/2/19	Thu 1/17/19
26	Table Update	12 days	Fri 11/23/18	Mon 12/10/18	Wed 1/2/19	Sat 1/26/19
27	Practice Placement Day	1 day	Sat 11/17/18	Sat 11/17/18	Sat 11/17/18	Sat 11/17/18
28	Mold Cut in CNC (DID NOT OCCUR)	44 days	Fri 11/9/18	Wed 1/9/19	NA	NA
29	Mold Finished by Hand	10 days	Tue 1/15/19	Sat 1/26/19	Sat 1/26/19	Sat 2/16/19
30	Hydration Tent Update (DID NOT OCCUR)	12 days	Sat 12/1/18	Sun 12/16/18	NA	NA
31	Canoe Placement Day	1 day	Sat 2/2/19	Sat 2/2/19	Mon 2/18/19	Mon 2/18/19
32	Canoe Curing	22 days	Fri 2/1/19	Sat 3/2/19	Mon 2/18/19	Mon 3/11/19
33	Canoe Sanding	10 days	Fri 3/15/19	Thu 3/28/19	Mon 3/4/19	Sat 3/30/19
34	Canoe Mold Removal	1 day	Sun 3/3/19	Sun 3/3/19	Fri 3/8/19	Fri 3/8/19
35	Non-Destructive Sonar Testing	1 day	Mon 3/18/19	Mon 3/18/19	Mon 4/1/19	Mon 4/1/19
36	Sectional Construction	32 days	Fri 2/15/19	Sat 3/30/19	Wed 3/13/19	Sat 3/16/19
37	Display Table Construction	22 days	Sun 11/25/18	Sat 12/22/18	Sat 12/1/18	Fri 3/22/19
38	Stand Construction	27 days	Mon 1/28/19	Tue 3/5/19	Sat 3/16/19	Mon 4/1/19
39	Canoe Sealing	3 days	Thu 3/28/19	Sat 3/30/19	Sat 3/30/19	Tue 4/2/19
40	**Paddling**	**120 days**	**Fri 10/12/18**	**Thu 3/28/19**	**Fri 10/12/18**	**Sat 4/6/19**
41	Fall Semester Practice	37 days	Fri 10/12/18	Sat 12/1/18	Fri 10/12/18	Sat 11/24/18
42	Spring Semester Practice	25 days	Sat 2/23/19	Thu 3/28/19	Mon 3/18/19	Sat 4/6/19
43	Paddling Team Roles Defined	1 day	Fri 3/1/19	Fri 3/1/19	Mon 3/18/19	Mon 3/18/19
44	**Paper**	**80 days**	**Sun 11/25/18**	**Fri 3/15/19**	**Thu 1/3/19**	**Mon 3/18/19**
45	Design Paper Rough Drafts	49 days	Sun 11/25/18	Wed 1/30/19	Thu 1/3/19	Fri 2/22/19
46	Design Paper Editing	33 days	Wed 1/30/19	Fri 3/15/19	Fri 2/22/19	Fri 3/8/19
47	Design Paper Submitted	1 day	Fri 3/15/19	Fri 3/15/19	Fri 3/8/19	Fri 3/8/19
48	**Presentation**	**54 days**	**Sun 1/20/19**	**Thu 4/4/19**	**Fri 3/8/19**	**Fri 4/5/19**
49	Presentation Script Development	11 days	Sun 1/20/19	Fri 2/1/19	Fri 3/8/19	Fri 3/15/19
50	Presentation PowerPoint Design	11 days	Sun 2/3/19	Fri 2/15/19	Fri 3/8/19	Wed 3/20/19
51	Mock Presentation for Faculty	1 day	Fri 2/22/19	Fri 2/22/19	Fri 3/29/19	Thu 3/29/18
52	Peer Presentations and Revisions	31 days	Thu 2/21/19	Thu 4/4/19	Fri 3/15/19	Thu 4/11/19
53	**Aesthetics**	**139 days**	**Tue 9/11/18**	**Fri 3/22/19**	**Tue 9/11/18**	**Mon 4/1/19**
54	Theme Research	10 days	Tue 9/11/18	Sat 9/22/18	Thu 9/1/16	Thu 10/20/16
55	Theme Selection	1 day	Sat 9/22/18	Sat 9/22/18	Fri 10/21/16	Fri 10/21/16
56	Design of Elements	20 days	Sat 9/22/18	Thu 10/18/18	Sat 9/22/18	Thu 10/18/18
57	Canoe Aesthetics	4 days	Tue 3/19/19	Fri 3/22/19	Tue 3/19/19	Fri 3/22/19
58	Tabletop Display Aesthetics	38 days	Thu 10/25/18	Sat 12/15/18	Fri 3/22/19	Fri 4/5/19
59	**Competition**	**2 days**	**Fri 4/5/19**	**Sun 4/7/19**	**Fri 4/12/19**	**Sun 4/14/19**
60	2019 New England Regional Concrete Canoe Competition	2 days	Fri 4/5/19	Sun 4/7/19	Fri 4/12/19	Sun 4/14/19



Tasks 🟥 Milestones ● Critical ▬ Summary ▬ Actual Task ▬ Actual Milestone ● Actual Summary ▬

CONSTRUCTION DRAWING



UMass Lowell

BILL OF MATERIALS	
MATERIAL	WEIGHT
PORTLAND CEMENT	70.85 LBS
SILICA FUME	7.07 LBS
METAKEOLIN	16.71 LBS
K-15	11.97 LBS
PORAVER	10.91 LBS
SHALE	24.52 LBS
PIGMENT	2.71 LBS
FIBERS	3.70 LBS
WATER	3.47 GAL
LATEX	2.55 GAL
AVDA	38.53 FL OZ
ECLIPSE	14.60 FL OZ

2019 ASCE
CONCRETE CANOE
COMPETITION

VITRUVIUS
CONSTRUCTION
DRAWING

Pro. No. 2019.01	Checked by KTE	03/02/2019
Drawn by YTC	Approved by JEG	NOT TO SCALE

Signature (Seal)

1 OF 1

APPENDIX A - REFERENCES

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APPENDIX B – MIX PROPORTIONS

MIXTURE DESIGNATION:

MAIN MIX (COLOR VARIES, RED PIGMENT SHOWN):

CEMENTITIOUS MATERIALS

Component	Specific Gravity	Volume (ft^3)	Amount of CM (mass/volume) (lb/yd^3)	
Type 1 White Portland Cement	3.15	3.184	625.856	Total Amount of cementitious materials 835.894 lb/yd^3 c/cm ratio 0.75
White Silica Fume	2.20	0.455	62.444	
Metakaolin	2.60	0.910	147.594	

FIBERS

Component	Specific Gravity	Volume (ft^3)	Amount of Fibers (mass/volume) (lb/yd^3)	
Nycon 0.315" PVA Fibers	1.3	0.403	32.674	Total Amount of Fibers 32.674 lb/yd^3

AGGREGATES

Aggregates	ASTM C330*	Abs (%)	SG$_{OD}$	SG$_{SSD}$	Base Quantity (lb/yd^3)		Volume (ft^3)
					OD	SSD	
K15 > 0.75µm	No	0	0.15	0.15	35.392	35.392	3.781
Poraver 0.25-0.5mm	No	55%	0.65	0.99	54.658	84.720	1.348
Norlite Shale	Yes	8%	1.87	2.02	200.553	216.597	1.719

ADMIXTURES

Admixture	lb/gal	Dosage (fl. oz / cwt)	% Solids	Amount of Water in Admixture (lb/yd^3)	
Mallard Creek Tylac 4190	8.59	335.27	50.0	94.037	Total Water from Admixtures, $\sum w_{admx}$ 120.755 lb/yd^3
ADVA Cast 555	8.90	38.18	17.1	18.396	
Eclipse Floor 200	8.00	16.09	1.0	8.322	

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

Component	Specific Gravity	Volume (ft^3)	Amount (mass/volume) (lb/yd^3)	
Mallard Creek Tylac 4190	1.06	1.422	94.037	Total Solids from Admixtures 188.361 lb/yd^3
K15 < 0.75 µm	0.15	7.519	70.376	
Medium Red Iron Oxide Pigment	4.90	0.078	23.948	

WATER

	Amount (mass/volume) (lb/yd^3)		Volume (ft^3)
Water, lb/yd^3		w: 376.152	6.028
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: 0	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: 120.755	
Batch Water, lb/yd^3		w_{batch}: 255.397	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	fibers	aggregates	solids	water	Total
Mass of Concrete, M, (lb)	835.894	32.674	336.709	188.361	376.152	$\sum M$:1769.79
Absolute Volume of Concrete, V, (ft^3)	4.549	0.403	6.848	9.019	6.028	$\sum V$:26.847
Theoretical Density, T, ($=\sum M / \sum V$)	65.92 lb/ft^3		Air Content [$= (T - D)/T \times 100\%$]			0.6%
Measured Density, D	65.55 lb/ft^3		Slump, Slump flow			¼ in.
water/cement ratio, w/c:	0.60		water/cementitious material ratio, w/cm:			0.45

* Indicate if aggregate, other than manufactured glass microspheres and/or cenospheres, is compliant with ASTM C330

VOLUME

$$V = \frac{Mass}{SG*62.4\frac{lb}{ft^3}}$$

Cement:

$$V = \frac{625.856\ lb}{3.15*62.4\frac{lb}{ft^3}} = 3.184\ ft^3$$

Silica Fume:

$$V = \frac{62.444\ lb}{2.20*62.4\frac{lb}{ft^3}} = 0.455\ ft^3$$

Metakaolin:

$$V = \frac{147.594\ lb}{2.60*62.4\frac{lb}{ft^3}} = 0.910\ ft^3$$

Shale:

$$V = \frac{200.553lb}{1.87*62.4\frac{lb}{ft^3}} = 1.719\ ft^3$$

Porover:

$$V = \frac{54.658lb}{0.65*62.4\frac{lb}{ft^3}} = 1.348\ ft^3$$

$K15 > 75\mu m$:

$$V = \frac{35.392lb}{0.15*62.4\frac{lb}{ft^3}} = 3.781\ ft^3$$

Fibers:

$$V = \frac{32.674lb}{1.3*62.4\frac{lb}{ft^3}} = 0.403\ ft^3$$

Water:

$$0.45 * 835.894\ lb = \frac{376.152lb}{62.4\frac{lb}{ft^3}} = 6.028\ ft^3$$

Pigment:

$$V = \frac{23.948lb}{4.90*62.4\frac{lb}{ft^3}} = 0.078\ ft^3$$

$K15 < 75\mu m$:

$$V = \frac{70.376\ lb}{0.15*62.4\frac{lb}{ft^3}} = 7.519\ ft^3$$

Latex:

$$V = \frac{94.037 lb}{1.06*62.4\frac{lb}{ft^3}} = 1.422\ ft^3$$

Air:

$$\%\ Air = \frac{65.92 \qquad .55}{65.92} * 100 = 0.6\%\ in\ plastic\ state$$

Water to Cement:

$$w/c\ ratio: \frac{376.152\ lb\ w}{625.856\ lb\ c} = 0.45\frac{w}{cm} ratio$$

Aggregate:

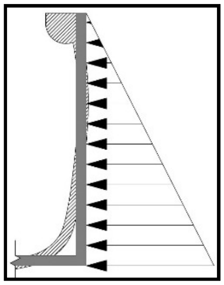
$$Aggregate\ Ratio: \frac{6.848 ft^3}{27 f\ \ ^3} = 0.2536; 25.36\% > 25\%$$

C330 Aggregate:

$$C330\ Aggregate\ Ratio: \frac{1.719 ft^3}{6.848 ft^3} = 0.2510; 25.10\% > 25\%$$

APPENDIX C – EXAMPLE STRUCTURAL CALCULATION

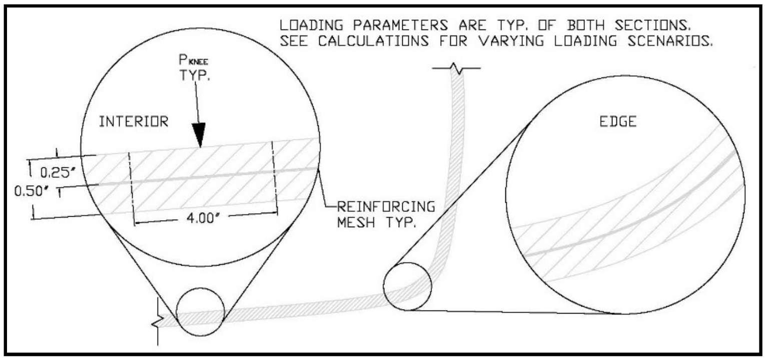
Shear Stress in Chine and Deflection in Gunwale



EQUATIONS	ASSUMTIONS
$V = \frac{\gamma H^2}{2}$ $V = 31.23\ lbs$	- The chine is to be simplified as a right angle moment connection. - $\gamma = 63\ \frac{lbs}{ft^3}$ and can assume a loading $A = 1\ ft^2$ so $\gamma = 63\ \frac{lbs}{ft}$ as well. - $H = 11.95\ in$ - The max shear is located longitudinally along the inside of the moment connection.
$M = \frac{\gamma H^2}{2}\frac{H}{3}$ $M = 10.37\ lbs \cdot ft$	- The aforementioned assumptions apply. - The moment is located at the moment connection.
$E_c = {w_c}^{1.5} 33\sqrt{f_c{}'}$ $E_c = 670,225\ psi$ $I = \frac{bH^3}{12}$ $I = 71.10\ in^4$ $\delta = \frac{\gamma H^4}{30E_cI}$	- The aforementioned assumptions apply. - *ACI 318-14 9.2.2.1.a* - $w_c = 65.92\ \frac{lbs}{ft^3}$ - $f_c' = 1440$ psi

$$\delta = 0.0106\ in$$

Punchout Stress per ACI 318-14 for a Two-Way Slab



EQUATIONS	REFERENCES	ASSUMTIONS
***All references made to ACI 318-14 unless otherwise noted**		
$V_c = \begin{cases} 4\lambda\sqrt{f_c{}'} \\ \left(2+\frac{4}{\beta}\right)\lambda\sqrt{f_c{}'} \\ \left(2+\frac{\alpha_s d}{b_0}\right)\lambda\sqrt{f_c{}'} \end{cases}$	Table 22.6.5.2A Table 22.6.5.2B Table 22.6.5.2C	- Minimum V_c value governs for punchout shear. - $f_c{}'$= 1440psi - λ = 0.75 for all calculations. *ACI 318-14 Table 19.2.4.2*

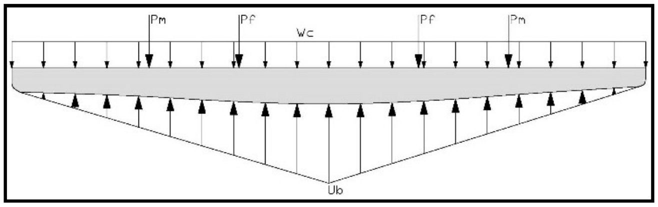
$V_c = \begin{cases} 4\lambda\sqrt{f_c'} & ? \\ \left(2+\frac{4}{\beta}\right)\lambda\sqrt{f_c'} & ✗ \\ \left(2+\frac{\alpha_s d}{b_0}\right)\lambda\sqrt{f_c'} & ? \end{cases}$	**TABLE 22.6.5.2A** **TABLE 22.6.5.2B** **TABLE 22.6.5.2C**	**- $\beta = \frac{4"}{4"} > 2.0 \Rightarrow \beta = 1 \ngtr 2.0 \Rightarrow$ ✗** **- β IS THE RATIO OF LONG AND SHORT SIDES OF THE RECTANGULAR LOADED AREA WHICH MUST BE GREATER THAN 2.0 PER *ACI 318-14 R22.6.5.2***
$V_c = \begin{cases} 4\lambda\sqrt{f_c'} \\ \left(2+\frac{\alpha_{int} d}{b_{int}}\right)\lambda\sqrt{f_c'} \\ \left(2+\frac{\alpha_{edge} d}{b_{edge}}\right)\lambda\sqrt{f_c'} \end{cases}$	Table 22.6.5.2A R22.6.5.3 R22.6.5.3	- α_s is 30 for an edge slab (when paddler knees are located directly on the chines) and 40 for an interior slab (when paddler knees are not located in the aforementioned location). Paddler knees will never be in proximity to the bulkhead transition zone so corner slab calculation can be ignored in this instance. *ACI 318-14 R22.6.5.3* - b_0 = perimeter of punchout located $^d/_2$ beyond loaded perimeter. *ACI 318-14 22.6.4.1*
$V_c = \begin{cases} 4\lambda\sqrt{f_c'} \\ (2.5882)\lambda\sqrt{f_c'} \\ (2.4478)\lambda\sqrt{f_c'} \end{cases}$	Table 22.6.5.2A R22.6.5.3 R22.6.5.3	The Edge equation governs for punchout calculation.
$\tau_{punch} = \frac{(L)}{(T)(P)}$ $\tau_{punch} = 18.75psi$	LCC-22 *Université Laval* (2017)	Knee Loading $L = (0.75)(200lb) = 150lb$ Loading Perimeter $P = 16"$ Loading Thickness $T = {}^1/_2"$
$V_c = 69.67\ psi > \tau_{punch} = 18.75psi$ ✓		

Scenario:

The co-ed race is regarded as the most rigorous loading scenario Vitruvius will encounter. The male paddlers are positions 52 inches from either bow and stern and female paddlers 86 inches from the bow and stern. Non-transformed cross-sectional properties are used.

Assumptions:

Canoe self-weight:	190 *pounds*	Uniformly distributed load spanning the canoe length
Canoe length:	240 *inches*	
Paddler load: P_{male} =	$170lbs$	Point loads located 52 in form bow and stern
	$P_{female} = 140lbs$	
Buoyant force:		Uniformly increasing to the center of canoe



Shear and Bending Moment Equations:

Canoe weight (W_c): $\frac{W_{canoe}}{L_{canoe}} \rightarrow \frac{190\ lbs}{240\ in} \rightarrow 0.792\ lbs/in$

Buoyancy (W_b): $\sum W_c + P_0 \rightarrow 190lbs + (2)170lbs + (2)140lbs \rightarrow 810\ lbs$

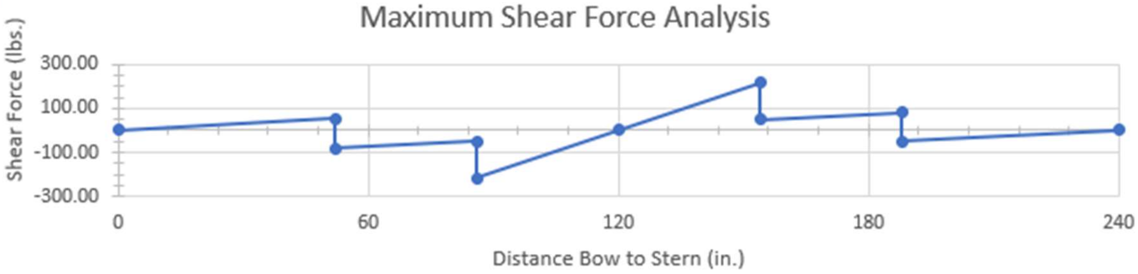
Buoyant intensity(U_b): $\frac{W_b}{L_{canoe}/_2} \rightarrow \frac{810\ lbs}{240\ in/_2} \rightarrow 6.750\ lbs/in$

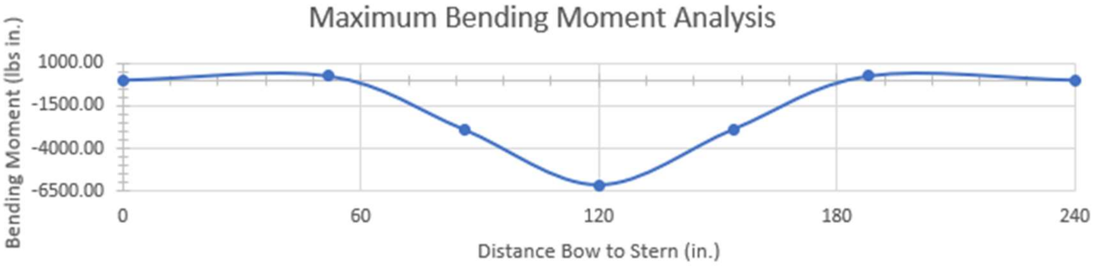
Buoyant int. per inch: $\frac{U_b}{L_{canoe}/_2} \rightarrow \frac{6.750\ lbs/in}{240\ in/_2} \rightarrow 0.05625\ lbs/in^2$

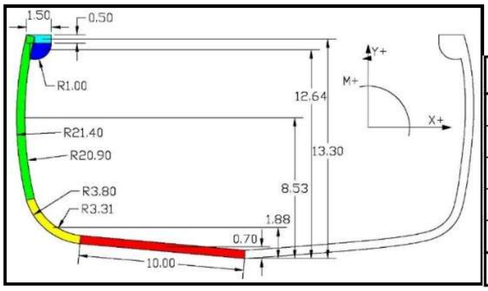
Integrals of load ration:

Variable	Ratio	V_x	M_x
U_b	$0.05625x$	$0.02813x^2$	$0.00938x^3$
W_c	-0.792	$-0.792x$	$-0.396x^2$
P_{male}	N/A	-170	$-170x$
P_{female}	N/A	-140	$-140x$

x_{bow}	V_x		M_x	
$0 in$	$U_b + W_c$	$0.0\ lbs$	$U_b + W_c$	$0\ lbs \cdot in$
$52 in$	$U_b + W_c + P_{male}$	$-135.1\ lbs$	$U_b + W_c$	$248.12\ lbs \cdot in$
$86 in$	$U_b + W_c + P_{male} + P_{female}$	$-170.1\ lbs$	$U_b + W_c + P_{male}$	$-2902.96\ lbs \cdot in$
$120 in$	$U_b + W_c + P_{male} + P_{female}$	$0.0\ lbs$	$U_b + W_c + P_{male} + P_{female}$	$-6190.60\ lbs \cdot in$
$154 in$	$U_b + W_c + P_{male} + P_{female}$	$170.1\ lbs$	$U_b + W_c + P_{male}$	$-2902.96\ lbs \cdot in$
$188 in$	$U_b + W_c + P_{male}$	$135.1\ lbs$	$U_b + W_c$	$248.12\ lbs \cdot in$
240				


Maximum Shear Force Analysis


Maximum Bending Moment Analysis



Segment	A (in^2)	$\bar{y}$ (in)	$A\bar{y}$ (in^3)	d (in)	I_x (in^4)	I_x+Ad^2 (in^4)
Red	5.00	0.70	3.50	4.02	0.104	80.89
Yellow	2.05	1.88	3.85	2.84	11.582	28.11
Green	4.99	8.53	42.56	3.81	2477.2	2549.65
L Blue	0.38	13.30	5.05	8.58	0.016	27.99
D Blue	0.46	12.64	5.81	7.92	0.196	29.05
Σ	12.88	4.72	60.79			2715.69

*Note: Above values were calculated by creating simple geometric shapes using the following formulas below.

Formulas Red, L Blue: $A_{rectangle} = bh$ $\quad I_{x_{rectangle}} = \frac{bh^3}{12}$

Formulas Yellow, Green: $A_{curve} = \frac{\pi(r_{out}{}^2 - r_{in}{}^2)}{4}$ $\quad I_{x_{curve}} = \frac{\pi(r_{out}{}^4 - r_{in}{}^4)}{24}$

Formulas D Blue: $A_{circle} = \frac{\pi(r^2)}{4}$ $\quad I_{x_{circle}} = \frac{\pi(r^4)}{16}$

$\Sigma\bar{y} = \frac{\Sigma A^{-}}{\Sigma A}$ $\quad d = |(\Sigma\bar{y}) - (\bar{y})|$

Maximum Compressive and Tensile Stresses:

Dynamic Amplification Factor: $DAF = 1.25$ (Paradis, 2007)

Mix Design Safety Factor: $MDF = 2.5$

Design Compressive Stress: $f_{c_{max}} = \frac{DAF \cdot MDF \cdot M_{max} \cdot C_c}{I_x}$ $\quad f_{c_{max}} = \frac{1.25 \cdot 2.5 \cdot -6190.60\ lbs \cdot in \cdot -4.72\ in}{2715.69\ in^4}$

$f_{c_{max}} = 33.62\ psi$

Design Compressive Stress: $f_{t_{max}} = \frac{DAF \cdot MDF \cdot M_{max} \cdot C_t}{I_x}$ $\quad f_{c_{max}} = \frac{1.25 \cdot 2.5 \cdot -6190.60\ lbs \cdot in \cdot 8.58\ in}{2715.69\ in^4}$

$f_{t_{max}} = -61.12\ ps$

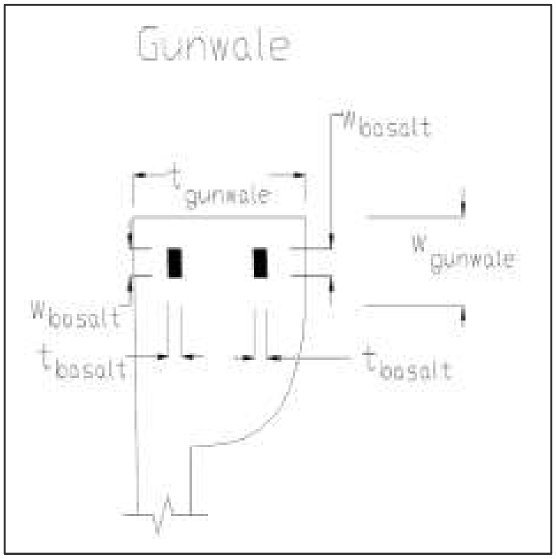
APPENDIX D – HULL THICKNESS/REINFORCMENT AND PERCENT OPEN AREA CALCULATIONS

Hull Thickness/Reinforcement

*** Note: Figures not to scale/**

$[(t_{mesh} / t_{concrete}) * 100] \leq 50\%$

$[(w_{mesh} / w_{concrete}) * 100] \leq 50\%$



Gunwale:

$t_{basalt} = 0.04$ in

$w_{basalt} = 0.16$ in

$t_{gunwale} = 0.75$ in

$w_{gunwale} = 1.50$ in

$[(w_{basalt} + w_{basalt}) / w_{gunwale}] * 100$

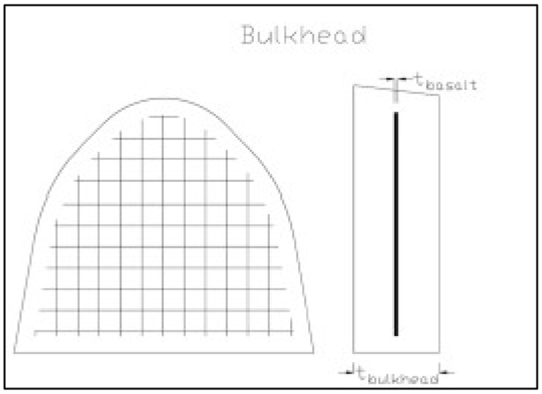
$[(0.16 \text{ in} / 0.75 \text{ in})] * 100$

$= \mathbf{21.33\% \leq 50\%}$

$[(t_{basalt} + t_{basalt}) / t_{gunwale}] * 100$

$[(0.04 \text{ in} + 0.04 \text{ in}) / (1.50 \text{ in})] * 100$

$= \mathbf{5.33\% \leq 50\%}$



Bulkheads:

$t_{basalt} = 0.04$ in

$t_{bulkhead} = 1.0$ in

$[(t_{basalt}) / t_{bulkhead}] * 100$

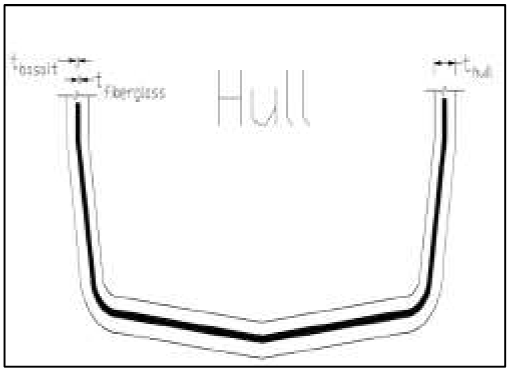
$[(0.04 \text{ in}) / (1.0 \text{ in})] * 100$

$= \mathbf{4.0\% \leq 50\%}$

Hull:

$t_{basalt} = 0.04$ in
$t_{fiberglass} = 0.03$ in
$t_{gunwale} = 0.375$ in

$[(t_{basalt} + t_{fiberglass})/\ t_{hull}]\cdot 100$
$[(0.04 \text{ in} + 0.03 \text{ in})/\ (0.375 \text{ in})]\cdot 100$
= **$18.75\ \% \leq 50\%$**



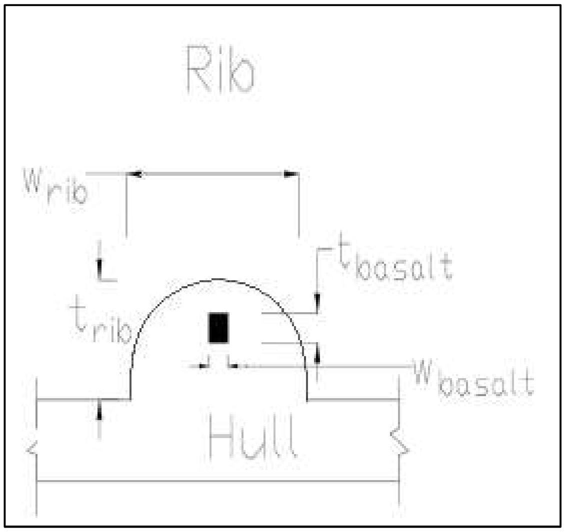
Ribs:

$t_{basalt} = 0.04$ in
$w_{basalt} = 0.16$ in
$t_{rib} = 1.0$ in
$w_{rib} = 0.75$ in

$[(t_{basalt})/\ (t_{rib})]\cdot 100$
$[(0.04 \text{ in})/\ (1.00 \text{ in})]\cdot 100$
= **$4.00\ \% \leq 50\%$**

$[(w_{basalt})/\ (w_{rib})]\cdot 100$
$[(0.16 \text{ in})/\ (0.75 \text{ in})]\cdot 100$
= **$21.33\ \% \leq 50\%$**

***All Reinforcements meet guidelines stated in NCCC 2019 Rules and Regulations**



Open Area:

Minimum Percent Open Area (POA)

POA = [($\text{Area}_{\text{open}}$ / $\text{Area}_{\text{total}}$) ·100] ≥ 40 %

n_1 = number of apertures along sample length

n_2 = number of apertures along sample width

d_1 = spacing reinforcing (center to center) along sample length

d_2 = spacing reinforcing (center to center) along sample width

t_1 = thickness of reinforcing along sample length

t_2 = thickness of reinforcing along sample width

POA: Fiberglass Mesh

d_1 = aperture dimension + 2 · (t_1/ 2) → (0.89 in + 2 · (0.12 in/ 2)) =1.01 in

d_2 = aperture dimension + 2 · (t_2 /2) → (1.0 in + 2 · (0.18 in/ 2)) = 1.18 in

$\text{Length}_{\text{sample}}$ = n_1/d_1 → [(10) · 1.01 in] = 10.1 in

$\text{Width}_{\text{sample}}$ = n_2·d_2 → [(10) · 1.18 in] = 11.8 in

Σ Areaopen = n_1·n_2·$\text{Area}_{\text{open}}$ → (10·10·0.89 in^2) = 89 in^2

$\text{Area}_{\text{total}}$ = $\text{Length}_{\text{sample}}$ · $\text{Widths}_{\text{ample}}$ → (10.1 in · 11.8 in) = 119.18 in2

POA = Σ Areaopen / Areatotal · 100% = 89 in^2/ 119.18 in^2 · 100 = **74.3% ≥ 40%**

POA: Basalt Mesh

d_1 = aperture dimension + 2· (t1/ 2) → (1.00 in + 2 · (0.24 in/ 2)) =1.24 in

d_2 = aperture dimension + 2· (t2 /2) → (1.0 in + 2 · (0.16 in/ 2)) = 1.16 in

$\text{Length}_{\text{sample}}$ = n_1/d_1 → [(10) x 1.24 in] = 12.4 in

$\text{Width}_{\text{sample}}$ = n_2· d_2 → [(10) x 1.16 in] = 11.6 in

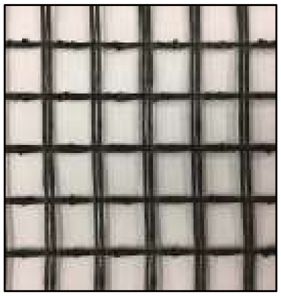
Σ Areaopen = n_1·n_2·$\text{Area}_{\text{open}}$ → = (10·10·1 in^2)= 100 in^2

$\text{Area}_{\text{total}}$ = $\text{Length}_{\text{sample}}$ · $\text{Width}_{\text{sample}}$ → (12.4 in x 11.6 in)= 143.84 in^2

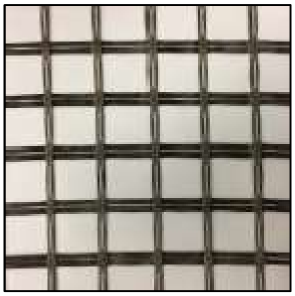
POA = Σ$\text{Area}_{\text{open}}$ / $\text{Area}_{\text{total}}$ · 100% = (100 in^2/ 143.84 in^2·100 in)= **69.5% ≥40%**

***Mesh meets guidelines stated in NCCC 2019 Rules and Regulations**

Sample Mesh:



Sample 1:
Fiberglass Mesh



Sample 2:
Basalt Mesh

Sample 3:
Strand of Basalt