Pathfinder

University of Massachusetts Lowell
2020 Technical Proposal

COVER LETTER AND PROJECT UNDERSTANDING

The design and construction of the University of Massachusetts Lowell's concrete canoe, *Pathfinder*, has been performed in full compliance with the specifications outlined in the Request for Proposal by the National Concrete Canoe Competition.

The team acknowledges that the Material Technical Data Sheets and Safety Data Sheets have been reviewed by the team.

The team acknowledges receipt of the Request for Information Summary and that their entry, *Pathfinder*, complies with responses provided.

The anticipated registered participants, listed below, are qualified student members and National Student Members of the American Society of Civil Engineers and meet all eligibility requirements.

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We certify that the information presented in the University of Massachusetts Lowell's Technical Proposal and Material Technical Data Sheet Addendum is valid.

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EXECUTIVE SUMMARY

Since 1895, the city of Lowell has found itself home to many of the educational institutes credited with educating some of the finest leaders in engineering, education and the textile industry. The University of Massachusetts Lowell (hereinafter referred to as UMass Lowell) produces students who are described as being hands-on, driven students whose education leaves them feeling prepared to face problems in engineering in a real-world setting. (Francis College of Engineering 2019)

UMass Lowell competes in the New England Regional Competition (NERC). In the past three competitions, the Concrete Canoe Team at Umass Lowell has a placed 2nd in 2017 with *Jester*, 3rd in 2018 with *Flintlock* and 4th place in 2019 with *Vitruvius*.

After the release of the Request for Proposal (RFP) by the National Concrete Canoe Competition, the concrete canoe team planned on utilizing previous hull designs in order to complete the RFP. Weighing the pros against the cons of modifying a previous year's hull, it was determined by the design and paddling teams that by using a previous hull, modifications could be made to accommodate the paddlers. Modifying a previously used hull also allowed for a faster design process, which is necessary when using a 3-axis CNC machine to mill the mold.

Based on a series of factors, it was decided that modifications would be done to the 2017 hull design, *Jester*, in order to create our 2020 entry, *Pathfinder*. The familiarity of the handling and speed of the canoe hull allowed for the design team to make decisions on hull specifications that resulted keeping all designed aspects of the *Jester* hull the same. (Table 1) Jester's length was 246 inches and weighed 210 pounds (Jester, 2017) whereas *Pathfinder* is estimated to have a length of 246 inches and weigh 220 pounds.

Table 1: ***Pathfinder*** **Specifications**	
Weight	220 lbs (estimated)
Length	20 ft 6 in
Width	28 in
Depth	13.8 in
Average Thickness	½ inch
Reinforcement	Basalt Mesh
Colors	Red, White, Grey, Blue

Table 2: Concrete Properties	
Plastic Unit Weight	64.62 lb/ft^3
Oven-Dried Unit Weight	61.55 lb/ft^3
Compressive Strength (7 Day)	2133 psi
Tensile Strength (7 Day)	324 psi
Flexural Strength (7 Day)	-
Slump	¼ inch
Air Content	0.97%

Some important characteristics of *Pathfinder's* hull design that differentiates itself from previous designs is the focus on maneuverability and stability for paddlers. In years previous to *Jester*, the team had used planing hulls as a way to reduce wave drag when racing. After observing racing techniques, the team realized that most of the paddlers couldn't get the canoe to a speed where wave drag would become an issue when paddling. (Jester 2017)

Instead, the design shift focused to current paddler complaints which consisted mostly of the stability of the canoe when on the water, thus prompting a tumblehome centered hull with a flatter bottom. (Jester, 2017) In 2019, *Vitruvius* was modeled and designed after canoes previous to the tumblehome and similar complaints of stability arose after the 2019 races. Both the female and male paddling teams told the design team that at multiple points during the race, the lighter and smaller canoe took on water during turns and did not feel stable. The paddling team also shared concerns that they felt even though *Vitruvius* was designed with second stability in mind, the canoe still felt like it was going to completely tip over. (Randall, 2010) The design team made the executive decision that the hull design would always be based around paddler comfort and safety, rather than what design features could produce a faster moving canoe.

Since the time allocated for the design process was cut in half by reusing a previous mold, the team was able to practice new mold creation techniques with a focus on cost reduction and sustainability. Looking to cut down on overall cost of the mold, the team reached out to a local vendor in order to purchase recycled foam to use as the primary mold material. To reduce the amount of foam used for the mold, small milk crates were incorporated into the mold to create a composite style mold that has the same strength properties as an all foam mold.

The mix design team faced a larger challenge than usual when the guidelines of the Request for Proposal eliminated the use of latex in any concrete mix. With the goals of the mix team being replacing the use of latex in the concrete mix, creating a lightweight mix that will float in water and be strong enough to withstand the tensile stress of racing, the team set off to create sample batches of concrete to test. The most favorable mix was then used at the Practice Placement Day that the team hosts in November in order to teach new members how to place a small section of the canoe and as a way for the mix team to see how their mix behaves outside of a laboratory testing setting.

After the release of the Request for Proposal, the concrete canoe team spent a significant amount of time searching for the correct path to take in creating a standardized hull prototype. Individual teams within the team spent time debating how to proceed design wise and construction wise, taking sustainability and our overall management structure into consideration. Even though members sometimes felt like they were lost in space with all of the ideas being considered, they never gave up on finding a solution to the request.

Based on the extensive research done by the UMass Lowell's hull design/structural analysis team and the practical application testing of the hull design done by the paddling team, UMass Lowell is confident that the hull design submitted by the concrete canoe prototype, *Pathfinder*, is the optimal choice for a standardized hull. With safety, stability and sustainability being the pillars of this hull design's success, UMass Lowell's concrete canoe team is making the journey back to Earth and is proud to present their 2020 concrete canoe, ***Pathfinder.***

INTRODUCTION TO THE PROJECT TEAM

ASCE Student Chapter Profile

UMass Lowell’s American Society of Civil Engineers student chapter has three current goals for their student body: Providing more opportunities for members to gain hands-on engineering experience while helping the local community, increasing the number of freshman and sophomore’s involvement and providing opportunities to expand members knowledge on the importance of professional engineer licensure. (ASCE Student Chapter’s 2018 Annual Report for the American Society of Civil Engineers, 2019)

In order to achieve these goals, the leaders of the chapter reached out to local communities in the area to offer the engineering services of students, created smaller positions on their executive board and reached out to leaders on American Society of Civil Engineers website in order to host guest lectures for students on the importance of licensure.

Some of the special projects, clubs and UMass Lowell society chapters that our ASCE student chapter supports are listed below:

- Engineering Outreach at the Boys and Girls Club – Lowell, MA
- Concrete Canoe Team – Lowell, MA
- Tewksbury Intersection Team – Tewksbury, MA
- Woburn MS-4 Storm Water Management Team – Woburn, MA
- Lexington Stream Team – Lexington, MA
- American Railway Engineering and Maintenance-of-Way Association (AREMA) – Lowell, MA
- North American Society for Trenchless Technology (NASTT) – Lowell, MA

Students are encouraged by faculty members to participate in student run projects to take concepts learned in a classroom and apply them practically in local communities. Students are also highly encouraged to start their own team if they wish to start a new project in their local community.

In addition to supporting different project teams related to civil engineering, the ASCE student chapter hosts professional development events pertaining to professional licensure and professional speakers on special topics in civil engineering, for all 164 members of the chapter. (ASCE Student Chapter’s 2018 Annual Report for the American Society of Civil Engineers, 2019) The intent of these professional events and speakers is to get students excited about all of the different opportunities that exist in civil engineering as an undergraduate student and as a licensed engineer.

Since everyone knows that all work and no play is not fun, the ASCE student chapter executive board also hosts an annual ice-cream social, spring picnic, Christmas party and a new event introduced by the current chapter leaders: A student versus faculty dodgeball tournament! Alumni from the Civil and Environmental Engineering department are always invited back to these invites for catching u with former faculty and networking for the undergraduate students that plan on entering the work force.

With the help of faculty in the Civil and Environmental Engineering Department and communities in the greater Lowell area, UMass Lowell’s ASCE student chapter was able to achieve all three of their goals for the 2019 – 2020 academic year. As for future plans, the current leaders are hopeful that new executive board leaders will be just as passionate about giving back to the community in order to extend their engineering service outreach to more cities in the area.

Core Team Members

In addition to having team leaders, Umass Lowell's Concrete Canoe team also has Junior Captain positions. The Junior Captains apply for the position with the idea that for the following competition year, they will step into the captain position. This system was put in place to close the gap that occurs when former team leaders leave their positions and before new team leaders are selected by educating the new captains on the roles and responsibilities they will be taking on the following competition year. The Junior Captains were given tasks to complete independently at their lead captain's discretion and assisted team leaders in their daily responsibilities.

Project Manager: Kathryn Evasius - Junior Project Manager: Meghan Pescatore
- Responsible for all scheduling, communications, processing documentation and overseeing daily operations in relation to the critical path.

Operations Manager: Robert (Frank) Feltes
- Responsible for managing overall construction and design, ensuring quality control of all teams and finalizing the weekly safety checklist.

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

Mix Development Captain: Dylan Shaffer - Junior Mix Development Captains: Grace Federiconi and Frank Feltes.
- Responsible for mix research and innovations, material selection, initial and final testing, and sample placement.

Construction Captain: Mauricio Reyes - Junior Construction Captain: Gabe Barragan
- Responsible for construction and finishing of the mold, canoe and structural elements of the stand, sectional, and display.

Budgeting Chair: Grace Federiconi
- Responsible for managing fundraising, sponsorship letters and securing funding/grants from various organizations.

Environmental Health and Safety Lead: Robert Bullock
- Responsible for ensuring student lab safety by working with the Environmental Health and Safety Board.

Quality Control Officer: Paul Dion
- Responsible for ensuring that all work is done to Request for Proposal specifications. Responsible for ensuring quality control of aesthetics, mold design and concrete placement.

Aesthetics Captain: Steven Fallon - Junior Aesthetics Captain: Jonathon Hovor
- Responsible for theme coordination, display board design, logos, final paper imaging and stand design.

Paddling Captain: Gabe Barragan
- Responsible for coordinating practices, conditioning paddlers, and coaching proper paddling technique.

Faculty Advisor: Dr. Raj Gondle

Staff Advisor: Gary Howe

Organization Chart

Management Team

Jr. Project Manager
Meghan Pescatore (Jr)

Project Manager
Kat Evasius (Sr)

Operations Manager
Frank Feltes (Jr)

Design Leads

Mix Development
Dylan Shaffer

Construction
Mauricio Reyes

Hull Design
Yushai Canteenwala

Jr. Mix Development Captains: Grace Federiconi & Frank Feltes
Jr. Construction Captain: Gabe Barragan

Officers

EHS Safety Lead
Robert Bullock (Jr)

Budget Chair
Grace Federiconi (Jr)

Quality Control Officer
Paul Dion (So)

Captains

Paddling Captain
Gabe Barragan (Jr)

Aesthetics Captain
Steven Fallon (Sr)

Jr. Aesthetics Captain
Jonathon Hovor (Jr)

Mix Team	Aesthetics Team	Analysis Team	Paddling Team	Construction Team
D. Shaffer	*S. Fallon*	*Y. Canteenwala*	*F. Feltes*	*M. Reyes, K. Evasius*
G. Federiconi	*K. Evasius*	*S. Fallon*	*K. Evasius*	*Z. Attoui (Sr), F. Feltes*
F. Feltes	*J. Hovor*	*F. Feltes*	*G. Federiconi*	*C. Tidd, B. Bullock*
J. Hovor	*M. Pescatore*	*K. Evasius*	*G. Barragan*	*W. Alban*
W. Alban (So)	*F. Feltes*			*J. Marquis (Jr)*

TECHNICAL APPROACH

Hull Design and Pre-Construction Analysis

UMass Lowell's 2019 concrete canoe, *Vitruvius,* was modeled after past canoes and designed with a smaller wetted hull area in order to decrease the lateral water flow and wave drag, with the assumption that the smaller hull would not affect paddle comfort, maneuverability and stability. (Vitruvius, 2019) After the 2019 New England Regional Competition, paddlers voiced complaints about the canoe's stability, ability to handle rough waters and smaller length. The assumptions that had been made during the hull design process were incorrect and in return, the paddling team struggled greatly during the races. While the design and paddling teams couldn't establish whether paddler inexperience or the hull design affected the racing results more, the design team decided to air on the side of caution and not reuse *Vitruvius's* hull design.

As previously discussed, the design team made the decision to revisit previous successful hull designs in order to provide a feasible solution to all problems listed, rather than starting from scratch. Since the Request for Proposal asked for a hull design to be standardized for all teams to use in the future, both the design team and paddling team wanted a hull that they believed would suit the needs of every paddler, in every regional competition area. Having turned the 2017 canoe entry, *Jester*, into a practice paddling canoe by reinforcing the hull in fiberglass in early 2018, all paddling team members were familiar with the way the canoe handled the water during practice. As a result, *Jester,* was chosen as the base model for the 2020 canoe entry, *Pathfinder*, because of the familiarity and firsthand testing of the hull for paddling.

Since *Pathfinder's* hull is a remake of a previous hull, the hull design research was essentially completed by October. The flat bottom of the canoe provides initial stability, whereas a rounded bottom is used for secondary stability. Because the hull is used to create a racing canoe, secondary stability is the more critical focus, but initial stability could not be ignored. The hull was designed with a rounder bottom toward the bow and a flatter bottom toward the stern. The hull also includes softer chines toward the bow and harder chines toward the stern, creating the ideal blend of initial and secondary stability for paddlers. (Jester, 2017) This hybrid format for a hull is ideal for a racing canoe, where initial stability is desired for efficiency during paddling and secondary stability is desired to resist tipping over during turns (Randall 2010). A V-notched bow was chosen for improved tracking and turning because it decreases delayed lateral water flow, which means better tracking and overall maneuverability.

In consideration of the free surface effect on paddling, two transverse ribs were placed 61 inches apart to prevent longitudinal sloshing of water and to provide transverse support. paddlers will splash more and more water into the canoe. As that amount of water increases, the moment on the canoe increases as the water moves further from the center of gravity (Gudmundsson 2009).The free surface effect subsequently makes paddling and overall control of the canoe harder. With paddler safety and comfort being the man design focus, transverse ribs were opted for rather than a large longitudinal rib. *Jester* originally had 3 transverse ribs located 32 inches apart (Jester, 2017), but the middle rib was removed from *Pathfinder* due to paddler complaints.

Table 3: Design Parameter's for Two-Paddler Loading

Canoe Name	*Jester*	*Flintlock*	*Vitruvius*	*Pathfinder*
Overall Length	246 in	245 in	240 in	246 in
Maximum Depth	13.78 in	13.8 in	13.55 in	13.78 in
Freeboard	8.29 in	8.91 in	8.25 in	8.29 in
Bow Rocker	3.7 in	3.8 in	6.56 in	3.7 in
Stern Rocker	3.9 in	4.3 in	4.49 in	3.9 in
Prismatic Coefficient (C_p)	0.446	0.417	0.438	0.446
Wetted Hull Surface Area	32.13 ft^2	30.23 ft^2	30.56 ft^2	32.13 ft^2

Pathfinder also has an asymmetrical design with the center of gravity located near the center of the canoe in order to increase maneuverability. The tumblehome design near the gunwales with flared sidewalls increases the secondary stability of the canoe, overall improving paddler efficiency. Since *Pathfinder* is a remodel of *Jester*, the baseline hull design was already completed in Prolines© 7 and in SolidWorks. A comparison of Lowell's previous hulls is shown in Table 3.

Lowell's analysis team decided to analyze *Pathfinder* in four different loading scenarios: two-paddler race conditions, four-paddler race conditions, two-person carry and static display. During transportation, the canoe will be fully supported and is not subject to loading, so transportation analysis was not conducted on the canoe. UMass Lowell hand calculated all 2D loading scenarios and logged all values into a Microsoft Excel spreadsheet in order to clearly and graphically show their results.

Pathfinder was modeled as a simply supported beam that was subject to bending about the longitudinal axis. Previous Lowell design teams discovered that adding gunwales and ribs to a hull can reduce the critical stresses in the canoe by up to 43% in comparison with a featureless canoe (Moswetuset, 2013). Ribs had been previously added to improve paddler ergonomics by reducing the free surface effect and gunwales were added to increase the moment of inertia about the longitudinal axis, reducing overall stress in the canoe.

Point loads representing paddler weights were applied to all race conditions. For a two-person race, loads were modeled acting at 37 inches and 209 inches from the bow. In addition to paddler loads, a cargo load was added to act along five feet along the center of the canoe, stretching from 93 inches to 153 inches from the bow. Four-person loading placed loads acting at 37 inches, 97 inches, 145 inches and 209 inches. A uniform distributed load acted as the dead weight of the canoe, based on the estimated total weight of the canoe. A uniform distributed load with an equivalent load equal to the dead load plus the sum of all point loads represented the buoyant force acting on the canoe.

The analysis team used an estimated weight of 220 lbs for the canoe, a weight of 200 lbs for each paddler and a cargo load equal to 80 psf. Shear and moment diagrams (Appendix B, B2**)** were created based on the loading scenarios to graphically show the results of the structural calculations. Maximum tensile and compressive bending stresses at critical locations were calculated by the analysis team based on the principles of mechanics of materials. A simplified analysis showing Lowell's ability to calculate the loading requirements is shown in Appendix B.

The highest bending moment (M_{max}) was found during coed loading and was located at both 37 inches and 209 from the bow of the canoe. The extreme fiber distances and moment of inertia (I_x) were calculated by hand using theories from mechanics of materials. Lowell's analysis team calculated the maximum tensile and compressive bending stresses (σ_b) using Equation 1.

$$\sigma_b = \frac{M_{max}}{I_x} \qquad \text{(Eq. 1)}$$

Mold Innovation and Construction

To create the most accurate male mold shape for *Pathfinder*, the team opted to use a CNC milling machine to create the mold. Due to time constraints in previous years, the CNC machine was only able to be utilized in 2017 for *Jester's* mold. Since the mold had already been created in Prolines© 7 and transferred to SolidWorks to add the rest of the features (gunwales, bulkheads and ribs), the software for mold was already completed, shaving off hours of hull design. The hull was divided into 6 sections per half with lengths ranging for 32 inches to 39 inches. Each of those sections were divided in half, totaling 12 sections needing to be milled. Based on previous experience, the bulkhead foam pieces are difficult to mill because of their small size, so the team opted to hand create those for placement day. The bulkhead foam pieces were created with 1 inch thick foam using printouts of the each section needed to create the entire bulkhead.

With the mold creation time frame cut in half for *Pathfinder*, the team decided to modify the mold in order to reduce the total volume of foam used to create it. Since the mold is milled in a 3-axis CNC machine, the material that is milled by the bit needed to be extruded polystyrene (XPS) foam. The design team explored the option of replacing the middle section of the mold with a reusable material in order to create a more sustainable mold. Small milkcrates were chosen as the reusable mold material by integrating their dimensions and shape into the mold via SolidWorks. In total, the milkcrates removed 5 ft^3 worth of foam from the mold, decreasing the total amount of foam used from 30 ft^3 to 25 ft^3. The milkcrates were attached to 3" recycled foam sheets to create the total length, width and height for a canoe section to be milled in the CNC machine. The individual sections were run through a hotwire setup that made sure all of the edges of the section where the same width. The 3-axis CNC machine's drill bit needs to "track" the edge of each section in order to start the milling process, so it was imperative that all sides of the section were the same width. If not, the drill bit could identify one individual piece, that is wider than the rest as the edge and the mold could become lopsided after it was done being milled.

Figure 1: Construction of Recycled Foam Composite Mold (Pre-Milling)

Figure 2: Comparison of Machine Finish vs. Sanded Finish

Sections of the mold took between 3 and 4 hours to cut, ending with a finishing raster pass creating a scalloped height of 0.015 inches. The individual sections were then glued together to create a full mold, and the mold was sanded lightly in order to remove the scalloped edges. Figure 2 shows the comparison between a section immediately after being removed from the CNC machine and after a light sanding. To eliminate any last imperfections, joint compound was applied in a thin layer to the mold and sanded off when dry. After the joint compound was applied, two ribs were hand routed into the mold spaced 77 inches apart because the CNC bit used to mill was too large to create the ribs. Aesthetic elements were then projected on the mold and routed out to in order to create 3D inlayed elements that protrude from the hull. The 3D elements were routed to be 1/8 inch thick so that they would not interfere with paddler positions. Side inlays were added this year as a way to carry the canoe theme continuously throughout the prototype. Following the joint compound, rib and 3D element creation, a thin layer of polyurethane was applied to prevent the joint compound on the mold from drying out the concrete layer touching it.

For removal, the team plans to remove the crates first and then remove the rest of the mold from the inside of the canoe with a hot wire. Since the team needed to purchase the crates and the recycled foam to create the mold, the overall cost was $262, with $70 being the cost of the crates. In the future, following the implementation of *Pathfinder* as the standardized hull, the cost of the mold will decrease because the crates will have already been purchased following this year.

Mix Development and Design

With latex no longer being used as a bonding adhesive in the concrete mix, UMass Lowell's mix development team's main design focus was workability. Previously, the latex gave the concrete mixture a smooth, wet feeling that stuck to surfaces easily, which is optimal for placement of multiple colors in order to blend the mix and decrease your chances of cold joints, or gaps in between layers.

Pathfinder's analysis team reported a magnified tensile stress of 132 psi, which was used as the governing stress in the canoe. In order to reach this requirement, Lowell's mix development team used *Vitruvius's* mix as a baseline (0.45 w/cm, 45% CP, 520 tensile strength, 1440 psi compressive strength) to begin the design process.

After selecting a baseline mix from which to work with, the mix development team began investigating different ways to get the same latex based consistency as years previous, without using latex. Problems arose in early November at the team's practice placement day when the preferred mix did not stick to the mold properly and crumbled upon touch.

To combat this, the mix team developed two new mixes based off of the failed practice placement mix. One mix was batched with a 0.45 w/cm and 36%CP, while the other was batched with a 0.55 w/cm and a 40%CP. To increase overall workability, super plasticizer was used with the higher water content batch to avoid decreasing strength with additional water.

After establishing that a mix with a higher water to cementitious material worked better for the specifications, different aggregates were experimented with in order to lower the overall density of the mix. Since the Request for Proposal specified that 30% of the mix by volume needed to be an aggregate, Lowell needed to find another material that acted as a lightweight aggregate. Materials smaller than No. 200 (75 μm) were classified as mineral filler and were not calculating in the aggregate volume, leaving the mix development team limited on what less dense material could be used. In order to lower the density of the concrete, the mix development team researched other natural aggregates, that have a low specific gravity, to use in the mix. Perlite, a natural glass that has a high water content, was used as a lightweight aggregate in order to lower the density and still fit the 30% aggregate by volume specification.

Two admixtures were used in compliance with the Request for Proposal specifications: Eclipse® Floor 200 Shrinkage Reducer and ADVA® Cast 555 Super Plasticizer. Both admixtures were use at the manufacturer's minimum recommended dosage rates in order to increase the overall workability of the mix and to decrease the shrinkage as the canoe cures over the 28 days. Since latex was no longer allowed in the team's mix, water was the only source of hydration used. Because the dosages of both admixtures were so small in comparison to other components, the team opted to not prebatch these liquids into smaller containers because it would be a waste of material. Instead, team members used water bottles collected during the can and bottle drive to hold both admixtures, in order to control the amount added to mix buckets on Placement Day and reduce overall waste.

In the interest of saving material and lowering waste, the mix development team used 3x6 cylinders instead of 4x8 cylinders for testing purposes. The cylinders were used during tension testing (ASTM C496) and compression testing (ASTM C39) and a flexural beam will be tested under third point loading (ASTM C1609).

Table 4: Comparison of Lowell Mixes

Canoe	*w/cm*	*%CP*	*Unit Weight (pcf)*	*Tensile Strength (psi)*	*Compressive Strength (psi)*
Pathfinder	0.48	38%	64.62	324	2133
Vitruvius	0.45	45%	65.55	520	1440
Flintlock	0.45	40%	59.4	526	1998
Jester	0.45	40%	61.9	310	1990

The final engineering properties of *Pathfinder's* mix will be determined from both the flexure beams and 3x6 cylinders cast on Placement Day after they have been cured for 28 days. While the mix development team and structural analysis team has preliminary testing results, it is imperative to test the mix actually used to create the canoe in order to confirm its strength properties. A comparison of this mix is shown above in Table 4 in comparison with previous mix designs.

Construction of Prototype

Pathfinder was placed in mid-February of 2020. In the week before placement, all dry cementitious materials were hand-sieved to ensure that each batch of concrete place was made to the predesigned mix. All materials were measured by weight, using multiple identical scales that read values to the nearest 0.00001 pounds.

Placement of concrete on the mall mold travelled from bow to stern, starting with a ¼ inch first layer, colored black with pigment prebatched before mixing. Wooden depth checkers were used to verify that the thickness of each layer was at ¼ inch. Before the second layer, basalt mesh was placed along the length of the hull, followed by a shmear layer of concrete to ensure that the mesh and concrete were bonded together. Another later of basalt mesh was placed on top of that layer and smeared in the same fashion. The gunwales and each rib received a strip of basalt and a strip of fiberglass mesh to create a skeletal reinforced for the entire canoe.

Before the first layer reached the first 3D element, the inlayed layers received white concrete and was then covered by the continuing first layer. A second layer of ¼ inch concrete followed the mesh layer, finishing the canoe in a layer of white concrete. Following each color change in concrete placed on the canoe, team members changed to their gloves to ensure there was no unwanted color transfer. At completion, the hull was at an overall thickness of 5/8 inch, allowing a buffer to account for irregularities during placement that would be sanded down to an average hull thickness of ½ inch.

Shortly after placement commenced, *Pathfinder* was covered in a layer burlap that had been saturated in water overnight and left in a humified environment to cure. After *Pathfinder* has been left in the tent for 21 days to cure, the burlap will be removed, and wet sanding will commence. At 28 days, *Pathfinder* will be removed from the hydration tent in order to continue the sanding process. The team ultimately decided to cure the canoe for 28 days to ensure that the concrete was able to reach full strength, as tested during cylinder strength tests. Knowing that the maximum strength of the concrete might not be reached if the canoe dries out (Neville and Brooks, 2010), team members verified that all the hydration systems were in working order and the canoe was receiving maximum hydration every day. A hydration sprinkler system was set up within the humidified tent to ensure that the burlap stayed wet and did not dry out the canoe from lack of moisture.

Post-Construction Finishing

After 21 days of curing, construction team members will begin the wet sanding process with 60-grit sandpaper. Wet sanding allows the team to begin the finishing process, while still allowing the canoe to reach full strength in a humidified environment. After 28 days, the construction team will remove the mold from the table and place the canoe on stands to fully support the structure while the mold is removed. Since the mold contains plastic crates and foam, the goal is to remove the crates without damaging them so that they can be used in mold construction for years to come. Any additional foam left on the canoe after the removal of the crates will be removed via hotwire. Excess joint compound used in the mold creation process will be sanded off after the foam has been removed. Dry sanding will begin following mold removal until the average thickness is ½ inch, found by using the shadow sanding method. Vinyl lettering will be adhered to both and bow and stern, and two layers of sealer will be applied, resulting in a smooth, glossy finish.

SCOPE, SCHEDULE AND FEE

Table 5: Major Project Milestones

Milestone	Planned Date	Actual Date	Reason for Variance
Pathfinder Hull Remodel *	10/24/19	11/25/19	Additional edits needed for sustainability
Practice Placement	11/23/19	11/23/19	-
Mold Completion *	1/28/20	2/1/20	CNC Availability
Pathfinder Mix Selection *	1/22/20	1/31/20	Workability requirements
Pathfinder Placement Day	2/1/20	2/15/20	Material Availability
Technical Proposal Submitted	2/17/20	-	Unknown
Pathfinder Finishing	4/13/20	-	Unknown

*Denotes critical path

In order to create a larger, more experienced core team for concrete canoe teams to come, the managerial structure of the team expanded to include new members. Previously, the structure included one project manager, one operations manager, four team captains and three officers. Following the 2019 competition, the concept of junior captains was introduced in order to train new members for core team positions and spread out the day to day tasks of position holding members. (Introduction to the Project Team, 2) All of the position holding members worked cohesively as a unit to ensure that tasks were completed on time and correctly and that safety/quality control procedures were being followed at all time.

The team captains directed one of the five project groups: hull design and structural analysis, mix development and testing, construction, paddling and aesthetics. Each captain was responsible for innovation in their area and ensuring the milestone deadlines along the critical path were still met (Table 5). The critical path was calculated in Microsoft Project by determining tasks that had no slack and would subsequently put the project behind in time if not met. The project managers held core team meetings once a week as a way to keep communication with captains open and held general meetings once a month to keep the other participating members informed on upcoming events. (Quality Control and Quality Assurance, 12)

Mold completion, a milestone on the critical path, was greatly affected by the availability of staff and team members to prepare the CNC machine for use. The CNC milling machine is operated by the Plastics Engineering Department at UMass Lowell, meaning that team members need to schedule their mold construction around the availability of the machine. To combat this, the team made sure to have weekly meetings with the faculty and staff in the Plastics Engineering Department to make sure that two weeks could be reserved for usage by the concrete canoe team.

Pathfinder's team was composed of 17 members accumulating a total of 3,850 person-hours (Itemized Budget Sheet, 10), an increase in the amount of time worked on *Pathfinder* versus *Vitruvius* by 1.8%. This increase in time is due to the length of time necessary to use the CNC machine to mill a mold. This increase in time is necessary in order to create a mold with the most precision and accuracy needed to create the best looking product. A more valuable comparison for *Pathfinder* is *Jester*, since the hull is ultimately a remake of the 2017 entry. *Pathfinder* had a decrease in time of 2.5% compared to *Jester*, due to most of the mold software being completing. More time would have been saved if the mold software had not been modified to reduce overall foam usage and waste material.

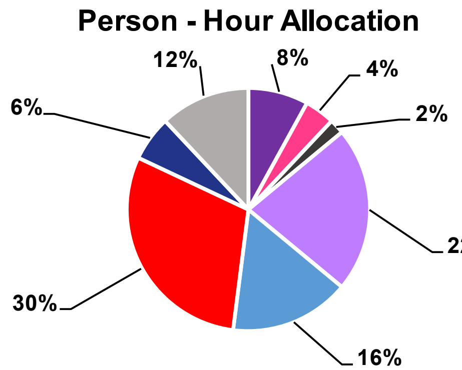
Pathfinder's financial plan was based upon previous experience, with an operating budget set at $10,400. This budget accounted for material procurement and construction. Team members utilized money saving techniques, such as purchasing recycled foam and seeking donations from local suppliers, as a way to reduce the overall cost of the canoe.

Itemized Budget Sheet

University of Massachusetts Lowell: Concrete Canoe Team

Total Projected Project Hours:	3850
Project Management	308
Hull Design	154
Structural Analysis	77
Mix Development	847
Mold Construction	616
Canoe Construction	1155
RFP Submittal	231
Finishing	462

** Note: Total hours estimated on percentage of completed tasks by submission date of technical proposal.*



2019 - 2020 Itemized Budget Sheet: *Pathfinder* Cost Estimation

ITEM NO.	ITEM DESCRIPTION	MATERIAL COST			LABOR COST			Total ($)
		QTY.	RATE	UM.	NO.	RATE	MN.HRS	
Project Management & Staff								
1	Project Construction Manager				1	40	770	$65,419.20
2	Principle Design Engineer				1	50	231	$24,532.20
3	Construction Superintendents				2	40	2233	$379,431.36
4	Project Design Engineer				1	35	847	$62,965.98
5	Quality Manager				1	35	443	$32,914.04
6	Graduate Field Engineer				2	25	1309	$139,015.80
7	Drafter				2	20	1040	$88,315.92
8	Office Administrator				1	15	539	$17,172.54
9	Laborer				10	25	1540	$817,740.00
10	Structural Consultant				1	200	58	$24,532.20
Canoe Construction								
11	Cement	124.15	0.03	$/lb				$4.10
12	Metakaolin	29.25	0.37	$/lb				$11.90
13	Perlite	11.99	0.18	$/lb				$2.16
	Silica Fume	12.42	0.44	$/lb				$6.01
	Poraver	23.77	0.25	$/lb				$6.54
	PVA Fibers	8.26	0.93	$/lb				$8.44
	ADVA Cast 555 SP	10.01	8.79	$/lb				$96.79
	Eclipse Floor 200 SRA	1.89	8.79	$/lb				$18.23
	Expanded Shale	25.99	0.05	$/lb				$1.43
	K1	15.54	0.05	$/lb				$0.85
	Basalt Mesh	120.00	1.60	$/sf				$211.20
	Bulkhead Foam	1.00	25.00	$/cf				$25.00
	Powdered Pigment	4.75	5.00	$/lb				$23.73
	Water (Non-carbonated)	8.51	0.03	$/gal				$0.26
	Glossy Sealer	60.00	0.50	$/sf				$30.00
	Mold Constrution	LS						$210.00
Shipping Cost (Lowell, MA to Madison, WI)								
	Penske Truck Rental	LS						$1,750.00
*Rental cost includes 22' Penske moving truck, gas mileage and fee to tow a vehicle on Penske.								
Total Cost of 2020 Concrete Canoe Construction								**$1,654,445.86**

HEALTH AND SAFETY

In order for members of the team to work in the concrete laboratory, members need to have taken and passed the silica dust certification quiz. The certification is granted by UMass Lowell's Environmental Health and Safety Department after a PowerPoint presentation on the dangers that silica dust poses to lab occupants. All non-position holding members are supervised by team leaders in the laboratory even after they have passed the silica dust certification. Power tools and testing equipment are only operated by team leaders after a safety training session provided by the team's staff advisor.

Before the team starts working in the laboratory, the Environmental Health and Safety Department does a safety inspection of the testing equipment and the air filtration system to make sure that all tools used by team members are in working condition. The safety inspection is led by the concrete canoe team's EHS Safety Lead, who keeps a list of all tools and machines that are owned and operated by the team.

Another role of the EHS Safety Lead is to make sure that each team member is aware of the risks of working in a concrete laboratory. The team's safety lead made sure that all Material Safety Data Sheets (MSDS) for each materials used in mix design was placed in a notebook, in the concrete laboratory. The sheets provide additional information about each material being used in mix design development to ensure that all team members have access to the safety information and precautions provided. In addition, the safety lead makes sure that there are always nylon gloves, safety glasses and respirators/masks for everyone on the team. The safety lead coordinates with the budgeting chair to make sure that the safety equipment is properly budgeted for and purchases in a timely manner.

Each mix team member is assigned their own silica dust mask and is provided with the proper cartridge filters to ensure that they are being sufficiently protected from all hazardous materials. Mix development team members are also provided with latex gloves that extend past the elbow and protective suits to cover their clothes from any dust particles that collect while testing. Eye protection is required for entering the lab and beside each mix bench is an eye washing station in case protocol is not followed.

Each construction and aesthetics team member are provided with safety glasses and disposable filter masks to protect them from any fumes created during the construction process. The laboratory space used for construction has air filter systems that allow fumes to be directed away from work spaces and has a separate room for any aerosol spray usage, decreasing team exposure to any aerosols. These systems are verified to be in working condition before every meeting, with construction starting only when all safety systems have been checked.

For dry sanding, team members are required to be fully covered with eye protection and mask use, in order to full protect them from the dust particles created by sanding concrete. The overhead air filter system remains on during times of sanding to ensure that the dust particles are being properly collected. Hoses with brushes are attached to the dust collection systems so that the canoe can be "vacuumed" during sanding in order to eliminate the amount of dust collected during the sanding process. After completion of sanding for that day, team members stay in their personal protection equipment while they vacuum any leftover dust that has accumulated on various surfaces in the lab.

Each team leader is ultimately responsible for the safety of their own team members during the meetings that they host. Team leaders are advised by laboratory staff to always ask questions and verify construction processes before beginning any work. Following the quality control processes for all materials and construction processes also diminishes other risks to construction and mix team members.

QUALITY CONTROL AND QUALITY ASSURANCE

Over the years, the concrete canoe team has had many shifts in how the team operates, along with who manages the team. This year, junior captains were added to the core team. In most situations, the junior captains served as quality assurance officers for their team leaders by reviewing all work put out by their team leaders. The Quality Control Officer's main focus was the quality of the overall project which included the canoe prototype, the display board and the stand. All of these components needed to be created exactly to the approved drawing and design by the core team, so it was imperative that there was an officer verifying that everything was built per specification.

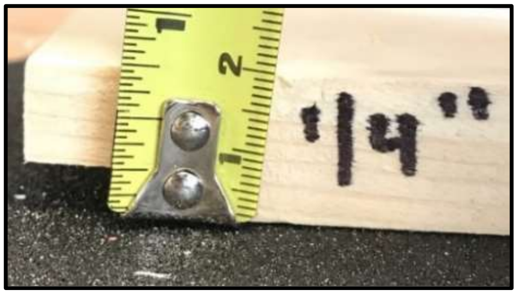


Figure 3: Quality Control Methods: Wooden Depth Checker

On Placement Day, the main quality control concern is the thickness of the layers of concrete on either side of the reinforcing mesh layer. Since *Pathfinder* has an overall hull thickness of ½ inch, team members needed to make sure to place each layer of concrete at ¼ inch. To do this, the team uses wooden depth checkers (Figure 3) to verify that each hand placed section of concrete is at the ¼ inch. After the canoe was placed and had time to start to cure, wet burlap was placed on top of the canoe and mold to ensure that the entire structure was hydrated throughout the 28-day curing period. The burlap was soaked in water overnight and was used in addition to a fogger/misting system to ensure the canoe was curing in an environment with 100% humidity.

Team leaders made sure to locate, review and understand MTDS and MSDS of every material that was used during construction and testing. Any important information not provided on either sheet was found either through testing by the relevant team or a request to the manufacturer or distributor. MTDS were compiled electronically to be reported in the Material Technical Data Sheet Addendum. MSDS were compiled in a notebook which was located in the laboratory where all team members could easily access it during any point in construction or mixing.

Since the use of latex was no longer allowed for mix development purposes, the mix team set out to find new materials that had not been previously used in order to meet their goals. The testing and review method, shown in Figure 4, was applied to every new material acquired in order to ensure that the specifications were met, and health and safety regulations were followed. Materials such as 3M K1, 3M K10 and perlite were all materials that were new to the team this year, requiring new data sheets to be acquired and specifications checked for compliance.

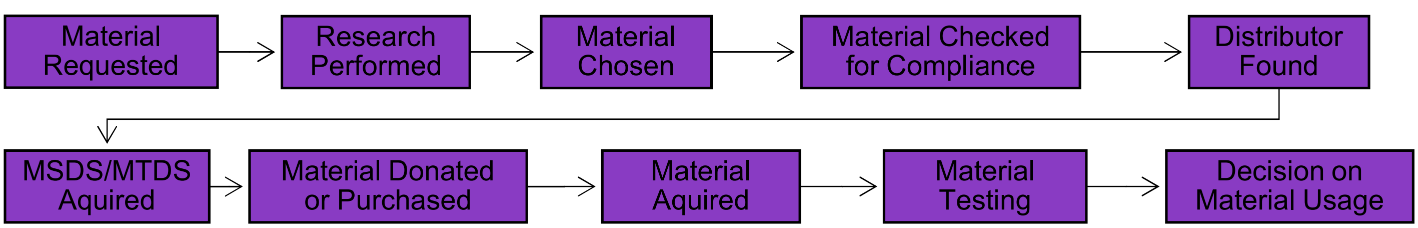


Figure 4: Quality Control Process for All Materials

As soon as the NCCC 2020 Request for Proposal was released, Lowell had core team captains read their individual sections to ensure compliance in all aspects of the project. Team members took notes of all rule changes and the quality control officer could begin checking that all teams were in complete understanding of all relevant rules. With the NCCC providing a Facebook page where all RFI's were answered publicly, all questions and answers could be analyzed by team members on their own time. Lowell's analysis team double-checked all important calculations, and all other teams knew to send calculations to the analysis team whenever they performed any non-routine calculations. The quality control officer reviewed documents to be submitted to confirm that all rules were followed.

APPROACH TO SUSTAINABILITY

Figure 5: Original Condition of Recycled Foam

Since UMass Lowell's mold removal process includes cutting the foam mold out with a hot wire, the team has not found a way to make a completely reusable male mold for placement. Currently, extruded polystyrene (XPS) foam gives the team the most accurate canoe shape and ultimately produces the best product. Instead, the team has started the practice of purchasing recycled XPS foam to use as mold material to make a composite style mold with a reusable middle section. The recycled foam is removed from buildings during demolition jobs and is resold in the condition it is obtained in.

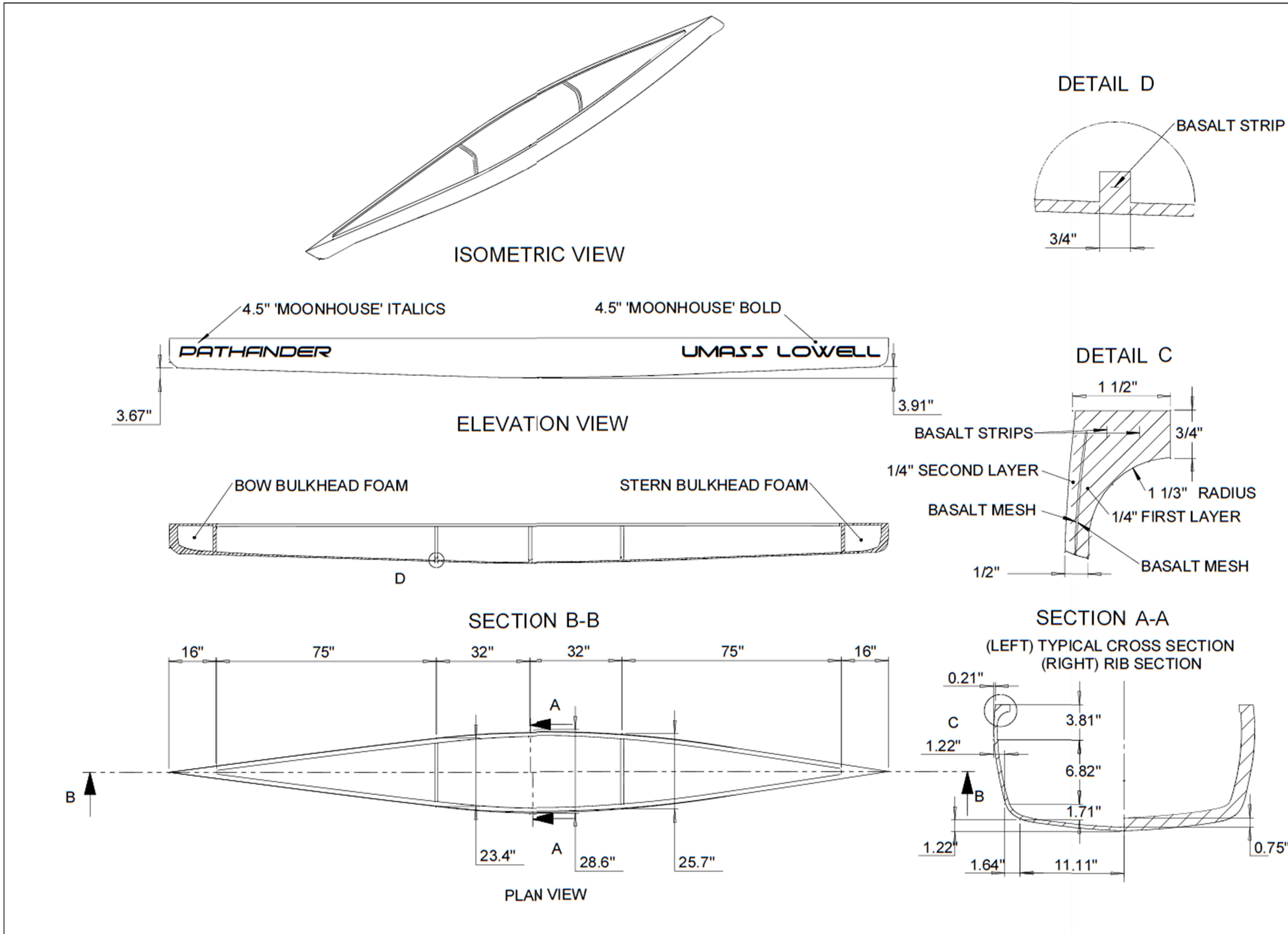
Originally, the concept of recycled foam was discovered in 2018 by the budgeting team as a way to drastically reduce construction costs for the mold. Upon realization that the recycled foam is more durable, larger in size and reuses a material that would be traditionally thrown away, the construction team worked with a family owned, local vendor to ensure that the foam would be available for the team to purchase. This year, sheets of 3" foam were purchased in various conditions in order to complete the mold. The thicker foam sheets created some trouble for the team because the mold software was programmed to have 2" foam sheet sections going down the length of the mold. To adjust for this, the construction team set up a hot wire to cut the foam ½" on either side of the sheet. This created a 2" thick sheet and also removed all surface imperfections on the foam that comes from the recycling process.

To make the male mold more sustainable rather than just recycled, the construction team wanted to find a material that could be used to support the majority of the mold, with the foam only used to shape the curved part of the hull. Originally, large milk crates (12" x 12" x 10.5") were experimented with and added to the hull modeling software as a way to remove a bulk amount of foam. Because of the tumblehome shape, overall width and location of the transverse ribs of the canoe, the larger milkcrates were not a good fit, since only three could fit along the total length of the canoe. Instead, "micro milk crates" (9" x 7.75" x 6") were used along the length of the canoe. The smaller dimensions allowed for the majority of the male mold to be reusable, with foam added to the top and sides for easy placement of the gunwales, ribs and bottom of the canoe. With careful removal of the crates during mold removal after the canoe has completed curing, the crates will be useable for male molds to come. Altogether, the crates eliminated the need for about 5 ft^3 of foam.

Additionally, the team has implemented a can and bottle drive as a way to both raise funds all year round for the team and to also practice greener processes. Large bins are placed all around campus with posters in the hallways pointing students in the direction of donation bins. After two week periods of time, the collection bins are emptied, and the team returns the cans for the deposits on them. Following the deposit, the bins are placed back around campus and collection starts again.

While the composite recycled foam and milk crate mold is a new practice, this is a construction process that the concrete canoe team hopes to continue to use. Being a donation-based team, the budget and management team are always looking for ways to cut down on construction cost while still producing a high-quality product. The recycled foam allows the team to shrink their mold construction budget while supporting a local, family owned business. The can and bottle drive serves as another recycling process that also helps to fund the team in order to be able to compete. The goal is for the team to participate in and encourage greener practices in other areas besides construction, since a reusable mold hasn't been perfected for use.

CONSTRUCTION DRAWING AND SPECIFICATIONS



Bill of Materials

Qty.	Description
124.15	Portland Cement
29.25	Metakaolin
11.99	Perlite
12.42	Silica Fume
23.77	Poraver
8.26	PVA Fiber
1.89	Eclipse Floor 200 SRA
25.99	Expanded Shale
15.54	K1
120.0	Basalt Mesh
4.75	Powdered Pigment
8.51	Water
60.00	Glossy Sealer
1.00	Bulkhead Foam

PATHFINDER

Construction Drawing

- Drawing not to scale
- Bulkhead foam used for floatation, comprised of 1" pieces glued together, stays >1" inside concrete on all sides

Engineer	Yushai Canteenwala
Drawn By	Steven Fallon
Checked By	Kathryn Evasius
Date	02/11/2020

PROJECT SCHEDULE

ID	Task Name	Duration	Planned Start	Planned Finish	Actual Start	Actual Finish
1	**Umass Lowell Concrete Canoe Project - Pathfinder**	**201 days**	**Mon 9/9/19**	**Mon 6/15/20**	**Mon 9/9/19**	**NA**
2	**Project Management**	**201 days**	**Mon 9/9/19**	**Mon 6/15/20**	**Mon 9/9/19**	**NA**
3	Request for Proposal Released	1 day	Mon 9/9/19	Mon 9/9/19	Mon 9/9/19	Mon 9/9/19
4	Safety Inspection of Laboratory Facilities	1 day	Fri 9/13/19	Fri 9/13/19	Fri 9/13/19	Fri 9/13/19
5	Role Establisment Meeting	1 day	Mon 9/16/19	Mon 9/16/19	Mon 9/16/19	Mon 9/16/19
6	Material Procurement	45 days	Sat 9/28/19	Thu 11/28/19	Sat 9/28/19	Mon 2/3/20
7	Freshman Presentations and Recruitment	5 days	Mon 9/16/19	Fri 9/20/19	Mon 9/16/19	Fri 9/20/19
8	Preliminary Project Schedule Submitted	1 day	Fri 11/1/19	Fri 11/1/19	Fri 11/1/19	Fri 11/1/19
9	First General Meeting	1 day	Wed 9/25/19	Wed 9/25/19	Thu 9/22/16	Thu 9/22/16
10	Register Team for Comeption	1 day	Fri 1/31/20	Fri 1/31/20	Wed 1/22/20	Wed 1/22/20
11	Fundraising	201 days	Mon 9/9/19	Mon 6/15/20	Mon 9/9/19	NA
12	**Mix Design**	**105 days**	**Mon 9/9/19**	**Fri 1/31/20**	**Mon 9/9/19**	**Sat 2/8/20**
13	Mix Design Material Research	55 days	Mon 9/9/19	Fri 11/22/19	Mon 9/9/19	Sat 2/8/20
14	Practice Placement Day Prebatching	1 day	Fri 11/22/19	Fri 11/22/19	Fri 11/22/19	Fri 11/22/19
15	Mix Design Testing	44 days	Fri 11/22/19	Wed 1/22/20	Fri 11/22/19	Fri 1/31/20
16	Canoe Mix Selected	1 day	Wed 1/22/20	Wed 1/22/20	Fri 1/31/20	Fri 1/31/20
17	Placement Day Prebatching	8 days	Wed 1/22/20	Fri 1/31/20	Fri 1/31/20	Sat 2/8/20
18	**Hull Design**	**87 days**	**Mon 9/9/19**	**Tue 1/7/20**	**Mon 9/9/19**	**Tue 1/7/20**
19	Hull Design Research	52 days	Mon 9/9/19	Tue 11/19/19	Mon 9/9/19	Tue 11/19/19
20	Hull Design (Prolines)	12 days	Thu 9/19/19	Fri 10/4/19	Thu 9/19/19	Fri 10/4/19
21	Hull Modeling (SolidWorks)	10 days	Fri 10/4/19	Thu 10/17/19	Fri 10/4/19	Thu 10/17/19
22	Convert Mold to Mastercam	6 days	Thu 10/24/19	Thu 10/31/19	Thu 10/17/19	Sun 12/15/19
23	Mold Remodel Completion	0 days	Thu 10/31/19	Thu 10/31/19	Sun 12/15/19	Sun 12/15/19
24	Structural Analysis	28 days	Sun 12/1/19	Tue 1/7/20	Sun 12/1/19	Tue 1/7/20
25	**Construction**	**150 days**	**Fri 9/20/19**	**Thu 4/16/20**	**Fri 9/20/19**	**NA**
26	Concrete Lab Cleanup	1 day	Fri 9/20/19	Fri 9/20/19	Fri 9/20/19	Sat 9/21/19
27	Table Update	12 days	Sun 9/29/19	Sat 10/12/19	Sun 9/29/19	Sat 10/12/19
28	Practice Placement Day	1 day	Sat 11/23/19	Sat 11/23/19	Sat 11/23/19	Sat 11/23/19
29	Mold Cut in CNC	43 days	Sun 12/1/19	Tue 1/28/20	Mon 1/27/20	Sun 2/2/20
30	Mold Finished by Hand	4 days	Tue 1/28/20	Fri 1/31/20	Thu 2/20/20	Fri 2/7/20
31	Hydration Tent Update	12 days	Sun 12/1/19	Mon 12/16/19	Mon 2/3/20	Wed 2/5/20
32	Canoe Placement Day	0 days	Sat 2/1/20	Sat 2/1/20	Sat 2/8/20	Sat 2/8/20
33	Canoe Curing	22 days	Sat 2/1/20	Sat 2/29/20	Sat 2/8/20	NA
34	Canoe Wet Sanding	7 days	Sat 2/22/20	Sat 2/29/20	NA	NA
35	Canoe Mold Removal	1 day	Sat 2/29/20	Sat 2/29/20	NA	NA
36	Canoe Dry Sanding	28 days	Sat 2/29/20	Tue 4/7/20	NA	NA
37	Sectional Construction	11 days	Wed 2/5/20	Wed 2/19/20	NA	NA
38	Display Table Construction	28 days	Sun 3/1/20	Tue 4/7/20	NA	NA
39	Stand Construction	19 days	Wed 11/27/19	Sat 12/21/19	NA	NA
40	Canoe Sealing	2 days	Sun 4/12/20	Mon 4/13/20	NA	NA
41	**Paddling**	**120 days**	**Sun 11/3/19**	**Thu 4/16/20**	**Sun 11/3/19**	**NA**
42	Fall Semester Practice	37 days	Fri 11/1/19	Mon 12/23/19	Fri 11/1/19	Sat 11/23/19
43	Spring Semester Practice	41 days	Thu 2/20/20	Thu 4/16/20	NA	NA
44	Paddling Team Roles Defined	1 day	Sun 3/1/20	Sun 3/1/20	NA	NA
45	**Technical Proposal**	**116 days**	**Mon 9/9/19**	**Mon 2/17/20**	**Mon 9/9/19**	**Mon 2/17/20**
46	Proposal Rough Drafts	61 days	Mon 9/9/19	Sun 12/1/19	Mon 9/9/19	Mon 12/2/19
47	Proposal Editing	24 days	Sun 12/1/19	Wed 1/1/20	Mon 12/2/19	Tue 2/11/20
48	Proposal Submitted	1 day	Mon 2/17/20	Mon 2/17/20	Mon 2/17/20	Mon 2/17/20
49	**Presentation**	**44 days**	**Tue 2/18/20**	**Fri 4/17/20**	**NA**	**NA**
50	Presentation Script Development	17 days	Sun 2/2/20	Sat 2/22/20	NA	NA
51	Presentation PowerPoint Design	17 days	Sun 2/2/20	Sat 2/22/20	NA	NA
52	Mock Presentation for Faculty	1 day	Fri 3/13/20	Fri 3/13/20	NA	NA
53	Peer Presentations and Revisions	26 days	Fri 3/13/20	Fri 4/17/20	NA	NA
54	**Aesthetics**	**157 days**	**Mon 9/9/19**	**Tue 4/14/20**	**Thu 9/19/19**	**NA**
55	Theme Research	22 days	Mon 9/9/19	Tue 10/8/19	Mon 9/9/19	Tue 10/8/19
56	Theme Selection	1 day	Tue 10/8/19	Tue 10/8/19	Tue 10/8/19	Tue 10/8/19
57	Design of Elements	20 days	Tue 10/8/19	Mon 11/4/19	Tue 10/8/19	NA
58	Canoe Aesthetics	7 days	Tue 4/7/20	Wed 4/15/20	NA	NA
59	Tabletop Display Aesthetics	32 days	Sun 3/1/20	Mon 4/13/20	NA	NA
60	**Competitions**	**42 days**	**Fri 4/17/20**	**Mon 6/15/20**	**NA**	**NA**
61	2020 New England Regional Concrete Canoe Competition	2 days	Fri 4/17/20	Sun 4/19/20	NA	NA
62	2020 National Concrete Canoe Competition	2 days	Sat 6/13/20	Mon 6/15/20	NA	NA

Tasks | Milestones | Critical | Summary | Actual Task | Actual Milestone | Actually Summary

APPENDIX A: MIX PROPORTIONS AND PRIMARY MIX CALCULATIONS

Mixture: Primary Mix (Colored with Red Iron Oxide Pigment)

Cementitious Materials

Component	Specific Gravity	Volume	Amount of CM	
Lehigh Type I White Portland	3.15	4.4 ft^3	865.15 lb/yd^3	Total cm (includes c) 1155.49 lb/yd^3 c/cm ratio, by mass 0.75
White Silica Fume	2.2	0.63 ft^3	86.51 lb/yd^3	
Metakaolin	2.6	1.26 ft^3	203.83 lb/yd^3	

Fibers

Component	Specific Gravity	Volume	Amount of Fibers	
Nycon .315" PVA	1.3	0.59 ft^3	48. 47 lb/yd^3	Total Amount of Fibers 48.47 lb/yd^3

Aggregates (Excluding Mineral Fillers Passing No. 200 Sieve)

Aggregates	Expanded Glass (EG) or Cenosphere (C)[1]	Abs (%)	SG_{OD}	SG_{SSD}	Base Quantity, W		Volume, $V_{agg, SSD}$
					W_{OD}	W_{SSD}	
3M K1 (<75um)	Yes	0%	0.125	0.125	44.84 lb/yd^3	44.84 lb/yd^3	5.75 ft^3
Perlite	No	80%	0.345	0.6205	46.67 lb/yd^3	83.57 lb/yd^3	2.16 ft^3
Poraver	Yes	55%	0.65	0.99	106.9 lb/yd^3	165.64 lb/yd^3	2.68 ft^3
Norlite 8x0 Expanded Shale	No	8%	1.87	2.02	167.59 lb/yd^3	180.73 lb/yd^3	1.43 ft^3

Liquid Admixtures

Admixture	lb/ US gal	Dosage (fl. oz / cwt)	% Solids	Amount of Water in Admixture	
ADVA Cast 555 SP	8.91	8-20fl oz /100lbs	17.1%	48.31 lb/yd^3	Total Water from Liquid Admixtures, $\sum w_{admx}$ 59.44 lb/yd^3
Eclipse Floor 200 SRA	8.0	192 fl oz /yd^3	1%	11.13 lb/yd^3	

Solids (Dyes, Powdered Admixtures, and Mineral Fillers)

Component	Specific Gravity	Volume (ft^3)	Amount (lb/yd^3)	
Red Iron Oxide Pigment$_d$	4.9	0.108 ft^3	33.06 lb/yd^3	Total Solids. S_{total} 96.47 lb/yd^3
3M K1 (>75um)mf	.125	8.13 ft^3	63.41 lb/yd^3	

Water

		Amount	Volume
Water, w, $[=\sum (w_{free} + w_{admx} + w_{batch})]$	w/c ratio, by mass **.579** w/cm ratio, by mass **.434**	489.57 lb/yd^3	7.85 ft^3
Total Free Water from All Aggregates, $\sum w_{free}$		-6.07 lb/yd^3	
Total Water from All Admixtures, $\sum w_{admx}$		.5057 lb/yd^3	
Batch Water, w_{batch}		495.14 lb/yd^3	

Densities, Air Content, Ratios, and Slump

Values for 1 cy of concrete	cm	Fibers	Aggregate (SSD)	Solids, S_{total}	Water, w	Total
Mass, M	1.0204 lb	.0428 lb	.4197 lb	.0853 lb	.41472 lb	$\sum M$: 1.984 lb
Absolute Volume, V	.00556 ft^3	.00132 ft^3	.0106 ft^3	.00728 ft^3	.0066 ft^3	$\sum V$: .0314 ft^3
Theoretical Density, T, $(=\sum M / \sum V)$	61.55 lb/ft^3		Air Content, Air, $[= (T - D)/T \times 100\%]$			18.1 %
Measured Density, D	72.9 lb/ft^3		Air Content, Air, $[= (27 - \sum V))/27 \times 100\%]$			0.99%
Total Aggregate Ratio[2] $(=V_{agg,SSD} / 27)$	.000392 %		Slump, Slump flow, Spread (as applicable)			¼in.
EG+C Ratio[3] $(=V_{EG+C} / V_{agg,SSD})$	70%					

Volume:

$$Volume = \frac{Mass}{(S.G)(62.4\,pcf)}$$

Cement:

$$Volume = \frac{865.15}{(3.15)(62.4\,pcf)} = 4.4\,ft^3$$

Silica Fume:

$$Volume = \frac{86.51}{(2.2)(62.4\,pcf)} = 0.630\,ft^3$$

Metakaolin:

$$Volume = \frac{203.83}{(2.6)(62.4\,pcf)} = 1.25\,ft^3$$

Shale:

$$Volume = \frac{180.73}{(2.02)(62.4\,pcf)} = 1.43\,ft^3$$

Poraver:

$$Volume = \frac{165.64}{(0.99)(62.4\,pcf)} = 2.68\,ft^3$$

K1 < 75 μm:

$$Volume = \frac{44.84}{(0.125)(62.4\,pcf)} = 5.75\,ft^3$$

Fibers:

$$Volume = \frac{48.47}{(1.3)(62.4\,pcf)} = 0.59\,ft^3$$

Perlite:

$$Volume = \frac{83.57}{(0.6205)(62.4\,pcf)} = 2.16\,ft^3$$

Water:

$$Volume = \frac{\left(\frac{w}{cm}\right)(Mass)}{(62.4\,pcf)} = \frac{(0.48)(495.17)}{(62.4\,pcf)} = 3.72\,ft^3$$

Pigment:

$$Volume = \frac{(33.06)}{(4.9)(62.4\,pcf)} = 0.108\,ft^3$$

K1 > 75 μm:

$$Volume = \frac{(63.41)}{(0.125)(62.4\,pcf)} = 8.13\,ft^3$$

Air:

$$\%\,Air = \frac{(64.22)(0.0097)}{(62.4\,pcf)} * 100 = 0.99\%\,air\ in\ plastic\ state$$

APPENDIX B: SAMPLE STRUCTURAL CALCULATIONS

Loading Scenario: Two 200 lb paddler loads are located at 15% and 85% the length of the canoe. 80 plf distributed load (W_{cargo}) is applied to a 5' length at the longitudinal center. Calculate: The internal stresses for the above loading, bending moment at the cracking of concrete and the ultimate bending moment.

Known: * = Estimated/Assumed Value

$\mathrm{P_1 = P_2 = 200\ lbs}$

$\mathrm{L_{canoe} = 20\ ft\ 6\ in = 246\ in}$

$\mathrm{w_{cargo} = 80\ lbs/ft}$

$\mathrm{* \ w_{canoe} = 220\ lb}$

Critical Shear, V(x) and Critical Moment, M(x):

$\mathrm{X_0 = 0\ in, X_1 = (0.15)(246\ in) = 37\ in, X_2 = (123\ in) - \left(\frac{60\ in}{2}\right) = 93\ in}$

$\mathrm{X_3 = \left(\frac{246\ in}{2}\right) = 123\ in, X_4 = (123\ in) + \left(\frac{60\ in}{2}\right) = 153\ in,\ \ X_5 = (0.85)(246\ in) = 209in,\ \ X_6 = 246\ in}$

Load Constants:

$\mathrm{w_{canoe} = w_c = (Distributed\ Weight)/(Length) = (220\ lbs/246\ in) = 0.894\ lb/in}$

$\mathrm{w_{cargo} = w_1 = \left(80\frac{lb}{ft}\right)\left(\frac{1\ ft}{12\ in}\right) = 6.66\ lb/in}$

$\mathrm{Bouyancy = (Total\ Load\ on\ Canoe) = (200\ lbs * 4) + (220\ lbs) = 1020\ lbs}$

$\mathrm{Bouyancy\ Intensity = (Bouyancy)/(Half\ Length\ of\ the\ Canoe) = (1020\ lbs)/(0.5 * 246\ in) = 8.29\ lb/in}$

$\mathrm{Bouyancy\ Intensity\ per\ Square\ Inch = U_b = (Bouyancy\ Intensity)/(Half\ Length\ of\ the\ Canoe) =}$
$\mathrm{(8.29\ lb/in)/(0.5 * 246\ in) = 0.06742\ lb/in^2}$

*Buoyancy acts like a triangular load, maxing in the middle of the canoe and reaching 0 lb/in at $\mathrm{X_0 = 0\ in}$ and $\mathrm{X_6 = 246\ in}$.

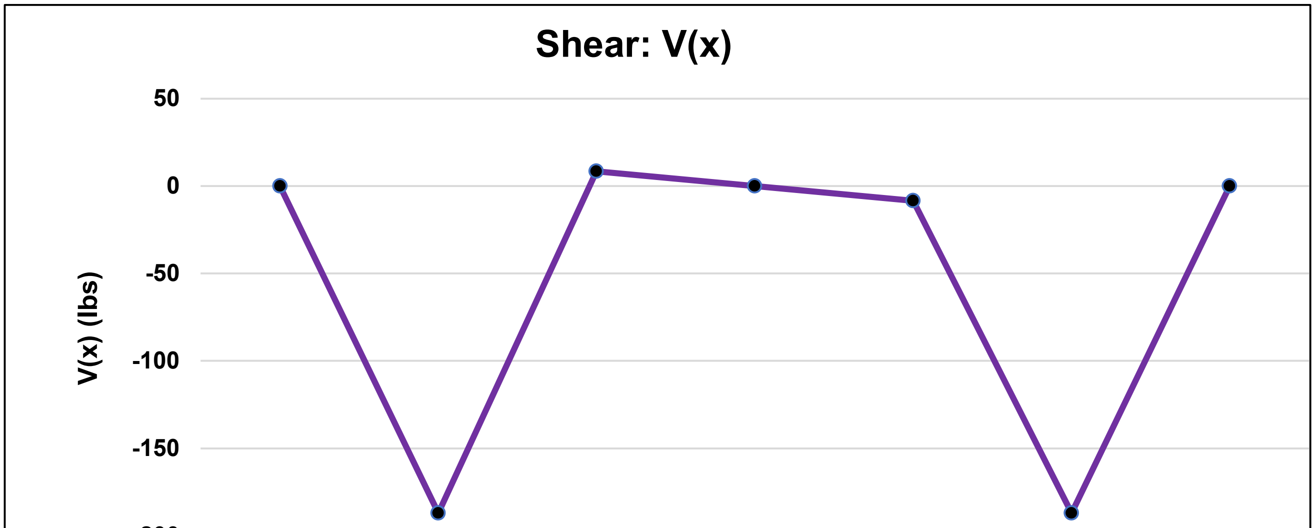
Integrals of Load Ratio:

Variable	Ratio	Shear (V_x)	Moment (M_x)
U_b	0.06742x	$(0.06742x)(x/2) = 0.034x^2$	$(0.034x^2)(x/3) = 0.0113x^3$
w_c	0.894	$(0.894)(x) = -0.894x$	$(-0.894x)(x/2) = -0.447x^2$
w_1	6.66	$(6.66)(x) = -6.66x$	$(-6.66x)$
$P_1 = P_2$	0	-200	$(-200)(x) = -200x$

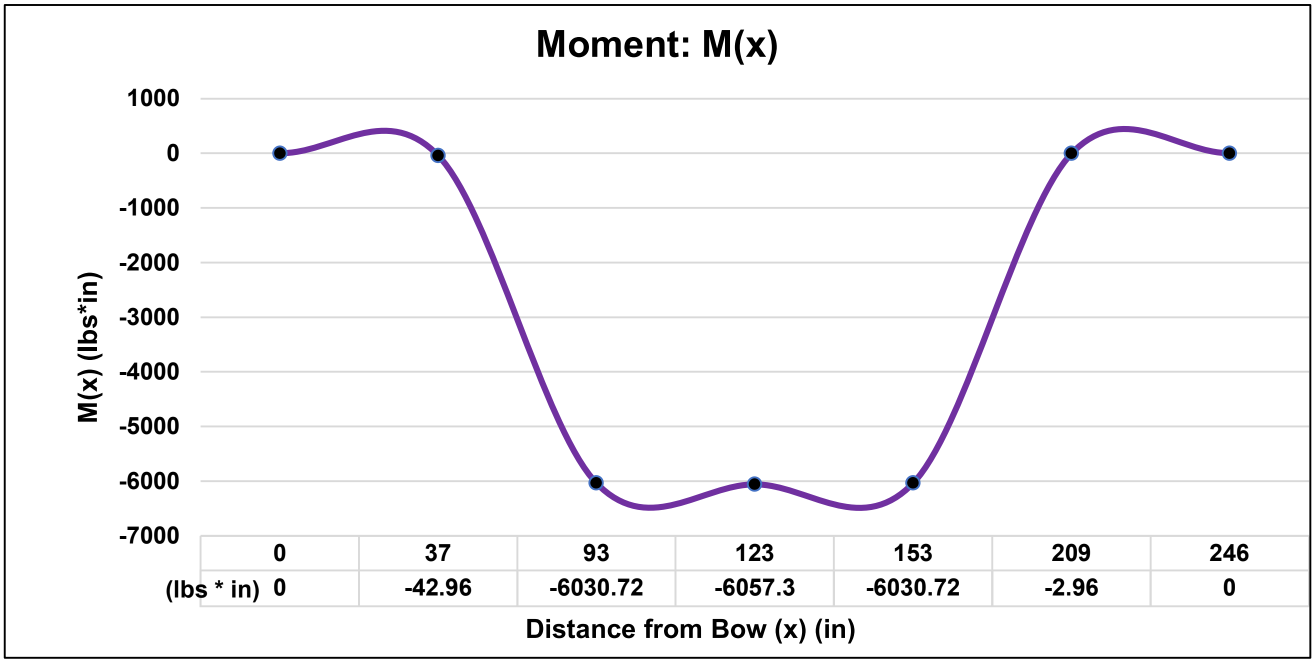
Summary Table

Distance from Bow (in)	Shear Diagram (lbs)	Moment Diagram (lbs * in)
$X_0 = 0$	$V_0 = U_b + W_c = 0$	$M_0 = U_b + W_c = 0$
$X_1 = 37$	$V_1 = U_b + W_c + P_1 = -186.94$	$M_1 = U_b + W_c = -42.96$
$X_2 = 93$	$V_2 = U_b + W_c + W_1 = 8.34$	$M_2 = U_b + W_c + P_1 = -6030.72$
$X_3 = 123$	$V_3 = U_b + W_c + W_1 = 0$	$M_3 = U_b + W_c + P_1 + W_1 = -6057.3$
$X_4 = 153$	$V_4 = U_b + W_c + W_1 = -8.34$	$M_4 = U_b + W_c + P_1 - 6030.72$
$X_5 = 209$	$V_5 = U_b + W_c + P_2 - 186.94$	$M_5 = U_b + W_c = -42.96$
$X_6 = 246$	$V_0 = U_b + W_c = 0$	$M_0 = U_b + W_c = 0$

Shear and Moment Diagrams



(in)	0	37	93	123	153	209	246
(lbs)	0	-186.94	8.34	0	-8.34	-186.94	0



Moment of Inertia

Moment of Inertia Calculations were obtained by turning all cross sections of hull into simple shapes to allow ease of *calculation of values by hand.*

Segment Areas and Moment of Inertia Equations:

Segments 1, 3, 4, 5 and 6:

$A_{rectangle} = b * h$

$I_{x_{rectangle}} = (b * h^3)/12$

Segment 2:

$A_{Annulus} = [(\pi)(r_o^2 - r_i^2)]/4$

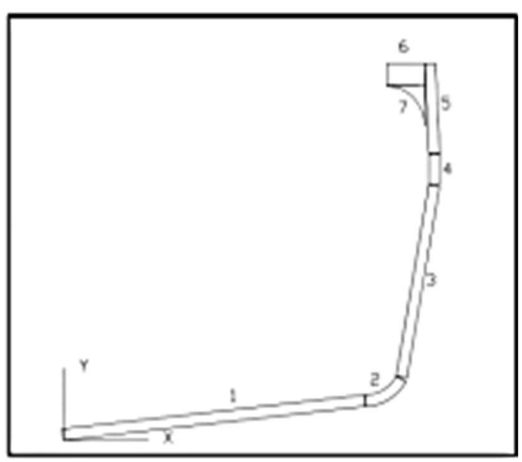
$I_{x_{rectangle}} = (b * h^3)/12$

Segment 7:

$A_{square} - A_{circle} = [b^2] - \left[\frac{r^2 * \pi}{4}\right]$

$I_{x_{square}} - I_{x_{circle}} = [(\pi)(r^4)]/16$

Segment	*Area (in^2)*	*y (in)*	*Ay (in^3)*	*d (in)*	*I_x (in^4)*	*$I_x + Ad^2$ (in^4)*
1	5.35	0.75	4.01	1.96	0.05	20.6
2	0.67	2.00	1.34	1.34	0.59	1.79
3	3.23	5.31	17.15	17.15	8.44	958.45
4	0.51	8.99	4.59	4.59	0.03	10.77
5	1.51	10.99	16.59	16.59	0.86	416.45
6	1.00	12.13	12.13	12.13	0.05	147.78
7	0.38	11.05	4.20	4.20	-0.05	6.65



$Y: \frac{\sum Ay}{\sum Area} = \frac{60.01}{12.65} = 4.74 \text{ in}$

$I_{x_{half}} = 781.25 \text{ in}^4$

$I_x = 1562.49 \text{ in}^4$

Determination of Maximum Compressive and Tensile Stresses:

Height of sectional: 13.56 in

$C_c = -Y = -4.74$ in

$C_t = \text{Height} - Y = 8.82$ in

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

Mix Design Safety Factor: MDF = 2.5

Design Compressive Stress

$$f_{c_{maximum}} = (DAF * MDF * M_{max} * C_c)/I_x = (1.25 * 2.5 * 6057.3 * -4.74)/1562.49 = -57.42 \text{ psi}$$

Design Tensile Stress

$$f_{t_{maximum}} = (DAF * MDF * M_{max} * C_t)/I_x = (1.25 * 2.5 * 6057.3 * 8.82)/1562.49 = 106.85 \text{ psi}$$

Cracking Moment of Concrete (M_{cr})

$$M_{cr} = \frac{f_r I_g}{y_t}$$

$f_r = 7.5\sqrt{f_c'}$ (ACI Eq. 9 – 10, 318 – 14)

*Assuming $f_c' = 2000$ psi (Table 1, Executive Summary, iii)

$$f_r = 7.5\sqrt{f_c'} = 7.5\sqrt{2000} = 335.41 \text{ psi}$$

$$I_g = I_{z_{half}} = 781.25 \text{ in}^4$$

Using the following values: (Table 1, Executive Summary, iii)

Width: 28 in

Height: 13.8 in

Thickness: 0.5 in

$$y = C_{NA} = \frac{\sum A_i Y}{\sum A_i} = \frac{2\left[(13.8)(0.5)\left(\frac{13.8}{2}\right)\right] + (28)(0.5)\left(\frac{0.5}{2}\right)}{(2)(13.8)(0.5)+(28)(0.5)} = 3.551 \text{ in (from bottom of hull)}$$

$$y_t = \text{Height} - C_{NA} = 13.8 - 3.551 = 10.249 \text{ in}$$

$$M_{cr} = \frac{f_r I_g}{y_t} = \frac{(335.41 \text{ psi})(781.25 \text{ in}^4)}{(10.249 \text{ in})} = 25{,}2567.28 \text{ lb} * \text{in}$$

Ultimate Bending Moment (ΦM_n)

$$p = \frac{A_s}{bd} = \frac{2.24}{(28)(13.8)} = 0.0057,\ p_{min} = \frac{200}{550 \text{ ksi}} = 0.0036,\ p_{max} = 0.75\left(\frac{0.85(0.8)(2)}{550}\right)\left(\frac{87}{587}\right) = 0.03$$

$$p > p_{min} \longrightarrow \text{ok.}$$

$$a = \frac{p f_y d}{0.85\ {}'_c} = \frac{(0.0057)(550)(13.8)}{(0.85)(2)} = 25.45,\ M_n = A_s f_y\left(d - \frac{a}{2}\right) = (550)(2.24)\left(13.8 - \frac{25.45}{2}\right) = 1330.3 \text{ kip} * \text{in}$$

$$\phi M_n = 0.9 * M_n = (0.9)(1330.3 \text{ kip} * \text{in}) = 1197.3 \text{ kip} * \text{in})$$

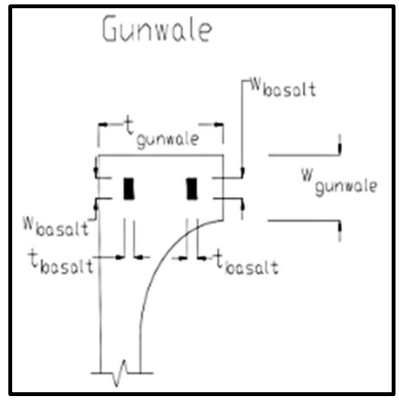
APPENDIX C: HULL THICKNESS/REINFORCEMENT & PERCENT OPEN AREA CALCULATIONS

Hull Thickness/Reinforcement (Jester, 2017)

*** Note: Figures not to scale**

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

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



Gunwhale:

$t_{basalt} = 0.04\text{ in},\ w_{basalt} = 0.16\text{ in}$

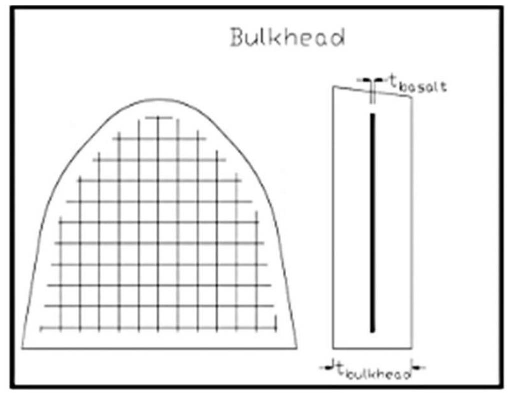
$t_{gunwhale} = 0.75\text{ in},\ w_{basalt} = 1.50\text{ in}$

$[w_{basalt}/w_{gunwale}] * 100\text{: } [(0.16\text{ in})/(0.75\text{in})] * 100$

$= 21.33\% \leq 50\%$

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

$= 5.33\ \% \leq 50\%$



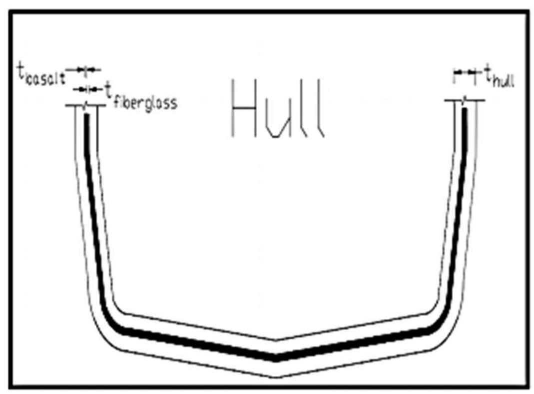
Bulkheads:

$t_{basalt} = 0.04\text{ in}$

$t_{bulkhead} = 1.0\text{ in}$

$[(0.04\text{ in})/(1.00\text{ in})] * 100$

$= 4.00\% \leq 50\%$



Hull:

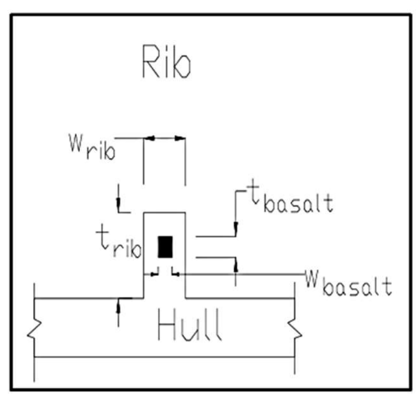
$t_{basalt} = 0.04\ in$

$t_{fiberglass} = 0.03\ in$

$t_{gunwhale} = 0.375\ in$

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

$= 14\% \leq 50\%$



Ribs:

$t_{basalt} = 0.04\ in$

$w_{basalt} = 0.16\ in$

$t_{rib} = 1.0\ in$

$w_{rib} = 0.75\ in$

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

$= 4.00\% \leq 50\%$

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

$= 21.33\% \leq 50\%$

****All reinforcements meet guidelines stated in NCCC 2020 Request for Proposals.**

Percent Open Area Calculations

Minimum Percent Open Area (POA)
$POA = [(Area_{open} / Area_{total}) \cdot 100] \geq 40\ \%$

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: Basalt Mesh

$d_1 = aperture\ dimension + 2 \cdot (t_1/2) \rightarrow (1.00\ in + 2 \cdot (0.24\ in/2)) = 1.24\ in$

$d_2 = aperture\ dimension + 2 \cdot (t_2/2) \rightarrow (1.0\ in + 2 \cdot (0.16\ in/2)) = 1.16\ in$

$Length_{sample} = n_1/d_1 \rightarrow [(10)\ x\ 1.24\ in] = 12.4\ in$

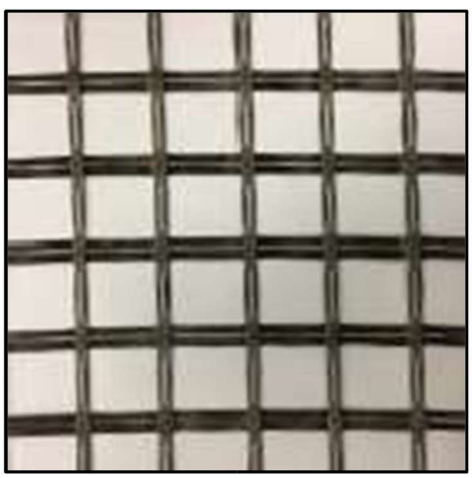
$Width_{sample} = n_2 \cdot d_2 \rightarrow [(10)\ x\ 1.16\ in] = 11.6\ in$

$\Sigma Area_{open} = n_1 \cdot n_2 \cdot Area_{open} \rightarrow = (10 \cdot 10 \cdot 1\ in^2) = 100\ in^2$

$Area_{total} = Length_{sample} \cdot Width_{sample} \rightarrow (12.4\ in\ x\ 11.6\ in) = 143.84\ in^2$

$POA = \Sigma Area_{open}/Area_{total} \cdot 100\% = (100\ in^2/143.84\ in^2 \cdot 100\ in) = 69.5\% \geq 40\%$

***Mesh meets guidelines stated in NCCC 2020 Request for Proposals.**



Sample 1: Basalt Mesh

Sample 2: Strip of Basalt Mesh used in Ribs and Gunwales

APPENDIX D: REFERENCES

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APPENDIX D: SUPPORTING DOCUMENTS

Appendix E contains the following supporting documentation for the University of Massachusetts Lowell 2020 Concrete Canoe Team:

1. Pre-Qualification Form (Appendix E, E – 2)
2. Acknowledgement of RFP Addendums (Appendix E, E – 3)

Pre-Qualification Form

University of Massachusetts Lowell (UMass Lowell)
School Name

We acknowledge that we have read the 2020 ASCE National Concrete Canoe Competition Request for Proposal and understand the following: (Initialed by Project Manager and ASCE Faculty Advisor):

1. The requirements of all teams to qualify as a participant in the Conference and National Competitions as outlined in Section 2.0 and Attachment 1. KTE ELH

2. The requirements for teams to qualify as a potential Wildcard team including scoring in the top 1/3 of all Annual Reports, submitting a Statement of Interest, and finish within the top 1/2 of our Conference Concrete Canoe Competition (Attachment 1) KTE ELH

3. The eligibility requirements of registered participants (Section 2.0 + Attachment 1) KTE ELH

4. The deadline for the submission of Preliminary Project Delivery Schedule and Pre-Qualification Form (uploaded to ASCE server) is November 1, 2019; 11:59 p.m. Eastern. KTE ELH

5. The last day to submit ASCE Student Chapter Annual Reports to be eligible for qualifying (so that they may be graded) is February 1, 2020 KTE ELH

6. The last day to submit Request for Information (RFI) to the CNCCC is January 15, 2020. KTE ELH

7. Teams are responsible for all information provided in this Request for Proposal, any subsequent RFP addendums, and general questions and answers posted to the ASCE Concrete Canoe Facebook Page, from the date of the release of the information. KTE ELH

8. The submission date of Technical Proposal and MTDS Addendum for Conference Competition (Hard copies to Host School and uploading of electronic copies to ASCE server) is Monday, February 17, 2020. KTE ELH

9. The submission date of Technical Proposal and MTDS Addendum for National Competition (Hard copies to ASCE and uploading of uploading of electronic copies to ASCE server) is May 19, 2020; 5:00 p.m. Eastern. KTE ELH

Kathryn Evasius — 10/30/19
Project Manager (Print Name) — *(date)*

(Signature)

EDWARD L. HAJDUK P.Eng PE — 10/30/19
ASCE Student Chapter Faculty Advisor (Print Name) — *(date)*

(Signature)

RFP Addendum Acknowledgment Form

University of Massachusetts Lowell (UMass Lowell)
(school name)

We acknowledge that we have received and acknowledge the following Addendums to the 2020 ASCE National Concrete Canoe Competition Request for Proposal (*initialed by team project manager and ASCE Faculty Advisor):*

Addendum No. 1: Presentation Q&A

This Addendum provides the Technical Presentation score card and a list of questions that the judges can use during the 10-minute Judge's question & answer period. In addition, a scorecard was provided.

KTE ELH

Per Section 8.0 of the Request for Proposals (RFP), the presentation is limited to 3 minutes and will be cutoff at precisely 3 minutes by a signal. Also, per Section 8.0 of the RFP, the technical presentation "…should focus on the primary aspects of the design, construction, and technical capabilities. Briefly summarize the major aspects of the project, with the intent of demonstrating why your team, design, and prototype should be selected by the panel of judges for the standardized design (recall this is a hypothetical scenario to provide an end goal for the RFP and the competition)."

Addendum No. 2: Durability & Repairs

This Addendum provides information regarding how the durability of the Canoe prototype is to be assessed, allowable repairs and materials, and forms including *Damage / Accident Report, Repair Procedure Report, and Reconstruction Request.*

KTE ELH

Addendum No. 3: Detailed Cost Assessment

This Addendum provided a list of material costs for a variety of cementitious materials, pozzolans, admixtures, fibers, aggregates, and other constituents that were not presented in *Attachment 4: Detailed Cost Assessment* of the Request for Proposal.
Teams were also advised that if they have products that were not given a specific price for, they should use their best judgement to use a price for a similar material in their Material Cost Estimate.

KTE ELH

Kathryn Evasius — 2/10/2020
Project Manager (Print Name) — *(Date)*

____
(Signature)

Edward L. Hajduk P.Eng PE — 2/10/2020
ASCE Student Chapter Faculty Advisor (Print Name) — *(Date)*

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(Signature)