CARD SHARK

Michigan Technological University
Project Proposal
2023

Michigan Technological University Concrete Canoe Team
Grover C. Dillman Hall
1700 Townsend Drive
Houghton, Michigan 49931

February 17, 2023

Committee on Concrete Canoe Competitions
1801 Alexander Bell Drive
Reston, Virginia 20191
Attn: Technical Proposal Cover Letter

Dear Committee on Concrete Canoe Competitions,

The 2022-2023 Michigan Technological University Concrete Canoe Team hereby certifies:

The hull design, mix design, reinforcement scheme, and construction of the prototype are completed and in full compliance with the specifications stated in the *2023 Request for Proposals.* Our team also has reviewed all Material Technical Data Sheets (MTDS) and Safety Data Sheets (SDS) that the team deems relevant towards this year's prototype. The team also acknowledges receipt of the *Request for Information* (RFI) Summary and that all submissions comply with their provided responses. The anticipated competition participants are qualified student members and Society Student Members of ASCE and meet all eligibility requirements.

Student Name	Member Number
Connor Dykehouse	12223835
Luke Sturm	12346579
Colin Vander Beek	11949737
Samuel Pendell	12304936
Lydia Lamey	12308843
Sydney Streveler	12305049
Michele Reinke	12372585
Lauren Kubow	12371557
Jacob Hazel	12306733

Sincerely,

Team Captain
Lydia Lamey
763-232-7085
llamey@mtu.edu

ASCE Student Chapter Faculty Advisor
Dr. Andrew Swartz
906-487-2439
raswartz@mtu.edu

Table of Contents

Executive Summary……1
Introduction to the Project Team
Chapter Profile……3
Key Team Roles……4
Organizational Chart……5
Technical Approach
Hull Design……6
Structural Analysis……7
Mix Design & Testing Protocol……8
Reinforcement Design & Testing Protocol……10
Construction Process……11
Scope, Schedule & Fee……13
Quality Control & Quality Assurance……13
Sustainability……14
Health & Safety……15
Value & Innovation……15
Construction Drawings……17
Project Schedule……19
List of Figures
Figure 1: Portage Lake Lift Bridge Honored by ASCE……1
Figure 2: The Michigan Tech Concrete Canoe Team at the 2022 Regional Symposium……3
Figure 3: Hull Comparison……6
Figure 4: Structural Analysis……7
Figure 5: Binder Composition by Mass……9
Figure 6: Aggregate Composition by Volume……10
Figure 7: 3-Point Bend Test……11
Figure 8: Members Spackling the Mold……12
Figure 9: Staggered Approach……12
Figure 10: Placement Day Troweling……14
Figure 11: Snow Melting for Placement Day……14
Figure 12: Curing Tent Structure……15
List of Tables
Table 1: Properties of *Card Shark*……1
Table 2: Mixture Properties of *Card Shark*……2
Table 3: Hull Design Comparison……6
Table 4: Binder Tier Testing Results……9
Table 5: Aggregate Tier testing Results……10
List of Appendices
Appendix A: Bibliography……20
Appendix B: Mixture Proportions and Primary Mixture Calculations……21
Appendix C: Hull Thickness/Reinforcement and Percent Open Area Calculations……29
Appendix D: Detailed Fee Estimate……31
Appendix E: Supporting Documentation……33

Executive Summary

Risk and reward has always been an alluring subject. This is exactly why so many people find themselves in casinos. When enjoyed responsibly, these places bring us together over the joy of spending time with friends. A little bit of risk combined with a lot of calculations goes a long way. This is the metaphor that the Michigan Technological University (Michigan Tech) Concrete Canoe team applied to their boat, *Card Shark,* this year. Statistically, 11% of people make money from casinos (Berzon & Maremont, 2013). This is why the team knew they had to heavily rely on research and development to have a successful boat this year.

The name, *Card Shark*, has been known to imply a meaning surrounded by notions of cheating. This is the exact opposite of the intended meaning. More commonly, when a person thinks of the phrase "card shark" an image of cunning and diligent calculations comes to mind. In addition to all of this, the team believes the name combined a water theme and a larger theme of casino nights with friends.

Michigan Tech's concrete canoe team is not only backed by a strong civil engineering department, but an overall strong engineering department in general. The civil, geospatial, and environmental departments make up 14% of the College of Engineering by enrollment (Michigan Technological University, 2022). This department has always strongly supported the concrete canoe team. In fact, the team's best boat, *Yooper*, is permanently on display in the DOW Environmental building.

In addition, this department has been on the forefront of many Civil engineering projects within nearby Houghton and the greater US. In June 2022, two students of the department worked to get the Portage lift bridge named a national historical site (Weingarten, 2022). The depth that this Civil & Environmental engineering department has is greatly extended throughout its student organizations. The Michigan Tech Concrete Canoe Team is no exception.

Figure 1: Portage Lake Lift Bridge was honored by ASCE as a national landmark in June 2022.

Card Shark is Michigan Tech's most innovative boat in recent years. This has been achieved through careful and calculated changes. 2022's boat, *Kraken*, albeit a practical and simple boat, lacked a keel. The team felt this negatively impacted *Kraken's* ability to paddle straight. In 2022, it placed first in one race, the women's slalom race. This makes sense as this race is an excellent test of maneuverability. The keel on *Card Shark* has been specifically designed to optimize maneuverability and straight-line tracking.

Table 1: Properties of Card Shark

Card Shark	
Colors	Green, Red, and Black
Length	20 feet
Width	2.8 feet
Thickness	0.375 inches
Weight	300 lbs
Primary Reinforcement	SpiderLath
Secondary Reinforcement	GlasGrid 8511 & 1/16th in PT cables

The reinforcement scheme of *Card Shark* has been reimagined. In the run-up to casting day, the team thoroughly tested a brand-new post-tensioning system. This is a new concept for the Michigan Tech team. In past years, a pretensioned cable has been placed in the gunnels. *Kraken* lacked any kind of cable system. This new cable system was designed to add the needed structural support to the canoe without damaging the prototype. Cables were tensioned to the needed value to allow for maximum support.

A committee was created to model the cables through structural analysis. This needed to be done so the team could find the best placement for the cables within the concrete. Not to mention, the number of cables had to be decided upon. This committee worked closely with the mixture crew to figure out how much force could be placed upon the mixture by the cables.

The mixture committee focused on three qualities with this year's structural mixes. They prioritized strength, weight, and environmentally conscious factors throughout *Card Shark's* mixture design. *Card Shark's* aesthetics were also at the forefront of this year's design. The team designed an exterior that reflected the theme of casino night with card suit inlays along the hull of the boat. These inlays required three different testing cycles to refine the color, workability, and location of the inlays. For the interior of the boat, a semi-transparent green concrete stain was used, alluring to a poker table.

At the top of the team's management scheme is one project manager, in charge of overall construction and process flow, and one deliverables lead, in charge of the display, paper, and presentation. This split in management allows for flexibility between the two positions. The split also ensures one person is not under too much strain. During the construction of *Kraken*, the team operated under a senior and junior captain. Members found these roles to be too vague. The new management scheme was designed for better efficiency and control over different aspects of competition. Besides the two lead positions, there are a handful of sub-committee heads working on construction, display, or presentation, for example.

Sustainability remains at the forefront of Michigan Tech's construction processes. When designing *Card Shark*, the team utilized melted snow as their source of water. The team also relied on recycled concrete for many of its test mixes.

The Michigan Tech concrete canoe team is eager and pleased to present their 2023, *Card Shark*, as an example of how far a little bit of risk and a lot of calculation can take a design team.

Table 2: Mixture Properties of Card Shark

Mixture	Unit Weight (pcf)		Strength (psi)				Air Content (%)	Slump (in.)
			Compressive		Tensile			
	Wet	Oven-Dry	14-day	28-day	14-day	28-day		
Primary Structural	**70.2**	**64.7**	**1470**	**1600**	**250**	**290**	**0.1**	**1.0**
Secondary Structural	**72.1**	**66.2**	**1380**	**1520**	**210**	**240**	**0.1**	**1.0**
Pigmented Finishing	**74.9**	**69.9**	**930**	**1000**	**200**	**220**	**0.1**	**1.5**
28-day Composite Flexural Strength: 1040 psi								

Chapter Profile

Michigan Technological University is a public, mid-level research university located in the town of Houghton, near the top of the Upper Peninsula of Michigan. Founded in 1885, the university offers a prestigious STEM education for its over seven thousand students (Michigan Technological University, 2022).

Michigan Tech's student ASCE chapter currently has 146 student members, with 83 being registered national members. Once every month, the school's ACSE chapter hosts a meeting in which school faculty and industry partners are invited to speak about their engineering experiences while exposing the student members to the field. ACSE aims to increase its student engagement even more by hosting these meetings.

Alongside said meetings, the chapter and University organizes "Make a Difference Day" on campus, where student organizations gather to make a positive impact on the local environment and community. A few other projects that ASCE has participated in include the Adopt a Highway program, where students are assigned to clean up a two mile stretch of road, as well as cleaning parks, raking leaves in the community and working at local food pantries.

Since 1992, the Michigan Tech Concrete Canoe team has competed in the North Central Student Conference, placing first in 10 out of the last 11 competitions. In 2022, the team competed in the Eastern Great Lakes Conference and placed 3rd overall in the regional competition.

In addition, Michigan Tech's Steel Bridge Team competes in the annual ASCE Steel Bridge Competition. The Michigan Tech Steel Bridge Team earned 2nd place overall at the 2022 North Central Regional Competition, allowing them to continue to the national competition. The team placed 1st in Economy, 2nd in Construction Speed. 3rd on Efficiency and Stiffness and 4th in Lightness. At the national competition, the team placed 5th.

Figure 2: The Michigan Tech Concrete Canoe Team at the 2022 Regional Symposium

Key Team Roles

Michigan Tech's concrete canoe team underwent a redesign of its team structure. During the construction of the team's 2022 boat, *Kraken*, the team was led by a sole project manager. At the conclusion of the 2021-2022 school year, the team met to discuss a different management scheme. This discussion resulted in the following team structure:

Key Member and Role	Responsibilities
Project Manager: Lydia Lamey	Meetings Scheduling Technical Proposal
Deliverables Lead: Samuel Pendell	Scheduling Technical Presentation
Treasurer: Patrick Mungcal	Fundraising Outreach Budget
Paddling Coordinator: Colin Vanderbeek	Paddling Practices Prototype Demonstration Technical Presentation
Lab Supervisor: Connor Dykehouse	Lab Cleanliness Final Mixture Design Technical Proposal Curing Process PPE Manager
Mix Design Lead: Duffy Karstrom	Mix Research and Development Final and Finishing Mixture Design Sieve Analysis MTDS
Structural Analysis Lead: Jacob Byron	Structural Analysis Tensioning System Design
Hull Design Lead: Max Hazen	Prototype Dimensions Displacement and Drag Calculations Technical Proposal Mold Preparation
Reinforcement Design Lead: Jake Hazel	Three-point Bend Tests Reinforcement Scheme Structural Analysis
Aesthetics Leads: Suraiya Siddiqi and Alicja Grzegorzek	Stands & Display Construction Prototype Finishing
QC/QA Lead: Luke Sturm	Compliance Quality Checks Sieve Analysis
Safety Lead: Sydney Laforest	Lab Training & Tours PPE Manager

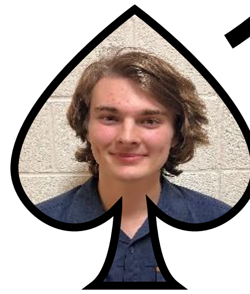
Advisor:
Dr. Tess Ahlborn
Assisted with any questions.
Presenters:
Sydney Streveler, Jr.
Samuel Pendell, So.
Luke Sturm, Jr.
Lauren Kubow, Fr.

Lydia Lamey, So.
Project Manager & Captain
Oversaw all construction-related committees. Worked with: Max Hazen, Jr., Jacob Byron, Sr., Jake Hazel, So., and Duffy Karstrom, Jr.

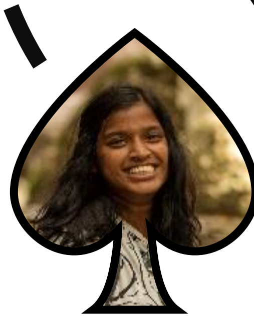
Samuel Pendell, So.
Deliverables Lead & Captain
Oversaw all academic related committees. Worked with: Lydia Lamey(paper), So., and Colin Vanderbeek(presentation), Sr.

Duffy Karstrom, Jr.
Mixture Design Lead
Oversaw design of structural and finishing mixes

Connor Dykehouse, Sr.
Lab Supervisor
Oversaw all lab activities and developed final mix.



Colin Vanderbeek, Sr.
Paddling Coordinator
Oversaw paddling practice and conditioning.



Suraiya Siddiqi, Jr.
Aesthetics Lead
Oversaw all finishing elements of prototype, stands, and display design.
Assisted by:
Alicja Grzegorzek, So.

Luke Sturm, Jr.
QC/QA Lead
Oversaw all compliance checks and ensured project met RFP requirements.

Sydney Laforest, Sr.
Safety Lead
Ensured all processes followed proper safety guidelines.

Technical Approach

Hull Design

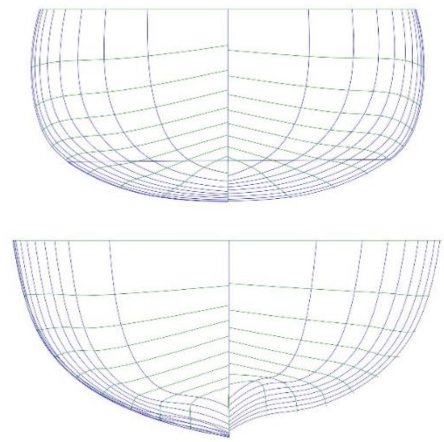
This year, the hull design committee focused on achieving two goals: developing a prototype that met the RFP requirements and improving upon last year's canoe, *Kraken*. This first goal was met with a thorough reading of the RFP requirements. A length of 20 feet was decided upon because it would allow for enough displacement while also falling within the guidelines.

Last year, a more conservative and traditional design approach was used when creating *Kraken*. *Kraken* featured a flat bottom with moderate curves, allowing for a more forgiving ride to paddlers. This also resulted in increased maneuverability during the slalom races, as reported by the paddlers. High total displacement of approximately 1930 lbs. and a higher overall block coefficient of 0.431 allowed for greater stability. Despite having a higher optimum speed than *Card Shark*, the paddlers had to use more energy to steer the boat, preventing *Kraken* from reaching a higher speed. This effect was worsened by drawbacks that occurred during last year's construction process. The team had to improvise the reconstruction of each endcap of *Kraken* due to difficulties that arose during the de-molding process. Because of this, *Kraken* suffered even more in straight-line tracking.

A combination of qualitative experiences and simulation durations from 2022's prototype demonstrations allowed the hull design committee to come to a consensus. To improve upon last year's prototype, a design with higher displacement and straight-line tracking was developed.

Using a canoe template provided in the CAD software, Prolines8 ®, we began to contour the boat. *Card Shark* features two shallow channels running down the bottom of the hull, with a short keel in the middle. The keel doesn't run the entire length of the canoe as the paddlers felt this would lead to difficulty turning. As *Card Shark* traverses, water is directed through the channels that coincide with the direction of travel. The keel also coincides with the direction of travel. Both features increase resistance to any motion from paddlers that is not in the direction of travel. The intention of this design was to promote better straight-line tracking. Paddlers would be able to spend more energy towards speed rather than steering the canoe.

Figure 3: Hull Comparison, Kraken above and Card Shark below, to scale, left of diagrams: bow view, right of diagrams: stern view.



Because of these features, *Card Shark's* walls are wider, and this resulted in a deck beam of 2.823 ft. The keel and channels also resulted in a higher surface area of 64.840 ft². Using a safety factor of 1.25 and by assuming the boat would have a weight of 300 lbs., a conservative ballast of 375 lbs was calculated. This led to a combined weight of 675 lbs. Using Prolines8®, the following properties were calculated:

Table 3: Hull Design Comparison

Property	*Kraken (2022)*	*Card Shark (2023)*
Length (ft)	20.0	20.0
Max Deck Beam (ft)	2.41	2.82
Max Freeboard (ft)	0.684	0.640
Male Race Displacement (lbs)	580	675
Block Coefficient	0.410	0.334
Optimum Speed (knots)	4.46	4.01

In comparison to 2022's boat, *Kraken, Card Shark's* design is better suited for sprint-style races. However, it does not completely sacrifice the ability to make hairpin turns as required in the Prototype Demonstration.

Structural Analysis

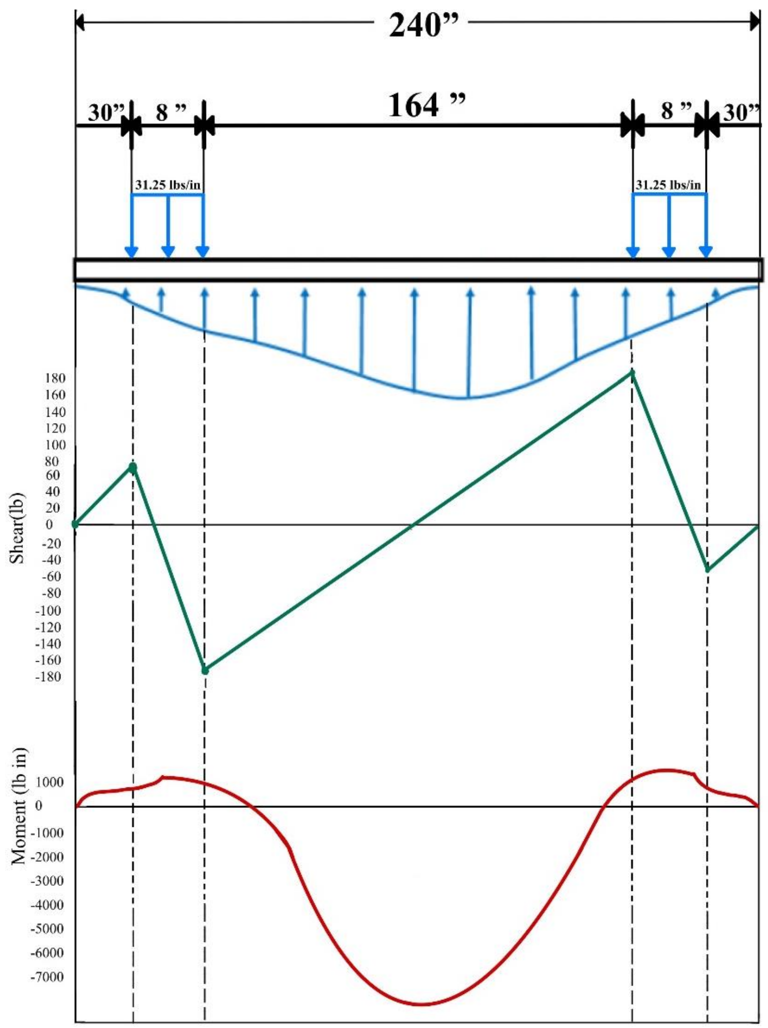
After *Card Shark's* hull design was decided upon, the structural analysis committee set out to provide the material development committee with some baseline information. This included necessary material requirements and the future location of the six steel cables. The minimum compression value of the concrete cylinders also needed to be found.

The men's sprint was used in the analysis as a baseline for the punching shear and flexural stress under load. Using our hull design software Prolines 8®, we found the resultant force of 811.39 lbs. over an area of 42.014 ft^2. When conducting the 2D structural analysis of our hull design under load, the following assumptions had to be made:

1. Paddlers in the stern and bow sit an equal distance from both ends.
2. The uniform thickness of the canoe is 0.375 in or 3/8 inches throughout.
3. The paddlers both sit on the centerline of the canoe allowing us to neglect torsional stresses.
4. The assumption is that both paddlers weigh 250 lbs. each and are distributed over an 8'' by 12'' area for a seat position.
5. The area for the moment of inertia was calculated as a C-channel, neglecting the Gunwale of the canoe.
6. The canoe's weight was approximated using the number of mixes and the weighing of individual components such as the mesh/foam/cables/and plates.
7. This was also assuming that the canoe is static under the load of the weight of the paddles, canoe, and bouncy force of the canoe.

Hand calculations were completed for the shear and moment diagrams. The shear stress was calculated by applying the loads in a 2-D analysis. The shear diagram was then used to determine the moment diagram. The punching shear was then calculated at the critical location of 202 inches from the bow of the canoe. Resulting from these calculations was a value of 491.902 psi for maximum flexural stress at a location of 117.3 inches from the bow. The punching shear was calculated by modeling an area of 8" by 12" under a sitting load. Men's weights were conservatively given a value of 250lbs. A punching shear stress of 12 psi at a location of 202 inches from the bow was determined using the shear diagram. It was found through ACI 318 Table 19.2.4.2 and Table 22.6.5.2 that our concrete's capacity was 241.11 psi, showing our punching shear load of 12 psi is well within our concrete's capacity (ACI).

Figure 4: Structural Analysis



From these findings, the team recognized they needed to account for flexural stress. This was accomplished with the usage of two types of reinforcement mesh, along with a tensioning system.

The team found a reinforcement scheme that had an average flexural strength of 240 psi. The remaining strength needed (to counteract the calculated 491 psi flexural stress) came from the tensioning system.

Six 1/16" cables were uniformly distributed throughout the hull of the canoe. These cables were placed between the two types of mesh. Specifically, one set of the cables was placed near the gunwales to account for flexural stresses. Michigan Tech's 2019 boat, *Driftwood*, experienced cracks in the middle due to torsional stress while turning (MTUCC, 2019). This is what led the team to use a cable in the gunwales in 2020's boat, *Dozer* (MTUCC, 2020). This cable was pre-tensioned, meaning it would only prevent cracks from worsening. The other two sets of cables in the prototype were also post-tensioned to the same force of 80 lbf. .

Mix design and Testing Protocol

The primary goals of the mixture committee this year included developing a final mix that is less dense than water, acquiring, and incorporating new materials into our mix designs. The committee also made it a priority to create a final mix that meets the gradation requirements from the sieve analysis while also having good workability for our trowelers. The team worked towards these goals in a step-by-step process that began with an in-depth review of this year's RFP.

Shortly after this year's competition rules were released, the mixture committee identified the sieve analysis gradation requirements as an addition to the competition rules and a requirement that could potentially cause some difficulty. In previous years, our team had used large amounts of very fine aggregate materials that are low in density such as K1 and K37. These materials were also shown to be beneficial to the trowelers because they are very fine-grained and much easier to trowel than other coarser-grained aggregates. The mix committee identified that these materials were no longer considered mineral filler and that the amount of K1 and K37 that was used in previous years mixtures would have to be significantly reduced to ensure less than ten percent of the composite aggregate material did not pass the number 100 sieve. New materials were immediately ordered to account for this.

The mixture committee developed and researched a list of new materials to consider incorporating into our mix designs. Three different gradations of Hess Pumice (ASTM C330) were ordered: Pumice #3, Pumice #5, and Pumice #7. This type of aggregate material was selected due to its low density and tested in various mix designs throughout the fall semester. In addition to aggregates, the mix committee ordered Metakaolin (ASTM C618) to be used as a supplementary cementitious material in our mix designs. Metakaolin is shown to have high early age strength as well as having the lowest density of all our binder materials (Justice & Kurtis, 2007).

Due to the inexperience of our mix committee, recruiting new members was emphasized early in the year. Mix committee leads held information sessions detailing how mixture designs were created and adjusted. After completing the required training, new members of the team were taken to our lab and shown how to measure out, mix, and then properly fill concrete test cylinders (ASTM C192). Team members were also shown how to operate the concrete compression machine. The emphasis the mix committee placed on knowledge transfer helps set up the team for success in future years.

Sustainable practices were thoroughly incorporated into the mix committee's operations. In previous years, the team would make 8-cylinder concrete batches when testing different designs. This year, 4-cylinder batches were used to help reduce waste while still providing an adequate quantity of cylinders to test at 7- and 14-day intervals. Cylinder molds were also reused with the help of a release agent and a small hole in the bottom of the molds, allowing for an air compressor to gently remove the concrete cylinder. Lastly, recycled crushed concrete was used from previously tested mixes as an aggregate in the committee's mix designs. Using this recycled material helped reduce waste as well as incorporate a material that is produced frequently throughout the fall semester.

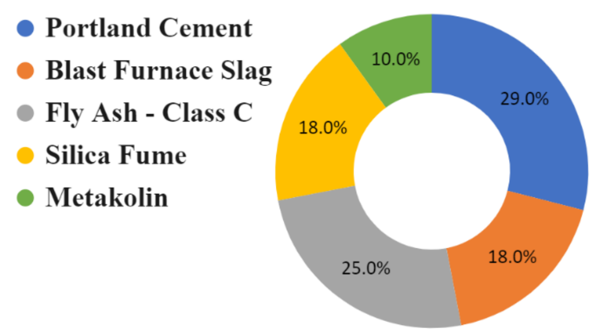
Throughout the testing process, concrete cylinders were filled (ASTM C192) for every individual concrete mixture and the cylinders were submerged in water for the first seven days. This promoted better hydration of tricalcium silicate, which is associated with concrete's initial setting and early strength development (Garrault at al., 2005). The cylinders were then tested at seven- and fourteen-day intervals for compressive strength (ASTM C39) and unit weight (ASTM C138). Predominant attributes from *Kraken* (MTU Concrete Canoe Team, 2022) were used to establish a baseline for this year's structural mix testing. After obtaining the unit weight and compressive strength of our baseline mix, testing began using a tiered system.

In the first tier of testing, the binder ratios were adjusted slightly with each mix while the remaining components of the mix were held constant. The results of our binder tier testing are shown in table 4. The tests highlighted in red were immediately disregarded, regardless of their unit weight, because they were considered too difficult to trowel. Using the data from table 4 as well as qualitative notes about the workability of the different mixtures, mix B7 (table 4) was selected as our final binder blend. Our testing indicated that a hydraulic to pozzolanic ratio of approximately 0.57 yielded the best compressive strength results. A breakdown of the binder mass composition that was used in our final primary structural mix can be found in figure 5. A large percentage of Portland Cement was used due to its high early strength test results, while remaining below the competition maximum of 30% by mass. Large amounts of Class C Fly Ash were used due to its combination of hydraulic and pozzolanic properties. Incorporating Metakaolin and Silica Fume was shown to lower the concrete density as well as serve as a pozzolanic supplementary cementitious material that could react with the other hydraulic materials such as Portland Cement, Blast Furnace Slag, and Class C Fly Ash.

Table 4: Binder Tiered Testing Results

Binder Test Number	Cylinder Mass (grams)	Unit Weight (lb/ft3)	14 Day Comp. Strength (PSI)
B1	743.9	66.8	1529
B2	690.3	62.0	952
B3	708.5	63.6	1111
B4	718.9	64.6	1453
B5	728.5	65.4	1273
B6	748.8	67.3	1550
B7	681.4	61.2	1375
B8	704.2	63.3	1490

Figure 5: Binder Composition by Mass



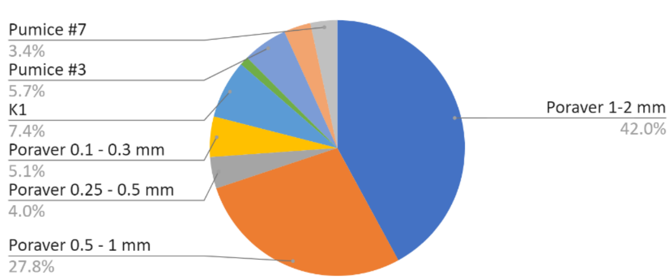
Aggregates were tested in a similar fashion. The results of our aggregate tier testing is shown in table 5. This data, as well as our notes on the workability of the mixtures, allowed us to determine that mix A12 (table 5) was our best aggregate blend. A breakdown of the aggregate volume composition that was used in our final primary structural mix can be found in figure 6. Most of our aggregate volume was comprised of different gradations of Poraver due to the materials' combination of high strength and low-density test results. The K1 and K37 aggregates, as well as the different gradations of Pumice were incorporated due to low density test results. All our aggregate materials are relatively round, as opposed to angular, which makes placing the concrete much easier on the troweling team.

Table 5: Aggregate Tiered Testing Results

Aggregate Test Number	Cylinder Mass (grams)	Unit Weight (lb/ft3)	14 Day Comp. Strength (PSI)
A1	632.7	56.8	719
A2	722.2	64.9	1113
A3	776.7	69.8	1298
A4	753.2	67.7	1592
A5	741.7	66.6	1439
A6	812.7	73.0	1706
A7	812.3	73.0	1655
A8	775.9	69.7	1619
A9	767.6	68.9	1607
A10	721.0	64.8	1304
A11	784.5	70.5	1521
A12	738.3	66.3	1571
A13	822.2	73.9	1526
A14	730.1	65.6	1490
A15	797.4	71.6	1584

The binder and aggregate blend were both utilized to create an optimized final tier of testing. NYCON PVA RFS400 and NYCON PVA RF4000 fibers were used throughout testing and a 60/40 blend was used to lessen the difficulty of troweling. Water to cement ratios of 0.36, 0.38, and 0.40 were tested. A final ratio of 0.38 was selected based on a combination of strength and workability factors. The conclusion of these final tests resulted in this year's primary structural mix, *Two Pair.*

Figure 6: Aggregate Composition by Volume



BASF MasterGlenium 7500 was used as a full-range water reducing admixture to improve the workability of the concrete and allow for the water to cement ratio to be reduced, thus increasing the concrete compressive strength. The full-range water reducer also improves early age strength. BASF MasterSet DELVO was used as a set retarder to give the trowelers more time to place the reinforcement and cables before the concrete set. The manufacturer recommended dosages were used for all admixtures.

In addition to the primary structural mix, the mix committee decided to design and place a secondary structural mix that was used on the third and final inside layer of the canoe. This mix was very similar to the primary structural mix, however, coarser aggregates such as Poraver 0.5-1.0 were reduced or removed to ensure that the trowelers were able to easily create a smooth finish on the inside of the canoe.

Finally, a finishing mix was designed to create a single 8-cylinder batch of concrete that would be used for the inlays on the boat. Large percentages of Blast Furnace Slag and Metakaolin were chosen due to their light color. Finer aggregates were used to allow the concrete to be easily applied. Red and black concrete pigments were added for color.

Reinforcement Design and Testing Protocol

This year, the team decided to spend their time reaffirming last year's reinforcement scheme used in *Kraken.* They also wanted to improve the structural integrity of the prototype with the implementation of a post-tensioning cable system. Finally, the team aimed to better their testing capabilities with a new reinforcement mold.

Two types of mesh, GlasGrid 8511® and SpiderLath were chosen for *Card Shark*. Both methods have been used in past boats to great success. *Kraken (2021)* experienced no major cracking. Previous three-point bend tests showed SpiderLath having the worst seam strength and greatest continuous strength (MTUCC 2020). Keeping this in mind, the reinforcement committee decided to use GlasGrid for its greater seam strength. Three-point bend tests were completed with a SpiderLath/GlasGrid layering scheme. The values found from these tests confirmed the team's decision to stick with a SpiderLath/GlasGrid (SL/GG) layering scheme. Using a SL/GG scheme, the average flexural stress tests last year yielded a value of 263 psi while this year's yielded a slightly lower value of 241 psi. This could be due to the smaller sample size and different mixture used during the 2022-2023 testing period.

The design of the post-tensioning system began early in the school year. Once a general plan was made, the team met to cast a practice end cap with an anchor point. The first design used ¼" diameter steel cables. The trowlers reported difficulty with achieving lamination between the two reinforcement layers because of the large diameter cable in between. This created delays and led to prematurely setting concrete, preventing the proper bond between layers. The second design used a smaller 1/16th diameter cable. This practice resulted in better bonded layers, but there was still a delay due to the tying of cables between the layers. For placement day, cables were tied to the layer of GlasGrid prior to placement to eliminate any delay.

A new reinforcement mold for three-point bend tests was constructed for more precise tests. The previous mold was warped and led to non-cohesive beam sizes. The new mold was constructed with plywood and epoxy to add to its longevity.

Figure 7: 3-Point Bend Test Mold

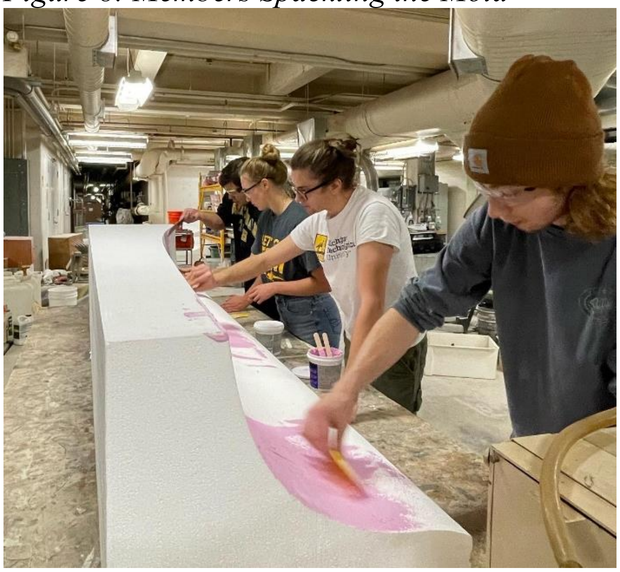
Construction Process

Michigan Tech's construction process started with multiple practice sessions with the whole team present. These sessions focused on concrete placement, working with different reinforcement types, mixing the concrete, and group dynamics. These sessions offered invaluable experience to each member, preparing them for the final concrete placement. During these practices, members got to apply their health & safety knowledge that had been outlined in the required lab safety program. Once all new members felt confident in their capabilities and the team felt ready for the final placement, these skill sessions were discontinued so the team could focus on physical preparations for casting day.

The physical preparations began with the decision to choose a high-density foam (HDF) material for the canoe form. Current members remembered casting with foam to build 2022's boat, *The Kraken*. HDF is an easier material to work with and can be CNC milled to exact specifications. Other materials like wood were considered; however, wood takes considerably more time to work with which makes it inefficient and costly. The HDF came in four sections. This made the form more maneuverable as opposed to a wooden basis. This year, the team continued to use a female-style mold. The concave form allowed the team to cast the gunnels and end caps during the initial concrete placement. The concrete used to make the gunnels cured in conjunction with the rest of the boat. The team was also able to achieve a smooth finish along the exterior of the boat, limiting sanding time.

After the mold arrived, the team began prepping the individual sections for construction. This started with an initial application of a thin layer of a spackle-type product to fill in any impurities in the foam. After curing, the layer was sanded and cleared off with pressurized air. The team applied thin layers of epoxy in 24-hour increments with sanding in between. All grits used in the sanding process were predetermined from future years. Sanding began with an aggressive 80 grit paper and gradually moved up to 220 grit. Team members working on mold construction consulted with the mix committee to ensure the mold would not be too slick for concrete to stick during the placement process. The individual pieces were prepped, and a small group of members gathered to assemble the final mold. The pieces were roughly joined before the mold was permanently assembled. Inlay placeholders were positioned into their final locations. A thickness of 1/16th inch was chosen for the inlays. Cardstock was cut out, stacked, and then wrapped in duct tape to prevent any bonding to the concrete.

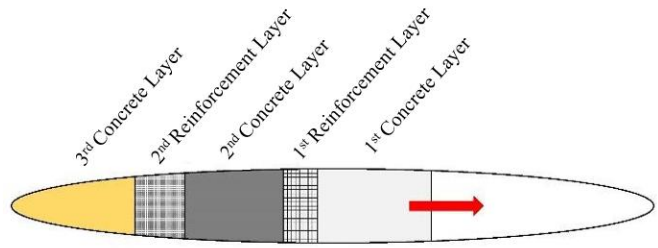
Figure 8: Members Spackling the Mold



The team used a fine-tuned method for the placement of concrete and reinforcement. The method started with the readying of all materials needed for casting day. Members completed one hour shifts to "pre-batch" all mixtures that would be required on casting day. The reinforcement was pre-cut and measured, along with the cables used in the post-tensioning system. After this was done, the reinforcement materials were pre-formed to the HDF mold, These processes ensured the team could focus on constructing the boat instead of measuring materials and cutting reinforcement during casting day. This eliminated issues like running out of mixture or prematurely setting concrete that could arise during the placement process.

Concrete placement proceeded on a step-by-step basis. The team started off with a 1/16th inch of concrete, followed by a mesh of Glasgrid®8511 reinforcement. This middle layer contained the team's cables and once placed is followed by a 1/8th inch of concrete. The team placed a mesh of Spider lath reinforcement followed by a final 1/8th inch of concrete. This was all accomplished through a staggered approach to reduce cold joints. Trowelers started on one end of the boat and worked towards the other. Once a layer was placed, reinforcement is installed where possible even if the initial layer is not in place over the entire boat. Once all layers were placed, the quality assurance team checked over the final layer, ensuring the smoothest possible finish.

Figure 9: Staggered Approach



The canoe was cured in a new curing tent in accordance with ASTM C511 standards. The new tent allowed for more humid curing conditions. In the past, the team used a rudimentary set up that involved draping a tarp over the boat. The team believed the previous set-up, although effective, lacked the efficiency that a more air-tight tent could provide. This is why the team built a new structure made of wooden rafters that can be placed over the mold to hold up a tarp. Ultrasonic humidifiers were then placed within this tent. The team achieved a temperature of 75 within the curing tent. The humidity was kept above 95%. This initial curing process continued for 2 weeks.

Mold removal occurred in a delicate manner. The mold pieces were un-screwed and released from each other. Along the gunnels, thin wedges were inserted between the mold and concrete to help release the boat from the mold. This was gradually repeated to deeper depths until the boat was finally free of the mold.

Once free of the mold, the steel cables were tensioned. The team carefully tensioned the cables to 80 lbf of force. After inserting the flotation foam into the end cap, the end cap was sealed off with extra reinforcement to prevent any negative effects that may arise from a cold joint.

The inlays located on the outside layer of the concrete were filled in with the respective finishing mixes before any sanding could occur on the outside of the boat. The inlay locations were inspected for any potential cracks before filling them with pigmented mix.

The aesthetics committee began the process of sanding the interior of the canoe soon after the canoe was inspected for any structural discrepancies. After the prototype passed inspection, any fibers sticking out were clipped. The inside of the boat was initially sanded with a 120-grit sandpaper and slowly progressed up to a 1000 grit sandpaper with water. The outside of the canoe was also brought to a 1000 grit level. The aesthetics committee stained the inside of *Card Shark* with a semi-transparent green color to add more color to the interior of the boat. After a final 10-day cure in normal conditions, a concrete sealer was applied to the entirety of the boat to prepare it for the prototype demonstration (ASTM C309).

Scope, Schedule, and Fee

The Concrete Canoe team is headed by a Project Manager and a Deliverables Lead, each in charge of maintaining specific sections of the committees. The Project Manager (PM), while acting as the main team captain, works closely with the team committees to ensure the project has the correct outcomes. The Deliverables Lead (DL) also works with said committees to ensure that the team sticks to the schedule while also securing the correct information gets submitted. More specifically, the PM oversees construction while the DL focuses on paper and presentation.

The project schedule is developed as early as possible by the PM and DL. The schedule is made using outlines from previous successful years, separating research and development into the fall semester, while the competition display and aesthetics land into the spring semester. This process allows the PM and DL to reflect on the previous year and make changes as they see fit.

After forming a schedule, fundraising for the upcoming year begins. A team newsletter is sent out to known alumni, parents, and donors. The purpose of the newsletter is to update those interested in the upcoming year and to ask for funding. The donations garnered from the newsletter help considerably. The treasurer reaches out to various departments for further donations. The budget is primarily dedicated to buying construction materials and regionals accommodations. This means that material purchases need to be planned out with the project manager and treasurer to ensure there is enough money left in the budget for the regional symposium.

Some of the major milestones occurring during the length of the project include selection of the final structural mixes, finishing mix, and reinforcement scheme, along with the completion of the technical proposal and presentation. Milestones were determined by their importance on the critical path, with the most important moments being decided as a milestone. The team meets these milestones by carefully coordinating the project while having constant communication with the Project Manager. The actions that form the critical path must be completed by their respective deadlines for the project to finish on time. These actions were chosen based on if the project could not continue based on their completion.

Quality Control and Quality Assurance

The construction of a successful prototype is only possible with diligently set protocols ensuring all processes are completed correctly. An engineering team should be able to replicate their projects exactly. This is one goal the Michigan Tech team kept in mind when designing this year's prototype. The team continues to build off previous year's quality control and quality assurance (QC/QA) programs.

For Michigan Tech, this starts when a team member is assigned the role of overseeing QC/QA. This person is charged with a multitude of roles that are fulfilled during concrete mixing, reinforcement testing, construction, and all finishing processes.

During the construction of 2022's boat, *Kraken*, Michigan Tech used melted snow water to save on water usage. This year, to further purify this water, it was strained through a sanitized sheet of a high thread count. The sheet was swapped for a clean sheet between batches of water. These processes exemplify the team's desire to control every aspect of the concrete mix.

The concrete mixes were further regulated during the pre-batching process. Each batch was measured out a week before placement day. This allows the team to spend extra time ensuring each material used was a precise weight.

Concrete placement day is the most demanding day for QC/QA. The team recognizes this and creates a schedule of QC/QA tasks to be followed during casting day. Routine layer checks are completed continuously during the placement of concrete. This is done using 3D printed depth-gauges created by a team member. If the concrete is too thick, a circle will appear on the hull. This process was used during the construction of Kraken; however, the team felt the time intervals could be more structured and stuck to a 5-10 minute schedule. This process ensures the boat will have a uniform thickness.

Figure 10: Placement day

The QC/QA lead is also charged with compliance review. They work closely with all aspects of the project to ensure that each material used is meeting the required specifications. With this year's requirement of a sieve analysis, the QC/QA lead ensures each aggregate meets the required passing rate.

Knowledge transfer continues to be at the forefront of Michigan Tech's mission. This year, the team met this goal through training sessions. This allowed the QC/QA lead to train in new members with the proper troweling technique and methodology. Focus is on uniform layers and learning to work with different types of reinforcement. This was applied during casting day and helped the team to achieve a uniform thickness of 3/8" throughout the canoe.

Sustainability

The Michigan Tech concrete canoe team is aware of the need for the concrete industry to transition to a more sustainable future. It is estimated that concrete industry contributes 8% of total emissions to the globe (Rodgers 2018). Not to mention, there are various social and economic impacts pertaining to job security and wage-fairness. The team addressed each pillar of sustainability: social, economic, and environmental.

Knowledge transfer is a major goal of Michigan Tech's and directly aligns with social sustainability. Without the pass down of knowledge, the team would have nothing to build off. More innovations can be made if less time is spent on re-learning processed. This conserves valuable time and energy.

The pandemic greatly tested the team's ability to transfer knowledge. During the 2022 competition season, there were only a handful of members that had seen real competition on the team. The 2021-2022 school year was spent re-learning and building a wealth of resources that could be used by following teams. This was done through the creation of numerous "how-to" documents, describing the processes of constructing a canoe. By doing this, knowledge is thereby sustainably conserved for the convenient usage of future teams.

Economically, the team transitioned to a more structured inventory scheme. This means the team took a more detailed approach to understanding how much their stockpiles were worth and the lifespan they had left of a certain item. This was accomplished at the beginning of the year with a thorough survey. The inventory was updated periodically throughout the year.

Finally, the team continued with their use of snowmelt as a source of water in the final prototype. This brought up a few initial concerns with the possibility of contaminants in the mixture; however, this was remedied with the usage of a sustainable filtering system. Overall, the team saved a total of 15 gallons of water. This exercise puts into perspective how much water the concrete industry uses. In the following years, the team the team hopes to expand on their sustainable practices, whether they are socially, economically, or environmentally sustainable.

Figure 11: Snow melting for placement day

Health & Safety

The Michigan Tech team approaches the health & safety of the team with the utmost sincerity. This begins with naming a person on the team with the role of safety lead. From paddling to construction, this person oversees all processes safety related. At the start of the year, this person oversees lab training. It is their job to make sure each person on the team is up to date on various protocols employed in the team's lab space. Each member must complete a thorough training module and attend a lab tour. This allows members to get acquainted with the lab space before working in it. The safety lead also briefs the members at each weekly meeting with any reminders for the lab. While working in the lab, long pants, close-toed shoes, and safety glasses are a requirement. The Occupational Safety & Health Administration (OSHA) is referred to for all guidelines.

During paddling practices, each paddler is equipped with a life jacket and briefed on what to do if a canoe were to flip. A member of the team is always on shore as well. The team relies on Michigan Tech's water safety protocol for guidelines.

Materials testing is another core part of the safety program. Proper personal protection equipment (PPE) is always employed. For concrete mixers, they must always wear gloves, safety glasses, and respirators. During reinforcement tests, members are also required to wear gloves and safety glasses, even if they aren't in the normal lab space.

Before placement day, the team is reminded of proper PPE to ensure everyone arrives with the proper clothing. On the day of, members are once again briefed on safety procedures. These include wearing the proper lab PPE, effective and clear communication, and overall coordination between the different aspects of construction. For example, the reinforcement team needs to remind members not to handle any reinforcement without wearing gloves.

During the sanding and staining of the canoe, extra care is taken. Members are equipped with respirators during any sanding and are not allowed to sand for over an hour at a time. Per the manufacturer guidelines for staining concrete, any person staining the boat is required to wear full PPE including chemical goggles, a respirator, and chemically resistant gloves. The team lab manager also coordinates with faculty for assistance with the application of the stain.

The pandemic greatly impacted the team's ability to function during the 2020-2021 school year. This led to the inability to make a canoe during that year. The effects greatly decreased during the 2021-2022 school year as Michigan Tech transitioned to an in-person learning schedule and classes resumed as normal. Mask restrictions were lifted during the spring semester. This school year, 2022-2023, continues the trend of relaxing restrictions and the team experiences little to no restrictions because of the pandemic.

The health of each member remains a top priority. This is why the team continued to employ the usage of masks when exposed to a possible case of Covid-19. Members were encouraged to alert each other when they tested positive and socially distance when needed.

Value and Innovation

The Michigan Tech concrete canoe team strives to add value to each product they create. The team also believes value stems both from innovation and reflection. Each part of the RFQ connects to both aspects.

The Project Proposal is viewed largely as a method of reflection. This allows the team to look back on the project and figure out what could be done better. By doing this, year after year, the team has increasingly added value to each Project Proposal that is written. Each new paper reflects the previous year and contains instrumental differences that make the new paper more thoughtful than the last.

The team also considers the Prototype Display as a reflection of the value of the prototype, *Card Shark*. It is through the display that the innovative aspects of the canoe can be seen. This is done with the cross section, showing a post-tensioning system, and the various materials samples stationed at the display. The theme is also emphasized in the creation of the display, showcasing a more artistic side of the team.

The Technical Presentation, essentially, is a condensed version of the Project Proposal. The team sees fit to highlight the most important details to add the most value to the presentation. This means that construction processes and material testing sections had to be shortened. The presentation that the team delivers is not unlike any other presentation an engineer might give in a design meeting. Overall, the visuals employed in the presentation are used to reflect the value of the prototype, along with any questions that are answered.

During the Prototype Performance Demonstration, each innovation made during the construction process is put to the test. The Demonstration is an integral part of the process and a culmination of the work put in throughout the year to produce a functional prototype. This year, the team focused on hull design and structural integrity. These core changes are seen as valuable because they reflect previous boats, but also innovative as they improve on previous designs.

Overall, the team focused on innovating their practices from construction to management. At the start of the school year, Michigan Tech knew they wanted to implement a post-tensioning system in their prototype. The team spent the fall semester testing and designing a working system. Value lies in the integrity of the innovation. This meant testing needed to be comprehensive. The team met this goal through two main practice sessions when opposing end caps of the prototype were constructed with possible systems. The end caps were allowed to cure and then tested for strength later. At first, cables from previous years were used, but the team decided these were too large to fit in between the layers. A smaller cable diameter is used in the final boat.

Hull design was also a big part of the innovations made this year. *Kraken*, 2022's prototype, struggled with straight-line tracking. The hull design lead decided to create a prototype model that is both wider and has a keel. The thought behind this being that the boat would perform better in the sprint and co-ed races.

A new curing tent was constructed to cure the prototype more efficiently. In previous years, a rudimentary tarp was hung approximately seven feet over the mold. The new tarp is hung over a four-foot-tall wooden-rafter style structure. This difference in height creates a much smaller curing environment. In turn, the team can sustain a 95% humidity level with less humidifiers than previous years required. In addition to the tent, ultrasonic humidifiers were primarily used to maintain a higher relative humidity within the curing tent compared to conventional humidifiers.

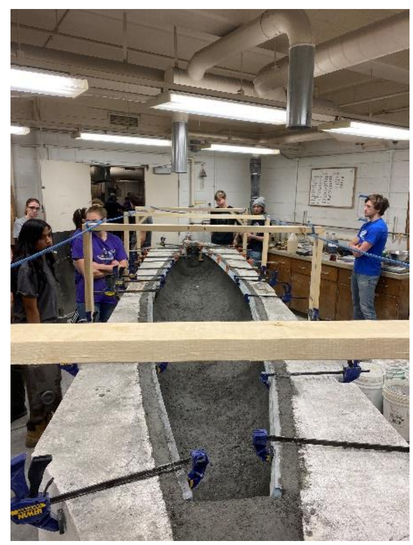
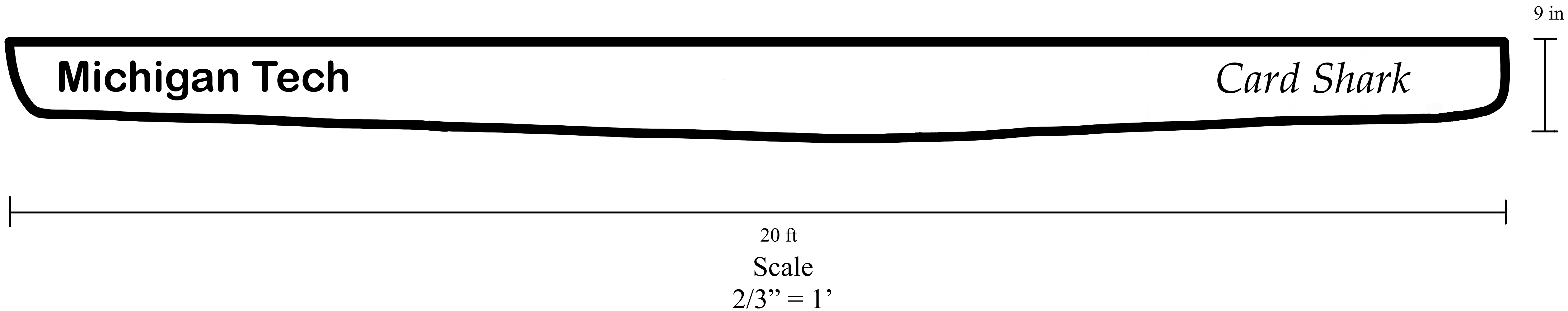
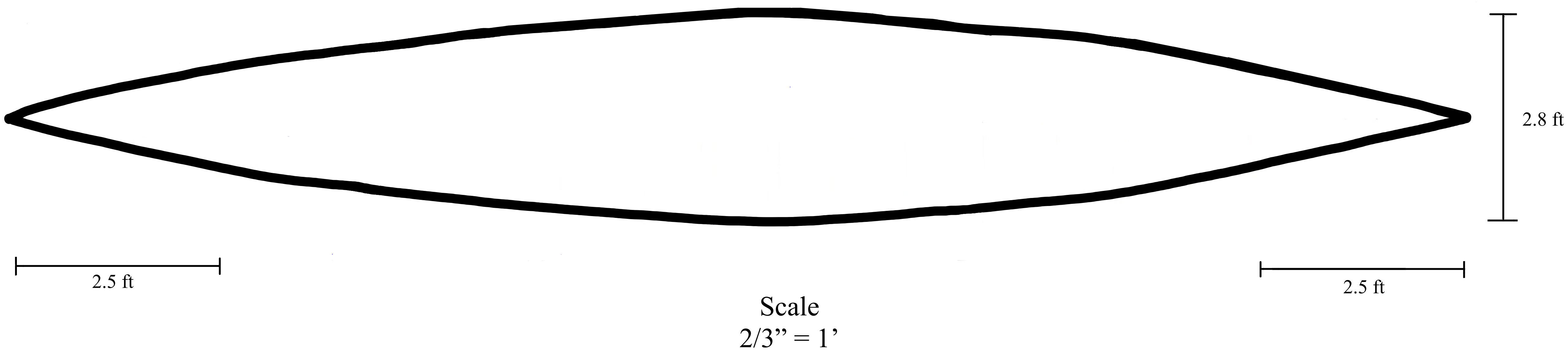


Figure 12: Curing tent structure without tarp

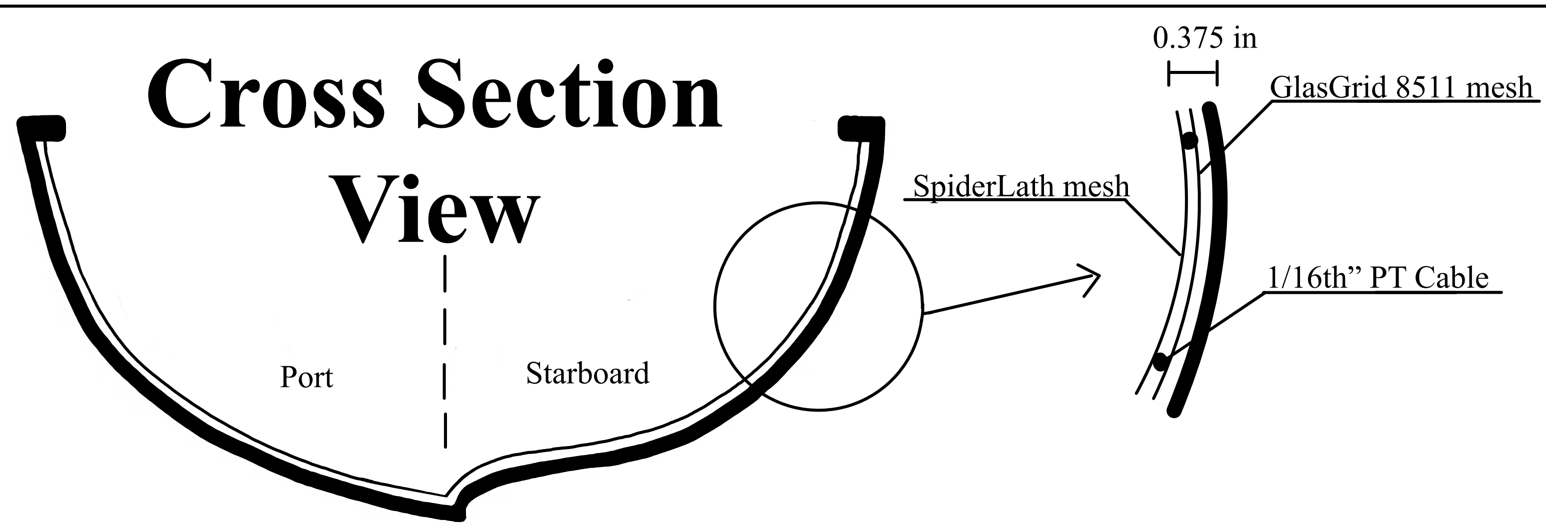
Construction Drawings



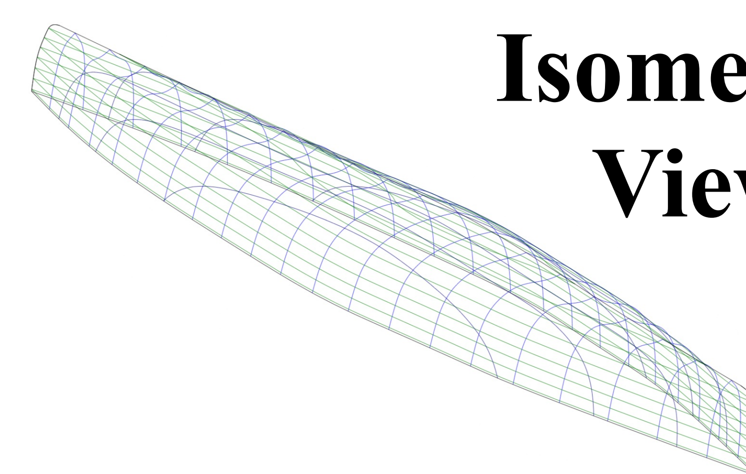
Elevation View



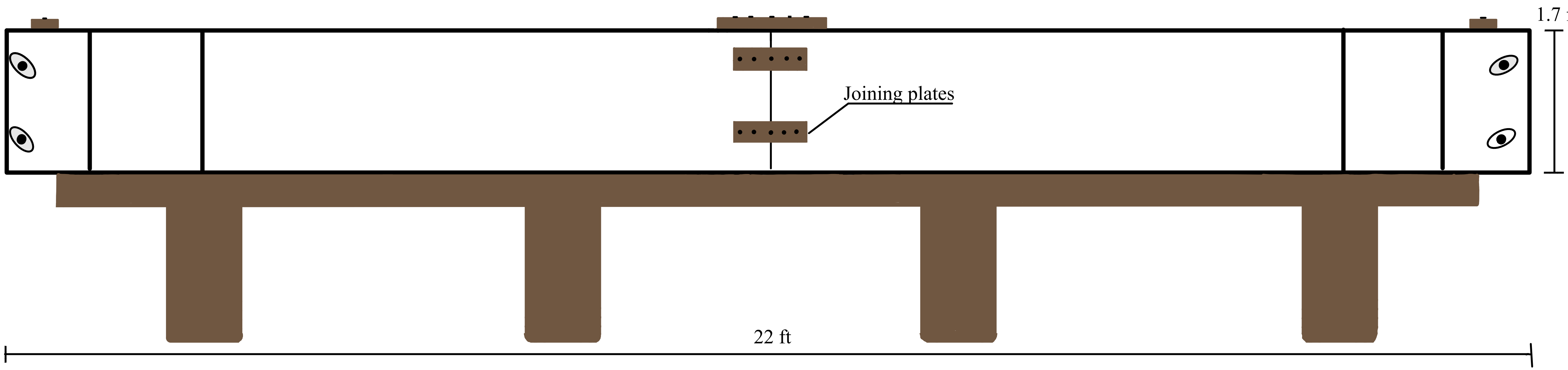
Plan View



Cross Section View

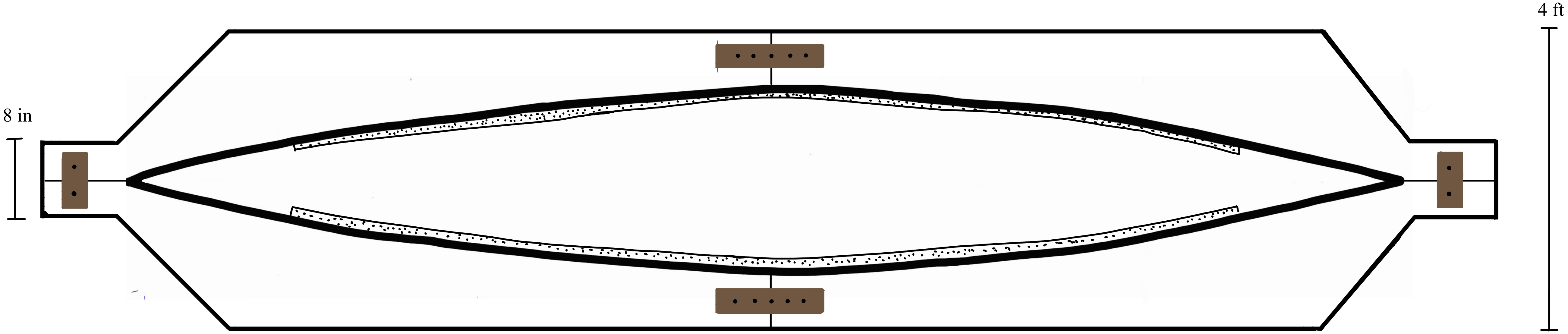


Isometric View

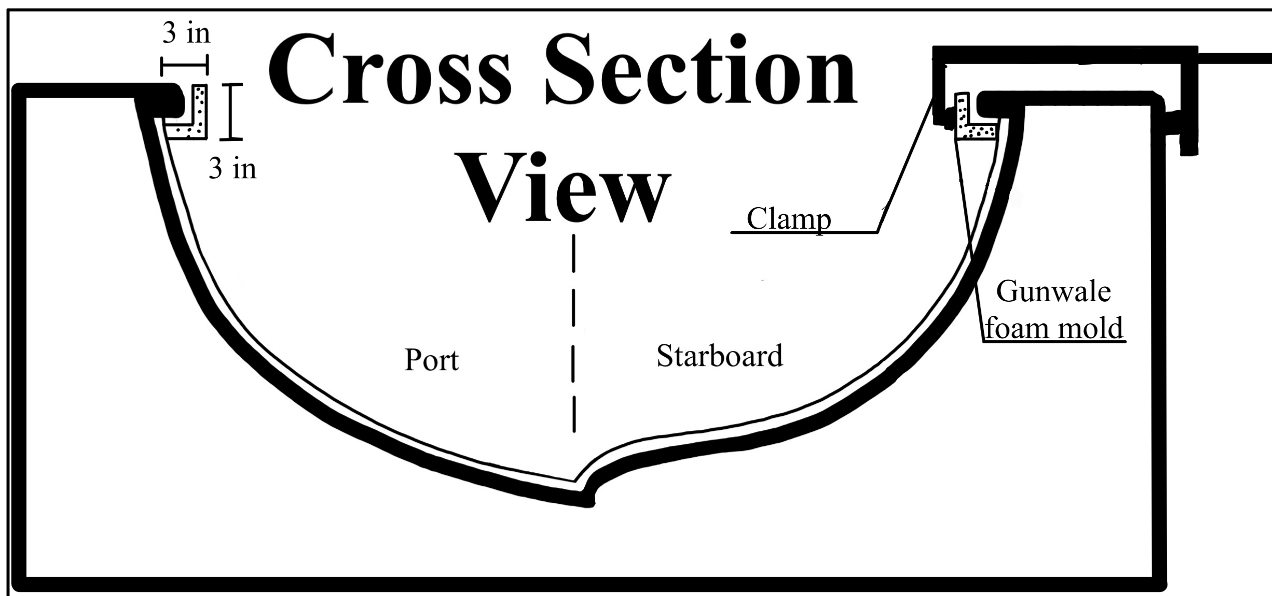


Elevation View

Scale
2/3” = 1’



Plan View

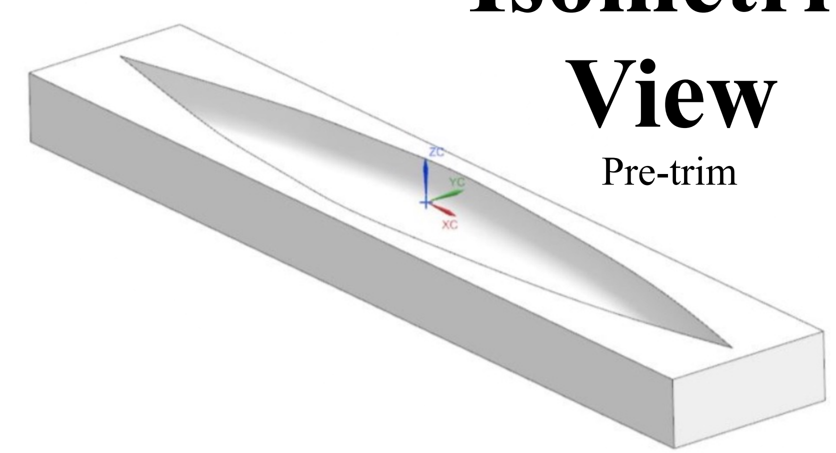


Cross Section View

Michigan Tech

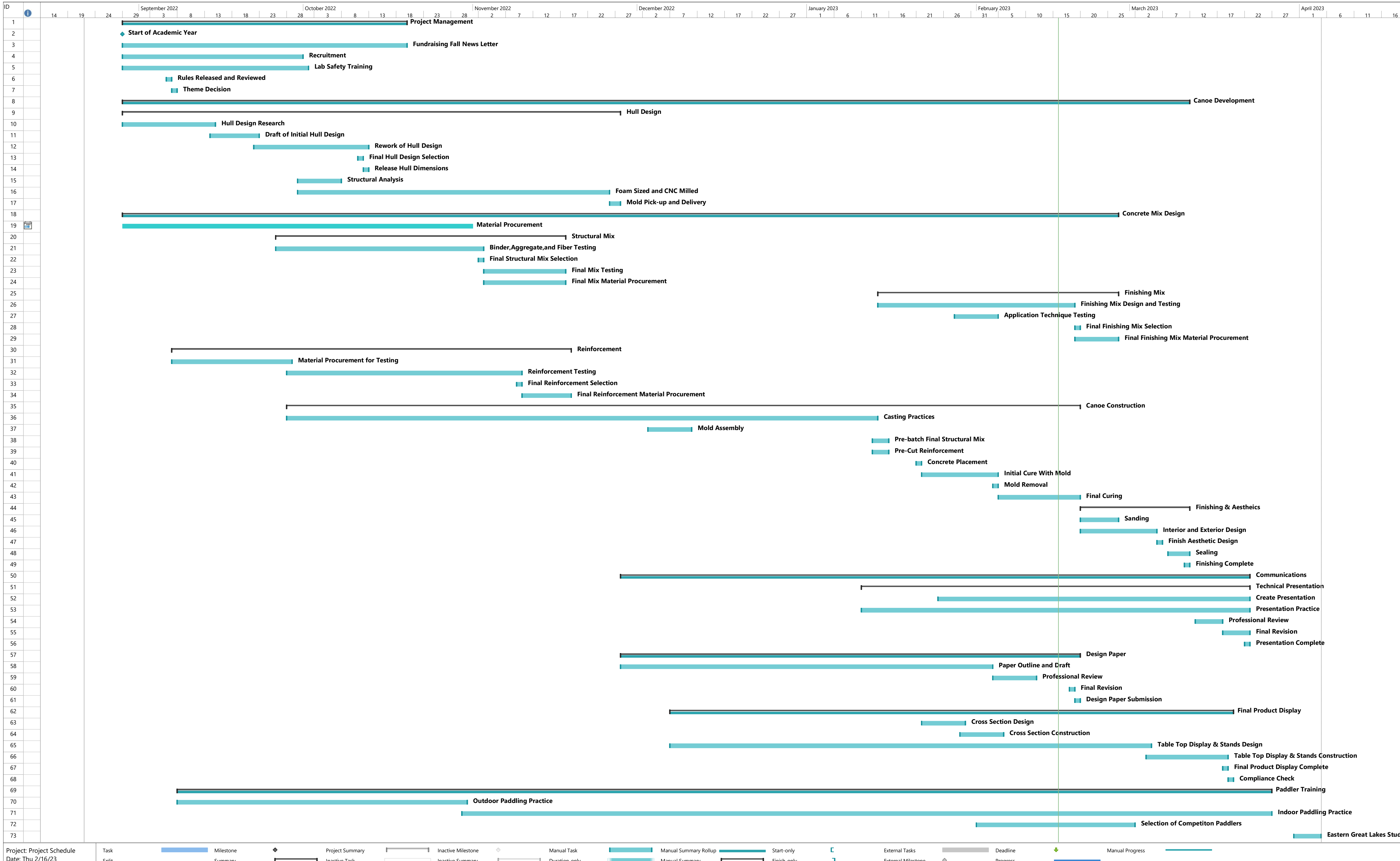
Card Shark
Drawn by: Lydia Lamey
Checked by: Max Hazen

Job: 2023 Card Shark



Isometric View

Pre-trim



September 2022
October 2022
November 2022
December 2022
January 2023
February 2023
March 2023
April 2023
1 Project Management
2 Start of Academic Year
3 Fundraising Fall News Letter
4 Recruitment
5 Lab Safety Training
6 Rules Released and Reviewed
7 Theme Decision
8 Canoe Development
9 Hull Design
10 Hull Design Research
11 Draft of Initial Hull Design
12 Rework of Hull Design
13 Final Hull Design Selection
14 Release Hull Dimensions
15 Structural Analysis
16 Foam Sized and CNC Milled
17 Mold Pick-up and Delivery
18 Concrete Mix Design
19 Material Procurement
20 Structural Mix
21 Binder,Aggregate,and Fiber Testing
22 Final Structural Mix Selection
23 Final Mix Testing
24 Final Mix Material Procurement
25 Finishing Mix
26 Finishing Mix Design and Testing
27 Application Technique Testing
28 Final Finishing Mix Selection
29 Final Finishing Mix Material Procurement
30 Reinforcement
31 Material Procurement for Testing
32 Reinforcement Testing
33 Final Reinforcement Selection
34 Final Reinforcement Material Procurement
35 Canoe Construction
36 Casting Practices
37 Mold Assembly
38 Pre-batch Final Structural Mix
39 Pre-Cut Reinforcement
40 Concrete Placement
41 Initial Cure With Mold
42 Mold Removal
43 Final Curing
44 Finishing & Aestheics
45 Sanding
46 Interior and Exterior Design
47 Finish Aesthetic Design
48 Sealing
49 Finishing Complete
50 Communications
51 Technical Presentation
52 Create Presentation
53 Presentation Practice
54 Professional Review
55 Final Revision
56 Presentation Complete
57 Design Paper
58 Paper Outline and Draft
59 Professional Review
60 Final Revision
61 Design Paper Submission
62 Final Product Display
63 Cross Section Design
64 Cross Section Construction
65 Table Top Display & Stands Design
66 Table Top Display & Stands Construction
67 Final Product Display Complete
68 Compliance Check
69 Paddler Training
70 Outdoor Paddling Practice
71 Indoor Paddling Practice
72 Selection of Competiton Paddlers
73 Eastern Great Lakes Student
Project: Project Schedule
Date: Thu 2/16/23
Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress

Appendix A- Mixture proportions and calculations

ASTM International. (2023). *Annual Book of ASTM Standards*.

ACI Committee 19. (2019). *Building Code Requirements for Structural Concrete*

Garrault, S., Behr, T., & Nonat, A. (2005, December 8). *Formation of the C−S−H Layer during Early Hydration of Tricalcium Silicate Grains with Different Sizes*. ACS Publications. Retrieved February 16, 2023, from https://pubs.acs.org/doi/10.1021/jp0547212

Justice, J. M., & Kurtis, K. E. (2007, September). Influence of Metakaolin Surface Area on Properties of Cement-Based Materials. Retrieved February 16, 2023, from http://yetl.yabesh.ir/yetl1/handle/yetl/46358

Maremont, M., & Berzon, A. (2013, October 11). *How often do gamblers really win?* The Wall Street Journal. Retrieved February 14, 2023, from https://www.wsj.com/articles/SB10001424052702304626104579123383535635644

Michigan Technological University. (2022, November 11). Michigan Technological University Enrollment of All Students by Major & Class Fall 2022. Houghton, MI.

MTU Concrete Canoe Team. (2020). *Dozer*, ASCE Regional Concrete Canoe Competition Report, (April 2020).

MTU Concrete Canoe Team. (2019). *Driftwood*, ASCE Regional Concrete Canoe Competition Report, (April 2019).

MTU Concrete Canoe Team. (2022). *Kraken*, ASCE Regional Concrete Canoe Competition Report, (April 2022).

Rodgers, L. (2018, December 17). *Climate change: The massive CO2 emitter you may not know about*. BBC News. Retrieved February 16, 2023, from https://www.bbc.com/news/science-environment-46455844

Weingarten, D. (2022, June 21). *Portage Lake Lift Bridge recognized as Historic Landmark*. SOM - State of Michigan. Retrieved February 16, 2023, from https://www.michigan.gov/mdot/news-outreach/pressreleases/2022/06/21/portage-lake-lift-bridge-recognized-as-historic-landmark

Appendix B- Mixture Proportions and Primary Mixture Calculation

MIXTURE: Primary Structural Mix

Cementitious Materials

Component	*Specific Gravity*	*Volume*	*Amount of CM*	
Portland Cement Type 1, *c*	3.15	1.154 ft^3	226.77 lb/yd^3	Total cm (includes c) **781.96** lb/yd^3 c/cm ratio, by mass **0.29**
Blast Furnace Slag, cm_1	2.99	0.754 ft^3	140.75 lb/yd^3	
Fly Ash - Class C, cm_2	2.75	1.139 ft^3	195.49 lb/yd^3	
Silica Fume, cm_3	2.22	1.016 ft^3	140.75 lb/yd^3	
Metakaolin, cm_4	2.2	0.570 ft^3	78.20 lb/yd^3	

Fibers

Component	*Specific Gravity*	*Volume*	*Amount of Fibers*	
Nycon PVA RF4000, f_1	1.3	0.065 ft^3	5.26 lb/yd^3	Total Amount of Fibers **13.14** lb/yd^3
Nycon PVA RFS400, f_2	1.3	0.097 ft^3	7.88 lb/yd^3	

Aggregates

Aggregates	*Abs (%)*	SG_{OD}	SG_{SSD}	*Base Quantity, W*		*Volume,*
				W_{OD}	W_{SSD}	$V_{agg,\,SSD}$
Poraver 1 mm -2 mm, agg_1	20 %	0.39	0.468	178.95 lb/yd^3	214.74 lb/yd^3	7.350 ft^3
Poraver .5 mm -1 mm, agg_2	25 %	0.47	0.5875	143.16 lb/yd^3	178.95 lb/yd^3	4.880 ft^3
Poraver .25 mm -.5 mm, agg_3	30 %	0.59	0.767	25.56 lb/yd^3	33.23 lb/yd^3	0.694 ft^3
Poraver .1 mm -.3 mm, agg_4	35%	0.90	0.7965	51.13 lb/yd^3	69.03 lb/yd^3	0.910 ft^3
K1, agg_5	7.2 %	0.125	0.134	10.23 lb/yd^3	10.23 lb/yd^3	1.312 ft^3
K37, agg_6	6.8 %	0.37	0.395	5.11 lb/yd^3	5.11 lb/yd^3	0.221 ft^3
Hess Pumice #3, agg_7	16 %	0.769	0.892	46.02 lb/yd^3	53.38 lb/yd^3	0.959 ft^3
Hess Pumice #5, agg_8	17 %	0.737	0.8623	25.56 lb/yd^3	29.91 lb/yd^3	0.556 ft^3
Hess Pumice #7, agg_9	18 %	0.737	0.8679	25.56 lb/yd^3	30.16 lb/yd^3	0.556 ft^3

Liquid Admixtures

Admixture	*lb/ US gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture*	
MasterGlenium 7500, $admx_1$	8.76	8	26 %	3.168 lb/yd^3	Total Water from Liquid Admixtures, $\sum w_{admx}$ 6.291 lb/yd^3
MasterSet DEVLVO, $admx_2$	8.97	6	5%	3.124 lb/yd^3	

Solids (dyes, powdered admixtures)

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (lb/yd^3)*	
Concrete Pigment , S_p	4.70	0 ft^3	0 lb/yd^3	Total Solids. S_{total} 0 lb/yd^3

Water

	Amount		*Volume*
Water, *w, [=$\sum$ (w_{free} + w_{admx} + w_{batch})]*	w/c ratio, by mass **1.31** w/cm ratio, by mass **0.38**	297.14 lb/yd^3	4.762 ft^3
Total Free Water from All Aggregates, $\sum w_{free}$		-114.54 lb/yd^3	
Total Water from All Admixtures, $\sum w_{admx}$		6.29 lb/yd^3	
Batch Water, w_{batch}		405.39 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	781.96 lb	13.14 lb	625.82 lb	0 lb	297.14 lb	$\sum$M:1718.07 lb
Absolute Volume, V	4.633 ft^3	0.162 ft^3	17.44 ft^3	0 ft^3	4.762 ft^3	$\sum$V:26.98 ft^3
Theoretical Density, T, *(=$\sum$M / $\sum$V)*	63.68 lb/ft^3		***Air Content, Air,*** *[= (T – D)/T x 100%]*			-1.6 %
Measured Density, D	64.7 lb/ft^3		***Air Content, Air,*** *[= (27 – $\sum$V))/27 x 100%]*			0.085 %
Total Aggregate Ratio[1] *(=$V_{agg,SSD}$ / 27)*	64.52 %		***Slump, Slump flow, Spread*** *(as applicable)*			1 in.

MIXTURE: Secondary Structural Mix

Cementitious Materials

Component	Specific Gravity	Volume	Amount of CM	
Portland Cement Type 1, *c*	3.15	1.154 ft^3	226.77 lb/yd^3	Total cm (includes c) **781.96** lb/yd^3 c/cm ratio, by mass **0.29**
Blast Furnace Slag, cm_1	2.99	0.754 ft^3	140.75 lb/yd^3	
Fly Ash - Class C, cm_2	2.75	1.139 ft^3	195.49 lb/yd^3	
Silica Fume, cm_3	2.22	1.016 ft^3	140.75 lb/yd^3	
Metakaolin, cm_4	2.2	0.570 ft^3	78.20 lb/yd^3	

Fibers

Component	Specific Gravity	Volume	Amount of Fibers	
Nycon PVA RF4000, f_1	1.3	0.065 ft^3	5.26 lb/yd^3	Total Amount of Fibers **13.14** lb/yd^3
Nycon PVA RFS400, f_2	1.3	0.097 ft^3	7.88 lb/yd^3	

Aggregates

Aggregates	Abs (%)	SG_{OD}	SG_{SSD}	Base Quantity, W		Volume,
				W_{OD}	W_{SSD}	$V_{agg,SSD}$
Poraver 1 mm -2 mm, agg_1	20 %	0.39	0.468	195.12 lb/yd^3	234.14 lb/yd^3	8.018 ft^3
Poraver .5 mm -1 mm, agg_2	25 %	0.47	0.5875	0 lb/yd^3	0 lb/yd^3	0 ft^3
Poraver .25 mm -.5 mm, agg_3	30 %	0.59	0.767	88.69 lb/yd^3	115.30 lb/yd^3	2.409 ft^3
Poraver .1 mm -.3 mm, agg_4	35%	0.90	0.7965	29.56 lb/yd^3	39.91 lb/yd^3	0.526 ft^3
K1, agg_5	7.2 %	0.125	0.134	0 lb/yd^3	0 lb/yd^3	0 ft^3
K37, agg_6	6.8 %	0.37	0.395	23.65 lb/yd^3	25.26 lb/yd^3	1.024 ft^3
Hess Pumice #3, agg_7	16 %	0.769	0.892	70.95 lb/yd^3	82.30 lb/yd^3	1.479 ft^3
Hess Pumice #5, agg_8	17 %	0.737	0.8623	100.52lb/yd^3	117.60 lb/yd^3	2.186 ft^3
Hess Pumice #7, agg_9	18 %	0.737	0.8679	82.78 lb/yd^3	97.68 lb/yd^3	1.800 ft^3

Liquid Admixtures

Admixture	lb/ US gal	Dosage (fl. oz / cwt)	% Solids	Amount of Water in Admixture	
MasterGlenium 7500, $admx_1$	8.76	8	26 %	3.168 lb/yd^3	Total Water from Liquid Admixtures, $\sum w_{admx}$ 6.291 lb/yd^3
MasterSet DEVLVO, $admx_2$	8.97	6	5%	3.124 lb/yd^3	

Solids (dyes, powdered admixtures)

Component	Specific Gravity	Volume (ft^3)	Amount (lb/yd^3)	
Concrete Pigment , S_p	4.70	0 ft^3	0 lb/yd^3	Total Solids. S_{total} 0 lb/yd^3

Water

	Amount		Volume
Water, w, $[=\sum (w_{free} + w_{admx} + w_{batch})]$	w/c ratio, by mass **1.31** w/cm ratio, by mass **0.38**	297.14 lb/yd^3	4.762 ft^3
Total Free Water from All Aggregates, $\sum w_{free}$		-120.93 lb/yd^3	
Total Water from All Admixtures, $\sum w_{admx}$		6.29 lb/yd^3	
Batch Water, w_{batch}		412.78 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	781.96 lb	13.14 lb	712.19 lb	0 lb	297.14 lb	$\sum$M:1804.43 lb
Absolute Volume, V	4.633 ft^3	0.162 ft^3	17.44 ft^3	0 ft^3	4.762 ft^3	$\sum$V:26.98 ft^3

Theoretical Density, T, $(=\sum M / \sum V)$	66.88 lb/ft^3	***Air Content, Air,*** $[= (T - D)/T \times 100\%]$	1.02 %
Measured Density, D	66.2 lb/ft^3	***Air Content, Air,*** $[= (27 - \sum V))/27 \times 100\%]$	0.08 %
Total Aggregate Ratio[1] $(=V_{agg,SSD} / 27)$	64.52 %	***Slump, Slump flow, Spread*** (as applicable)	1 in.

MIXTURE: Finishing Mix

Cementitious Materials

Component	Specific Gravity	Volume	Amount of CM	
Portland Cement Type 1, *c*	3.15	0.783 ft^3	153.86 lb/yd^3	Total cm (includes c) **769.31** lb/yd^3 c/cm ratio, by mass **0.20**
Blast Furnace Slag, cm_1	2.99	1.237 ft^3	230.79 lb/yd^3	
Fly Ash - Class C, cm_2	2.75	0.897 ft^3	153.86 lb/yd^3	
Silica Fume, cm_3	2.22	0 ft^3	0 lb/yd^3	
Metakaolin, cm_4	2.2	1.681 ft^3	230.79 lb/yd^3	

Fibers

Component	Specific Gravity	Volume	Amount of Fibers	
Nycon PVA RF4000, f_1	1.3	0 ft^3	0 lb/yd^3	Total Amount of Fibers **4.38** lb/yd^3
Nycon PVA RFS400, f_2	1.3	0.054 ft^3	4.38 lb/yd^3	

Aggregates

Aggregates	Abs (%)	SG_{OD}	SG_{SSD}	Base Quantity, W		Volume,
				W_{OD}	W_{SSD}	$V_{agg,\,SSD}$
Poraver 1 mm -2 mm, agg_1	20 %	0.39	0.468	0 lb/yd^3	0 lb/yd^3	0 ft^3
Poraver .5 mm -1 mm, agg_2	25 %	0.47	0.5875	0 lb/yd^3	0 lb/yd^3	0 ft^3
Poraver .25 mm -.5 mm, agg_3	30 %	0.59	0.767	149.00 lb/yd^3	193.70 lb/yd^3	4.047 ft^3
Poraver .1 mm -.3 mm, agg_4	35%	0.90	0.7965	164.68 lb/yd^3	222.32 lb/yd^3	2.932 ft^3
K1, agg_5	7.2 %	0.125	0.134	0 lb/yd^3	0 lb/yd^3	0 ft^3
K37, agg_6	6.8 %	0.37	0.395	15.68 lb/yd^3	16.75 lb/yd^3	0.679 ft^3
Hess Pumice #3, agg_7	16 %	0.769	0.892	149.00 lb/yd^3	172.84 lb/yd^3	3.106 ft^3
Hess Pumice #5, agg_8	17 %	0.737	0.8623	149.00 lb/yd^3	174.33 lb/yd^3	3.191 ft^3
Hess Pumice #7, agg_9	18 %	0.737	0.8679	156.84 lb/yd^3	185.07 lb/yd^3	3.411 ft^3

Liquid Admixtures

Admixture	lb/ US gal	Dosage (fl. oz / cwt)	% Solids	Amount of Water in Admixture	
MasterGlenium 7500, $admx_1$	8.76	8	26 %	3.117 lb/yd^3	Total Water from Liquid Admixtures, $\sum w_{admx}$ 3.117 lb/yd^3
MasterSet DEVLVO, $admx_2$	8.97	0	5%	0 lb/yd^3	

Solids (dyes, powdered admixtures)

Component	Specific Gravity	Volume (ft^3)	Amount (lb/yd^3)	
Concrete Pigment, S_p	4.70	0.017 ft^3	5 lb/yd^3	Total Solids. S_{total} 5 lb/yd^3

Water

	Amount		Volume
Water, *w*, $[=\sum(w_{free} + w_{admx} + w_{batch})]$	w/c ratio, by mass **2.0** w/cm ratio, by mass **0.4**	307.73 lb/yd^3	4.931 ft^3
Total Free Water from All Aggregates, $\sum w_{free}$		-180.81 lb/yd^3	
Total Water from All Admixtures, $\sum w_{admx}$		3.12 lb/yd^3	
Batch Water, w_{batch}		485.56 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*	769.31 lb	4.38 lb	965.01 lb	5 lb	307.73 lb	∑M2051.43 lb
Absolute Volume, *V*	4.598 ft^3	0.054 ft^3	17.37 ft^3	0.017 ft^3	4.931 ft^3	∑V:26.97 ft^3
Theoretical Density, *T*, $(=\sum M / \sum V)$	68.45 lb/ft^3		***Air Content, Air***, $[= (T - D)/T \times 100\%]$			-2.12 %
Measured Density, *D*	69.9 lb/ft^3		***Air Content, Air***, $[= (27 - \sum V))/27 \times 100\%]$			0.11 %
Total Aggregate Ratio[1] $(=V_{agg,SSD} / 27)$	64.52 %		***Slump, Slump flow, Spread*** (as applicable)			1.5 in.

Cementitious Materials

Mass= Given
SG= Given
Volume= Mass/(SG*62.4 lbs/ft^3)

Portland Cement
$Mass_{PC}$= 226.77 lbs
SG_{PC}= 3.15
VPC=226.77 lbs3.15*62.4 lbs/ft3=1.154 ft3

Blast Furnace Slag
$Mass_{BFS}$= 140.75 lbs
SG_{BFS}= 2.99
VBFS=140.75 lbs2.99*62.4 lbs/ft3=0.754 ft3

Fly Ash Class C
$Mass_{FA}$= 195.49 lbs
SG_{FA}= 2.75
VFA=195.49 lbs2.75*62.4 lbs/ft3=1.139 ft3

Undensified Silica Fume
$Mass_{SF}$= 140.75 lbs
SG_{SF}= 2.22
VSF=140.75 lbs2.22*62.4 lbs/ft3=1.016 ft3

Metakaolin
$Mass_{MK}$= 78.20 lbs
SG_{MK}= 2.20
VMK=78.20 lbs2.20*62.4 lbs/ft3=0.570 ft3

$\Sigma Mass_{Cementitious}$= 781.96 lbs
$\Sigma Volume_{Cementitious}$= 4.633 ft^3

C/CM= $Mass_{PC}$ / $\Sigma Mass_{Cementitious}$ = 0.29

Fibers

Mass= Given
SG= Given
Volume= Mass/(SG*62.4 lbs/ft^3)

$Mass_{RF}$= 5.26 lbs
SG_{RF}= 1.3
VRF=5.26 lbs1.3*62.4 lbs/ft3=0.065 ft3

$Mass_{RFS}$= 7.88 lbs

SG_{RFS}= 1.3
VRFS=7.88 lbs1.3*62.4 lbs/ft3=0.097 ft3

ΣMass$_{fibers}$= 13.14 lbs
ΣVolume$_{fibers}$= 0.162 ft^3

Aggregates

Mass (W_{OD})= Given
SG_{OD}= Given
Absorption(Abs)= Given
Mass (W_{STK})= Given
Mass (W_{SSD})= (1+ Abs/100)*W_{OD}
SG_{SSD}=(1+ Abs/100)*SG_{OD}
Volume= W_{SSD}/(SG_{SSD}*62.4 lbs/ft^3)
MC_{TOTAL}= ((W_{STK}-W_{OD})/W_{OD})*100
MC_{FREE}= MC_{Total}-Abs
W_{FREE}= W_{OD}* (MC_{FREE}/100)

Poraver 1 mm- 2 mm

$W_{ODp1\text{-}2}$= 178.95 lbs
$SG_{ODp1\text{-}2}$= 0.39
$Abs_{p1\text{-}2}$= 20%
$W_{STKp1\text{-}2}$= 178.95 lbs
$W_{SSDp1\text{-}2}$= (1+(20/100))*178.95= 214.74 lbs
$SG_{SSDp1\text{-}2}$= (1+(20/100))*0.39= 0.468
$V_{SSDp1\text{-}2}$=214.74 lbs0.468*62.4 lbs/ft3=7.35 ft3
$MC_{TOTALp1\text{-}2}$= ((178.95-178.95)/178.95)*100= 0%
$MC_{FREEp1\text{-}2}$= 0%-20% = -20%
$W_{FREEp1\text{-}2}$= 178.95*(-20%/100) = -35.79 lbs

Poraver 0.5 mm- 1 mm

$W_{ODp0.5\text{-}1}$= 143.16 lbs
$SG_{ODp0.5\text{-}1}$= 0.47
$Abs_{p0.5\text{-}1}$= 25%
$W_{STKp0.5\text{-}1}$= 143.16 lbs
$W_{SSDp0.5\text{-}1}$= (1+(25/100))*143.16= 178.95 lbs
$SG_{SSDp0.5\text{-}1}$= (1+(25/100))*0.47= 0.5875
$V_{SSDp0.5\text{-}1}$=178.95 lbs0.5875*62.4 lbs/ft3=4.88 ft3
$MC_{TOTALp0.5\text{-}1}$= ((173.16-143.16)/143.16)*100= 0%
$MC_{FREEp0.5\text{-}1}$= 0%-25% = -25%
$W_{FREEp0.5\text{-}1}$= 143.16*(-25%/100)= -35.79 lbs

Poraver 0.25 mm-0.5mm

$W_{ODp0.25\text{-}0.5}$= 25.56 lbs
$SG_{ODp0.25\text{-}0.5}$= 0.59

$Abs_{p0.25\text{-}0.5}$= 30%
$W_{STKp0.25\text{-}0.5}$= 25.56 lbs
$W_{SSDp0.25\text{-}0.5}$= (1+(30/100))*25.56 = 33.228 lbs
$SG_{SSDp0.25\text{-}0.5}$= (1+(30/100))*0.59= 0.767
$V_{SSDp0.25\text{-}0.5}$=33.228 lbs0.767*62.4 lbs/ft3=0.6943 ft3
$MC_{TOTALp0.25\text{-}0.5}$= ((25.56-25.56)/25.56)*100= 0%
$MC_{FREEp0.25\text{-}0.5}$= 0%-30% = -30%
$W_{FREEp0.25\text{-}0.5}$= 25.56*(-30%/100)= -7.668 lbs

Poraver 0.1 mm- 0.3 mm
$W_{ODp0.1\text{-}0.3}$= 51.13 lbs
$SG_{ODp0.1\text{-}0.3}$= 0.90
$Abs_{p0.1\text{-}0.3}$= 35%
$W_{STKp0.1\text{-}0.3}$= 51.13 lbs
$W_{SSDp0.1\text{-}0.3}$= (1+(35/100))*51.13 = 69.0255 lbs
$SG_{SSDp0.1\text{-}0.3}$= (1+(35/100))*0.90 = 1.215
$V_{SSDp0.1\text{-}0.3}$=69.0255 lbs1.215*62.4 lbs/ft3=0.9104 ft3
$MC_{TOTALp0.1\text{-}0.3}$= ((51.13-51.13)/51.13)*100= 0%
$MC_{FREEp0.1\text{-}0.3}$= 0%-35% = -35%
$W_{FREEp0.1\text{-}0.3}$= 51.13*(-35%/100)= -17.896 lbs

K1
W_{ODK1}= 10.23 lbs
SG_{ODK1}= 0.125
Abs_{ODK1}= 7.2%
W_{STKK1}= 10.23 lbs
W_{SSDK1}= (1+(7.2/100))*10.23 = 10.967 lbs
SG_{SSDK1}= (1+(7.2/100))*0.125 = 0.134
V_{SSDK1}=10.967 lbs0.134*62.4 lbs/ft3=1.3116 ft3
$MC_{TOTAL\ K1}$= ((10.23-10.23)/10.23)*100= 0 %
$MC_{FREE\ K1}$= 0%-7.2% = -7.2%
$W_{FREE\ K1}$= 10.23*(7.2%/100)= -0.737 lbs

K37
W_{ODK37}= 5.11 lbs
SG_{ODK37}= 0.37
Abs_{ODK37}= 6.8%
W_{STKK37}= 5.11 lbs
W_{SSDK37}= (1+(6.8/100))*5.11 = 5.46 lbs
SG_{SSDK37}= (1+(6.8/100))*0.37 = 0.395
V_{SSDK37}=5.46 lbs0.395*62.4 lbs/ft3=0.2215 ft3
$MC_{TOTAL\ K37}$= ((5.11-5.11)/5.11)*100= 0%
$MC_{FREE\ K37}$= 0%-6.8% = -6.8%
$W_{FREE\ K37}$= 5.11*(6.8%/100)= -0.347 lbs

Hess Pumice #3

$W_{ODp\#3}$= 46.02 lbs
$SG_{ODp\#3}$= 0.769
$Abs_{ODp\#3}$= 16%
$W_{STKp\#3}$= 46.02 lbs
$W_{SSDp\#3}$= (1+(16/100))*49.02 = 53.3832 lbs
$SG_{SSDp\#3}$= (1+(16/100))*0.769 = 0.892
$V_{SSDp\#3}$=53.3832 lbs0.892*62.4 lbs/ft3=0.9591 ft3
$MC_{TOTALp\#3}$ ((46.02-46.02)/46.02)*100= 0%
$MC_{FREEp\#3}$= 0%-16% = -16%
$W_{FREEp\#3}$= 46.02*(-16%/100)= -7.36 lbs

Hess Pumice #5
$W_{ODp\#5}$= 25.56 lbs
$SG_{ODp\#5}$= 0.737
$Abs_{ODp\#5}$= 17%
$W_{STKp\#5}$= 25.56 lbs
$W_{SSDp\#5}$= (1+(17/100))*25.56 = 29.9052 lbs
$SG_{SSDp\#5}$= (1+(17/100))*0.737 = 0.8623
$V_{SSDp\#5}$=29.9052 lbs0.8623*62.4 lbs/ft3=0.5558 ft3
$MC_{TOTALp\#5}$= ((25.56-25.56)/25.56)*100= 0%
$MC_{FREEp\#5}$= 0%-17% = -17%
$W_{FREEp\#5}$= 25.56*(-17%/100)= -4.35 lbs

Hess Pumice #7
$W_{ODp\#7}$= 25.56 lbs
$SG_{ODp\#7}$= 0.737
$Abs_{ODp\#7}$= 18%
$W_{STKp\#7}$= 25.56 lbs
$W_{SSDp\#7}$= (1+(18/100))*25.56 = 30.1608 lbs
$SG_{SSDp\#7}$= (1+(18/100))*0.737 = 0.8697
$V_{SSDp\#7}$=30.1608 lbs0.8697*62.4 lbs/ft3=0.5557 ft3
$MC_{TOTALp\#7}$= ((25.56-25.56)/25.56)*100= 0%
$MC_{FREEp\#7}$= 0%-18% =-18%
$W_{FREEp\#7}$= 25.56*(-18%/100)= -4.6 lbs

$\Sigma Mass_{Aggregates}$= 625.82 lbs
$\Sigma Volume_{AggregatesSSD}$= 17.44 ft^3
ΣW_{FREE}= -114.538 lbs

Admixtures
Dosage(D)= Given
%Solids= Given
Density(ρ)= Given
Water Content (WC)= 100 - %Solids
Water = Dosage * cwt * WC*(1/128)*Density

MasterGelenium 7500
D_{MG7500} = 8 fl oz/cwt
ρ_{MG7500}= 8.76 lb/Gal
%S_{MG7500} = 26%
%WC_{MG7500} =100%- 26%= 74%
W_{MG7500} = 8*(781.96/100)*0.74*(1/128)*8.76= 3.168 lbs

MasterSet DELVO
$D_{MSDELVO}$ = 6 fl oz/cwt
$\rho_{MSDELVO}$= 8.97 lb/Gal
%$S_{MSDELVO}$ = 5%
%$WC_{MSDELVO}$ = 100%- 5%= 95%
$W_{MSDELVO}$ = 6*(781.96/100)*0.95*(1/128)*8.97= 3.124 lbs

ΣW_{ADMX}= 6.291 lbs

Water

w/cm= 0.38
M_{water} = M_{CM}*w/cm
V_{water} = (M_{water} /62.4 lbs/ft^3)
W_{BATCH}= M_{water}-(ΣW_{ADMX}+W_{FREE})

M_{water}= 781.96 *0.38= 297.14 lbs
V_{water} =297.145/62.4 = 4.762 ft^3
W_{BATCH}= 297.145 -(6.291+-114.538)= 405.392 lbs

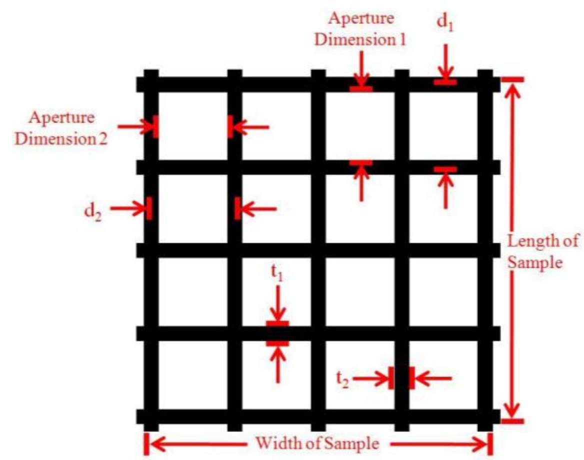
Concrete Analysis

$\Sigma Mass_{Total}$=781.96 +13.14 + 625.82 + 297.145 =1718.065 lbs
$\Sigma Volume_{Total}$=4.633 + 0.162 + 17.44 + 4.762 = 26.977 ft^3
w/c=297.145/226.77 = 1.31
Theoretical Density: 1718.065/26.977 = 63.68 lb/ft^3
Total Aggregate Ratio: 17.44/27 *100 = 64.59 % OK
Air content: ((63.68-64.7)/63.68) *100 = -1.6 %
Air content: ((27-26.977)/27) *100 = 0.085 %

Appendix C- Hull Thickness/Reinforcement and Percent Open Area Calculations

Percent Open Area Calculations

Samples: SpiderLath(SL) and GlasGrid®8511(GL) Mesh



Given

$N_{1,SL} = 34$	number of apertures along length
$N_{1,GG} = 9$	
$N_{2,SL} = 35$	number of apertures along width
$N_{2,GG} = 5$	
$T_{1,SL} = 0.103$ in	average thickness of reinforcement along length
$T_{1,GG} = 0.262$ in	
$T_{2,SL} = 0.051$ in	average thickness of reinforcement along width
$T_{2,GG} = 0.173$ in	

Aperture_Dimension_1_SL = 0.312 in
Aperture_Dimension_1 _GG= 0.737 in
Aperture_Dimension_2 _SL= 0.288 in
Aperture_Dimension_2 _GG= 0.808 in

D_1 = Aperture_Dimension_1 + 2*(t1/2)	$D_{1,SL} = 0.42$ in $D_{1,GG} = 0.99$ in	Average spacing of reinforcement (center-to-center) along the sample length
D_2 = Aperture_Dimension_2 + 2*(t2/2)	$D_{2,SL} = 0.34$ in $D_{2,GG} = 0.98$ in	Average spacing of reinforcement (center-to-center) along the sample width

Demonstrated Compliance

$Length_{Sample} = N_1 * D_1$	$Length_{SL} = 14.09$ in $Length_{GG} = 8.98$ in
$Width_{Sample} = N_2 * D_2$	$Width_{SL} = 11.85$ in $Width_{GG} = 4.91$ in
$Area_{Open}$ = N_1*n2*Aperture_Dimension_1*Aperture_Dimension_2	$Area_{Open,SL} = 106.76\ in^2$ $Area_{Open,GG} = 680\ in^2$
$Area_{Total} = Length_{Sample} * Width_{Sample}$	$Area_{Total,SL} = 167.05\ in^2$ $Area_{Total,GG} = 1120\ in^2$

POA = $(Area_{Open}/Area_{Total}$l)*100
POA _SL= 63.9% > 40% ***Compliant***
POA_GG = 60.7% > 40% ***Compliant***

Hull Thickness

Known Values

T_G = 0.045 in	Average thickness of first layer of reinforcement, GlasGrid®8511 Mesh
T_S = 0.050 in	Average thickness of second layer of reinforcement, SpiderLath Mesh
T_C = 0.0625 in	Thickness of PT cable
T_H = 0.375 in	Overall hull thickness

$$\frac{0.045in + 0.050in + 0.0625in}{0.375in} * 100\% = 42\%$$

$$42\% < 50\% \ \boldsymbol{Compliant}$$

Bow and Stern Thickness

Known Values

T_G = 0.045 in	Average thickness of first layer of reinforcement, GlasGrid®8511 Mesh
T_S = 0.050 in	Average thickness of second layer of reinforcement, SpiderLath Mesh
T_H = 0.500 in	Nominal hull thickness in bow and stern

$$\frac{0.045in + 0.050in}{0.500\ in} * 100\% = 19\%$$

$$19\% < 50\% \ \boldsymbol{Compliant}$$

Gunwale Thickness

Known Values

T_G = 0.045 in	Average thickness of gunwale reinforcement, GlasGrid®8511 Mesh
T_W = 1 in	Nominal thickness of gunwale rail

$$\frac{0.045in}{1in} * 100\% = 4.5\%$$

$$4.5\% < 50\% \ \boldsymbol{Compliant}$$

PT Anchor Thickness

Known Values

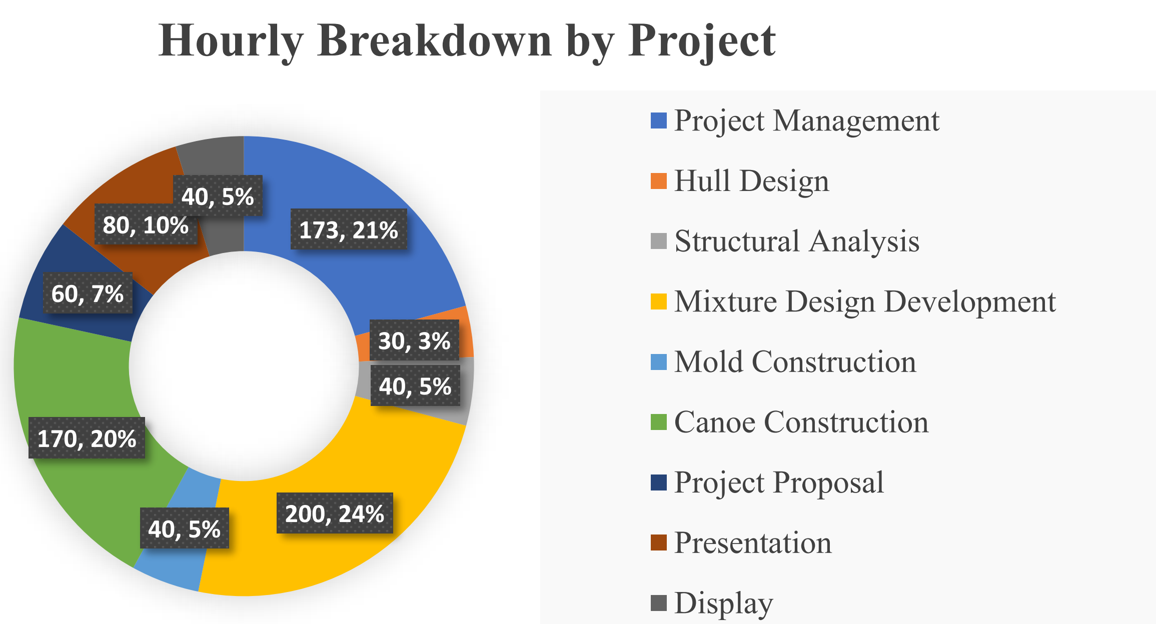
T_B = 0.0359 in	Thickness of bearing plate
T_S = 0.050 in	Average thickness of reinforcement, SpiderLath Mesh
T_C = 0.0625 in	Thickness of PT cable
T_{PT} = 2 in	Anchor concrete thickness

$$\frac{0.0359\ in + 0.050\ in + 0.0625\ in}{2\ in} * 100\% = 7.42\ \%$$

$$7.42\ \% < 50\ \% \ \boldsymbol{Compliant}$$

Appendix D- Detailed Fee Estimate

Role	Projected Person-Hours	Hourly Rate	Cost
Principle Design Engineer	100	$50	$5,000
Design Manager	68	$45	$3,060
Project Construction Manager	30	$40	$1,200
Construction Superintendent	75	$40	$3,000
Project Design Engineer	50	$35	$1,750
Quality Manager	42	$35	$1,470
Graduate Field Engineer	0	$35	$0
Technician Drafter	18	$25	$450
Laborer/Technician	425	$25	$10,625
Clerk/ Office Admin	30	$15	$450
Outside Consultants	10	$200	$2,000
Total	**848 hours**	**--**	**$29,005**
		Labor costs with direct, indirect, and profit multipliers	**$115,439.90**



Expenses

Material	Unit Cost	Amount Used	Net Cost
Type 1 Portland Cement C-150	$0.26/lb	40.8 lbs	$10.61
Blast Furnace Slag	$0.08/lb	26.3 lbs	$2.10
Fly Ash - Class C	$0.02/lb	35.3 lbs	$0.71
NORCHEM Undensified Silica Fume	$0.04/lb	24.6 lbs	$0.98
Metakaolin	$1.10/lb	15.4 lbs	$16.94
NYCON PVA RF4000	$11.10/lb	1 lbs	$11.10
NYCON PVA RFS400	$11.00/lb	1.4 lbs	$15.40
Poraver 1-2 mm	$0.75/lb	29.5 lbs	$22.13
Poraver 0.5-1 mm	$0.75/lb	15.6 lbs	$11.70
Poraver 0.25-0.5 mm	$0.75/lb	11.5 lbs	$8.63
Poraver 0.1-0.3 mm	$0.75/lb	8.5 lbs	$6.38
K1	$14.78/lb	1.1 lbs	$16.26
K37	$9.40/lb	2.6 lbs	$24.44
Pumice #3	$0.70/lb	10.6 lbs	$7.42
Pumice #5	$0.67/lb	11.8 lbs	$7.91
Pumice #7	$0.67/lb	10.8 lbs	$7.24
Pigment	$7.99/lb	0.15 lbs	$1.20
Water	$0/gal	74.8 lbs	$0.00
BASF MasterSet DELVO	$22.60/gal	0.06 gal	$1.36
BASF MasterGelenium 7500	$53.34/gal	0.08 gal	$4.26
GlasGrid® 8511 Mesh	$2.51/ft^2	65 ft^2	$163.15
SpiderLath Mesh	$0.78/ft^2	65 ft^2	$50.70
Steel Cable	$0.29/ft	130 feet	$37.70
Cable Sleeve	$0.29/ft	130 feet	$37.70
Bearing Plate	$1.16/unit	1 unit	$1.16
Wire Rope Stop	$0.24/unit	6 units	$1.44
Expanding Foam	$124.99/2 gal kit	1 kit	$124.99
Concrete Stain	$444/ gal	.25 gal	$111.00
Concrete Sealant	$79.60/gal	2 gal	$159.20

Total Cost: $893.81
With markup: total cost * 1.10 = $983.20

Lump sum fee for mold construction = material cost + transportation = $500 + $400 = $900
Lump sum fee for transportation to Platteville, WI= gas + accommodations = $500 + $600 = $1100
using MTUCC trailer and members to drive

Combined cost: Labor + Materials + Mold Construction + Transportation
= 115,439.90 + 983.20 + 900 + 1100
= $118,423.10

Appendix E: Supporting Documentation

November 4th, 2022

Michigan Technological University Concrete Canoe Team
Grover C. Dillman Hall
1700 Townsend Drive
Houghton, Michigan 49931

To: ASCE Student Services
1801 Alexander Bell Drive
Reston, Virginia 20191

To the Committee on Concrete Canoe Competitions,

The Michigan Technological University Concrete Canoe team wishes to express they have read and fully understand the 2023 request for proposals (RFP). Our team must design a prototype with a mix design, reinforcement scheme, hull design, and structural analysis completed for the proposed prototype. The team will also prepare a presentation and display for the prototype. The project proposal and MTDS addendum must be uploaded to the team's folder no later than 5pm EST, February 17th.

After taking an in-depth look at the RFP, the team would like to acknowledge the many changes to this year's competition. The Enhanced Focus Area (EFA) requirement has been removed from this year's RFP; however, the team acknowledges they are still free to focus on any topic beneficial to the progress of the team. With respect to the mix design, the amount of hydraulic cement is limited to 30% by mass and the volume of total aggregates is limited to 30% by volume. In addition to these requirements, the team must complete a sieve analysis of each individual aggregate and composite aggregate. This is our understanding of the rules for this year's competition.

We can't wait to bring our final prototype to competition this year. With knowledge transfer at the core of our values, we look forward to a successful year.

Sincerely,
Michigan Technological University Concrete Canoe Team

Lydia Lamey
Team Captain
llamey@mtu.edu
763-232-7085

Samuel Pendell
Team Captain
sjpendel@mtu.edu
989-475-1488

Dr. Andrew Swartz
ASCE Student Chapter Faculty Advisor
raswartz@mtu.edu
906-487-2439

Pre-Qualification Form (Page 1 of X)

Michigan Technological University
(school name)

We acknowledge that we have read the 2023 ASCE Society-wide Concrete Canoe Competition Request for Proposal and understand the following (*initialed by team project manager and ASCE Faculty Advisor*):

The requirements of all teams to qualify as a participant in the ASCE Student Symposium and Society-wide Competitions as outlined in Section 3.0 and Exhibit 3.	LL	RAS
The eligibility requirements of registered participants (Section 3.0 and Exhibit 3)	LL	RAS
The deadline for the submission of *Letter of Intent, Preliminary Project Delivery Schedule* and *Pre-Qualification Form* (uploaded to ASCE server) is November 4, 2022; 5:00 p.m. Eastern	LL	RAS
The last day to submit *ASCE Student Chapter Annual Reports* to be eligible for qualifying (so that they may be graded) is February 1, 2023	LL	RAS
The last day to submit *Request for Information* (RFI) to the C4 is January 27, 2023	LL	RAS
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.	LL	RAS
The submission date of *Project Proposal*, and *MTDS Addendum* for the Student Symposium Competition (uploading of electronic copies to ASCE server) is Friday, February 17, 2023.	LL	RAS
The submission date of *Project Proposal, and MTDS Addendum* for Society-wide Final Competition (hard copies postmarked to ASCE and uploading of uploading of electronic copies to ASCE server) is May 10, 2023; 5:00 p.m. Eastern.	LL	RAS

Lydia Lamey	10/28/22	R. Andrew Swartz	10/28/22
Team Captain	*(date)*	*ASCE Student Chapter Faculty Advisor*	*(date)*
Lydia Lamey		Raymond A. [signature]	
(signature)		*(signature)*	

Pre-Qualification Form (Page 2 of X)

Michigan Technological University
(school name)

As of the date of issuance of this Request for Proposal, what is the status of your school / university's 2022-23 classroom instruction (in-person, remote, hybrid)? What is anticipated after Thanksgiving and winter holiday break? If in-person or hybrid, do you have access to laboratory space or other facilities outside of classes?

Michigan Technological University is completely online for classroom instruction with no restrictions. It is anticipated that this will still be the case after Thanksgiving and winter holiday break. We have full access to a lab space.

In 250 words or less, provide a high-level overview of the team's Health & Safety (H&S) Program. If there is currently not one in place, what does the team envision their H&S program will entail? Include a discussion on the impact of COVID-19 on the team's ability to perform work and what plans would be implemented assuming work could be performed.

Our health & safety program is made up of two parts. Communication and prevention. We make sure to communicate with one another if we are not feeling well. This also ties into prevention. By continuing with open communication, we inherently prevent the spread of COVID-19. To continue preventing, we wear masks at all times when working in the concrete lab. Not only does this help stop the spread, but it's also an important measure we will take to protect our lungs from dust. In the lab, all members are required to wear proper PPE. We discuss new safety tips at each weekly meeting.

COVID-19 is not significantly impacting the team's ability to work at the moment. The most notable impact it has is the sudden absence of team members when they must quarantine.

In 150 words or less, provide a high-level overview of the team's current QA/QC Program. If there is currently not one in place, what does the team envision their QA/QC program will entail?

Quality control: The team uses depth gauges to ensure even layering of the canoe, checks humidity levels during the curing process, and checks for well mixed concrete during the casting and curing processes. After curing, the canoe is sanded and sealed.

Quality Assurance: All mixes and pre-batched and weighed to ensure they are meeting standards. Practices are held to make sure all members have casting experience prior to placement day.

Has the team reviewed the Department and/or University safety policies regarding material research, material lab testing, construction, or other applicable areas for the project?

All members of the team have completed a guided lab tour and lab safety training. All testing procedures have been reviewed.

The anticipated canoe name and overall theme is – *(please provide a brief description of the anticipated theme. The intent is to allow ASCE to follow up to determine if there may be copyright or trademark issues to contend with, as well as to provide insight.)*

Our overall theme is Vegas/Casino night. Our boat name has yet to be decided, but some options the team has discussed are Blitz or Card Shark. We intend to portray this with card suit inlays into the boat.

Has this theme been discussed with the team's Faculty Advisor about potential Trademark or Copyright issues?

The theme has been discussed and there should be no Trademark or Copyright issues.

The core project team is made up of 9 people.

Thank you to our advisors

Dr. Tess Ahlborn
Dr. R. Andrew Swartz

Thank you to any additional members not mentioned

Adam Katers
Brock Maloney
Chris Eder
Emily Mackintosh
Jack Simons
Kalib Perry
Liam Silverman
Lyza Brandner
Pan Prathonkham
Ryan Schumacher
Tyler Parker
Wes Reif