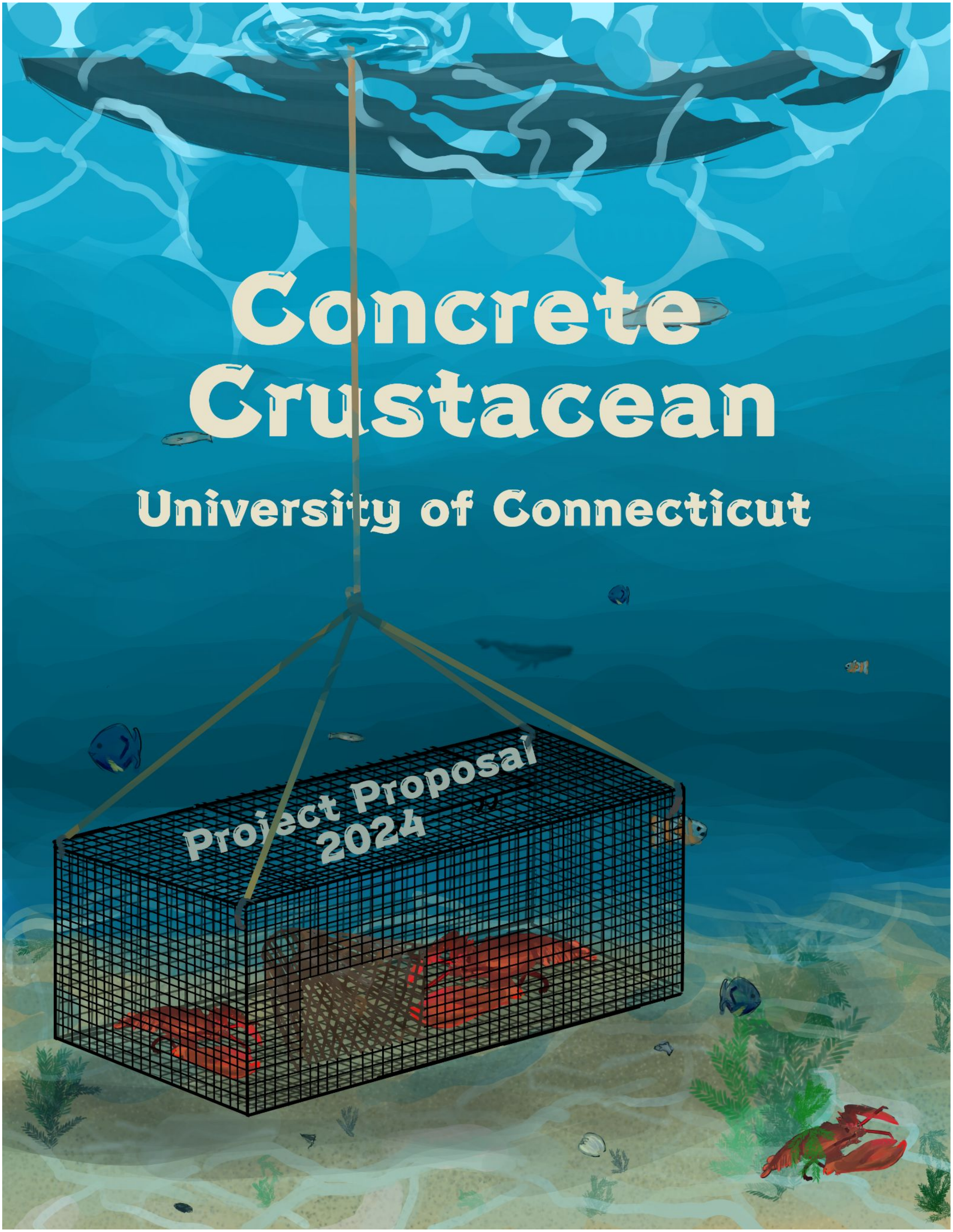
Concrete
Crustacean
University of Connecticut
Project Proposal
2024

The University of Connecticut 2023-2024 Concrete Canoe team acknowledges and agrees to the Request for Proposal Solicitation from C4. Throughout this request for proposal, the team will detail all relevant information including the analysis and design of the prototype, the development of the project team, and the insurance of a safe and sustainable construction process.
The University of Connecticut 2023-2024 Concrete Canoe team endorses and certifies the following:

I. The design of The *Concrete Crustacean*, including the hull design, concrete mixture design, reinforcement scheme, and construction of the prototype canoe, has been produced in full compliance with the specifications outlined in the Request for Proposal.
II. The Material Technical Data Sheets (MTDS) and the Safety Data Sheet (SDS) have been reviewed and critiqued by the team for full completeness and compliance.
III. The team acknowledges the receipt of the Request for Information (RFI) Summary and that the submissions comply with the responses provided.
IV. The anticipated registered participants are qualified student members and Society Student Members of ASCE and meet all eligibility requirements.
V. Any and all text generation AI/NLP algorithms are properly cited within the respective document.

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Registered Participants	ASCE Member Number
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University of Connecticut
The Concrete Crustacean

UConn's Concrete Canoe was founded in 2013 and has been learning and improving ever since!

"Big Catch" Years

- **Pre 2017**: From 14th to 10th to 8th place!
- **2017**: 4th Place!
- **2018 and 2019**: 2nd Place!
- **2021**: 1st Place!

Trapping more "Crustaceans":

- Covid-19 hit the team hard and with few numbers
- The 2024 team laid more traps and bait to recuperate the losses

Our **New** Mixer helped us cut down development time significantly!

The utility and value our canoe offers C4 makes our prototype the optimal choice! Through the process, we were able to lower the cost of each canoe while maintaining high **strength** and **durability**. Using our design, C4 will be able to produce **reliable** and **sturdy** canoes at a **materials cost** of **$1.8k per canoe** for use in America's waterways!

	Mix Properties
Density (Wet)	63.26 lbs/ft^3
Density (Dry)	60.25 lbs/ft^3
Slump/spread	0 in
Air Content	15%
Compressive Strength	3800 psi 28 Days
Tensile Strength	318 psi 28 Days

Depth: 11.875 in

Length: 216 in

Weight: 200 lbs (Estimate)

Thickness: 5/8 in

Flexural Strength:
Unreinforced: 213 psi - 28 Days
Reinforced: 2100 psi = 28 Days

Carbon Fiber: C50

Fiberglass: AR Glass Net


The Team's Catch
Our Other Catches:
Kay Wille, Adv.
Brian Lassy Jr., Grad.
Ben Shatzel, Fr.
Evan Root, Fr.
George Ji, Fr.
James White, Fr.
Catherine Peng, Jr
Team Captain
Mia Larkin, So.
Team Captain
Project Management
Priya Rao, So.
Secretary
David Hart, Sr.
Treasurer
Graphic Designer
Communications
Maria Tuxbury, So.
Treasurer
Adeline Richard, So.
Public Relations.
Inventory
Finances
Catherine Cala, So.
Public Relations
Finances
General Outreach
Social Media

Project Scope

In order to understand the project scope, the team reviewed the 2024 Request for Proposals to determine the necessary deliverables for the proposal requirements: a finished concrete canoe prototype, design paper, materials notebook and mix design sheets, sectional, display and stand.

The necessary sequence of tasks was then identified: to complete the hull design, material selection and procurement, mix design and testing, mold construction, canoe construction, and canoe sanding and finishing. These tasks were used to determine the overall project schedule and mark milestone activities.

Project Management

The planning process for the project began in September 2023. The project schedule was a priority as it allowed the team to plan ahead towards milestone tasks.

The budget was based on the maintained inventory of materials from previous years, the transportation, and housing fees for the competition. For materials, an adequate amount of aggregates carried over from previous years. The main purchases included foam for the mold, cement, and pigments. For the construction process of the mold and canoe, the team regularly visited the lab to ensure that progress was made in a steady manner. In terms of risk management, the team discussed new construction methods to be tested this year to ensure the project schedule was maintained.

The team was able to determine the critical path activities: the hull design decision, final mix design decision, mold cutting, mold construction, pour day, submission of the design paper, mix design sheets, and materials notebook, the stand, display, sectional, and finished canoe after sanding and sealing. The obstacles to the critical path activities were the procurement of materials and cutting of the mold due to a reliance on outside vendors and the availability of the shop schedule to cut the mold.

There was a rearrangement of tasks from the Preliminary Project Delivery Schedule (PPDS) due to one of the obstacles of the critical path. Due to the schedule and space availability of the UConn Machine Shop, the cutting of the mold took place several weeks later than planned in the PPDS. This pushed the completion of the mold back by two weeks from the intended date, forcing the team to move pour day from December 2023 to January 2024 (Fig. 1).

Fig. 1. 2023/24 UConn Concrete Canoe Team.

Health and Safety

During construction of the canoe it was important that the health and safety of all members was ensured. All members were prepared to enter the lab following the guidelines for all required equipment from eyeware to respirators that are to be worn within. For handling of the dry materials involved in the concrete mix, members were to wear respirators (Fig. 2) or N-95 masks to prevent inhalation of any dust particles. Those dealing with glass microspheres and sanding the canoe were also equipped with goggles on top of their masks, given the fine particle size of those materials. In addition, glass microspheres were measured in a separate lab space by designated members.

Fig. 2. Respirators to protect from particulates.

During the mixing process fans, vacuums, and damp towels were also frequently used to help reduce the amount of material in the air. To protect beyond breathing in dust particles, latex gloves were also worn when handling materials, especially the concrete mix, to prevent chemical burns.

Outside of the main laboratory, life vests were applied during paddle practices, and protective doors and eyewear were used during compression testing for personal safety. In order to make sure all these policies were applied, a safety officer was designated during meetings.

Fig. 3. Wooden shims and caulking putty fine-tuned the mold.

Quality Assurance and Quality Control

Several changes to the mix had to be considered, given the updated requirements for the 2024 competition. To determine the optimal concrete mix, the team performed extensive mix design testing, using compressive strength and slump tests to analyze the quality of each mix design.

While getting started with mix designs, the team continued to perform quality assurance tests to prevent possible setbacks later on in the process. For this reason, the team constantly checked the measuring scales for proper function to ensure ingredients were mixed to exact proportions. The next step in process quality control was to properly design, cut, and sand the mold. Caulking putty was applied to fill in any gaps in the foam so the concrete could not bleed into it and to minimize the amount of sanding required once the canoe was de-molded. Finally, to assure that the mold was level, wooden shims were placed underneath the retaining lip (Fig. 3).

During pour day itself, members would check the depth of the concrete using toothpick depth gauges. This would assure an even layer of concrete was laid on the mold. Concerning quality assurance, workshops were held to teach new members the skills needed for building a concrete canoe.

Research and Development Cost

The material costs for this project were primarily represented in the concrete supplies and mold supplies, with significant costs from shipping. After being lost at sea, the team was returning from a hiatus, and so it was decided that past suppliers would be used rather than exploring uncharted waters. In the future, sources with cheaper shipping will be considered over current shipping costs.

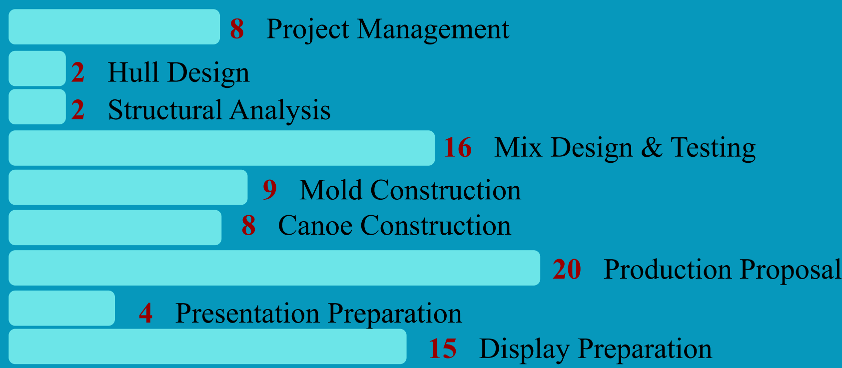
Both returning team members and the new recruits were very excited to participate in a wide array of tasks for this project. Since the organization is a growing extracurricular team, the project managers decided that providing as much learning experience as possible was of greater importance than making considerations for hypothetical labor costs. In the end, most of the people-power costs come from laborers who contributed to the construction of the canoe, as well as the lead engineering design roles.

The costs associated with tools and machinery were relatively minimal since lab resources are always available to the team. Estimates were made for the non-reusable supplies like cylinders and sandpaper, as well as the costs of electricity for using the university's machine.

Research and Development

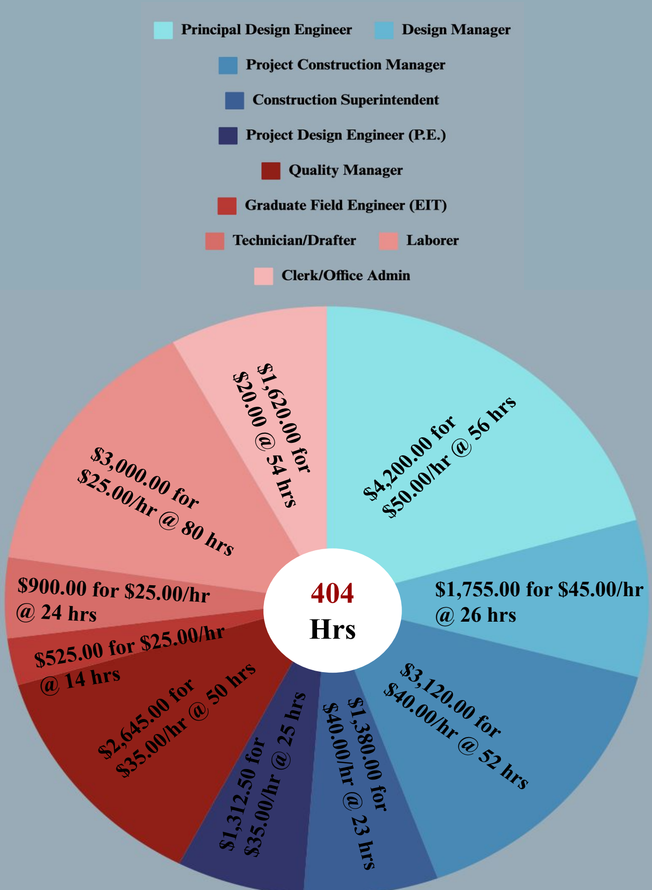
Project Total Hours

84 Hours
Per Worker
@ 10 Workers
840
Total Hours



Labor Costs

Labor Subtotal: $20,437.50
18% Profit Multiplier: $3,678.75
Direct Labor Total: $24,116.25



Expenses

MATERIALS
Concrete Supplies: $267.24
Paddling Supplies: $172.00
Mold (Lump Sum Cost): $401.10
Testing Tools: $22.78

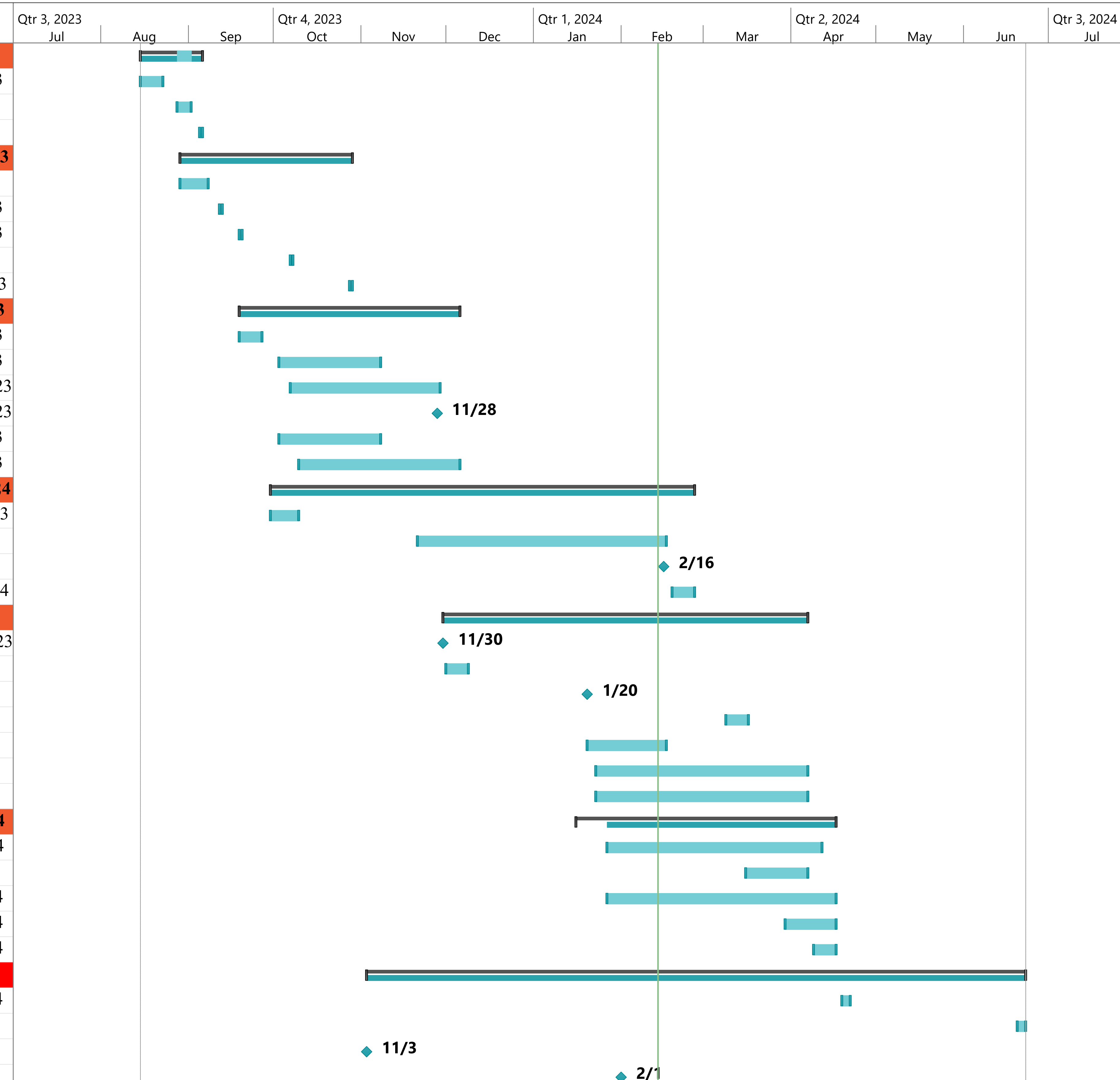
DISPLAY/PAPER/PRESENTATION COSTS
Display Materials: $200.00
Printing: $18.00
Shipping: $782.86

SHIPPING/TRAVEL COSTS FOR COMPETITION
Vehicle/ Fuel: $350.00
Accommodations: $1,500.00

Expense Subtotal: $3,713.98
10% Markup: $371.40
Expenses: $4,085.38

Total Cost:
$28,201.63

ID	Task Mode	Task Name	Duration	Start	Finish
1		**Pre-Construction Planning**	**16 days**	**Tue 8/15/23**	**Tue 9/5/23**
2		Summer Planning	6 days	Tue 8/15/23	Tue 8/22/23
3		Final Planning Meeting	5 days	Mon 8/28/23	Fri 9/1/23
4		Inventory	1 day	Tue 9/5/23	Tue 9/5/23
5		**Member Training**	**45 days**	**Tue 8/29/23**	**Sat 10/28/23**
6		Recruitment	8 days	Tue 8/29/23	Thu 9/7/23
7		First Members Meeting	1 day	Tue 9/12/23	Tue 9/12/23
8		Member Preliminary Work	1 day	Tue 9/19/23	Tue 9/19/23
9		Intro to Concrete & Workspace	1 day	Sat 10/7/23	Sat 10/7/23
10		Paddle Practice (Fall)	1 day	Sat 10/28/23	Sat 10/28/23
11		**Design**	**56 days**	**Tue 9/19/23**	**Tue 12/5/23**
12		Theme Design & Decision	6 days	Tue 9/19/23	Tue 9/26/23
13		Hull Design	26 days	Tue 10/3/23	Tue 11/7/23
14		Mix Design	38 days	Sat 10/7/23	Tue 11/28/23
15		Final Mix Design Decision	0 days	Tue 11/28/23	Tue 11/28/23
16		Mold Design	26 days	Tue 10/3/23	Tue 11/7/23
17		Display Design	41 days	Tue 10/10/23	Tue 12/5/23
18		**Design Paper & Presentation**	**107 days**	**Sat 9/30/23**	**Mon 2/26/24**
19		Rules Overview	7 days	Sat 9/30/23	Mon 10/9/23
20		Design Paper	64 days	Tue 11/21/23	Fri 2/16/24
21		Design Paper & Materials Notebook Completi	0 days	Fri 2/16/24	Fri 2/16/24
22		Oral Presentation Practice	6 days	Mon 2/19/24	Mon 2/26/24
23		**Construction**	**93 days**	**Thu 11/30/23**	**Sat 4/6/24**
24		Mold Cutting	0 days	Thu 11/30/23	Thu 11/30/23
25		Mold Construction	6 days	Fri 12/1/23	Fri 12/8/23
26		Pour Day	0 days	Sat 1/20/24	Sat 1/20/24
27		Sectional Assembly	7 days	Sat 3/9/24	Sat 3/16/24
28		Concrete Setting	21 days	Sat 1/20/24	Fri 2/16/24
29		Display Construction	55 days	Tue 1/23/24	Sat 4/6/24
30		Stand Construction	55 days	Tue 1/23/24	Sat 4/6/24
31		**Finishing**	**66 days**	**Tue 1/16/24**	**Tue 4/16/24**
32		Canoe Sanding	55 days	Sat 1/27/24	Thu 4/11/24
33		Sectional Finishing	17 days	Sat 3/16/24	Sat 4/6/24
34		Display Decoration	58 days	Sat 1/27/24	Tue 4/16/24
35		Canoe Polishing/Sealing	13 days	Sat 3/30/24	Tue 4/16/24
36		Completion/Finishing Touches	6 days	Tue 4/9/24	Tue 4/16/24
37		**Important Dates & Deadlines**	**167 days**	**Fri 11/3/23**	**Sat 6/22/24**
38		Regional Symposium	2 days	Fri 4/19/24	Sun 4/21/24
39		National Competition	3 days	Thu 6/20/24	Sat 6/22/24
40		Preliminary Forms Due	0 days	Fri 11/3/23	Fri 11/3/23
41		ASCE Annual Dues	0 days	Thu 2/1/24	Thu 2/1/24



Hull Design

The hull is a crucial part of the overall performance and speed of the canoe. A precise and technically sound design is the most important part of the development process. Designing the *Concrete Crustacean* proved to be a challenge. After COVID-19 and the graduation of senior members, the team was left with small numbers. This resulted in the organization having to be revived and the team skipping the previous two regional competitions. With many of the experienced members leaving, there was a considerable learning curve that led to the team relying on the concepts of the previous years' structural design.

The team's initial design plans for the hull included changing the rocker angle. After the team's first paddle practice, it was decided that the team wouldn't change the rocker, as the original angle provided sufficient control and balance for the rowers. Thus, the team decided to keep a shallow angle and focus modifications on the comfort of the rowers. The major hull innovation that the team decided to make was to smooth out the ribs in the front and the back of the canoe. Smoothing out the ribs resulted in sides that were further angled towards the inside of the hull rather than having a rectangular rib across the bottom of the hull. This design choice improved the structural strength of the rib, as it is wider and larger than the previous iteration and it also improved the ergonomics of the canoe, as it will allow for increased comfort for the rowers when kneeling on the ribs.

Another innovation was using steel wire reinforcement in the gunnels rather than a line of carbon fiber grid reinforcement. This reduced costs as steel wire is cheaper than carbon fiber. Furthermore, steel wire is more malleable, making it easier to work with than the comparably stiffer and more brittle carbon fiber.

Finally, concrete bulkheads were added to the canoe, which were sharpened to a point. The end caps were attached after removing the mold using grooved cuts in the underlying concrete and steel wire reinforcement running into the foam caps. This was both a stylistic and structural choice as having these tips relates to the team's chosen theme of *Concrete Crustacean*; the tips act as claws on a crustacean. Structurally, these tips allow the canoe to be more aerodynamic and increase its durability in the case that the canoe impacts or collides with something in the water.

Structural Analysis

The team defined the critical load case to be the absolute worst loading the canoe might be subjected to. The critical load case for the canoe was determined to be two rowers, weighing 200 lbs each, sitting 6 feet from either end of the canoe, with the canoe simplified to be a simply supported beam at both ends and out of the water. This loading event might occur following a successful race, carrying the captains out of the water to victory. A longitudinal analysis for the critical load case was performed and determined that the maximum shear force, V_{max}, was 300 lbs and the location of V_{max} was at 0 ft and 18 ft along the length of the canoe (Fig. 4). It was also determined that the maximum bending moment, M_{max}, was 1650 lb-ft and the location of M_{max} was at the center of the canoe (Fig. 5). At the location of M_{max}, the team determined that the moment of inertia, I_x, was 640.27 in^4. At the critical section, c_c was 8.75" and c_t was 3.75".

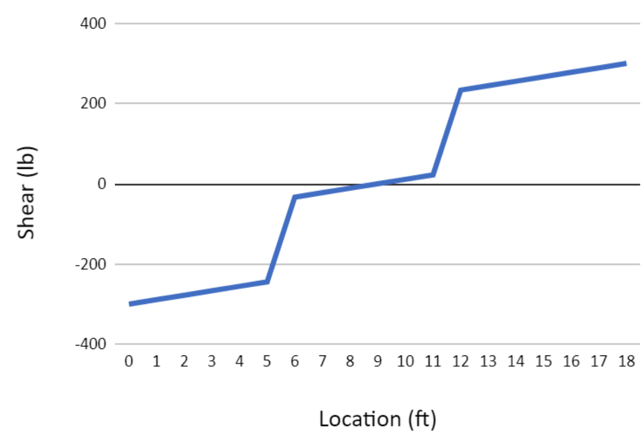


Fig. 4. Shear Force Diagram.

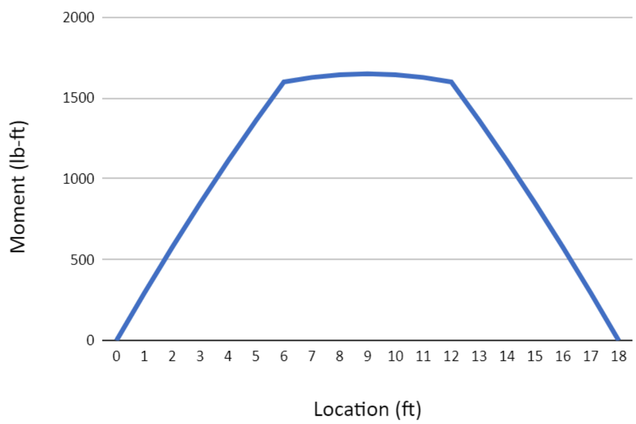


Fig. 5. Bending Moment Diagram.

For the punching shear analysis, the critical area for punching shear for the critical load case was defined in the longitudinal analysis would be under the rower's knee while paddling. It was assumed that the 200 lb rower would put 70% of their weight on their knee and that their knee would cover a 2x2" area. The result of the punching shear analysis showed a maximum stress of 28 psi. Comparing the results to the longitudinal analysis, the punching shear is significantly less than either V_{max} or M_{max}. This means that the team should primarily design against failure due to shear force and bending moment.

The failure envelope analysis yielded a maximum compressive stress, σ_c, of 270 psi and a maximum tensile stress, σ_t, of 115 psi. The experimental result found that the mix in *Concrete Crustacean* had a compressive strength, f_c', of 3800 psi and tensile strength, f_t, of 318 psi. The team lead engineer developed a plot of Mohr's Circle to find the failure envelope. Compressive and tensile strengths of the *Concrete Crustacean* were plotted as blue and red circles, respectively, with the maximum stresses plotted in green (Fig. 6). The tangent line between the Mohr's Circle for compressive and tensile strength had a slope of -1.58 psi and a maximum predicted shear stress, τ_{max}, of 550 psi.

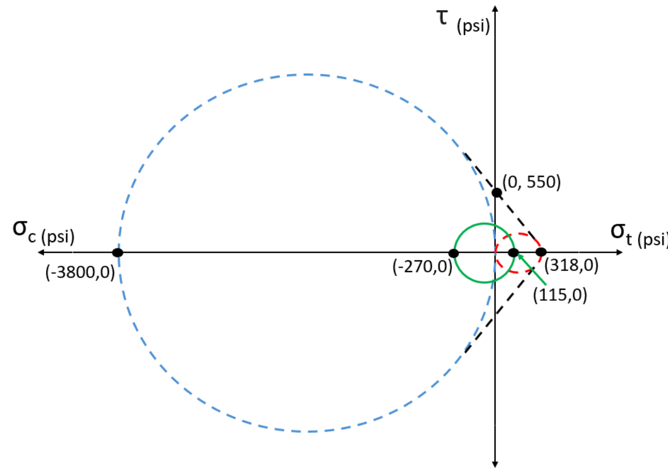


Fig. 6. Simplified Mohr's Criterion for Failure Envelope Analysis.

Mix Design

The team based the *Concrete Crustacean'*s mix off the mixes used in previous years such as the *Graveyacht*. Specifically, the team utilized the already proven and tested materials, aggregates, and admixtures used in *Graveyacht*'s mix, while adjusting the ratios of the mix to comply with this year's Request for Proposals. The goals when creating this year's mix were to maintain characteristics such as the workable texture, light dry unit weight of around 55 pcf, and a compressive strength of at least 1800 psi.

The team's mix design engineers began by adjusting the ratio of cementitious materials in the mix in accordance with this year's requirements that hydraulic cement cannot exceed 50% by mass of the total cementitious materials. The mix utilized Type I White Portland Cement and White Silica Fume as the cementitious materials. The cement in the mix was reduced and the silica fume was increased until both were 50% by mass of the total cementitious materials, which complies with this year's rules. This change had the added benefit of decreasing the unit weight of the mix because the specific gravity of silica fume (SG = 2.5) is less than that of cement (SG = 3.15), which aided in maintaining a low dry unit weight. Additionally, silica fume has significantly less carbon emissions than cement, which helped improve the sustainability of the canoe's mixes.

For the aggregates, pumice and expanded glass were used to keep the mix light and strong. The pumice was chosen as a highly sustainable, strong, light, and neutral colored aggregate. It also has a porous surface that could aid in binding the mix together. The pumice had a maximum particle size of approximately 0.09", a SG of 1.5, and an absorption of 23%. Expanded glass aggregates were chosen due to their high strength to weight ratios, which would help achieve an overall high strength to weight ratio for the mix. The selected expanded glass bubble size had a grain size of 1-2 mm, a SG of 0.41, and an absorption of 20%. The glass microspheres had a top particle size of 120 microns, a SG of 0.13, and an absorption of 0%.

In total, four new mix designs were tested, excluding the baseline mix used for comparison purposes. The mix maintained 50% of the total mass of the cementitious materials for both the cement and the silica fume for each test mix. The percentages of each of the aggregates was then adjusted, while maintaining that the total aggregate volume was above 30% of the total mix volume. The compressive strength of each mix was tested 7 days after pouring and then 28 days after pouring, where each mix can be considered to be at full strength. The mixes were tested using 3x6" cylinders in accordance with ASTM C39. The compressive strength results for each test mix are shown in Table 1.

Table 1. Test Results for Test Mixes

Mix Number	7 Days (psi)	28 Days (psi)
Baseline	3190	6200
1	2170	4100
2	240	280
3	3400	4860
4	500	790

For the secondary reinforcement, 6 mm polyvinyl alcohol (PVA) fibers were selected, which provided more tensile and flexural strength to the mix. The primary reinforcement used in the canoe's construction was composed of 0.4 x 0.4" flexible fiberglass mesh and 1.65 x 1.25" carbon fiber mesh. The fiberglass mesh was layered on first, after the first layer of concrete, and was chosen to prevent punching shear failure along the bottom of the hull. The carbon fiber mesh was layered on after the fiberglass mesh and was chosen to help add longitudinal tensile strength to the canoe. Additionally, 16 gauge steel rebar tie wire was used to reinforce the gunwales of the canoe and to add additional tensile strength to the upper half of the canoe.

The team also added two liquid admixtures to the test mixes, which were the Optimum 380 superplasticizer and the MasterLife SRA 20 shrinkage reducer. These were added to the mixes in varying amounts. The superplasticizer helped to achieve the desired clay-like consistency and high compressive strength of the mix and permitted a decrease in the water to cement ratio of the mixes. The shrinkage reducer helps to prevent the concrete from shrinking during the curing process and, thus, helps to circumvent undesirable cracks in the finished canoe.

Several 3 x 6" cylinders samples of the final mix used on pour day were tested to find the final material properties. Compressive strength tests and split cylinder tests were performed on the cylinders in accordance with ASTM C39 and ASTM C496. A composite flexural strength test was performed on a 12x2x0.625 in plate in accordance with ASTM C293. The results of the tests are shown in Table 2. The summary of all components used in the final mix design and corresponding ASTM standards can be found in Table 3.

Table 2. *Concrete Crustacean* Material Properties	
Compressive Strength (ASTM C39)	3800 psi
Tensile Strength (ASTM C496)	318 psi
Composite Flexural Strength (ASTM C293)	2100 psi
Slump, Spread (ASTM C143)	0 in
Air Content (ASTM C138)	15.00%
Wet Unit Weight (ASTM C138)	63. 26 pcf
Oven Dry Unit Weight (ASTM C567)	60.25 pcf

Table 3. ASTM Standards for Final Mix Components	
Concrete Crustacean Mix Components	ASTM Standard
Federal White Portland Cement Type I	C150
Doral White Silica Fume	C1240
Hess Pumice (Grade7)	C330
Poraver 1-2 mm	C330
3M K1 Glass Bubbles	C330
Nycon PVA 6mm Fibers	C1116
Optimum 380 Superplasticizer	C494
Masterlife SRA 20 Shrinkage Reducer	C494
Conspec Materials Cement and Mortar Color	C979

The team made a few changes in the mixing methods that improved the safety, efficiency, and quality control of the mixes. The order that the aggregates were mixed into the cementitious materials was changed so the K1 was added all at once, before any liquids were added. The previous method of incorporating the liquids and K1 in an alternating sequence resulted in a lot of the K1 puffing up out of the mixer, which posed a health and safety concern, as well as a quality control issue. The new mix procedure resulted in far less K1 leaving the mixer. The team also improved the efficiency and quality of the final pour day mix by utilizing a larger mixer and larger batch sizes, which resulted in a decrease in the time spent mixing and a more consistent mix.

Construction Process

To start the construction process, the team assembled a plywood table in the lab space where the mold and canoe would be built on. This involved increasing the length of the table to accommodate the length of the canoe and adding reinforcement which would keep the mold aligned and stable. The last time the team competed was when COVID-19 peaked in 2020. Because of this, the team was unable to build a canoe from the mold designed for that year's competition. Therefore, the mold designed for *Kaiju Kanoe* was used this year. The team cut the mold from sheets of foam using the CNC machine at the Engineering Machine Shop (Fig. 7), resulting in 102 individual foam pieces. After fitting the mold pieces along a wooden guide, the pieces were caulked together.

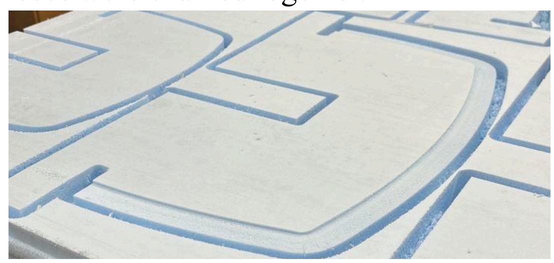


Fig. 7. The margin between sections was as little as ½".

Due to time constraints at the machine shop, the ribs of the canoe were not properly cut into the mold of the canoe. So, using a hot knife, the ribs were cut (Fig. 8) after the foam pieces were caulked together. The bottom of the ribs were also rounded out to add structural strength and comfortability. The team then used expanding foam to fill in a large gap between two foam pieces that were not properly spaced together. Finally, the mold was sanded, then spackle was applied on to the surface of the mold to fill in any gaps, and the mold was sanded again to ensure a smooth finish. By repeating this process, the mold was prepared for concrete application.

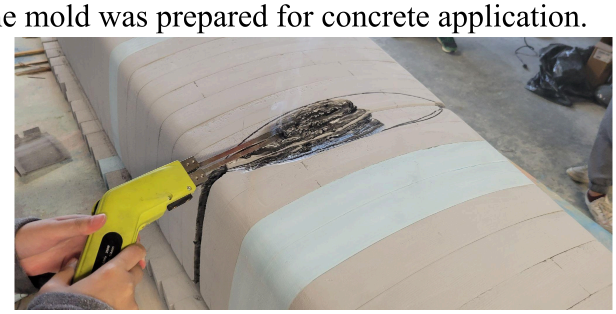


Fig. 8. Cutting and Shaping the Ribs

When pour day arrived, the team first went over all of the health and safety requirements. Then, PAM cooking spray was applied over the mold of the canoe, to help the demolding process. With all the preliminary preparation finished, the team was split into three groups: the measurement team, the mixing team, and the application team. The measuring group measured out the components of the mix. Then, the mixing group would mix together the dry components, then wet components, resulting in a consistent mix. The mixing process was improved due the the use of a larger mixer that allowed for larger batch sizes of concrete to be mixed at a time (Fig. 9). This year, only two large batches and two small batches of concrete needed to be mixed, compared to the 20 small batches needed for previous years. Finally, the application team would apply the concrete to the mold of the canoe by hand. By maintaining this three-team structure, the flow of work was continuous and efficient.

Fig. 9. A single large mixer was used during pour day.

The application process was kept consistent by using depth gauges to maintain a uniform thickness (Fig. 10). To create the visual appeal to match the crustacean theme, the canoe was designed to have white concrete layering on the inside and the red concrete on the outside, mimicking the shell of a lobster.

Fig 10. Custom depth gauges kept thickness standardized throughout the construction.

Between the layers of white and red concrete, a fiberglass net reinforcement layer was placed for longitudinal and tensile reinforcement. Then, on top of the fiberglass net, carbon fiber net reinforcement was added (Fig. 11), held in place with thin patches of concrete. Then, the final layer of red concrete was laid. Finally, the concrete surface was smoothed out using concrete floats to reduce the amount of work during the sanding process.

Fig. 11. A carbon fiber net was used as reinforcement.

To finish, the canoe was covered in damp towels and a plastic covering was laid on top to create a sealed environment, keeping in the moisture to help the concrete cure and gain strength.

Once the concrete was set and cured, the canoe was demolded. Then, both the inside and outside of the canoe was sanded down. Finally, a layer of concrete sealer was applied and then sanded down. Two layers of sealer were applied using this process.

Value

The design for the concrete canoe, aptly dubbed the *Concrete Crustacean*, exhibits several innovations that provide both monetary and utility benefits to C4 and its stated needs. The team reduced overall costs through a combination of practices.

During the construction of the foam mold, each sectional piece was deliberately mapped and cut with separating margins of only 0.5" thick to reduce excess foam. By reducing material waste, the team spent less money on buying foam. The use of steel wire in the gunwale rather than traditional carbon fiber within the canoe also lowered the cost of construction.

The team also introduced a new component to the mixing system; the utilization of the 12 cubic foot capacity Vertical Shaft Mixer. Such a large concrete mixer was able to mix a relatively large amount of concrete compared to the shrimp-sized industrial cake mixers used in previous years. This reduced the time spent on the project as well as electricity and manpower, proving that the methods and mix are scalable.

Finally, the team designed a concrete mix that produced a lightweight concrete while maintaining exceptional compressive strength relative to mass. In testing, the concrete mix withstood a force of 3800 psi, well above that of typical and previous year's mixes. This was accomplished by incorporating less cement, opting instead for silica fume. Furthermore, the incorporation of silica fume into concrete mix ultimately extends the longevity of concrete, according to an EPA report to Congress (EPA 530-R-08-007, Life 365 version 2.0, and Bath University's Inventory of Carbon & Energy (ICE)). For every 1% substitution of concrete for silica fume, there is an average of 18% improvement in the life cycle of concrete. In the context of C4, canoes constructed according to the UConn design parameters will require less repairs, replacements, and time to maintain.

The monetary and utility value the design brings to C4 is obvious. Through the so-fish-ticated mix design and canoe construction, the team significantly lowered the cost of building each concrete canoe while maintaining exceptional strength and durability. Implementation of the design would benefit C4 in creating highly resilient canoes for use in America's waterways.

Sustainability

This year, UConn Concrete Canoe took efforts to improve sustainability for the *Concrete Crustacean*. In accordance with the revised Request for Proposals, the team adjusted the overall mix design to accommodate C4's specifications. Among the specifications provided, it was noted that the amount of hydraulic cement in the mix was to be limited to 50%, by mass, of the total amount of cementitious materials present in the mix used for the canoes. UConn's previous mix designs have only utilized two materials as a part of the cementitious material content of the mix: cement and silica fume. Thus, the team decided to increase the content (percent mass) of silica fume in order to accommodate for the reduction in cement content. The ratio change of cementitious materials greatly improved *Concrete Crustacean*'s impact on the environment; specifically, silica fume has a significantly smaller amount of carbon emissions than cement. According to Norchem, the largest producer of Silica Fume in North America, Silica Fume avoids about 2.10 lbs of CO_2 per pound of substitution for cement, which is very significant compared to other possible substitution materials like slag cement or fly ash.

The use of the aforementioned Vertical Shaft Mixer greatly improved both the economic and environmental sustainability of the prototype canoe.

Prior to construction, the team prepared and assessed the materials available in the lab. This included general inventory of mix materials, and equipment such as masks and safety glasses. Over the years, the team has amassed a collection of protective safety glasses and reusable masks for use in the lab. Thus, the amount of single use masks bought decreased. These masks and glasses can also be used for future generations, increasing the logistical sustainability of the team. In addition, by reusing materials already in the lab, the team did not need to buy new equipment, accounting for financial sustainability.

Furthermore, the team counted inventory of mix materials to assess their quality and quantity. There ended up being enough remaining aggregates so that another investment wasn't needed. Following this, the team identified what needed to be replaced or bought and solely invested in those items. This way, the team was financially efficient, and could purchase higher quality materials, while still falling within budget.

Finally, while mixing the concrete itself, whether that be during the mix design testing or pour day, there was often leftover concrete after packing the test cylinders. This concrete was subsequently used to create miniature figurines and animals as decoration for the stand during competition (Fig. 12). This way, no concrete went to waste.

Fig. 12. Excess concrete was used to make stand decorations.

Improvements

One of the biggest improvements for the 2023-2024 competition year was the use of the large concrete mixer. In previous years, the team used two smaller mixers. However, the main benefit of switching out the two small mixers with one large mixer is increased efficiency. A single batch meant all hands could be on deck for applying the concrete once each batch was finished. Overall this new process reduced the time spent mixing and measuring so more people could focus on building the canoe.

Another improvement to the design of the canoe included swapping the carbon fiber mesh in the gunwale for steel rebar tie wire (Fig. 13). This helped lower the cost of the canoe, as steel wire is significantly less expensive than carbon fiber mesh. Previous designs used both carbon fiber mesh and steel wire in the gunwale. This year's design simplified mold construction as it was easier to place the wire in the gunwale than the more difficult to work with carbon fiber mesh.

The team also augmented the compressive strength of the concrete itself to be much higher than previous years, en-shore-ing that the canoe will be able to endure the conditions of the competition. Great care was taken to smooth out the wet concrete before letting it cure, reducing the amount of time spent on sanding while also making it easier to get a nice smooth finish for the final product.

In terms of mold construction, the team optimized the cutting of the foam mold by placing each cut-section within 0.5" clearance of one another, effectively positioning them so that more sections could fit per foam sheet. This process meant that only two foam sheets were required rather than three or more, reducing the material cost.

During Pour Day 2024, the team had to measure out the reinforcements and depth gauges before proceeding with other tasks, delaying the completion of the *Concrete Crustacean*. For the future, the team might consider pre-measuring reinforcements and depth gauges ahead of time, such as during earlier meetings, thus freeing up hands for other tasks.

Fig. 13. Steel rebar tie wire being inserted into the canoe gunwale.

Manufacturing Cost Estimate

The final cost to produce a single canoe, including material costs, labor costs, and additional expenses totaled to $19,319.78.

The material costs for one canoe alone totaled to just over one-thousand dollars. The most significant part of that sum comes from the use of C-Grid Carbon Fiber Reinforcement, totaling just under six-hundred dollars. The glass bubbles, K1, are also an expensive material, totaling approximately one-hundred-eighty dollars, but the team considers this cost crucial to the effectiveness of the design.

In addition to the basic materials that the canoe is built out of, costs for personal protective equipment, and other consumable products totaled approximately two-hundred-fifty dollars per canoe. For basic protection, most team members made use of N95 protective masks and nitrile gloves. The greater cost for protective equipment would be the respirators and goggles used for handling hazardous materials, but these items can be reused as laborers manufacture multiple canoes.

The costs to construct the mold are fairly simple. The greatest cost is the raw cost of foam boards, which totaled to approximately $365 dollars. The additional costs of caulk and PAM, used to bond and lubricate the foam boards, is relatively insignificant. Since the university machine lab is available to the construction team, there were no additional costs to cut the foam boards, aside from the cost of labor.

The labor costs for the mold construction are represented primarily in the lead design roles. This is because a significant portion of the mold construction involved a senior member of the team working directly with the university's machine shop. The labor costs for the canoe construction included a much greater proportion of hours for laborers, since a large number of new members were willing to contribute their efforts. At this stage in the production process, the drafter roles were no longer needed, as the review of design drawings had already been satisfied.

For the mass production of one-hundred iterations of this canoe design, some of the materials can be purchased at cheaper unit prices when bought in bulk. Comparing the unit canoe's material costs to the costs for one-hundred canoes when buying in bulk from the same sources, it was found that the production team could save $848.98. Relative to the overall costs of producing one-hundred canoes, these savings are relatively minimal, suggesting that the rates at which materials are already purchased for the unit canoe are fairly cost-effective.

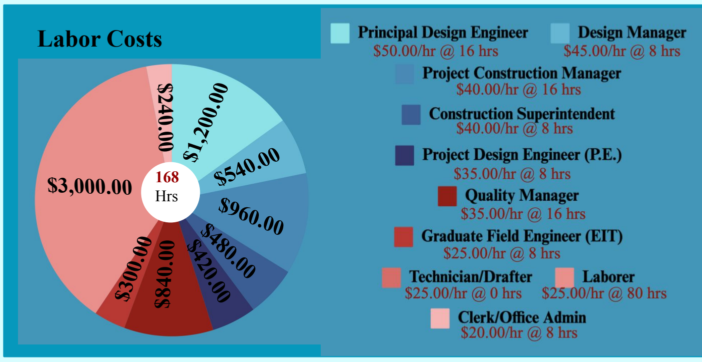
Manufacturing Cost Estimate

Permanent Material Costs Per Canoe

Sources:
- Fishstone: Portland Cement, Silica Fume, Superplasticizer, Shrinkage Reducer, Fiberglass Reinforcement, Carbon Fiber Reinforcement
- 3M: Glass Bubbles K1
- Poraver: Poraver Expanded Glass
- Hess Pumice Products: Pumice (Grade 7)
- Nycon: Nycon PVA Fibers
- Pigment: Conspec Materials Inc.
- University of Connecticut: Water

Permanent Material Costs per Canoe (MC): $1,036.45

Canoe Fabrication Labor Costs and Expenses Per Canoe



Expenses
MC: $1,036.45
PPE: $257.40
Other Consumables: $51.52

Labor Subtotal: $7,980.00
18% Profit Multiplier: $1,436.00
Canoe Fabrication Direct Labor Total: $9,416.40

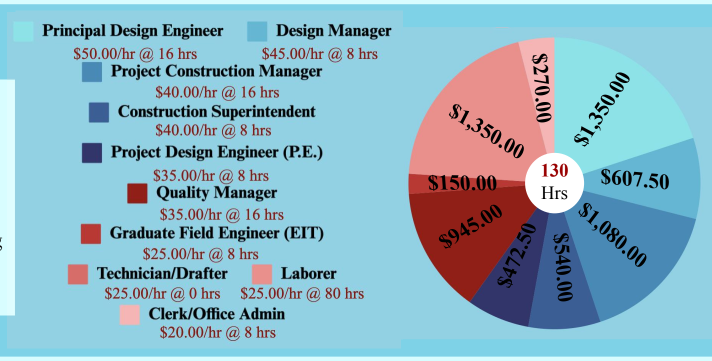
Expenses Subtotal: $1,344.97
10% Markup: $134.00
Canoe Fabrication Expenses Total: $1,479.47

Mold Fabrication Labor Costs and Expenses Per Canoe

Labor Subtotal: $6,765.00
18% Profit Multiplier: $1,217.70
Mold Fabrication Direct Labor Total: $7,982.70

Expenses Subtotal: $401.00
10% Markup: $40.11
Mold Fabrication Expenses: $441.21

Expenses
Foam: $364.95
Caulk: $17.40
PAM Cooking Spray: $18.75



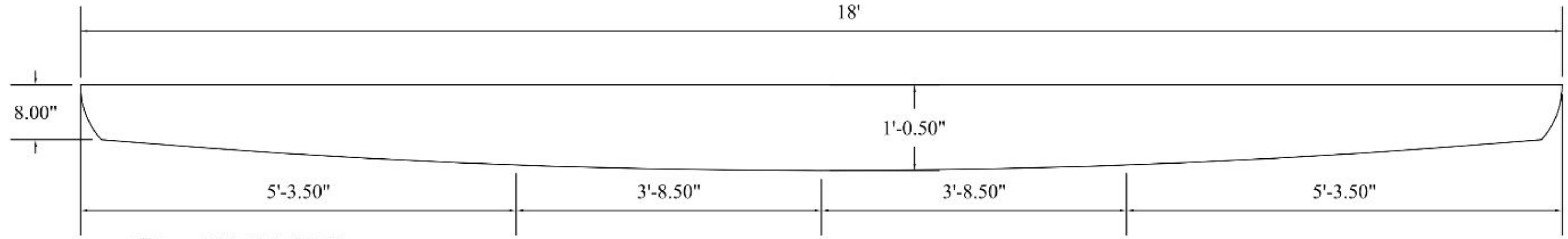
Total Canoe Cost: $10,895.87

Total Mold Cost: $8,423.91

Bulk Savings: $848.98

Total Cost Per Canoe: $19,319.78

Total Cost Per 100 Canoes: $1,931,977.57



1 ELEVATION
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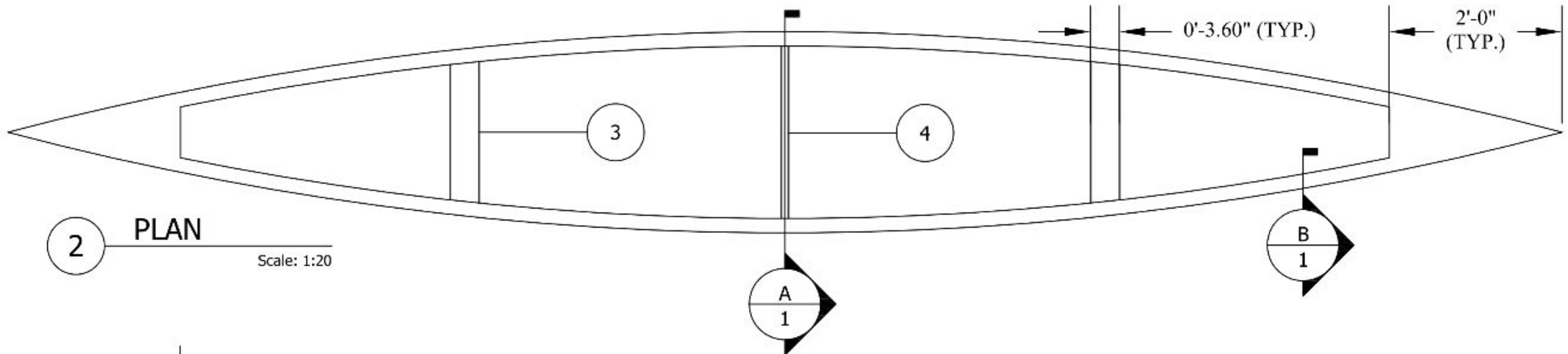
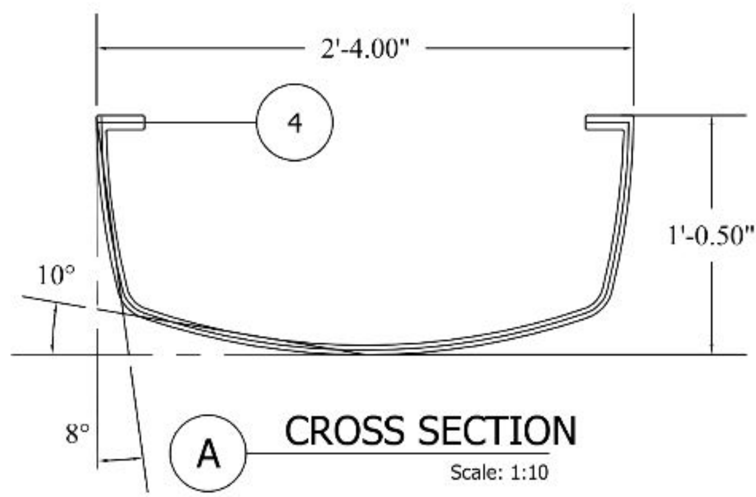


2 PLAN
Scale: 1:20



A CROSS SECTION
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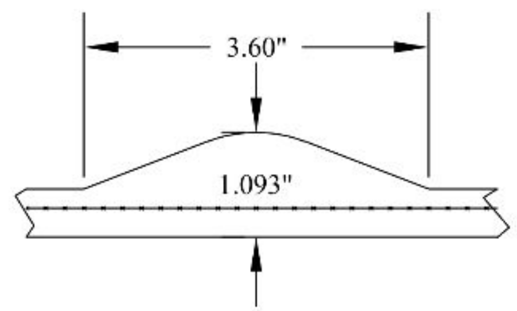
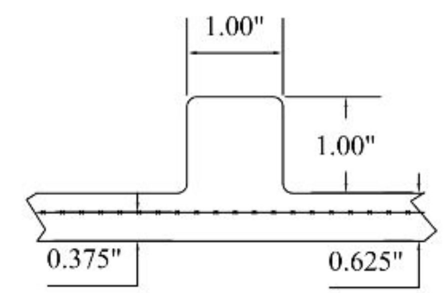
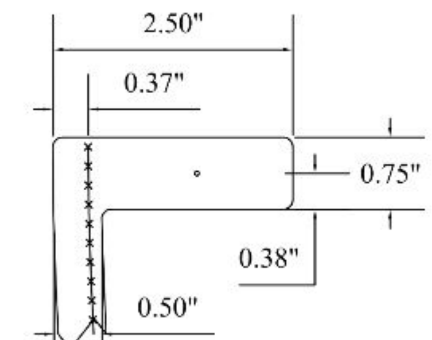


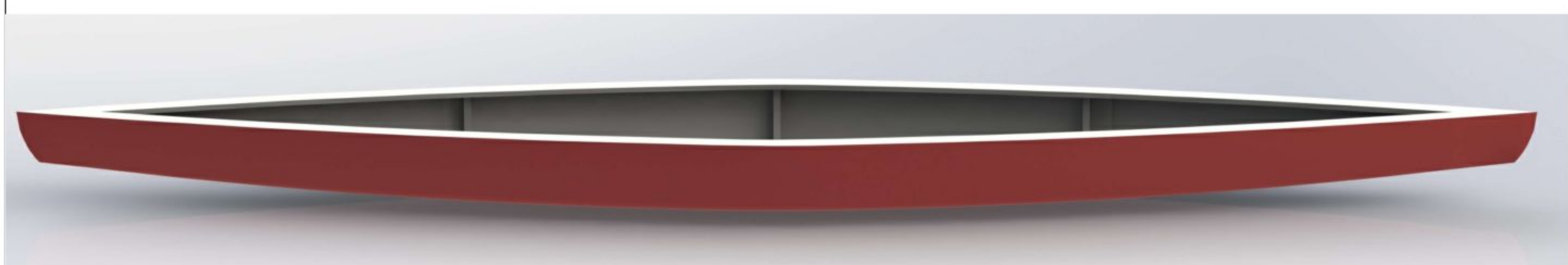
3 EDGE RIB DETAIL
Scale: 1:2



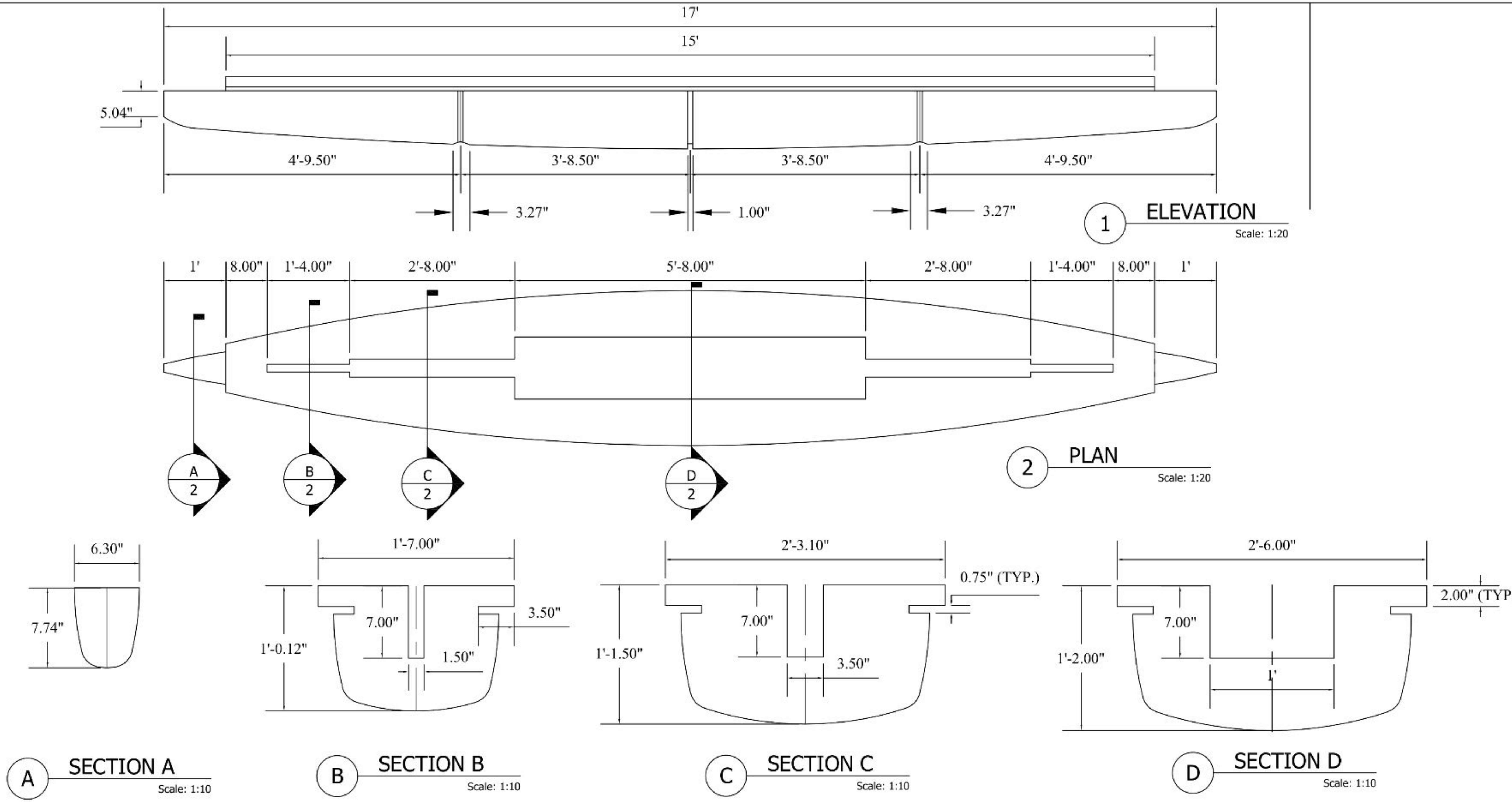
4 CENTER RIB DETAIL
Scale: 1:2

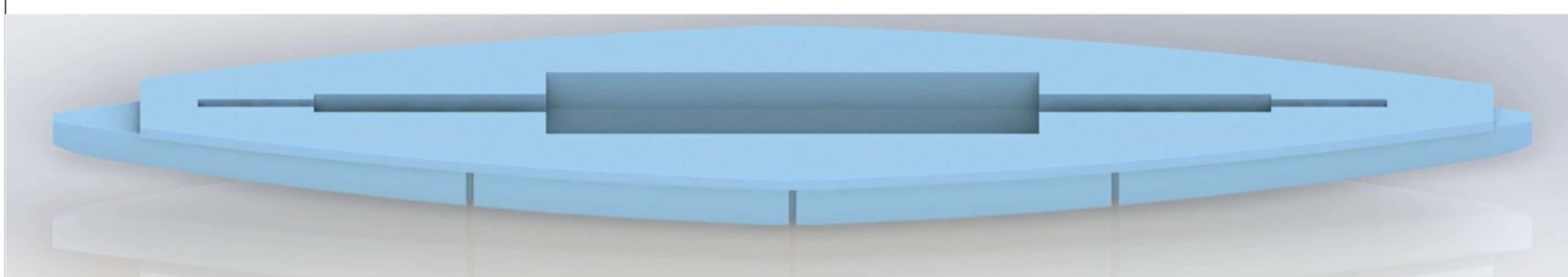


B GUNWALE
Scale: 1:2



PROJECT: DP2024_CC1	UCONN SCHOOL OF ENGINEERING Concrete Crustacean
DRAFTED BY: M. LARKIN	
CHECKED BY: C. PENG	
DATE: 2/14/2024	SHEET NO. 1 OF 2





PROJECT: DP2024_CC1	UCONN SCHOOL OF ENGINEERING Concrete Crustacean
DRAFTED BY: M. LARKIN	
CHECKED BY: C. PENG	
DATE: 2/14/2024	SHEET NO. 2 OF 2

Appendix A

ASTM (2023). "Standard Specification for Lightweight Aggregates for Structural Concrete." C330/C330M-23, West Conshokocken, PA.

ASTM (2016). "Standard Specification for Pigments for Integrally Colored Concrete." C979/C979M-16, West Conshokocken, PA.

ASTM (2016). "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading)." C293/C293M-16, West Conshokocken, PA.

ASTM (2017). "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens." C496/C496M-17, West Conshokocken, PA.

ASTM (2019). "Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete." C309-19, West Conshokocken, PA.

ASTM (2020). "Standard Test Method for Air Content of Hydraulic Cement Mortar." C185-20, West Conshokocken, PA.

ASTM (2020). "Standard Test Method for Determining Density of Structural Lightweight Concrete." C567/C567M-19, West Conshokocken, PA.

ASTM (2020). "Standard Test Method for Slump of Hydraulic-Cement Concrete." C143M-20, West Conshokocken, PA.

ASTM (2020). "Standard Specification for Chemical Admixtures for Concrete." C494/C494M-17, West Conshokocken, PA.

ASTM (2020). "Standard Specification for Silica Fume Used in Cementitious Mixtures." C1240-20, West Conshokocken, PA.

ASTM (2022). "Standard Specification for Portland Cement." C150M-22, West Conshokocken, PA.

ASTM (2023). "Standard Specification for Fiber-Reinforced Concrete." C1116/C1116M-10a, West Conshokocken, PA.

ASTM (2023). "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." C39M-21, West Conshokocken, PA.

ASTM (2023). "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete." C138M-23, West Conshokocken, PA.

Bühler, E., & Norchem-Ferroglobe. (2022). Silica Fume's Contribution to Sustainability. *Creative Concrete Construction*. Aspire Bridge Magazine.

G, A. (2012, September 12). *Finding external tangent points for two circles*. Andy G's Blog. https://gieseanw.wordpress.com/2012/09/12/finding-external-tangent-points-for-two-circles/

University of Connecticut Concrete Canoe (2019). "Graveyacht" NCCC Design Paper, University of Connecticut, Storrs, CT.

University of Connecticut Concrete Canoe (2020). "Yacht Rod" NCCC Design Paper, University of Connecticut, Storrs, CT.

University of Connecticut Concrete Canoe (2021). "Kaiju Kanoe" NCCC Design Paper, University of Connecticut, Storrs, CT.

Silica fume applications in sustainability. (n.d.-a). Norchem. https://norchem.com/applications-sustainability.html

SolidWorks [Computer software]. (2019). Vélizy-Villacoublay, France: Dassault Systemes.

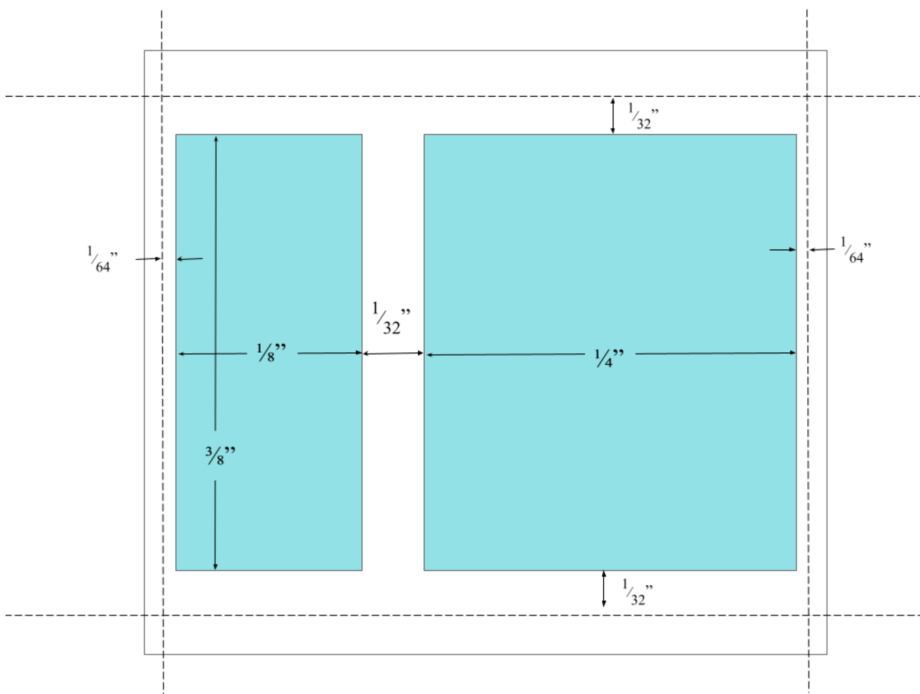
StructX. (2022, April 24). Statics. https://structx.com/statics.html

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

Table 4. Reinforcement Dimensions and Calculations for Carbon Fiber

Carbon Fiber			
	Length	**Width**	**Area** (Length x Width)
Open Area	1.59094in	1.59094in	2.5311in²
Total Area	1.65in	1.65in	2.7225in²
Percent Open Area	= (Open Area/ Total Area) * 100% = (2.5311in²/ 2.7225in²) * 100% **= 92.97%**		

A single repeatable section of reinforcement is called a unit. For the carbon fiber reinforcement, the unit was a square, with its length and width in Table 4 above. This open area and total area resulted in a 92.97% open area which is compliant to the 40% minimum. There are two different sized open areas within the fiberglass reinforcement. One open area is a thin rectangle while the other is a more stretched rectangle with the reinforcement separating the two and adding padding to the sides and tops, as seen in the following diagram.



Fiberglass Reinforcement Unit Section

This diagram was used to calculate the percent open area of the fiberglass and can be seen in the Table 5 below.

Table 5. Reinforcement Dimensions and Calculations for Fiberglass

Fiberglass Reinforcement			
	Length	Width	Area (Length x Width)
Smaller Rectangle Open Area	1/8 in	3/8 in	3/64 in²
Larger Rectangle Open Area	1/4 in	3/8 in	3/32 in²
Total Area	7/16 in	7/16 in	49/256 in²
Percent Open Area	= [(Small Open Area + Large Open Area)/ Total Area] * 100% = [(3/64 in² + 3/32 in²)/ 49/256 in²] * 100% **= 73.469%**		

These calculations resulted in 73.469% open area, meeting the minimum 40% open area. Both of the reinforcement types are compliant.

There are five major reinforcements and concrete thickness throughout *Concrete Crustacean* which are the following:

1. Bottom of the canoe
2. Bottom of the canoe at a transverse rib
3. Wall of the canoe
4. Wall of the canoe at a transverse rib
5. Gunwale

Layer Thicknesses (in)	
Bottom	0.625
Wall	0.625
Rib	1
Carbon Fiber	0.05906
Fiberglass	0.03937

Layer Specifications				
	Bottom	Bottom at Rib	Wall	Wall at Rib
Composition	0.375" Concrete Carbon Fiber Fiberglass 0.25" Concrete	1" Concrete Rib 0.375" Concrete Carbon Fiber Fiberglass 0.25" Concrete	0.375" Concrete Carbon Fiber Fiberglass 0.25"' Concrete	1" Concrete Rib 0.375" Concrete Carbon Fiber Fiberglass 0.25" Concrete
Total Reinforcement Thickness (in)	0.09843 (Fiberglass + Carbon Fiber)	0.09843 (Fiberglass + Carbon Fiber)	0.09843 (Fiberglass + Carbon Fiber)	0.09843 (Fiberglass + Carbon Fiber)
Total Thickness (in)	0.625	1.625 (Rib + Bottom)	0.625	1.625 (Rib + Wall)
Reinforcement Thickness (Total Reinforcement/ Total Thickness)	15.75%	6.06%	15.75%	6.06%
Status	Compliant	Compliant	Compliant	Compliant

Pre-Qualification Form (Page 1 of 2)

University of Connecticut
(school name)

We acknowledge that we have read the 2024 ASCE Society-wide Concrete Canoe Competition Request for Proposal and understand the following (*initialed by one (1) team captain and ASCE Faculty Advisor*):

Statement	Captain Initials	Advisor Initials
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.	CP	KW
The eligibility requirements of registered participants (Section 3.0 and Exhibit 3).	CP	KW
The deadline for the submission of *Letter of Intent, Preliminary Project Delivery Schedule* and *Pre-Qualification Form* (uploaded to ASCE server) is November 3, 2023; 5:00 p.m. Eastern.	CP	KW
The last day to submit *ASCE Student Chapter Annual Reports* to be eligible for qualifying (so that they may be graded) is February 1, 2024.	CP	KW
The last day to submit a *Request for Information* (RFI) to the C4 is January 29, 2024.	CP	KW
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.	CP	KW
The submission date of the *Project Proposa*l, *Mix Design Sheets*, and *Materials Notebook* for the Student Symposium Competition (uploading of electronic copies to ASCE server) is Friday, February 16, 2024.	CP	KW
The submission date of the *Project Proposa*l, *Mix Design Sheets*, and *Materials Notebook* for Society-wide Final Competition (hard copies received by ASCE and uploading of electronic copies to ASCE server) is May 15, 2024; 5:00 p.m. Eastern.	CP	KW

Catherine Peng — *Team Captain*   10/26/23 — *(date)*   Kay Wille — *ASCE Student Chapter Faculty Advisor*   10/26/2023 — *(date)*

Catherine Peng — *(signature)*   Kay Wille — *(signature)*

Pre-Qualification Form (Page 2 of 2)

__**University of Connecticut**_____________________
(school name)

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?

The University of Connecticut Concrete Canoe Association has a Health & Safety that has been approved by our faculty advisor and the UConn School of Engineering. Training must be completed on all equipment prior to use, and the club officers receive safety training to be able to safely oversee the members.

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?

QC checks are to be performed by the officers of the club before, during, and after the construction of the canoe. The officers will work alongside our club advisors to maintain the quality of our work, and also to keep the organization on schedule to be able to compete.

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?

The team has reviewed the University safety policies as well as the UConn School of Engineering's safety policies regarding research, material lab testing, construction, and transportation.

In 150 words or less, provide your team's perspective on the use of ChatGPT and other AI/NLP algorithms in the competition. Do you intend to use it? If so, in what areas? (Note: C4 neither encourages or discourages the use of AI/NLP algorithms, but is interested in collecting data on student usage in the competition.)

The team is not intending to use Chat GPT and other AI/NLP algorithms in the competition.

The core project team is made up of __20__ number of people.

November 3, 2023

ASCE Student Services
1801 Alexander Bell Drive Reston,
VA 20191
Attn: ASCE Concrete Canoe Competition Committee

Dear ASCE Concrete Canoe Competition Committee:

The University of Connecticut Concrete Canoe Association acknowledges the receipt of the Request for Proposals. We confirm the University of Connecticut's participation in the 2023-2024 competition in accordance with all rules and regulations. We are confident that we will be able to build a canoe and make a full technical report and presentation.

Sincerely,

Catherine Peng
(860) 328-4628
catherine.peng@uconn.edu

Kay Wille
(860) 486-2074
kay.wille@uconn.edu

University of Connecticut
223 Glenbrook Rd,
Storrs, CT 06269