THE MUSTANG

CONCRETE CANOE PROJECT PROPOSAL 2024

Brigham Young University
Engineering Building, Campus Drive, Provo, UT 84606

Brigham Young University
Concrete Canoe Team

February 16, 2024
Committee on Concrete Canoe Competitions (C4)
ASCE Student Services
1801 Alexander Bell Drive
Reston, VA 20191
Attn: Concrete Canoe

Subject: Response to C4 Request for Proposal– 2023-2024 Concrete Canoe

The 2024 Brigham Young University Concrete Canoe Team enthusiastically presents their Project Proposal to C4 in preparation for the ISWS Conference (April) and Championship Competition (June). While it took a few times to review and re-review portions of the *Request for Proposal*, the BYU Team assures that the following submission fulfills the required rules and regulations and hopes C4 will come to the same conclusion. The team gladly confirms that:

- "The proposed hull design, concrete mixture design, reinforcement scheme, and construction of the prototype canoe have been performed in full compliance with the specifications outlined in the *Request for Proposal*.
- "Material Technical Data Sheets (MTDS) and Safety Data Sheets (SDS) have been reviewed by the team for completeness and compliance.
- "The team acknowledges receipt of the *Request for Information* (RFI) Summary and that their submissions comply with the responses provided.
- "The anticipated registered participants are qualified student members and Society Student Members of ASCE and meet all eligibility requirements (including names and ASCE Society Member ID Numbers).
- "All text generation AI/NLP algorithm uses are properly cited within the respective document," (*Request for Proposal*, Section 5.4.1.2).

The following team members and their ASCE ID numbers are listed below:

Justin Booher	000012269057
Emily Cooper	000012218090
Josh Fenwick	000012335600
Josh Gleim	000012382012
Mary Lee	000012218740
Landon Moore	000012361453

As proud members of ASCE, BYU Team members are excited to participate and compete in this year's Concrete Canoe competition to "support regional lake and river transportation across the US", as predefined in section 1.1, *Problem Statement*, of the *Request for Proposal*.

The Captain and Advisor signatures below confirm the validity of the previous statements and hold members of the Brigham Young University Concrete Canoe Team responsible for any information included in this Project Proposal.

Sincerely,

Emily Cooper
Team Captain

(signature)

ewalmer@byu.edu
(530)608-7142

Clifton B. Farnsworth
ASCE Student Chapter Faculty Advisor

(signature)

clifton_farnsworth@byu.edu
(801)422-6494

Table of Contents

Table of Figures

List of Tables

Executive Summary

Brigham Young University (BYU) Concrete Canoe team was tasked with designing and casting a full-scale canoe made of concrete to in water and maneuver through obstacles. Team members prepared to present and race a full-scale model of our canoe at the regional and society-wide competitions. In the regional competition, the canoe placed 2nd in women's sprint, men's slalom, and the co-ed sprint. The canoe took 4th in women's slalom and 5th in Men's Sprint. The team finished in 3rd place in the overall competition.

The concrete mix we used was designed to be lightweight and strong. To accomplish this, we used Poraver and Utelite as aggregate. It had a moist unit weight of 71.4 pcf and a slump of 3.5 inches. The dry unit weight was found to be less than water at 58.98 pcf. Since it was less then water, the canoe exhibited excellent floatation and passed the swamp test on race day. The unreinforced compressive and tensile strengths were 1470 psi and 230 psi respectively. From a longitudinal structural analysis, the required compressive and tensile strengths were 92 and 198 psi.

In the regional competition, our canoe was one of the only ones to remain intact throughout the competition. The canoe handled the stress of the competition race day and would perform well in everyday use if chosen to be mass produced. During the races, it was also discovered that this canoe handles well in the water. The hydrodynamic hull design allows the ability to travel in a straight line without sacrificing the maneuverability of the canoe in the slalom courses.

The canoe was designed and cast in BYU's engineering facilities including the CAEDM labs and the concrete lab. The canoe was 19.5 feet long, 2.5 feet wide, and 1.25 feet tall. The walls were 0.75 inches thick. The canoe weighed 480 pounds during curing. The canoe was modeled after the P51 Mustang "shark mouth" design from World War II and took 2nd place in the regional competition for final product.

Preliminary Design Report

Project Management

Key Team Roles & Organization Chart

Capstone Member/Captain

JUSTIN BOOHER

Senior

Headed mix design and calculations as well as material purchases.

Capstone Member/Captain

EMILY COOPER

Senior

Coordinated canoe mold, hull design, and paper.

Capstone Member/Captain

JOSH FENWICK

Senior

Managed the schedule, structural analysis, and oversaw construction.

Club Members

All members participated in mixing materials in preparation of testing the concrete as well as in the canoe casting process.

JOSH GLEIM

Junior

MARY LEE

Junior

LANDON MOORE

Junior

<u>Advisors and Consultants</u>

Mason Millard (Graduate Student)
Dr. W. Spencer Guthrie
Dr. Clifton Farnsworth
Dr. Harold Mitchell
Dr. Rollin Hotchkiss

Introduction

The competition was formatted as a request for proposals. This report is our proposal and, as such, outlines the prototype design, project management, and final product of our canoe. The report begins with project management information including team organization, project scheduling, and QA/QC. Following project management, the hull design method, structural analysis, mix design and construction processes are outlined. Lastly, the production proposal is presented detailing why our team's product is the best option for the judges to contract and mass produce.

As outlined in the report, our canoe is the best option for several reasons. While it is relatively lightweight, it is also extremely strong and will hold up in most boating conditions. Also, the materials are sustainably sourced and will be available even as nonrenewable energy processes are phased out. Last, the white cement creates a blank canvas allowing it to be decorated with any imaginable design.

Project Scope

The scope for this project encompasses the research, design, testing, and construction of a fully functional canoe made of concrete. To fulfill this goal, the team will need to research and select materials that meet all competition guidelines provided by the Concrete Canoe Competition Committee (C4) and corresponding ASTM specifications. These specifications are found in the Request for Proposal document. Extensive testing of the concrete mix design will need to be performed to ensure structural integrity, buoyancy, and adequate competition performance. The canoe and corresponding report will need to be completed in order to compete in the competition. To achieve this goal the team is required to develop a hull design, a structural analysis, a concrete mix, and ultimately construct a canoe that meets the C4 requirements. The team will also be required to utilize skills such as project management, coordination of resources, budgeting, and risk management as we prepare all necessary deliverables for this project. The team's initial response to the request for proposals, supporting documentation, and qualifications are provided in Appendices C and D.

Health and Safety

Concrete Mixing

On mixing days, team members would wear safety glasses to protect their eyes from dust and flying particles as well as gloves to protect hands from reactive chemicals and materials. This followed lab protocol as well as gave students the assurance that no harm would come to them. Long hair was pulled back to ensure it did not become entangled in machinery or mixing materials. Long pants were worn to protect exposed skin from any possible but unlikely spills. Closed toed shoes were worn to ensure feet and toes were protected from heavy materials in the event that something fell. On days working with the steel reinforcement wire mesh, thick leather gloves were used to protect hands from cuts and scrapes on the sharp ends of the wire. Proper trainings from the lab instructor were also conducted on how to use lab tools and power tools in the BYU concrete laboratory. A training was given on how to use heavier machinery like the concrete mixer, to ensure that nobody was injured during the casting day.

Team Member Training

In order to meet in the Concrete Lab on BYU campus, at least one team member was required to have completed the full lab training. This team member would supervise any other member who was participating in mixing or testing activities. Only those who had passed the appropriate trainings were certified to run test machinery. If no one would be present who could meet those requirements, the team postponed meetings or found alternative meetings to review competition requirements as listed in the *Request for* Proposal, or research aggregates and reinforcement options so as to comply with training requirements.

Staining the Canoe

Concrete stains are inherently a hazardous chemical and because of this, the team decided that the stain would be applied after all other sanding and finishing was done. When the stain was applied there would be a small group of people working on it that were aware of the potential hazards. Each person helping with the stain was required to wear an N95 mask and gloves while handling this chemical. The stain was sprayed on using a one-gallon pump sprayer. Another team member would spread out any spots that were thick with a paint brush without getting close to the person spraying. The work was done in a well-ventilated area in the BYU Concrete Lab. Approval for use of the chemical was received by Dr. Guthrie, the faculty in charge of the lab. Team captains with the necessary training were present to ensure that the chemicals were handled properly. All people involved in the application of stain would promptly wash it off if any came in contact with their skin.

Project Management Plan

The team began planning our main schedule at the beginning of the BYU Fall 2023 Semester. Meetings were held to calculate inventory of materials in the Concrete Canoe Club supply as well as to recruit new team members for the upcoming competition. A kickoff meeting was held to determine the theme and gather design ideas from potential team members. This would serve as a starting block for the course of the rest of the planning process.

As Brigham Young University does not accept recurring sponsors or solicit recruiting sponsors from outside resources, the team acquired funding from a grant given by the Weidman Center, a part of the University. Due to the combination of awarded grant funds to the whole of the BYU ASCE Student Chapter, around half of the $3000 awarded to the Chapter was allotted to the concrete canoe team while the other half was reserved specifically for ISWS competition costs and the Championship Competition to be hosted by the University this coming June. An addition $200 was given to the capstone team as a general allotment from the University Civil Engineering Department. Any costs incurred over the course of the planning, building and purchasing process would have to be approved by the Faculty Advisor, Dr. Farnsworth. It was in the best interest of the team to spend as little as possible, relying mainly on supplies left from previous years, or to ask companies for donations when looking for supplies.

Captains Justin and Josh underwent the training course required to access the concrete lab on BYU campus so that meetings could be held without requiring the attendance of faculty members. All team members attending activities in the lab were required to work under the supervision of these two captains. Prior to the completion of these trainings by said captains, meetings were held under the supervision of Graduate Student, Mason Millard.

It was intended that most of the mix design and testing would take place during the beginning of the BYU Winter 2024 Semester beginning a week or two after classes started. The culminating club events would be the testing of the final mix design, the cutting of the canoe mold through the BYU Prototyping Lab, and the casting of the canoe. The casting was to begin close to the submission of the Proposal so as to give the canoe a full 28-day cure.

While the mix was intended to be finalized at least 2 weeks prior to the submission of the Project Proposal, it was discovered that the materials in the Concrete Canoe stock were not sufficient to support the creation of a full-length canoe. Due to this miscalculation in inventory, the mix was not finalized until the week before the submission of the Proposal. The missing expanded glass aggregates required a minimum shipping estimation of 2 weeks. Under these circumstances, as well as a price underestimate for the mold supplier, the construction of the canoe will not begin until at least 2 weeks after the submission of the Project Proposal. Once materials have been received and the mold has been completed by the BYU Prototyping Lab, construction may begin and will be completed a couple weeks before the ISWS competition in Utah State.

Quality Assurance and Quality Control

Quality Assurance (QA) is putting procedures in place to ensure that the project will meet all the project specifications. The team started the quality assurance plan by organizing the necessary lab training for the team captains to ensure lab safety compliance. A plan was made with the faculty member in charge of the lab to coordinate our concrete canoe club activities.

At the start of the mixing process the team referred to the specifications for the competition and planned a mix that conformed to the required aggregate and cementitious materials requirements. We chose aggregates, cementitious materials, chemical admixtures, and fibers that conformed to the necessary ASTM requirements specified in the RFP document. The team also ensured that we did not exceed 50 percent by mass of total cementitious material content.

When selecting reinforcement, the team ensured that our steel wire mesh conformed to the RFP standards and that our percent open area was at least 40 percent. To meet curing specifications, we decided to that we would not use a curing or sealing compound, and instead decided to cure the canoe by a conventional method of covering it in plastic and spraying it once a day with water to keep the mix wet and avoid plastic shrinkage cracking. When selecting finishing methods, we decided that we would sand the canoe to get a smooth finish and then apply concrete stain using the safety measures explained earlier in the report. Proper documentation was planned according to the contents of the RFP document to ensure our report meets the specifications as well.

Quality Control (QC) is applying methods of testing to assess the conformance specifications after development. The team put measures in place when in the lab to ensure that our product met specifications during and after development. On the mix design days, we made sure that there was good communication when weighing and mixing material to make sure that we had the correct amount of each material in our mix. We tested the slump of our mix and the unit weights according to ASTM standards. Cylinders were cast and tested according to ASTM standards as well.

For our casting day we planned to have popsicle sticks that were marked with our canoe wall thickness achieve the desired thickness. We had someone assigned to double check this and help people know where more mud was needed and where it was too thick. The team captains made sure that proper finishing techniques were used to make a smooth finish on the canoe. On casting day, the reinforcement cage also was checked and adjusted by cutting wire and patching it where necessary with steel wire ties of the same gauge to make it sit at the right height between the two layers of concrete.

The quality assurance and quality control plans helped to create plan for canoe construction and construct a canoe that meets all specifications in the RFP. Our QA plans were enacted on lab days and the QC was used to correct any defects that would not meet the specifications.

Research and Development Costs

As shown in the Research and Development Fee Schedule below, the primary cost was labor. Labor costs in the research and development (R&D) stage were much higher than projected labor costs for the product for two reasons. First, labor in the R&D stage consisted of a much higher percentage of testing, designing, and quality analysis by engineers and managers. Second, much of the labor in the R&D stage consisted of testing and analysis that won’t be required during the production of individual canoes. Our laboratory already had the requisite facilities to complete all R&D activities, reducing testing costs to that of disposable equipment such as cylinder molds.

Research and Development Cost – Fee Schedule

Fee Schedule - Page 1

Research and Development Fee Schedule

Project Total Hours	
Work Scope	Hours
Project Management	72
Hull Design	6
Structural Analysis	5
Mix Design & Testing	64
Mold Construction	11
Canoe Construction	110
Project Proposal Preparation	46
Presentation Preparation	5
Display Preparation	32
Total	**351**

R&D Labor Costs				
Role	RLR	DEC	HRS	Extended
Principal Design Engineer	$ 50.00	1.5	39	$ 2,925.00
Design Manager	$ 45.00	1.5	18	$ 1,215.00
Project Construction Manager	$ 40.00	1.5	8	$ 480.00
Construction Superintendent	$ 40.00	1.5	15	$ 900.00
Project Design Engineer (P.E.)	$ 35.00	1.5	42	$ 2,205.00
Quality Manager	$ 35.00	1.5	10	$ 525.00
Graduate Field Engineer (EIT)	$ 25.00	1.5	61	$ 2,287.50
Technician/Drafter	$ 25.00	1.5	29	$ 1,087.50
Laborer	$ 25.00	1.5	94	$ 3,525.00
Clerk/Office Admin	$ 20.00	1.5	24	$ 720.00
Labor Subtotal			340	$ 15,870.00
Profit Multiplier (P)			18%	$ 2,856.60
R&D Direct Labor Total (DL)				**$ 18,726.60**

DL Total	$ 18,726.60
Expenses Total	$ 6,367.96
R&D Total Cost	**$ 25,094.56**

R&D Expenses			Cost
Materials / Other Cost			
Concrete Supplies			$ 714.05
Concrete Supplies Shipping			$ 530.00
Testing Supplies			$ 84.00
Testing Equipment			$ 11.00
Mold (lump sum cost)			$ 783.00
Content Production Costs			
Display Materials			$ 42.00
Printing			$ 25.00
Shipping / Travel Costs for Competition			
Vehicle / Fuel			$ 740.00
Accommodations			$ 660.00
Outside Consultants	HRS	$/HR	Extended
	11	200	$ 2,200.00
Expenses Subtotal			$ 5,789.05
Markup (M)	10%		$ 578.91
R&D Expenses (E)			**$ 6,367.96**

Project Schedule

SCHEDULE

Date	Deadline/Activity
9/5/2023	Issuance of Request for Proposal
9/25/2023	Kick-Off Webinar
10/3/2023	Lab Training
10/5/2023	Miniature Canoe Practice Mold
10/19/2023	Theme Design Session
11/3/2023	Letter, PQ Form, and Schedule Deadline
11/9/2023	Miniature Canoe Practice Pour
11/14/2023	Structural Calculations Webinar
11/16/2023	Mix Design
11/30/2023	Mix Design
12/--/2024	Infographic Webinar
12/14/2023	Finals Week
1/--/2024	Materials Notebook Webinar
1/18/2024	Welcome Activity
1/25/2024	Mold construction
1/29/2024	RFI Deadline
2/1/2024	Construction Preparation
2/1/2024	ASCE Reports and Dues Deadline
2/3/2024	Casting activity weekend
2/8/2024	Project Paperwork
2/15/2024	Project Paperwork
2/16/2024	Symposia Content Deadline
2/22/2024	Leadership Meeting
2/29/2024	Club Logistics Meeting
3/2/2024	Demold Canoe
3/7/2024	Presentation boards and display
3/14/2024	Build transport
3/21/2024	Rowing Activity
3/28/2024	Leadership Meeting
4/4/2024	Conference Preparation
4/11-13/2024	Symposia Competition
5/15/2024	Society-wide Content Deadline
6/20-22/2024	Society-wide Competition

Legend
ASCE Deadlines
Design and Construction

Technical Design and Construction Support

Hull Design

The hull of "The Mustang" was taken from a Brigham Young University team hull designed in 2010. This hull design is shown in the Construction Drawings section of the appendix (pages 19-20). The hull was chosen due to its flat but slightly rounded base, its slight variation between bow and stern, its curved hull, and its dimensions. In the 2023 ISWS Concrete Canoe Competition, the BYU Banana Float canoe had difficulty in maintaining control while steering. The flat base of the canoe, though gave it more stability, created an exceptionally difficult canoe to control. This did not pose a real threat during the slalom race—as the natural tendency for the canoe to turn made it easy to maneuver the buoys with little redirection—but it made the sprint quite difficult as racers constantly had to overcorrect when the canoe began to divert from the definite path ahead.

The 2010 BYU canoe is relatively long and wide in comparison to most recent years and has a shallow hull. Although these dimensions may seem to create a slower build, it aids the canoe in floatation and steering. The added width and length on the canoe create more surface area which will be in contact with the water. This addition of surface area will make it easier for the canoe to float given its weight. The shortened depth in comparison to the Banana Float is offset by the raised canoe ends. Raising the bow and stern will set the center of the hull deeper into the water, reducing the risk of overturning—the center of gravity of the boat will be lower to the water, ideally below the water level outside of the boat—and make it harder for the canoe to turn due to wake. The hull walls will be 0.75" thick with reinforcement at a depth of 0.375" as shown in appendix B.

Structural Analysis

Longitudinal Analysis

In this longitudinal analysis the canoe was modeled as a beam with point loads representing the weight of the paddlers. The controlling load scenario was found to be the coed race. For this scenario, the maximum moment and shear forces are 307 pound-feet and 141 pounds respectively as plotted in Figure 1. The moment of inertia is 553 inches to the fourth and the extreme compressive and tensile fiber distances are 4.34 inches and 9.31 inches respectively. The safety factor of 3.2 was applied to account for any inconsistencies in concrete production, dynamic increases in load due to paddling, and potential errors during fabrication. With these values, the required compressive and tensile strengths are 92 psi and 198 psi respectively.

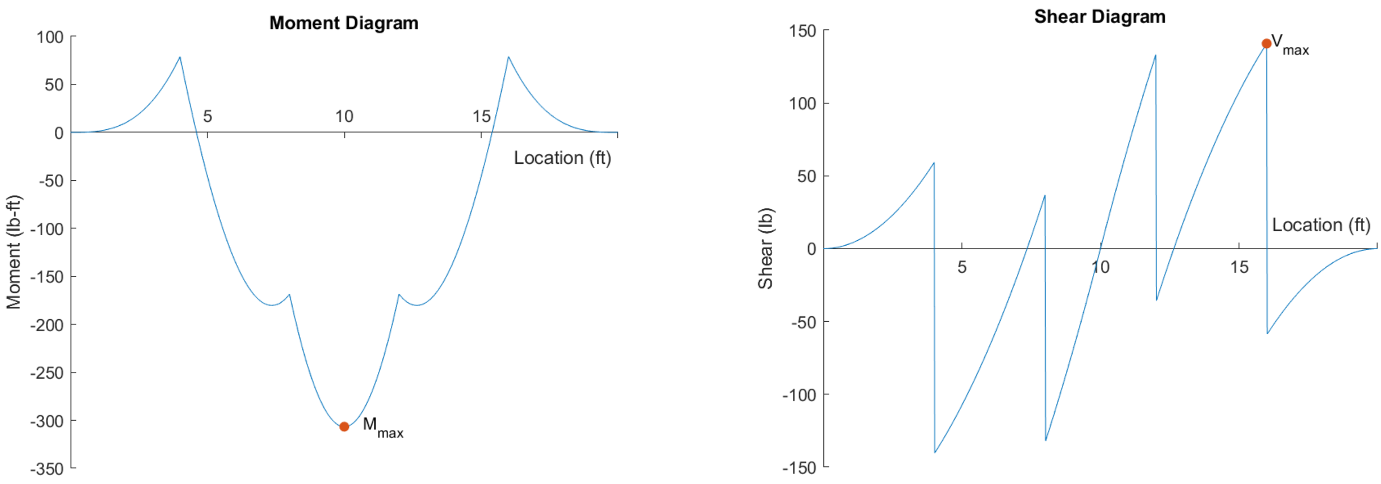


Figure 1: Moment and Shear Diagrams

Failure Envelope Analysis

The concrete mixture's allowable compressive and tensile strengths were determined through testing to be 2100 psi and 324 psi respectively. The Mohr's circles for these strengths are plotted in Figure 2. These circles are connected by tangent lines to create a failure envelope. The y-intercept of these tangent lines is the allowable shear of 416 psi. The slope of these lines is 1.09. The previously defined required strengths are plotted in an additional circle. As the circle for the required strengths is totally enclosed in the failure envelope, the canoe is not expected to fail due to flexure.

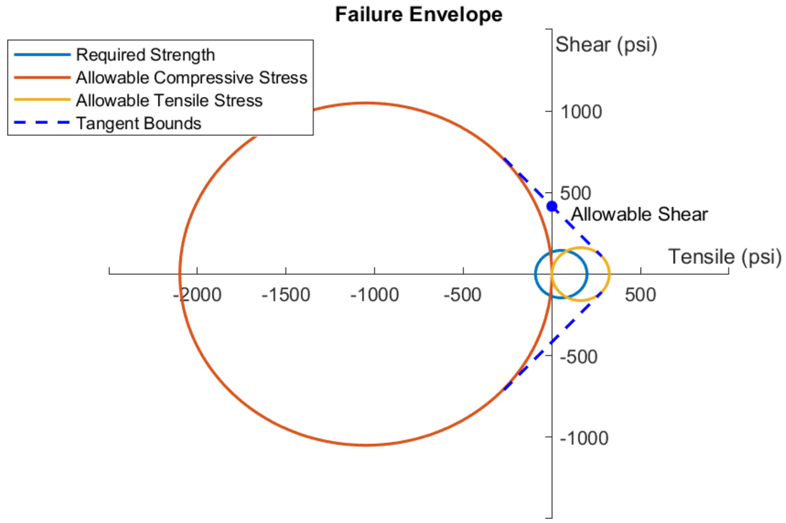


Figure 2: Failure Envelope

Punching Shear Analysis

Punching shear from paddlers' knees is modeled as a circular column with a radius of 3 inches. With this, the critical area is 14.1 square inches and the punching shear demand is 9.96 psi. The punching shear capacity, calculated using the equations in ACI 318, Table 22.6.5.2 is 96.1 psi. The capacity is 10% of the demand, so the canoe is not expected to fail due to punching shear.

Conclusion

The stresses computed in the longitudinal and punching shear analyses both result directly from the weight loads of the paddlers. However, the longitudinal stresses result from flexure while the punching shear stresses result from shear stresses normal to the canoe's surface. The canoe must be designed against both modes of failure to ensure it will safely perform under the anticipated loads. As shown in these three analyses the canoe is not expected to fail due to flexure or punching shear.

Mix Design

Materials Selection

For our mix design this year, we started by referencing the mix design from the BYU Banana Float Canoe from the 2022-2023 competition. Their mix from last year was less dense than water, had a low slump to make it easier to apply on casting day, had high air content, was ductile in flexural strength, and it experienced minimal cracking during transportation to the ISWS competition. We adjusted the mix according to the availability of materials. The team also used Geofortis which has not been used in BYU concrete canoes before.

For our aggregates we primarily used Poraver expanded glass aggregate due to its lightweight properties. We used this product in 2-4mm, 0.5-1mm, 0.25-0.5mm, 0.1-0.3mm, and 0.04-0.125mm particle sizes. We also used expanded shale aggregate from the Utelite company. Utelite was used because it will provide more strength to our mix than the expanded glass but is still considered lightweight aggregate. Material specific gravities and absorption values are listed below in Table 1.

Table 1: Aggregate Properties

Aggregate	SG	Absorption Value (%)
Utelite	1.78	13.3
Poraver 2-4mm	0.37	23.0
Poraver 0.5-1mm	0.45	20.0
Poraver 0.25-0.5mm	0.68	28.0
Poraver 0.1-0.3mm	0.85	35.0
Poraver 0.04-0.125mm	0.80	35.0

For our cementitious materials we used Type 1 Portland White Cement, blast furnace slag, Geofortis natural pozzolan, metakaolin, and lime. Our original plan was to use fly ash however, with changes to environmental standards, coal production has decreased making fly ash less available on the market. To complete our canoe, we decided to use Geofortis natural pozzolan because it is marketed to be a valid substitute for fly ash. The Geofortis company donated some material to us for use in the canoe to see how it would perform in that setting.

The chemical admixtures used in the team's mix consisted of a superplasticizer, an air entrainer, and a hydration stabilizer. These admixtures have yielded positive results in previous canoes for ease of casting, higher air content, and reduced set times.

We tested four batches of concrete during our mix design phase, however due to an inventory mishap three of the four mixes were unable to be used. One of our buckets of slag was mislabeled as white cement and was used in those three mixtures. When removing our material from the cylinder molds after casting we discovered that the mix crumbled and was not setting properly. We discovered our error and then designed our fourth and final batch. It yielded satisfactory test results, so we decided to use that for our final mix design (see pages 21-22).

Selection of Reinforcement

The team selected reinforcement based off of materials used in previous years. Carbon fiber, hexagonal chicken wire, and square steel fencing wire were all considered. We ultimately decided that we would use 19-gauge 1/2 in square steel fencing wire because it met the open area requirements (as shown in appendix B), was cost effective, and would be easier to shape and work with than the hexagonal wire.

Figure 3: Steel Reinforcement Shaping

Test Results

We performed the following test per ASTM standards on our final concrete mixture. When we were mixing our concrete, we performed a slump test and got a value of 3.5 inches. This slump would allow the mix to hold its shape when casting it on the canoe walls. The team also performed a unit weight bucket test and from this we calculated a wet density of 71.4 pcf and a dry density of 58.98 pcf, less than the unit weight of water. Our compressive strength testing yielded an average 7-day compressive strength of 1470 psi which would correlate to a 28-day strength of 2100 psi. The splitting tensile strength test yielded a result of 230 psi. We also performed a flexural strength test, and it yielded a value of 1640 psi. These results showed that we had a concrete mix that would perform well at the competition and in transit. Figure 4 below shows the set up for our three strength tests.

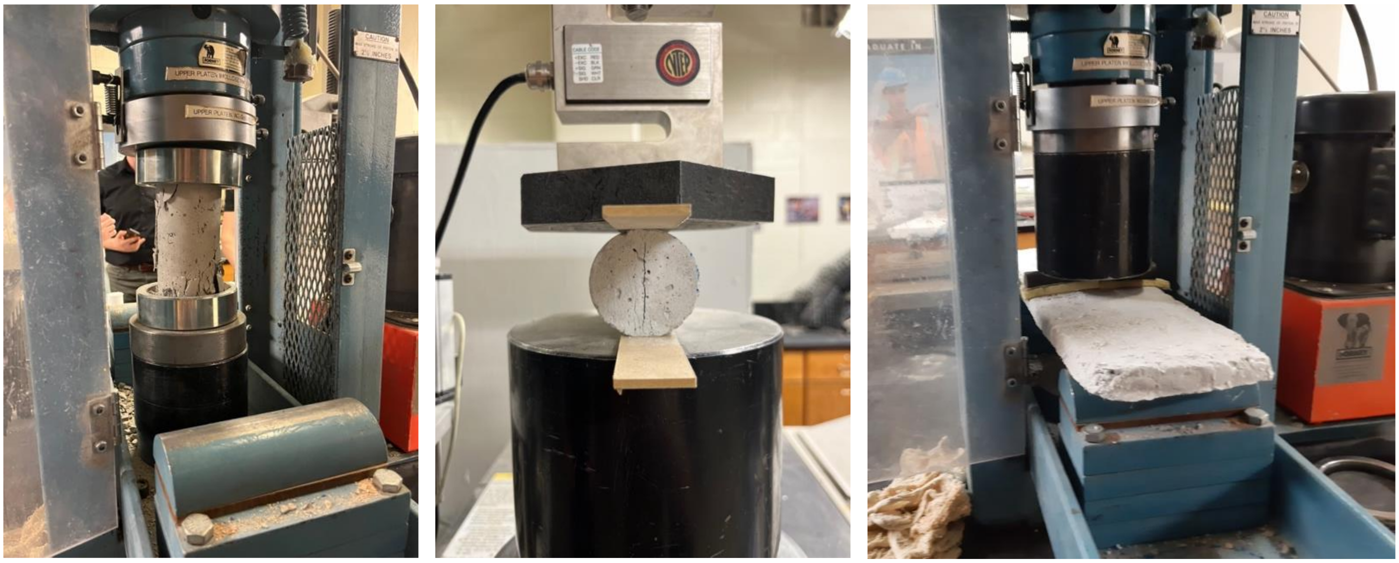


Figure 4: Compressive (left), Splitting Tensile (middle), and Flexural (right) Strength Testing

Construction Process

We cast the canoe over a male polystyrene foam mold. The foam sheets were cut into sections in the BYU Prototyping lab using a CNC routing machine. The team took the final cross sections and assembled the final mold in the lab using rebar and silicone sealant. The team then sanded the mold to the smooth shape of the canoe. Figure 5 below shows this process from the Prototyping Lab to the sanded mold.

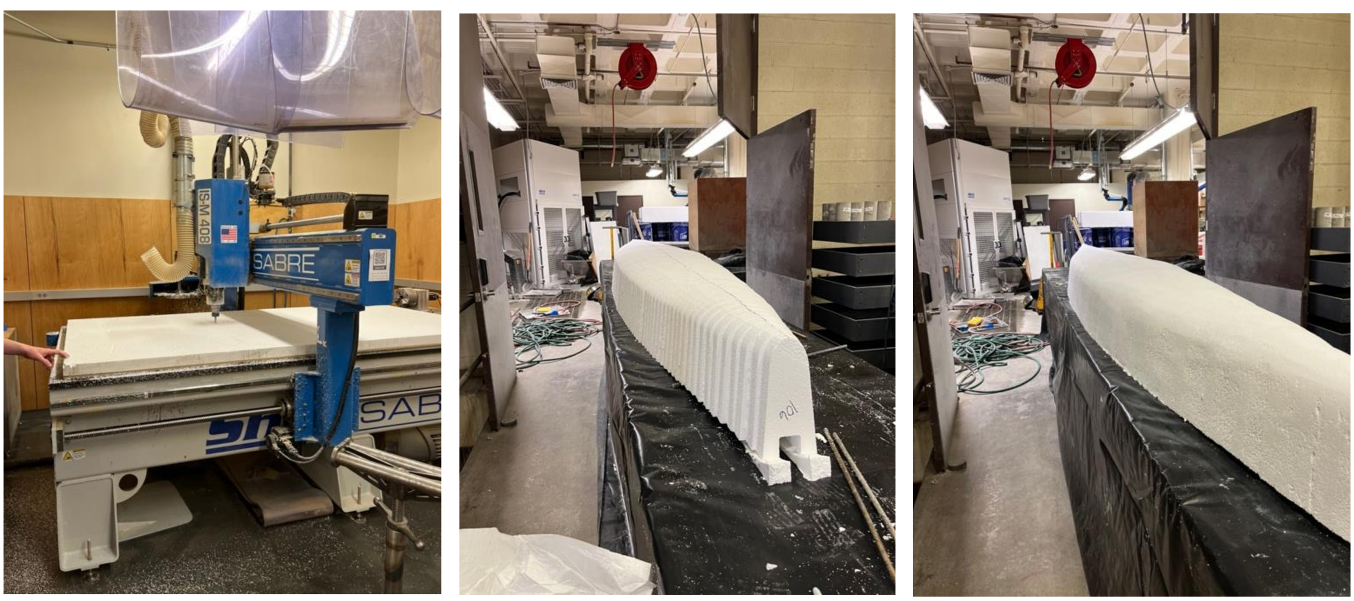


Figure 5: Foam Cutting on the CNC (left), Assembling the Mold (middle), Sanded Foam Mold (right)

The next step in the process was to cut and shape the steel fencing wire to match the contours of the foam mold. This was done by using three sheets of fencing wire, one on the bottom of the canoe and two down the sides and fastening them using steel wire of the same gauge as the reinforcement. Prior to casting, the completed reinforcement cage was removed, and plastic wrap was applied as a form release for the mold.

On the pour day, we mixed the concrete in a concrete mixer and placed it in bins to aid in application by club members. Concrete was placed in two separate lifts of equal thickness with the wire reinforcement cage placed between them. A team captain monitored the thickness of the cement with popsicle sticks labeled at 3/8” to ensure that each lift was consistent with that thickness. Proper finishing techniques were used by club members to ensure that a smooth finish was achieved using magnesium floats. After a 14-day strength was achieved, the foam mold was released, the final canoe was sanded, and stain was applied in the desired P-51 Mustang design. Figure 6 below illustrates the process from creating the reinforcement cage to the final canoe design.

Figure 6: Assembling the Steel Reinforcement (left), Casting the Canoe (middle), Final Stained Canoe (right)

Production Proposal

Value

The team aimed to provide a valuable product in all aspects of the competition by providing the client with a canoe that met all of the specifications and would perform well under the desired usage. Our prototype design provides value in both a monetary sense and also through worth, utility, and importance. Our materials will provide value to the client because we chose to utilize materials that are readily available in the industry. Materials that are harder to procure were left out so as to simplify the prototype design.

We also provided value by using white cement that can provide a blank canvas for any stain design. If a change in design is requested when manufacturing, different stains can be used to alter the appearance of the final canoe without sacrificing strength or utility in the concrete mixture. Our canoe meets the desired material specifications which provides value in the sense that it can be utilized for its intended purpose. Our concrete mix design provides a very ductile mix that will aid in overall durability of the canoe. When there are impacts with objects that may be in the water, the canoe will behave in a ductile fashion. The rigid reinforcement cage can also better take tensile stress rather than just flexing or bending under the stresses that occur in normal usage.

Our canoe has a high material cost due to the use of specialty aggregates and white cement. To provide more monetary value to C4, we found ways to cut back on labor costs. We contracted out the foam cutting to the

BYU prototyping lab where they cut it using a CNC machine. This drove down labor costs that would have added up, had we cut the sheets by hand. We also used saran wrap as a form release which allowed for less sanding needed on the inside due to the smooth finish it created. This also adds value by adding comfort to the rides of the canoe. Less labor costs were used for sanding because of this.

Sustainability

This year our team has mainly improved the project's sustainability in two areas. First, we have continued our school's trend towards sustainable sourcing for pozzolans; we have eliminated the usage of fly ash as it is becoming harder to find and have introduced Geofortis's natural pozzolan as its replacement. Second, we have focused on reusing waste material from the subtractive manufacturing processes associated with fabricating the canoe. The leftover foam from cutting the mold cross sections was used as safety covers for the reinforcement cage during assembly and as stands for the canoe during curing and surface finishing. Both these improvements were based on competitive (economic) incentives: Geofortis allowed us to continue using light pozzolans and reusing foam allowed us to reduce material costs. However, both improvements also aided the environmental sustainability: using the natural pozzolan supports the reduction of coal energy production and reusing foam decreases net waste output.

Improvements

Our team has several new processes that should be implemented in future years. One of the main improvements is using plastic wrap as a form release. After the mold has been completely formed and sanded and the reinforcement cage has been assembled to fit the mold, the cage should be removed. A layer of plastic wrap segments oriented perpendicular to the mold should be glued to the rim of the mold using a thin line of silicone sealant. A second layer should be added to ensure total coverage and to protect against tearing. The plastic wrap doesn't bond with the concrete allowing the mold to easily be removed from the canoe. The plastic wrap should not extend onto the segments that will remain in the canoe as bulkheads.

Another improvement is the usage of stitching segments of steel fencing wire to create a rigid reinforcement cage. In previous years, the school has used hexagonal fencing wire and made a flexible layer of reinforcement. By using stainless steel square fencing wire, the reinforcement cage remains rigid, allowing it to take most of the tensile force. This cage is more technical to form as three pieces must be cut to form snuggly at the specified depth around the mold and then stitched using wire with an identical gauge.

Manufacturing Cost Estimate

The manufacturing fee schedule is shown on the following page. As expected, the materials cost for producing a lightweight canoe is higher than for producing normal concrete. The most significant deviation is due to the cost of the lightweight expanded glass bubbles. White portland cement also costs quite a bit more than conventional cement. This cost is justified by the larger spectrum of colors available for the canoe's design.

The labor cost for mold fabrication has been decreased by using a CNC machine to automatically cut cross sections. Each mold is estimated to function for at least ten canoes as no significant degradation was found after removal. Canoe fabrication is projected to take significantly less labor hours than the initial prototype as the process will be optimized and require less training and quality analysis from project managers.

Manufacturing Cost Estimate – Fee Schedule

Manufactoring Fee Schedule

Permanent Material Costs - Per Canoe					
Material	QTY	Unit	Cost/Unit	Cost	Source
White Portland Cement, Type I	30.00	lb	$ 0.25	$ 7.50	Intermountain Concrete
Lime	10.48	lb	$ 1.60	$ 16.77	Lhoist Group
Slag	34.92	lb	$ 0.18	$ 6.18	Heidelberg Cement Group
Geofortis Natural Pozzolan	45.23	lb	$ 1.50	$ 67.85	Geofortis
Metakaolin	17.46	lb	$ 1.25	$ 21.83	Heidelberg Cement Group
Structural Fine Utelite	34.92	lb	$ 0.06	$ 2.17	Utelite
2-4mm Poraver	17.46	lb	$ 1.20	$ 20.95	Poraver
0.5-1mm Poraver	13.10	lb	$ 1.20	$ 15.72	Poraver
0.25-0.5mm Poraver	17.47	lb	$ 1.20	$ 20.96	Poraver
0.1-0.3mm Poraver	17.47	lb	$ 2.96	$ 51.71	Terra Firma
0.04-0.125mm Poraver	17.47	lb	$ 4.74	$ 82.81	Terra Firma
Admixtures	0.31	oz	$ 0.49	$ 0.15	Master Builders Solutions
Mesh Reinforcement	20.00	lb	$ 3.50	$ 70.00	Home Depot
Water	22.00	gal	$ 0.00	$ 0.02	Provo City
Stain	0.38	gal	$ 80.00	$ 30.00	Direct Colors
Example - Floatation Foam	3.00	lb	$ 4.70	$ 14.10	-
Permanent Material Costs per Canoe (MC)				**$ 428.72**	

Canoe Fabrication Labor Costs - Per Canoe				
Role	RLR	DEC	HRS	Extended
Principal Design Engineer	$ 50.00	1.5		$ -
Design Manager	$ 45.00	1.5	1	$ 67.50
Project Construction Manager	$ 40.00	1.5	2	$ 120.00
Construction Superintendent	$ 40.00	1.5	4	$ 240.00
Project Design Engineer (P.E.)	$ 35.00	1.5	1	$ 52.50
Quality Manager	$ 35.00	1.5	4	$ 210.00
Graduate Field Engineer (EIT)	$ 25.00	1.5	3	$ 112.50
Technician/Drafter	$ 25.00	1.5	1	$ 37.50
Laborer	$ 25.00	1.5	26	$ 975.00
Clerk/Office Admin	$ 20.00	1.5	2	$ 60.00
Labor Subtotal			44	$ 1,875.00
Profit Multiplier (P)			18%	$ 337.50
Canoe Fabrication Direct Labor Total (DL)				**$ 2,212.50**

Canoe Fabrication Expenses - Per Canoe		
Description		Cost
Material Costs Per Canoe (MC) - Above		$ 428.72
Mixing Supplies		$ 7.00
PPE		$ 25.00
Reinforcement Preparation		$ 3.00
Sanding Supplies		$ 5.00
Miscellaneous Supplies		$ 10.00
Staining Supplies		$ 1.00
Expenses Subtotal		$ 479.72
Markup (M)	10%	$ 47.97
Canoe Fabrication Expenses		**$ 527.69**

Mold Fabrication Costs per Canoe	**$ 121.07**
Total Canoe Fabrication Expenses (E)	**$ 648.76**

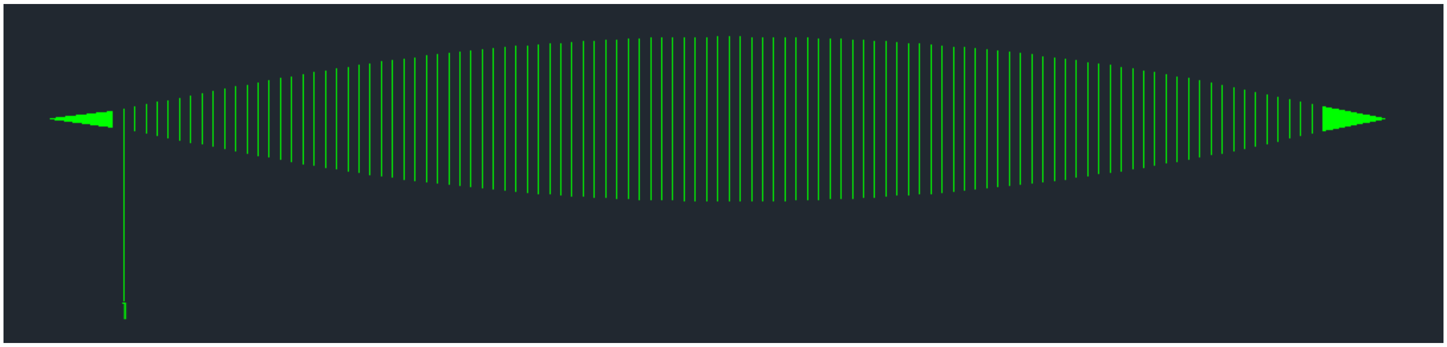
Total Cost Per Canoe	
Labor (DL)	$ 2,212.50
Expenses (E)	$ 648.76
Total	**$ 2,861.26**

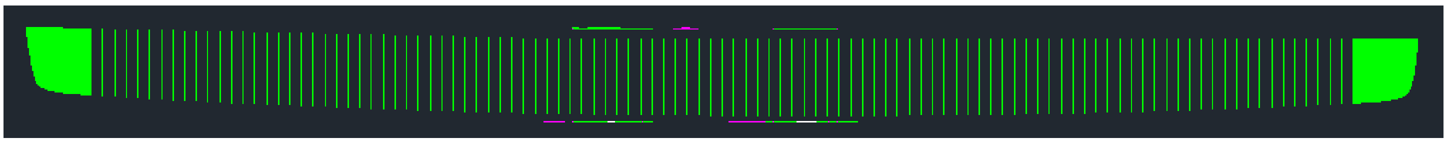
Mold Fabrication Labor Costs				
Role	RLR	DEC	HRS	Extended
Principal Design Engineer	$ 50.00	1.5		$ -
Design Manager	$ 45.00	1.5		$ -
Project Construction Manager	$ 40.00	1.5	0.5	$ 30.00
Construction Superintendent	$ 40.00	1.5	1.5	$ 90.00
Project Design Engineer (P.E.)	$ 35.00	1.5		$ -
Quality Manager	$ 35.00	1.5	1.5	$ 78.75
Graduate Field Engineer (EIT)	$ 25.00	1.5	1	$ 37.50
Technician/Drafter	$ 25.00	1.5	2	$ 75.00
Laborer	$ 25.00	1.5	3	$ 112.50
Clerk/Office Admin	$ 20.00	1.5	0.5	$ 15.00
Labor Subtotal			10	$ 438.75
Profit Multiplier (P)			18%	$ 78.98
Mold Fabrication Direct Labor Total (DL)				**$ 517.73**

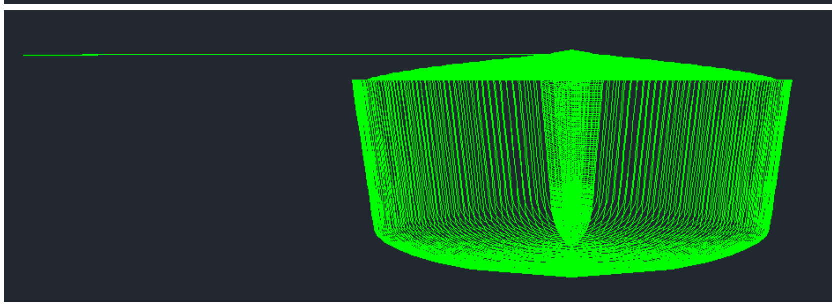
DL Total	$ 517.73
Expenses Total	$ 693.00
Mold Fabrication Original Cost	**$ 1,210.73**
Quantity of Canoes Cast Before Replacing Mold	10
Mold Fabrication Cost Per Canoe	**$ 121.07**

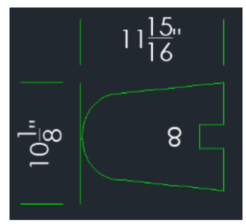
Mold Fabrication Expenses		Extended
Materials Cost		
Foam		$ 550.00
Reinforcement		$ 3.00
Silicone Sealant		$ 62.00
Plastic Wrap		$ 7.00
Sanding Supplies		$ 8.00
Expenses Subtotal		$ 630.00
Markup (M)	10%	$ 63.00
Mold Fabrication Expenses (E)		**$ 693.00**

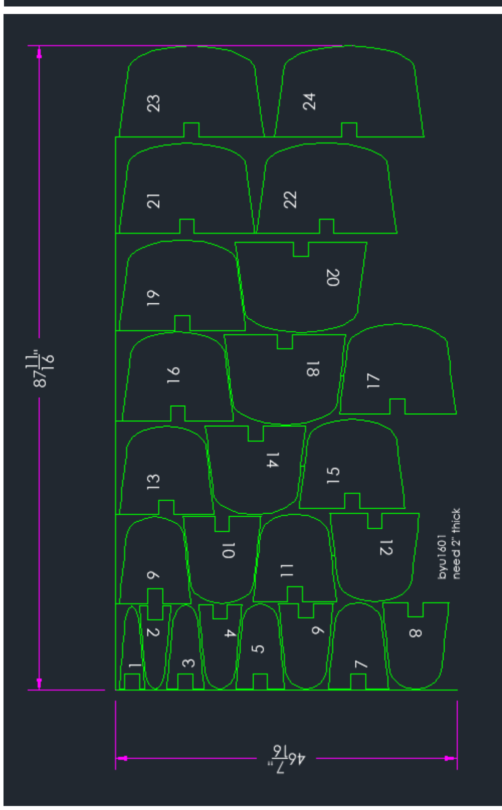
Construction Drawings and Canoe Cross Sections

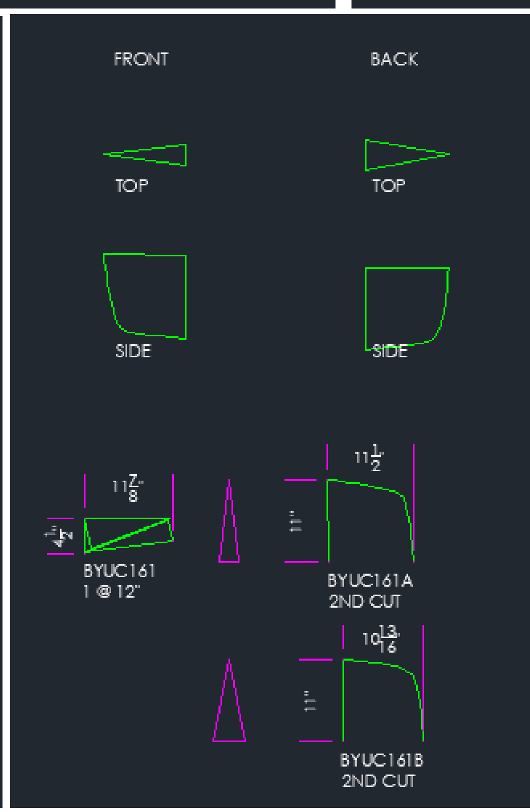


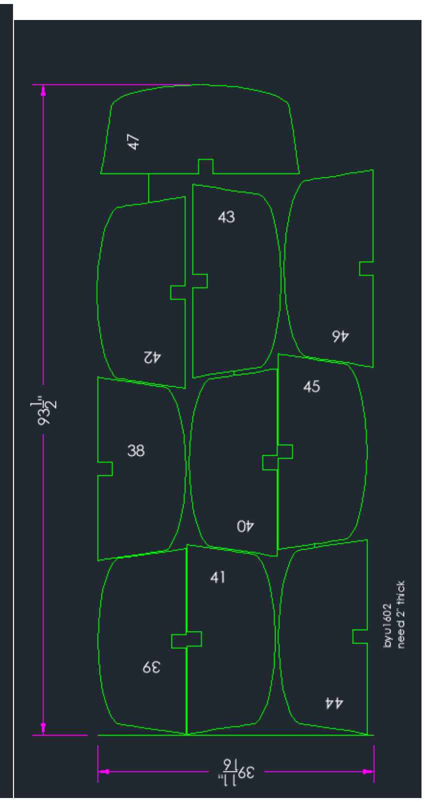


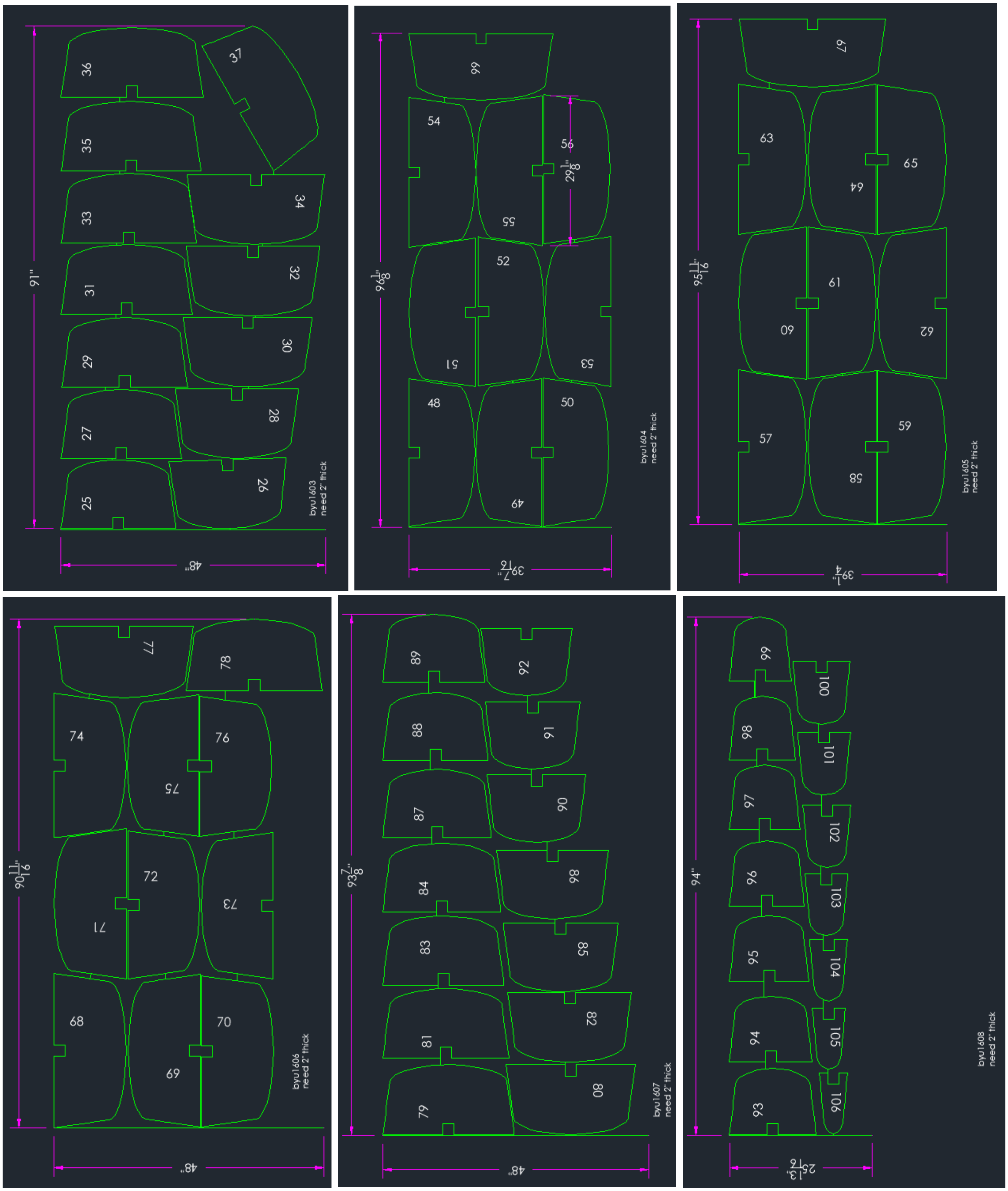











91"
48"
byu1603
need 2" thick
byu1604
need 2" thick
byu1605
need 2" thick
byu1606
need 2" thick
48"
byu1607
need 2" thick
48"
94"
byu1608
need 2" thick

Concrete Mixture Materials and Proportions

Values Given for 1 Cubic Yard of Concrete

CEMENTITIOUS MATERIALS

Component	Specifc Gravity	Volume (cf)	Amount (lbs)
Type 1L Portland White Cement	3.15	1.27	249.65
Lime	2.30	0.34	49.11
Enter Cement/ Lime	-	-	-
Slag	2.89	0.91	163.71
Geofortis Natural Pozzolan	2.38	1.43	212.00
Metakaolin	2.50	0.52	81.85
Enter SCM/ Pozzolan	-	-	-
Enter SCM/ Pozzolan	-	-	-
Enter SCM/ Pozzolan	-	-	-
Enter SCM/ Pozzolan	-	-	-

Total C= 298.77 lbs

Total CM = 756.33 lbs

c/cm = 0.40

FIBERS

Component	Specifc Gravity	Volume (cf)	Amount (lbs)
Enter Fiber	0.91	0.07	4.09
Enter Fiber	-	-	-
Enter Fiber	-	-	-
Enter Fiber	-	-	-

Total Fibers 4.09 lbs

AGGREGATES

Aggregate	Absorption (%)	SG_{OD}	SG_{SSD}	Amount OD (lbs)	Amount SSD (lbs)	Volume (cf)
Utelite	13.3	1.570	1.78	N/A	163.71	1.47
2-4mm Poraver	23.0	0.370	0.46	81.85	100.68	3.55
0.5-1mm Poraver	20.0	0.450	0.54	61.43	73.72	2.19
0.25-0.5mm Poraver	28.0	0.680	0.87	81.89	104.82	1.93
0.1-0.3mm Poraver	35.0	0.850	1.15	81.89	110.56	1.54
0.04-0.125mm Poraver	35.00	0.80	1.08	81.89	110.56	1.64
Enter Aggregate	-	-	-	-	-	-
Enter Aggregate	-	-	-	-	-	-
Enter Aggregate	-	-	-	-	-	-
Enter Aggregate	-	-	-	-	-	-
Enter Aggregate	-	-	-	-	-	-
Enter Aggregate	-	-	-	-	-	-
Enter Aggregate	-	-	-	-	-	-

ADMIXTURES (liquid form only)						
Admixtures	lb/gal	dose (fl oz/cwt)	% solids	Amount Water (lbs)		
Liquid Dye (if used)	-	-	-	-		
MasterGlenium 3030	8.50	4.03	6.7	0.03		
MasterSet Delvo	9.00	2.56	13.5	0.02	Total Water from Admixtures	
MasterAir AE 90	8.80	5.49	20.3	0.05	0.11	lbs
Enter Liquid Admixture	-	-	-	-		
Enter Liquid Admixture	-	-	-	-		
Enter Liquid Admixture	-	-	-	-		
Enter Liquid Admixture	-	-	-	-		
Enter Liquid Admixture	-	-	-	-		
Enter Liquid Admixture	-	-	-	-		

SOLIDS (Powdered Admixtures or Fillers)					
Solids	Specific Gravity	Volume (cf)	Amount (lbs)		
Enter Fillers, Powder Admixtures	-	-	-		
Enter Fillers, Powder Admixtures	-	-	-	Total Solids from Admixtures	
Enter Fillers, Powder Admixtures	-	-	-	0.00	lbs
Enter Fillers, Powder Admixtures	-	-	-		
Enter Fillers, Powder Admixtures	-	-	-		
Enter Fillers, Powder Admixtures	-	-	-		
Enter Fillers, Powder Admixtures	-	-	-		
Enter Fillers, Powder Admixtures	-	-	-		
Enter Fillers, Powder Admixtures	-	-	-		

WATER				
			Amount (lbs)	Volume (cf)
w/c ratio	1.34	*Water = w/cm * cm*	399.26	6.40
w/cm ratio	0.53	*Free Water from Aggregate*	-111.37	
		Free Water from Admixture	0.11	
		Batch Water	510.52	

		cm	fiber	aggregate (SSD)	solids	water	Totals
Mass (lbs)	*M*	756.33	4.09	664.04	0.00	399.26	1823.72
Volume (cf)	*V*	4.47	0.07	12.32	0.00	6.40	23.26
Theoretical Density (pcf)	*D = M/27*	67.55					
Total Aggregate Ratio		0.53					
				Theoretical Air Content	13.84	%	

Measured Properties		
Measured Mix Density	72.02	lb/ft^3
Reported Air Content	13.73	%

Project Outcomes

Competition Performance

The ISWS regional competition was held at Utah State University. The judging was split into four categories: Project Proposal, Technical Presentation, Final Product, and Prototype Demonstration (Racing). Because a partially completed draft was submitted, we placed relatively low in the Project Proposal category. While our Technical Presentation wasn't as tidy as some teams, it contained convincing content showing why our canoe is marketable, so we placed relatively high.

Figure 7: Canoe Competition Display (Left and Center) and Technical Presentation (Right)

Our canoe held up incredibly well and was one of the only canoes that remained wholly intact throughout the entire event. This combined with the eye-catching design helped us win second place in the Final Product category. On race day, the canoe easily passed the swamp test, proving that its density (including the bulkheads) is less than water. The canoe handled quite well during the races. It was slightly heavier than the other competitive canoes but was easy to maneuver around turns and to keep straight on the sprints. We took 4th in the women's slalom, 2nd in the men's slalom, 2nd in the women's sprint, 5th in the men's sprint, and 2nd in the coed sprint.

Figure 8: Canoe Swamp Test and Canoe Team After Races

Overall, our team placed third in the competition and will advance to the society-wide competition. With the project proposal completed, the team will only be more competitive as they continue.

Related Issues

Safety Factors

Our Project has several impacts on different issues. The concrete canoe project has a big impact on safety. Throughout the project the team had safety at the forefront of our minds. The goal of this competition is to produce a canoe prototype and then give a presentation on why this canoe should be mass produced to be used on America's waterways. Our final canoe product is durable which provides a design that will protect the safety of future users. The prototype canoe has a greater compressive and flexural strength than is required to withstand transportation and competition loading. This attention to a stronger and more ductile design, ensures that the canoe, if mass produced, will be able to withstand the stresses encountered in daily usage in American Waterways and thus protect the safety of the user.

The previous discussion on Health and Safety on page 5-6 of this report, emphasizes the team's focus on safety throughout the manufacturing procedure. When building the prototype, safety when in the lab was a priority. Trainings and safety measures were put in place for the use of power tools and other lab equipment. Safety measures were also put in place for the use of hazardous materials in the construction phase. The same safety procedures would be applied if this canoe is chosen to be mass produced.

Health and Welfare Factors

The prototype canoe design also impacts public health and welfare. Canoeing is an outdoor sport that allows people to be active and enjoy the outdoors. The physical activity of taking the prototype canoe and subsequently the mass-produced canoes out to use them at the lake will positively impact the public health and welfare of the community. This concrete canoe will make it possible for individuals and families to enjoy physical exercise and leisure at the lake or on the rivers. This will benefit the physical and mental health of those using the canoe.

Environmental Factors

This project also had an impact on environmental factors. Currently, there is a big push to look for greener ways to manufacture products. In this year's mix design, we did not use fly ash. Fly ash is a byproduct of coal production which is a large source of greenhouse gas emissions. We instead used Geofortis Natural Pozzolan which is a naturally occurring volcanic rock that is ground into fine powder. Geofortis is a more sustainable choice as it is more friendly to the environment and more readily available. In mass production, this would decrease carbon emissions and provide for a greener product. The aggregates that are used in this year's mix are all recycled or naturally occurring materials. Poraver expanded glass aggregate is made from recycled glass and Utelite is made from expanding naturally occurring shale in a kiln till the gases expand. The use of naturally occurring and recyclable aggregate will also provide for a greener and a more sustainable design. This will reduce the carbon footprint and the effects on climate change.

Economic Factors

The team attempted to drive down manufacturing costs of the final canoe product wherever it was possible. The team achieved the construction of an economic final product. During the research and design phase the team needed a replacement of Fly Ash. The Geofortis company was contacted to find an alternative. The supplier contact chose to donate a 600 lb bag of Natural Pozzolan to the Concrete Canoe team for use this year and years moving forward. The most expensive material in our mix is Poraver expanded glass aggregate. A company with the lowest prices was chosen to supply this aggregate material. The use of these materials lowered the economic impact of the final product.

A generous donation of polystyrene geofoam blocks was used to construct the mold of the canoe. Once we had the foam, it needed to be cut into cross sections. A company quoted us at $1500 to machine the mold on their machine. In order to further drive down cost of the foam cutting and labor, the team contacted the BYU

Prototyping Lab and enlisted there help to cut the foam cross sections on a CNC router machine. Due to the team being a part of BYU, the foam cross sections were cut for free. This largely decreased the cost of the canoe. Cutting the mold with the Prototyping Lab also reduced the time and manpower needed which further drove down overall costs. Actual numbers for the manufacturing cost estimate can be found on page 18 of this report. Numbers for the research and development cost can be found on page 9.

Social Factors

Our project had impacts on social factors throughout the timeline of the project. The project brought people together from the BYU Civil Engineering department and also other friends and family of the team members who are in other majors. This provided opportunities to have cross disciplinary discussions and input on design and aesthetics. It also allowed for networking opportunities to grow our circle of influence with other colleagues and companies with whom we were in contact. Being involved in this project also sparked a lot of discussion with friends and family about how you can get concrete to float. This had the impact of spreading awareness of the club and what you can do when using lightweight aggregates.

Figure 9: BYU Teams Post-Closing Ceremonies (Left) Team and Volunteers Coming Together on Casting Day (Right)

There is also a social impact that is involved with the competition. The Concrete Canoe Competition gives students the ability to communicate with other schools and hear more about new ideas that were implemented on other teams. This helped to expand the knowledge of our team on the many techniques that can be used when designing a concrete canoe.

Cultural Factor

The final design and theme of “The Mustang” for our final product took inspiration from the P-51 Mustang airplane from World War II. With a design focused on history, the team was able to explain that the inspiration for our design came from an airplane that turned the tide of the war and revolutionized air combat. This theme helped to provide more background into American History and in turn served to improve cultural awareness of the achievements and innovations that Americans made during the war. During our display at the competition, we had the chance to talk about the history to each person that asked about our theme.

Lessons Learned

Throughout our project we had several challenges and obstacles that we were faced with. Overcoming these obstacles has helped us learn valuable lessons that will aid us in future projects within our careers. The overarching lesson that we learned was that there are a lot of unforeseen challenges that surface in a large-scale engineering project. The way to overcome this is to have a very clear project schedule with deadlines. These deadlines must be adhered to otherwise problems begin to escalate and the team can fall behind very quickly.

On the technical side of things, we learned the value of having a well labeled inventory. We had a few times in the project where the wrong material was used in a test batch due to mislabeling inventory. In future projects we need to improve our inventory techniques so that this will not happen. One specific inventory problem led to us not having enough time to do better research for our concrete mix, meaning that we had to go with the first design that gave us good strength results. We learned from this that we need to do better initial researching and allow the proper time to undertake this task.

From the club or group perspective we learned the value of good communication. We had many times where ideas or thoughts were miscommunicated. Clear communication and expectations can help a project run smoothly. We also learned that when working with groups such as the club it can be hard to get everyone to buy in and show up to the activities. If we were to do this again, we would market our activities better and talk about them more openly to hopefully encourage more club turnout. This would have sped up some parts of the project.

We also learned the challenges of material procurement. We had some materials that were just not available and others that were hard to get with supply chain issues. There is great value in planning to get materials right away so that the lead times on orders do not affect the project schedule. The last lesson we learned is the value of networking. We had several opportunities to network with people in the industry. Some of these conversations led to the donation of supplies to the club to help construct the canoe. Other conversations have given us contacts that will have moving forward in the industry. It is important to form relationships in our industry so that looking for jobs, finding clients, or materials can be easier in the future.

Conclusion

This project took a large amount of dedicated time from capstone and club members alike. While we could have approached several components better, these components highlighted our weaknesses, allowed us to struggle in an environment with lower stakes, and increased our ability to function as professional engineers.

This year we were able to create a mix with similar weight to last years' with more than a 50% increase in strength. While we originally thought next year's team should use this extra strength to decrease the canoe wall thickness and thereby weight, the super high strength the walls gave us significantly decreased the probability of the canoe breaking during transportation and usage. Small optimizations in weight only slightly increase the performance of the water, so we'd recommend next year's team focus on optimizing the shape of the canoe rather than taking chances with the wall thickness.

We were also able to implement several improvements the previous capstone team recommended including using a CNC machine to cut the mold's foam cross sections and using plastic wrap as a form release. Additionally, we used steel stitching to create a rigid stainless steel reinforcement cage.

With the regional competition behind us, the team looks forward to the society-wide competition. The regional competition project proposal was the only item the team did not fully complete as anticipated. All other deliverables have been submitted and our scope of work has been completed.

Appendix A – Bibliography

Adhikary, S. K., Ashish, D. K., & Rudžionis, Ž. (2021). Expanded glass as light-weight aggregate in concrete–A review. Journal of Cleaner Production, 313, Article 127848. https://doi.org/10.1016/j.jclepro.2021.127848

Ahmadi, S. F., Reisi, M., & Sajadi, S. M. (2023). Comparing Properties of Foamed Concrete and Lightweight Expanded Clay Aggregate Concrete at the Same Densities. Case Studies in Construction Materials, 19, Article e02539. https://doi.org/10.1016/j.cscm.2023.e02539

American Concrete Institute. (n.d.). Standards for 7-day and 28-day strength test results. American Concrete Institute. https://www.concrete.org/tools/frequentlyaskedquestions.aspx?faqid=13

ASTM (2009).“Standard Specification for Concrete Aggregates.”C33/C33M-08, West Conshohocken, PA.

ASTM (2009).“Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.” C39/C39M-05, West Conshohocken, PA.

ASTM (2009).“Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).”C78-08, West Conshohocken, PA.

ASTM (2009).“Standard Terminology Relating to Concrete and Concrete Aggregates.” C125-07, West Conshohocken, PA.

ASTM (2009). “Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate.” C127-07, West Conshohocken, PA.

ASTM (2009) “Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate.” C128-07a, West Conshohocken, PA.

ASTM (2009).“Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.” C136- 06, West Conshohocken, PA.

ASTM (2009).“Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete.” C138/C138M-09, West Conshohocken, PA.

ASTM (2009).“Standard Specification for Portland Cement.”C150-07,West Conshohocken, PA.

ASTM (2009).“Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.” C192/C192M-07, West Conshohocken, PA.

ASTM (2009).“Standard Specification for Flow Table for Use in Tests of Hydraulic Cement.” C230/C230M-08, West Conshohocken, PA.

ASTM (2009).“Standard Test Method for Time of Setting of Hydraulic-Cement Paste by Gillmore Needles.”C266-08, West Conshohocken, PA.

ASTM (2009).“Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression.” C469-02, West Conshohocken, PA.

ASTM (2009).“Standard Specification for Chemical Admixtures for Concrete.” C494/C494M-08a, West Conshohocken, PA.

ASTM (2009).“Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.”C496/C496M-04e1, West Conshohocken, PA.

ASTM (2009).“Standard Test Method for Drying Shrinkage of Mortar Containing Hydraulic Cement.” C596-07, West Conshohocken, PA.

ASTM (2009).“Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.” C618-08a, West Conshohocken, PA.

ASTM (2009).“Standard Specification for Pigments for Integrally Colored Concrete.” C979-05, West Conshohocken, PA.

ASTM (2009).“Standard Specification for Slag Cement for Use in Concrete and Mortars.” C989- 09, West Conshohocken, PA.

ASTM (2009).“Standard Specification for Fiber-Reinforced Concrete.” C1116/C1116M-09, West Conshohocken, PA.

ASTM (2009).“Standard Specification for Silica Fume Used in Cementitious Mixtures.” C1240- 05, West Conshohocken, PA.

ASTM (2009).“Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete. ”C1315-08, West Conshohocken, PA.

ASTM (2009). “Standard Specification for Latex and Powder Polymer Modifiers for Hydraulic Cement Concrete and Mortar.” C1438-99(2005)e1. West Conshohocken, PA

ASTM (2008).“Standard Test Method for Tensile Properties of Polymer Matric Composite Materials.” D3039/D3039M-08, West Conshohocken, PA.

Brigham Young University Concrete Canoe. (2010). Design Document DWGs, Brigham Young University, Provo, UT.

Brigham Young University Concrete Canoe. (2023). “Banana Float” Design Paper, Brigham Young University, Provo, UT.

Du, Y., Qi, H. H., Jiang, J., & Liew, J. R. (2022). Experimental study on the dynamic behaviour of expanded-shale lightweight concrete at high strain rate. Materials and Structures, 55, Article 4. https://doi.org/10.1617/s11527-021-01846-z

Mo, K. H., Ling, T. C., Alengaram, U. J., Yap, S. P., & Yuen, C. W. (2017). Overview of supplementary cementitious materials usage in lightweight aggregate concrete. Construction and Building Materials, 139, 403-418. https://doi.org/10.1016/j.conbuildmat.2017.02.081

Ries, J. (2008, June). Structural lightweight aggregate and concrete. Structure, 30(6), 62-63.

Sadek, M. M., Ismail, M. K., & Hassan, A. A. (2020). Stability of lightweight self-consolidating concrete containing coarse and fine expanded slate aggregates. ACI Materials Journal, 117(3), 133-143. https://doi.org/10.14359/51722407

Sharma, B., Sharma, R., & Bansal, P. P. (2022). Effect of fine aggregate replacement with expanded perlite and pumice on the development of lightweight concrete. Australian Journal of Civil Engineering, 20(1), 115-129. https://doi.org/10.1080/14488353.2021.1930635

Sharma, L., Taak, N., & Bhandari, M. (2021). Influence of ultra-lightweight foamed glass aggregate on the strength aspects of lightweight concrete. Materials Today: Proceedings, 45, 3240-3246. https://doi.org/10.1016/j.matpr.2020.12.383

Tawfik, T. A., AlSaffar, D. M., Tayeh, B. A., Metwally, K. A., & ElKattan, I. M. (2021). Role of expanded clay aggregate, metakaolin and silica fume on the of modified lightweight concrete properties. Geosystem Engineering, 24(3), 145–156. https://doi.org/10.1080/12269328.2021.1887002

Wu, T., Yang, X., Wei, H., & Liu, X. (2019). Mechanical properties and microstructure of lightweight aggregate concrete with and without fibers. Construction and Building Materials, 199, 526-539. https://doi.org/10.1016/j.conbuildmat.2018.12.037

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

Thickness

Canoe thickness: 0.75” typical

Depth to reinforcement: 0.375” typical

Maximum stem thickness: 2.25”

Bulwark covering thickness: 0.5”

Reinforcement

Wire thickness: 19 gauge (0.0418”)

Wire spacing: 0.5”

Wire percent open area:

A_{open} = (0.5” - 0.0418”)^2

= 0.210 in^2

A_{total} = (0.5”)^2

= 0.25 in^2

POA = 100% (A_{open} / A_{total})

= 100% (0.210 in^2 / 0.25 in^2)

= 84.0%

Appendix C – Supporting Documentation

Prequalification Forms

Pre-Qualification Form (Page 1 of 3)

Brigham Young University

We acknowledge that we have read the 2024 ASCE Society-wide Concrete Canoe Competition Request for Proposal and understand the following (*initialed by (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.	ESC	CBF
The eligibility requirements of registered participants (Section 3.0 and Exhibit 3).	ESC	CBF
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.	ESC	CBF
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.	ESC	CBF
The last day to submit a *Request for Information* (RFI) to the C4 is January 29, 2024.	ESC	CBF
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.	ESC	CBF
The submission date of the *Project Proposal*, *Mix Design Sheets*, and *Materials Notebook* for the Student Symposium Competition (uploading of electronic copies to ASCE server) is Friday, February 16, 2024.	ESC	CBF
The submission date of the *Project Proposal*, *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.	ESC	CBF

Emily Cooper 11/2/23

Team Captain (date)

Emily Cooper

(signature)

CLIFTON B. FARNSWORTH

ASCE Student Chapter Faculty Advisor (date)

Clifton B. Farnsworth

(signature)

Pre-Qualification Form (Page 2 of 3)

Brigham Young University

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?

Students involved in the concrete canoe team at BYU will complete an online concrete safety training course before working in the lab. In addition to the module, students will be required to pass a safety test prior to handling concrete materials. Team leaders will supervise member use of the materials to ensure safety standards are being met. Dr. Guthrie will offer an additional safety training for all club members as an introduction to the lab. All needed personal protective equipment will be supplied in the lab.

Field trips to practice rowing will require university approval and proper apparel, including floatation devices and supervision.

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?

The BYU concrete canoe team is currently creating an updated QA/QC Program.

The team envisions selecting materials from the current supply—a conglomeration of purchased materials used in previous years—and new purchases. The final mix and design will likely mimic those in past years based on ease of creation, previous canoe performance, and the extent of club budget.

Based on industry practices and standards, the team will iteratively test concrete strength and construction properties. Construction materials and processes such as form materials, form release, and curing will be prepared to meet hull design specifications. The team will perform mix tests over both fall and winter semesters on wet and dry concrete to ensure uniformity in the mix under the procedures used. Adjustments will be made to account for updates in the 2024 competition regulations.

Leadership will hold weekly meetings and write summaries to record club progress.

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 BYU concrete canoe team has reviewed the Department and University safety measures and completed the associated laboratory training. In addition to the concrete safety training course, the team will have an additional training given in the lab by the Concrete lab professor Dr. Guthrie.

Pre-Qualification Form (Page 3 of 3)

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 concrete canoe team for the 2023-2024 year approves the use of ChatGPT as far as it is used in an appropriate manner. Said manner may involve the use of:

1. Creating prompts to generate answers whose format may be mimicked by team members upon writing reports.
2. Doing research to spawn ideas and give students additional sources when looking for materials, designs, and the functionality of each.
3. Formatting paperwork and formal documents that students may look toward when formatting their own reports and documents.
4. Content generation, given that said content is not copied and pasted as a final product of BYU, but used as a spring board for students to adapt and adjust at their leisure.

The core project team is made up of _3_ people.

Brigham Young University Concrete Canoe Team

10/30/2023

Engineering Building, Campus Drive
Provo, Ut 84602
Attn: Concrete Canoe Competition Request for Proposals

Dear Utah State University ISWS Planning Committee:

The BYU Concrete Canoe team submits this Letter of Intent to the Concrete Canoe Competition Committee as well as Utah State University's ISWS planning committee as confirmation that we have received and read the Request for Proposal for the 2024 competition.

We are prepared to present and race a full-scale model of our canoe at the competition this upcoming March or April. We also understand that a Technical Proposal is required and will provide such in accordance with the set timeline outlined in the rules.

The Technical Proposal will detail the design and analysis of the technical aspects that went into building the canoe such as the hull design, concrete mix design, and construction plans. The technical aspects will be overseen by a group of senior students in BYU's Civil and Construction Engineering program as well as by Dr. Farnsworth, the ASCE Student Chapter Advisor, and Dr. Guthrie, a faculty member at BYU who researches various applications of concrete.

We are excited to work with you and thank you for your Request for Proposal.

Sincerely,

Emily Cooper — 11/2/23
Team Captain — *(date)*

Emily Cooper
(signature)

ewalmer@byu.edu
(530)608-7142

Clifton B. Farnsworth — 11/2/23
ASCE Student Chapter Faculty Advisor — *(date)*

Clifton B. Farnsworth
(signature)

clifton_farnsworth@byu.edu
(801)422-6494

ENGINEERING BUILDING, CAMPU DRIVE, PROVO, UT 84602

Appendix D – Capstone Team Resumes

Justin Booher

Phone: 720-545-3006
Email: justinbooher9@gmail.com
LinkedIn: https://www.linkedin.com/in/justinbooher/

Education

Brigham Young University **(April 2024)**
Candidate for Bachelor of Science
Civil and Environmental Engineering
GPA: 3.66

Work Experience

Acute Engineering (Orem, UT) (January 2022-Present)
Student Engineer

- Performed structural analysis and created structural plans for residential structures
- Resolved complex problems through the use of engineering principles and software applications
- Processed and provided engineering on submittals, RFIs, and other construction documents
- Adapted to new company practices and workflow during a company acquisition
- Learned basic drafting skills in AutoCAD

BYU Life Science IT (Provo, UT) (October 2020-December 2021)
Computer Technician

- Provided base level IT support for Windows and Apple systems to help professors continue with their work
- Developed problem solving skills in order to fix complex computer hardware and software issues

BYU Heritage Halls Building Care (Provo, UT) (January 2020-October 2020)
Crew Leader

- Oversaw and organized a team of 7 individuals to provide building care for Heritage Hall dorms
- Exercised leadership and coordination skills to work and clean efficiently

Leadership

Full-time Volunteer Representative (Cusco, Peru)
The Church of Jesus Christ of Latter Day Saints (January 2018-December 2019)

- Supervised and assisted 160 full-time volunteers to increase productivity and their teaching skills
- Provided training and motivational messages to other volunteers to boost morale
- Collaborated with others to strategize potential ways to increase productivity and efficiency

Skills/Achievements

- Proficient in AutoCAD, CIVIL 3D, GIS software, and REVIT
- Proficient in the Microsoft suite including VBA coding basics within Excel
- Proficient at a conversational level in the Spanish Language
- The Boy Scouts of America - Eagle Scout **(March 2017)**
  - Obtained skills including integrity, teamwork, honesty, discipline, and hard work

Joshua Fenwick

(801) 888-6095 • 19jfenwick@gmail.com • www.linkedin.com/in/joshua-fenwick

EDUCATION

Brigham Young University Dec 2024
Bachelor of Science: Civil Engineering Provo, UT

- GPA 3.93
- 4 year full-tuition scholarship
- Completed courses include:
  - CCE 214 Geomatics
  - WRTG 316 Technical Communication
  - CS 235 Data Structures

EXPERIENCE

BYU School of Music Aug 2022-Present
Associate Carillonneur Provo, UT

- Perform recitals twice a week
- Lead public carillon tours

BYU College of Engineering Aug 2022-Present
Engineering Dynamics Teaching Assistant Provo, UT

- Reviewed course curriculum, rewriting homework and tests as needed
- Mentor for over 200 students
- Audited students to ensure academic honesty

BYU Physical Facilities Jun 2023-Aug 2023
Civil Engineering Intern Provo, UT

- Directed a team of 3 interns
- Provided surveying and stakeout services for over 560 acres
- Assembled data base of over 4000 storm drain structures
- Updated campus utilities and hardscapes drawings in Civil 3D

VOLUNTEER EXPERIENCE

Nauvoo Historic Sites May 2021-Aug 2021
Young Performing Missionary Nauvoo, IL

- Interacted with thousands of tourists

Welfare Square Jul 2020-May 2021
Service Missionary Salt Lake City, UT

- Led volunteer crews at Dairy Factory and Church Storehouse

SKILLS

- Revit, AutoCAD, and Civil 3D
- Microsoft Excel, Word, and PowerPoint
- ArcGIS Pro

EMILY COOPER

https://www.linkedin.com/in/emily-walmer-55b411210
CELL: (530) 608-7142
EWALMER43@GMAIL.COM

A confident, hardworking individual who completes tasks as assigned, is not afraid to ask questions, and who respects authority.

EDUCATION

Brigham Young University, Provo, UT - *3.51 average GPA (current)*
EXPECTED GRADUATION – APRIL 2024
Bachelor of Science - Civil Engineering

WORK EXPERIENCE

Acute Engineering, Internship, 744 S 400 E, Orem, UT 84097- *Engineer in Training*
MAY 2022 - CURRENT

- Created solutions to problems clients encountered during construction through engineering
- Laid out framing, beams, and foundations in AutoCAD for various projects, addendums, re-engineering, etc.

BYU Utah Lake Research Assistant, Dr. Williams, CE Department, Provo, UT 84602- *RA*
MAY 2021 – APRIL 2022

- Gathered data from Utah Lake during the course of (3) 6-hour periods through probe calibration, chemical tests (TSS, TDS, VSS, TKN, COD, K, Al), drone pictures and heat imaging on Utah Lake
- Performed in-water maintenance on limno corrals, drove a boat and a truck
- Updated data from daily sample collections in excel and recorded events in a daily log
- Formatted a website and wrote web pages according to data collections and research patterns
- Co-authored and presented a research paper at a UVU conference among 50+ students

Timpanogos Special Services District (TSSD) Lab Tech Internship, 6400 N 5050 W, American Fork, UT 84003- *Lab Technician*
JULY 2021 – AUGUST 2021

- Conducted chemical vial tests (TSS, TDS, VSS, TKN, COD, Phosphorous, Aluminum) twice a week
- Ran on site automatic testing equipment, and collected water and solid samples during a month-long startup project

BYU Teaching Assistant (CE 112) W21, Provo, UT 84602- *Teaching Assistant*
JANUARY 2021 – APRIL 2021

- Answered questions from a class of 60+ student concerning AutoCAD, Revit, and Civil 3D
- Guided students to find resolutions to technical and computer issues through remote communication

Church of Jesus Christ of Latter Day Saints- *Personal Religion Teacher (Spanish speaking)*
MARCH 2019 – APRIL 2020 Vina Del Mar, Chile
MAY 2020 – AUGUST 2020 Florida, Ft Lauderdale

- Taught over 100 lessons to different individuals about religious subjects that helped them change their lives and habits
- Aided in constructive goal setting and individual progress to achieve said goals
- Conducted in-person group devotionals in Chile, Florida, and remote discussions through social media

SKILLS

Microsoft Word	Python	AutoCAD	Spanish Speaking
Microsoft Excel	Revit	Programming	Bluebeam

- BYU Architecture Association Media Outreach (Winter 2022 – Winter 2023)
- Concrete Canoe Club participant and ISWS attendee/canoe racer