NORTHERN ARIZONA UNIVERSITY

canoe captains

2022-23 ASCE CONCRETE CANOE

2023 Concrete Canoe

Design Report

Northern Arizona University

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DATE:	May 9, 2023
SUBJECT:	2023 Concrete Canoe Design Report Letter of Transmission

The following design report details the process and results of designing and constructing a prototype for and competing in the 2023 ASCE Concrete Canoe Competition. The design process began in September of 2022 and the competition took place from April 13th through 15th of 2023. A summary of the ASCE Student chapter and the project team are provided before the technical approach to the project is discussed. The design, analysis, and construction processes are reported in depth in addition to the results of competing at the Intermountain Southwest Student Symposium at the University of Nevada, Reno. The Quality Control, Quality Assurance Program and Health and Safety considerations are specified in addition to an analysis of the environmental, economic, and social impacts of the project.

For the final prototype, the team selected a concrete mix that contained three aggregates – Utelite Crushed Fines, Perlite, and Post-Consumer Carpet Calcium Carbonate, a recycled lightweight, high-volume sand replacer derived from carpet – and three cementitious materials – Type IL Cement, Slag Cement, and Fly Ash. The final concrete mixture had a unit weight of 69 pcf and a compressive strength of 1.25 ksi. A symmetrical shallow-arched bottom, flared sides, and rockered body hull design was chosen for the canoe as it provided the team with a boat that was stable, predictable, and simple to construct.

The project cost a total of $78,643 and 1,052 hours to complete, a $2,556 difference from the proposed cost of $76,087 and 10.2 percent increase from the proposed 950 hours. Summaries of the changes between the proposed and actual engineering work completed and project costs are provided in this design report.

If there are any questions or comments, please contact the Project Manager, Anne Hritz.

Sincerely,
The 2022-2023 Northern Arizona University Concrete Canoe Team

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Acknowledgements

The 2022-23 Northern Arizona University Concrete Canoe Capstone team would like to thank Dr. Robin Tuchscherer, Dr. Jefferey Heiderscheit, Dr. Bridget Bero, Mark Lamer, and Russell Collins for their mentorship, guidance, and support throughout this project. To Dr. Tuchscherer, our Capstone Grading Instructor, for his constant feedback and support over the course of this project, as he was one of our most valuable resources for the structural design of the canoe. To Russell Collins, our Technical Advisor, for giving us insight on aspects of the project we were unsure of how to go about, for both technical and logistical facets. To Dr. Heiderscheit and Dr. Bero, for helping us to understand what it means to put together professional submissions and presentations as well as the views and feedback from an outside perspective, which allowed the team to portray a clearer understanding and explanation to the individuals unfamiliar with the project. Lastly, to Mark Lamer for providing the team with insight on competition rules and regulations and for helping to transport the canoe to the competition.

In addition, this gratitude is extended to the many project donors and sponsors, whose financial and material donations made the final product possible. CalPortland donated their AdvanCement LT Type IL cement and slag cement, and provided their invaluable support in starting our concrete mixture design. National Waste Recovery provided the team with Post-Consumer Carpet Calcium Carbonate and gave various tips and suggestions on how to use the product effectively. Holcim-Utelite donated a last-minute aggregate request and, without this supply, the team would have been unable to complete the project successfully. SUNDT purchased a $1,000 t-shirt sponsorship that provided the team with funds used for traveling. Circular Polymer purchased a $500 logo sponsorship that allowed the team to purchase additional aggregates and mold materials. The final donors the team would like to thank are Laura Roubicek and Alan Trimmer for their financial aid.

The team would also like to thank Jerry Andre from F3 Online for being a kind and efficient mold manufacturer for the team. His patience and willingness to work with the team on a budget let students learn the process of real-world model creation and working with subcontractors.

Lastly, we'd like to thank the members of the 2021-2022 NAU Concrete Canoe Team for setting us up for success and for their guidance and insights throughout the project. Thanks to Hannah Thelen, Steven Procaccio, Cole Robertson, Eric Moore, and Hunter Kassens.

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List of Abbreviations

ASTM	American Society for Testing and Materials
C4	Committee on Concrete Canoe Competitions
CECEE	Civil Engineering, Construction Management, and Environmental Engineering
CS	Construction Superintendent
DM	Design Manager
DT	Drafting Technician
EIT	Graduate Field Engineer
ft	feet
in	inches
ISWS	Intermountain Southwest Student Symposium
ksi	kips per square inch
LT	Lab Technician
NAU	Northern Arizona University
OA	Office Admin
PC4	Post-Consumer Carpet Calcium Carbonate
pcf	pounds per cubic foot
PCM	Project Construction Manager
PDE	Principle Design Engineer
PE	Project Design Engineer
psi	pounds per square inch
QM	Quality Control, Quality Assurance Manager
RFI	Request for Information
RFP	Request for Proposal
SSD	Saturated Surface Dry

1.0 Executive Summary

Northern Arizona University's Canoe Captains sought to bring the spirit of competition to this year's Intermountain Southwest Student Symposium. Over the past two years, NAU's Concrete Canoe Competition teams have been rising through the rankings. 2021's Ponderosa placed third, while Pinecone scored an impressive second place in 2022. While one of the primary goals for the project set by the team was to see the University continue to progress, the Canoe Captains having had their sights set on first place, the team placed fourth overall at 2023's competition. The team's theme for the year is Sailing because it takes a dedicated team to not only construct a high-quality, sea-worthy vessel, but also to steer the ship to victory. The Canoe Captains ensured success at this year's competition by implementing a variety of innovative design choices that made the final product structurally stable and environmentally sustainable.

Sustainability was a key factor in many of the decisions made for the design of this year's canoe. Recycled and low-impact materials were used whenever possible over the course of the project, especially in the mix design and construction processes. The use of Fly Ash, Slag, and Post-Consumer Carpet Calcium Carbonate (PC4) aided in this. PC4 is derived from recycled carpets and is a lightweight, high-volume aggregate. Fly Ash is a pozzolan that is sourced from the coal power industry. Rather than letting the material sit in piles and adversely impact the environment, it was used in the concrete mix as it has several beneficial attributes when combined with cement. Slag cement, a byproduct of the ironworks industry, was used for a similar reason.

The mix design chosen for the canoe utilizes a mixture of aggregates that ensure both strength of the hull as well as buoyancy. The mix adheres to both the gradation requirements and the cementitious material content guidelines stated in the Request for Proposal. PC4, a mixture of fine grain particles and fibers, increases air content and reduces weight was used as a sand replacement. The material's fibrous compound not only provides a higher tensile strength, but limits cracking as well. Various ASTM tests were performed to evaluate material properties of the concrete and the results requested in the RFP are provided in *Table 1-1*.

Table 1-1: Concrete Mixture Properties

Property	Value	Units	ASTM Standard
Plastic Unit Weight	85	pcf	C138
Oven Dry Unit Weight	69	pcf	C642
Compressive Strength (28-Day)	1,250	psi	C39
Tensile Strength (28-Day)	130	psi	C496
Composite Flexural Strength (28-Day)	270	psi	C78
Slump	4.0	in	C143
Spread	9.25	in	C1611
Air Content	7.8	%	C138

The primary goals of the hull design were to ensure that the canoe's shape provided stability, good tracking, and satisfactory maneuverability in the water. Given the various parameters, the team chose a symmetrical design, which allows for more predictable movements, in addition to a shallow-arched bottom, flared sides, and a rockered body. These features provide adequate stability during rowing maneuvers, a reduction in the probability of tipping, and improved tracking. The hull specifications are presented in *Table 1-2*.

Table 1-2: Canoe Hull Properties

Property	Value	Units
Length	19	ft
Width	2.75	ft
Depth	15	ft
Thickness	1	in
Weight	370	lb

The Canoe Captains have taken the opportunity to recruit younger engineers to be a part of the concrete canoe experience. By including mentees in the project, a wider range of students are able to attain hands-on experience and gain new or improve technical skills. Involving these younger engineers provides them with the opportunity to apply skills to real world problems.

2.0 Project Delivery Team

2.1 ASCE Student Chapter Profile

Northern Arizona University's (NAU) American Society of Civil Engineers (ASCE) Student Chapter is an organization comprised of students from every grade level at the University. The academic club has more than thirty active members, including ten student officers. The student chapter meets once a week during the Spring and Fall semesters, with the primary focus of providing students with the opportunity to gain experience and create connections in the engineering and construction industries. Through presentations by industry professionals, community service activities, internship opportunities, and competition events such as the Intermountain Southwest Student Symposium (ISWS), NAU's civil and environmental engineering students are provided with the experience to succeed in school and life after graduation.

2.2 Key Team Roles

The team roles and their corresponding acronyms are as follows: Principal Design Engineer (PDE), Design Manager (DM), Project Construction Manager (PCM), Construction Superintendent (CS), Project Design Engineer (PE), Quality Control, Quality Assurance Manager (QM), Graduate Field Engineer (EIT), Drafting Technician (DT), Lab Technician (LT), and Office Admin (OA).

The PDE oversees and approves all designs over the duration of the project while the DM supervises the designs from start to finish. The PCM ensures that the project stays on schedule and that all necessary materials are procured and readily available. The CS manages all construction processes and reports to the PCM to confirm that everything is on track for the projected completion date. The PE creates all the designs for the project and reports to the DM for inspection and appraisal. The QM ensures that everything in the project is completed properly and in a safe manner, mitigating risk and preventing injury to members of the team and project mentees. The EIT provides assistance to the CS, PE, and PCM. DT's will aid the PE in creating technical plan sheets and running analyses in computer programs while LT's will complete required testing and report the results of analysis during various stages of the concrete mix design process. The OA is responsible for client contact and scheduling meetings with the client, project advisors, and the PDE

For the purpose of the race demonstrations, the Competition Team is comprised of ten members, though the Core Project Team is made up of only five: Anne Hritz, Matt Leazier, Brendon Napier, Mason Timosko, and Victor Wing.

Anne Hritz is the Project Manager for the team. This position encompasses the duties of the OA, EIT, PDE, and PCM. They are responsible for being the primary connection between the team and the client. As a result, they review all products being sent to the client, schedule the team's hours, and plan financials. Products under Anne's review include the structural, hull, and mix designs in addition to all items needed for the competition, including the prototype, cylinder samples, aggregate samples, and other required presentation and demonstration materials are brought to the competition. Hourly logs and important schedule milestones are closely monitored by Anne to ensure the project stays on track. Financials are organized in an income-outcome style record to ensure the team does not overspend their budget.

Matt Leazier is the Quality Control, Quality Assurance Lead for the project, which covers the responsibilities of the QM, LT, and DM. As a result, he ensures that all practices are performed correctly, safely, and with optimal accuracy. Such practices include the development and creation of a concrete mix that adheres to the requirements stated in the RFP, testing according to ASTM standard methods, and compliance with lab safety requirements. Matt guarantees that effective communication occurs between team members to prevent oversights and errors prior to the Project Manager's review of project products.

Brendon Napier is the Structural Design Lead for the project. Tasks associated with this position incorporate those assigned to the DT, EIT, and PE. His role is to ensure that the canoe is structurally sound and can withstand the demand of not only the races, but long-distance transportation as well. Brendon is tasked with determining the flexure, shear, and punching shear demands and capacities using concrete design principles.

Mason Timosko is the project's Mix Design Lead. He is responsible for not only creating a mix design that allows the canoe to float, but acquiring materials and product information as well. Mason must test each material to obtain unknown technical properties and ensure that aggregates meet the gradation requirements. These tasks are associated with the LT, DM, QM, PE, and PCM roles.

Victor Wing is the team's Hull Design Lead. His job includes designing, drafting, and assembly for the canoe, encompassing the duties of the CS, PE, and DT. Victor is responsible for researching canoe hull curvature needs, drafting the final design in SolidWorks, and communicating with the sub-contracted hull mold manufacturer.

Figure 2-1 below presents an organizational chart that details how these roles are related to each other. Also included is a list of mentees and advisors that made the project possible.

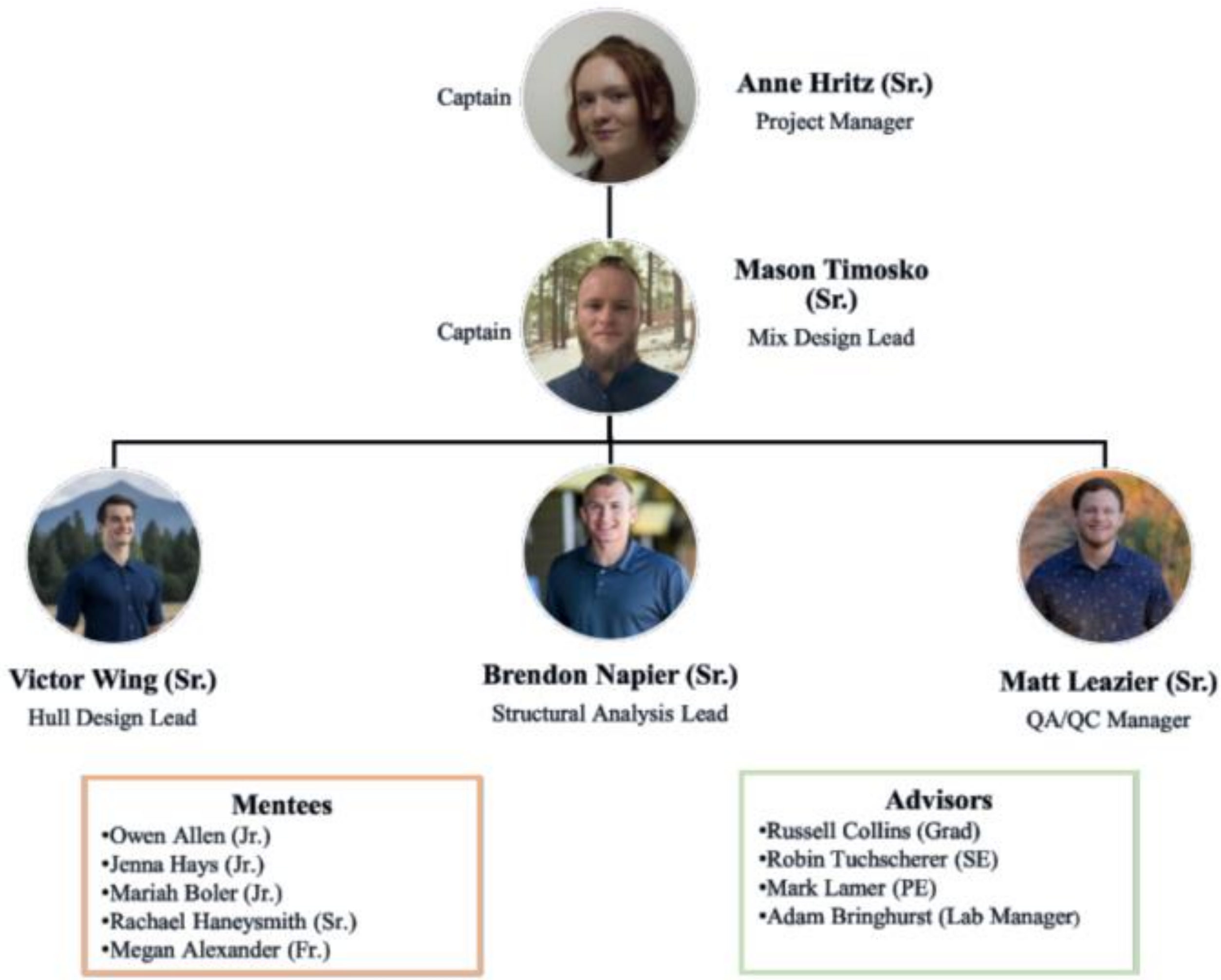


Figure 2-1: Organizational Chart

3.0 Technical Approach to Project

3.1 Concrete Mix Design

The concrete mixture design process began with the primary goal of a dry density of between 65 and 90 pounds per cubic foot (pcf) for the final structural mix. These values were intended to give the canoe enough weight to provide adequate freeboard. Proper floatation is assured despite the weight of the concrete through the use of foam-filled bulkheads in both the bow and stern. A secondary goal was to make the final mix environmentally friendly, using recycled materials whenever possible.

With these goals in mind, aggregates were selected based on weight, strength, and quantity available from previous years' canoe teams. Sieve analyses were performed for each aggregate separately and for a composite of all aggregates used to ensure compliance with the gradation by volume requirements stated in the RFP. These sieve analyses were performed following the procedure outlined in ASTM C136, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

Utelite Crushed Fines were used as the primary aggregate for the structural concrete mixture. The material was obtained from 2022's *Ponderosa* Concrete Canoe Team, and a supplementary donation was provided by Utelite to ensure enough of the aggregate was available to construct the canoe. The material is expanded shale that is quarried then kilned at high temperatures, creating air voids. This process provides the material with a high strength and light weight. Because of this, the Crushed Fines were selected to make up 60 percent of *D.A.S. Boat's* aggregate mixture while still adhering to the gradation requirements. The expanded shale complies with ASTM C330. The aggregate has an oven-dried specific gravity of 1.82, a saturated surface dry (SSD) specific gravity of 2.19, and an absorption rate of 20 percent [1].

A Request for Information (RFI) was sent to the Committee on Concrete Canoe Competitions (C4) concerning the use of Post-Consumer Carpet Calcium Carbonate (PC4) as an aggregate. The inclusion of this material is desired, as the material decreases the overall weight of the concrete, and it allows the team to explore the uses of recycled materials bound for landfills. PC4 is derived from recycled carpet that is blended into fines. The team has decided to implement this material in the canoe because it has not previously been used by a team in the Concrete Canoe Competition, setting *D.A.S. Boat* apart from the rest. Because of its recycled nature, this material increases the environmental sustainability of the canoe. PC4 naturally entrains air into concrete and has a specific gravity of 1.33, providing a lighter final concrete mix. The material has an absorption rate of 40 percent.

To further increase the environmental sustainability of the canoe, the team initially selected AeroAggregate to fulfill the larger particle size distribution requirements. The material was favored because of its 99 percent recycled glass composition and light unit weight, though the process of crushing the large pieces into particles that adhered to the gradation requirements proved to be time-intensive and costly. The aggregate could only be crushed in relatively small quantities and each batch was required to undergo a sieve analysis. This was a tedious process, leading the team to look for alternatives. Perlite and AeroAggregate were found to have similar material properties and behaviors as aggregates. Perlite has an oven-dried specific gravity of 0.18 and an SSD specific gravity of 0.49. A disadvantage to the material is that it has an absorption rate of 170 percent, requiring the team to use a high range water reducer admixture [2].

Table 3-1 on the next page presents the particle size distributions for the three aggregates used, in addition to the composite gradation curve and particle size distribution requirements stated in the RFP.

Under the competition rules, there is a restriction on the amount of cement that can be used in a mix: a maximum of thirty percent of the cementitious materials used can be cement. This required the team to find a high strength cement as well as compatible pozzolans and alternative supplementary cementitious materials to gain the desired concrete strengths.

CalPortland's Type IL *Advancement LT* Portland cement makes up 30 percent of the cementitious materials and was chosen for the structural mix for three primary reasons. First, the cement is high strength, which is a necessity in a mixture with lightweight aggregates. Second, a primary property of the cement is its high sulfate resistance. With the water qualities and characteristics of the race location unknown, sulfate resistance was desired to ensure cracking or disintegration of concrete would be minimized. Finally, the cement has a light color, allowing for stain colors to have a more aesthetically appealing appearance [3].

Table 3-1: Aggregate Gradations

Sieve	% Volume Retained per RFP	% Retained by Volume of 19.4 ft^3			Totals
		Utilite Crushed Fines	PC4	Perlite	
9.5-mm (3/8-in.)	0	0%	0%	0%	0%
4.75-mm (No. 4)	0-5	0.66%	0%	0%	0.66%
2.36-mm (No. 8)	0-20	8.5%	0%	11.5%	20%
1.18-mm (No. 16)	0-35	12.2%	0.43%	22.2%	34.8%
600-um (No. 30)	0-35	17.7%	1.43%	0%	19.1%
300-um (No. 50)	0-25	9.51%	3.14%	0%	12.7%
150-um (No. 100)	0-10	4.62%	3.38%	0%	8%
Pan	0	0.18%	4.57%	0%	4.75%
Total Volume of Composite Aggregate =					100%

120 Grade Slag was chosen to make up 50 percent of the cementitious materials. This pozzolan was chosen because it bonds well with the Type IL cement used in addition to providing a high strength. A disadvantage of slag cement is that it takes longer to cure when compared to normal cement. As a result, testing cylinders could not be subjected to optimized curing conditions, as they were required to cure for an extra two days.

Class F Fly Ash was chosen as the final 20 percent of cementitious materials. Fly ash was chosen because it was readily available at NAU's field work facility, and it is environmentally and economically sustainable. Since Fly Ash is a particulate matter that can be toxic when airborne, it is typically donated from coal burning facilities, making it financially available. By using Fly Ash within concrete as a pozzolan, it traps the fly ash in stone, preventing the particulate matter from contaminating the environment.

MasterFiber M35 polypropylene fibers were chosen as the secondary reinforcement to control cracking from shrinkage during curing. These are intended to maintain the water-tight exterior of the canoe.

Several admixtures were experimented with during the testing phase including viscosity modifiers, air entrainers, and water reducers. However, since the team already achieved a 4-inch slump and had a high air content due to the PC4 aggregate, the only admixture used in the final mix is water reducer. MasterGlenium 3400 is a high-range water reducer that was used in the mix because of its ability to lower viscosity and increase concrete spread.

Three prospective mixes were created during this phase of the project, and they were compared using a decision matrix. The design that scored highest based on four desired qualities – compression strength, density, cracking, and aesthetics – was chosen as the final design. Each category was assigned a weight based on the perceived importance of the quality in creating a concrete mixture that would achieve project goals set by the team. Compression strength and density were both chosen to be 35 percent, as they would have the highest impact on the canoe's performance structurally through resistance to applied forces and hydraulically through buoyancy. Compression values used to assess each mix were gained from ASTM C39 compression tests conducted on 28-day cylinders. Densities for each mix were the dry unit weights taken before compression tests. Cracking was assigned a weight of 20 percent as it was important that patchwork was avoided. During

Table 3-2: Concrete Mix Design Decision Matrix

Mixture Design	Compression Strength (35%)	Density (35%)	Cracking (20%)	Aesthetics (10%)	Weighted Total
Mix 1: PC4 | AeroAgg | Utilite | High Water | 0.3 W/CM Ratio	4	3	4	4	3.65
Mix 2: PC4 | Perlite | Utilite | Low Water | 0.25 W/CM Ratio	3	5	5	5	4.3
Mix 3: PC4 | Poraver | Utilite | Low Water | 0.4 W/CM Ratio	3	4	3	3	3.35

Scoring: 1 – Insufficient, 2 – Sufficient, but does not meet Standards, 3 – Meets Standards, 4 – Exceeds Standards, 5 – Exceeds Expectations the mix design phase, testing cylinders and 6 x 12 x 1 inch test slabs were analyzed for visually observable cracking or significant shrinkage. Aesthetics is one of the aspects the final prototype is scored on during the competition, leading to its weight of 10 percent. This was measured during the mix design phase by comparing the color and natural finish of the cured concrete cylinders and slabs to those of other prospective mixtures. These qualities were rated on a scale of 1 to 5, where 1 signified that the concrete mix did not meet the needs of the team, 3 signified a design meeting the criteria defined by the team prior to testing, and 5 exceeded expectations. The needs of the team include, at a minimum, a compressive strength of 1,000 psi, a maximum unit weight of 75 pcf, cracking less than 10 mm, and a color light enough to be stained. This design matrix is presented in *Table 3-2* on the previous page. The selected final mix, *Mix 2*, received a 3 for compression strength as the results from testing under ASTM C39 yielded a compression strength lower than the team's target, but was deemed to be sufficient for the project. This mix scored a 5 in the density, cracking, and aesthetics categories as the mix had an average density of 69 pcf, an absence of cracking in both the testing cylinders (ASTM C39) and slabs (ASTM C78) during curing, and the anticipated natural light color that showed the aggregates in the concrete after sanding, another desired outcome.

Table 3-3 provides a summary of the quantitates of each material used in the final structural mix while a detailed cubic yard mix table and associated calculations for the mix can be found in *Appendix A*.

Table 3-3: Primary Mixture Proportions

Concrete Material	Quantity (lb/yd^3)
Type IL AdvanCement LT Cement	179
Class F/C 80/20 Blend Fly Ash	121
120 Grade Slag Cement	300
MasterFiber M35	0.5
PC4	238
Perlite	162
Utelite Crushed Fines	1623
MasterGlennium 3400 Water Reducer	69
Water	150

3.2 Reinforcement Design

The reinforcement used for *D.A.S. Boat* is a CSS-BCG Bidirectional Carbon Grid produced by Simpson Strong-Tie. This bidirectional grid was chosen based on materials readily available at the Field Station and guidance from the project's Technical Advisor who recommended its use because of the high tensile strength. Although the Ponderosa Pinecones from last year's competition used two layers of reinforcement, only one layer of grid is required for flexural capacity demands because of the high tensile strength. As a result, the cost requirement of reinforcement and the labor demand of placing reinforcement is ultimately reduced by using a stronger and more high-quality grid. Relevant specifications for the reinforcement are provided in *Table 3-4* and an image is provided in *Figure 3-1*. *Appendix B* contains Percent Open Area calculations required by the RFP to ensure that proper mechanical bonding could occur during curing [4].

Table 3-4: Grid Reinforcement Properties

Property	Value	Units
Vertical Aperture Opening	0.6875	in
Horizontal Aperture Opening	0.625	in
Vertical Strand Thickness	0.1875	in
Horizontal Strand Thickness	0.125	in
Tensile Strength	9.5	kip/ft

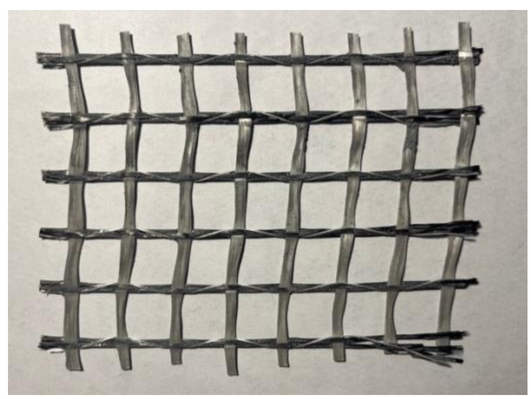


Figure 3-1: Carbon Grid Reinforcement

3.3 Hull Design

A primary goal that the team had for the design of the canoe, *D.A.S. Boat,* was for the hull to be stable, predictable, and practical. After reading through Technical Proposals from previous teams and notes left for future teams, it was found that many of the previous NAU Concrete Canoe Teams saw problems relating to the stability of their canoes during paddling movements. Because of this, extensive research regarding different canoe shapes and their advantages and disadvantages was completed prior to designing the hull. As part of this research, the team studied the available canoes from previous NAU teams to determine beneficial characteristics to consider and detrimental characteristics to avoid. A secondary goal was to ensure that the canoe would be easy to maneuver for a paddler of any skill level. Access to paddling practice is not readily available in Flagstaff during most of the academic year due to the local climate.

While it was found that asymmetrical canoes yield better speed and tracking, a symmetrical hull was ultimately chosen to provide more predictable movements. A symmetrical hull also affords itself to easier constructability and improved efficiency, with the creation of a mold proving to be more simple than its asymmetrical counterpart [5, 6].

To improve both initial and secondary stability, a shallow arch hull profile was chosen. Research returned that a shallow arch canoe would provide the initial stability of a flat bottom canoe and the secondary stability and efficiency of a round bottom canoe, without the expense of sensitivity to tipping. A shallow-vee design was explored for its improved tracking and stability, but crude hydrodynamic analyses demonstrated a reduction in efficiency and freeboard. A flared wall canoe profile was chosen to reduce the likelihood of tipping, increasing the overall stability of *D.A.S. Boat* and providing sufficient room in the hull for paddlers [5, 6].

The hull was initially drafted in AutoCAD to assign basic dimensions to the model. Through research, it was found that, based on 2022's *Pinecone*, an 18-foot hull did not provide sufficient space for practical paddling during the co-ed sprint. Because of this, a hull length of 19 feet was selected for *D.A.S. Boat*. At the widest point, the hull is 2 feet, 8 inches wide to allow paddlers to comfortably situate themselves within the canoe. To provide satisfactory freeboard while still allowing paddlers to be close to the water surface, the hull is designed to be 15 inches deep. Freeboard was found to be 9 inches and its calculations are shown in *Appendix B*.

A decision matrix was used to determine the final hull design based on the following categories: speed, maneuverability, initial stability, secondary stability, and ease of construction. Four combinations of the two main components of a canoe – cross section shape and wall shape – when a rockered body was used, and the combination that scored highest was selected to be the final design. Speed, maneuverability, and secondary stability were all assigned weight of 20 percent as they all have equal impact of the physical performance of the canoe during racing and were deemed to be the most important. Ease of construction was also assigned a weight of 15 percent as it is necessary that the canoe be able to be constructed as modeled within budget without supplemental design. Initial stability was given a weight of 15 percent as, while it has no impact on racing, it is necessary to ensure that the boat can be entered with some level of ease. Comfortability is not a necessity, though a comfortable canoe increases a paddler's performance, causing the criteria category to have a weight of 10 percent. These categories were rated on a scale of 1 to 5, where 1 signified a design

Table 3-5: Hull Design Decision Matrix

Hull Design	Speed (20%)	Maneuverability (20%)	Initial Stability (15%)	Secondary Stability (20%)	Ease of Construction (15%)	Comfortability (10%)	Weighted Total
D1: Shallow-Arched Bottom | Flared Sides | Rockered Body	4	5	4	4	5	4	4.35
D2: Shallow-Arched Bottom | Tumblehome Sides | Rockered Body	4	5	4	4	2	5	4
D3: Flat Bottom | Flared Sides | Rockered Body	2	2	5	4	5	5	3.6
D4: Shallow-Vee | Straight Sides | Rockered Body	5	5	2	5	3	2	3.95

Scoring: 1 – Insufficient Performance, 2 – Sufficient, but does not meet Standards, 3 – Meets Standards, 4 – Exceeds Standards, 5 – Exceeds Expectations performing poorly in relation to the category standards, 3 represented the design meeting the category standards, and 5 exceeded expectations. Category Standards refers to minimum quality that the canoe should have, as agreed upon by the team. These were largely based on qualities of store-bought canoes and the team's experience with them while practicing at Lake Mary and include aspects such as speed, effective turning, stability, and body shape. Speed, maneuverability, initial stability, and secondary stability scores were based on qualitative data found during research and paddling practices. Speed is related to the hydrodynamic nature of the canoe and how well it performed when starting from a stationary position and maintaining a constant velocity. Maneuverability is associated with how well the canoe can turn and navigate around obstacles. Initial and secondary stability refer to how balanced the boat is while stepping into it and during paddling, respectively, both of which consider a design's inclination towards tipping or overturning. Ease of construction scores were determined on how possible it would be to construct the canoe based on mold shape, cost, effectiveness, and efficiency. Comfortability, a subjective measurement of how comfortable a paddler feels while in the canoe, was determined in relation to previous years canoes and remarks from previous teams. Provided on the previous page in *Table 3-5* is the Decision Matrix for the final canoe hull design.

Construction drawings and specifications for the canoe hull and mold are provided in *Section 4.0* of this document.

3.4 Structural Analysis

Structurally, *D.A.S. Boat* was designed based on three primary criteria: a high concrete compressive strength, the implementation of a high tensile strength reinforcement, and the use of a lightweight concrete mix. Prior to beginning the structural analysis process, the high compressive strength of the concrete in combination with the high tensile strength of the reinforcement were expected to provide enough capacity to resist the loading demands caused by paddlers and buoyancy forces on the hull. In addition, it was anticipated that the lightweight concrete would ensure that the magnitude of the buoyancy forces would be large enough to allow the canoe to float.

Structural analysis calculations were performed for several load cases to reflect the five expected race demonstrations to ensure the safety and stability of the canoe. The analyses utilized principles from statics and reinforced concrete design to create shear force and bending moment diagrams, determine the punching shear demand, and explore maximum loadings that the canoe will be subjected to. The process began with the team establishing point load magnitudes for each load case in addition to other forces acting on the canoe. Three primary forces were considered: self-weight, buoyancy, and point loads representing paddlers. For simplified, reliable results, the canoe was modeled as a simply supported beam.

For the two-male sprint case, point load magnitudes of 180lbs were chosen based on the average weight of the males on the Competition Team. These loads were placed three feet apart from each other, equidistant from the midspan point. To represent the self-weight of the canoe, the concrete oven dry unit weight of 69 pcf was multiplied by the 5.36 cubic foot volume of concrete used for the hull to produce a resultant with a magnitude of 370 lb This value was divided by the 19-foot length of the hull to generate a 20 pound per lineal foot (plf) distributed load acting in the direction of gravity. The buoyancy force was determined by multiplying the volume of water displaced by the canoe's 69 pcf unit weight and dividing the result by the length of the canoe. This provided a buoyancy force of 39 plf. While the paddler point loads and buoyancy force would generally be considered live loads, they were conservatively solved for as dead loads in LRFD Load Combination 1 because they will be applied to the canoe with greater certainty than how live loads are typically assigned. While other load combinations were considered, due to the loose nature of how paddlers and buoyancy forces are defined, they were not used. The design loads placed on the simply supported analytical model of the canoe are shown in *Figure 3-2*. Supports were added to the beam for stability purposes when showing the shear force and moment created in the canoe; however, no physical reactions occur at the supports.

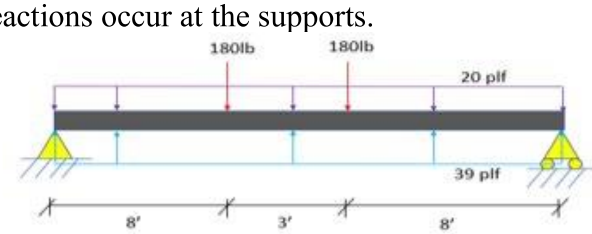


Figure 3-2: Canoe Analytical Model

These loads and the reactions at the supports were used to create the shear force and bending moment diagrams presented in *Figures 3-3 and 3-4* on the next page*,* respectively. The maximum shear force for the load case was found to be 150 lb and the maximum moment was found to be 600 lb-ft. Utilizing LRFD Load Combination 1 under ASCE 7-16, a load factor of 1.4 was used to obtain a shear demand of 210 lb and a moment demand of 840 lb-ft [7].

To determine if the capacity of the hull is greater than the required demand for the load case, the flexure and shear capacities were calculated using *Equations 3-1* and *3-2*. The calculations were completed under the assumption that the canoe can accurately be modeled as a simply supported beam, where the beam's width is equivalent to two times the thickness of the hull. The shear capacity was found to be 1590 lbs, which is larger than the demand of 210 lb. It was determined that the moment capacity was also larger than the demand, with a solved-for value of 1290 lb-ft, surpassing the demand of 840 lb-ft. Moment capacity was conservatively solved with a strength reduction factor of 0.65 in case the canoe is in compression control. Another reduction of 3 was given to the tensile strength, and therefore the moment capacity, since only one third of the recommended lap length was used for the reinforcement.

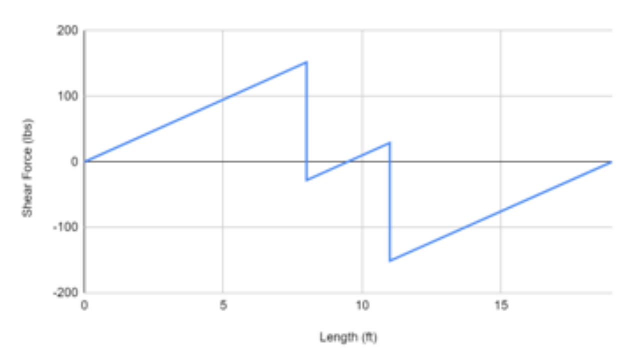


Figure 3-3:Two Male Sprint Case Shear Force Diagram

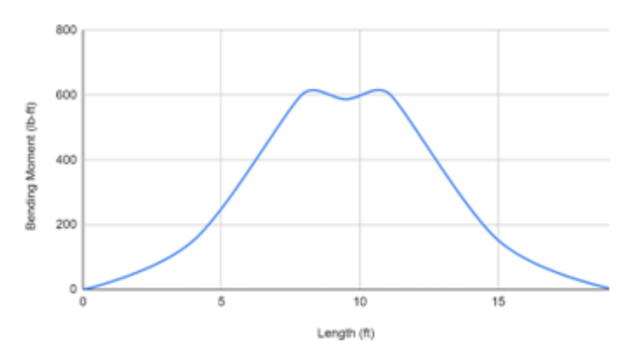


Figure 3-4:Two Male Sprint Case Bending Moment Diagram

To calculate the punching shear, the shear force resulting from a male paddler's weight was applied over the rectangular shape created from a paddler kneeling with their knees together. This rectangular shape was roughly 6 inches by 3 inches and an additional inch was added to each side to be considered the critical area. This loading scenario was chosen to represent the maximum probable punching shear pressure, which was found to be 16 pounds per square inch (psi) using *Equation 3-3*. The hull base was analyzed as a two-way slab. *Equation 3-4* was used to determine the punching shear capacity. This value was found to be 80 psi, which exceeds the demand. *Table 3-6* below presents the calculated demands and capacities for each force as well as the ratio of the two values.

Table 3-6: Demand and Capacity Values

Force	Factored Demand	Capacity	Demand to Capacity Ratio
Shear Force (kip)	210	1590	13%
Bending Moment (kip-ft)	840	1290	65%
Punching Shear (kip)	16	80	20%

Equation 1: Flexural Capacity of Concrete [8]

$$\varphi M_n = \frac{\varphi * T * (d - \left(\frac{\beta_1 * c}{2}\right))}{12}$$

Where:
M_n *= Flexural Capacity (lb-ft)*
φ *= Strength Reduction Factor*
T *= Tension Force (lb)*
β_1 *= Depth Factor*
c *= Distance to Neutral Axis (in)*

Equation 2: Shear Capacity of Concrete [8]

$$\varphi V_c = \varphi * 2 * \sqrt{f_c'} * b_w * d$$

Where:
V_c *= Shear Capacity of Concrete (lb)*
φ *= Strength Reduction Factor*
f_c' *= Compressive strength of concrete (psi)*
b_w *= Width of canoe (in)*
d *= Depth to rebar (in)*

Equation 3: Punching Shear Demand [9]

$$V_{pd} = \frac{P}{C * t}$$

Where:
V_{pd} = *Punching shear demand (psi)*
P = *Load (lbs)*
C = *Circumference/Perimeter of critical area*
t = *Thickness (in)*

Equation 4: Punching Shear Capacity [8]

$$V_p = \varphi * 4 * \Delta * \sqrt{f_c'}$$

Where:
V_p = *Punching shear capacity (lb)*
φ = *Strength Reduction Factor*
Δ = *Factor for lightweight concrete*
f_c' = *Compressive strength of concrete (psi)*

The three values solved within the shear moment diagram, bending moment diagram, and punching shear calculation are all connected in a primary way, being that they are demand values. While the actual load values given by the demand and capacity for shear, moment, and punching shear are different, they share a safe ratio between demand and capacity. Demand over capacity for shear, moment, and punching shear are summarized in *Table 3-5*. These ratios ensured the canoe's structural success, even under unforeseen load conditions.

To optimize tensile strength, overlap length of reinforcement was considered. The bidirectional carbon grid reinforcement used in the canoe has a recommended lap length of twelve inches. However, this lap length is for industry grade concrete, allowing for 114 ksi of tensile strength when full lap length occurs with two layers of reinforcement. Since a canoe needs significantly less tensile strength, approximately 500 psi, this required lap length was reduced for the canoe. In order to fit the canoe shape, lap length was determined to be a minimum of four inches. Since lap length was only one third of what was required by the manufacturer, the tension strength of the reinforcement was reduced by a third, creating a low, yet conservative moment capacity [4].

While tensile stresses and cracking seen from shrinkage during curing can be considered two of the largest concerns, the team focused on moment and shear calculations during the structural analysis phase of this project based on the requirements stated in the RFP. During the concrete mix design process, minimal shrinking and cracking was seen during the curing processes of all considered concrete mixes. Had it been a problem that required attention, shrinkage reducing admixtures would have been considered during the mix design phase and the amount of secondary fiber reinforcing would have been increased. To ensure structural stability, the team optimized tensile strength through additional testing of mixes and reinforcement lap and development length.

The final structural consideration was the load case for the floatation test conducted prior to racing at the competition. To ensure that the canoe is recoverable if it breaks or sinks, the floatation test requires that the canoe be filled with water and submerged and still be able to resurface based on buoyancy. For this to occur, the volume of water displaced must be reduced by the volume of water in the canoe after being submerged. Under the competition rules, bulkheads could be a maximum of 3 feet. With this restriction, calculations using *Equation 3-5* produced results that revealed that the team would need a concrete mixture with a maximum density of 66 pcf for the canoe to be considered buoyant. A reduction of 1.32 was used as a safety factor and was chosen by error approximation. Using *Equation 3-6*, 69 pcf mix would need 3-foot, 4-inch bulkheads to meet this standard, where a factor of safety of 2.0 was used. The team initially disregarded this load case, but calculations were completed after the competition to verify results seen during the test. These calculations can be seen in *Appendix C*.

Equation 5: Required Density

$$\gamma_c = \frac{(V_c + V_b) * \gamma_w}{V_c * 1.35}$$

Where:
γ_c = *Required Density (pcf)*
V_c = *Canoe Volume (ft^3)*
V_b = *Bulkhead Volume (ft^3)*
γ_w = *Density of Water (pcf)*

Equation 6: Required Bulkhead Length

$$L_B = \frac{\left(\frac{V_c * \gamma_c * 2}{\gamma_w} - V_c\right)}{2A_B}$$

Where:
L_B = *Bulkhead Length (ft)*
V_c = *Canoe Volume (ft^3)*
γ_c = *Required Density (pcf)*
γ_w = *Density of Water (pcf)*

3.5 Construction

Prior to constructing the canoe, the hull mold was acquired from the subcontracted manufacturer in Palm Springs, California. The mold is a female sectional form cut from a high-density, low absorption styrofoam where each section is 4 inches thick. Once the mold was obtained, a table was built in the CECMEE Field Station from OSB plywood and pieces of 2x4 lumber. Each section of the formwork was glued together using a construction adhesive. Any sharp edges on the inside of the mold were sanded down to create a smooth, uninterrupted surface that accurately reflected the final hull design chosen. Following the sanding of the mold, drywall joint compound was used to fill any holes in the styrofoam and further smooth the mold surface. A team meeting during the mold preparation is shown in *Figure 3-5* on the next page.

Aggregates, cementitious materials, and fibers were pre-proportioned prior to placement such that each one-half cubic foot batch of concrete could be mixed promptly when needed. Rectangular sections of the reinforcement grid were also pre-cut to improve placement efficiency. Approximately 12 hours before placement began, petroleum jelly was applied to the inner surface of the mold to act as a releasing agent such that the formwork could be easily removed from the cured concrete.

On placement day, the concrete was placed with the help of project mentees. Placement day began with a safety meeting, where general safety practices were discussed to mitigate risk and injury. While the first batch of concrete was being mixed, the mold was inspected to ensure that the entirety of the inner surface was covered in the releasing agent, and if any portion were found to be bare, they were covered. Batch mixing for the concrete was done using a mixing drum, as shown in *Figure 3-6*. Concrete placement began at one end of the canoe and moved towards the other, gradually building up the thickness of the walls. During this process, the concrete began at the bottom of the canoe and was pulled up the sides using concrete floats and masonry trowels until the wall was uniformly half an inch thick. Measurements were taken periodically during placement to verify wall thickness. When a section of the hull longer than the pre-cut reinforcement piece consistently met the required thickness, the carbon mesh grid was placed such that sufficient lap length was achieved. Reinforcement placement is shown in *Figure 3-7*. The reinforcement was trimmed to ensure that it would not stick up above the gunwales. A second half-inch layer of concrete was placed over the reinforcement layer for a total hull thickness of one inch. Once the hull was a uniform thickness, the surface was finished using hand tools to smooth the concrete surface.

Once the concrete was placed and the surface was smoothed with hand tools, a curing chamber was built around the mold using PVC pipe, PEX pipe, and medium-weight plastic sheeting. Humidifiers were placed inside the chamber to create wet curing conditions, as shown in *Figure 3-8*. For the first 10 days of curing, the canoe was periodically examined, and any cracking or surface damage was recorded. Although cracking was not precisely measured, the team did not see any visual cracks during the canoe's curing period. On day 10, repairs were completed in

Figure 3-5: Mold Preparation

Figure 3-6: Concrete Mixing

Figure 3-7: Concrete and Reinforcement Placement

Figure 3-8: Curing Chamber

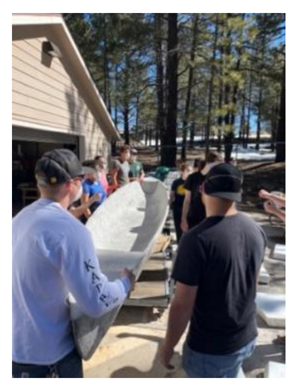


Figure 3-9: Mold Removal

the form of patching using the structural concrete mix. On day 28, the inner surface of the canoe was sanded down. On day 35, the canoe was removed from the mold, shown in *Figure 3-9*, and any voids were patched with the structural mix. Four days later, the outer surface was sanded creating a smooth, uniform surface. Following this, two days later, silane sealant was applied ensuring that water would no longer be able to hydrate the concrete.

3.5 Competition

Following the application and curing of the sealant, the canoe was transported to Reno, Nevada in a trailer along with materials and supplies for other competitions and events at the ASCE Intermountain Southwest Student Symposium at the University of Nevada, Reno. Concrete Canoe Competition prototype displays and technical presentations took place on the same day and were judged based on score cards provided in the RFP.

Race Demonstrations took place on the last day of the symposium. Prior to the races, a floatation test was performed to verify the safety of the canoe and to determine whether or not the boat is truly buoyant. This test, known colloquially as the 'swamp' test, sees that the canoe is filled just below the gunwale line with water and then submerged into the body of water used for the races. Under this year's competition rules, the canoe had to resurface within two minutes to be considered buoyant. Unfortunately, *D.A. S. Boat* did not pass this test due to a small oversight on the team's part: the additional weight of the canoe being filled with water and fully submerged was not considered during structural analysis and buoyancy calculations; only the load cases where the boat was empty or when paddlers were in the boat were considered.

Overall, *D.A.S. Boat* and the Canoe Captains placed fourth of nine schools in the competition, receiving 65.5 of 100 possible points over the duration of the competition. The team placed first in the *Technical Proposal* category, fifth in the *Technical Presentation* category, and seventh in the *Final Product Prototype* category. These technical categories were worth 30 percent, 25 percent, and 25 percent of the total final score, respectively. For the technical presentation, the team saw a large deduction for exceeding the allotted time which drastically dropped the score for that category. The *Final Product Prototype* placing was the result of not passing initial floatation and failing to meet criteria stated in the RFP for the display cross-section. For the *Race Demonstrations*, *D. A. S. Boat* placed seventh of eight schools for the women's slalom, sixth for the men's slalom, fourth for the women's sprint, third for the men's sprint, and seventh of seven schools for the co-ed sprint for an overall race ranking of sixth of nine schools.

3.7 Project Management

The team created a project scope that outlined the major tasks to be completed, focusing on the following: Concrete Mixture Design, Reinforcement Design, Hull Design, Construction, General Conference Deliverables, Project Management, and Evaluation of Project Impacts. Each major task has several sub-tasks associated with it. This approach allowed the team to more easily put together and maintain a schedule and understand how certain aspects of the project impacted one another. The order of these tasks was selected based on the amount of time needed to complete all associated sub-tasks. The Project Manager and QA/QC Manager oversee the work being completed and update the project schedule as necessary such that dates of completion and anticipated milestones accurately reflect the team's progress. The project schedule can be seen in *Section 5.0* of this document.

Various milestones were determined at the beginning of the project, allowing a critical path to be established. Critical path activities included researching various materials, developing a structural concrete mixture, drafting and analyzing a final design for the hull, acquiring the hull mold, constructing the canoe, and completing major competition deliverables. The extensive research of prospective aggregates, cementitious materials, admixtures, and reinforcement included speaking with companies such as Utelite and CalPortland about the advantages of the different materials they produce as well as acquiring Material Technical Data Sheets to determine critical material properties. This allowed the team to hone in on selecting materials that would produce a concrete mix that met the goals set at the beginning of the project. Once a final mix was determined, the proposed hull design could be analyzed to ensure that the structural capacities met the expected demands. This necessitated conducting test adhering to ASTM standards to determine material properties of the concrete, both with and without reinforcement. The final hull design was sent to a subcontracted manufacturer for fabrication. Following the completion of the mold, the canoe was constructed and cured. While the concrete cured, other competition deliverables were prepared, including the technical report and presentation.

The Project Manager and QA/QC Manager are also responsible for financial aspects of the project. This includes the securing of funding and procurement of materials. They worked closely with NAU's ASCE Student Chapter treasurer to ensure that the project was completed under budget. Many of the materials used by the team to construct the canoe were acquired through sponsorships and donations. For other required materials, quantities needed were determined and various suppliers were researched to find the most comparable pricing. This was done to ensure that enough funds were set aside to hire a professional to manufacture the mold. Income and expenses were tracked in a spreadsheet and monitored closely over the course of the project.

Two primary scheduling obstacles were encountered during the project, requiring the project schedule to change. The first was unexpected delays in the mix design process. Initially, the team performed sieve analyses based on mass and developed mix designs based on those results. Following the RFI that specified gradations should be completed by volume, the team was required to reconduct the sieve analyses and redesign the structural concrete mix in order to be in compliance with the competition rules, extending the time allotted to the task. This created conflicts in scheduling with the subcontracted hull mold manufacturer, who required a considerable amount of time to fabricate the canoe mold. These changes to the schedule fairly early on in the project meant that other dependent tasks, such as construction, were also required to be pushed back. When the project schedule was created, allotted time periods for certain tasks included float time to account for unforeseen circumstances.

3.8 QA/QC Program

To ensure that a high-quality canoe was produced, a Quality Control/Quality Assurance (QA/QC) plan was carefully created. The main goal of this QA/QC program was to ensure that work completed met the standards and guidelines set forth in the RFP and by the team before beginning the project. This aided in the mitigation of risk and the production of exceptional work. These were achieved through constant communication, common industry safety practices, in-depth reviews of both the competition rules and all relevant ASTM standards needed to complete the project, and members constantly backchecked one another's work by reviewing calculation's, analyses, and even measurements.

As mentioned previously, multiple meetings were held each week, constantly progressing through the project. During these meetings, plans were established to complete tasks and safe practices for each were discussed. When ASTM tests were being performed, core team members and mentees involved read the standard fully before setting up the workstation. A copy of the relevant standard was present for any testing procedure. This process ensured that each test method was completed properly such that accurate test results were generated.

During the concrete mixture design phase, several concrete mixes were created, and each was tested. Following ASTM methods, multiple sieve analyses were conducted on each of the aggregated proposed for use to ensure that the gradation requirements were met. The iterative process of creating multiple mixtures allowed the team to learn from mistakes and more fully understand how each material used interacts with one another. This insight helped move this phase of the project forward. Several ASTM tests were conducted on each concrete mixture made, that includes ASTM C31, Making and Curing Concrete Test Specimens in the Field, and ASTM C143, Slump Test of Hydraulic Cement Concrete [10, 11]. During the curing process, cylinders and the canoe were subjected to warm, humid conditions to allow the concrete to reach the desired strength. Seven-day compressive breaks were conducted to gain a sense of how each concrete mixture would perform. These tests were conducted following ASTM C39, Concrete Cylinder Compression Testing [12]. In addition, tests adhering to ASTM C496, Splitting Tensile Strength of Cylindrical Concrete Specimens, were performed to determine the tensile capacity of the concrete [13]. ASTM C78, Flexural Strength of Concrete, was also used to determine the flexural capacity of a reinforced concrete slab [14]. This allowed the team to understand how vital the reinforcement would be during this process. Following extensive research on the final materials selected, and an intensive trial and error process, an optimal mixture that met the team's design goals was created.

Prior to placing the canoe, a meeting with the core project team members and all project mentees was held to review safety and placement best practices and procedures. To ensure a successful placement process, the team made proactive choices such as explaining and assigning roles to all individuals involved and providing in-depth instructions and examples. A foam mold cut by a subcontracted professional allowed the team to create an exterior that matched the construction drawings. A mixture of releasing agents, including degreaser and cooking spray, were applied to the mold before the concrete was placed to ensure that the cured canoe would separate from the mold without damage. Structural concrete used to make the canoe hull was mixed in batches over the duration placement process with another team member verifying that the measurements were accurate. This was done to prevent the occurrence of cold joints and to ensure that materials were not wasted. While the concrete was being applied to the mold, measurements were taken by multiple team members in several locations around the hull to inform the individuals placing the concrete on the depth of the layer. This process allowed the hull to be constructed in two layers with grid mesh reinforcement between the two, with the depth totaling one inch. To provide enough clear cover and improve the canoe's structural soundness, the two layers of concrete were placed as evenly and equally as possible. The interior of the canoe was finished with trowels to create a smooth surface. Following the placement of the canoe, a curing chamber was built around the formwork using plastic drop sheeting, wood framing, and humidifiers to ensure optimal curing conditions.

During the hull design process, ENERCALC was used to verify structural analysis calculations completed by hand [15]. This allowed the team to be confident that the prototype design could withstand the expected maximum demands.

3.9 Evaluation of Project Impacts

When discussing primary and secondary goals for this project, the team decided that sustainability was an important factor in attaining successful results, as it was deemed important to study and address the environmental impacts of the project. Creating an environmentally conscious canoe was at the forefront of all design considerations. To achieve this, a sand replacement aggregate, Post Consumer Carpet Calcium Carbonate (PC4), was used in the developed concrete mixture. This material is sourced from used carpets, making it a completely recycled material. The carpet is shredded and washed before being separated into three separate materials: nylon, polypropylene, and calcium carbonate. Typically, in the carpet recycling process, calcium carbonate is relegated to landfills. The team's use of this material proves that PC4 can be used for alternate purposes. For every cubic yard of concrete made, 200 pounds of carpet material is being recycled and diverted from landfills.

To further reduce the environmental impact of the canoe, a cement material that is less imposing was chosen. CalPortland's Type IL *Advancement LT* cement ensured that the concrete mixture design would not have the same long-term impacts as typical cement. In comparison to the widely used Type II-V cement, this *Advancement* cement contains 15% more limestone by mass and has been proven to reduce CO_2 emissions by 10% during the manufacturing process [3]. The team's use of Fly Ash, a byproduct of coal burning, and 120 Grade Slag, a recovered material from the steel production industry, allows the carbon footprint of the mixture to be reduced further [16]. With this combination of cementitious materials, the mix design has a reduced impact on the environment when compared to standard concrete.

Sustainable alternatives for the formwork were discussed. The use of lumber was considered, as well as forming and placing the canoe in the ground. Due to the lack of carpentry skills, the geotechnical properties of the soil near the field work facilities, and the local climate, these options were not viable. Instead, the team hired a subcontractor to shape the sectional mold used, which can potentially be reused in the future.

To be economically sustainable, the team utilized leftover concrete and construction materials from previous years. This reduced the number of purchases that needed to be made over the course of the project, leading the project to be completed under budget. Materials that were purchased were acquired from local companies or smaller businesses, helping to support the local economy, and it was ensured that the materials were sourced from the southwestern United States to minimize shipping costs and time. The team spent time acquiring donations and sponsorships to push the project forward and provide future teams with funding. This helps the project to be socially sustainable in addition to continuing to host a mentee program to gain younger engineers' interest, keeping the tradition of competing in the Concrete Canoe Competition alive. Attending the symposium also provides the team with the ability to form new connections by connecting with industry professionals and students from other schools at the competition.

3.10 Health and Safety

Northern Arizona University's Civil Engineering Construction Management, and Environmental Engineering programs require that all lab and field work facilities follow health and safety regulations and procedures [17]. Prior to beginning lab and field work for the project, the team was instructed to compose a safety binder, which was submitted to the faculty lab manager for revision. This binder contained contact information for all team members, project advisors, the lab manager, and emergency contacts such as the University's Environmental Health and Safety Department, the Local Emergency Medical Center, and Poison Control. The Safety Binder also included both safety and emergency response plans that outline what should be done in the event of an emergency and how to prevent hazards from occurring. Once the binder was approved, meetings were held with the lab manager to address any hazards that pertained to the project. Lab safety agreements were signed by all members of the team, acknowledging that each person understood the risks of working in the Field Station and lab facilities and would ensure that hazards are mitigated by following best practice procedures.

During material testing and concrete mixing processes, all individuals present in the lab space wore dust masks, safety glasses, and gloves as necessary. It was ensured that the masks used were sufficient enough to filter any airborne particulates of concrete materials. Any safety precautions and measures specified in relevant ASTM methods and material specifications were taken.

Any prospective mentees that expressed interest in the project were made aware of potential hazards and were required to follow all safety procedures set forth by the team and the University's lab regulations and policies.

The team followed Northern Arizona University's policies to mitigate the spread of COVID-19 as well as current CDC guidelines. Team members were required to get tested if they felt ill and isolated for the full time required if they tested positive.

3.11 Value and Innovation

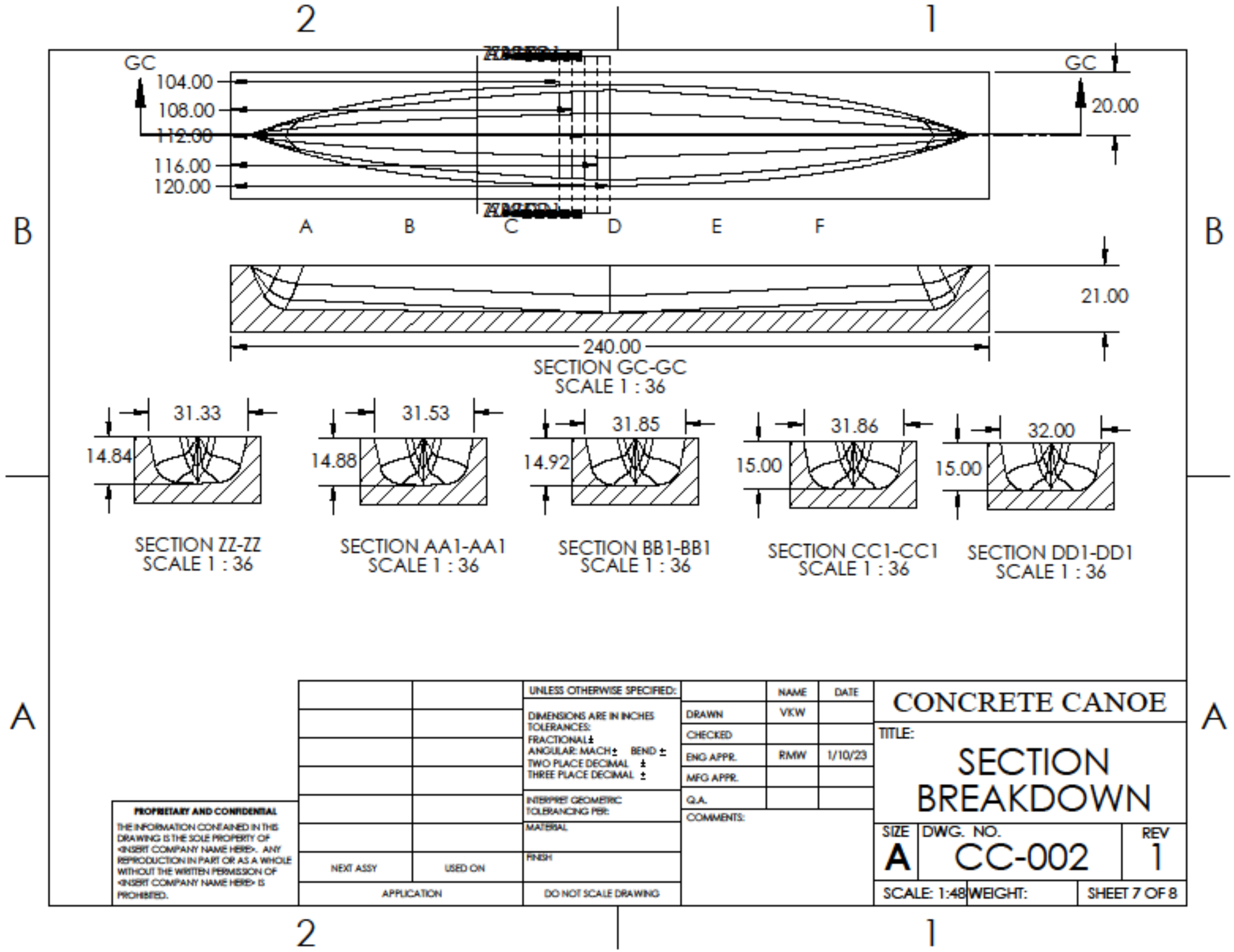
Both value and innovation mean a great deal to the team. Value is created through hard work, determination, and the inclusion of innovative practices in a project. Without value, a team cannot stand out amongst others, losing the opportunity to become a top-placing team in the Concrete Canoe Competition. Because of this, special care was taken to ensure that all specified deliverables, including the Technical Proposal and this Design Report, reflected the team's highest quality of workmanship.

Value was ensured over the course of the design process by seeking innovative ways to perform structural design calculations accurately and efficiently. This ensured that the team's project would stick out amongst the rest of the competitors and perform as a high-ranking team. The team members benefit from this mindset because their names were put on something they can be proud of. Additionally, the ISWS competition invites many engineers to come out and watch. With a high-value canoe, the team will earn more exposure from the professionals that will be in attendance. Generally, structural design is a linear process that begins after all material properties are determined. To overcome the obstacles associated with uncertainty and the iterative process of the concrete mix design, the team developed a calculator in Microsoft Excel to automate the computation of forces acting on the canoe. Values for shear force, bending moment, and punching shear change based on the material properties of a proposed structural concrete mixture. An automated calculation process allowed the team to get updated structural analysis values almost immediately after obtaining concrete test results. Values solved for include the compressional demand, tensional demand, flexural capacity, shear capacity, and punching shear capacity.

The use of PC4 as an aggregate was an innovative choice made by the team, as the material is relatively new to the concrete industry. The reaction that occurs between the calcium carbonate and the other materials in the concrete produce air, causing the material to act as a natural air entrainer. Because of this, chemical air entrainer admixtures are not needed.

Though it is used as a sand replacement, the aggregate contains leftover fibers from the recycling, which helps to control cracking and increases strength. As previously mentioned, the material is both lightweight and high volume, which decreases the overall unit weight of a concrete mixture. The team believe that this is the first time PC4 has ever been used before in the ASCE Concrete Canoe Competition, increasing the value of the prototype.

Innovation was also explored during the construction process. Notes from previous years' Concrete Canoe teams solidified the expectation that the creation of the final prototype is a lengthy process if only the Core Project Team members are present. As a result, the team recruited mentees to assist in the construction process. By having this additional help on the concrete placement day, it ensured that separate teams for mixing, placement, and reinforcement preparation could be formed to make the process as efficient as possible.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108.00
112.00
116.00
120.00
20.00
A B C D E F
21.00
240.00
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31.33
14.84
SECTION ZZ-ZZ
SCALE 1 : 36
31.53
14.88
SECTION AA1-AA1
SCALE 1 : 36
31.85
14.92
SECTION BB1-BB1
SCALE 1 : 36
31.86
15.00
SECTION CC1-CC1
SCALE 1 : 36
32.00
15.00
SECTION DD1-DD1
SCALE 1 : 36
PROPRIETARY AND CONFIDENTIAL
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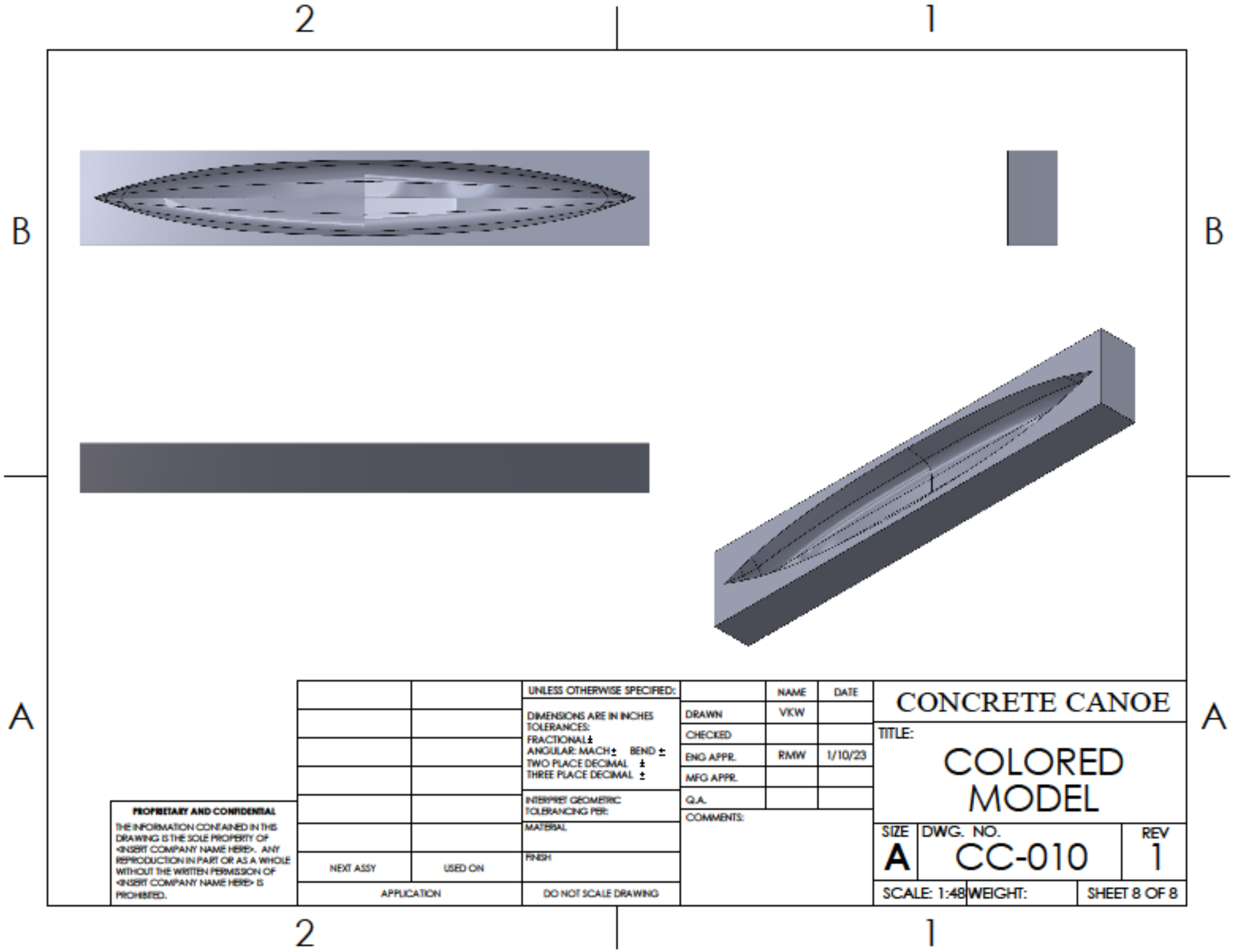

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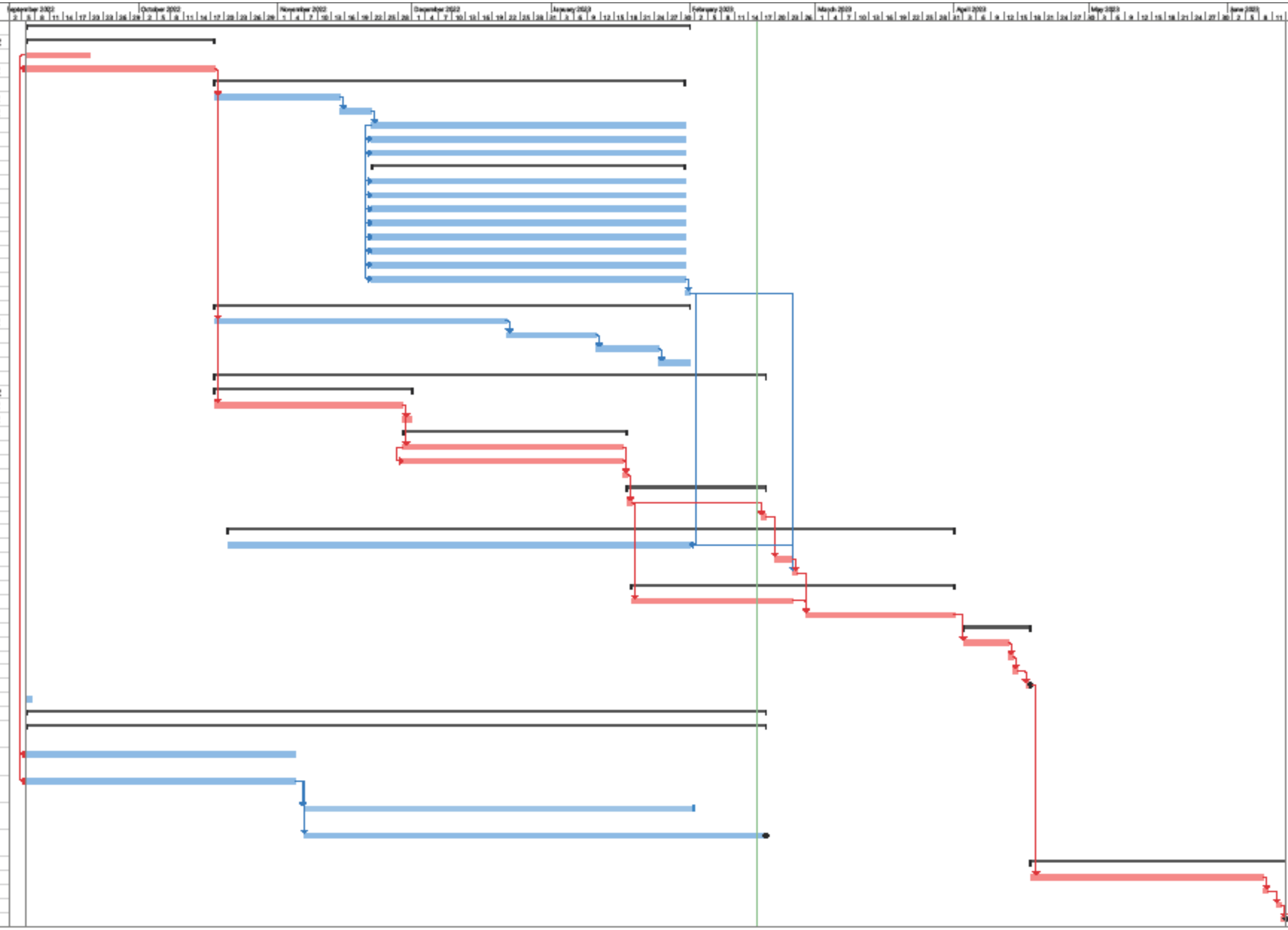
SHEET 8 OF 8

ID	Task Name	Start	Finish
1	TASK 1: Concrete Mixture Design	Tue 9/6/22	Tue 1/31/23
2	Task 1.1: Concrete Materials Research	Tue 9/6/22	Mon 10/17/22
3	Task 1.1.1: Competition Rules	Tue 9/6/22	Mon 9/19/22
4	Task 1.1.2: Materials Research	Tue 9/6/22	Mon 10/17/22
5	Task 1.2: Concrete Mixture Development	Tue 10/18/22	Mon 1/30/23
6	Task 1.2.1: Procurement of Concrete Materials	Tue 10/18/22	Mon 11/14/22
7	Task 1.2.2: Sieve Analysis	Tue 11/15/22	Mon 11/21/22
8	Task 1.2.3: Mixing of Concrete	Tue 11/22/22	Mon 1/30/23
9	Task 1.2.4: Collection of Test Cylinders	Tue 11/22/22	Mon 1/30/23
10	Task 1.2.5: Curing of Test Cylinders	Tue 11/22/22	Mon 1/30/23
11	Task 1.3: Concrete Mixture Testing	Tue 11/22/22	Mon 1/30/23
12	Task 1.3.1: Air Content Testing	Tue 11/22/22	Mon 1/30/23
13	Task 1.3.2: Slump Testing	Tue 11/22/22	Mon 1/30/23
14	Task 1.3.3: Density Testing	Tue 11/22/22	Mon 1/30/23
15	Task 1.3.4: Compressive Strength Testing	Tue 11/22/22	Mon 1/30/23
16	Task 1.3.5: Flexural Strength Testing	Tue 11/22/22	Mon 1/30/23
17	Task 1.3.6: Flexural Strength Testing	Tue 11/22/22	Mon 1/30/23
18	Task 1.3.7: Specific Gravity Testing	Tue 11/22/22	Mon 1/30/23
19	Task 1.4: Analyisis of Concrete Test Results	Tue 11/22/22	Mon 1/30/23
20	Task 1.5: Selection of Final Mix Design	Tue 1/31/23	Tue 1/31/23
21	TASK 2: Reinforcement Design	Tue 10/18/22	Tue 1/31/23
22	Task 2.1: Reinforcement Materials Research	Tue 10/18/22	Wed 12/21/22
23	Task 2.2: Procurement of Reinforcement	Thu 12/22/22	Tue 1/10/23
24	Task 2.3: Reinforcement Testing	Wed 1/11/23	Tue 1/24/23
25	Task 2.4: Creation of a Reinforcement Scheme	Wed 1/25/23	Tue 1/31/23
26	TASK 3: Hull Design	Tue 10/18/22	Fri 2/17/23
27	Task 3.1: Hull Design Preparation	Tue 10/18/22	Wed 11/30/22
28	Task 3.1.1: Software Skills and Training	Tue 10/18/22	Mon 11/28/22
29	Task 3.1.2: Selection of Mold Manufacturer	Tue 11/29/22	Wed 11/30/22
30	Task 3.2: Selection of Final Hull Design	Tue 11/29/22	Tue 1/17/23
31	Task 3.2.1: Drafting	Tue 11/29/22	Mon 1/16/23
32	Task 3.2.2: Structural/Hydrodynamic Analysis	Tue 11/29/22	Mon 1/16/23
33	Task 3.2.4: Selection of Final Hull Design	Tue 1/17/23	Tue 1/17/23
34	Task 3.3: Mold Acquisition	Wed 1/18/23	Fri 2/17/23
35	Task 3.3.1: Contracting	Wed 1/18/23	Wed 1/18/23
36	Task 3.3.2: Mold Pick Up	Fri 2/17/23	Fri 2/17/23
37	TASK 4: Construction	Fri 10/21/22	Fri 3/31/23
38	Task 4.1: Recruitment of Mentees	Fri 10/21/22	Tue 1/31/23
39	Task 4.2: Assemble Formwork	Mon 2/20/23	Thu 2/23/23
40	Task 4.3: Canoe Construction	Fri 2/24/23	Fri 2/24/23
41	Task 4.4: Curing	Thu 1/19/23	Fri 3/31/23
42	Task 4.4.1: Curing Chamber Construction	Thu 1/19/23	Thu 2/23/23
43	Task 4.4.2: Refilling Humidifiers	Mon 2/27/23	Fri 3/31/23
44	TASK 5: ISWS Regional Competition	Mon 4/3/23	Mon 4/17/23
45	Task 5.1: Trailer Preparation	Mon 4/3/23	Wed 4/12/23
46	Task 5.2: Transportation to Conference	Thu 4/13/23	Thu 4/13/23
47	Task 5.3 Display and Presentation	Fri 4/14/23	Fri 4/14/23
48	Task 5.4 Racing	Mon 4/17/23	Mon 4/17/23
49	TASK 6: Evaluation of Project Impacts	Tue 9/6/22	Tue 9/6/22
50	TASK 7: Project Deliverables	Tue 9/6/22	Fri 2/17/23
51	Task 7.2: ASCE Concrete Canoe Competition Deliverables	Tue 9/6/22	Fri 2/17/23
52	Task 7.2.1: Letter of Intent and Pre-Qualification Form	Tue 9/6/22	Fri 11/4/22
53	Task 7.2.2: Preliminary Project Delivery Schedule	Tue 9/6/22	Fri 11/4/22
54	Task 7.2.3: Student Chapter Annual Report/Dues Deadline	Mon 11/7/22	Wed 2/1/23
55	Task 7.2.4: Project Proposal and MTDS Addendum	Mon 11/7/22	Fri 2/17/23
56	TASK 8: ASCE Society-Wide Competition	Tue 4/18/23	Tue 6/13/23
57	Task 8.1: Canoe Packing and Flight Preparation	Tue 4/18/23	Thu 6/8/23
58	Task 8.2: Flight to Conference	Fri 6/9/23	Fri 6/9/23
59	Task 8.3 Display and Presentation	Mon 6/12/23	Mon 6/12/23
60	Task 8.4 Racing	Tue 6/13/23	Tue 6/13/23



Project: Final Proposal Concrete
Date: Thu 2/16/23

6.0 Summary of Engineering Work

The proposed project schedule is provided in *Appendix C* while the final project schedule can be seen above in *Section 5.0*. Initially, project tasks were outlined in accordance with the *Scope of Services* stated in the Project Proposal. Changes to tasks and associated dates were adjusted over the course of the project as they were completed. This included the reordering of concrete testing methods and the consolidation of the *Suite of Potential Solution* subtasks into a single task for both the Concrete Mix Design and Hull Design phases. These changes were made to better organize the project tasks chronologically and to remove redundancies from the final design selection tasks. Other changes to the prospective schedule were made based on the actual duration of tasks that were found to have required an amount of time different than that of which was allotted initially. This included the Mix Design phase, which required a significant amount of additional time compared to what was anticipated due to changes to the competition rules, and all concrete testing completed concurrently with the mix design. The hull design also took longer to complete than expected as the process of learning to use SolidWorks was more involved than expected. In the project proposal, the team stated that advanced hydrodynamic modeling would be completed using the program MAXSURF, however these analyses were not completed. The team was unable to acquire the software and all necessary licenses, and it was determined that the MAXSURF modeling was not necessary to ensure proper floatation of the canoe. The team intended to use the results of analysis as an additional margin of safety and to more completely understand how the canoe would perform.

A copy of the initial proposed project schedule is presented in *Appendix D*.

Table 6-1 presents a summary of the proposed project hours compared with the actual project hours and *Table 6-2* shows the percent difference in these hours. A detailed Engineering Work Hours Matrix is provided in *Appendix E*.

Table 6-1: Engineering Work Hours Summary

	Proposed Hours					Actual Hours				
Task	**SENG**	**ENG**	**TECH**	**SO**	**INT**	**SENG**	**ENG**	**TECH**	**SO**	**INT**
Task 1: Concrete Mixture Design	20	59	78	32	72	10	29	116	45	86
Task 2: Reinforcement Design	5	24	16	2	25	2	9	6	3	8
Task 3: Hull Design	24	63	10	7	48	14	32	0	1	89
Task 4: Construction	18	22	29	36	49	12	22	38	46	87
Task 5: Competition	0	2	0	28	33	3	4	5	14	29
Task 6: Evaluation of Project Impacts	6	12	0	15	6	1	5	0	0	10
Task 7: Project Deliverables	16	19	10	5	59	42	62	9	9	87
Task 8: Project Management	36	24	7	25	8	34	31	1	25	26
Subtotal	**125**	**225**	**150**	**150**	**300**	**118**	**194**	**175**	**143**	**422**
Total	**950**					**1052**				

Table 6-2: Work Hour Difference Analysis

Total Project Hours		
Proposed	**Actual**	**Percent Difference**
950	1052	10.2%

7.0 Summary of Engineering Costs

A summary of the total cost of engineering services is provided in *Table 7-1*. Staffing costs were determined using the billing rates provided in the project proposal.

A comparison of the proposed and actual cost of engineering services is summarized in *Table 7-2*. A copy of the proposed cost summary is provided in *Appendix F*. The largest difference was seen in the hours spent on the project versus the hours proposed for each major project role.

Table 7-1: Cost of Engineering Services Summary

Description	Quantity	Unit of Measure	Rate (USD)	Cost
Personnel				
SENG	118	Hr.	$120	$14,160
ENG	194	Hr.	$88	$17,072
TECH	175	Hr.	$62	$10,850
SO	143	Hr.	$87	$12,441
INT	422	Hr.	$38	$16,036
			Total Personnel	**$70,559**
Travel				
Travel for Material Acquisition				
Transportation	300	Miles	$0.40	$120
Travel for Competition				
Transportation	1,500	Miles	$0.40	$600
Van Rental	1	Van/Week	$400	$400
Hotel Rooms (3 nights)	3	Nights	$200	$600
Meals (5 People, 4 Days)	15	Meals/Day	$20/Meal	$1,200
			Total Travel	**$2,920**
Lab Use				
Field Station	8	Days	$100	$800
Materials Testing Lab	4	Days	$100	$400
			Total Lab Use	**$1,200**
Subcontracting				
ASTM Testing	8	Hr.	$200	$1,600
Mold Cutting	1	Mold	$2,000	$1,700
			Total Subcontracting	**$3,300**
Materials				
Cementitious Materials	10	Cubic Feet	$8	$80
Aggregate	12	Cubic Feet	$22	$264
Admixtures	1	GAL	$20	$20
Reinforcement	20	Square Yard	$15	$300
			Total Materials	**$664**
			Project Total	**$78,643**

Table 7-2: Cost Difference Analysis

Total Project Cost		
Proposed	**Actual**	**Difference**
$76,087	$78,643	($2,556)

8.0 Conclusion

The purpose of the ASCE Concrete Canoe Competition is to provide students with the opportunity to explore concrete mix design and project management through hands-on, practical experience and exposure to new leadership roles. This allows students to gain real-world experience by collaborating as a team to achieve a common goal for a client. The project highlights ASCE's commitment to students, educators, and the general public by inspiring the next generation of civil engineers to develop solutions to rising problems. The Concrete Canoe Competition also helps the participants to recognize the dynamic and innovative aspects of the profession that are essential to the engineering and construction industry. The problem statement for the competition this year was to produce concrete canoes for interested consumers and construct full-scale prototypes that could withstand the rigors of transportation and a series of race demonstrations.

While putting together the Project Proposal, the Canoe Captains as a team identified three main goals: to design, construct, and race a fully functional concrete canoe at the 2023 American Society of Civil Engineers Intermountain Southwest Student Symposium, to design an environmentally conscious concrete mixture, and place well within the ISWS Concrete Canoe Competition. With the evidence provided in this design report, the team believes that two of the three project goals were met. A full-scale prototype was successfully created and raced at ISWS, and the final concrete mixture selected saw that three of the six primary components were recycled materials: Post-Consumer Carpet Calcium Carbonate, 120 Grade Slag Cement, and Fly Ash. However, the team did not place within the top three at competition because of oversights and failure to meet criteria stated in the Request for Proposal. However, these mistakes provided beneficial insight into real-world engineering and construction projects.

9.0 References

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Appendices

Appendix A: Mixture Proportions and Primary Mixture Calculations

MIXTURE: ***Structural Mix, USS PC4-Daryl***

CEMENTITIOUS MATERIALS				
Component	***Specific Gravity***	***Volume***	***Amount of CM***	
Type IL Advancement LT Cement, *c*	3.15	*0.92 ft³*	*180 lb/yd³*	*Total cm (includes c)* ***600*** *lb/yd³* *c/cm ratio, by mass* ***0.30%***
Class F/C 80/20 Blend, cm_1	2.33	*0.83 ft³*	*120 lb/yd³*	
120 grade Slag, cm_2	3.44	*1.40 ft³*	*300 lb/yd³*	

FIBERS				
Component	***Specific Gravity***	***Volume***	***Amount of Fibers***	
MasterFiber M35, f_1	0.91	*0.0088 ft³*	*0.5 lb/yd³*	*Total Amount of Fibers* ***0.5*** *lb/yd³*

AGGREGATES						
Aggregates	***Abs (%)***	SG_{OD}	SG_{SSD}	***Base Quantity, W***		***Volume,***
				W_{OD}	W_{SSD}	$V_{agg,\ SSD}$
Utelite Crushed Fines, agg_1	*23%*	1.82	2.24	*1322 lb/yd³*	*1623.4 lb/yd³*	*11.62 ft³*
Post-Consumer Carpet Calcium Carbonate, agg_2	*40%*	1.33	1.86	*198.4 lb/yd³*	*277.8 lb/yd³*	*2.39 ft³*
Perlite, agg_3	*170%*	0.18	0.49	*60.0 lb/yd³*	*162.0 lb/yd³*	*5.34 ft³*

LIQUID ADMIXTURES					
Admixture	***lb/ US gal***	***Dosage (fl. oz / cwt)***	***% Solids***	***Amount of Water in Admixture***	
MasterGlenium 3400, $admx_1$	*9.2*	*6*	*44%*	*1.45 lb/yd³*	*Total Water from Liquid Admixtures,* $\sum w_{admx}$ ***1.45*** *lb/yd³*

SOLIDS (DYES, POWDERED ADMIXTURES)				
Component	***Specific Gravity***	***Volume (ft³)***	***Amount (lb/yd³)***	
N/A	*N/A*	*N/A*	*N/A*	*Total Solids.* S_{total} ***0*** *lb/yd³*
N/A	*N/A*	*N/A*	*N/A*	

WATER			
	Amount		***Volume***
Water, *w,* $[=\sum (w_{free} + w_{admx} + w_{batch})]$	*w/c ratio, by mass* ***0.84*** *w/cm ratio, by mass* ***0.25***	*150.0 lb/yd³*	*2.4 ft³*
Total Free Water from All Aggregates, $\sum w_{free}$		*-370.3 lb/yd³*	
Total Water from All Admixtures, $\sum w_{admx}$		*1.45 lb/yd³*	
Batch Water, w_{batch}		*518.85 lb/yd³*	

DENSITIES, AIR CONTENT, RATIOS, AND SLUMP						
Values for 1 cy of concrete	***cm***	***Fibers***	***Aggregate*** *(SSD)*	***Solids,*** S_{total}	***Water, w***	***Total***
Mass, *M*	*600 lb*	*0.5 lb*	*2063.2 lb*	*N/A*	*150 lb*	*∑M: 2813.7 lb*
Absolute Volume, *V*	*3.1 ft³*	*0.1 ft³*	*19.4 ft³*	*N/A*	*2.4 ft³*	*∑V: 24.9 ft³*
Theoretical Density, *T, (=∑M / ∑V)*	*112.9 lb/ft³*		***Air Content, Air,*** *[= (T – D)/T x 100%]*			*7.8%*
Measured Density, *D*	*104.2 lb/ft³*		***Air Content, Air,*** *[= (27 – ∑V))/27 x 100%]*			*7.8%*
Total Aggregate Ratio[1] $(=V_{agg,SSD} / 27)$	*0.72*		***Slump, Slump flow, Spread*** *(as applicable)*			*4.0 in.*

[1] *Ratio of total aggregate volume (in percent) compared to the total volume of concrete (min. allowable is 30%)*

Appendices

Appendix A: Mixture Proportions and Primary Mixture Calculations

Aggregates

Utelite Crushed Fines:

$$W_{od} = 1322.0\ lbs$$
$$W_{ssd} = 1623.4\ lbs$$
$$ABS = \frac{W_{ssd} - W_{od}}{W_{od}} * 100\%$$
$$ABS = \frac{1623.4 - 1322}{1322} * 100\% = 22.8\%$$
$$W_{stk} = W_{od} + (W_{od} * 0.5\%)$$
$$W_{stk} = 1322 + (1322 * 0.5\%) = 1328.6\ lb$$
$$MC_{total} = \frac{W_{stk} - W_{od}}{W_{od}} * 100\%$$
$$MC_{total} = \frac{1328.6 - 1322}{1322} * 100\% = 0.5\%$$
$$MC_{free} = MC_{total} - ABS$$
$$MC_{free} = 0.5\% - 22.8\% = -22.3\%$$
$$W_{ssd} = \left(1 + \left(\frac{ABS}{100\%}\right)\right) * W_{od}$$
$$W_{ssd} = \left(1 + \left(\frac{22.8\%}{100\%}\right)\right) * 1322 = 1623.4\ lb$$
$$W_{free} = W_{od} * \left(\frac{MC_{free}}{100\%}\right)$$
$$W_{free} = 1322 * \left(\frac{-22.3\%}{100\%}\right) = -294.8\ lbs$$
$$W_{stk} = W_{ssd} + W_{free}$$
$$W_{stk} = 1623.4 + (-294.8) = 1328.6\ lbs$$

Post-Consumer Carpet Calcium Carbonate:

$$W_{od} = 198.4\ lbs$$
$$W_{ssd} = 277.8\ lbs$$
$$ABS = \frac{W_{ssd} - W_{od}}{W_{od}} * 100\%$$
$$ABS = \frac{277.8 - 198.4}{198.4} * 100\% = 40\%$$
$$W_{stk} = W_{od} + (W_{od} * 0.5\%)$$
$$W_{stk} = 198.4 + (198.4 * 0.5\%) = 199.4\ lbs$$
$$MC_{total} = \frac{W_{stk} - W_{od}}{W_{od}} * 100\%$$
$$MC_{total} = \frac{199.4 - 198.4}{198.4} * 100\% = 0.5\%$$
$$MC_{free} = MC_{total} - ABS$$
$$MC_{free} = 0.5\% - 40\% = -39.5\%$$
$$W_{ssd} = \left(1 + \left(\frac{ABS}{100\%}\right)\right) * W_{od}$$
$$W_{ssd} = \left(1 + \left(\frac{40\%}{100\%}\right)\right) * 198.4 = 277.8\ lbs$$
$$W_{free} = W_{od} * \left(\frac{MC_{free}}{100\%}\right)$$
$$W_{free} = 198.4 * \left(\frac{-39.5\%}{100\%}\right) = -78.4\ lbs$$
$$W_{stk} = W_{ssd} + W_{free}$$
$$W_{stk} = 277.8\ lbs + (-78.4) = 199.4\ lbs$$

Perlite:

$$W_{od} = 60.0\ lbs$$
$$W_{ssd} = 162.0\ lbs$$
$$ABS = \frac{W_{ssd} - W_{od}}{W_{od}} * 100\%$$
$$ABS = \frac{162.0 - 60.0}{60.0} * 100\% = 170\%$$
$$W_{stk} = W_{od} + (W_{od} * .5\%)$$
$$W_{stk} = 60.0 + (60.0 * .5\%) = 60.3\ lbs$$
$$MC_{total} = \frac{W_{stk} - W_{od}}{W_{od}} * 100\%$$
$$MC_{total} = \frac{60.3 - 60.0}{60.0} * 100\% = 0.5\%$$
$$MC_{free} = MC_{total} - ABS$$
$$MC_{free} = 0.5\% - 170.0\% = -169.5\%$$
$$W_{ssd} = \left(1 + \left(\frac{ABS}{100\%}\right)\right) * W_{od}$$
$$W_{ssd} = \left(1 + \left(\frac{170\%}{100\%}\right)\right) * 60.0 = 162.0\ \text{lbs}$$
$$W_{free} = W_{od} * \left(\frac{MC_{free}}{100\%}\right)$$
$$W_{free} = 60.0 * \left(\frac{-169.5\%}{100\%}\right) = -101.7\ lbs$$
$$W_{stk} = W_{ssd} + W_{free}$$
$$W_{stk} = 162.0 + (-101.7) = 60.3\ lbs$$

Cementitious Materials

Type 1L Cement:

$$W_{od} = 179\ lbs$$

Water in Cementitious Materials:

$$W = \frac{W}{cm} * cm$$
$$W = .25 * 600 = 150\ lbs$$
$$SG_{cement} = 3.15$$
$$V_{cement} = \frac{W_{od}}{SG_{cement} * 62.4}$$
$$V_{cement} = \frac{179}{3.15 * 62.4} = 0.91\ ft^3$$

Appendix A: Mixture Proportions and Primary Mixture Calculations

Fly Ash – Class F:

$$W_{od} = 121\ lbs$$
$$SG_{Fly\ Ash} = 2.33$$
$$V_{Fly\ Ash} = \frac{W_{od}}{SG_{Fly\ Ash} * 62.4}$$
$$V_{Fly\ Ash} = \frac{121}{2.33 * 62.4} = 0.83\ ft^3$$

120 Grade Slag Cement:

$$W_{od} = 300\ lbs$$
$$SG_{Slag} = 3.44$$
$$V_{Slag} = \frac{W_{od}}{SG_{Slag} * 62.4}$$
$$V_{Fly\ Ash} = \frac{300}{3.44 * 62.4} = 1.4\ ft^3$$

Admixtures

$$CWT\ (mix) = \frac{cm}{100}$$
$$CWT\ (mix) = \frac{600}{100} = 6\ lbs$$

Water Reducer (MasterGlenium 3400):

$$W_{admx} = \frac{\#\ fl\ oz}{cwt} * CWT * WC * \frac{1\ gal}{128\ fl} * \frac{lb}{gal\ of\ admx}$$
$$W_{admx} = 6\frac{fl\ oz}{cwt} * 6 * 56\% * \frac{1\ gal}{128\ fl} * 9.2\frac{lb}{gal\ of\ admx}$$
$$W_{admx} = 1.45\ lbs$$

Water Addition:

$$W = 150\ lbs$$
$$W_{free} = -370.3\ lbs$$
$$\sum W_{admx} = 1.45\ lbs$$
$$W_{batch} = W - \left(W_{free} + \sum W_{admx}\right)$$
$$W_{batch} = 150 + 370.3 - 1.45 = 518.85\ lbs$$
$$V_{water} = \frac{M_{water}}{62.4}$$
$$V_{water} = \frac{150}{62.4} = 2.4\ ft^3$$

Densities, Air Content, Slump, and Ratios

Mass of Concrete:

$$M_{con} = W_{cm} + W_{fibers} + W_{agg} + W_{solids} + W_{water}$$
$$M_{con} = 600 + 0.5 + 2063.2 + 0 + 150 = 2813.7\ lbs$$

Volume of Concrete:

$$V_{con} = V_{cm} + V_{fibers} + V_{agg} + V_{solids} + V_{water}$$
$$V_{con} = 3.14 + .0088 + 19.35 + 0 + 2.4 = 24.9\ ft^3$$

Theoretical Density:

$$TD_{con} = \frac{M_{con}}{V_{con}}$$
$$TD_{con} = \frac{2813.7}{24.9} = 112.97\frac{lbs}{ft^3}$$

Air Content:

$$D_{Concrete} = 84.60\ lb/ft^3$$
$$Air\ Content = \frac{T_{Concrete} - D_{Concrete}}{T_{Concrete}} * 100$$
$$Air\ Content = \frac{112.97 - 104.2}{112.97} * 100 = 7.8\%$$
$$Air\ Content = \frac{27 - V_{Concrete}}{27} * 100$$
$$Air\ content = \left(\frac{27 - 24.9}{27}\right) * 100 = 7.8\%$$
$$7.8\% = 7.8\% = GOOD$$

Cement to Cementitious Materials Ratio:

$$\frac{c}{cm} = \frac{cement}{cementitious\ materials}$$
$$\frac{c}{cm} = \frac{179}{600} = 0.29$$

Water to Cementitious Material Ratio:

$$\frac{w}{cm} = \frac{water}{cementitious\ materials}$$
$$\frac{w}{cm} = \frac{150}{600} = 0.25$$

Aggregate to Concrete Ratio

$$Aggregate\ Ratio\ (\%) = \frac{V_{Aggregate}}{27} * 100\%$$
$$Aggregate\ Ratio\ (\%) = \frac{19.40}{27} * 100 = 71.85\%$$
$$71.85\% > 30\% = GOOD$$

Appendix B: Hull Design Calculations

Hull Thickness

Total Hull Thickness: 1 inch
Reinforcement Thickness: 0.02 inches
Layers of Reinforcement: 1

Equation B-1: Composite Thickness Ratio

$$CRT = \frac{Total\ Reinforcement\ Thickness}{Total\ Concrete\ Thickness}$$

$$CRT = \frac{0.02}{1.0} = 0.02$$

Composite Ratio = 2% < 50%, Compliant

Percent Open Area

Table B-1: Primary Reinforcement Sample Dimensions

Dimension	Value	Units
d1	0.625	in
d2	0.6875	in
t1	0.1875	in
t2	0.125	in
n1	7	--
n2	5	--
Sample Length	4.1875	in
Sample Width	5.875	in

Equation B- 2: Area of Apertures

$$A_{ap} = d_1 * d_2$$

Where:
A_{ap}: *Area of Single Aperture, in*^{2}
d_1: *Reinforcement Opening Width, in*
d_2: *Reinforcement Opening Hight, in*

Equation C-3: Open Reinforcement Area

$$\sum Area_{Open} = n_1 * n_2 * A_{ap}$$

Where:
n_1: *Number of apertures along width*
n_2: *Number of apertures along height*
A_{ap}: *Area of single aperture, in*^{2}

Equation B-4: Total Area of Reinforcement

$$Area_{Total} = Sample\ Length * Sample\ Width$$

Equation B-5: Percent Open Area

$$POA = \frac{\sum Area_{Open}}{Area_{Total}}$$

Table B- 2: Results of Percent Open Area Analysis

Dimension	Value	Units
Open Area	15.039	in^2
Total Area	24.602	in^2
POA > 40%	61.13	%

Hull Calculations

Equation B-6: Volume of Water Displaced

$$V_d = \frac{\sum F_y}{\gamma_w}$$

$$V_d = \frac{(180 * 2 + 20 * 19)}{62.4} = 12$$

Where:
V_d = *Volume of water displaced* (ft^3)
F_y = *Vertical forces acting on the canoe (lbs)*
γ_w = *Unit weight of water (pcf)*

Equation B-7: Drought

$$D = \frac{V_d}{L * W} * 1.75$$

$$D = \frac{12}{18.5 * 2.5} * 1.75 = .454$$

Where:
D = *Drought (ft)*
H = *Canoe height (ft)*
V_d = *Volume of water displaced* (ft^3)
L = *Length of canoe (ft)*
W = *Width of canoe (ft)*

Equation B-8: Freeboard

$$F = \frac{H - D}{12}$$

$$F = \frac{1.25 - .454}{12} = 9$$

Where:
F = *Freeboard (in)*
H = *Height of Canoe (ft)*
D = *Drought (in)*

Appendices

Appendix C: Structural Analysis

Equation C-1: Flexural Capacity of Concrete [8]

$$\varphi M_n = \frac{\varphi * T * (d - \left(\frac{\beta_1 * c}{2}\right))}{12}$$

$$\varphi M_n = \frac{.65 * 6587 * (11.3 - \left(\frac{.85 * 3.6}{2}\right))}{12} = 3489$$

Where:

M_n = *Flexural Capacity (pre-lap length reduction) (lb-ft)*

φ = *Strength Reduction Factor*

T = *Tension Force (lb)*

β_1 = *Depth Factor*

c = *Distance to Neutral Axis (in)*

Equation C-2: Shear Capacity of Concrete [8]

$$\varphi V_c = \varphi * 2 * \sqrt{f_c'} * b_w * d$$

$$\varphi V_c = .75 * 2 * \sqrt{1254} * 2 * 11.3 = 1593$$

Where:

V_c = *Shear Capacity of Concrete (lb)*

φ = *Strength Reduction Factor*

f_c' = *Compressive strength of concrete (psi)*

b_w = *Width of canoe (in)*

d = *Depth to rebar (in)*

Equation C-3: Punching Shear [9]

$$V_{pd} = \frac{P}{C * t}$$

$$V_{pd} = \frac{180}{22 * 1} = 8$$

Where:

V_{pd} = *Punching shear demand (psi)*

φ = *Strength Reduction Factor*

P = *Load (lbs)*

C = *Circumference/ Perimeter of critical area*

t = *Thickness (in)*

Equation C-4: Punching Shear Capacity [8]

$$V_p = \varphi * 4 * \Delta * \sqrt{f_c'}$$

$$V_p = .75 * 4 * .75 * \sqrt{1254} = 79$$

Where:

V_p = *Punching shear capacity (lb)*

φ = *Strength Reduction Factor*

Δ = *Factor for lightweight concrete*

f_c' = *Compressive strength of concrete (psi)*

Swamp Test

Equation C-5: Required Density

$$\gamma_c = \frac{(V_c + V_b) * \gamma_w}{V_c * 1.35}$$

$$\gamma_c = \frac{(5.36 + 2.33) * 62.4}{5.36 * 1.35} = 66$$

Where:

γ_c = *Required Density (pcf)*

V_c = *Canoe Volume (ft^3)*

V_b = *Bulkhead Volume (ft^3)*

γ_w = *Density of Water (pcf)*

Equation C-6: Bulkhead Length

$$L_B = \frac{(\frac{V_c * \gamma_c * 2}{\gamma_w} - V_c)}{2A_B}$$

$$L_B = \frac{(\frac{5.36 * 69 * 2}{62.4} - 5.36)}{2 * .97} = 3.33$$

Where:

L_B = *Bulkhead Length (ft)*

V_c = *Canoe Volume (ft^3)*

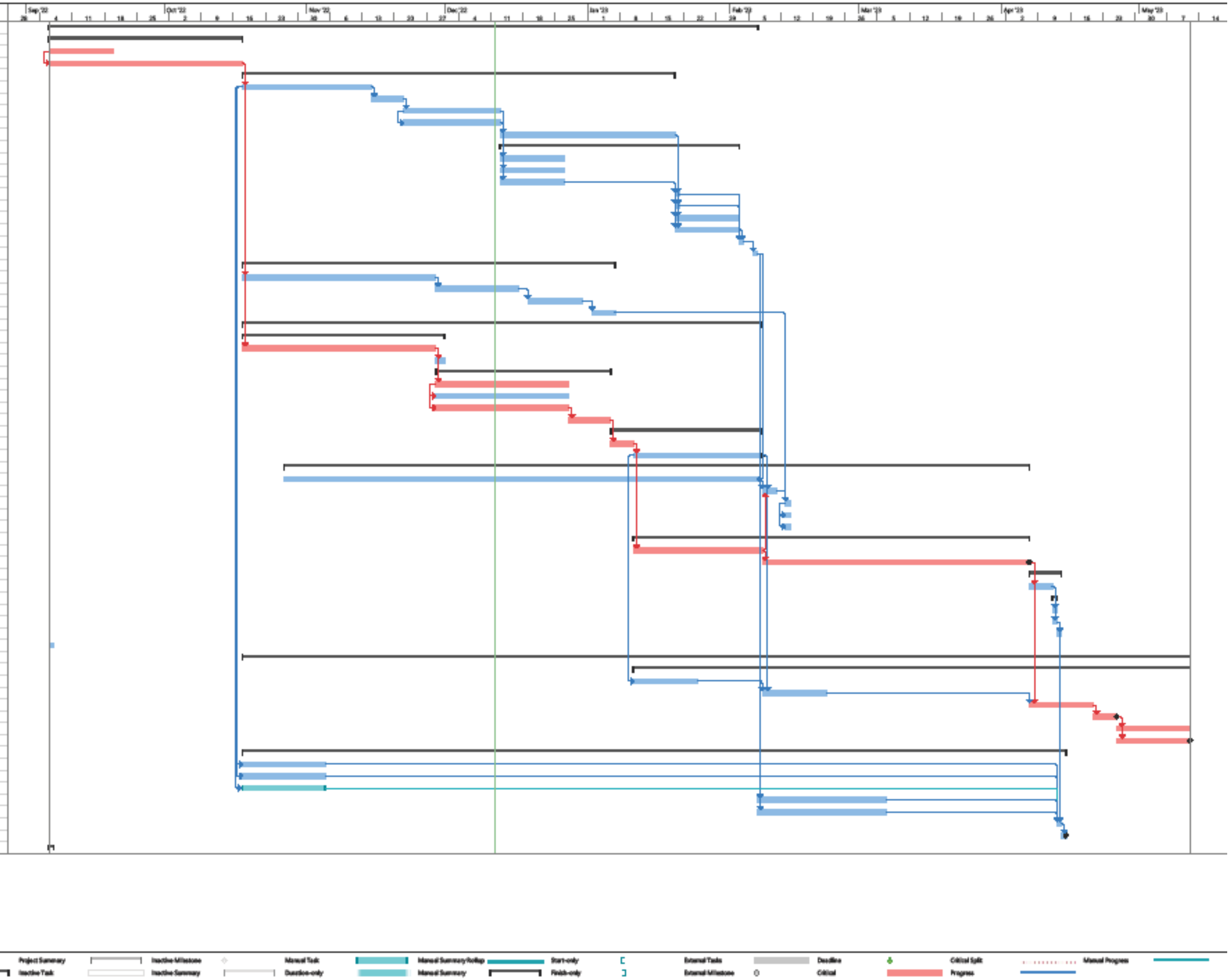
γ_c = *Required Density (pcf)*

γ_w = *Density of Water (pcf)*

A_B = *Average Cross-Sectional Area of Bulkhead (ft^3)*

Appendix D: Proposed Project Schedule

ID	Task Name	Start	Finish
1	TASK 1: Concrete Mixture Design	Tue 9/6/22	Mon 2/6/23
2	Task 1.1: Concrete Materials Research	Tue 9/6/22	Mon 10/17/22
3	Task 1.1.1: Competition Rules	Tue 9/6/22	Mon 9/19/22
4	Task 1.1.2: Materials Research	Tue 9/6/22	Mon 10/17/22
5	Task 1.2: Concrete Mixture Development	Tue 10/18/22	Thu 1/19/23
6	Task 1.2.1: Procurement of Concrete Materials	Tue 10/18/22	Mon 11/14/22
7	Task 1.2.2: Sieve Analysis	Tue 11/15/22	Mon 11/21/22
8	Task 1.2.3: Mixing of Concrete	Tue 11/22/22	Mon 12/12/22
9	Task 1.2.4: Collection of Test Cylinders	Tue 11/22/22	Mon 12/12/22
10	Task 1.2.5: Curing of Test Cylinders	Tue 12/13/22	Thu 1/19/23
11	Task 1.3: Concrete Mixture Testing	Tue 12/13/22	Thu 2/2/23
12	Task 1.3.1: Air Content Testing	Tue 12/13/22	Mon 12/26/22
13	Task 1.3.2: Slump Testing	Tue 12/13/22	Mon 12/26/22
14	Task 1.3.3: Density Testing	Tue 12/13/22	Mon 12/26/22
15	Task 1.3.4: Compressive Strength Testing	Fri 1/20/23	Fri 1/20/23
16	Task 1.3.5: Flexural Strength Testing	Fri 1/20/23	Fri 1/20/23
17	Task 1.3.6: Flexural Strength Testing	Fri 1/20/23	Thu 2/2/23
18	Task 1.3.7: Specific Gravity Testing	Fri 1/20/23	Thu 2/2/23
19	Task 1.4: Analysis of Concrete Test Results	Fri 2/3/23	Fri 2/3/23
20	Task 1.5: Selection of Final Mix Design	Mon 2/6/23	Mon 2/6/23
21	TASK 2: Reinforcement Design	Tue 10/18/22	Fri 1/6/23
22	Task 2.1: Reinforcement Materials Research	Tue 10/18/22	Mon 11/28/22
23	Task 2.2: Procurement of Reinforcement	Tue 11/29/22	Fri 12/16/22
24	Task 2.3: Reinforcement Testing	Mon 12/19/22	Fri 12/30/22
25	Task 2.4: Creation of a Reinforcement Scheme	Mon 1/2/23	Fri 1/6/23
26	TASK 3: Hull Design	Tue 10/18/22	Tue 2/7/23
27	Task 3.1: Hull Design Preparation	Tue 10/18/22	Wed 11/30/22
28	Task 3.1.1: Software Skills and Training	Tue 10/18/22	Mon 11/28/22
29	Task 3.1.2: Contacting Mold Manufacturer	Tue 11/29/22	Wed 11/30/22
30	Task 3.2: Selection of Final Hull Design	Tue 11/29/22	Thu 1/5/23
31	Task 3.2.1: Drafting	Tue 11/29/22	Tue 12/27/22
32	Task 3.2.2: Structural Analysis	Tue 11/29/22	Tue 12/27/22
33	Task 3.2.3: Hydrodynamic Analysis	Tue 11/29/22	Tue 12/27/22
34	Task 3.2.4: Selection of Final Hull Design	Wed 12/28/22	Thu 1/5/23
35	Task 3.3: Mold Acquisition	Fri 1/6/23	Tue 2/7/23
36	Task 3.3.1: Contracting	Fri 1/6/23	Tue 1/10/23
37	Task 3.3.2: Mold Pick Up or Delivery	Wed 1/11/23	Tue 2/7/23
38	TASK 4: Construction	Thu 10/27/22	Thu 4/6/23
39	Task 4.1: Recruitment of Mentees	Thu 10/27/22	Mon 2/6/23
40	Task 4.2: Assemble Formwork	Wed 2/8/23	Fri 2/10/23
41	Task 4.3: Concrete Batch Mixing	Mon 2/13/23	Mon 2/13/23
42	Task 4.4: Concrete Placement	Mon 2/13/23	Mon 2/13/23
43	Task 4.5: Concrete Suface Finishing	Mon 2/13/23	Mon 2/13/23
44	Task 4.6: Curing	Wed 1/11/23	Thu 4/6/23
45	Task 4.6.1: Curing Chamber Construction	Wed 1/11/23	Tue 2/7/23
46	Task 4.6.2: Refilling Humidifiers	Wed 2/8/23	Thu 4/6/23
47	TASK 5: Competition	Fri 4/7/23	Thu 4/13/23
48	Task 5.1: Trailer Preparation	Fri 4/7/23	Tue 4/11/23
49	Task 5.2: Transportation	Wed 4/12/23	Wed 4/12/23
50	Task 5.2.1: Student Transportation	Wed 4/12/23	Wed 4/12/23
51	Task 5.2.2: Canoe Transportation	Wed 4/12/23	Wed 4/12/23
52	Task 5.3 Canoe Racing	Thu 4/13/23	Thu 4/13/23
53	TASK 6: Evaluation of Project Impacts	Tue 9/6/22	Tue 9/6/22
54	TASK 7: Project Deliverables	Tue 10/18/22	Thu 5/11/23
55	Task 7.1: CENE 486 Deliverables	Wed 1/11/23	Thu 5/11/23
56	Task 7.1.1: 30% Submittal	Wed 1/11/23	Tue 1/24/23
57	Task 7.1.2: 60% Submittal	Wed 2/8/23	Tue 2/21/23
58	Task 7.1.3: 90% Submittal	Fri 4/7/23	Thu 4/20/23
59	Task 7.1.4: Final Presentation	Fri 4/21/23	Tue 4/25/23
60	Task 7.1.5: Final Report	Wed 4/26/23	Thu 5/11/23
61	Task 7.1.6: Final Website	Wed 4/26/23	Thu 5/11/23
62	Task 7.2: ASCE Concrete Canoe Competition Deliverables	Tue 10/18/22	Fri 4/14/23
63	Task 7.2.1: Letter of Intent and Pre-Qualification Form	Tue 10/18/22	Fri 11/4/22
64	Task 7.2.2: Preliminary Project Delivery Schedule	Tue 10/18/22	Fri 11/4/22
65	Task 7.2.3: Student Chapter Annual Report/Dues Deadline	Tue 10/18/22	Fri 11/4/22
66	Task 7.2.3: Project Proposal	Tue 2/7/23	Mon 3/6/23
67	Task 7.2.4: MTDS Addendum	Tue 2/7/23	Mon 3/6/23
68	Task 7.2.5: Display	Thu 4/13/23	Thu 4/13/23
69	Task 7.2.6: Presentation	Fri 4/14/23	Fri 4/14/23
70	TASK 8: Project Management	Tue 9/6/22	Tue 9/6/22



Project: Concrete Canoe Schedu
Date: Mon 12/12/22

Appendix E: Engineering Work Hours Matrix

Task	SENG	ENG	TECH	SO	INT
Task 1: Concrete Mix Design	10	29	116	45	86
Task 1.1: Concrete Materials Research	4	6	28	12	17
Task 1.1.1: Competition Rules	*3*	*0*	*24*	*5*	*14*
Task 1.1.2: Materials Research	*1*	*6*	*4*	*7*	*3*
Task 1.2: Concrete Mixture Development	1	17	63	18	57
Task 1.2.1: Procurement of Concrete	*0*	*7*	*0*	*1*	*3*
Task 1.2.2: Sieve Analysis	*0*	*0*	*10*	*3*	*12*
Task 1.2.3: Mixing of Concrete	*1*	*7*	*45*	*8*	*37*
Task 1.2.4: Collection of Test Cylinders	*0*	*3*	*3*	*4*	*2*
Task 1.2.5: Curing of Test Cylinders	*0*	*0*	*5*	*2*	*3*
Task 1.3: Concrete Mixture Testing	0	2	25	15	11
Task 1.3.1: Air Content Testing	*0*	*0*	*1*	*2*	*0*
Task 1.3.2: Slump Test	*0*	*0*	*2*	*2*	*0*
Task 1.3.3: Density Testing	*0*	*0*	*1*	*2*	*0*
Task 1.3.4: Compressive Strength Testing	*0*	*1*	*10*	*4*	*4*
Task 1.3.5: Flexural Strength Testing	*0*	*1*	*7*	*2*	*3*
Task 1.3.6: Tensile Strength Testing	*0*	*0*	*2*	*2*	*4*
Task 1.3.7: Specific Gravity Testing	*0*	*0*	*2*	*1*	*0*
Task 1.4: Analysis of Concrete Test Results	2	3	0	0	1
Task 1.5: Selection of Final Concrete Mix Design	3	1	0	0	0
TASK 2: Reinforcement Design	2	9	6	3	8
Task 2.1: Reinforcement Materials Research	1	4	2	0	5
Task 2.2: Procurement of Reinforcement	0	0	0	2	1
Task 2.3: Reinforcement Testing	0	0	4	1	1
Task 2.4: Creation of a Reinforcement Scheme	1	5	0	0	1
TASK 3: Hull Design	14	32	0	1	89
Task 3.1: Hull Design Preparation	2	4	0	0	6
Task 3.1.1: Software Skills and Training	*0*	*4*	*0*	*0*	*6*
Task 3.1.2: Contact Mold Manufacturer	*2*	*0*	*0*	*0*	*0*
Task 3.2: Suite of Potential Hull Designs	11	28	0	0	27
Task 3.2.1: Drafting	*2*	*4*	*0*	*0*	*15*
Task 3.2.2: Structural Analysis	*4*	*14*	*0*	*0*	*9*
Task 3.2.3: Hydrodynamic Analysis	*0*	*6*	*0*	*0*	*0*
Task 3.2.4: Selection of Final Hull Design	*5*	*4*	*0*	*0*	*3*
Task 3.3: Mold Acquisition	1	0	0	1	56
Task 3.3.1: Contracting	*1*	*0*	*0*	*0*	*0*
Task 3.3.2: Mold Pick Up or Delivery	*0*	*0*	*0*	*1*	*56*
TASK 4: Construction	12	22	38	46	87
Task 4.1: Recruitment of Mentees	7	8	6	4	5
Task 4.2: Assemble Formwork	1	5	8	4	8
Task 4.3: Concrete Batch Mixing	1	1	5	14	19
Task 4.4: Concrete Placement	2	5	10	12	20
Task 4.5: Concrete Surface Finishing	0	2	7	4	17
Task 4.6: Curing	1	1	2	8	18
Task 4.6.1: Curing Chamber Construction	*1*	*1*	*2*	*0*	*11*
Task 4.6.2: Refilling Humidifiers	*0*	*0*	*0*	*0*	*7*

Appendix E: Engineering Work Hours Matrix

Task	SENG	ENG	TECH	SO	INT
TASK 5: Competition	3	4	5	14	29
Task 5.1: Trailer Preparation	2	2	0	1	4
Task 5.2: Transportation	1	2	5	13	18
Task 5.2.1: Student Transportation	*0*	*0*	*0*	*10*	*28*
Task 5.2.2: Canoe Transportation	*1*	*2*	*5*	*3*	*2*
Task 5.3 Canoe Racing	0	0	0	0	6
TASK 6: Evaluation of Project Impacts	1	5	0	0	10
TASK 7: Project Deliverables	42	62	9	9	87
Task 7.1: CENE 486 Deliverables	24	37	3	4	55
Task 7.1.1: 30% Submittal	*11*	*15*	*1*	*0*	*15*
Task 7.1.2: 60% Submittal	*7*	*8*	*1*	*2*	*15*
Task 7.1.3: 90% Submittal	*2*	*6*	*1*	*2*	*11*
Task 7.1.4: Final Report	*3*	*0*	*0*	*0*	*6*
Task 7.1.5: Final Website	*0*	*5*	*0*	*0*	*2*
Task 7.1.6: Final Presentation	*1*	*3*	*0*	*0*	*6*
Task 7.2: ASCE Concrete Canoe Competition Deliverables	18	25	6	5	32
Task 7.2.1: Letter of Intent and Pre-Qualification Form	*4*	*4*	*0*	*0*	*1*
Task 7.2.2: Preliminary Project Delivery Schedule	*3*	*2*	*0*	*2*	*0*
Task 7.2.3: Student Chapter Annual Report/Dues Deadline	*1*	*0*	*0*	*0*	*0*
Task 7.2.4: Project Proposal	*7*	*11*	*2*	*1*	*14*
Task 7.2.5: MTDS Addendum	*1*	*1*	*2*	*0*	*6*
Task 7.2.6: Display	*1*	*5*	*2*	*2*	*8*
Task 7.2.7: Presentation	*1*	*2*	*0*	*0*	*3*
TASK 8: Project Management	34	31	1	25	26
Task 8.1: Meetings	27	27	27	27	27
Task 8.1.1: Team Meetings	*19*	*12*	*0*	*12*	*13*
Task 8.1.2: Grading Instructor Meetings	*3*	*2*	*1*	*6*	*5*
Task 8.1.3: Technical Advisor Meetings	*2*	*5*	*0*	*6*	*4*
Task 8.1.4: Client Meetings	*3*	*0*	*0*	*1*	*0*
Task 8.2: Schedule Management	4	4	0	0	3
Task 8.3: Resource Management	3	8	0	0	1
Subtotal	**118**	**194**	**175**	**143**	**422**
Total	**1052**				

Appendix F: Proposed Cost of Engineering Services

Description	Quantity	Unit of Measure	Rate (USD)	Cost
Personnel				
SENG	125	Hr.	$120	$14,950
ENG	225	Hr.	$88	$19,872
TECH	150	Hr.	$62	$9,315
SO	150	Hr.	$87	$13,041
INT	300	Hr.	$38	$11,385
			Total Personnel	**$68,563**
Travel				
Travel for Material Acquisition				
Transportation	300	Miles	$0.40	$120
Travel for Competition				
Transportation	1,500	Miles	$0.40	$600
Van Rental	1	Van/Week	$340	$340
Hotel Rooms (3 Nights)	3	Rooms	$200	$1,800
Meals (5 People, 4 Days)	3	Meals/Day/Person	$20	$1,200
			Total Travel	**$4,060**
Lab Use				
Field Station	8	Days	$100	$800
Materials Testing Lab	4	Days	$100	$400
			Total Lab Use	**$1,200**
Subcontracting				
ASTM Testing	8	Hr.	$200	$1,600
Mold Cutting	1	Mold	$2,000	$2,000
			Total Subcontracting	**$3,600**
Materials				
Cementitious Materials	10	Cubic Feet	$8	$80
Aggregate	12	Cubic Feet	$22	$264
Admixtures	1	GAL	$20	$20
Reinforcement	20	Square Yard	$15	$300
			Total Materials	**$664**
			Project Total	**$78,087**