ASCE AT ASU

SPEEDY UNICORN

ISWS 2022

PROJECT PROPOSAL

COVER LETTER AND PROJECT UNDERSTANDING

Date: November 5, 2021
To: Committee on Concrete Canoe Competitions (C4)
Subject: Response to Request for Proposal – Arizona State University

Dear Committee on Concrete Canoe Competitions,

For the Arizona State University canoe, *Speedy Unicorn*, this statement certifies that:

1. The proposed hull design, concrete mix design, and construction of the mold and canoe plan are in full compliance with the specifications outlined in the *2022 Request for Proposal*.

2. Relevant Material Technical Data Sheets (MTDS) and Safety Data Sheets (SDS) to the project have been reviewed by the team. Updated MTDS and SDS are being sent out to the team as well.

3. The team also recognizes that the last day to submit *Request for Information* (RFI) is January 21st, 2022 and that their submissions comply with the provided responses.

4. The team is following CDC guidelines in hopes of participating in an in-person competition in 2022.

5. The anticipated registered participants (for presenting and racing) are qualified student members and Student Members of ASCE and meet all eligibility requirements. The names, preferred pronouns, and ASCE IDs for the registered participants are listed below:

Name	Preferred Pronouns	ASCE ID	Name	Preferred Pronouns	ASCE ID
Gabriella Stadler	She/Her	11951359	Antonio Blair	He/Him	12261024
Caleb Siff	He/Him	11944944	Xana Lee	She/Her	12275035
Susanna Westersund	She/Her	12225540	Josh LaPorta	He/Him	12270684
Peter Nguyen	He/Him	11951429	Alexis Ahumada	She/Her	12281331
Janelle Miguel	She/Her	12219495	Alexander Owen	He/Him	12270234

Thank you,

Arizona State University Concrete Canoe Team

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EXECUTIVE SUMMARY

After the peak of COVID-19, many feel stir crazy and ready for adventure. What better way to leave COVID-19 than a magical canoe made entirely out of concrete? Speedy Unicorn is a colorful canoe based on a show called *Adventure Time*, epitomizing youth, excitement, and exploration. *Adventure Time* is a fantasy show created in 2010 by Pendleton Ward and produced by Cartoon Network. The adventures of the two main characters, Finn and Jake, remain in the hearts of many, especially Generation Z. Speedy Unicorn was born to replicate the lively and magical escapades of Finn and Jake, reminding everyone the importance of courage, friendship, and childhood. Fulfilling the quest of Dr. R. John Craig, this bright-colored canoe was created with lightweight materials, bright colors, and lots of "magic."

The Concrete Canoe team of Arizona State University operates in Tempe, Arizona. With a highly motivated team, *Speedy Unicorn* is ready to enter as one of 12 participants in the Intermountain Southwest Symposium (ISWS), hosted by the University of Nevada, Las Vegas in April 2022. At the Pacific Southwest Conference (PSWC), the concrete canoe team at ASU placed 3rd with *Sun Devil Crossing* (2021) and 6th with *Legacy* (2020). Using the knowledge of past teams, the 2022 canoe team is determined to produce a quick and light canoe that has high strength and beautiful colors. The team this year consisted of a Project Manager with experience as the Aesthetics captain, an inspired PM assistant, a talented artist as the Aesthetics Captain, two innovative Hull Design captains, a motivated Mix Design Captain, two creative Construction Captains, a mathematic whiz as the Structural Analysis Captain, a computer guru as the Coding Captain for the canoe website, a trained paddling team, many eager volunteers, and helpful alumni/faculty. With an ambitious team like this, *Speedy Unicorn* is best suited to be a standardized design for concrete canoe manufacturing.

Although COVID-19 created a lack of experience with the new team, innovation remains. The hull design was created using a MATLAB code and AutoCAD. For an innovative canoe, the hull design continued to leave out the gunwales for easy mold removal and added a flatter bottom for stability while keeping a slim structure to promote speed. The constructed properties of the canoe can be seen in **Table 1**. For construction, the mold included a new step: contact paper. To remain on task, the project manager created a strict schedule, had bi-weekly meetings, and maintained open communication using an app called GroupMe. For sustainability, the team tried their best to use materials from previous seasons which included recycled aggregate.

Table 1: Canoe Physical Properties

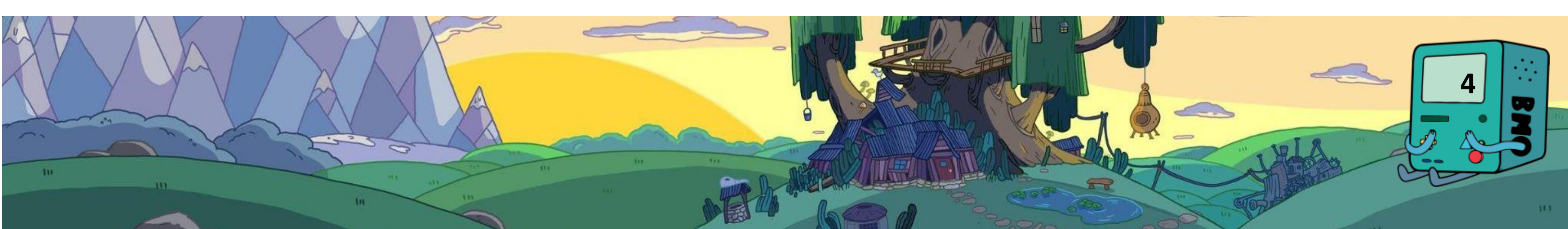
Property	Value
Name	Speedy Unicorn
Length	248 in
Maximum Width	28 in
Maximum Depth	16 in
Average Thickness	9/16 in
Estimated Weight	213 lbs
Colors	Red, Yellow, Green, Blue, Purple, Pink
Primary Reinforcement	Carbon Fiber Mesh
Secondary Reinforcement	Polypropylene Miro-Fibers Copolymer Macro-Fibers

Adhering to C4 rules, the mix design was based on ASTM standards aiming for a strong yet lightweight mix. This year, two different mixes were used: a structural mix for an intermediate middle layer and an aesthetic mix with pigment for surface layers. Concrete properties can be seen in **Table 2**.

Table 2: Mix Design Properties

Property (28-day tests)	Reported Accuracy	
	Structural Mix	**Aesthetic Mix**
Compressive Strength	1955.48 psi	2073.61 psi
Flexural Strength	319.40 psi	332.40 psi
Tensile Strength	309.55 psi	318.76 psi
Density (hardened concrete)	65.59 pcf	66.39 pcf
Density (fresh concrete)	68.85 pcf	68.26 pcf
Slump	1/8 in	1/8 in
Weight	65.59 lbs	66.39 lbs
Air Content	3.62%	4.03%

The 2022 Concrete Canoe team at ASU proudly presents *Speedy Unicorn*: an innovative, vibrant, speedy canoe ready to enter adventure and to fulfill the quest of consumers ready to race.



PROJECT DELIVERY TEAM

ASCE STUDENT CHAPTER PROFILE

The student-led chapter of American Society of Civil Engineers at Arizona State University began in 1962 and has continuously participated in student-led conferences. Currently, ASCE at ASU has 263 members. ASCE at ASU is made up of many majors, each a part of Ira A. Fulton Schools of Engineering. As of 2021, over 26,000 students study engineering at ASU with a little under 2,000 of them being a part of SSEBE. SSEBE includes Civil Engineering, Construction Engineering, Construction Management, and Environmental Engineering. Five programs in the engineering schools at Arizona State University rank in the top 25 of the country, including Civil and Environmental Engineering (Strawder, 2021). For seven years now, ASU has been ranked as #1 in innovation (U.S. News, 2022).

ASU's chapter of ASCE is a part of the Arizona Section led by Jose Aguilar, PE. In 2021, ASU became a part of region 8, the largest geographic area in ASCE consisting of 12 sections. The Arizona Section of ASCE has been operational since 1925, comprised of four different branches and 2,300 civil engineers/students. These four branches are Phoenix, Southern Arizona, Northern Arizona, and Yuma. The three student chapters of the Arizona section are Arizona State, University of Arizona, and Northern Arizona University.

As a large Civil Engineering club, ASCE at ASU has won many awards. In 2021, the *Speedy Unicorn*'s Project Manager won an Outstanding Senior Award for her excellence in engineering academic achievement and service to the profession. One of the most noteworthy awards ASCE at ASU received was the Outstanding Undergraduate Fulton Student Organization award in 2018. Dr. Edward Kavazanjian from ASU received the Distinguished Member of ASCE award in October of 2018. In 2018, Arizona State also received an honorable mention from ASCE due to being in the top 1/3 of student chapters.

The ASU student chapter of American Society of Civil Engineers is run by 11 students, 2 faculty advisors, and 3 Phoenix YMF industry advisors. Year-long positions of this chapter include: President, Vice President, Treasurer, Secretary, Facilities Manager, Conference Coordinator, and Competition Manager. Semester long positions include: Undergraduate Student Government Representative, Outreach Chair, Recruitment Chair, Fundraising Chair, Social Char, Public Relations Director, and Industry Liaison.

ASCE at ASU participates in many activities throughout the school year, including but not limited to bi-weekly general body meetings that feature guest speakers. To further help students understand Civil Engineering and to inspire their future careers, guest speakers from various civil firms come to speak at the general body meetings. Not only are students able to learn and network with these professionals, but students also engage in external activities like ASCE competitions, technical tours, and community service. The technical competitions that ASU will be participating in this year at ISWS include Concrete Canoe, Sustainable Solutions, Steel Bridge, and Timber-Strong Design Build.

Outside of general body meetings and ASCE competitions, students also collaborate with other clubs like Chi Epsilon at ASU and ASCE at UofA. In 2021, Valley Metro graciously invited Chi Epsilon and ASCE students to tour the extension of the Phoenix metropolitan area light rail system. As another one of the chapter's activities, ASU and UofA played a volleyball tournament. The executive board team also has team bonding activities like bowling and Feed My Starving Children. **Figure 1** shows images of chapter activities from 2021.

Figure 1: Valley metro tour with Chi Epsilon (top left), volleyball tournament (top right), FMSC community service (bottom left), and bowling bonding (bottom right).

KEY TEAM MEMBERS

VOLUNTEERS

Alex Rubio
Antonio Blair
Caleb Siff
Carlos Corral-Williams
Carlos Mendez
Harshil Kunarpal Sheth
Luis Corrales

Jakob Pongratz
Jason Grelck
Jose Hilao
Joshua LaPorta
Julia Zimmerman
Muneer Al-Rawahi

Peter Nguyen
Valentina Rivera
Luis Corrales
Taylor Davis
Marilyn Mendoza
Amr Hanafy

PROJECT DELIVERY TEAM

ORGANIZATIONAL CHART

PROJECT MANAGEMENT

Gabriella Stadler (Sr) – Project Manager/Construction Captain
Caleb Siff (Jr) – Assistant Project Manager

WEBMASTERS

Carlos Corral Williams (So) – Coding Captain
Gabriella Stadler (Sr) – PM/Construction Captain
Arya Mathreja (So)
Brandon Bello (So)

ACADEMICS

Initial Research
Gabriella Stadler (Sr) – PM/Construction Captain
Susana Westersund (Jr) – Mix Design Captain

Technical Report
All Captains

Enhanced Focus Area Report
Carlos Corral Williams (So) – Coding Captain
Gabriella Stadler (Sr) – PM/Construction Captain

Presentation
Gabriella Stadler (Sr) – PM/Construction Captain
Susana Westersund (Jr) – Mix Design Captain

PADDLING

Peter Nguyen (Jr) – Paddling Captain
Caleb Siff (Jr) – Assistant Project Manager
Susana Westersund (Jr) – Mix Design Captain
Janelle Miguel (So) – Aesthetics Captain
Josh LaPorta (Fr)
Antonio Blair (Fr)
Alexis Ahumada (Fr)
Xana Lee (Fr)

STRUCTURAL ANALYSIS

Structural Analysis
Jillian Barcena (Sr) – StructuralAnalysis Captain

Concrete Mixture Analysis
Susana Westersund (Jr) – Mix Design Captain
Gabriella Stadler (Sr) – PM/Construction Captain

MIX DESIGN

Design Phase
Susana Westersund (Jr) – Mix Design Captain
Gabriella Stadler (Sr) – PM/Construction Captain
Christina Galanis (Sr) – Hull/Construction Captain
Jillian Barcena (Sr) – Structural Analysis Captain
Janelle Miguel (So) – Aesthetics Captain
Carlos Mendez (So)
Antonio Blair (Fr)
Muneer Al-Rawahi (Jr)
Jose Hilao (Jr)
Maya Elliot (Sr)
Tiffany Fu (Fr)

Casting
Alex Rubio
Antonio Blair
Caleb Siff
Carlos Corral-Williams
Carlos Mendez
Christina Galanis
Harshil Kunarpal Sheth
Jakob Pongratz
Jason Grelck
Jill Barcena
Janelle Miguel
Jose Hilao
Joshua LaPorta
Julia Zimmerman
Peter Nguyen
Susanna Westersund
Valentina Rivera
Luis Corrales
Taylor Davis
Marilyn Mendoza
Amr Hanafy
Luis Corrales
Muneer Al-Rawahi

HULL DESIGN

Alex Owen (Sr) – Hull Design Captain
Christina Galanis (Sr) – Hull/Construction Captain
Nic Peters (Sr)

CONSTRUCTION

Mold Construction
Gabriella Stadler (Sr) – PM/Construction Captain
Christina Galanis (Sr) – Hull/Construction Captain
Peter Nguyen (Jr) – Paddling Captain
Jillian Barcena (Sr) – StructuralAnalysis Captain
Susana Westersund (Jr) – Mix Design Captain
Janelle Miguel (So) – Aesthetics Captain
Muneer Al-Rawahi (Jr)
Carlos Mendez (So)
Will Owens (Sr)

Casting
Gabriella Stadler (Sr) – PM/Construction Captain
Alex Rubio
Antonio Blair
Caleb Siff
Carlos Corral-Williams
Carlos Mendez
Christina Galanis
Harshil Kunarpal Sheth
Jakob Pongratz
Jason Grelck
Jill Barcena
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Peter Nguyen
Susanna Westersund
Valentina Rivera
Luis Corrales
Taylor Davis
Marilyn Mendoza
Amr Hanafy
Luis Corrales
Muneer Al-Rawahi

AESTHETICS

Janelle Miguel (So) – Aesthetics Captain
Gabriella Stadler (Sr) – PM/Construction Captain

TECHNICAL APPROACH TO OVERALL PROJECT

HULL DESIGN

The hull design team of *Speedy Unicorn* sought to combine previous knowledge from prior designers with feedback from the current paddling team to develop a new hull design that would provide better stability for paddlers. A MATLAB code developed by project alumni was utilized as in the past several years to design the canoe hull. By assigning coordinates to key features of the model, like the bow, stern, keel, and the cross-section at the widest point, an input file of canoe data was created in Excel. MATLAB read this file and performed quadratic spline interpolation, creating the outline of the hull. **Figure 2** shows the model output by the program.

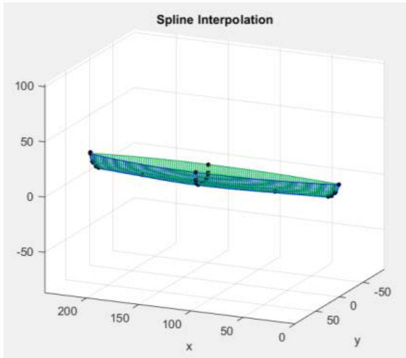


Figure 2: Spline interpolation figure from MATLAB.

One of the challenges presented this year was a gap in experience from two years of canoes that were designed but not fully constructed nor tested in racing conditions due to the COVID-19 pandemic. By the time the 2021-2022 hull design team began work, most of the students who had key roles on previous constructed and race-tested iterations of the project had graduated. As current team members were not present on earlier projects that were constructed, contacting and incorporating feedback from the designers of previous canoes was an important step in the hull design process. Support documents and advice from alumni were used as the bases for this year's goals and design decisions. Feedback from *The Maroon Machine* (2019) and *Legacy* (2020) were primarily considered when developing the current design, as *Sun Devil Crossing* was not constructed. Post-construction preparation of *Legacy* was completed by the *Speedy Unicorn* team so that *Legacy* could be tested and used for feedback from the current paddling team. The paddlers of *Speedy Unicorn* were primarily concerned with the stability of the canoe which was the primary driver of hull design development.

Several potential canoe hulls were modeled and compared to previous canoes. The addition of gunnels to the body of the canoe was considered and rejected due to crack propagation from the top of the hull during transport of the canoe on prior projects and difficulty in removing the male mold from the canoe body after curing. The depth of *Speedy Unicorn* was increased from the *Sun Devil Crossing* design as a deeper canoe provides more carrying capacity and will take on less water in rough conditions, though the canoe may be less responsive. The widest cross-section of the canoe was increased to provide more stability for paddling at the expense of speed. It was anticipated that this reduction in speed could be counteracted with adequate paddling training and practice. A slightly flared shape was chosen to resist tipping, deflect water, and enable ease of mold removal. A cross-section of the canoe at the widest point is shown in **Figure 3**. **Table 3** shows the individual characteristics of *Speedy Unicorn* compared to the previous designs.

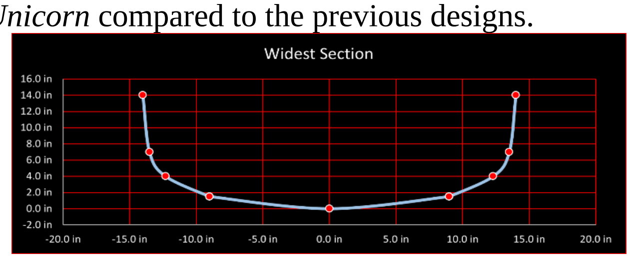


Figure 3: Widest section of the canoe displayed in Excel.

Table 3: Comparison of hull designs.

Hull Model Specifications				
Model	**Bow Height**	**Stern Height**	**Max Depth**	**Max Width**
Legacy	7.7 in	7.5 in	15 in	26 in
Sun Devil Crossing	9 in	9 in	15 in	25 in
Speedy Unicorn	8 in	8 in	16 in	28in

The final hull design of *Speedy Unicorn* is longitudinally asymmetric with slightly flared sides and a shallow arch bottom. The overall designed hull length is 20 ft., 0 in., the beam width at the widest section is 28 in., and depth at the stern is 16 in. The thickness of the canoe is 9/16 in. throughout. The length of the canoe did increase due to construction.

STRUCTURAL ANALYSIS

To ensure *Speedy Unicorn* is able to endure the foreseeable loading conditions, two-dimensional longitudinal and lateral analyses were performed. MATLAB was used in conjunction with Microsoft Excel to assess the cross-sectional properties and perform the analysis. Five loading conditions were considered: (1) two female paddlers, (2) two male paddlers, (3) four co-ed paddlers, (4) display, and (5) carrying. For analysis, the weights of each female and male paddler were estimated to be 130 lb. and 190 lb., respectively. In all loading cases, the canoe was considered as a beam. For the paddling analysis, the self-weight of the canoe and the weight of the paddlers were considered to be acting positive to gravity and the buoyant force was acting negative to gravity. For the display analysis, supports were estimated to be located at 20% of the total length relative to the bow and stern. For the carrying analysis, supports were estimated to be located at the bow and stern.

Cuts in 1-in. intervals were taken along the beam to account for the variation of the cross-section and the material. These intervals were used to calculate the behavior of internal forces and moments along the canoe as modeled in **Figure 4**. Microsoft Excel was used to enter the dimensions and material data into the team's MATLAB code.

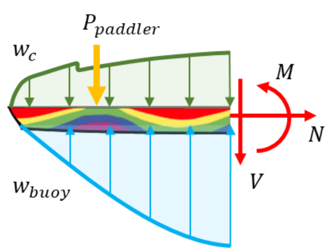


Figure 4: Free Body Diagram for Longitudinal Analysis

The average unit weight of concrete was estimated to be 66.12 pcf. based on 28-day tests of the two different mixes used to construct the canoe, and the unit weight of the bulkhead material was estimated to be 1.5 lb. pcf. This resulted in a total estimated weight of 198.2 lb., a 8% reduction from the theoretical weight of *Sun Devil Crossing*, 215 lb.

The buoyancy force was modeled as a third-degree polynomial distribution. Using a system of three equations, a MATLAB algorithm was used to calculate the coefficients of the buoyancy polynomial function for each of the load cases. This allowed for the buoyancy force to be more accurately represented versus the linearly distributed model used in the analysis of *Sun Devil Crossing.*

The variation of the bending moment as a function of the length along the canoe relative to the stern was graphed as shown in **Figure 5** where carrying is shown to be the most critical load case. To assess the variation of lateral stresses in the paddling load cases, the theory of simple bending, $\sigma = Mc/I_x$, was used within the canoe MATLAB code. M is the bending moment, c is the distance from the neutral axis of the canoe's cross section, and I_x is the mass moment of inertia. The lateral stress study allows for a quantitative comparison between various cross section designs. The stress analysis confirmed the four co-ed paddlers load case to be the most critical loading condition in water. A summary of lateral stresses for the chosen hull design ais provided in **Table 4**.

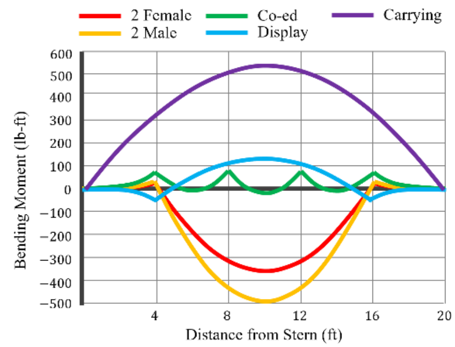


Figure 5: Bending moment along beam.

Table 4: Maximum Theoretical Structural Stresses

Load Case	Compressive (psi)	Tensile (psi)
2 Female	194.04	189.51
2 Male	248.70	242.97
4 Co-ed	378.75	370.19

DEVELOPMENT AND TESTING

The goal of the mix design team was to develop a structural mix and an aesthetics mix. This required a variety of testing to find the optimal mix as well as research to discover what amount of each component was needed. Last year's mix (*Sun Devil Crossing)* was used as a starting point for this year's mix composition. Initial goals and the final results of the structural mix are listed in **Table 5**.

Table 5: Final 28-day Testing Results

Property	Mix Design Goals	2021-2022 Structural	2021-2022 Structural
Wet Density	60-68 psf	65.7 pcf	68.85 pcf
Dry Density	<62 psf	60 psf	65.59 pcf
Compressive Strength	1200 psi	1450 psi	1955.48 pci
Tensile Strength	200 psi	210 psi	309.55 psi
Flexural Strength	500 psi	880 psi	319.40 psi

The cementitious mixture was first developed. Last year's mix consisted of 60% ordinary portland cement (ASTM C150), 20% Class F fly ash (ASTM C618), 21.5% limestone (ASTM C568), and 7.5% silica fume (ASTM C1240). The team's primary goal was to reduce the amount of OPC to achieve sustainability as it contributes to a significant amount of CO_2 emissions every year and is a leading cause of concrete pollution. The main decrease in cement usage was achieved by replacing a significant amount of cement with silica fume. Silica fume is a byproduct of elemental silicon production with a specific gravity two-thirds that of OPC; the final mix had a decrease of 8% in OPC. The other components of the cementitious mixture were fly ash and limestone. Each was tested incrementally until what was considered an optimal amount was achieved. Although silica fume aids in removing reducing the content of cement, silica fume in excess decreases strength performance of concrete. The final cementitious ratios decided for the mix were selected to be 52% OPC, 25.5% Class F fly ash, 13.1% limestone, and 9.3% silica fume. The compositions of this year's and last year's cementitious mixtures are compared in **Figure 6**.

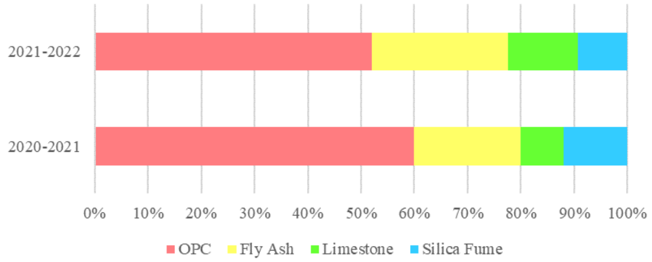


Figure 6: Comparison of cementitious compositions.

Following the design of the cementitious materials content, the team developed the aggregate proportions. *Speedy Unicorn* improved upon 2020 *Legacy*'s design which greatly improved workability and absorption. The Poraver graduation was altered several times throughout the testing process. The final proportions were chosen to be 20.9% 0.1-0.3 mm., 18.6% 0.25-0.5 mm., and 40.8% 0.5-1.0 mm. These ratios resulted in a slight strength advantage and increase workability compared to different ratios. Greater values of the smaller aggregates also allowed for thinner layers on the canoe.

The team then took into consideration previous studies of absorption rates of the Poraver and clay shale using the ASTM C127 standards for testing absorption of fine aggregates. For the clay shales, absorption rates were found to be much lower than believed in previous years. The absorbance for fine clay shales was 17.6%, crushed fine clay shales 16.5%, and 10 mesh clay shales was 14.3%. Similarly, these tests were performed on the Poraver values, finding absorption values were 35% for 0.1-0.3 mm., 28% for 0.25-0.5 mm., and 20% for 0.5-1.0 mm. As experimental values were found to be lower than previously understood, the amount of water needed was reduced. Aggregate saturated-surface-dry condition was achieved with less water than was anticipated, resulting in an overestimation of how much excess water was present in the mix. Consequently, the calculated water-cementitious material ratio required adjustment, leading to an increase in strength and in unit weight from previous years. **Table 6** displays the absorption values as well as properties of aggregates.

Table 6: Properties of Aggregates

Aggregate		Specific Gravity	Absorption (%)
Clay Shale	Fine	0.845	17.6
	Crushed Fine	0.854	17.6
	10 Mesh	0.825	17.6
Poraver	0.1-0.3mm	0.400	35
	0.25-0.5mm	0.340	28
	0.5-1.0mm	0.260	20

Figure 7: Flexural samples after testing.

Once the aggregate content was specified, the team proceeded to test for an optimal amount of fibers for the mix. Prior teams used only micro-fibers of 1/4 in. length. Two years previously, the *Legacy* team added Tuf-Strand Maxten macro-fibers. These fibers are 1.25 in. in length and are still used today. The micro-fibers helped to reduce the occurrence of plastic shrinkage cracks and helped to increase the flexural and tensile strength of the mix. The addition of the macro-fibers also added to the flexural and tensile strength. Toughness, durability, and crack control were also improved. As when steel reinforcements are added to concrete, macro-fibers aid to increase the non-compressive strength of concrete. The fibers used are also lightweight, able to increase strength without adding much to the unit weight. **Figure 7** displays the strands in the hardened concrete samples protruding after the flexural strength test was performed. These samples were able to bear and withstand great stresses without failing with the macro-fibers.

The final component of the concrete mix for the team to investigate was the admixtures. The primary goal of the admixtures component is to achieve ideal workability. This is imperative as the team must be able to easily place the concrete on the mold in thin layers during a short amount of time before the concrete starts hardening. With the change in aggregate water due to the absorption findings, the admixture ratio also required adjustments. The two admixtures used were Plastol 6400 (superplasticizer) and AEA 92 (air entrainer).

The addition of superplasticizer does not affect the water-cementitious materials ratio, but workability is increased to a level optimal for the application of concrete onto a male mold. However, if superplasticizer is added in excess, the concrete will have a high level of slump, decreasing its ability to maintain its shape and adhere to the mold. The final dosage for superplasticizer was chosen to be 5.89 fl. oz./cwt.

Air entrainer is added to entrap microscopic air voids in the mixture which contributes to a lower unit weight of concrete. The admixture also provides resistance to changes in temperature by allowing room for expansion as needed. The final dosage for air entrainer was selected to be 10.75 fl. oz./cwt.

With values selected for each respective admixture component, little change was found in the compressive strength while workability increased to a level of slump desired for pouring the concrete.

Figure 8: Cylinder in compression test machine.

To reinforce the adequacy of the chosen concrete mix design, the team performed tests according to established procedures. The standards used for testing were ASTM C39, C143, C192, and C470 for mixing concrete, sampling concrete, curing, and testing concrete cylinders respectively. This year, 3 in. by 6 in. cylinders were used for testing to increase the sustainability of the testing process and to decrease the volume of concrete produced per batch. For each batch, 4 cylinders were created, allowing for multiple test samples to be assessed for a final average strength value. **Figure 8** displays a cylinder in the compression test device. The cylinders were tested until failure, and the maximum compressive strength was noted in psi.

Every week, the team tested two new mixes which were cured for seven days and tested after they dried. Based on the compressive strength recorded for each mix, subsequent mixes were adjusted. This chosen procedure allowed for iterative design based on qualitative analysis of the proposed mixes. After 14 mixes, the team chose the best combination of high compressive strength and low unit weight. Another factor considered during the decision-making process was the workability of the concrete mix. If the concrete was unable to adhere to the side of the mixing bucket, then it was deemed unable to adhere to the mold. Based on these various criteria, the "best" two mixes were chosen.

The final step of the mix design process was the selection of pigment. The aesthetics team selected a rainbow unicorn–themed canoe hull in accordance with the overall project theme. As such, six different colors were needed. If pigment was added in excess, the predetermined ratios of the mix or the strength of the canoe would be compromised. The mix team deliberated upon an optimal amount of pigment, and additional compressive tests were performed on the two mixes chosen to constitute the layers of the canoe. One mix did not experience significant change in strength; however, the other mix lost greater strength with the addition of pigment. Based on these behaviors, the first mix was selected for the "inside" and "outside" aesthetic layers to depict the rainbow, and the second mix became the structural mix on the inside layer of the canoe.

As pour day approached, the team considered the ideal method for rapidly creating batches of concrete. During testing, the mixing of two batches took as long as two hours while the canoe was estimated to require 100 batches of concrete. In accordance with previous pour days, the team pre-measured all the cementitious materials and aggregates into Ziploc bags, the admixtures into syringes, and the water into empty cylinder molds. With all components labeled, mixing teams were able to quickly retrieve materials and efficiently create batches of concrete.

The actual process of mixing a batch is shown in **Figure 9**. A team of two people was found to function well, one holding the bucket and one operating the drill. Mixing teams took care to scrape the bottom of the bucket to ensure all the materials were incorporated well.

Figure 9: Mixing a batch of concrete on pour day.

One issue faced this year was the transfer of knowledge, or lack thereof. Due to the COVID-19 pandemic, many people of the mix design team had never physically participated in the development of the concrete. Consequently, the team faced many learning challenges. The earlier mixes faced many problems unrelated to the material selection. The problems encountered are explained in the *Enhanced Focus Area*. Ultimately, however, the largely inexperienced team, comprised of several eager volunteers, united to learn the mix design process.

CONSTRUCTION

Construction of *Speedy Unicorn* was largely based on the construction process of ASU's past canoes, especially *Legacy*. As with hull and mix design, the construction process heavily utilized past concrete canoe reports and advice from former project managers as well as other schools. Former Project Manager, Brielle Januszewski, contributed invaluable information, advising the current team on how to properly build the canoe. The initial stages of construction involved much research, beginning with the materials needed for the mold: Styrofoam, wood putty, resin, contact paper, and a releasing agent. Contact paper was a new method employed into ASU's concrete canoe mold with gratitude to the advice of University of California, Los Angeles's chapter of ASCE.

A male mold was used as past ASU teams have utilized this shape. No gunnels were applied to the hull design to maintain a simplistic design and to encourage easy removal of the mold after the concrete cured. The spline data from MATLAB was exported as text files which were then imported into

Figure 10: CNC machine cutting cross sections of the mold.

AutoCAD to create cross sections of the canoe. The AutoCAD files were converted to ShopBot files at the ASU Polytechnic campus. Using expanded polystyrene (EPS) foam, individual cross sections of the mold were also produced at the Polytechnic campus where a computer numerical control machine is located (**Figure 10**). Sixteen sheets of foam were used to mill the cross section of the mold. However, one sheet was discarded due to errors in the CNC machine configuration. Fortunately, the errant sheet was partially usable and was chosen to comprise the cut-away display.

Figure 11: Comparison of Legacy's bulkhead process (left) to Speedy Unicorn's process (right).

The cross-section cuts were transported to the USE lab in Tempe for assembly. A square steel bar was used to align the cross sections. Using Glidden Gripper, the Styrofoam sheets were glued together. As each cross section is two in. wide, the mold has a stair-step pattern. Several layers of Durham's Rock Hard Water Putty™ were used to the mold surface and eliminate the abrupt changes in the mold's geometry. Determining the appropriate consistency of the putty was required to avoid waste from the material drying too quickly before being applied to the mold. To taper the ends of the canoe, putty was sculpted onto cardboard extensions at the stern and bow. This was done with *Legacy* as well, but the process was improved by using one piece of cardboard rather than several small pieces to promote a smoother edge (**Figure 11**). The cardboard was recycled from a previous package, contributing to the limitation of waste in this project.

Once all layers of putty were applied, the mold was smoothed with a hand sander and an orbital sander, using both 80-grit and 120-grit sandpaper. Previously, the mold was then painted white to easily display the design. This year, this step was considered to be unnecessary as the putty dries as a light tan color, thus saving the team money and time. Using the paint-by-numbers method developed from *Legacy*, a marker was used to draw the design of the canoe, numbering each section according to the planned color. The intended depth of each concrete layer was also marked at the mold base as a reference for pour day volunteers. To seal the design and smooth its surface, epoxy resin was painted on the mold, including its base edges. Marker ink transferred onto *Legacy*, so it was important to ensure the entire mold was covered in resin. As discussed earlier, a new step was added to the mold process: contact paper. Strips of clear contact paper were used to cover the entire mold to promote easy removal after the canoe was done curing. The last layer of the mold was a releasing agent, WD-40, applied evenly across the surface during the morning of pour day. WD-40 was determined to be a satisfactory lubricant after its use in the creation of the sample molds. The liquid allows for the concrete to more easily release from the plastic. With little experience, the team was still able to make a relatively smooth mold (**Figure 12**).

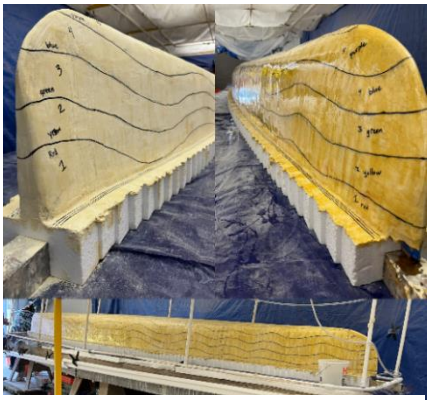


Figure 12: The mold after sanding and adding sharpie (left), the mold after adding resin (right), and the finished mold (bottom).

Preparation for pour day began afterwards. The reinforcement material used for the canoe was carbon fiber mesh, applied between the three layers of concrete. The mesh was purchased in bulk in a previous year, contributing to the cost savings in this year's budget. The mesh was pre-cut to the shape of the mold for time efficiency during casting. Minimizing task times during casting was vital to prevent the concrete from hardening too early while still allowing for the mesh to be pressed onto the concrete. As described in the *Development and*

Figure 13: Pour day photos: first layer (top left), second layer of concrete with mesh on top (top right), and last layer (bottom).

Testing section, materials were pre-measured, allowing for time efficiency, but it was also unsustainable with the amount of plastic bags used. To reduce plastic waste, the bags shall be reused for next year's pour day. The curing chamber was also reconfigured as it was last used in 2020. The curing chamber is comprised of a simple misting system attached to PVC pipes. To save water, a new hose timer was purchased as the old was no longer running properly. N95 masks and WD-40 cans were purchased prior to casting.

A video was created to explain personal protective equipment, safety, mixing, and casting, distributed the night before pour day and shown to volunteers before casting. As COVID-19 prevented canoe construction in 2021, the majority of the volunteers were novices. PPE consisted of N95 masks, gloves, and safety glasses/goggles. Following COVID-19 protocols and ASU's guidelines, masks were worn at all times in the canoe lab. To instruct the process of casting, the cut-away mold/canoe was created prior to pour day (**Figure 14**). Doing so allowed the team to visualize the process of casting and the layers that comprise the canoe.

Figure 14: Cut-away canoe showing the different layers.

Pour day was held in January to allow for 28-day curing, sanding, and finishing prior to conference which will be held in April. Volunteers were encouraged to attend through the ASCE, ASU chapter, and lunch was provided. The first layer of concrete was simplistic due to the rainbow design. Four people were tasked with making concrete mixes while the remaining volunteers applied concrete to the mold. The first layer of concrete was 3/16 in. thick. To ensure an even layer of concrete was casted each time, tread-depth gauges were used through the process of casting. Although challenging, the carbon fiber mesh was able to be imbedded into the first layer of concrete. Spray bottles filled with water were used to wet the concrete and mesh surface to more easily smooth the mesh into the concrete. The second layer of concrete was gray structural concrete, also 3/16 in. thick. The second layer of mesh was then impregnated into the concrete, proving to be easier than the first layer of mesh as the volunteers were more familiar with the process. The rainbow design was continued on the outside of the canoe for the third layer, but as the marked guides were no longer visible, the volunteers had to estimate the appropriate pattern. This last layer was laid carefully for a smooth and even finish. Putty knives were used to scrape and press against the concrete to promote a uniform surface. Communication between the project manager, captains, experienced volunteers, and new volunteers was constant through the casting to prevent mistakes.

Curing the canoe consisted of misting the canoe with a curing chamber made of PVC pipes, tubes, misting heads, plastic tarps, and a hose timer. Previously, the chamber operated for five minutes every hour. This year, the canoe was covered in cheesecloth to minimize drying between misting times (**Figure 15**). With the tarps and the cheesecloth, the canoe was able to stay moist with less frequent watering. The chamber operated for ten minutes every three hours, saving approximately 64 gallons of water a day.

Figure 15: Cheesecloth laid on the canoe along with hand towels to protect the canoe from water drips.

At the 21-day cure mark, wet sanding began. Wet sanding has proven to eliminate dust, thus providing a safer work environment. Wet sanding also contributes to smoothness as it allows for greater concrete removal compared to dry sanding (Abrahamson, 2009). The sanding process consisted of a range of sandpaper, from 80 to 1200-grit, to provide a smooth surface. While wet sanding, holes and inconsistencies in the concrete were patched with concrete. After sanding the outside of the canoe, the canoe was overturned, and the mold was removed. The inside of the canoe was also smoothed, again using a range of sandpaper from 80 to 1200 grit. The same foam used for the mold was hand cut and placed into the ends of the canoe for 3 feet–long bulk heads. The foam was encased with concrete and cured for 7 days before the surface was sanded. Adhesive appliques of the canoe and school names were adhered to the canoe, and all was sealed with EverClear 350 acrylic sealant. The canoe was flipped once more to seal the bottom of the boat, thus completing the construction of a fast and lightweight canoe, *Speedy Unicorn*.

SCOPE, SCHEDULE, AND FEES

In 2020, the concrete canoe competition was cancelled due to COVID-19. In 2021, the concrete competition was held online via Zoom. The teams created hypothetical canoes in place of physical canoes due to college campuses maintaining an online learning environment. The 2022 season reintroduced the in-person conferences, but due to the disruption caused by the pandemic, the majority of ASCE members within the ASU chapter lacked experience. The 2020 ASU Concrete Canoe PM created a comprehensive "how-to" document which guided the team.

Prior to the start of the academic year, Zoom meetings were held with the 2021 PM and the 2022 PM to discuss logistics and captains. Captains for this year's team included: Assistant Project Manager, Mix Design Captain, Hull Design Captain, Construction Captain, Aesthetics Captain, Paddling Captain, and Structural Analysis Captain. Each captain was handpicked and interviewed for the position. The first in-person step was to clean the concrete canoe lab. Doing so included the completion of the 2020 canoe, *Legacy*, which was to be transported to ASU's paddling practice location, Tempe Town Lake. *Legacy* was intended to be finished in 2021, but with COVID-19 restrictions, this never took place. *Legacy's* logos were placed, and the canoe was sealed with EverClear 350. The boat was then transferred to the lake for storage and paddling practice. **Figure 16** shows the process of concluding *Legacy's* journey.

Figure 16: Sealing Legacy (top left), moving Legacy (top right), and rowing Legacy in Tempe Town Lake (bottom).

Captains incorporated constructive feedback from PSWC 2020 and 2021 judges to improve the project from past years. The team met on Saturdays, bi-weekly, to discuss scheduling, updates, tasks, and other matters. These meetings were implemented last year and continued because of their previous success. This constant communication resulted in prompt task completion and minimal confusion. A Google Drive was created and shared across all captains and volunteers. With an organized drive, students were provided a hub for any needed information. For quick and easy communication, a group chat app called GroupMe was utilized.

The team was comprised of seven core members and 29 volunteers. The 36 members on the team dedicated approximately 1,554 man-hours to the creation of *Speedy Unicorn*, resulting in an18.5% decrease in manpower from *Sun Devil Crossing* (**Figure 17**). However, as 2021 numbers were hypothetical, they may have been a bit inaccurate.

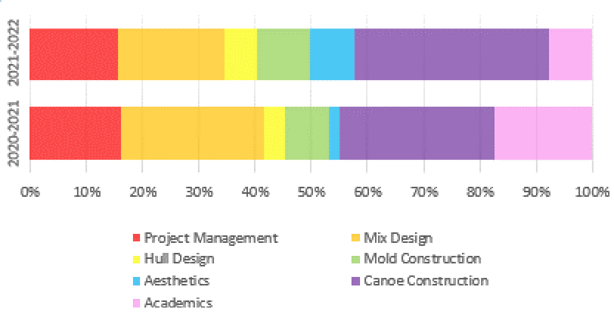


Figure 17: Comparison of Person-Hour Allocation

The schedule of *Speedy Unicorn* was inspired by past years as well as the advice of past PMs, created with the aim to improve scheduling. The preliminary schedule was created based a mid-March ISWS event, not mid-April. Milestone dates were affected, but the conference date change provided more time for the project. The delay which most negatively affected the team was a theme change due to usage restrictions by the trademark owners; Cartoon Network graciously allowed ASU to use *Adventure Time*. The project milestones within the critical path can be seen in **Table 7**.

Table 7: Project Milestones

Milestone	Delay	Cause
Rules Release	None	-
Paddling Team Selection	None	-
Finalize Theme	3.5 weeks	Original plans to use *Tom & Jerry* were vetoed due to Warner Brothers declining our request due to copyright.
Mold Construction	None	-
Finalize Structural Mix	None	-
Cast Day	2 weeks	Needed to complete pigment testing and moved the date due to the ISWS date change.
ISWS	4 weeks	The host school changed the conference date due to their venue for the canoe racing.

Expenses were minimal due to an abundance of supplies from previous seasons. The most significant expenses were transportation and team shirts for conference. The usual budget was decreased due to a sponsorship called *KEEN* no longer working with ASU. Funding was maintained through *FOCEE*, an organization which coordinates with the School of Sustainable Engineering and the Built Environment at ASU. The team also acquired smaller sponsorships from companies through outreach via calls and emails. **Figure 18** shows the expenses and budgets from 2020 through 2022.

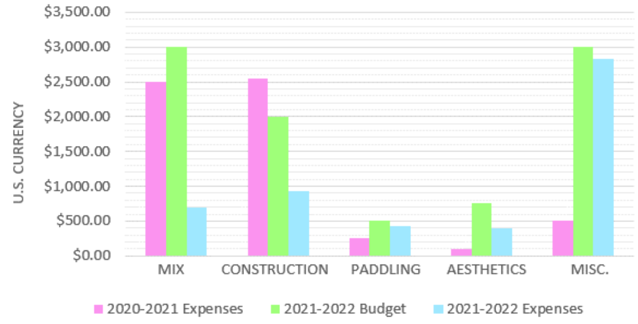


Figure 18: Budget and Expenditure Estimates

QUALITY CONTROL & QUALITY ASSURANCE

To accomplish quality control in the concrete mixture, each mix was observed and tested through slump, compressive, and flexural tests following ASTM standards. The data for each mix was recorded into a spreadsheet and the unit weights were calculated. Prior to the creation of *Speedy Unicorn*, pre-proportioned batches of cementitious and aggregate materials as well as admixtures and water were measured to produce consistent batches of concrete. As the canoe was constructed, experienced members assisted and corrected the casting team. The PM also provided clear direction for people to review the concrete layer depth throughout casting

For quality assurance, the entire process of this project was supervised by the project manager. Coaching was provided to both younger members and motivated but inexperienced captains. The mix design captain had not taken the Civil Engineering Materials class at ASU until the spring, so the design process was a collaborative effort in determining a mix with optimal workability and strength. During mixing sessions, both the PM and mix design captain instructed volunteers how to correctly pack a cylinder to ensure proper compaction. The aesthetics captain is a talented artist, but with the guidance of the PM, she was able to elevate her abilities and produce impressive artwork for the project, with designs being applied to t-shirts, report aesthetics, and canoe aesthetics. University faculty as well as alumni were contacted for mix design, construction, and technical proposal recommendations. Quality assurance was also established during pour day through a "how-to" casting and mixing video created by the PM. Communication between the leader of the team was essential for the fine craftsmanship of *Speedy Unicorn*.

SUSTAINABILITY

As civil engineering majors, part of the School of Sustainable Engineering and the Built Environment at ASU, the team recognizes the importance of sustainability, especially in a project which involves a non-environmentally friendly material like concrete. The team appreciates that ASCE continues to push for a more sustainable standard in the civil engineering profession. For social sustainability, the team encourages all majors to join the team. This year, multiple majors from ASU joined the team including computer science, informatics, construction management, as well as civil engineering. Diversity is one of the best qualities to have in a team; therefore, ASCE at ASU is dedicated to accepting people of all majors and backgrounds into the club.

The team was committed to saving money due to the abundance of materials and equipment acquired and present in the lab space. For economical sustainability, the team saved thousands of dollars on concrete material, Styrofoam, and mold milling. In terms of environmental sustainability, the team saved 64 gallons of water per day by decreasing misting frequency during curing. For 28-day cured samples, the team opted for submerging the samples underwater instead of using a curing chamber that would mist by the hour. The team plans to use another type of recycled aggregate by crushing old concrete samples in the future.

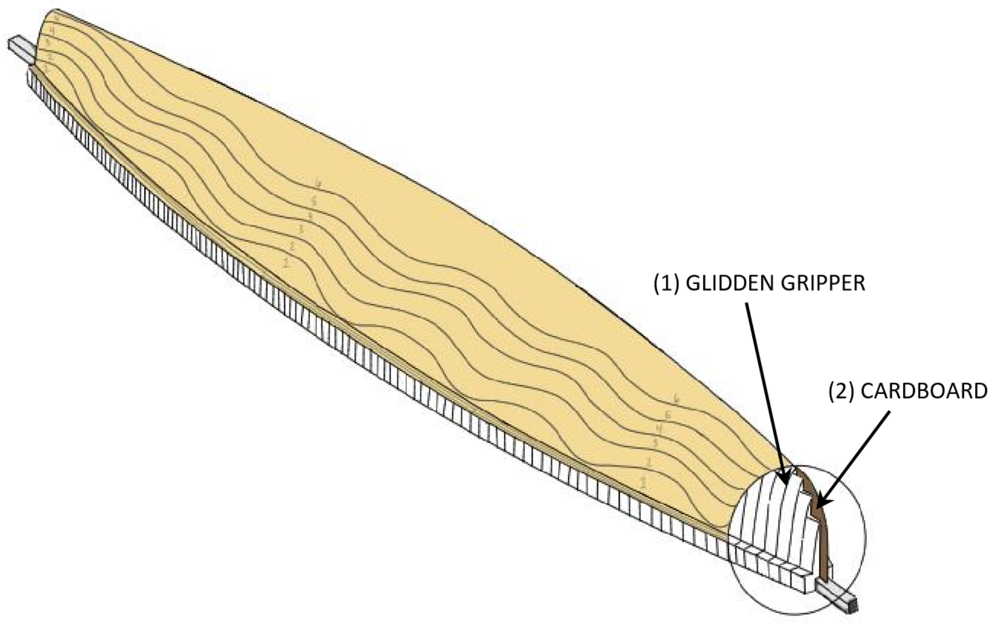
APPROACH TO HEALTH & SAFETY

Health and safety were paramount during this project. Captains received lab trainings to acquire unsupervised access to testing labs and the canoe lab. These trainings included: Hazard Waste Safety, Fire Safety, and two Lab Safety trainings. The PM and mix design captain also underwent special equipment training for the concrete compression machine. After reading ASTM C39, ASU Faculty Jeff Long, demonstrated how to operate the machine. The knowledge of these trainings was conveyed to the volunteers during an initial tour of the canoe lab; exits, PPE, the sink, and the fire extinguisher were explicitly addressed during the tours. Respirators and N-95s were worn during work which produced excessive airborne particulate matter such as casting, sanding, and sealing the canoe. Proper PPE, including long pants, close toed shoes, gloves, and protective eyewear, were worn during mix design, casting, and finishing sessions.

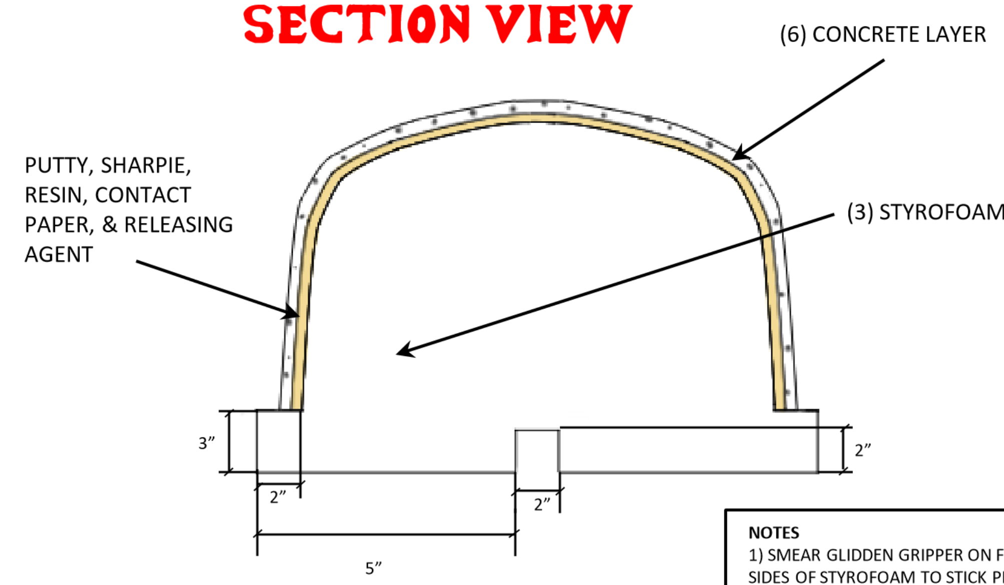
Arizona is one of the states in the United States with high COVID-19 cases; as such, maintaining a healthy environment was actively pursued throughout the process of *Speedy Unicorn*. ASU requires masks to be worn at all times in classrooms and lab spaces, including the concrete canoe lab (**Figure 19**). Daily health checks were also required in order to be allowed on campus due to ASU policy. During cast day, lunch was provided, but the team ate outside for safety. Through the efforts of the team, no one tested positive for COVID-19 because of canoe events. When a member did test positive, and if they had been around the team, they were required to inform the PM and quarantine based on the CDC recommendations.

Figure 19: Proper PPE demonstration (left) and mask demonstration (two pictures on right).

MOLD ISOMETRIC VIEW



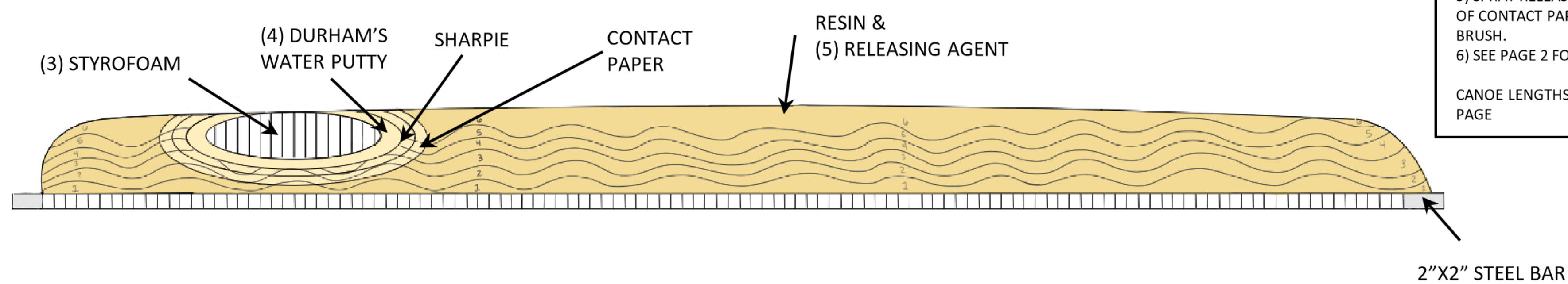
MOLD CROSS SECTION VIEW



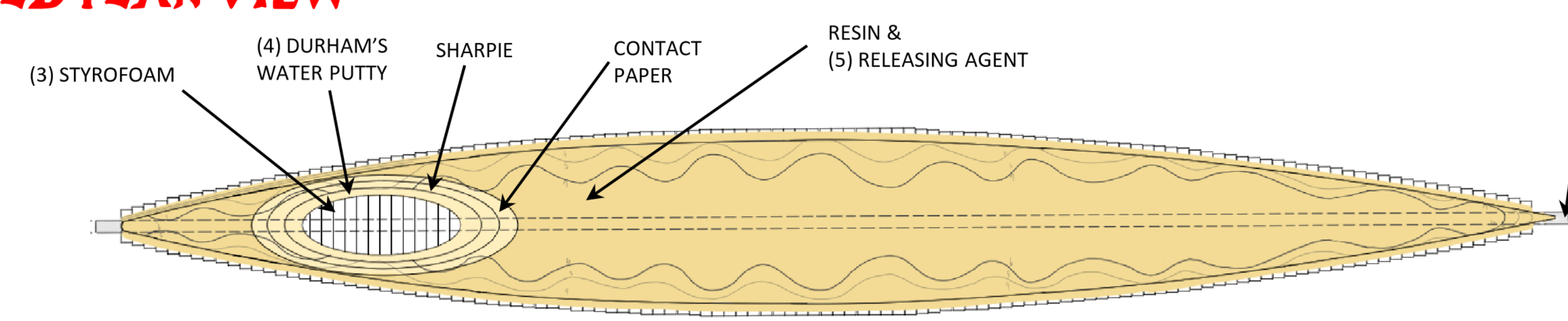
NOTES
1) SMEAR GLIDDEN GRIPPER ON FLAT SIDES OF STYROFOAM TO STICK PIECES TOGETHER
2) USE RECYCLED CARDBOARD TO CREATE SMOOTH EDGE ON BOTH ENDS OF CANOE.
4) SMOOTH PUTTY WITH PUTTY KNIFE. LAYER UNTIL SMOOTH. SAND WITH 80 GRIT.
5) SPRAY RELEASING AGENT ON TOP OF CONTACT PAPER. SPREAD WITH BRUSH.
6) SEE PAGE 2 FOR CONCRETE LAYERS

CANOE LENGTHS ARE ON THE NEXT PAGE

MOLD ELEVATION VIEW



MOLD PLAN VIEW



Arizona State University ASCE Concrete Canoe

BILL OF MATERIALS

Material	Quantity
3 Styrofoam	139
Glidden Gripper	0.25 gal
Cardboard	1 sq ft
Durham's Water Putty	90 lbs
Sharpie	1-2
Epoxy Resin	1 gal
Clear Contact Paper	90 sq ft
5 WD-40	0.25 gal

SPEEDY UNICORN
ASCE AT ASU
ISWS 2022

Project: 2022 INTERMOUNTAIN SOUTHWEST CONFERENCE - LAS VEGAS, NEVADA

Title: MOLD – CONSTRUCTION DOCUMENT

Drawn By: GBS

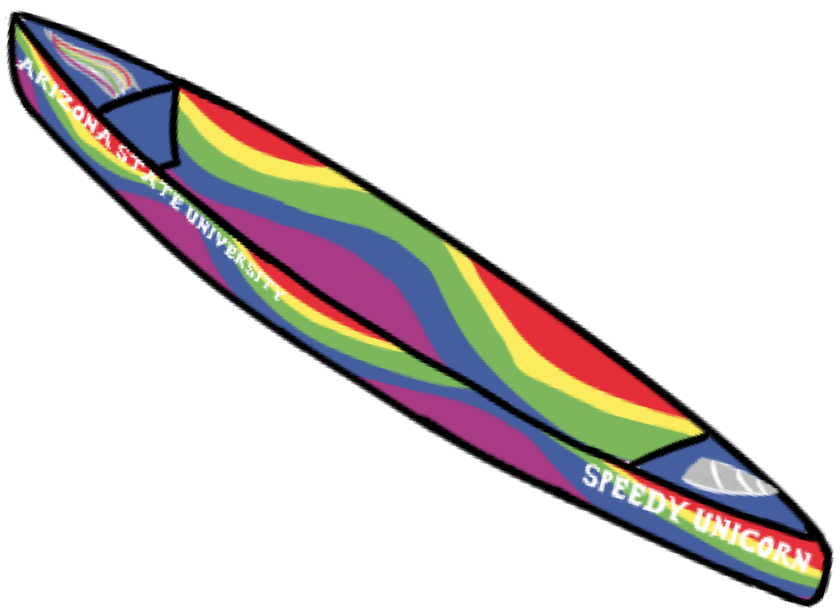
Checked By: CJB

Scale: VARIES

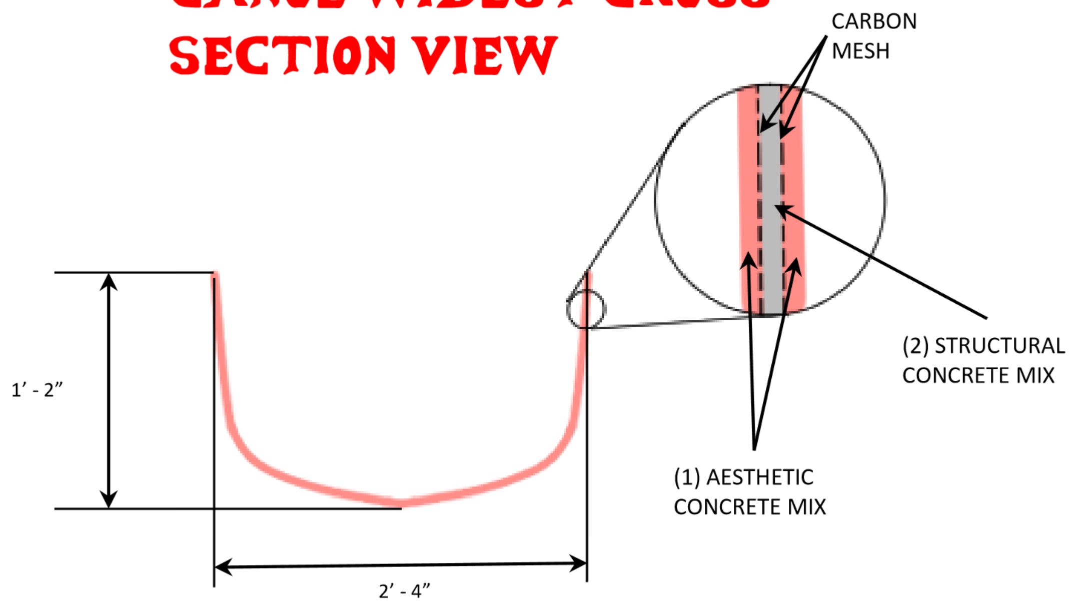
Date: 2/11/22

Page: 1 of 2

CANOE ISOMETRIC VIEW

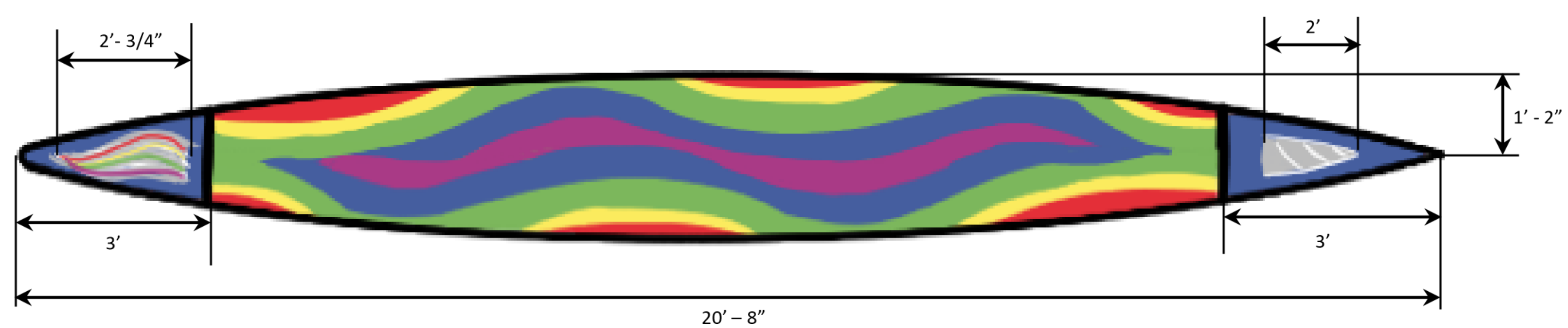


CANOE WIDEST CROSS SECTION VIEW



NOTES
1) AESTHETIC MIX COMPONENTS ARE IN APPENDIX B
2) STRUCTURAL MIX COMPONENTS ARE IN APPENDIX B

CANOE ELEVATION VIEW



Arizona State University
ASCE Concrete Canoe

BILL OF MATERIALS

Material	Quantity
Cementitious Materials	
Ordinary Portland Cement	103.878 lbs
Class F Fly Ash	34.626 lbs
Type S Hydrated Lime	21.634 lbs
Silica Fume	12.992 lbs
Aggregates	
Clay Shale (Fines)	36.152 lbs
Clay Shale (Crushed Fines)	16.866 lbs
Clay Shale (10 Mesh)	16.129 lbs
AGSCO® 0.1-0.3mm	30.74 lbs
AGSCO® 0.25-0.5mm	23.026 lbs
AGSCO® 0.5-1.0mm	38.396 lbs
Admixtures	
AEA-92	0.1454 gal
Plastol 6400	0.0797 gal
Non-Carbonated Water	10.45 gal
Solids	
Direct Colors Pigment	3.69 lbs
Concrete Fibers	
Grace MicroFiber™	0.87 lbs
Tuf-Strand Maxten	1.102 lbs
Reinforcement	
Carbon Fiber Mesh	165 sq ft
Finishing	
Vinyl Lettering	
Everclear 350	1 gal
Styrofoam	1.05 cu ft

Project: 2022 INTERMOUNTAIN SOUTHWEST CONFERENCE - LAS VEGAS, NEVADA

Title: CANOE – CONSTRUCTION DOCUMENT

Drawn By: JM/GBS

Checked By: CJB

Scale: VARIES

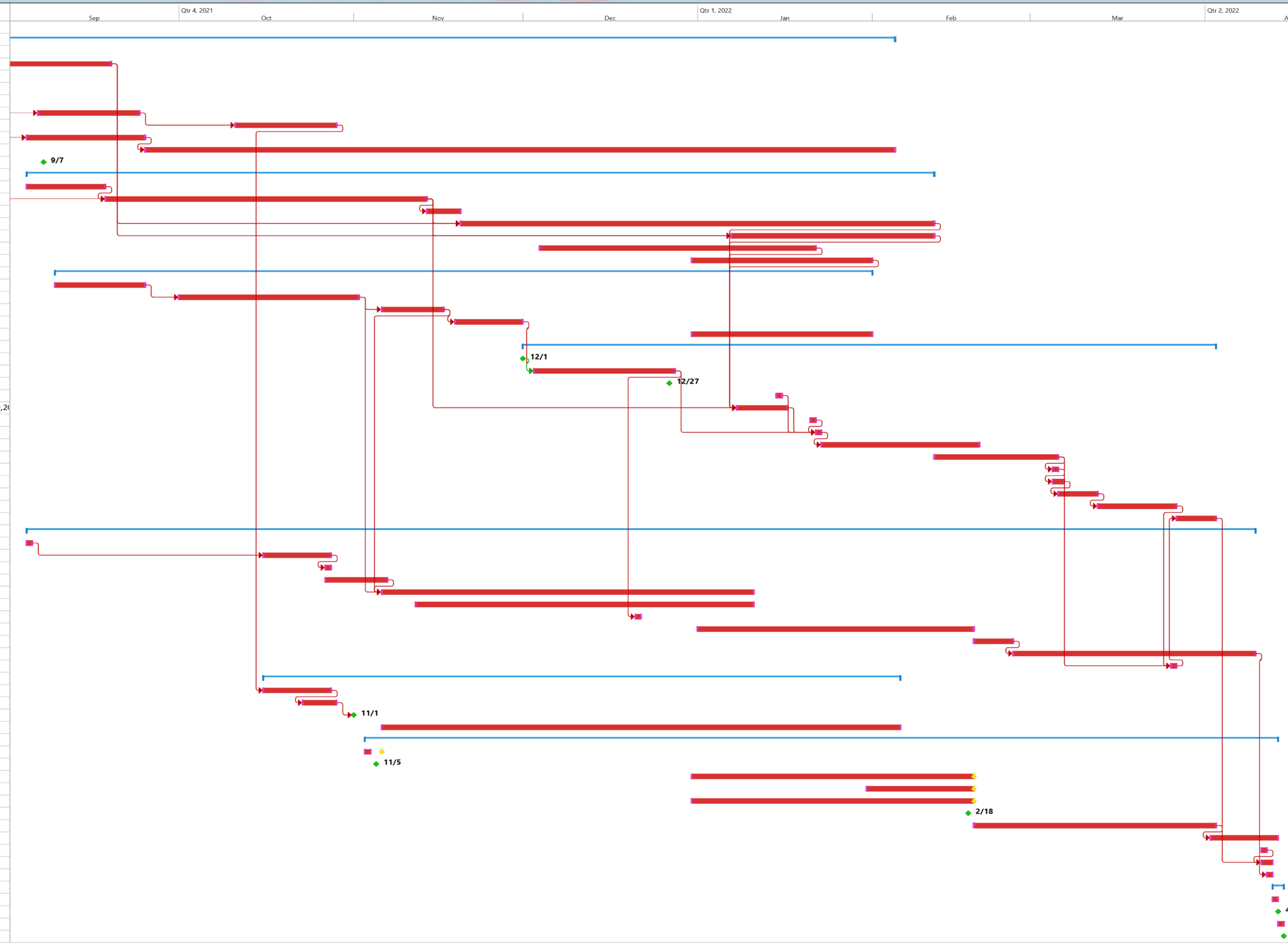
Date: 2/11/22

Page: 2 of 2

N

PROJECT SCHEDULE

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Concrete Canoe (2021-2022)**	**265 days**	**Sun 7/25/21**	**Fri 4/15/22**	
2	**Project Planning & Research**	**195 days**	**Sun 7/25/21**	**Fri 2/4/22**	
3	Interview Possible Captains	7 days	Sun 7/25/21	Sat 7/31/21	
4	Safety Trainings	35 days	Sun 8/15/21	Sat 9/18/21	
5	Take inventory	9 days	Wed 8/11/21	Thu 8/19/21	
6	Clean USE	12 days	Wed 8/11/21	Sun 8/22/21	
7	Sand Legacy	4 days	Mon 8/16/21	Thu 8/19/21	
8	Seal Legacy	18 days	Mon 9/6/21	Thu 9/23/21	7
9	Transfer Legacy to Tempe Town Lake	18 days	Mon 10/11/21	Thu 10/28/21	8
10	Call companies for sponsorships/materials	21 days	Sat 9/4/21	Fri 9/24/21	5
11	Order Supplies	133 days	Sat 9/25/21	Fri 2/4/22	10
12	Rules Release Date	0 days	Tue 9/7/21	Tue 9/7/21	
13	**Mix Design**	**161 days**	**Sat 9/4/21**	**Fri 2/11/22**	
14	Research for Mixes	14 days	Sat 9/4/21	Fri 9/17/21	
15	Weekly Mix Designs (every Saturday)	57 days	Sat 9/18/21	Sat 11/13/21	5,14
16	Finalize Structural Mix	6 days	Sat 11/13/21	Fri 11/19/21	15
17	Compression Testing (every Friday)	84 days	Sat 11/20/21	Fri 2/11/22	4,15
18	Flexural Testing	36 days	Fri 1/7/22	Fri 2/11/22	4,15
19	Pigment Testing	49 days	Sat 12/4/21	Fri 1/21/22	
20	Perform Mix Design Calculations	32 days	Fri 12/31/21	Mon 1/31/22	
21	**Hull Design and Structural Analysis**	**145 days**	**Thu 9/9/21**	**Mon 1/31/22**	
22	Research	16 days	Thu 9/9/21	Fri 9/24/21	
23	Redesign Using MATLAB Code	32 days	Fri 10/1/21	Mon 11/1/21	22
24	AutoCAD/Shotbot Files	11 days	Sat 11/6/21	Tue 11/16/21	23
25	Cutting Styrofoam Pieces for Mold at Poly	12 days	Fri 11/19/21	Tue 11/30/21	24
26	Perform Structural Analysis Calculations	32 days	Fri 12/31/21	Mon 1/31/22	
27	**Construction**	**123 days**	**Wed 12/1/21**	**Sat 4/2/22**	
28	Research Releasing Agent for Mold	0 days	Wed 12/1/21	Wed 12/1/21	
29	Construct the Mold	25 days	Fri 12/3/21	Mon 12/27/21	25,28
30	Mold Constructed Milestone	0 days	Mon 12/27/21	Mon 12/27/21	
31	Assemble Curing Chamber	1 day	Sat 1/15/22	Sat 1/15/22	
32	Prebatch Mixes	9 days	Sat 1/8/22	Sun 1/16/22	15,17,18,19,2(
33	Safety Training for Volunteers	1 day	Fri 1/21/22	Fri 1/21/22	
34	Cast Day	1 day	Sat 1/22/22	Sat 1/22/22	29,31,32,33
35	Curing	28 days	Sun 1/23/22	Sat 2/19/22	34
36	Sand the Outside of the Canoe	22 days	Sat 2/12/22	Sat 3/5/22	
37	Flip & Mold Removal	1 day	Sat 3/5/22	Sat 3/5/22	36
38	Bulkhead Placement	2 days	Sat 3/5/22	Sun 3/6/22	37
39	Curing of Bulkheads	7 days	Sun 3/6/22	Sat 3/12/22	38
40	Sand the Inside of the Canoe & Bulkheads	14 days	Sun 3/13/22	Sat 3/26/22	39
41	Seal the Canoe	7 days	Sun 3/27/22	Sat 4/2/22	53
42	**Aesthetics**	**218 days**	**Sat 9/4/21**	**Sat 4/9/22**	
43	Theme Ideas	1 day	Sat 9/4/21	Sat 9/4/21	
44	Research Copyright & ask for Permission	12 days	Sat 10/16/21	Wed 10/27/21	43
45	Finalize Theme	1 day	Wed 10/27/21	Wed 10/27/21	44
46	Preliminary Canoe Design	11 days	Wed 10/27/21	Sat 11/6/21	
47	Finalize Canoe Design	66 days	Sat 11/6/21	Mon 1/10/22	23,24,46
48	Design & Order Teeshirts	60 days	Fri 11/12/21	Mon 1/10/22	
49	Draw "Paint-by-Number" on Canoe	1 day	Tue 12/21/21	Tue 12/21/21	29
50	Report Aesthetics/Formatting	49 days	Sat 1/1/22	Fri 2/18/22	
51	Design Display	7 days	Sat 2/19/22	Fri 2/25/22	
52	Create Display	43 days	Sat 2/26/22	Sat 4/9/22	51
53	Place Lettering on Canoe	1 day	Sat 3/26/22	Sat 3/26/22	36,40
54	**Paddling**	**113 days**	**Sat 10/16/21**	**Sat 2/5/22**	
55	Information Sessions & Open Training	12 days	Sat 10/16/21	Wed 10/27/21	9
56	Tryouts	6 days	Sat 10/23/21	Thu 10/28/21	55
57	Team Selection Milestone	0 days	Mon 11/1/21	Mon 11/1/21	56
58	Practice (Fridays or Saturdays)	92 days	Sat 11/6/21	Sat 2/5/22	
59	**Conference Preparation**	**162 days**	**Wed 11/3/21**	**Wed 4/13/22**	
60	Pre-qualification Forms	1 day	Wed 11/3/21	Wed 11/3/21	
61	Pre-Qualification Forms Turned In Milestone	0 days	Fri 11/5/21	Fri 11/5/21	
62	Technical Proposal Report	50 days	Fri 12/31/21	Fri 2/18/22	
63	Enhanced Focus Area Report	19 days	Mon 1/31/22	Fri 2/18/22	
64	MTDS Addendum	50 days	Fri 12/31/21	Fri 2/18/22	
65	Deliverables Turned in Milestone	0 days	Fri 2/18/22	Fri 2/18/22	
66	Technical Presentation Powerpoint	43 days	Sat 2/19/22	Sat 4/2/22	
67	Reherse Technical Presentation	12 days	Sat 4/2/22	Wed 4/13/22	66
68	Retreive Canoe Cart from Tempe Town Lake	1 day	Mon 4/11/22	Mon 4/11/22	
69	Pack Speedy Unicorn into Trailer	2 days	Mon 4/11/22	Tue 4/12/22	41,68
70	Pack Displays	1 day	Tue 4/12/22	Tue 4/12/22	52
71	**Attend ISWS in Las Vegas**	**2 days**	**Wed 4/13/22**	**Fri 4/15/22**	
72	Registration	1 day	Wed 4/13/22	Wed 4/13/22	
73	Canoe Display	0 days	Thu 4/14/22	Thu 4/14/22	
74	Canoe Presentation	1 day	Thu 4/14/22	Thu 4/14/22	
75	Concrete Canoe Swamp Test and Races	0 days	Fri 4/15/22	Fri 4/15/22	



Project: Project Schedule 21-22 | Summary | Task | Milestone | Start-only | Finish-only | Deadline

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APPENDIX B: MIXTURE PROPORTIONS AND PRIMARY CALCULATIONS

MIXTURE STRUCTURAL MIX USED AS MIDDLE LAYER

Cementitious Materials

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (lb/yd^3)*	
Type II Ordinary Portland Cement	3.15	1.893	372.00	Total cm (includes c) **620.00** lb/yd^3 c/cm ratio, by mass **0.60**
Class F Fly Ash	2.14	0.929	124.00	
Silica Fume	2.20	0.339	46.50	
Type S Hydrated Lime	2.60	0.478	77.50	

Fibers

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of Fibers (lb/yd^3)*	
GRACE Micro-Fibers	0.91	0.055	3.10	Total Amount of Fibers 7.10 lb/yd^3
Tuf-Strand Maxten Macro-Fibers	0.91	0.070	4.00	

Aggregates (Excluding Mineral Fillers Passing No. 200 Sieve)

Aggregates	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity, W (lb/yd^3)*		*Volume, $V_{agg,\ SSD}$ (ft^3)*
				W_{OD}	*W_{SSD}*	
Clay Shale (Fines)	17.60	0.726	0.854	93.54	110.00	2.064
Clay Shale (Crushed Fines)	16.50	0.725	0.845	62.94	73.33	1.391
Clay Shale (10 Mesh)	14.30	0.722	0.825	32.08	36.67	0.712
Agsco® 0.1-0.3mm	35.00	0.296	0.400	81.48	110.00	4.402
Agsco® 0.25-0.5mm	28.00	0.266	0.340	64.53	82.50	3.889
Agsco® 0.5-1.0mm	20.00	0.217	0.260	114.58	137.50	8.475

Liquid Admixtures

Admixture	*lb/US gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
Euclid AEA 92	8.50	10.75	6.0	4.16	Total Water from Liquid Admixtures, $\sum w_{admx}$ 5.64 lb/yd^3
Euclid Plastol 6400	8.80	5.89	41.0	1.48	

Solids (Dyes Powdered Admixtures)

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (lb/yd^3)*	
Direct Colors Concrete Pigment	2.5	0	0	Total Solids. S_{total} 0 lb/yd^3

Water

	Amount (lb/yd^3)		*Volume (ft^3)*
***Water**, w, [$=\sum (w_{free} + w_{admx} + w_{batch})$]*	w/c ratio, by mass **0.55** w/cm ratio, by mass **0.33**	204.60	3.28
***Total Free Water from All Aggregates**, $\sum w_{free}$*		-99.61	
***Total Water from All Admixtures**, $\sum w_{admx}$*		5.64	
***Batch Water**, w_{batch}*		298.57	

Densities, Air Content, Ratios, and Slump

Values for 1 cy of concrete	*cm*	*Fibers*	*Aggregate (SSD)*	*Solids, S_{total}*	*Water, w*	*Total*
***Mass**, M*	620 lbs	7.10 lbs	550 lbs	0 lb	204.6 lbs	$\sum M$: 1381.70 lbs
***Absolute Volume**, V*	3.64 ft^3	0.13 ft^3	20.94 ft^3	0 ft^3	3.28 ft^3	$\sum V$: 27.98 ft^3
***Theoretical Density**, T, ($=\sum M / \sum V$)*	49.38 lb/ft^3		***Air Content**, Air, [= (T – D)/T x 100%]*			-3.62%
***Anticipated Density**, D*	51.17 lb/ft^3		***Air Content**, Air, [= (27 – $\sum V$))/27 x 100%]*			-3.62%
***Total Aggregate Ratio** ($=V_{agg,SSD} / 27$)*	77.55%		***Slump, Slump flow, Spread** (as applicable)*			1/8 in
***C330 + RCA Ratio** ($=V_{C330+RCA} / V_{agg}$)*	100%					

APPENDIX B: MIXTURE PROPORTIONS AND PRIMARY CALCULATIONS

MIXTURE STRUCTURAL MIX USED AS OUTSIDE LAYERS

Cementitious Materials

Component	Specific Gravity	Volume (ft^3)	Amount of CM (lb/yd^3)	
Type II Ordinary Portland Cement	3.15	1.893	372.00	Total cm (includes c) **620.00** lb/yd^3 c/cm ratio, by mass **0.6**
Class F Fly Ash	2.14	0.929	124.00	
Silica Fume	2.20	0.339	46.50	
Type S Hydrated Lime	2.60	0.478	77.50	

Fibers

Component	Specific Gravity	Volume (ft^3)	Amount of Fibers (lb/yd^3)	
GRACE Micro-Fibers	0.91	0.055	3.10	Total Amount of Fibers 7.10 lb/yd^3
Tuf-Strand Maxten Macro-Fibers	0.91	0.070	4.00	

Aggregates (Excluding Mineral Fillers Passing No. 200 Sieve)

Aggregates	Abs (%)	SG_{OD}	SG_{SSD}	Base Quantity, W (lb/yd^3)		Volume, $V_{agg, SSD}$ (ft^3)
				W_{OD}	W_{SSD}	
Clay Shale (Fines)	17.60	0.726	0.854	116.92	137.50	2.580
Clay Shale (Crushed Fines)	16.50	0.725	0.845	47.21	55.00	1.043
Clay Shale (10 Mesh)	14.30	0.722	0.825	24.06	27.50	0.534
Agsco® 0.1-0.3mm	35.00	0.296	0.400	81.48	110.00	4.402
Agsco® 0.25-0.5mm	28.00	0.266	0.340	64.45	82.50	3.889
Agsco® 0.5-1.0mm	20.00	0.217	0.260	114.58	137.5	8.475

Liquid Admixtures

Admixture	lb/US gal	Dosage (fl. oz / cwt)	% Solids	Amount of Water in Admixture (lb/yd^3)	
Euclid AEA 92	8.50	10.75	6.0	4.16	Total Water from Liquid Admixtures, $\sum w_{admx}$ 5.64 lb/yd^3
Euclid Plastol 6400	8.80	5.89	41.0	1.48	

Solids (Dyes Powdered Admixtures)

Component	Specific Gravity	Volume (ft^3)	Amount (lb/yd^3)	
Direct Colors Concrete Pigment	2.5	0.119	18.6	Total Solids. S_{total} 18.6 lb/yd^3

Water

	Amount (lb/yd^3)		Volume (ft^3)
Water, w, [$=\sum (w_{free} + w_{admx} + w_{batch})$]	w/c ratio, by mass **0.55** w/cm ratio, by mass **0.33**	204.60	3.28
Total Free Water from All Aggregates, $\sum w_{free}$		-99.98	
Total Water from All Admixtures, $\sum w_{admx}$		5.64	
Batch Water, w_{batch}		298.94	

Densities, Air Content, Ratios, and Slump

Values for 1 cy of concrete	cm	Fibers	Aggregate (SSD)	Solids, S_{total}	Water, w	Total
Mass, M	620 lb	7.10 lb	550 lb	18.6 lb	204.60 lb	$\sum M$: 1400.30 lb
Absolute Volume, V	3.638 ft^3	0.125 ft^3	23.286 ft^3	0.281 ft^3	3.28 ft^3	$\sum V$: 28.09 ft^3
Theoretical Density, T, ($=\sum M / \sum V$)	49.85 lb/ft^3		Air Content, Air, [$= (T - D)/T \times 100\%$]			-4.03%
Anticipated Density, D	51.86 lb/ft^3		Air Content, Air, [$= (27 - \sum V))/27 \times 100\%$]			-4.03%
Total Aggregate Ratio ($=V_{agg,SSD} / 27$)	77.51%		Slump, Slump flow, Spread (as applicable)			1/8 in
C330 + RCA Ratio ($=V_{C330+RCA} / V_{agg}$)	100%					

MIXTURE CALCULATIONS FOR STRUCTURAL MIX

$$\boldsymbol{Volume} = \frac{\boldsymbol{Mass}}{\boldsymbol{SG*62.4\frac{lb}{ft^3}}}$$

CEMENTITIOUS MATERIALS

$\boldsymbol{Mass = given}$

$Mass_{portland\ cement} = 372\ lbs$

$Mass_{F\ ash} = 124\ lbs$

$Mass_{silica\ fume} = 46.5\ lbs$

$Mass_{lime} = 77.5\ lbs$

$\boldsymbol{\sum Mass_{cementitious} = cm = 620\ lbs}$

$Volume_{portland\ cement} = \frac{372\ lbs}{3.15*62.4\ lb/ft^3} = 1.89\ ft^3$

$Volume_{F\ ash} = \frac{124\ lbs}{2.14*62.4\ lb/ft^3} = 0.929\ ft^2$

$Volume_{silica\ fume} = \frac{46.5\ lbs}{3.15*62.4\ lb/ft^3} = 0.339\ ft^3$

$Volume_{lime} = \frac{372\ lbs}{3.15*62.4\ lb/ft^3} = 0.478\ ft^3$

$\boldsymbol{\sum Volume_{cementitous} = 3.64\ ft^3}$

FIBERS

$\boldsymbol{Mass = given}$

$Mass_{micro\ fibers} = 3.10\ lbs$

$Mass_{macro\ fibers} = 4.00\ lbs$

$\boldsymbol{\sum Mass_{fibers} = 7.10\ lbs}$

$Volume_{micro\ fibers} = \frac{3.10\ lbs}{0.91*62.4\ lb/ft^3} = 0.0546\ ft^3$

$Volume_{micro\ fibers} = \frac{4.00\ lbs}{0.91*62.4\ lb/ft^3} = 0.0704\ ft^3$

$\boldsymbol{\sum Volume_{fibers} = 0.1250\ ft^3}$

AGGREGATES

$\boldsymbol{Mass(W_{SSD}) = given}$

$W_{SSD-clay\ shale\ (fine)} = 110\ lbs$

$W_{SSD-clay\ shale\ (crushed\ fine)} = 73.33\ lbs$

$W_{SSD-clay\ shale\ (10\ Mesh)} = 36.67\ lbs$

$W_{SSD-foamed\ glass\ (0.1-0.3)} = 110\ lbs$

$W_{SSD-foamed\ glass\ (0.25-0.5)} = 82.5\ lbs$

$W_{SSD-foamed\ glass\ (0.5-1.0)} = 137.5\ lbs$

$\boldsymbol{\sum W_{SSD-aggregates} = cm = 550\ lbs}$

$Volume_{clay\ shale\ (fine)} = \frac{110\ lbs}{0.854*62.4\ lb/ft^3} = 2.064\ ft^3$

$Volume_{clay\ shale\ (crushed\ fines)} = \frac{73.33\ lbs}{0.845*62.4\ lb/ft^3} = 1.391\ ft^3$

$Volume_{clay\ shale\ (10\ Mesh)} = \frac{36.67\ lbs}{0.825*62.4\ lb/ft^3} = 0.712\ ft^3$

$Volume_{foamed\ glass\ (0.1-0.3)} = \frac{110\ lbs}{0.4*62.4\ lb/ft^3} = 4.407\ ft^3$

$Volume_{foamed\ glass\ (0.25-0.5)} = \frac{82.5\ lbs}{0.34*62.4\ lb/ft^3} = 3.889\ ft^3$

$Volume_{foamed\ glass\ (0.5-1.0)} = \frac{137.5\ lbs}{0.26*62.4\ lb/ft^3} = 8.475\ ft^3$

$\boldsymbol{\sum Volume_{aggregates} = 20.938\ ft^3}$

APPENDIX B: MIXTURE PROPORTIONS AND PRIMARY CALCULATIONS

$$\boldsymbol{Specific\ Gravity(SG_{SSD}) = given}$$

$SG_{SSD-clay\ shale\ (fine)} = 0.854$

$SG_{SSD-clay\ shale\ (crushed\ fines)} = 0.845$

$SG_{SSD-clay\ shale\ (10\ Mesh)} = 0.825$

$SG_{SSD-foamed\ glass\ (0.1-0.3)} = 0.400$

$SG_{SSD-foamed\ glass\ (0.25-0.5)} = 0.340$

$SG_{SSD-foamed\ glass\ (0.5-1.0)} = 0.260$

$$\boldsymbol{Absorption\ (Abs) = given}$$

$Abs_{clay\ shale\ (fine)} = 17.6\%$

$Abs_{clay\ shale\ (crused\ fines)} = 16.5\%$

$Abs_{clay\ shale\ (10\ Mesh)} = 14.3\%$

$Abs_{foamed\ glass\ (0.1-0.3)} = 35\%$

$Abs_{foamed\ glass\ (0.25-0.5)} = 28\%$

$Abs_{foamed\ glass\ (0.5-1.0)} = 20\%$

$$\boldsymbol{Specific\ Gravity(SG_{OD}) = \frac{SG_{SSD(Aggregate)}}{1+Abs_{Aggregate}}}$$

$SG_{OD-clay\ shale\ (fine)} = \frac{0.854}{1+0.176} = 0.726$

$SG_{OD-clay\ shale\ (crushed\ fines)} = \frac{0.845}{1+0.165} = 0.725$

$SG_{OD-clay\ shale\ (10\ Mesh)} = \frac{0.825}{1+0.143} = 0.722$

$SG_{OD-foamed\ glass\ (0.1-0.3)} = \frac{0.400}{1+0.35} = 0.296$

$SG_{OD-foamed\ glass\ (0.25-0.5)} = \frac{0.340}{1+0.28} = 0.266$

$SG_{OD-foamed\ glass\ (0.5-1.0)} = \frac{0.260}{1+0.20} = 0.217$

$$\boldsymbol{Mass(W_{OD}) = Volume_{aggregate} * SG_{OD(aggregate)} * 62.4\ lb/ft^3}$$

$W_{OD-clay\ shale\ (fine)} = 2.064ft^3 * 0.726 * 62.4\frac{lb}{ft^3} = 93.54\ lbs$

$W_{OD-clay\ shale\ (crushed\ fine)} = 1.391ft^3 * 0.725 * 62.4\frac{lb}{ft^3} = 62.94\ lbs$

$W_{OD-clay\ shale\ (10\ Mesh)} = 0.712ft^3 * 0.722 * 62.4\frac{lb}{ft^3} = 32.08\ lbs$

$W_{OD-foamed\ glass\ (0.1-0.3)} = 4.407ft^3 * 0.296 * 62.4\frac{lb}{ft^3} = 81.48\ lbs$

$W_{OD-foamed\ glass\ (0.25-0.5)} = 3.889ft^3 * 0.266 * 62.4\frac{lb}{ft^3} = 64.45\ lbs$

$W_{OD-foamed\ glass\ (0.5-1.0)} = 8.475ft^3 * 0.217 * 62.4\frac{lb}{ft^3} = 114.58\ lbs$

$\boldsymbol{\sum W_{OD} = 449.08\ lbs}$

$$\textbf{Check} - \boldsymbol{Mass(W_{SSD}) = W_{OD} * (1 + Abs)}$$

$W_{SSD-clay\ shale\ (fine)} = 93.54lbs * (1 + 0.176) = 110\ lbs$

$W_{SSD-clay\ shale\ (crushed\ fine)} = 62.36lbs * (1 + 0.176) = 73.33\ lbs$

$W_{SSD-clay\ shale\ (10\ Mesh)} = 31.18lbs * (1 + 0.176) = 36.67\ lbs$

$W_{SSD-foamed\ glass\ (0.1-0.3)} = 92.45lbs * (1 + 0.19) = 110\ lbs$

$W_{SSD-foamed\ glass\ (0.25-0.5)} = 69.33lbs * (1 + 0.19) = 82.5\ lbs$

$W_{SSD-foamed\ glass\ (0.5-1.0)} = 115.55lbs * (1 + 0.19) = 137.5\ lbs$

$\boldsymbol{\sum W_{SSD(aggregates)} = 550\ lbs}$

APPENDIX B: MIXTURE PROPORTIONS AND PRIMARY CALCULATIONS

$\boldsymbol{Stock\ Moisture\ Contents\ (MC_{stk})}$

$MC_{clay\ shale\ (fine)} = 0\%$

$MC_{clay\ shale\ (crushed\ fine)} = 0\%$

$MC_{clay\ shale\ (10\ mesh)} = 0\%$

$MC_{foamed\ glass\ (0.1-0.3)} = 0.5\%$

$MC_{foamed\ glass\ (0.25-0.5)} = 0.5\%$

$MC_{foamed\ glass\ (0.5-1.0)} = 0.5\%$

$\boldsymbol{Mass\ at\ Stock\ Moisture\ \left(W_{stk(aggregate)}\right) = W_{OD(aggregate)} * \left(1 + \frac{MC_{stk}}{100\%}\right)}$

$W_{stk-clay\ shale\ (fine)} = 93.54\ lbs * \left(1 + \frac{0\%}{100\%}\right) = 93.54\ lbs$

$W_{stk-clay\ shale\ (crushed\ fine)} = 62.94\ lbs * \left(1 + \frac{0\%}{100\%}\right) = 62.94\ lbs$

$W_{stk-clay\ shale\ (10\ Mesh)} = 32.08\ lbs * \left(1 + \frac{0\%}{100\%}\right) = 32.08\ lbs$

$W_{stk-foamed\ glass\ (0.1-0.3)} = 81.48\ lbs * \left(1 + \frac{0.5\%}{100\%}\right) = 81.89\ lbs$

$W_{stk-foamed\ glass\ (0.25-0.5)} = 64.45\ lbs * \left(1 + \frac{0.5\%}{100\%}\right) = 64.77\ lbs$

$W_{stk-foamed\ glass\ (0.5-1.0)} = 114.58\ lbs * \left(1 + \frac{0.5\%}{100\%}\right) = 115.15\ lbs$

$\boldsymbol{Moisture\ Contents\ \left(MC_{free}\right) = MC_{total} - Abs}$

$MC_{free-clay\ shale\ (fine)} = 0\% - 17.6\% = -17.6\%$

$MC_{free-clay\ shale\ (crushed\ fine)} = 0\% - 16.5\% = -16.5\%$

$MC_{free-clay\ shale\ (10\ mesh)} = 0\% - 14.3\% = -14.3\%$

$MC_{free-foamed\ glass\ (0.1-0.3)} = 0.5\% - 35\% = -34.5\%$

$MC_{free-foamed\ glass\ (0.25-0.5)} = 0.5\% - 28\% = -27.5\%$

$MC_{free-foamed\ glass\ (0.5-1.0)} = 0.5\% - 20\% = -19.5\%$

$\boldsymbol{Free\ water\ \left(w_{free}\right) = W_{OD} * \left(\frac{MC_{free}}{100\%}\right)}$

$w_{free-clay\ shale\ (fine)} = 93.54lbs * \left(\frac{-17.6\%}{100\%}\right) = -16.46lbs$

$w_{free-clay\ shale\ (crushed\ fine)} = 62.94lbs * \left(\frac{-16.5\%}{100\%}\right) = -10.39lbs$

$w_{free-clay\ shale\ (10\ mesh)} = 32.08lbs * \left(\frac{-14.3\%}{100\%}\right) = -4.59lbs$

$w_{free-foamed\ glass\ (0.1-0.3)} = 81.48lbs * \left(\frac{-34.5\%}{100\%}\right) = -28.11lbs$

$w_{free-foamed\ glass\ (0.25-0.5)} = 64.45lbs * \left(\frac{-27.5\%}{100\%}\right) = -17.72lbs$

$w_{free-foamed\ glass\ (0.5-1.0)} = 114.58lbs * \left(\frac{-19.5\%}{100\%}\right) = -22.34lbs$

$\boldsymbol{\sum w_{free} = -99.61\ lbs}$

APPENDIX B: MIXTURE PROPORTIONS AND PRIMARY CALCULATIONS

ADMIXTURES

$$\boldsymbol{Dosage = given}$$

$$Dosage_{AEA92} = 10.75\frac{fl\,oz}{cwt}$$

$$Dosage_{Plastol6400} = 5.89\frac{fl\,oz}{cwt}$$

$$\boldsymbol{water\ content = 1 - \%solids}$$

$$\boldsymbol{water_{admixture} = \left(Dosage\left(\frac{fl\,oz}{cwt}\right)\right) * cm * wc(\%) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * \left(\frac{lb}{1\,gal}\ of\ admixture\right)}$$

$$water_{AEA92} = \left(10.75\left(\frac{fl\,oz}{cwt}\right)\right) * 6.2 * (1 - 0.06) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * \left(\frac{8.5\,lb}{1\,gal}\right) = 4.16lbs$$

$$water_{Plastol6400} = \left(5.89\left(\frac{fl\,oz}{cwt}\right)\right) * 6.2 * (1 - 0.41) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * \left(\frac{8.8\,lb}{1\,gal}\right) = 1.48lbs$$

$$\boldsymbol{\sum water_{admixtures} = 5.64\ lbs}$$

WATER

$$\boldsymbol{water = \frac{w}{cm} * cm}$$

$$Mass_{water} = w = 0.33 * 620lbs = 204.6lbs$$

$$\boldsymbol{Volume = \frac{Mass}{SG * 62.4\ lb/ft^3}}$$

$$Volume_{water} = \frac{204.6lbs}{1 * 62.4lb/ft^3} = 3.28ft^3$$

$$\boldsymbol{Batch\ Water\ (w_{batch}) = w - (\sum w_{free} + \sum w_{admix})}$$

$$w_{batch} = 204.6\ lbs - (-99.61lbs + 5.64lbs) = 298.57\ lbs$$

CONCRETE ANALYSIS

$$\sum Mass = Mass_{concrete} = 1381.70\ lbs$$

$$\sum Volume = Volume_{concrete} = 27.98\ ft^3$$

$$Theoretical\ Density\ (T) = 49.38\ lb/ft^3$$

$$Anticipated\ Density\ (D) = 51.17\ lb/ft^2$$

Air Content

$$Air\ Content = \frac{|T-D|}{T} * 100\% = \frac{49.38-51.17}{49.38} * 100\% = -3.62\%$$

$$Air\ Content = \frac{27-\sum Vol}{27} * 100\% = \frac{27-27.98}{27} * 100\% = -3.62\%$$

Cement/cementitious ratio

$$\frac{c}{cm} = \frac{372}{620} = 0.6$$

Water/cementitious ratio

$$\frac{w}{cm} = \frac{204.6}{620} = 0.33$$

Water/cement ratio

$$\frac{w}{c} = \frac{204.6}{372} = 0.55$$

AGGREGATE RATIO CHECK

$$Total\ Aggregate\ Ratio = \frac{V_{aggSSD}}{27} * 100\% = \frac{20.938}{27} * 100\% = 77.55\% > 30\%\ (OK!)$$

$$C330 + RCARatio = \frac{V_{C330+RCA}}{V_{agg,SSD}} * 100\% = \frac{20.938}{20.938} * 100\% = 100\% > 50\%\ (OK!)$$

SLUMP

Measured to be 1/8 in

MIXTURE CALCULATIONS FOR AESTHETIC MIX

$$\boldsymbol{Volume = \frac{Mass}{SG*62.4\frac{lb}{ft^3}}}$$

CEMENTITIOUS MATERIALS

$\boldsymbol{Mass = given}$

$Mass_{portland\ cement} = 372\ lbs$

$Mass_{F\ ash} = 124\ lbs$

$Mass_{silica\ fume} = 46.5\ lbs$

$Mass_{lime} = 77.5\ lbs$

$\boldsymbol{\sum Mass_{cementitious} = cm = 620\ lbs}$

$Volume_{portland\ cement} = \frac{372\ lbs}{3.15*62.4\ lb/ft^3} = 1.89\ ft^3$

$Volume_{F\ ash} = \frac{124\ lbs}{2.14*62.4\ lb/ft^3} = 0.929\ ft^2$

$Volume_{silica\ fume} = \frac{46.5\ lbs}{3.15*62.4\ lb/ft^3} = 0.339\ ft^3$

$Volume_{lime} = \frac{372\ lbs}{3.15*62.4\ lb/ft^3} = 0.478\ ft^3$

$\boldsymbol{\sum Volume_{cementitous} = 3.64\ ft^3}$

FIBERS

$\boldsymbol{Mass = given}$

$Mass_{micro\ fibers} = 3.10\ lbs$

$Mass_{macro\ fibers} = 4.00\ lbs$

$\boldsymbol{\sum Mass_{fibers} = 7.10\ lbs}$

$Volume_{micro\ fibers} = \frac{3.10\ lbs}{0.91*62.4\ lb/ft^3} = 0.0546\ ft^3$

$Volume_{micro\ fibers} = \frac{4.00\ lbs}{0.91*62.4\ lb/ft^3} = 0.0704\ ft^3$

$\boldsymbol{\sum Volume_{fibers} = 0.1250\ ft^3}$

AGGREGATES

$\boldsymbol{Mass(W_{SSD}) = given}$

$W_{SSD-clay\ shale\ (fine)} = 137.50\ lbs$

$W_{SSD-clay\ shale\ (crushed\ fine)} = 55.00\ lbs$

$W_{SSD-clay\ shale\ (10\ Mesh)} = 27.5\ lbs$

$W_{SSD-foamed\ glass\ (0.1-0.3)} = 110\ lbs$

$W_{SSD-foamed\ glass\ (0.25-0.5)} = 82.5\ lbs$

$W_{SSD-foamed\ glass\ (0.5-1.0)} = 137.5\ lbs$

$\boldsymbol{\sum W_{SSD-aggregates} = cm = 550\ lbs}$

$Volume_{clay\ shale\ (fine)} = \frac{137.50\ lbs}{0.854*62.4\ lb/ft^3} = 2.580\ ft^3$

$Volume_{clay\ shale\ (crushed\ fines)} = \frac{55.00\ lbs}{0.845*62.4\ lb/ft^3} = 1.043\ ft^3$

$Volume_{clay\ shale\ (10\ Mesh)} = \frac{27.50\ lbs}{0.825*62.4\ lb/ft^3} = 0.534\ ft^3$

$Volume_{foamed\ glass\ (0.1-0.3)} = \frac{110\ lbs}{0.4*62.4\ lb/ft^3} = 4.407\ ft^3$

$Volume_{foamed\ glass\ (0.25-0.5)} = \frac{82.5\ lbs}{0.34*62.4\ lb/ft^3} = 3.889\ ft^3$

$Volume_{foamed\ glass\ (0.5-1.0)} = \frac{137.5\ lbs}{0.26*62.4\ lb/ft^3} = 8.475\ ft^3$

$\boldsymbol{\sum Volume_{aggregates} = 20.938\ ft^3}$

APPENDIX B: MIXTURE PROPORTIONS AND PRIMARY CALCULATIONS

$\boldsymbol{Specific\ Gravity(SG_{SSD}) = given}$

$SG_{SSD-clay\ shale\ (fine)} = 0.854$

$SG_{SSD-clay\ shale\ (crushed\ fines)} = 0.845$

$SG_{SSD-clay\ shale\ (10\ Mesh)} = 0.825$

$SG_{SSD-foamed\ glass\ (0.1-0.3)} = 0.400$

$SG_{SSD-foamed\ glass\ (0.25-0.5)} = 0.340$

$SG_{SSD-foamed\ glass\ (0.5-1.0)} = 0.260$

$\boldsymbol{Absorption\ (Abs) = given}$

$Abs_{clay\ shale\ (fine)} = 17.6\%$

$Abs_{clay\ shale\ (crused\ fines)} = 16.5\%$

$Abs_{clay\ shale\ (10\ Mesh)} = 14.3\%$

$Abs_{foamed\ glass\ (0.1-0.3)} = 35\%$

$Abs_{foamed\ glass\ (0.25-0.5)} = 28\%$

$Abs_{foamed\ glass\ (0.5-1.0)} = 20\%$

$\boldsymbol{Specific\ Gravity(SG_{OD}) = \frac{SG_{SSD(Aggregate)}}{1+Abs_{Aggregate}}}$

$SG_{OD-clay\ shale\ (fine)} = \frac{0.854}{1+0.176} = 0.726$

$SG_{OD-clay\ shale\ (crushed\ fines)} = \frac{0.845}{1+0.165} = 0.725$

$SG_{OD-clay\ shale\ (10\ Mesh)} = \frac{0.825}{1+0.143} = 0.722$

$SG_{OD-foamed\ glass\ (0.1-0.3)} = \frac{0.400}{1+0.35} = 0.296$

$SG_{OD-foamed\ glass\ (0.25-0.5)} = \frac{0.340}{1+0.28} = 0.266$

$SG_{OD-foamed\ glass\ (0.5-1.0)} = \frac{0.260}{1+0.20} = 0.217$

$\boldsymbol{Mass(W_{OD}) = Volume_{aggregate} * SG_{OD(aggregate)} * 62.4\ lb/ft^3}$

$W_{OD-clay\ shale\ (fine)} = 2.580ft^3 * 0.726 * 62.4\frac{lb}{ft^3} = 116.92\ lbs$

$W_{OD-clay\ shale\ (crushed\ fine)} = 1.043ft^3 * 0.725 * 62.4\frac{lb}{ft^3} = 47.21\ lbs$

$W_{OD-clay\ shale\ (10\ Mesh)} = 0.534ft^3 * 0.722 * 62.4\frac{lb}{ft^3} = 24.06\ lbs$

$W_{OD-foamed\ glass\ (0.1-0.3)} = 4.407ft^3 * 0.296 * 62.4\frac{lb}{ft^3} = 81.48\ lbs$

$W_{OD-foamed\ glass\ (0.25-0.5)} = 3.889ft^3 * 0.266 * 62.4\frac{lb}{ft^3} = 64.45\ lbs$

$W_{OD-foamed\ glass\ (0.5-1.0)} = 8.475ft^3 * 0.217 * 62.4\frac{lb}{ft^3} = 114.58\ lbs$

$\boldsymbol{\sum W_{OD} = 448.71\ lbs}$

Check – $\boldsymbol{Mass(W_{SSD}) = W_{OD} * (1 + Abs)}$

$W_{SSD-clay\ shale\ (fine)} = 116.92lbs * (1 + 0.176) = 110\ lbs$

$W_{SSD-clay\ shale\ (crushed\ fine)} = 46.77lbs * (1 + 0.176) = 73.33\ lbs$

$W_{SSD-clay\ shale\ (10\ Mesh)} = 23.38lbs * (1 + 0.176) = 36.67\ lbs$

$W_{SSD-foamed\ glass\ (0.1-0.3)} = 92.44lbs * (1 + 0.19) = 110\ lbs$

$W_{SSD-foamed\ glass\ (0.25-0.5)} = 69.33lbs * (1 + 0.19) = 82.5\ lbs$

$W_{SSD-foamed\ glass\ (0.5-1.0)} = 115.55lbs * (1 + 0.19) = 137.5\ lbs$

$\boldsymbol{\sum W_{SSD(aggregates)} = 550\ lbs}$

$\boldsymbol{Stock\ Moisture\ Contents\ (MC_{stk})}$

$MC_{clay\ shale\ (fine)} = 0\%$

$MC_{clay\ shale\ (crushed\ fine)} = 0\%$

$MC_{clay\ shale\ (10\ mesh)} = 0\%$

$MC_{foamed\ glass\ (0.1-0.3)} = 0.5\%$

$MC_{foamed\ glass\ (0.25-0.5)} = 0.5\%$

$MC_{foamed\ glass\ (0.5-1.0)} = 0.5\%$

$\boldsymbol{Mass\ at\ Stock\ Moisture\ \left(W_{stk(aggregate)}\right) = W_{OD(aggregate)} * \left(1 + \frac{MC_{stk}}{100\%}\right)}$

$W_{stk-clay\ shale\ (fine)} = 116.92\ lbs * \left(1 + \frac{0\%}{100\%}\right) = 116.92\ lbs$

$W_{stk-clay\ shale\ (crushed\ fine)} = 47.21\ lbs * \left(1 + \frac{0\%}{100\%}\right) = 47.21\ lbs$

$W_{stk-clay\ shale\ (10\ Mesh)} = 24.06\ lbs * \left(1 + \frac{0\%}{100\%}\right) = 24.06\ lbs$

$W_{stk-foamed\ glass\ (0.1-0.3)} = 81.48\ lbs * \left(1 + \frac{0.5\%}{100\%}\right) = 81.89\ lbs$

$W_{stk-foamed\ glass\ (0.25-0.5)} = 64.45\ lbs * \left(1 + \frac{0.5\%}{100\%}\right) = 64.77\ lbs$

$W_{stk-foamed\ glass\ (0.5-1.0)} = 114.58\ lbs * \left(1 + \frac{0.5\%}{100\%}\right) = 115.15\ lbs$

$\boldsymbol{Moisture\ Contents\ \left(MC_{free}\right) = MC_{total} - Abs}$

$MC_{free-clay\ shale\ (fine)} = 0\% - 17.6\% = -17.6\%$

$MC_{free-clay\ shale\ (crushed\ fine)} = 0\% - 16.5\% = -16.5\%$

$MC_{free-clay\ shale\ (10\ mesh)} = 0\% - 14.3\% = -14.3\%$

$MC_{free-foamed\ glass\ (0.1-0.3)} = 0.5\% - 35\% = -34.5\%$

$MC_{free-foamed\ glass\ (0.25-0.5)} = 0.5\% - 28\% = -27.5\%$

$MC_{free-foamed\ glass\ (0.5-1.0)} = 0.5\% - 20\% = -19.5\%$

$\boldsymbol{Free\ water\ \left(w_{free}\right) = W_{OD} * \left(\frac{MC_{free}}{100\%}\right)}$

$w_{free-clay\ shale\ (fine)} = 116.92 lbs * \left(\frac{-17.6\%}{100\%}\right) = -20.58 lbs$

$w_{free-clay\ shale\ (crushed\ fine)} = 47.21 lbs * \left(\frac{-16.5\%}{100\%}\right) = -7.79 lbs$

$w_{free-clay\ shale\ (10\ mesh)} = 24.06 lbs * \left(\frac{-14.3\%}{100\%}\right) = -3.44 lbs$

$w_{free-foamed\ glass\ (0.1-0.3)} = 81.48 lbs * \left(\frac{-34.5\%}{100\%}\right) = -28.11 lbs$

$w_{free-foamed\ glass\ (0.25-0.5)} = 64.45 lbs * \left(\frac{-27.5\%}{100\%}\right) = -17.72 lbs$

$w_{free-foamed\ glass\ (0.5-1.0)} = 114.58 lbs * \left(\frac{-19.5\%}{100\%}\right) = -22.34 lbs$

$\boldsymbol{\sum w_{free} = -99.98\ lbs}$

APPENDIX B: MIXTURE PROPORTIONS AND PRIMARY CALCULATIONS

ADMIXTURES

$$\boldsymbol{Dosage = given}$$

$$Dosage_{AEA92} = 10.75\,\frac{fl\,oz}{cwt}$$

$$Dosage_{Plastol6400} = 5.89\,\frac{fl\,oz}{cwt}$$

$$\boldsymbol{water\ content = 1 - \%solids}$$

$$\boldsymbol{water_{admixture} = \left(Dosage\left(\frac{fl\,oz}{cwt}\right)\right) * cm * wc(\%) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * \left(\frac{lb}{1\,gal}\ of\ admixture\right)}$$

$$water_{AEA92} = \left(10.75\left(\frac{fl\,oz}{cwt}\right)\right) * 6.2 * (1 - 0.06) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * \left(\frac{8.5\,lb}{1\,gal}\right) = 4.16lbs$$

$$water_{Plastol6400} = \left(5.89\left(\frac{fl\,oz}{cwt}\right)\right) * 6.2 * (1 - 0.41) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * \left(\frac{8.8\,lb}{1\,gal}\right) = 1.48lbs$$

$$\boldsymbol{\sum water_{admixtures} = 5.64\ lbs}$$

SOLIDS

$$\boldsymbol{Mass = given}$$

$$Mass_{pigment} = 18.60\ lbs$$

$$\boldsymbol{\sum Mass_{solids} = 18.60\ lbs}$$

$$\boldsymbol{Volume = \frac{Mass}{SG*62.4\ lb/ft^3}}$$

$$Volume_{pigment} = \frac{18.60}{2.5*62.4\ lb/ft^3} = 0.119\ ft^3$$

$$\boldsymbol{\sum Volume_{solids} = 0.119\ ft^3}$$

WATER

$$\boldsymbol{water = \frac{w}{cm} * cm}$$

$$Mass_{water} = w = 0.33 * 620lbs = 204.6lbs$$

$$\boldsymbol{Volume = \frac{Mass}{SG*62.4\ lb/ft^3}}$$

$$Volume_{water} = \frac{204.6lbs}{1*62.4lb/ft^3} = 3.28ft^3$$

$$\boldsymbol{Batch\ Water\ (w_{batch}) = w - (\sum w_{free} + \sum w_{admix})}$$

$$w_{batch} = 204.6\ lbs - (-99.98lbs + 5.64lbs) = 298.94\ lbs$$

CONCRETE ANALYSIS

$$\sum Mass = Mass_{concrete} = 1400.3\ lbs$$

$$\sum Volume = Volume_{concrete} = 28.09\ ft^3$$

$$Theoretical\ Density\ (T) = 49.85\ lb/ft^3$$

$$Anticipated\ Density\ (D) = 51.86\ lb/ft^2$$

Air Content

$$Air\ Content = \frac{|T-D|}{T} * 100\% = \frac{49.85-51.86}{49.85} * 100\% = -4.03\%$$

$$Air\ Content = \frac{27-\sum Vol}{27} * 100\% = \frac{27-28.09}{27} * 100\% = -4.03\%$$

Cement/cementitious ratio

$$\frac{c}{cm} = \frac{372}{620} = 0.6$$

Water/cementitious ratio

$$\frac{w}{cm} = \frac{204.6}{620} = 0.33$$

Water/cement ratio

$$\frac{w}{c} = \frac{204.6}{372} = 0.55$$

AGGREGATE RATIO CHECK

$$Total\ Aggregate\ Ratio = \frac{V_{aggSSD}}{27} * 100\% = \frac{20.928}{27} * 100\% = 77.51\% > 30\%\ (OK!)$$

$$C330 + RCARatio = \frac{V_{C330+RCA}}{V_{agg,SSD}} * 100\% = \frac{20.928}{20.928} * 100\% = 100\% > 50\%\ (OK!)$$

SLUMP

Measured to be 1/8 in

APPENDIX C: STRUCTURAL & FREEBOARD CALCULATIONS

BENDING MOMENTS

SUMMARY OF VARIABLES			
Variable	**Description**	**Value**	**Units**
L	Length of the canoe	20	ft
L_{cg}	Length from stern to canoe's center of gravity	10.16	ft
L_{cb}	Length from stern to canoe's center of buoyancy	10.16	ft
P_F	Weight of 1 female paddler	130	lb
P_M	Weight of 1 male paddler	190	lb
R_b	Support reaction at bow when simply supported	100.61	lb
R_s	Support reaction at stern when simply supported	97.58	lb
W_{buoy}	Buoyancy force acting on canoe	$Varies$	lb
W_c	Total weight of the canoe	198.20	lb
w_{buoy}	Buoyancy force as a distributed load	$Varies$	lb/ft
w_c	Weight of canoe as a distributed load	$Varies$	lb/ft
x	Variable length from stern	$Varies$	ft
γ_{bulk}	Unit weight of the bulkhead	1.50	pcf
γ_{conc}	Unit weight of the concrete, averaged	66.12	pcf
γ_1	Unit weight of aesthetic layers of concrete	66.39	pcf
γ_2	Unit weight of structural layer of concrete	65.59	pcf

Givens and Assumptions

1. The length of the canoe, L, is 20 ft.
2. The location of the center of mass of the canoe, L_{cg}, is assumed to be 10.17 ft away from the stern.
3. Bulkheads begin at the stern and bow and extend 3 $feet$ into the canoe interior.
4. The unit weight of the concrete w_{conc}, is assumed to be 66.12 lb/ft^3.
5. The total weight of the canoe, W_c, is assumed to be 198.20 lb.
6. The weight of each female paddler, P_F, is assumed to be 130 lb.
7. The weight of each male paddler, P_M, is assumed to be 200 lb.
8. The paddlers are placed at 20% increments relative to the full length of the canoe.
9. The self-weight of the canoe is considered as a distributed load pointing downward and is incremented in 1 in intervals.
10. The buoyancy force is considered as a distributed cubic load pointing upward, is 0 at the longitudinal ends of the canoe, and is at equilibrium with loads acting down on the canoe. It is incremented in 1 in intervals.
11. The weight of the mesh reinforcement is neglected.
12. No load factors nor factors of safety are applied.
13. The canoe is analyzed as a 2-dimensional beam parallel to the ground.

Average unit weight of concrete based on three concrete layers:

$$\gamma_{conc} = \frac{1}{3}(2 \times \gamma_1 + 1 \times \gamma_2) = \frac{1}{3}(2 * (66.39\, pcf) + 1 * (65.59\, pcf)) = 66.12\, pcf$$

Self-weight of concrete as a function of length:

$$w_c = \gamma_{conc} A_c + \gamma_{bulk} A_{bulk}$$

Note that w_c is a simplification of the true variation of canoe weight as the canoe's cross-sectional geometry varies along the boat. When performing integration to find the constants in the moment equations, the weight was approximated to be linearly changing, but it is acknowledged that this is not the case with the physical canoe.

To calculate the buoyancy force along the distance for each load case, a cubic function was developed and analyzed in MATLAB to meet three criteria for load cases when the canoe is in the water:

1. The force distribution goes to zero at the bow and stern of the canoe.
2. The buoyancy force (the integral of the force distribution) is at equilibrium with the loads acting down on the canoe.
3. The centroid of the cubic function is at the location of the center of gravity.

The buoyancy force as a function of distance from the stern to some length x ft on the boat is as follows:

$$w_{buoy} = ax^3 + bx^2 + cx + d$$

$$\int w_{buoy} dx = \frac{1}{4}ax^4 + \frac{1}{3}bx^3 + \frac{1}{2}cx^2 + dx + e$$

$$L_{cb} W_{buoy} = \int x * w_{buoy} dx = \frac{1}{5}ax^5 + \frac{1}{4}bx^4 + \frac{1}{3}cx^3 + \frac{1}{2}dx^2 + ex + f$$

1. $w_{buoy}(0) = 0 = d$
   $w_{buoy}(20) = 0 = a(20)^3 + b(20)^2 + c(20)$
2. $\sum F_{down} = \sum P + W_c = \frac{1}{4}a(20)^4 + \frac{1}{3}b(20)^3 + \frac{1}{2}c(20)^2$
   a. Constant e is known to be 0 as the buoyancy force when $x = 0$ is 0.
3. $L_{cg} * \sum F_{down} = L_{cg} * (\sum P + W_c) = L_{cb} W_{buoy} = \frac{1}{5}a(20)^5 + \frac{1}{4}b(20)^4 + \frac{1}{3}c(20)^3$
   a. Constant f is known to be 0 as the buoyancy force when $x = 0$ is 0.

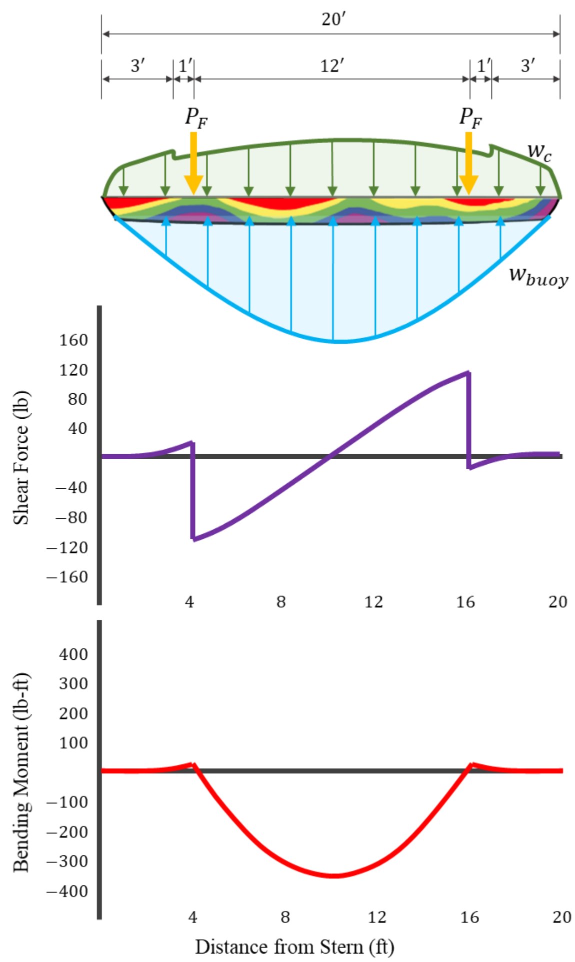
Shear and moment are calculated in MATLAB through spline interpolation with descriptive equations produced by hand as shown below. To calculate the constants in the moment equations, the equations were set to known conditions of the segments based on MATLAB outputs. Example calculations are shown in ***Case 1***. As the self-weight of the canoe is non-uniform, the calculated constants are approximations for the sections. For consistency in the calculation process, the midpoint of each segment was selected with the exception of the end sections. The use of the MATLAB program allowed for the calculation of maximum and minimum bending moments which otherwise can be solved for using cuts at the respective longitudinal locations along the canoe.

APPENDIX C: STRUCTURAL & FREEBOARD CALCULATIONS

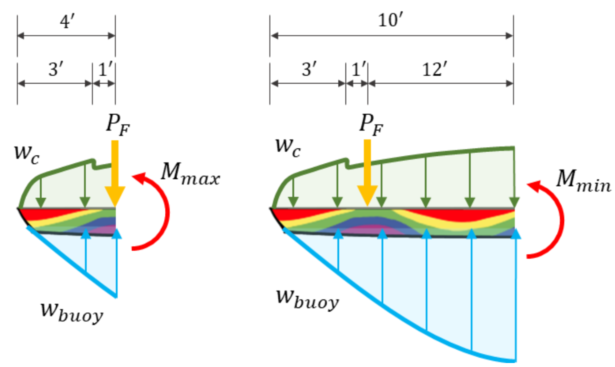
SUMMARY OF MOMENTS				
Load Case	Maximum Positive Bending Moment		Maximum Negative Bending Moment	
	x (ft)	Value (lb-ft)	x (ft)	Value (lb-ft)
1	4.00	10.76	10.00	361.98
2	4.00	28.04	10.00	496.98
3	8.00	71.77	10.00	29.48
4	10.08	549.94	N/A	N/A

CASE 1: FEMALE TANDEM

$$w_{buoy} = -0.0029x^3 - 0.258x^2 + 6.299x$$



SUMMARY OF EQUATIONS		
Segment (ft)	$V(x)$ (lb)	$M(x) = \int V(x)dx$ (lb-ft)
$0 < x < 3$	$-\int_0^x w_c dx - 0.0029x^3 - 0.258x^2 + 6.299x$	$-\int_0^x x * w_c dx - 0.0007x^4 - 0.086x^3 + 3.150x^2$
$3 < x < 4$	$-\int_0^x w_c dx - 0.0029x^3 - 0.258x^2 + 6.299x$	$-\int_0^x x * w_c dx - 0.0007x^4 - 0.086x^3 + 3.150x^2 + 15.75$
$4 < x < 16$	$-\int_0^x w_c dx - 130 - 0.0029x^3 - 0.258x^2 + 6.299x$	$-\int_0^x x * w_c dx - 130x - 0.0007x^4 - 0.086x^3 + 3.150x^2 + 1200.6$
$16 < x < 17$	$-\int_0^x w_c dx - 260 - 0.0029x^3 - 0.258x^2 + 6.299x$	$-\int_0^x x * w_c dx - 260x - 0.0007x^4 - 0.086x^3 + 3.150x^2 + 5278.5$
$17 < x < 20$	$-\int_0^x w_c dx - 260 - 0.0029x^3 - 0.258x^2 + 6.299x$	$-\int_0^x x * w_c dx - 260x - 0.0007x^4 - 0.086x^3 + 3.150x^2 + 6726.2$



$$M_{max} = M(4) = 10.76\ lb\text{-}ft \quad M_{min} = M(10) = -361.98\ lb\text{-}ft$$

Moment for segment $0 < x < 3$:

$M(0) = -\frac{1}{2}w_c(0)^2 - 0.0007(0)^4 - 0.086(0)^3 + 3.150(0)^2 + C = 0$ $\qquad C = 0$

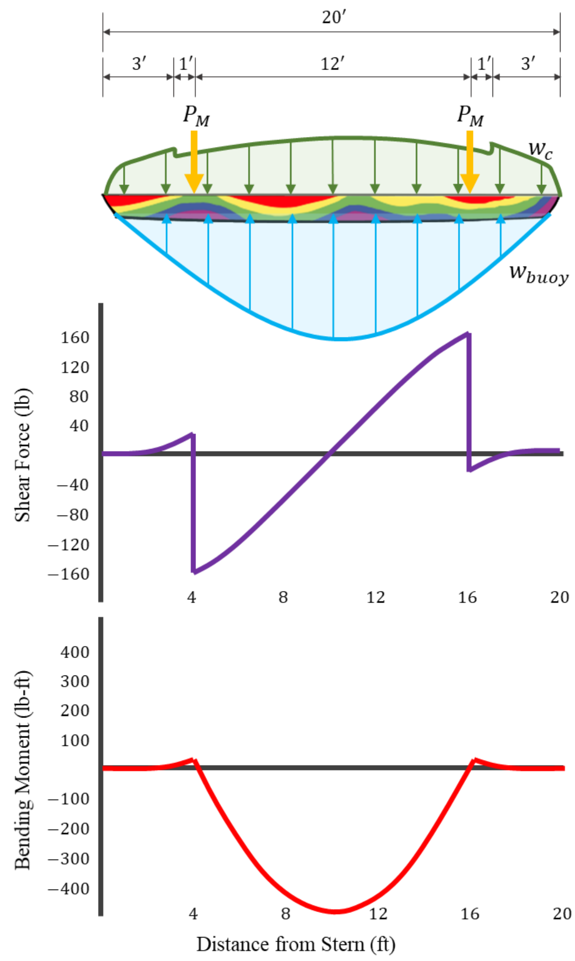
Moment for segment $3 < x < 4$:

$M(3.5) = -\frac{1}{2}w_c(3.5)^2 - 0.0007(3.5)^4 - 0.086(3.5)^3 + 3.150(3.5)^2 + C = 14.287$ $\qquad C = 15.75$

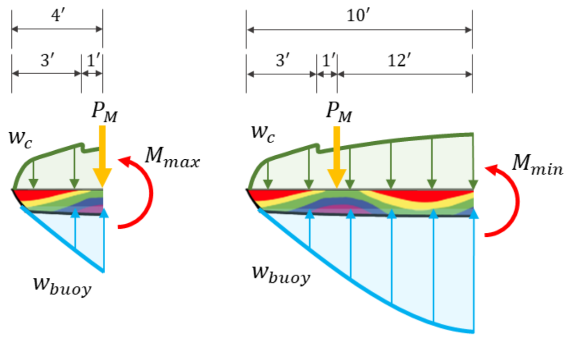
Note: $\frac{1}{2}W_c(3.5\,) = \frac{1}{2}26.43 * 4 = 52.86$

CASE 2: MALE TANDEM

$w_{buoy} = -0.0036x^3 - 0.325x^2 + 7.949x$



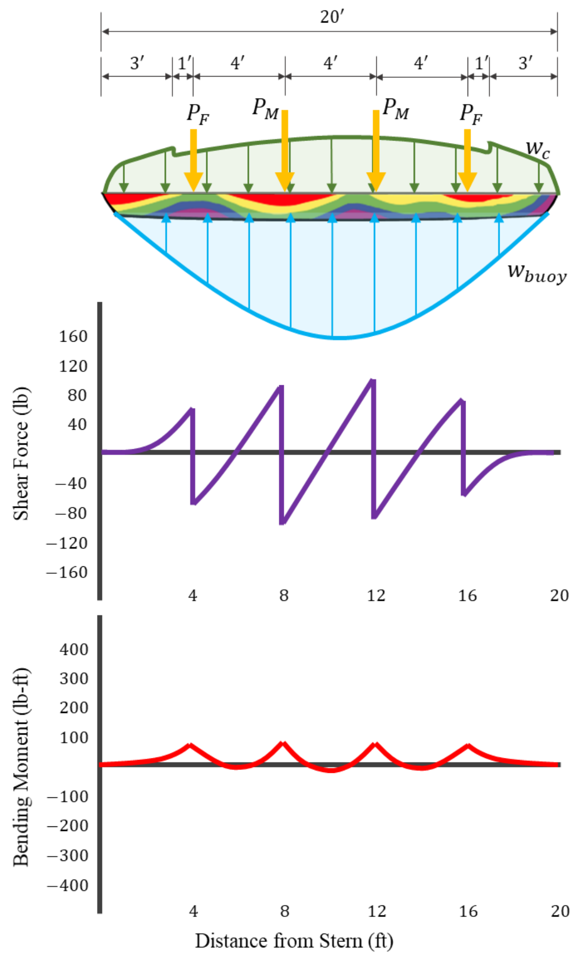
SUMMARY OF EQUATIONS		
Segment (ft)	$\boldsymbol{V(x)}$ **(lb)**	$\boldsymbol{M(x) = \int V(x)dx}$ **(lb-ft)**
$0 < x < 3$	$-\int_0^x w_c dx - 0.0036x^3 - 0.325x^2 + 7.949x$	$-\int_0^x x * w_c dx - 0.0009x^4 - 0.108x^3 + 3.974x^2$
$3 < x < 4$	$-\int_0^x w_c dx - 0.0036x^3 - 0.325x^2 + 7.949x$	$-\int_0^x x * w_c dx - 0.0009x^4 - 0.108x^3 + 3.974x^2 + 18.36$
$4 < x < 16$	$-\int_0^x w_c dx - 190 - 0.0036x^3 - 0.325x^2 + 7.949x$	$-\int_0^x x * w_c dx - 190x - 0.0009x^4 - 0.108x^3 + 3.974x^2 + 1607.2$
$16 < x < 17$	$-\int_0^x w_c dx - 380 - 0.0036x^3 - 0.325x^2 + 7.949x$	$-\int_0^x x * w_c dx - 380x - 0.0009x^4 - 0.108x^3 + 3.974x^2 + 7162.2$
$17 < x < 20$	$-\int_0^x w_c dx - 380 - 0.0036x^3 - 0.325x^2 + 7.949x$	$-\int_0^x x * w_c dx - 380x - 0.0009x^4 - 0.108x^3 + 3.974x^2 + 9002.8$



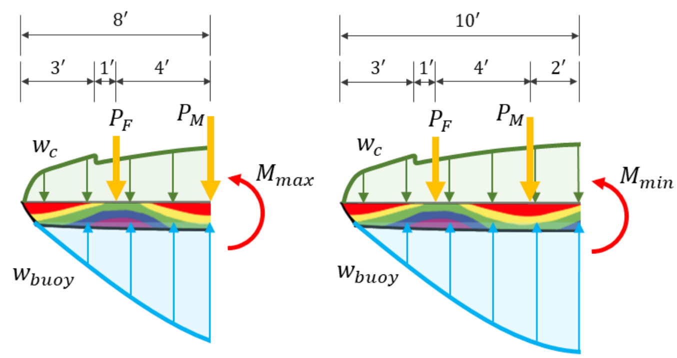
$\boldsymbol{M_{max} = M(4) = 28.04\ lb\text{-}ft} \qquad \boldsymbol{M_{min} = M(10) = -496.98\ lb\text{-}ft}$

CASE 3: FOUR PERSON CO-ED

$$w_{buoy} = -0.0052x^3 - 0.471x^2 + 11.52x$$



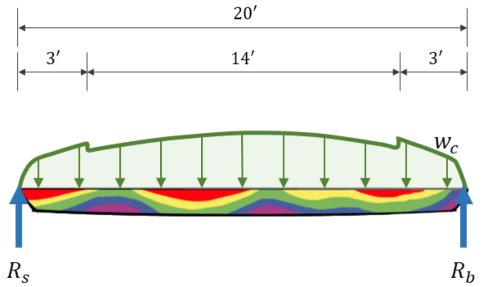
SUMMARY OF EQUATIONS		
Segment (ft)	$\boldsymbol{V(x)}$ **(lb)**	$\boldsymbol{M(x) = \int V(x)dx}$ **(lb-ft)**
$0 < x < 3$	$-\int_0^x w_c dx - 0.0052x^3 - 0.471x^2 + 11.52x$	$-\int_0^x x * w_c dx - 0.0013x^4 - 0.157x^3 + 5.762x^2$
$3 < x < 4$	$-\int_0^x w_c dx - 0.0052x^3 - 0.471x^2 + 11.52x$	$-\int_0^x x * w_c dx - 0.0013x^4 - 0.157x^3 + 5.762x^2 + 24.07$
$4 < x < 8$	$-\int_0^x w_c dx - 130 - 0.0052x^3 - 0.471x^2 + 11.52x$	$-\int_0^x x * w_c dx - 130x - 0.0013x^4 - 0.157x^3 + 5.762x^2 + 746.77$
$8 < x < 12$	$-\int_0^x w_c dx - 320 - 0.0052x^3 - 0.471x^2 + 11.52x$	$-\int_0^x x * w_c dx - 320x - 0.0013x^4 - 0.157x^3 + 5.762x^2 + 3248.8$
$12 < x < 16$	$-\int_0^x w_c dx - 510 - 0.0052x^3 - 0.471x^2 + 11.52x$	$-\int_0^x x * w_c dx - 510x - 0.0013x^4 - 0.157x^3 + 5.762x^2 + 7487.0$
$16 < x < 17$	$-\int_0^x w_c dx - 640 - 0.0052x^3 - 0.471x^2 + 11.52x$	$-\int_0^x x * w_c dx - 640x - 0.0013x^4 - 0.157x^3 + 5.762x^2 + 11240$
$17 < x < 20$	$-\int_0^x w_c dx - 640 - 0.0052x^3 - 0.471x^2 + 11.52x$	$-\int_0^x x * w_c dx - 640x - 0.0013x^4 - 0.157x^3 + 5.762x^2 + 13942$



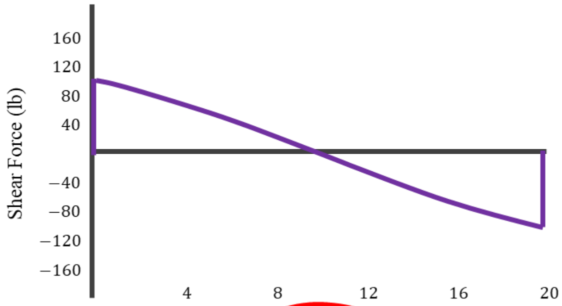
$\boldsymbol{M_{max} = M(8) = 71.77\ lb\text{-}ft}$ $\boldsymbol{M_{min} = M(10) = -29.48\ lb\text{-}f}$

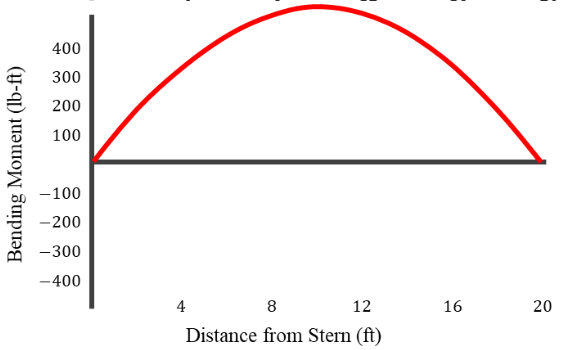
CASE 4: SIMPLY SUPPORTED CANOE RIGHT SIDE UP AND CANOE UPSIDE DOWN

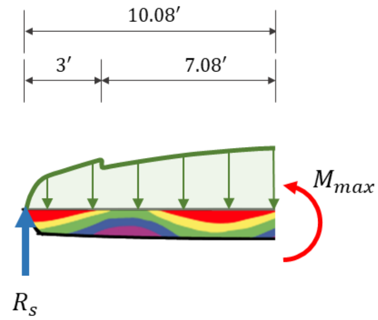
The simply supported canoe models the boat as it is being displayed or carried. As the canoe is being modeled as a simply supported beam, the distribution of forces and thus the bending moment are both the same along the length for the two cases.



SUMMARY OF EQUATIONS		
Segment (ft)	$\boldsymbol{V(x)}$ **(lb)**	$\boldsymbol{M(x) = \int V(x)dx}$ **(lb-ft)**
$0 < x < 3$	$83.11 - \int_0^x w_c dx$	$83.11x - \int_0^x x * w_c dx$
$3 < x < 17$	$83.11 - \int_0^x w_c dx$	$83.11x - \int_0^x x * w_c dx + 58.37$
$17 < x < 20$	$83.11 - \int_0^x w_c dx$	$83.11x - \int_0^x x * w_c dx + 30.29$







$$\boldsymbol{M_{max} = M(10.08) = 549.94\ lb\text{-}ft}$$

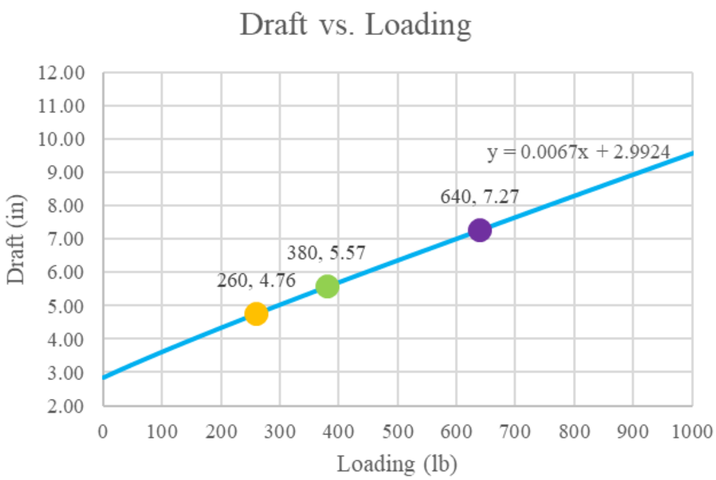
As the bending moment for this load case is always positive, there is no minimum negative moment present

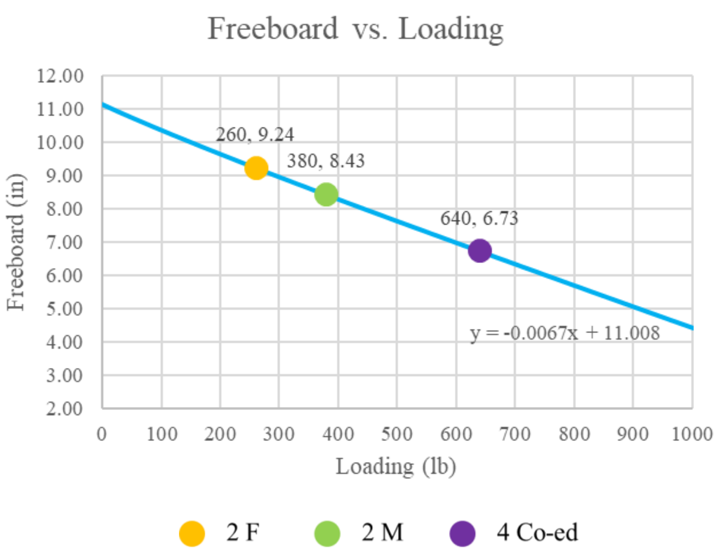
APPENDIX C: STRUCTURAL & FREEBOARD CALCULATIONS

FREEBOARD CALCULATION

DELFTship™ was used to generate draft values for different loading conditions. The table presented shows the draft and freeboard based on loadings of 50 lb intervals for brevity, but calculations were performed in 10 lb intervals.

$$Freeboard = Max.Height\ (14\ in) - Draft$$





WATERLINE VS LOADING		
Weight (lb)	**Draft (in)**	**Freeboard (in)**
0	2.844	11.156
50	3.241	10.759
100	3.619	10.381
150	3.984	10.016
200	4.341	9.659
250	4.691	9.309
260	***4.760***	***9.240***
300	5.034	8.966
350	5.372	8.628
380	***5.573***	***8.427***
400	5.706	8.294
450	6.037	7.963
500	6.365	7.635
600	7.015	6.985
640	***7.274***	***6.726***
650	7.339	6.661
700	7.662	6.338
750	7.983	6.017
800	8.304	5.696
850	8.624	5.376
900	8.943	5.057
950	9.261	4.739
1000	9.578	4.422

APPENDIX D: HULL THICKNESS/REINFORCEMENT AND PERCENT OPEN AREA CALCULATIONS

REINFORCEMENT CALCULATIONS

Canoe Hull Thickness:

Carbon Fiber Mesh reinforcement (2 layers): $2(0.26\ in) = 0.052\ in$

Hull Thickness: $2(0.25\ in) = 0.75\ in = \frac{3}{4} in$

Wall Thickness (total): $0.75\ in + 0.052\ in = 0.802\ in$

Hull Thickness Ratio:
Percent of hull thickness composed of carbon fiber mesh reinforcement layers:

$$\left(\frac{0.052\ in}{0.802\ in}\right) \times 100 = 6.48\%$$

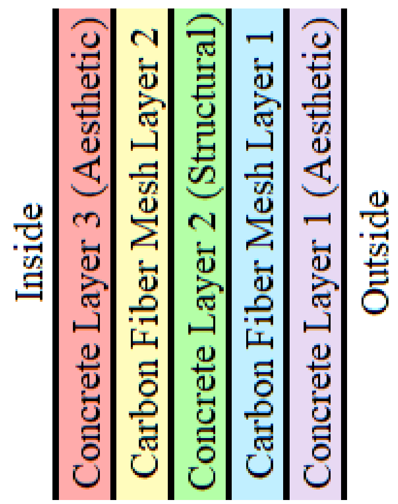
$$\boldsymbol{6.48\% < 50\%\ acceptable\ ratio}$$

Bulkhead:
Percent of bulkhead thickness composed of carbon fiber mesh reinforcement layers:

$$\left(\frac{0.052\ in}{0.802\ in}\right) \times 100 = 6.48\%$$

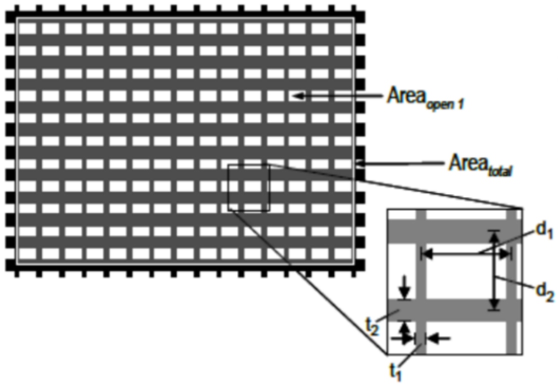
$$\boldsymbol{6.48\% < 50\%\ acceptable\ ratio}$$

CROSS SECTIONAL LAYER VIEW



APPENDIX D: HULL THICKNESS/REINFORCEMENT AND PERCENT OPEN AREA CALCULATIONS

PERCENT OPEN AREA CALCULATIONS



Annotation:

n_1: Number of apertures along sample length
n_2: Number of apertures along sample width
d_1: Spacing of reinforcing (center-to-center) along the sample length
d_2: Spacing of reinforcing (center-to-center) along the sample width
t_1: Thickness of reinforcing along sample length
t_2: Thickness of reinforcing along sample width

Equations:

$$d_1 = aperture\ length\ dimension + 2\left(\frac{t_1}{2}\right)$$
$$d_2 = aperture\ width\ dimension + 2\left(\frac{t_2}{2}\right)$$
$$Length_{sample} = n_1 d_1$$
$$Width_{sample} = n_2 d_2$$
$$\sum Area_{open} = n_1 * n_2 * Area_{open}$$
$$Area_{total} = Length_{sample}\left(Width_{sample}\right)$$
$$\%\ Open\ Area = \frac{Area_{open}}{Area_{total}} \times 100$$

Carbon Fiber Mesh:

$t_1 = 1.0\ mm \quad t_2 = 1.5\ mm$
$d_1 = 2.5\ mm + 2\left(\frac{1.0\ mm}{2}\right) = 3.5\ mm$
$d_2 = 2.0\ mm + 2\left(\frac{1.5\ mm}{2}\right) = 3.5\ mm$

$$Length_{sample} = 15(3.5\ mm) = 52.5\ mm$$
$$Width_{sample} = 11(3.5\ mm) = 38.5\ mm$$
$$\sum Area_{open} = (15)(11)(5mm^2) = 825\ mm^2$$
$$Area_{total} = 52.5\ mm(38.5\ mm) = 2021.25\ mm^2$$
$$\%\ Open\ Area = \frac{825\ mm^2}{2021.25\ mm^2} \times 100\% = 40.82\% > 40\%(\boldsymbol{OK}!)$$

APPENDIX E: DETAILED FEE ESTIMATE

ITEMIZED FEE SUMMARY SHEET

BILL OF MATERIALS				
Material	**Quantity**	**Units**	**Unit Price**	**Total**
Cementitious Materials				
Ordinary Portland Cement	103.878	lbs	$0.09	$9.39
Class F Fly Ash	34.626	lbs	$0.07	$2.58
Type S Hydrated Lime	21.634	lbs	$0.26	$5.61
Silica Fume	12.992	lbs	$0.85	$11.01
Aggregates				
Clay Shale (Fines)	36.152	lbs	$0.05	$1.81
Clay Shale (Crushed Fines)	16.866	lbs	$0.05	$0.84
Clay Shale (10 Mesh)	16.129	lbs	$0.05	$0.81
AGSCO® 0.1-0.3mm	30.740	lbs	$1.00	$30.74
AGSCO® 0.25-0.5mm	23.026	lbs	$1.00	$23.03
AGSCO® 0.5-1.0mm	38.396	lbs	$1.00	$38.40
Admixtures				
AEA-92	0.1454	gal	$5.33	$0.77
Plastol 6400	0.0797	gal	$24.31	$1.94
Non-Carbonated Water	10.450	gal	$0.03	$0.31
Solids				
Direct Colors Pigment	3.690	lbs	$7.59	$28.01
Concrete Fibers				
Grace MicroFiber™	0.870	lbs	$10.98	$9.55
Tuf-Strand Maxten	1.102	lbs	$5.58	$6.15
Reinforcement				
Carbon Fiber Mesh	165	sq ft	$6.32	$1,042.80
Finishing				
Vinyl Lettering	Lump Sum		$130.00	$130.00
Everclear 350	1.000	gal	$35.77	$35.77
Styrofoam	1.05	cu ft	$25.00	$26.25
Total				**$1,405.76**

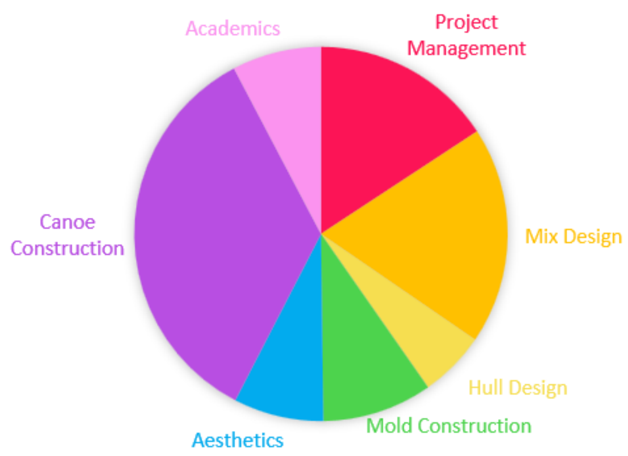
MOLD CONSTRUCTION			
Material	**Quantity**	**Unit Price**	**Total**
Foam Mold	Lump Sum	$710.88	$710.88
Total			**$710.88**

TRANSPORTATION FROM TEMPE, AZ TO RUSTON, LA			
Material	**Quantity**	**Unit Price**	**Total**
Shipping (Gas, Labor, Lodging)	Lump Sum	$2,006.38	$2,006.38
Total			**$2,006.38**

BILL OF LABOR (BY POSITION)			
Job Description	**Total Hours**	**Unit Price**	**Total**
Principal Design Engineer	317	$50	$15,850.00
Design Manager	53	$45	$2,385.00
Project Construction Manager	52	$40	$2,080.00
Construction Superintendent	34	$40	$1,360.00
Project Design Engineer	28	$35	$980.00
Quality Manager	45	$35	$1,575.00
Graduate Field Engineer (EIT)	50	$25	$1,250.00
Technician/Drafter	24	$20	$480.00
Laborer/Technician	903	$25	$22,575.00
Clerk/Office Admin	48	$15	$720.00
Total			**$49,255.00**

BILL OF LABOR (BY DISCIPLINE)			
Discipline	**Total Hours**	**Unit Price**	**Total**
Project Management	245	Varies	$10,267.00
Mix Design	292	Varies	$12,363.13
Hull Design	89	Varies	$1,791.00
Mold Construction	148	Varies	$4,610.25
Aesthetics	121	Varies	$2,349.00
Canoe Construction	539	Varies	$16,721.63
Academics	20	Varies	$1,153.00
Total			**$49,255.00**

Person Hour Distribution 2021-2022 (Total – 1554 Hours)



APPENDIX E: DETAILED FEE ESTIMATE

DETAILED COST ASSESSMENT

Labor Costs are calculated using the equation below where DL is Direct Labor, RLR is Raw Labor Rates provided by the Committee on Concrete Canoe Competitions, and HRS is the total hours spent on the project. The multipliers in the following equation are Direct Employee Costs (DEC), and Indirect Employee Costs (IEC) as well as Profit (P). The DEC provided by the Committee is 1.50 which includes employee taxes, benefits, insurance, and vacation. The IEC is 1.30, also provided by the committee is 1.30 which includes project expenses and other costs not related to the employees (like vehicle use). The Profit applied is 18%. Using the data from the Bill of Labor tables, the following Direct Labor was calculated.6+

$$DL = [\sum(RLR * HRS)] * (DEC + IEC) * (1 + P)$$
$$DL = \$49{,}255.00 * (1.50 + 1.30) * (1 + 0.18)$$
$$\boldsymbol{DL} = \$\mathbf{162{,}738.52}$$

The total expenses of this project are calculated using the material costs (MC), the direct expenses (DE), and a markup (M). The material includes all materials of the canoe, mold construction costs, and transportation costs. Direct expenses include the costs of outside consultants with their rate at \$200 an hour. The total expenditure can be seen below.

$$E = (\sum MC + \sum DE) * (1 + M)$$
$$E = [(\$1{,}405.76 + \$710.88 + \$2{,}006.38) + (\$200 * 15)] * (1 + 0.10)$$
$$\boldsymbol{E} = \$\mathbf{7{,}835.32}$$

MATERIAL UNIT PRICES						
Name	**Material Classification**	**Total Price**	**Total Unit**	**Units**	**Unit Price**	**Linked URL**
Ordinary Portland Cement	Cementitious Material	\$8.50	94	lbs	\$0.09	Salt River Materials Group
Class F Fly Ash	Cementitious Material	\$6.25	84	lbs	\$0.07	Salt River Materials Group
Type S Hydrated Lime	Cementitious Material	\$12.97	50	lbs	\$0.26	Home Depot
Silica Fume	Cementitious Material	\$21.18	25	lbs	\$0.85	Euclid Chemical
Clay Shale (Fines)	Recycled Aggregate	\$5.00	100	lbs	\$0.05	Utelite
Clay Shale (Crushed Fines)	Recycled Aggregate	\$5.00	100	lbs	\$0.05	Utelite
Clay Shale (10 Mesh)	Recycled Aggregate	\$5.00	100	lbs	\$0.05	Utelite
AGSCO® 0.1-0.3mm	Recycled Aggregate	\$40.00	40	lbs	\$1.00	AGSCO®
AGSCO® 0.25-0.5mm	Recycled Aggregate	\$27.00	27	lbs	\$1.00	AGSCO®
AGSCO® 0.5-1.0mm	Recycled Aggregate	\$25.00	25	lbs	\$1.00	AGSCO®
Tuf-Srand Maxten	Macro-Fibers	\$5.58	1	lbs	\$5.58	Euclid Chemical
Direct Colors Pigment	Powered Pigment	\$37.95	5	lbs	\$7.59	Direct Colors
AEA-92	Admixture	\$5.33	1	gal	\$5.33	Euclid Chemical
Plastol 6400	Admixture	\$24.31	1	gal	\$24.31	Euclid Chemical
Everclear 350	Sealing Compound	\$35.77	1	gal	\$35.77	Euclid Chemical

Pre-Qualification Form (Page 1)

Arizona State University
(school name)

We acknowledge that we have read the 2022 ASCE Society-wide Concrete Canoe Competition Request for Proposal and understand the following (*initialed by team project manager and ASCE Faculty Advisor*):

The requirements of all teams to qualify as a participant in the ASCE Student Symposium and Society-wide Competitions as outlined in Section 3.0 and Exhibit 3.

The eligibility requirements of registered participants (Section 3.0 and Exhibit 3)

The deadline for the submission of *Letter of Intent, Preliminary Project Delivery Schedule* and *Pre-Qualification Form* (uploaded to ASCE server) is November 5, 2021; 5:00 p.m. Eastern

The last day to submit *ASCE Student Chapter Annual Reports* to be eligible for qualifying (so that they may be graded) is February 1, 2022

The last day to submit *Request for Information* (RFI) to the C4 is January 22, 2022

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

The submission date of *Project Proposal*, *Enhanced Focus Area Report*, and *MTDS Addendum* for the Student Symposium Competition (hard copies to Host School and uploading of electronic copies to ASCE server) is Friday, February 18, 2022.

The submission date of *Project Proposal*, *Enhanced Focus Area Report*, and *MTDS Addendum* for Society-wide Final Competition (hard copies to ASCE and uploading of uploading of electronic copies to ASCE server) is May 10, 2022; 5:00 p.m. Eastern.

Gabriella Stadler	10/29/21	Christion G. Hoover	11/1/21
Team Captain	*(date)*	*ASCE Student Chapter Faculty Advisor*	*(date)*

(signature) *(signature)*

Pre-Qualification Form (Page 2)

Arizona State University
(school name)

As of the date of issuance of this Request for Proposal, what is the status of your school / university's 2021-22 classroom instruction (in-person, remote, hybrid)? What is anticipated after Thanksgiving and winter holiday break? If in-person or hybrid, do you have access to laboratory space or other facilities outside of classes?
ASU currently has in-person classes. It is up to the discretion of the professor to have a hybrid class if a student cannot attend in-person. ASU would like to continue being in person for the rest of the school year, if possible. Masks are required in classes and lab spaces, including our Concrete Canoe lab space and are highly recommended in all buildings. ASU provides free COVID testing and encourages students/staff to STAY home if affected with/exposed to COVID-19.

In 250 words or less, provide a high-level overview of the team's Health & Safety (H&S) Program. If there is currently not one in place, what does the team envision their H&S program will entail? Include a discussion on the impact of COVID-19 on the team's ability to perform work and what plans would be implemented assuming work could be performed.
The team has been and plans to continue following the CDC's and ASU COVID-19 policies. Since ASU requires masks in lab areas, team members have been wearing masks in our lab space. When working with concrete, we wear N-95 and/or respirators to ensure we don't breathe in the harsh chemicals/dust. PPE is incredibly important when working with the dangerous materials we use; PPE we require is N-95/respirators, disposable gloves, safety goggles, long pants, and closed toed shoes. Students are not allowed to help with lab activities if proper PPE is not worn. Disposal of hazardous materials goes through ASU's Hazardous Waste Pickup. Cleaning up our lab space in USE162, was our #1 priority before we even began the project. Over the years, this room has continuingly gotten messier. Organizing our materials into Tupperware was a huge step in the right direction of ensuring we have a clean space to build a canoe for 2021-2022. To maintain this quality, we put everything back in their proper spots and we vacuum the lab area to make sure dust is maintained at a very low level.

In 150 words or less, provide a high-level overview of the team's current QA/QC Program. If there is currently not one in place, what does the team envision their QA/QC program will entail?
The current quality assurance and quality control priorities have been the mold construction and canoe removal from the mold. The team captains have held trainings prior to construction and mix design sessions. Last year, bi-weekly meetings were implemented. This year, the trainings and bi-weekly meetings are continuing to be implemented. The team meets on Saturdays every other week for updates regarding project management, mix design, hull design, aesthetics, rowing, and construction. On top of these meetings, we have a GroupMe chat as well as an email list. This allows clear communication between the captains/team and the volunteers. To ensure quality of the canoe material the team plans to do compression, tensile, flexural, and buoyancy tests on concrete samples.

Has the team reviewed the Department and/or University safety policies regarding material research, material lab testing, construction, or other applicable areas for the project?
Yes. The team leads have gotten access and the proper training for the lab areas including compression testing of concrete samples. The trainings the team leads have gone through are as follows: EHS Hazardous Waste

Pre-Qualification Form (Page 3)

__Arizona State University________________________
(school name)

Management, EHS Fire Safety Annual Training 2021 2.0, EHS Initial Laboratory Safety Training, Laboratory Safety Information and Training, and Compression Test Machine Training. These trainings have been communicated to the entire team to ensure safety.

The anticipated canoe name and overall theme is – Adventure Time is ASU's Concrete Canoe 2022 theme, and the name of the canoe is *Speedy Unicorn*.

Has this theme been discussed with the team's Faculty Advisor about potential Trademark or Copyright issues? Adventure Time is protected by the copyright and trademark law under © Cartoon Network. The usage of this cartoon does fall under Fair Use because we are using it for education purposes, and we are non-profit. To ensure we wouldn't be copyrighted, we formally asked Cartoon Network for their approval. On October 27th, 2021, Cartoon Network gave us permission to use Adventure Time as long as we don't use it for promotion or profit (*Figure 1*).

Cartoon Network Support (Cartoon Network)
Oct 27, 2021, 12:31 EDT

Thanks for reaching out. We appreciate you taking the time to contact us with a formal request.

First, we have to include the following legal response: While we love the enthusiasm and creativity of fans who create non-commercial fan art, we are committed to protecting the integrity and intellectual property rights to the characters and trademarks of Cartoon Network. For that reason, we are not granting permissions for commercial initiatives like those involved in creating and selling merchandise such as t-shirts, games, or other products featuring our intellectual property.

Now that the lawyers are satisfied: Basically, you're good-to-go as long as you don't sell it, use it to promote yourself, a business, an organization, or make money off the creation. It's awesome to hear how much our fans connect with our characters. We want you to be able to create things that express that connection and inspiration. However, we do have to make sure that we take the proper legal precautions.

When you're done with the personal project that is not going to be used for commercial purposes, sold, or to promote a business or organization, be sure to tag us if you post it on Twitter, Instagram, or Facebook. We'd love to see it... Just make sure it's brand-appropriate :^)

Figure 1: Email from Cartoon Network Support approving our theme.

The core project team is made up of __10__ number of people.


SPEEDY
UNICORN
ASCE AT ASU
ISWS 2022


SPEEDY
UNICORN
ASCE AT ASU
ISWS 2022
ENHANCED
FOCUS AREA

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ENHANCED FOCUS AREA SELECTION PROCESS

In 2021, the enhanced focus area involved the utilization of DELFTship during the hull design and structural analysis processes of the canoe as well as the development of a website dedicated to the Concrete Canoe team at ASU. The usage of DELFTship led to an improved design process and a greater understanding of the canoe shape and strength. The website provided the team, other ASU students, and curious individuals a description of the Concrete Canoe program, past reports, and the current team. It also served as a resource for potential sponsorship of ASCE at ASU's canoe team. The initial plan for 2022 was to use the website as the focus area again, updating and adding new features. Although it has served as a useful tool, using the same enhanced focus area was deemed as repetitive, adding no value for neither current nor future team members. However, the website was still updated to include the current team, the 2022 sponsors, and the 2021 report, *Sun Devil Crossing* (Figure 1).

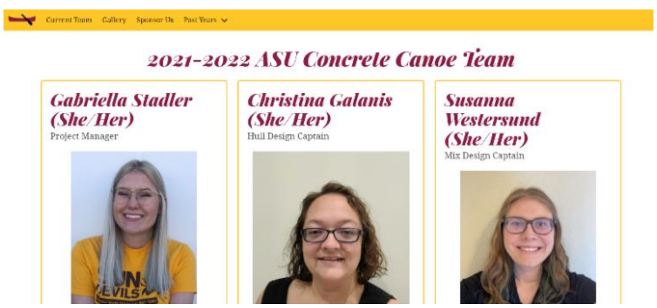

Figure 1: Concrete Canoe at ASU Website (current team tab).

When assessing pigmented concrete mixes, the wet unit weight of the concrete resulted in larger unit weights than those studied for 7-day structural tests. To determine if the unit weights would still increase without pigment, structural mixes were also assessed. As is clear in Figure 3, the 7-day sample from October had significantly more visible voids than the 28-day test sample from December. The 7-day sample was cured in a misting chamber while the 28-day sample was cured in a water-filled bucket, submerged for the entirety of curing due to complications with the misting chamber.

Figure 3: Comparison of 7-day sample (left) to 28-day sample (right).

Although the same mix was used, the 28-day samples were heavier than the 7-day samples, resulting in the former sinking underwater while curing. The team noted that the only differences in the construction process were the weather, which would have resulted in colder water being used in the mixes, and the curing method. When making the flexural samples, the team decided to mist them like the original cylinder samples due to their large size, and the complication with the curing chamber had been remedied. Once the canoe was made, the flexural samples had to be moved into a tub of water to allow the hose of the misting chamber to be used on the canoe. Shockingly, these samples floated with no changes to the mix as with the 7-day test cylinders (Figure 2). With the flexural samples floating and the 28-day cylinder samples sinking, the team was concerned about the mix of the concrete despite the selected mixes floating in October. This prompted a study of the effects of water temperature and curing methods on concrete in hopes of finding new ways to prevent the increase of the unit weight in the future.

Figure 2: Flexural samples floating in a tub of water

HOW WATER TEMPERATURE AND CURING METHODS AFFECT THE UNIT WEIGHT OF CONCRETE

ENHANCED FOCUS AREA VALUE ADDED

The intent of studying temperature and curing effects on concrete for the enhanced focus area is to provide enough research for future ASU concrete canoe teams to avoid increasing unit weight in colder months and to use the best curing method for the concrete test samples as well as the canoe after casting.

The mixes studied in this report will not include pigment. The mix compositions are listed in the Appendix. **Table 1** shows the differences in unit weights between the samples, all using the same mix types.

Table 1: Unit Weights of Concrete Mixes

Mix	Avg. Wet Unit Weight (pcf)	Avg. Dry Unit Weight (pcf)
Structural (7-day)	60.06	55.44
Aesthetics without pigment (7-day)	59.59	56.53
Structural (28-day)	68.85	65.86
Aesthetics without pigment (28-day)	71.57	68.52
Structural (flexural, 28- day)	-	60.55
Aesthetics without pigment (flexural, 28-day))	-	61.22

This enhancement will prepare the team to improve methods of developing concrete mixes, filling molds properly, and using the most appropriate curing method.

ENHANCED FOCUS AREA

After speaking with Dr. Narayanan Neithalath, an expert in materials science of concrete and the Concrete Canoe Faculty Advisor, he advised that an error occurred with the air entrainer used based on the air void difference (Figure 4). Dr. Neithalath advised that misting versus submerging methods can cause a change in unit weight, but it was unlikely that it would be the cause of a 10 pcf unit weight change; however, with the different steps involved in making a mix, it is likely that the cause of the increase was a combination of mixing, compaction, and curing variation. Many factors can affect the air content in concrete including, but not limited to, concrete temperature, mixing action, and mold compaction. Concrete temperature does affect air-entrainers; however, it does not affect the concrete as expected. According to The Constructor, a construction encyclopedia, the increase of temperature actually decreases the air content (Hamakareem). Thus, the theory that the 28-day samples had less air voids due to the cold weather does not appear to be the case.

Figure 4: Comparison of a 7-day sample (left) to a 28-day sample (right).

During mixing, air entrainment can increase due to fast rotation (Shraddhu). One of the learning curves of the mixing method used was understanding how to properly use the mixing tool, a Ridgid Drill (Figure 5). When using this type of drill, it is easy to accidentally mix too fast which may have been the cause of so many air voids in the 7-day samples as the team was unfamiliar with mix design. Although air voids are desired for lightweight concrete, it is likely that when the 28-day samples were made, the drill was used in a more controlled setting (a slower rotation) causing less air to be in the concrete.

Figure 5: Ridgid 1/2 in Spade Handle Mud Mixer Drill

Vibrative compaction is another common way to affect air in concrete. Many team members newly learned how to compact concrete correctly in the cylindrical molds. ASTM C192 states that between layers, the concrete must be rodded uniformly. The standard continues, "After rodding each layer, the outsides of the mold must be tapped lightly 10-15 times with a mallet to close any holes left by rodding." As shown in Figure 6, when learning to pack, it was common for individuals to not tap the outside of the molds enough to fill the pockets created by rods. Towards the end of creating mix samples, team members improved upon their technique; however, something that ASTM C192 does *not* state is slamming the molds on a flat surface. To fill the rod holes, tapping the mold on the ground multiple times was not uncommon within the team, especially when creating the 28-day samples. Doing this method likely caused the concrete to be too compacted, thus ridding the concrete of many air voids. As the flexural molds were much larger than the cylindrical molds, they were most likely not over compacted. Over-compacting the molds can result in inaccurate data as the actual concrete canoe is not extremely compacted. Compaction of the molds needs to be uniform for a controlled variable when testing for a mix design.

Figure 6: Test sample with rod holes.

Curing concrete is vital to prevent cracking, thus creating a strong concrete mix. The curing process involved a reaction between cement and water, which causes heat to release (Rodriguez, 2019). The two curing methods used for testing and the actual canoe were immersion and misting. Typically, immersion is done with concrete testing, especially concrete test samples, while misting is performed on bigger projects and when humidity is low. ASTM C192 recommends that all test specimens created in labs must be moist cured (meaning the specimens should always have water on the entire surface area using a storage tank or moist room). According to research by Raheem, Soyingbe, and Emenike from 2013, densities increase between 7-day cure and 28-day cure. Their research also shows an increase of concrete density between Water Submerge Curing and Spray Curing (Figure 7).

Curing method	Curing period (days)	Density (Kg/m^3)	Mean (Kg/m^3)	Range (Kg/m^3)	Standard Deviation
Water Submerged Curing	3 7 14 21 28	2459.26 2459.26 2469.14 2400.00 2518.52	2461.23	118.52	42.13
Spray Curing	3 7 14 21 28	2404.94 2439.51 2498.77 2479.01 2429.63	2450.37	93.83	38.00

Figure 7: Relationship between Curing Methods and Density of Specimens. Test results are from Amaka and Raheem (2013).

A similar research study by Amusan, Popoola, and Shittu from 2021 also shows concurring results to the 2013 study. As shown in their results in Figure 8, the average density of ponding (also known as submerging) is higher than the average densities when the concrete is wet covered (misting).

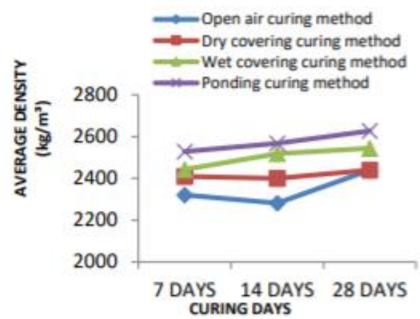

Figure 8: Density of concrete using different curing methods. Test results from Amusan, Popoola, and Shittu (2021).

These two studies reflect the results of the *Speedy Unicorn* concrete unit weights. All 7-day samples were cured through a misting chamber. These samples were misted by the hour. All 28-day cylindrical samples were cured through immersion. As discussed earlier, the flexural samples were cured with both methods. They were cured in a misting chamber for approximately 2 weeks before being submerged in water which resulted in a lighter unit weight than the 28-day samples. Graphing the results of Table 1, it is evident that submerging concrete for 28-days produces a heavier unit weight than misting for 7 days (Figure 9).

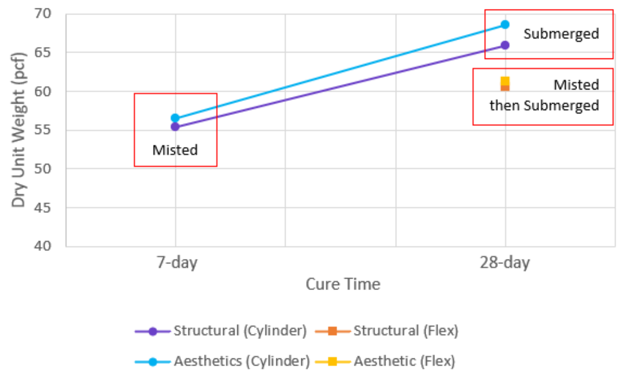

Figure 9: Graph of Speedy Unicorn's dry unit weights from Table 1.

Upon reflection, this year's team should have created the 7-day and 28-day samples on the same day to ensure all methods of mixing and filling were consistent. Same-day creation also allows quality control of measuring the materials and packing the molds. The team also should have cured the test specimens the same way so all results are uniform and anomalous data is avoided. Creating more concrete samples to test before the deadline would have ensured a uniform mix. In the future, it is advised that the teams carefully review ASTM standards when mixing, molding, and curing the concrete.

Based on the results of this study, it is evident that temperature did not affect the unit weight of the concrete samples while mixing methods, compaction methods, and curing methods did. For the future years, it is suggested that the team ensures 7-day tests and 28-day tests have the same curing method and compaction methods. It is vital that the team does not tap the cylinder samples in excess when filling the molds but does tap hard enough so no dowel holes are left in the concrete. Fortunately, Speedy Unicorn was misted for 28 days, resulting a lighter mix than if it were to be submerged. With the 28-day strength and misting technique, Speedy Unicorn is more than likely to succeed in the submerge test and in holding paddlers.

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APPENDIX: MIX DESIGNS

Mixture: Structural Mix (USED AS MIDDLE LAYER)

CEMENTITIOUS MATERIALS

Component	Specific Gravity	Volume (ft^3)	Amount of CM (lb/yd^3)	
Type II Ordinary Portland Cement	3.15	1.893	372.00	Total cm (includes c) **620.00** lb/yd^3 c/cm ratio, by mass **0.60**
Class F Fly Ash	2.14	0.929	124.00	
Silica Fume	2.20	0.339	46.50	
Type S Hydrated Lime	2.60	0.478	77.50	

FIBERS

Component	Specific Gravity	Volume (ft^3)	Amount of Fibers (lb/yd^3)	
GRACE Micro-Fibers	0.91	0.055	3.10	Total Amount of Fibers 7.10 lb/yd^3
Tuf-Strand Maxten Macro-Fibers	0.91	0.070	4.00	

AGGREGATES (EXCLUDING MINERAL FILLERS PASSING NO. 200 SIEVE)

Aggregates	Abs (%)	SG_{OD}	SG_{SSD}	Base Quantity, W (lb/yd^3)		Volume, $V_{agg, SSD}$ (ft^3)
				W_{OD}	W_{SSD}	
Clay Shale (Fines)	17.6	0.726	0.854	93.54	110.00	2.064
Clay Shale (Crushed Fines)	16.5	0.725	0.845	62.36	73.33	1.391
Clay Shale (10 Mesh)	14.3	0.722	0.825	31.18	36.67	0.712
Agsco® 0.1-0.3mm	35.0	0.296	0.400	92.44	110.00	4.402
Agsco® 0.25-0.5mm	28.0	0.266	0.340	69.33	82.50	3.889
Agsco® 0.5-1.0mm	20.0	0.217	0.260	115.55	137.50	8.475

LIQUID ADMIXTURES

Admixture	lb/US gal	Dosage (fl. oz / cwt)	% Solids	Amount of Water in Admixture (lb/yd^3)	
Euclid AEA 92	8.50	10.75	6.0	4.16	Total Water from Liquid Admixtures, $\sum w_{admx}$ 5.64 lb/yd^3
Euclid Plastol 6400	8.80	5.89	41.0	1.48	

SOLIDS (DYES POWDERED ADMIXTURES)

Component	Specific Gravity	Volume (ft^3)	Amount (lb/yd^3)	
Direct Colors Concrete Pigment	2.5	0	0	Total Solids. S_{total} 0 lb/yd^3

WATER

		Amount (lb/yd^3)	Volume (ft^3)
Water, w, $[=\sum (w_{free} + w_{admx} + w_{batch})]$	w/c ratio, by mass **0.55** w/cm ratio, by mass **0.33**	204.60	3.28
Total Free Water from All Aggregates, $\sum w_{free}$		-99.61	
Total Water from All Admixtures, $\sum w_{admx}$		5.64	
Batch Water, w_{batch}		298.57	

DENSITIES, AIR CONTENT, RATIOS, AND SLUMP

Values for 1 cy of concrete	cm	Fibers	Aggregate (SSD)	Solids, S_{total}	Water, w	Total
Mass, M	620 lbs	7.10 lbs	550 lbs	0 lb	204.6 lbs	$\sum M$: 1381.70 lbs
Absolute Volume, V	3.64 ft^3	0.13 ft^3	20.94 ft^3	0 ft^3	3.28 ft^3	$\sum V$: 27.98 ft^3
Theoretical Density, T, $(=\sum M / \sum V)$	49.38 lb/ft^3		Air Content, Air, $[= (T - D)/T \times 100\%]$			-3.62%
Anticipated Density, D	51.17 lb/ft^3		Air Content, Air, $[= (27 - \sum V))/27 \times 100\%]$			-3.62%
Total Aggregate Ratio $(=V_{agg,SSD} / 27)$	77.55%		Slump, Slump flow, Spread (as applicable)			1/8 in
C330 + RCA Ratio $(=V_{C330+RCA} / V_{agg})$	100%					

APPENDIX: MIX DESIGNS

Mixture: Aesthetic Mix (WITHOUT PIGMENT)

Cementitious Materials

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (lb/yd^3)*	
Type II Ordinary Portland Cement	3.15	1.893	372.00	Total cm (includes c) **620.00** lb/yd^3 c/cm ratio, by mass **0.6**
Class F Fly Ash	2.14	0.929	124.00	
Silica Fume	2.20	0.339	46.50	
Type S Hydrated Lime	2.60	0.478	77.50	

Fibers

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of Fibers (lb/yd^3)*	
GRACE Micro-Fibers	0.91	0.055	3.10	Total Amount of Fibers 7.10 lb/yd^3
Tuf-Strand Maxten Macro-Fibers	0.91	0.070	4.00	

Aggregates (Excluding Mineral Fillers Passing No. 200 Sieve)

Aggregates	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity, W (lb/yd^3)*		*Volume, $V_{agg, SSD}$ (ft^3)*
				W_{OD}	W_{SSD}	
Clay Shale (Fines)	17.6	0.726	0.854	116.92	137.50	2.580
Clay Shale (Crushed Fines)	16.5	0.725	0.845	46.77	55.00	1.043
Clay Shale (10 Mesh)	14.3	0.722	0.825	23.38	27.50	0.534
Agsco® 0.1-0.3mm	35.0	0.296	0.400	92.44	110.00	4.402
Agsco® 0.25-0.5mm	28.0	0.266	0.340	69.33	82.50	3.889
Agsco® 0.5-1.0mm	20.0	0.217	0.260	115.55	137.5	8.475

Liquid Admixtures

Admixture	*lb/US gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
Euclid AEA 92	8.50	10.75	6.0	4.16	Total Water from Liquid Admixtures, $\sum w_{admx}$ 5.64 lb/yd^3
Euclid Plastol 6400	8.80	5.89	41.0	1.48	

Solids (Dyes Powdered Admixtures)

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (lb/yd^3)*	
Direct Colors Concrete Pigment	2.5	0	0	Total Solids. S_{total} 0 lb/yd^3

Water

		Amount (lb/yd^3)	*Volume (ft^3)*
Water, *w, [$=\sum (w_{free} + w_{admx} + w_{batch})$]*	w/c ratio, by mass **0.55** w/cm ratio, by mass **0.33**	204.60	3.28
Total Free Water from All Aggregates, *$\sum w_{free}$*		-99.98	
Total Water from All Admixtures, *$\sum w_{admx}$*		5.64	
Batch Water, *w_{batch}*		298.94	

Densities, Air Content, Ratios, and Slump

Values for 1 cy of concrete	*cm*	*Fibers*	*Aggregate (SSD)*	*Solids, S_{total}*	*Water, w*	*Total*
Mass, *M*	620 lb	7.10 lb	550 lb	0 lb	204.60 lb	$\sum M$: 1381.70 lb
Absolute Volume, *V*	3.638 ft^3	0.125 ft^3	23.286 ft^3	0 ft^3	3.28 ft^3	$\sum V$: 27.97 ft^3
Theoretical Density, *T, ($=\sum M / \sum V$)*	49.40 lb/ft^3		***Air Content, Air,*** *[= (T – D)/T x 100%]*			-3.58%
Anticipated Density, *D*	51.17 lb/ft^3		***Air Content, Air,*** *[= (27 – $\sum V$))/27 x 100%]*			-4%
Total Aggregate Ratio *($=V_{agg,SSD} / 27$)*	77.51%		***Slump, Slump flow, Spread*** *(as applicable)*			1/8 in
C330 + RCA Ratio *($=V_{C330+RCA} / V_{agg}$)*	100%					


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