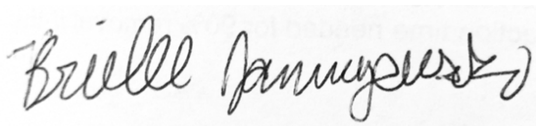
Technical Proposal

Cover Letter and Project Understanding

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

1. The design and construction of the canoe has been performed in full compliance with the specifications outlined in the *Request for Proposal*.
2. The team acknowledges that Material Technical Data Sheets (MTDS) and Safety Data Sheets (SDS) have been reviewed by the team, and the team acknowledges receipt of the *Request for Information* (RFI) Summary and that their entry complies with responses provided.
3. The anticipated registered participants are qualified student members and National Student Members of ASCE and meet all eligibility requirements.

Registered Participants and ASCE Member ID Numbers			
Edward Apraku	11175672	**Brielle Januszewski**	11307130
Jay Depler	11951281	**Jared Kahler**	11854267
Tyler Dolyniuk	1195138	**Peter Nguyen**	11951429
Shaela Hogue	11805382	**Valentina Rivera**	11933914
Camila Ibarra	11853937	**Katie Sinclair**	11951361



Brielle Januszewski – Project Manager
bjanusze@asu.edu
602-814-3054

Kristen Ward – Faculty Advisor
kmward6@asu.edu
480-965-5623

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Executive Summary

On August 25, 1916, President Woodrow Wilson signed the National Park Service Organic Act into law, thus establishing the National Park Service (NPS) (National Park Service, 2018). The mission of the NPS is to conserve landscapes to "provide for the enjoyment of the same in such a manner and by such of future generations" (History.com Editors, 2018). Similarly, this year's team aimed to preserve the history of past canoes while leaving future years a stable footing upon which to succeed. Thus, this year's canoe is named *Legacy* to acknowledge the legacy that has been passed down through the years and to symbolize the legacy that this team leaves behind, just like how the government celebrated the history of rich American landscapes by leaving them untouched for the future.

Founded in 1885, Arizona State University is located in Tempe, Arizona and is home to 75,000 student Sun Devils (Arizona State University, 2020). The Ira A. Fulton Schools of Engineering within ASU currently enrolls more than 23,900 students with approximately 1,800 of those in the School of Sustainable Engineering and the Built Environment (SSEBE) as civil, environmental, or construction engineering and construction management majors (Arizona State University, 2020). As a program, ASU ranks in the top 50 best Engineering schools in the US and has been named #1 in innovation five years in a row (U.S. News, 2019).

The ASU Concrete Canoe team competes in the Pacific Southwest Conference as one of 18 concrete canoe teams, which will be held at CSU, Fullerton. In previous years, the team placed ninth with *Firebolt* (2017), seventh with *Bullet Bill* (2018), and fifth with *The Maroon Machine* (2019). The CNCCC should choose the ASU team submission as the standard design due to the teams experienced leadership, increased funding, alumni support, and innovations in mix design, aesthetics, construction, and the curing process.

Table 1. Canoe Physical Properties

Property	Value
Name	Legacy
Length	242 in.
Maximum Width	26 in.
Maximum Depth	15 in.
Average Thickness	9/16 in.
Estimated Weight	230 lbs.
Colors	Orange, Tan, Brown
Primary Reinforcement	Carbon Fiber Mesh
Secondary Reinforcement	Polypropylene Micro-Fibers, Copolymer Macro-Fibers

This year's team consisted of the returning project manager and two captains from last year, dedicated team alumni, two new captains, and the largest number of volunteers the team has had in recent years. This composition allowed the team to build off of extensive knowledge and experience from returning members and allowed them to complete ambitious tasks through improved volunteer recruitment.

Poor racing performance last year motivated the team to drastically change the hull to reflect the lessons learned. The hull design captain was a paddler last year, thus the team changed the design to better aid paddlers in straight-line speed and turning without compromising stability, as seen in Table 1.

The mix design team created two mixes, one for structural components, and one for aesthetics that would not add excessive weight. The team added in two new cementitious materials to reduce the environmental burden caused by cement usage. The team developed the strongest structural mix in ASU's history and incorporated macro-fibers and carbon fiber mesh to facilitate the construction team in making the thinnest canoe in ASU's history, shown in Table 2.

Table 2. 28-Day Mix Design Properties

	Structural	Aesthetic
Density (Fresh Concrete)	65.1 pcf	65.7 pcf
Density (Hardened Concrete)	60 pcf	51 pcf
Compressive Strength	2620 psi	1860 psi
Tensile Strength	280 psi	160 psi
Composite Flexural Strength	1060 psi	N/A
Air Content	4.4%	18.4%

The construction team changed the mold construction to create a better final product in terms of hull design accuracy and to make mold removal easier. The team developed an innovative aesthetic process to create stunning designs without cold-jointing and redesigned the curing chamber to achieve a better cure while reducing the water usage by 50%.

The ASU team is excited to present *Legacy*: an innovative, visually striking canoe that displays the history of the canoe team and the country, while symbolizing the future that we hope to leave behind.

Introduction to the Project Team

ASCE Student Chapter Profile

The Arizona State University chapter of the American Society of Civil Engineers (ASU ASCE) is a student chapter subset of the ASCE Arizona Section, along with Northern Arizona University (NAU) and University of Arizona (U of A). The chapter was founded in 1962 and has competed in the Pacific Southwest Conference (PSWC) since 1962.

The objective of the American Society of Civil Engineers student chapter at ASU shall be the development of a professional consciousness, to afford an opportunity for civil engineering students to become acquainted and to practice working together effectively, promote a spirit of congeniality among them, and provide friendly contact with the engineering professions.

The organization also puts an emphasis on community outreach and volunteering, attending events like Night of the Open Door at ASU that focus on inspiring the next generation of engineers by interacting with elementary, middle, and high school students. The organization has also participated in Engineering Projects in Community Service (EPICS) and Habitat for Humanity projects.

ASCE is the largest student organization on campus, with 507 members. Of these, 130 members are ASCE National Society-level members (about 25% of the members) and 186 members have a Junior, Senior, or Graduate-level status. Of the 237 Juniors and Seniors within the Civil Engineering Major, 78% are members of ASU student chapter. This shows the high retention rate of students in the organization and the major, with many students citing ASCE competitions as the main reason why they stay in their major.

The organization offers professional meetings with an industry speaker, technical tours, and social functions, and encourages members to attend the Section/Branch meetings and the Younger Member meetings. In the 2018 - 2019 academic year, the organization offered 11 professional meetings, 4 student presentation meetings, 1 ethics/finance meeting, 2 technical tours, and 12 social functions, among others. These activities allow students to engage with professional engineers, learn about the civil engineering profession, network with students and companies, and gain exposure to real problems.

The organization is run by a group of officers, faculty advisors, alumni, and industry advisors. The officer positions include the year long positions of Treasurer, Secretary, Facilities Manager, Conference Coordinator, Competition Manager, and Concrete Canoe Project Manager. The officer positions also include the semester long positions of President, Vice President, Undergraduate Student Government Representative, Outreach Chair, Recruitment Chair, Fundraising Chair, Social Chair, Public Relations Direction, and Industry Liaison. This division of officer positions into different lengths of time allows for consistency in the organization leadership through the year long positions, but also allows for younger members (especially freshman and sophomores) to gain experience in their major, in leadership roles, and in networking. This variety of positions allows each officer to specialize in one activity, allowing for efficiency in executing organizational tasks and for improved task delegation. The advisors (both faculty and industry) and alumni help with the transition between officers and in offering advice to the current officers to better lead the organization.

The organization has participated in the regional PSWC in all of the technical, sporting, and miscellaneous competitions for many years. The ASU ASCE chapter co-hosted the 2018 PSWC with NAU, where it placed 6^{th} overall out of 18 teams. Last year, the organization placed 13^{th} overall out of 18 competing universities with the best individual team finishes being: 4^{th} in the Concrete Canoe Presentation and Co-ed race, 5^{th} overall in Concrete Canoe, 2^{nd} in Volleyball, 1^{st} in the Mystery event, and 6^{th} in Surveying. ASU consistently has high PSWC attendance, with 73 attendees last year, and 65 attendees in 2018. A picture of the 2019 PSWC attendees is shown in Figure 1.

Figure 1. 2019 PSWC ASU attendees on Race Day

Introduction to the Project Team

Project Team - Core Team Members

PROJECT MANAGER
Responsible for recruitment, scheduling, fundraising, task delegation, rule compliance, quality assurance, quality control, safety, and material procurement.

HULL DESIGN CAPTAIN
Responsible for design and analysis of the hull, determining strength requirements, and performing structural calculations.

MIX DESIGN CAPTAIN
Responsible for research and development of multiple concrete mixes and performing laboratory testing.

AESTHETICS CAPTAIN
Responsible for designing the aesthetics for the canoe, report, and conference display.

CONSTRUCTION CAPTAIN
Responsible for mold construction, concrete casting, finishing, and curing chamber construction.

PADDLING CAPTAIN
Responsible for coordinating practices and tryouts, and teaching paddling techniques

Introduction to the Project Team
Organizational Chart

PROJECT MANAGEMENT

Brielle Januszewski (Sr) – Team Captain

CONSTRUCTION

Mold Construction

Brielle Januszewski (Sr) – Team Captain
Camila Ibarra (Jr) –Aesthetics Captain
Sam Suwarno (So) – Construction Captain

Casting

Brielle Januszewski (Sr) – Team Captain
Katie Sinclair (Sr) – Team Captain
Camila Ibarra (Jr) –Aesthetics Captain
Jared Kahler (Sr) – Paddling Captain
Sam Suwarno (So) – Construction Captain
Nicholas Reichman (Sr)
Jose Fernandez (Sr)
Matthew Mavrosakis (Jr)
Jay Depler (Jr)
Julia Zimmerman (Jr)
Alejandro Munoz (Jr)
Lazaros Karakozis (So)
Jeremy Guerrero (Jr)
Edward Apraku (Jr)
Marisela Arias (Jr)
Shaela Hogue (Sr)
Isaac Parra (Jr)
Peter Nunes (So)
Caleb Siff (Fr)
Susanna Westersund (Fr)
Molly Gambill (Fr)
Ameyalli Santibanez (Sr)
Susan Cihelka (Sr)
Emily Ford (Grad)
Belchor Sebastiao (Grad)
Kasey Fitch (Fr)
Ken Niimi (Sr)

Finishing

Brielle Januszewski (Sr) – Team Captain
Camila Ibarra (Jr) –Aesthetics Captain
Sam Suwarno (So) – Construction Captain
Jared Kahler (Sr) – Paddling Captain
Katie Sinclair (Sr) – Team Captain
Jay Depler (Jr)
Edward Apraku (Jr)
Caleb Siff (Fr)
Susanna Westersund (Fr)

MIX DESIGN

Design Phase

Elton Formelu (Sr)
Brielle Januszewski (Sr) – Team Captain
Katie Sinclair (Sr) – Team Captain
Camila Ibarra (Jr) –Aesthetics Captain
Jared Kahler (Sr) – Paddling Captain
Sam Suwarno (So) – Construction Captain
Nicholas Reichman (Sr)
Alejandro Munoz (Jr)
Ameyalli Santibanez (Sr)
Allyson Camillucci (Sr)
Caleb Siff (Fr)
Valentina Rivera (So)
Jacquelyn Hermosillo (Sr)
Matt Fund (Sr)
Susan Cihelka (Sr)
Joseph Todsen (So)
Shaela Hogue (Sr)

Casting Day

Brielle Januszewski (Sr) – Team Captain
Katie Sinclair (Sr) – Team Captain
Sam Suwarno (So) – Construction Captain
Nicholas Reichman (Sr)
Alejandro Munoz (Jr)
Ameyalli Santibanez (Sr)

AESTHETICS

Camila Ibarra (Jr) –Aesthetics Captain
Nancy Rodriguez Perez (Jr)
Leslie Olivares (Jr)
Shaela Hogue (Sr)
Austin Heller (Jr)

ACADEMICS

Initial Research

Brielle Januszewski (Sr) – Team Captain

Report

Brielle Januszewski (Sr) – Team Captain
Katie Sinclair (Sr) – Team Captain

Presentation

Brielle Januszewski (Sr) – Team Captain
Katie Sinclair (Sr) – Team Captain

HULL DESIGN AND STRUCTURAL ANALYSIS

Brielle Januszewski (Sr) – Team Captain

PADDLING

Females

Brielle Januszewski (Sr) – Team Captain
Katie Sinclair (Sr) – Team Captain
Camila Ibarra (Jr) –Aesthetics Captain
Shaela Hogue (Sr)
Valentina Rivera (So)

Males

Jared Kahler (Sr) – Paddling Captain
Edward Apraku (Jr)
Peter Nguyen (So)
Jay Depler (Jr)
Tyler Dolyniuk (Sr)

ALUMNI

Mark Natale
Steven Sherant
Connor Fegard
Natalie Miller
Basil Miller
Hilary Merline
Victoria Flys

FACULTY / STAFF ADVISORS

Kristen Ward
Narayan Neithalath
Stan Klonowski
Jeffrey Long
Peter Goguen

Hull Design

This year, the team decided to take a more competitive approach to hull design. Improvements were needed in the maneuverability and ease of steering of the canoe. The 2019 canoe was slow during acceleration, and difficult to turn. Weight aside, the main contributing factors were hull slenderness and cross-sectional width. As with the past four years, the team used a MATLAB code developed by alumni to design and analyze the canoe hull. The code takes inputs in Excel, and splines together these points, resulting in Figure 2.

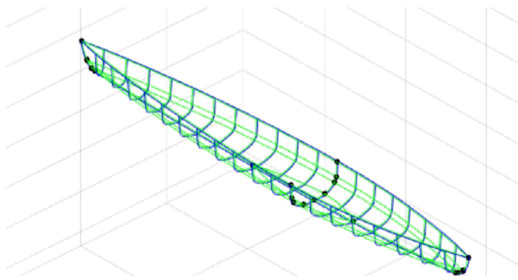


Figure 2. MATLAB Quadratic Spline Output

The team decided to build upon last years design, *The Maroon Machine* due to the stability it provided during races, especially the co-ed race. The primary goal was to decrease the angle of attack at the bow of the canoe. To do this, the widest point was moved 4" towards the stern, a total of 18" behind the center of the canoe. This displaces water slower and allows for the canoe to cut instead of push water out of the way. The overall length of the canoe was decreased 4", to provide a slight turning advantage and reduction in concrete use. Last year's canoe formed a wave of water in front of the canoe instead of pushing it aside.

The hull profile was similar as a mixture of a flat and round bottom, giving the canoe fast straight-line speed, while still providing enough maneuverability to navigate the course. The sides of the hull above the chine remained straight, with a slight flare outward to provide ease of paddling, and a slight advantage to secondary stability. The gunnels were removed completely, due to the inability to prevent against cracking propagating from the top of the hull in tension during transportation. The bow and stern rocker were increased to 7.5" and 7.7" respectively, to ensure advanced maneuverability and primary stability during sprints.

The next main goal was to decrease the displacement of water at the widest cross section. To do this, the max beam was decreased, and the chine was made slightly sharper (Figure 3). The shortened beam allowed for a smoother design and sharper angle of attack through the water. Chine sharpness provides enhanced secondary stability, and less surface area touching the water, increasing efficiency.

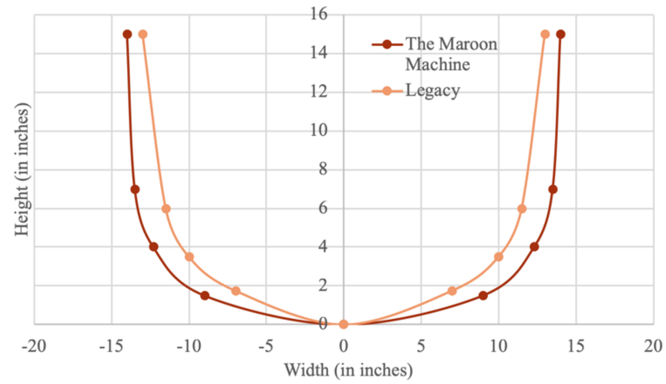


Figure 3. Hull Profile with spline node inputs

Additionally, secondary stability was another goal the hull design team wanted to improve. *The Maroon Machine* was a dynamically sturdy canoe and very hard to tip. This is beneficial to a certain point. ASU's paddlers are taught to lean into turns and allow the canoe to naturally lean to help turn. *Legacy* will allow paddlers to easily lean the canoe just by shifting weight slightly, which was the ultimate goal.

The design of the chine plays an important role outside of stability assurance. The team worked to design the chine so that the sidewall would minimize wetted surface area, decreasing drag resistance due to water. Moreover, having a sharper chine also allows for a wider hull at higher waterlines, which increases beam length vertically along the cross-section. Though this increases stability, it decreases the L/B ratio which should be maximized to produce a hull much longer than it is wide, similar to an arrow, but there had to be compromise between stability and efficiency.

The beam length increases from the end of the chine to the top of the sidewall. As the boat sits lower in the water, this allows the length of the waterline to increase, providing an increase in speed, since length of the waterline is related to speed of the hull. This design will allow the transverse metacentric height (GM_T) to remain at 1.10, a value that provided a good compromise between overturning resistance and primary stability on *The Maroon Machine* (Figure 4).

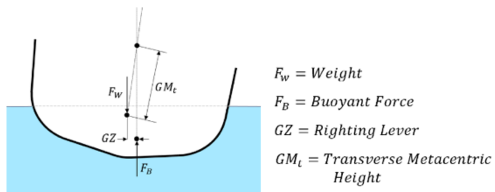


Figure 4. Righting Lever and GM_T

Legacy's final hull design is asymmetric with a shallow arc bottom on the ends, a flat bottom in the center, and slightly flared walls. The overall length is 20'-2", and at the widest section, beam width is 25" and depth is 15". The bow and stern both have depths of 16", while the thickness of the boat is 9/16" throughout.

Structural Analysis

Upon completing the hull design, the team performed a two-dimensional longitudinal and lateral analysis to ensure *Legacy* would endure all loading conditions. MATLAB was used in combination with Excel to compute cross-sectional properties and perform each analysis. Five loading cases were taken into account: (1) display, (2) carrying, (3) two female paddlers, (4) two male paddlers, and (5) coed.

To complete the longitudinal analysis, the canoe was modeled as a simply supported beam with self weight and paddler weight acting in the negative gravity direction and buoyant force acting in the positive gravity direction. Cuts were taken at 1" intervals to compute the internal forces and moments acting on the cross section, shown in Figure 5.

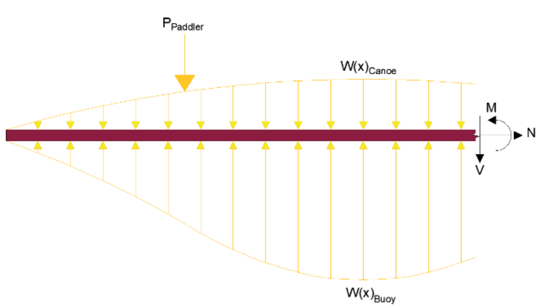


Figure 5. Free Body Diagram for longitudinal analysis

Unit weight of concrete was estimated at 60 pcf, a conservative estimate resulting in a total weight of 230 lbs. The paddlers were modeled as 190 lbs point loads for males, and 130 lbs for females. To analyze paddling load cases, the net downward forces were set equal to the resultant of the upward buoyant force, allowing for the canoe to remain in static equilibrium and the elimination of simple support reactions. The resultants of the net downward and upward forces were aligned at the centroid of the canoe, to eliminate any residual moments. Bending stresses were determined using the theory of simple bending: $\sigma = Mc/I_x$, where: M is the bending moment, c is the distance from the neutral axis to the outer most fiber, and I is the section modulus. The bending stresses were computed using MATLAB (Figure 6). On-land load cases were analyzed as a simply supported beam. Bending moment diagrams were created for each load case. A dynamic load amplification factor of 2 was applied to account for momentum generated by paddlers. Final analysis values are shown in Table 3.

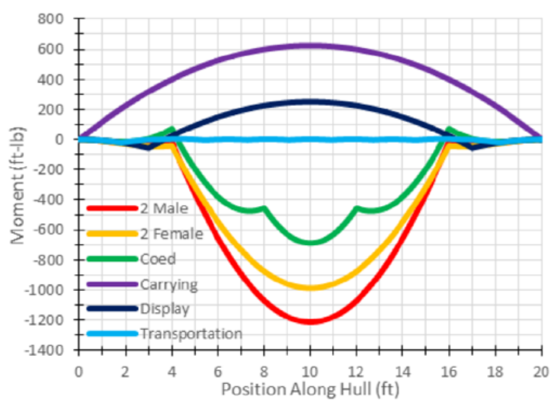


Figure 6. Bending moment envelope

Table 3. Maximum Theoretical Structural Stresses

Load Case	Compressive (psi)	Tensile (psi)
2 Male	160	155
2 Female	127	123
Coed	231	224
Carrying	131	110
Display	16	31

Concrete Development and Testing

The goals of the mix design team were to develop a pigmented structural mix and a secondary aesthetic mix for placement on the bulkheads, and increase sustainability of the mix. Last year's mix (*The Maroon Machine*) was used as the baseline for the mix, and, in line with the theme, the team also referenced *Pondicherry*'s 2015-2016 mix.

The Maroon Machine mix consisted of 49% ordinary Portland cement (OPC) (ASTM C150), 26% Class F Fly Ash (ASTM C618), 10% Metakaolin (ASTM C618), and 15% VCAS-8 (ASTM C618) for cementitious materials. For aggregates, the team used Poraver and lightweight clay shale of varying sizes (ASTM C330). Other materials used in the mix were 3M™ glass bubbles, pigments (ASTM C979), superplasticizer (Plastol 6400) (ASTM C494), air entrainer (AEA 92) (ASTM C260), and Grace microfibers (ASTM C1116). The mix had a unit weight of 61 pcf and a compressive strength of 1800 psi.

The team first focused on increasing the sustainability of the structural mix. To do so, the team reduced the amount of cement (which contributes 5-7% of global CO_2 emissions every year) in the final mix by replacing it with sustainable cementitious materials and by reducing the total amount of cementitious materials in the mix (Chen, 2010). Slag cement (ASTM C989) and silica fume (ASTM C1240) were used to reduce the amount of cement in the concrete by 15%. Slag cement was used as a sustainable alternative because it is a recovered byproduct of iron production, its specific gravity is less than that of OPC, it results in better workability than OPC, and its color is lighter than that of OPC, thus lending itself to the aesthetics goals (SCA). Silica fume was used because it is a byproduct of elemental silicon production and because its specific gravity is two-thirds that of OPC (Mindess, 2019). It was determined that the mix would feature 10% slag and 10% silica fume as these were the strongest dosage.

The quantities of the other cementitious materials (Fly Ash, Metakaolin, and VCAS) were also tested incrementally to determine the proper ratios for maximum strength. As a result, the fly ash in the mix was switched from Class F to Class C (ASTM C618) due to the improved strength properties and its ability to better replace the cement due to its primarily cementitious features (instead of pozzolanic) (Sutter, 2020). The amount of fly ash used was reduced from 26% to 20% due to better strength performance and workability of the mix. All the cementitious tests were performed according to ASTM C109 and C305 mortar cube preparation and compression testing standards. For sustainability reasons, the team switched from cylinder compression tests to mortar cube compression tests for the cementitious tests, thus saving the team almost 100 person-hours, and pounds of aggregates, fibers, and admixtures.

The final cementitious distribution of the structural mix was determined to be composed of 35% OPC, 20% Class C Fly Ash, 10% Metakaolin, 15% VCAS, 10% Slag, and 10% Silica Fume. The composition of this year's cementitious mix is compared to the composition of last year in Figure 7.

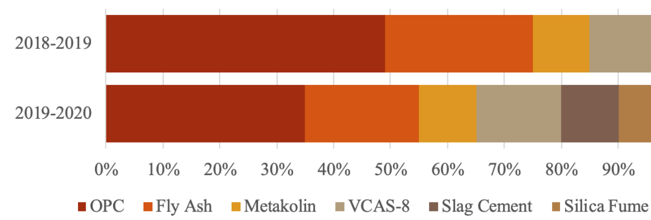


Figure 7. Cementitious Material Gradation

The team then shifted its focus to the aggregate gradation of the mix. The team focused on the Poraver gradation and used *Pondicherry*'s mix as a baseline. ASTM C39, C143, C192, and C470 standards for mixing concrete, sampling concrete, curing, and testing concrete cylinders were followed, and 3"x6" cylinders were used to increase sustainability and reduce the necessary batch volume needed to create testing samples. After testing, the team switched the Poraver gradation from 12.8% 0.1-0.3mm, 6.4% 0.25-0.5mm, 36.8% 0.5-1mm, and 14.1% 1-2mm by volume for *The Maroon Machine* to 2.7% 0.1-0.3mm, 21.1% 0.25-0.5mm, 43.7% 0.5-1.0mm, and 2.5% 1.0-2.0mm by volume to better reflect *Pondicherry's* mix. This change resulted in only a slight increase in strength, but improved the workability of the mix and used larger ratios of smaller aggregates which helped the construction team create thinner layers.

The team re-evaluated the absorption values of the Poraver and the clay shale using the ASTM C127 standards for testing absorption of fine aggregates. The values of clay shale absorption were 80% in previous years, but this was deemed inaccurate by the team, and thus, the team conducted absorbance tests to determine that the absorbance of fine clay shales was 17.6%, crushed fine clay shales was 16.5%, and 10 mesh clay shale was 14.3%. The same tests were used on Poraver, whose previous absorption values were 70% for 0.1-0.3mm grain size, 60% for 0.25-0.5mm grain size, 50% for 0.5-1.0mm grain size, and 40% for 1.0-2.0mm grain size. As with the clay shale, these values were deemed inaccurate, so the team researched appropriate values and tested the absorption to find that more accurate absorption values were 35% for 0.1-0.3mm grain size, 28% for 0.25-0.5mm grain size, 20% for 0.5-1.0mm grain size, and 20% for 1.0-2.0mm grain size. This change in absorption values greatly reduced the amount of water needed to reach the aggregate saturated-surface-dry (SSD) condition which is standard for concrete mixing. Thus, before these changes, the water that was used to reach SSD was contributing to the free water in the mix, inadvertently adding to the w/cm ratio. This reduction resulted in a large increase in strength and in unit weight and reduced the overall water demand by about 5 gallons. The properties of the aggregates are shown in Table 4.

Table 4. Properties of Aggregates

Aggregate		Specific Gravity	Adsorption (mass %)	Grain Size (Mesh #)
Poraver	0.1-0.3mm	0.9	35	140-50
	0.25-0.5mm	0.68	28	60-35
	0.5-1.0mm	0.47	20	35-18
	1.0-2.0mm	0.41	20	18-10
Clay Shale	Fine	0.845	17.6	4-pan
	Crushed Fine	0.854	16.5	4-pan
	10 Mesh	0.825	14.3	4-pan

After determining the aggregate portioning, the team iteratively changed the batch weight of aggregates and cementitious materials to optimize strength and reduce the unit weight (measured using ASTM C138 and C567). Here again, the team used *Pondicherry* as a baseline and determined that the team should switch from using 632 lb/yd^3 of cementitious materials to 500 lb/yd^3 and switch from 543 lb/yd^3 of aggregates to 340 lb/yd^3. This resulted in a 20% increase in strength with a slight 3% decrease in unit weight.

The team then moved on to testing fiber portioning. On last year's canoe, extensive micro-cracks formed on the exterior face which can be caused by shrinkage in the finished concrete. The canoe also suffered extensive damages due to failure in tensile and flexural strengths. So, the team researched and incorporated additional reinforcing fibers into the mix. The team already uses GRACE micro-fibers, so Tuf-Strand Maxten macro-fibers (ASTM C1116) were used to supplement the mix. These synthetic microfibers are ¾" long and reduced the occurrence of plastic shrinkage cracks, and helped to increase the tensile and flexural strength of the mix. The fibers were tested iteratively using concrete cylinders to determine the optimal fiber dosage of 4.0 lbs/yd^3. Flexural and tensile testing were also utilized for the first time in many years on the ASU team to determine optimal fiber usage. The flexural testing relied on ASTM C947 standards to guide the testing procedure for thin specimens. The tensile testing used ASTM C496 standards as a guide for the testing procedure. The micro-fiber dosage remained the same at 3.10 lb/yd^3 because of its reliability when used with macro-fibers.

Finally, the team tested the admixtures to find suitable dosages to achieve appropriate workability for placement on the mold and to reduce the unit weight of the concrete. *The Maroon Machine* used 10.00 fl oz/cwt AEA 92 (air entrainer) and 3/33 fl oz/cwt Plastol 6400 (superplasticizer). This ratio needed to be changed due to the decrease in aggregate water, which decreased the workability and time until setting of the concrete. When superplasticizer is added to a mix, it increases the workability of the concrete without changing the w/cm ration. However, if the dosage is too high, it makes the concrete more fluid, like a non-Newtonian fluid, and does not lend itself to sticking to the male mold. Superplasticizer was added to the mix at a dosage of 9.96 fl oz/cwt to increase the workability of the mix, but only to a certain point (about 12.17 fl oz/cwt) so that the workability did not leave the optimal window. Air entrainer is typically added to mixes to entrap microscopic air bubbles into the mix to reduce the unit weight of the concrete and to provide resistance to freeze/thaw conditions. Through iterative testing, the team discovered that the air entrainer works in tandem with the superplasticizer to increase workability, but in a way that increases the adhesion of the mix to the mold. The optimal dosage of air entrainer was determined to be 18.26 fl oz/cwt (almost a two-fold increase from *The Maroon Machine*) to decrease the unit weight to compensate for the loss of air voids due to the decrease in batch water. This dosage of air entrainer did not significantly alter the compressive strength of the concrete, but greatly remedied the workability problems. With these dosages of superplasticizer and air entrainer, the mix retained its high compressive strength, while creating a workability that allowed for easy placement on the mold, and that increased the time to setting for better placement on the mold.

Last year's canoe failed because too much structural concrete was placed on the bulkheads, putting the body of the canoe in a negative moment. However, the placement of concrete on the bulkheads was aesthetically pleasing and allowed for intricate inlays. To remedy these conflicting results, the mix team developed a lighter aesthetic mix for use on the bulkhead. This mix was chosen out of the iterations of the structural mix design due to its lower unit weight (by over 10 pcf) and receptiveness to pigmentation.

The team reconsidered the use of the previous year's fiberglass mesh which had been used for at least the past four canoes. The past canoes all broke within one day to one year of the end of conference due to low flexural strength. Thus, the team looked further into the past and decided to switch back to using carbon fiber mesh, as seen in the 2013-2014 canoe, *Avanyu*, whose longevity allowed it to be used in conference and then for practice for five years before its retirement. To test the efficacy of the new carbon fiber mesh and the new secondary reinforcement scheme of the fibers, flexural and tensile tests were used. For the flexural testing, the new mix increased the composite flexural strength by 116% and the new mesh increased the strength by 23%. These two changes increased the total composite flexural strength by 180% to a strength of 1260 psi. This flexural strength was far greater than the required strength, thus the team used this as an opportunity to reduce the overall thickness of the concrete by 25%, from 3/4" to 9/16". This brought the final flexural strength down to 1060 psi, which is 135% stronger than last year's flexural strength. The tensile tests revealed that the new mix portioning increased the final tensile strength to 280 psi for the structural mix which is 17% increase in strength. The layering scheme was chosen to be three layers of 3/16" concrete, with two layers of carbon fiber mesh in between the concrete layers.

For quality assurance, the team decided to change the mixing process to create more consistent mixes and to make the process faster. To do so, the team purchased two 7-qt. KitchenAid® mixers. This switch allowed for more people to learn how to make the mixes without as much practice or skill and allowed the team to make mixes faster on the casting day. The team pre-batched the materials in Ziploc bags before the casting day to increase the efficiency. The team batched the pigments separately so that any mix could be made into any color to aid with quality assurance. Finally, the team built a new curing chamber using an old cooler to improve the cure of the prepared mortar cubes and flexural samples and used buckets of water to cure the cylinders in accordance with ASTM C511-19 standards. These measures resulted in a better cure, and better reflected the final cure the canoe received due to the new curing chamber set-up.

The team increased sustainability by using 15% less cement per mix and by reducing the thickness of the canoe, resulting in a savings of 30 lbs of cement. The team saved water using the new curing set-up because water was only needed for a 50 qt. cooler instead of a 100 cu. ft. room. The team participated in a recycling program that could recycle the used Ziploc bags instead of throwing them out.

Altogether, the changes that were made resulted in the final values shown in Table 5. The team was able to improve the strengths of the mix, sustainability, and the final quality of the canoe.

Table 5. Final 28-day Testing Results

Property	Required	2018-2019 Structural	2019-2020 Structural	2019-2020 Aesthetic
Dry Density	<62 pcf	61 pcf	60 pcf	51 pcf
Compressive Strength	230 psi	1800 psi	2620 psi	1860 psi
Tensile Strength	220 psi	240 psi	280 psi	160 psi
Flexural Strength	-	450 psi	1060 psi	N/A

Technical Approach to the Overall Project

Construction

Due to the failure modes of last year's canoe, the difficulty in removing the mold from the concrete, and lack of aesthetics of previous years' canoes, the construction of this year's canoe was focused on aesthetic design, reducing the weight of concrete at the bulkheads, and preparing an easily removable mold. A male mold was utilized because it facilitated the construction of the intricately designed inner layer and allowed for the placement of exlays on the outside of the canoe on the casting day, thus preventing cold-jointing of concrete on the interior and exterior aesthetics. The mold was made of 2 pcf expanded polystyrene (EPS) foam due to the additional buoyancy when left in the bulkheads and because of its easy constructability.

AutoCAD was used to draft the finalized hull design from a Matlab code where cross-section cuts were taken at two-inch intervals, generating a stair-step pattern when assembled. The inward-facing, rounded gunnels were removed from the design so that the mold could be removed in one piece from the concrete. For sustainability, this year's placement of cross-sections in the AutoCAD files used 3 less sheets of styrofoam than last year. These cross sections were imported into VCarve Pro, which converts AutoCAD cut files into readable CNC machine files. The ASU Innovation Hub provided free access to the CNC machine, resulting in a cost savings compared to out-sourcing the milling.

The sections were assembled and adhered along a continuous steel bar using Glidden Gripper. A rope was fed through the center of the pieces in preparation for the removal process. Durham's Rock Hard Water Putty™ was placed on the mold to smooth out the stair-step pattern of the styrofoam. The putty was orbital sanded with 80-grit and 120-grit sandpaper to remove inconsistencies and rough edges. By not sanding the styrofoam and using an orbital sander to sand the water putty, the team saved work hours and improved the quality of the mold. The switch from Rosco Foamcoat™ to the water putty resulted in $300 of savings, many work hours, and a smoother final product. During last year's casting, the concrete bulkheads were formed by hand around the rough stair-step pattern. This resulted in uneven and bulging bulkheads that took more experienced manpower and time to cast than the rest of the canoe. This year, the putty was placed to the very ends of the canoe, and used small pieces of cardboard to perfectly form the bulkheads according to the hull design. This led to easier casting by inexperienced members and reduced the amount of concrete on either bulkhead, thus reducing the weight on the very ends of the canoe. The mold was then painted and the aesthetics captain drew the interior design on the mold to indicate where to place colored concrete, essentially turning the mold into a paint-by-numbers activity. This improved upon aesthetics from last year's canoe, the interior of which was solid gray and the exterior of which was two toned. This process also expanded upon the team's innovative aesthetics process from last year to draw on the mold and the mesh to incorporate multiple colors of concrete that are cast at the same time, to allow for intricate aesthetics without cold jointing. The mold was coated in epoxy resin to provide a waterproof, hard shell to the mold. This prevented the markings in the drawing from transferring to the concrete, which would be difficult to sand away. The resin was poured onto the mold and was smoothed out using paint brushes to ensure that the resin was distributed evenly without lumps or drips. The resin aided in developing a non-destructive mold removal process, in which it helped the mold release from the concrete in one piece. Kleen Kote Releasing Agent was applied to the canoe on the cast day for easier removal of the mold from the canoe. This releasing agent promoted sustainability because of its biodegradability, low volatile organic compound (VOC) value of 15 g/L, and its shipment as a concentrate. The last step in mold preparation was the placement of shelf liner cut to the exact shape of small sections of the aesthetics design. This was done in order to retain the intricacy of the design while allowing for larger areas of one color to be placed without covering over smaller details.

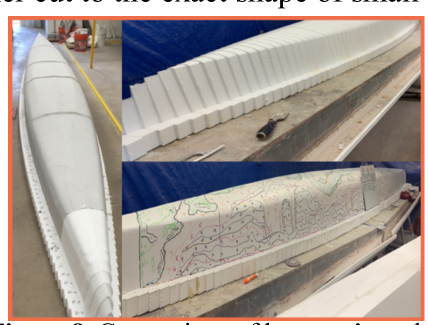


Figure 8. Comparison of last year's mold (left), the styrofoam pieces (top right) and the new mold (bottom right)

Figure 8 shows last year's canoe mold compared to this year's mold.

Legacy incorporates two layers of carbon fiber mesh that were pre-cut to the mold shape to expedite its placement while casting. This saved over an hour on casting day, compared to last year when the mesh was cut after each layer. This allowed for better impregnation of the mesh because the concrete was still workable when the mesh was placed.

During casting, the first layer was the most challenging layer to cast because of the intricate aesthetic details that were required. To accommodate this, the concrete was first placed on top of the mold and then worked down the side in order to prevent the concrete from slumping off the mold. Volunteers were split into groups, and tasked with placing specific colors and reconciling borders between neighboring colors to prevent jointing of the different colored concrete. Tire tread-depth gauges were used to ensure an even 3/16" thickness over the entire layer and hand tools were used to smooth out the concrete once it was placed. There was extensive communication between the construction team and the mix design team to dictate which colors needed to be made at what times. To aid in this, the pigments were batched in small condiment cups separate from the cementitious materials so that mixes could be made into any color depending upon what was needed.

Figure 9. First layer (left), last layer (middle), final product (right)

The carbon fiber mesh was placed over the body of the canoe and was smoothed into the layer of concrete to promote proper adhesion of the mesh to the layer of concrete. A second layer of 3/16" gray structural concrete was placed, followed by the second layer of carbon fiber mesh. For the third layer of 3/16" thick concrete, the color design changed so that the body of the canoe would resemble desert rocks. Guidelines were painted on the second layer of reinforcing mesh and the colored concrete was placed accordingly. After the body was casted, the leadership team sculpted a prickly-pear cactus exlay with maroon and gold flowers to complete the design. The concrete then set for 12 hours swathed in damp cheesecloth. The curing chamber was turned on, and the canoe was covered in towels to ensure the concrete remained moist in between misting cycles. The process of casting is shown in Figure 9.

For curing, the team constructed an efficient, automated curing chamber. A cage of PVC pipes was built to stand on the table and closely follow the shape of the canoe and was wrapped in plastic tarp to maintain humidity in the chamber and to direct the excess water to gutters attached to the table. The system reduced the distance between the misters and the top of the canoe and placed misters along the side of the cage, allowing for more water to directly hit the canoe, giving it a better cure. The misting system ran every hour for five minutes, creating a controlled environment providing proper hydration and humidity for an efficient wet curing process to combat the dry Phoenix air. This change in the timing of the misting system improved sustainability by reducing the water usage by half but resulted in a higher quality cure.

The sanding process was initiated after a 21-day cure starting with a wet sand. This reduced exposure to dust particles containing calcium hydroxide and crystalline silica, providing a safer work environment. A patching structural mix was applied to fill inconsistencies after the curing chamber was turned off and the concrete was given time to dry. The sanding process utilized 80-grit to 400-grit sandpaper which improved the final quality and smoothness of the concrete. Adhesive appliques of the name of the canoe and school were placed, and the outside was sealed with EverClear 350 acrylic sealant. The canoe was flipped and the mold was removed by pulling on the ropes that were threaded through the middle. The bulkheads were filled with 2.5 feet of styrofoam for flotation, which was sealed in with the aesthetic mix. An aesthetic mix was used on the bulkheads because of its lesser density, reducing the amount of weight on either bulkhead. The remainder of the aesthetics were constructed to complete the design. The inside of the canoe was patched and sanded with the same variety of sandpaper as the outside and was sealed, thus completing the construction.

Management Approaches

Approach to Scope, Schedule, and Fee

The team focused on overhauling the project and using knowledge from previous competitions to improve the overall process. The team worked on recruiting new members, increasing sustainability, improving safety, quality, and communication, and leaving infrastructure for next year.

Reflecting on lessons learned, the Project Manager (PM) role was reduced from two PM's to one PM due to budgetary issues and misunderstandings caused by lack of communication. The team leader was a returning PM, bringing experience to help with finances, delegation, time management, and task completion. Alumni returned as project advisors to provide expertise and guidance. Other positions on the team were: hull design captain, construction captain, mix design captain, aesthetics captain, and paddling captain. The construction and aesthetics captains were chosen because of their experience on the team, with the remaining members being chosen because of their enthusiasm for the project. Volunteers joined to help the team complete tasks as deadlines approached.

After PSWC (2019), the team reached out to the conference judges to receive constructive feedback about how to improve the project for the next year. Using this information, the PM and alumni held meetings to determine necessary changes for the project, brainstorm innovations, and draft a schedule of primary goals for the next year. Meetings were then held on an as-needed basis, opting for instant messaging and emailing to give weekly updates.

This year's schedule focused on incorporating more lead time into the project, instead of adding float time to the end of the tasks. For many of the tasks, there is a large learning curve, especially when using new processes and training new members, thus the tasks were started earlier than needed to account for this, so that the tasks were completed on time. The schedule and critical path were determined from lessons learned in previous years and from the change in deliverable deadlines in the rules. It was organized in a way that allowed for multiple tasks to be completed in parallel and to fit the accelerated timeline of the earlier conference date and report deadline. The project milestones within the critical path of the project are shown in Table 6.

Table 6. Project Milestones

Milestone	Delay	Cause
Hull Design	None	-
CNC Mill the Mold	8 weeks	Machine failure and transportation issues
Finalize Mix Design	7 weeks	Extra strength, sustainability, and workability testing
Casting the Canoe	None	-

After the release of the rules, the team began on the project and started work on mix design and mold construction. Mix design experienced delays because of the number of changes that were made. The CNC milling of the canoe mold experienced delays because the CNC machine was not leveled properly and broke multiple drill bits and because the ASU Innovation Hub that housed the machine experienced staff shortages making it unavailable for use on key dates. The construction of the mold was offset due to the delay in CNC milling and thus prevented the construction of a practice canoe. The team used a little over 1200 person-hours to complete the entire project, with the allocation of work hours of this year, compared to those of last year shown in Figure 10.

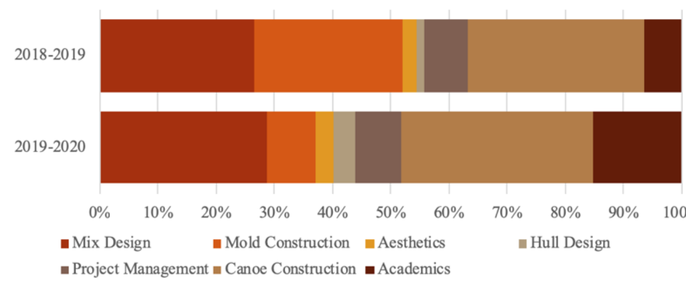


Figure 10. Comparison of Person Hour Allocation

Due to the focus on mix research, the proportion of person hours spent on mix design increased by 2%, while the improved mold construction process resulted in a decrease of 17% of the person hours. The focus on a better hull design and the emphasis on a higher quality finish of the final canoe resulted in increases of person hours of 3% each. Overall, the team used 21% more person-hours this year.

The PM created a budget using last year's budget as a baseline, which determined the amount of sponsorship that was needed. After suffering major setbacks from a large deficit last year, the PM this year worked to fundraise enough money to cover the project costs, provide financial support to the ASU ASCE chapter to encourage PSWC participation, and to leave a sizable amount to next year's team. The main reason to consolidate leadership into one PM was based on the previous year's lack of communication about budget and material procurement which led to overspending and the lack of proper materials for milestones. This change led to a three-fold increase in the final fundraising amount, and better material procurement. The project was made more economical through donations of cementitious materials, aggregates, and admixtures, and by utilizing free training and usage of an on-campus equipment. The breakdown of the budget is shown in Figure 11.

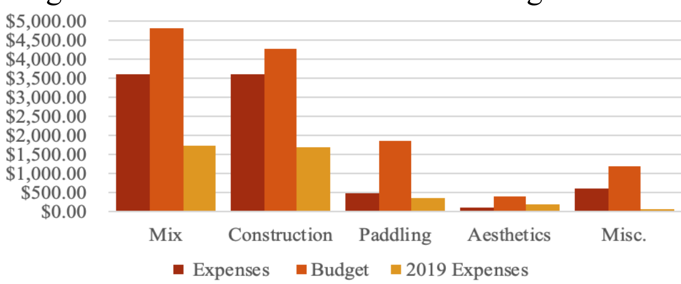


Figure 11. Budget and Expenditure Estimates

The team's budget doubled to provide the proper infrastructure for this year and future years, such as KitchenAid mixers and enough carbon fiber mesh for two to three future years' canoes.

Approach to Health & Safety

Safety was a priority throughout all processes. The PM and captains participated in fire safety, hazardous waste, and proper silica handling training. The PM set up a direct line of communication with the university lab mangers and had weekly meetings with them to approve material acquisitions and project activities. The team used personal protective equipment (PPE) such as contoured safety goggles, N95 face masks, and disposable gloves, as well as strictly enforced usage of long pants and close-toed shoes. The team worked with facilities management to dispose of concrete waste, old materials, and Styrofoam remnants, to ensure compliance with fire exits, cleared walkways, electrical cabinet accessibility, fire hazards, and cleanliness, and to update SOP's and SDS's.

Approach to Quality Control and Quality Assurance

For construction quality assurance, the team used different mold materials and procedures to better reflect the original hull design. The team placed pre-cut shelf liner on the mold's design to separate color swaths for accurate concrete placement. The team held a pre-training session before the casting day to brief members on how to achieve the goals for the final product. For mix design, the team ensured that each material in the mix was compliant with the rules before use in the mix. The team switched to KitchenAid® mixers for more consistent mixes. The team pre-batched the materials to reduce error on casting day.

For mix design quality control, the team implemented flexural, tensile, and buoyancy testing due to the lack of testing in these areas in previous years. The mix design team checked every mix for color and workability before its placement on the mold. For construction quality control, an orbital sander was used to create a smoother finish on the mold. Tread depth gauges checked the depth of the concrete after its placement on the mold. Finally, the leadership team monitored all aspects of the casting day activities to make sure all requirements were met.

Approach to Sustainability

In terms of social sustainability, the team worked to recruit a diverse group of students to encourage interaction between civil engineers in order to reduce stress on the leadership team in terms of workload and to ensure that the team has a stable footing for next year. For economic sustainability, the team saved over $200 by switching construction processes and saved almost $3000 by milling the mold at the ASU campus. While the team spent additional money this year to revamp infrastructure, this increase in spending will help the team save money and be better off next year. For environmental sustainability, the mix design team reduced the cement in the concrete, reduced batch volume to reduce concrete waste, reused concrete cylinders for testing, and used last year's remaining pre-batches to train new mix volunteers before starting testing. The team used buckets of water to cure multiple weeks' worth of cylinders to save on the water expenditure of typical curing chambers. The construction team used a releasing agent concentrate to save on the environmental impacts of shipping.

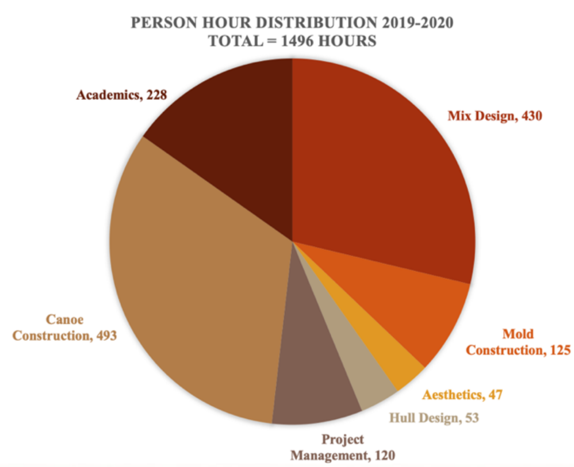
Management Approaches

Itemized Fee Summary Sheet

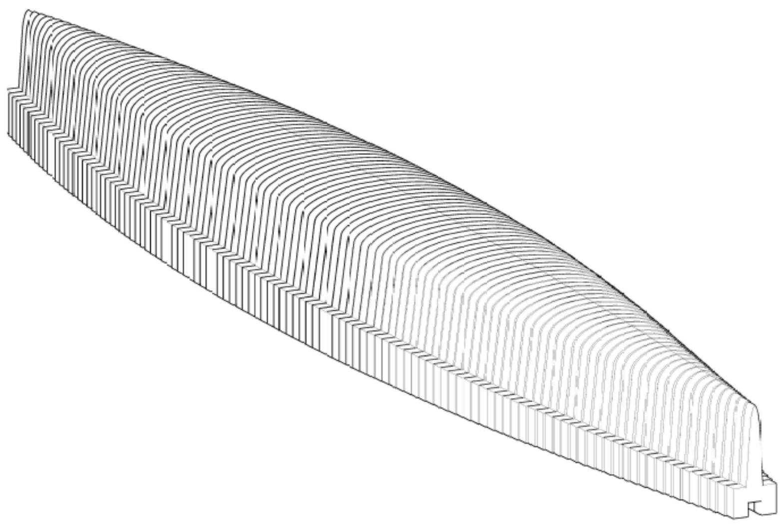
BILL OF MATERIALS				
Material	**Quantity**	**Units**	**Unit Price**	**Total**
Cementitious Materials				
Ordinary Portland Cement	47.06	lbs	$0.03	$1.41
Class C Fly Ash	26.86	lbs	$0.02	$0.54
Metakaolin	13.46	lbs	$0.37	$4.98
V-CAS 8™	20.20	lbs	$0.32	$6.46
Slag	13.46	lbs	$0.02	$0.27
Silica Fume	13.46	lbs	$0.44	$5.92
Aggregates				
Clay Shale (Fine)	18.41	lbs	$0.05	$0.92
Clay Shale (Crushed Fine)	12.14	lbs	$0.05	$0.61
Clay Shale (10 Mesh)	5.94	lbs	$0.05	$0.30
Poraver® 0.1-0.3mm	3.43	lbs	$0.25	$0.86
Poraver® 0.25-0.5mm	20.66	lbs	$0.25	$5.17
Poraver® 0.5-1.0mm	29.50	lbs	$0.25	$7.38
Poraver® 1.0-2.0mm	1.45	lbs	$0.25	$0.36
Admixtures				
Plastol 6400	0.10	gal	$8.79	$0.88
AEA-92	0.19	gal	$3.34	$0.63
Non-Carbonated Water	7.21	gal	$0.03	$0.22
Solids				
Direct Colors Pigment	3.30	lbs	$5.00	$16.50
3M™ K15 Glass Bubbles	6.53	lbs	$0.18	$1.18
Concrete Fibers				
Grace MicroFiber™	0.86	lbs	$0.93	$0.80
Tuf-Strand Maxten	1.06	lbs	$0.93	$0.99
Reinforcement				
Carbon Fiber Mesh	130	sq ft	$6.32	$821.60
Mold Construction				
Foam Mold	Lump Sum		$1,017.00	$1,017.00
Finishing				
Vinyl Lettering	Lump Sum		$104.00	$104.00
Everclear 350	130	sq ft	$0.50	$65.00
Styrofoam	1.05	cu ft	$25.00	$26.25
Shipping				
Transportation (Driving)	Lump Sum		$1,200.00	$1,200.00
TOTAL				**$3,290.21**

BILL OF LABOR (BY POSITION)			
Job Description	**Total Hours**	**Unit Price**	**Total**
Labor Costs			
Principal Design Engineer	373	$50	$18,650.00
Design Manager	60	$45	$2,700.00
Project Construction Manager	42	$40	$1,680.00
Construction Superindendent	30	$40	$1,200.00
Quality Manager	16	$35	$560.00
Technician/Drafter	5	$20	$100.00
Laborer/Technician	910	$25	$22,750.00
Clerk/Office Admin	50	$15	$750.00
Outside Consultants	10	$200	$2,000.00
TOTAL			**$50,390.00**

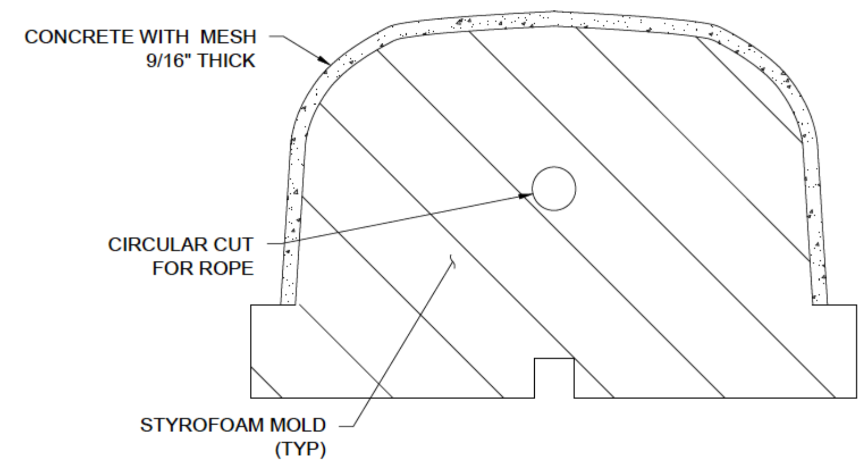
BILL OF LABOR (BY DISCIPLINE)			
Discipline	**Total Hours**	**Unit Price**	**Total**
Labor Costs			
Mix Design	430	Varies	$11,120
Mold Construction	125	Varies	$3,950
Aesthetics	47	Varies	$1,920
Hull Design	53	Varies	$2,050
Project Management	120	Varies	$6,000
Canoe Construction	493	Varies	$13,750
Academics	228	Varies	$11,600
TOTAL			**$50,390**



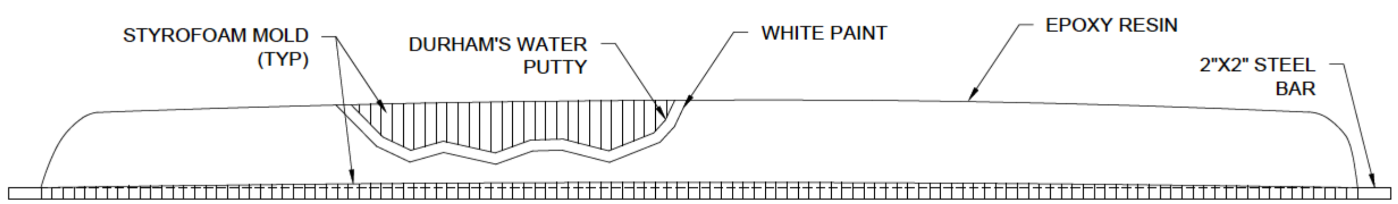
MOLD ISOMETRIC VIEW



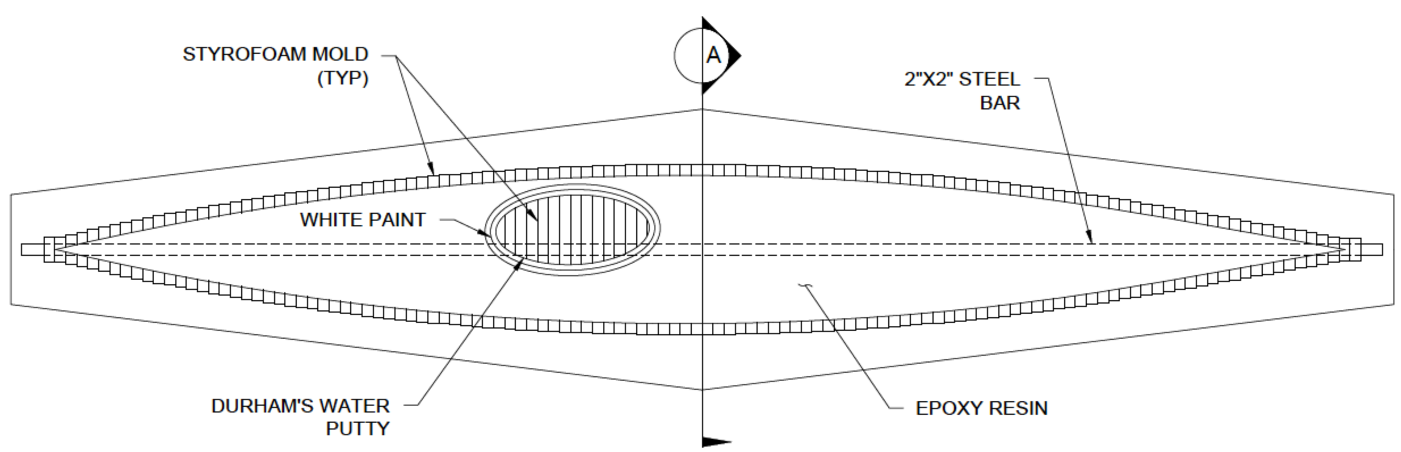
SECTION A-A WIDEST SECTION



MOLD ELEVATION VIEW



MOLD PLAN VIEW



ARIZONA STATE UNIVERSITY
CONCRETE CANOE

BILL OF MATERIALS	
Material	**Quantity**
Cementitious Materials	
Styrofoam	139 cu ft
Glidden Gripper	0.5 gal
Rope	50 ft
Durham's Water Putty	80 lbs
White Paint	1 gal
Epoxy Resin	2 gal
Kleen Kote	0.25 gal
Shelf Liner	3 sq ft

LEGACY
Arizona State University

PROJECT:	2020 PACIFIC SOUTHWEST CONFERENCE FULLERTON, CALIFORNIA
TITLE:	MOLD - CONSTRUCTION DOCUMENT

DRAWN BY:	MEN/CI	DATE: 2/12/20
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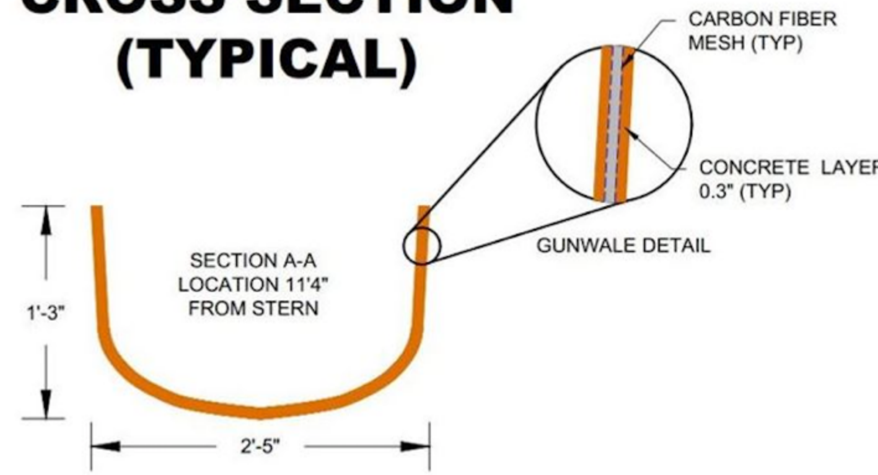
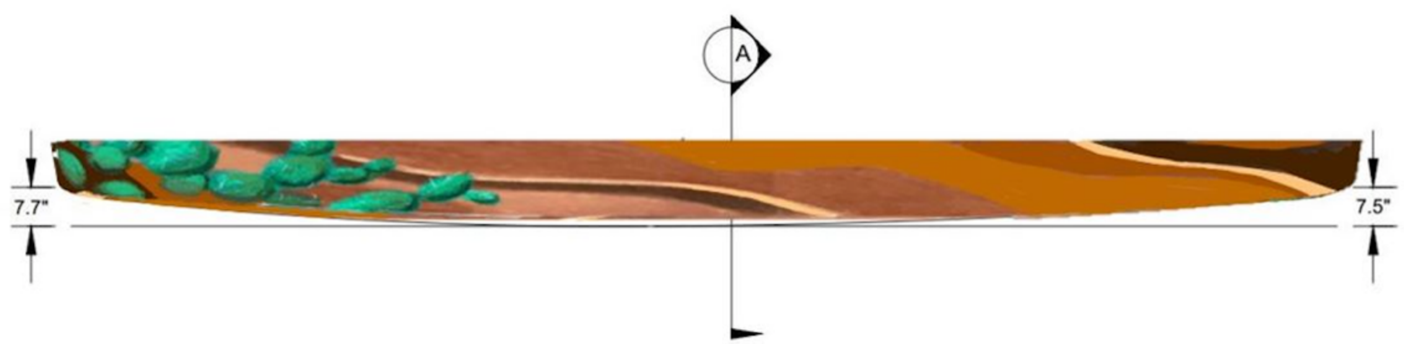
ISOMETRIC VIEW

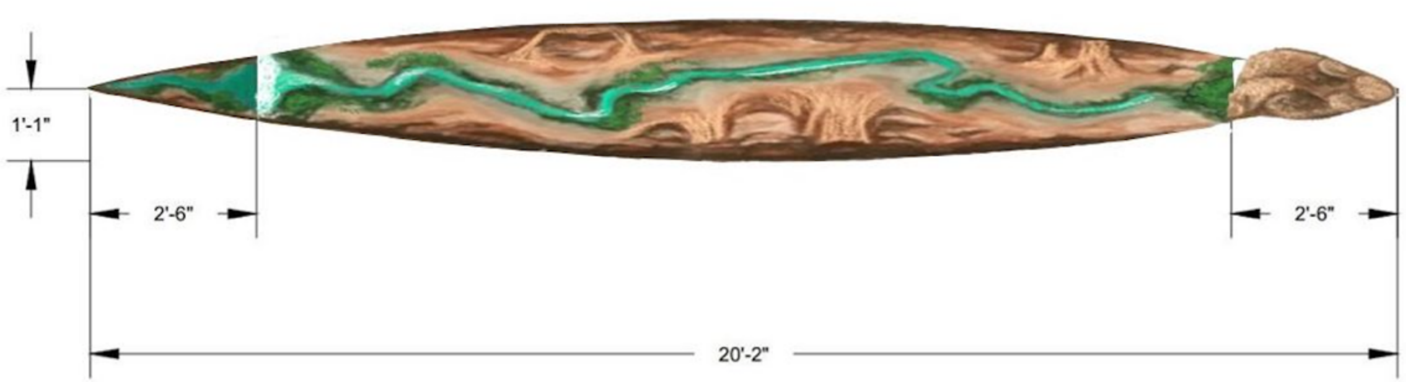
CROSS SECTION (TYPICAL)



ELEVATION VIEW



PLAN VIEW



ARIZONA STATE UNIVERSITY
CONCRETE CANOE

BILL OF MATERIALS	
Material	**Quantity**
Cementitious Materials	
Ordinary Portland Cement	47.06 lbs
Class C Fly Ash	26.86 lbs
Metakaolin	13.46 lbs
V-CAS 8™	20.2 lbs
Slag	13.46 lbs
Silica Fume	13.46 lbs
Aggregates	
Clay Shale (Fine)	18.41 lbs
Clay Shale (Crushed Fine)	12.14 lbs
Clay Shale (10 Mesh)	5.94 lbs
Poraver® 0.1-0.3mm	3.43 lbs
Poraver® 0.25-0.5mm	20.66 lbs
Poraver® 0.5-1.0mm	29.5 lbs
Poraver® 1.0-2.0mm	1.45 lbs
Admixtures	
Plastol 6400	0.1 gal
AEA-92	0.19 gal
Non-Carbonated Water	7.21 gal
Solids	
Direct Colors Pigment	3.3 lbs
3M™ K15 Glass Bubbles	6.534 lbs
Concrete Fibers	
Grace MicroFiber™	0.86 lbs
Tuf-Strand Maxten	1.06 lbs
Reinforcement	
Carbon Fiber Mesh	130 sq ft
Finishing	
Everclear 350	1.5 gal
Styrofoam	1.05 cu ft

LEGACY
Arizona State University

PROJECT:	**2020 PACIFIC SOUTHWEST CONFERENCE FULLERTON, CALIFORNIA**
TITLE:	**CANOE - CONSTRUCTION DOCUMENT**

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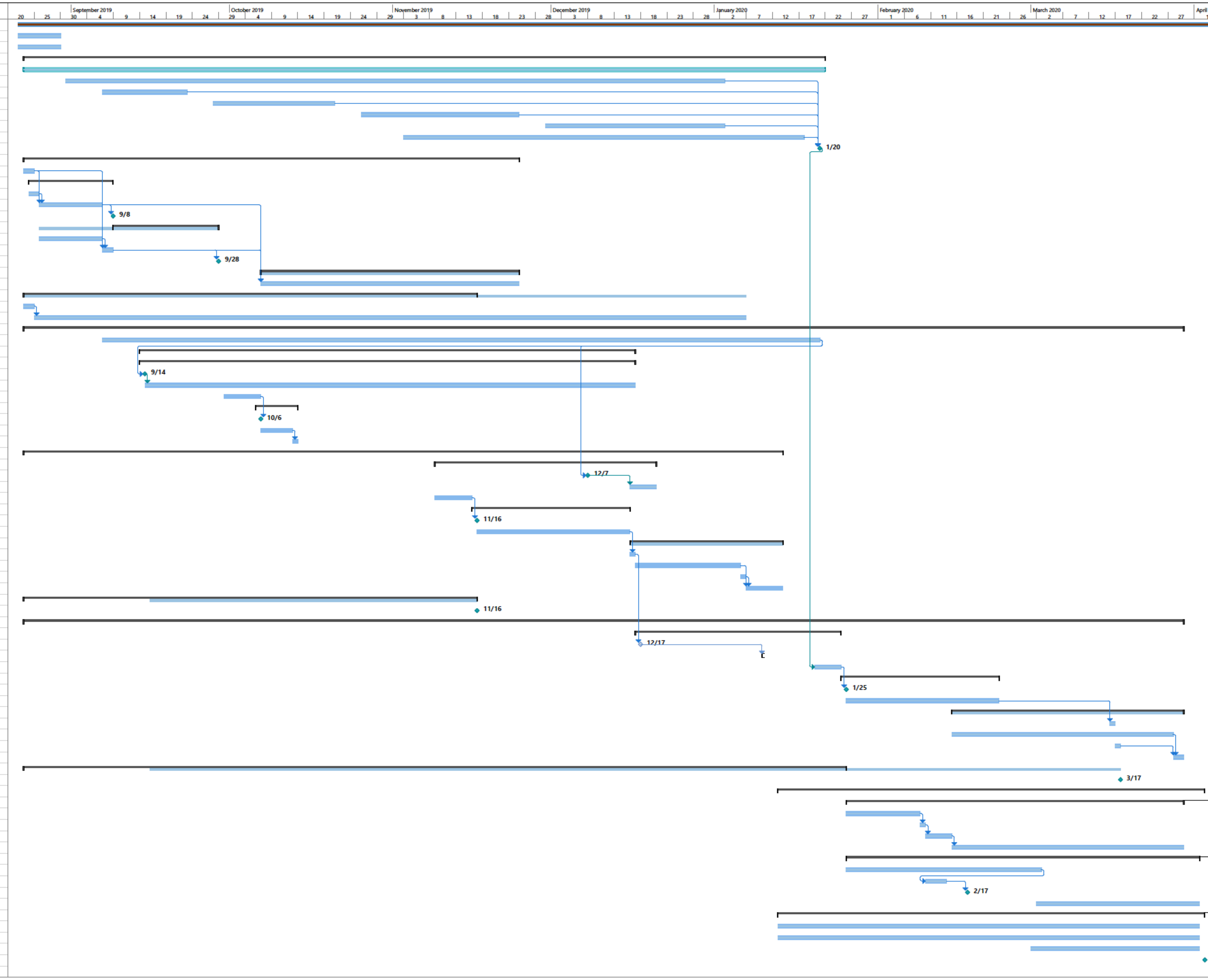
Project Schedule

ID	Task Name	Duration	Baseline Start	Baseline Finish	Actual Start	Actual Finish
1	**Concrete Canoe 2020**	163 days	Thu 8/22/19	Fri 4/3/20	Thu 8/22/19	Fri 4/3/20
2	**Performance Review**	7 days	Thu 8/22/19	Thu 8/29/19	Thu 8/22/19	Thu 8/29/19
3	**Project Planning & Research**	7 days	Thu 8/22/19	Thu 8/29/19	Thu 8/22/19	Thu 8/29/19
4	**Mix Design**	**109 days**	**Fri 8/23/19**	**Thu 1/23/20**	**Fri 8/23/19**	**Tue 1/21/20**
5	Materials Procurement	109 days	Fri 8/23/19	Thu 1/23/20	Fri 8/23/19	Tue 1/21/20
6	Materials Testing	90 days	Sat 8/31/19	Sun 11/17/19	Sat 8/31/19	Thu 1/2/20
7	Baseline Mixes	12 days	Sat 9/7/19	Sat 9/14/19	Sat 9/7/19	Sun 9/22/19
8	Cementious Materials Testing	17 days	Sun 9/15/19	Fri 10/4/19	Sat 9/28/19	Sun 10/20/19
9	Aggregate Testing	22 days	Sat 10/5/19	Fri 10/25/19	Sat 10/26/19	Sun 11/24/19
10	Admixture Testing	25 days	Sat 10/26/19	Fri 11/1/19	Sat 11/30/19	Thu 1/2/20
11	Fiber & Mesh Testing	56 days	Sat 11/2/19	Fri 11/8/19	Sun 11/3/19	Fri 1/17/20
12	Final Mix Selection	6 days	Mon 11/18/19	Mon 11/25/19	Mon 1/13/20	Mon 1/20/20
13	**Hull Design and Structural Analysis**	**67 days**	**Fri 8/23/19**	**Sun 11/24/19**	**Fri 8/23/19**	**Sun 11/24/19**
14	Revise MATLAB Program	2 days	Fri 8/23/19	Sat 8/24/19	Fri 8/23/19	Sat 8/24/19
15	**Hull Design (Miniature Canoe)**	**11 days**	**Sat 8/24/19**	**Sun 9/8/19**	**Sat 8/24/19**	**Sun 9/8/19**
16	Drafting & Modeling (Miniature C	2 days	Sat 8/24/19	Sun 8/25/19	Sat 8/24/19	Sun 8/25/19
17	Finalize Design (Miniature Canoe)	10 days	Mon 8/26/19	Fri 9/6/19	Mon 8/26/19	Fri 9/6/19
18	CNC Drafting (Miniature Canoe)	2 days	Sat 9/7/19	Sun 9/8/19	Sat 9/7/19	Sun 9/8/19
19	**Hull Design (Final Canoe)**	**16 days**	**Mon 9/9/19**	**Sat 9/28/19**	**Mon 8/26/19**	**Sat 9/28/19**
20	Drafting & Modeling (Final Canoe)	10 days	Mon 8/26/19	Fri 9/6/19	Mon 8/26/19	Fri 9/6/19
21	Finalize Design (Final Canoe)	2 days	Sat 9/7/19	Sun 9/8/19	Sat 9/7/19	Sun 9/8/19
22	CNC Drafting (Final Canoe)	6 days	Mon 9/23/19	Sat 9/28/19	Mon 9/23/19	Sat 9/28/19
23	**Structural Analysis**	**36 days**	**Mon 10/7/19**	**Sun 11/24/19**	**Mon 10/7/19**	**Sun 11/24/19**
24	Finalize Analysis	36 days	Mon 10/7/19	Sun 11/24/19	Mon 10/7/19	Sun 11/24/19
25	**Aesthetics**	**63 days**	**Fri 8/23/19**	**Sat 11/16/19**	**Fri 8/23/19**	**Mon 1/6/20**
26	Theme Selection	2 days	Fri 8/23/19	Sat 8/24/19	Fri 8/23/19	Sat 8/24/19
27	Design Sketching & Planning	97 days	Sun 8/25/19	Sun 9/15/19	Sun 8/25/19	Mon 1/6/20
28	**Construction**	**157 days**	**Fri 8/23/19**	**Sun 3/29/20**	**Fri 8/23/19**	**NA**
29	Material Procurement	97 days	Sat 9/7/19	Thu 9/12/19	Sat 9/7/19	Mon 1/20/20
30	**Miniature Canoe Construction**	**66 days**	**Sat 9/14/19**	**Sun 10/13/19**	**Sat 9/14/19**	**NA**
31	**Preparation**	**66 days**	**Sat 9/14/19**	**Sun 10/6/19**	**Sat 9/14/19**	**NA**
32	CNC Form	1 day	Sat 9/14/19	Sat 9/14/19	Sat 9/14/19	Sat 9/14/19
33	Mold Construction	67 days	Sun 9/15/19	Sun 9/29/19	Sun 9/15/19	Mon 12/16/19
34	Prebatching for Cast Day	6 days	Mon 9/30/19	Sun 10/6/19	NA	NA
35	**Casting Concrete**	**5 days**	**Sun 10/6/19**	**Sun 10/13/19**	**NA**	**NA**
36	Cast Day	1 day	Sun 10/6/19	Sun 10/6/19	NA	NA
37	Curing	6 days	Mon 10/7/19	Sat 10/12/19	NA	NA
38	Form Removal	1 day	Sun 10/13/19	Sun 10/13/19	NA	NA
39	**Practice Canoe Construction**	**103 days**	**Fri 8/23/19**	**Mon 1/13/20**	**Fri 8/23/19**	**NA**
40	**Preparation**	**30 days**	**Sat 10/5/19**	**Fri 11/15/19**	**Sat 11/9/19**	**NA**
41	CNC Form	2 days	Sat 10/5/19	Sat 10/5/19	Fri 12/6/19	Sat 12/7/19
42	Mold Construction	5 days	Sat 10/19/19	Fri 11/15/19	Mon 12/16/19	Fri 12/20/19
43	Prebatching for Cast Day	6 days	Sat 11/9/19	Fri 11/15/19	NA	NA
44	**Casting Concrete**	**20 days**	**Sat 11/16/19**	**Sun 12/15/19**	**NA**	**NA**
45	Cast Day	1 day	Sat 11/16/19	Sat 11/16/19	NA	NA
46	Curing	22 days	Sun 11/17/19	Sun 12/15/19	NA	NA
47	**Finishing**	**21 days**	**Mon 12/16/19**	**Mon 1/13/20**	**NA**	**NA**
48	Form Removal	1 day	Mon 12/16/19	Mon 12/16/19	NA	NA
49	Sanding	15 days	Tue 12/17/19	Sun 1/5/20	NA	NA
50	Bulkhead Placement and Const	1 day	Mon 1/6/20	Mon 1/6/20	NA	NA
51	Sealing	5 days	Tue 1/7/20	Mon 1/13/20	NA	NA
52	**Aesthetics**	**63 days**	**Fri 8/23/19**	**Sat 11/16/19**	**NA**	**NA**
53	Implement Inlays and Exlays	46 days	Mon 9/16/19	Sat 11/16/19	NA	NA
54	**Final Canoe Construction**	**157 days**	**Fri 8/23/19**	**Sun 3/29/20**	**Mon 9/16/19**	**NA**
55	**Preparation**	**29 days**	**Tue 11/26/19**	**Fri 1/24/20**	**Tue 12/17/19**	**NA**
56	Reassemble Form	1 day	Tue 12/17/19	Tue 12/17/19	NA	NA
57	Patch and Repair Mold	11 days	Fri 1/10/20	Fri 1/24/20	NA	NA
58	Prebatching for Cast Day	5 days	Tue 11/26/19	Mon 12/2/19	Mon 1/20/20	Fri 1/24/20
59	**Casting Concrete**	**20 days**	**Sat 1/25/20**	**Sun 2/23/20**	**Sat 1/25/20**	**Sun 2/23/20**
60	Cast Day	1 day	Sat 1/25/20	Sat 1/25/20	Sat 1/25/20	Sat 1/25/20
61	Curing	22 days	Sun 1/26/20	Sun 2/23/20	Sun 1/26/20	Sun 2/23/20
62	**Finishing**	**32 days**	**Sat 2/15/20**	**Sun 3/29/20**	**Sat 2/15/20**	**Sun 3/29/20**
63	Form Removal	1 day	Mon 3/16/20	Mon 3/16/20	Mon 3/16/20	Mon 3/16/20
64	Sanding	31 days	Sat 2/15/20	Fri 3/27/20	Sat 2/15/20	Fri 3/27/20
65	Bulkhead Placement and Const	1 day	Tue 3/17/20	Tue 3/17/20	Tue 3/17/20	Tue 3/17/20
66	Sealing	2 days	Sat 3/28/20	Sun 3/29/20	Sat 3/28/20	Sun 3/29/20
67	**Aesthetics**	**113 days**	**Fri 8/23/19**	**Sat 1/25/20**	**Mon 9/16/19**	**Tue 3/17/20**
68	Implement Inlays and Exlays	132 days	Mon 9/16/19	Sat 1/25/20	Mon 9/16/19	Tue 3/17/20
69	**Conference Preparation**	**59 days**	**Sat 8/31/19**	**Thu 4/2/20**	**Mon 1/13/20**	**Thu 4/2/20**
70	**Paddling**	**45 days**	**Sat 8/31/19**	**Sun 3/29/20**	**Sun 1/26/20**	**Sun 3/29/20**
71	Information Sessions & Open Trai	12 days	Sat 8/31/19	Fri 10/25/19	Sun 1/26/20	Sat 2/8/20
72	Tryouts	1 day	Sat 10/26/19	Sun 10/27/19	Sun 2/9/20	Sun 2/9/20
73	Team Selection	5 days	Mon 10/28/19	Fri 11/1/19	Mon 2/10/20	Fri 2/14/20
74	Practice	32 days	Sat 11/2/19	Sun 3/29/20	Sat 2/15/20	Sun 3/29/20
75	**Design Paper**	**48 days**	**Fri 1/3/20**	**Wed 4/1/20**	**Sun 1/26/20**	**Wed 4/1/20**
76	Rough Draft	27 days	Fri 1/3/20	Fri 1/31/20	Sun 1/26/20	Mon 3/2/20
77	Final Draft & Editing	4 days	Sat 2/1/20	Wed 2/12/20	Mon 2/10/20	Thu 2/13/20
78	Send Paper	3 days	Thu 2/13/20	Mon 2/17/20	Thu 2/13/20	Mon 2/17/20
79	Rehearse Technical Presentation	23 days	Mon 3/2/20	Wed 4/1/20	Mon 3/2/20	Wed 4/1/20
80	**Final Product Display**	**59 days**	**Mon 1/13/20**	**Thu 4/2/20**	**Mon 1/13/20**	**Thu 4/2/20**
81	Construct stand	58 days	Mon 1/13/20	Wed 4/1/20	Mon 1/13/20	Wed 4/1/20
82	Construct Table Display	58 days	Mon 1/13/20	Wed 4/1/20	Mon 1/13/20	Wed 4/1/20
83	Cutaway	24 days	Sun 3/1/20	Wed 4/1/20	Sun 3/1/20	Wed 4/1/20
84	Complete Display	1 day	Thu 4/2/20	Thu 4/2/20	Thu 4/2/20	Thu 4/2/20
85	**Attend PSWC at CSU Fullerton**	3 days	Thu 4/2/20	Sat 4/4/20	Thu 4/2/20	Sat 4/4/20



Milestone ◆ Summary Task Baseline

Page 1

MIXTURE: STRUCTURAL , MADE IN VARIETY OF SOUTHWESTERN COLORS

CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (lb/yd^3)*	
Portland Cement, ASTM Type 1	3.15	0.890	175	*Total cm (includes c)* **500** lb/yd^3 *c/cm ratio, by mass* **0.35**
Class C Fly Ash	2.30	0.697	100	
Metakaolin	2.20	0.364	50	
V-CAS 8™	2.60	0.462	75	
Slag Cement	2.90	0.276	50	
Silica Fume	2.20	0.364	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	*Expanded Glass (EG) or Cenosphere (C)*[1]	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity, W (lb/yd^3)*		*Volume, $V_{agg,SSD}$ (ft^3)*
					W_{OD}	*W_{SSD}*	
Clay Shale (Fine)	No	17.6	0.726	0.854	58.184	68.406	1.284
Clay Shale (Crushed Fine)	No	16.5	0.725	0.845	38.745	45.115	0.856
Clay Shale (10 Mesh)	No	14.3	0.722	0.825	19.286	22.040	0.428
Poraver (0.1-0.3)	Yes	35.0	0.667	0.9	9.448	12.755	0.227
Poraver (0.25-0.5)	Yes	28.0	0.531	0.68	59.940	76.723	1.809
Poraver (0.5-1.0)	Yes	20.0	0.392	0.47	91.557	109.868	3.743
Poraver (1.0-2.0)	Yes	20.0	0.342	0.41	4.546	5.455	0.213

LIQUID ADMIXTURES

Admixture	*lb/ US gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
AEA 92	8.5	18.26	6	5.70	*Total Water in Admixtures 7.72*
Plastol 6400	8.8	9.96	41	2.02	

SOLIDS (DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (lb/yd^3)*	
Direct Colors Pigment	2.50	0.078	12.20	*Total Amount of Solids 36.56*
3M™ K15 Glass Bubbles	0.15	2.602	24.36	

WATER

	Amount		*Volume*
Water, w	*w/c ratio, by mass* **0.91** *w/cm ratio, by mass* **0.32**	160 lb/yd^3	*2.564* ft^3
Total Free Water from All Aggregates, $\sum W_{free}$		-58.690 lb/yd^3	
Total Water from All Admixtures, $\sum W_{admx}$		7.72 lb/yd^3	
Batch Water, W_{batch}		210.970 lb/yd^3	

DENSITIES, AIR CONTENT, RATIOS, AND SLUMP

Values for 1 cy of concrete	*cm*	*Fibers*	*Aggregate (SSD)*	*Solids, S_{total}*	*Water, w*	*Total*
Mass, M *(lb)*	500	7.10	340.362	36.56	160	∑M: 1,044.02
Absolute Volume, V *(ft)*	2.69	0.125	8.56	2.69	2.564	∑V: 16.629
Theoretical Density, T, (=∑M / ∑V)	62.78 lb/ft^3		Air Content, Air, [= (T – D)/T x 100%]			4.43%
Measured Density, D	60 lb/ft^3		Air Content, Air, [= (27 – ∑V))/27 x 100%]			38.41%
Total Aggregate Ratio[2] *(=$V_{agg,SSD}$ / 27)*	*31.70%*		*Slump, Slump flow, Spread (as applicable)*			*1 in.*
EG+C Ratio[3] *(=V_{EG+C} / $V_{agg,SSD}$)*	*70%*					

MIXTURE: AESTHETICS, MADE IN A VARIETY OF SOUTHWESTERN COLORS

CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (ft³)*	*Amount of CM (lb/yd³)*	
Portland Cement, ASTM Type 1	3.15	1.567	307.98	*Total cm (includes c)* ***632.17*** *lb/yd³* *c/cm ratio, by mass* ***0.49***
Class C Fly Ash	2.30	1.129	162.09	
Metakaolin	2.20	0.472	64.84	
V-CAS 8™	2.60	0.599	97.26	
Slag Cement	2.90	0.000	0	
Silica Fume	2.20	0.000	0	

FIBERS

Component	*Specific Gravity*	*Volume (ft³)*	*Amount of Fibers (lb/yd³)*	
GRACE Micro-Fibers	0.91	0.055	3.10	*Total Amount of Fibers 3.10 lb/yd³*
Tuf-Strand Maxten Macro-Fibers	0.91	0.000	0.00	

AGGREGATES (EXCLUDING MINERAL FILLERS PASSING NO. 200 SIEVE)

Aggregates	*Expanded Glass (EG) or Cenosphere (C)*[1]	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity, W (lb/yd³)*		*Volume, $V_{agg,SSD}$ (ft³)*
					W_{OD}	*W_{SSD}*	
Clay Shale (Fine),	No	17.6	0.726	0.854	91.239	107.297	2.014
Clay Shale (Crushed Fine)	No	16.5	0.725	0.845	61.707	71.889	1.364
Clay Shale (10 Mesh)	No	14.3	0.722	0.825	30.951	35.377	0.687
Poraver (0.1-0.3)	Yes	35.0	0.667	0.9	85.448	115.354	2.053
Poraver (0.25-0.5)	Yes	28.0	0.531	0.68	102.551	131.265	3.095
Poraver (0.5-1.0)	Yes	20.0	0.392	0.47	62.840	75.408	2.569
Poraver (1.0-2.0)	Yes	20.0	0.342	0.41	37.731	45.277	1.768

LIQUID ADMIXTURES

Admixture	*lb/ US gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd³)*	
AEA 92	8.5	10.00	6	3.946	*Total Water in Admixtures 4.282*
Plastol 6400	8.8	1.31	41	0.336	

SOLIDS (DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)

Component	*Specific Gravity*	*Volume (ft³)*	*Amount (lb/yd³)*	
Direct Colors Pigment	2.50	0.078	12.20	*Total Amount of Solids 36.56*
3M™ K15 Glass Bubbles	0.15	2.602	24.36	

WATER

	Amount		*Volume*
Water, w	*w/c ratio, by mass* ***0.66*** *w/cm ratio, by mass* ***0.32***	202.294 lb/yd³	*3.242 ft³*
Total Free Water from All Aggregates, $\sum W_{free}$		-109.386 lb/yd³	
Total Water from All Admixtures, $\sum W_{admx}$		4.282 lb/yd³	
Batch Water, W_{batch}		307.398 lb/yd³	

DENSITIES, AIR CONTENT, RATIOS, AND SLUMP

Values for 1 cy of concrete	***cm***	***Fibers***	***Aggregate (SSD)***	***Solids, S_{total}***	***Water, w***	***Total***
Mass, M *(lb)*	632.17	3.10	581.867	36.56	202.294	∑M: 1455.991
Absolute Volume, V *(ft)*	3.767	0.055	13.55	2.69	3.242	∑V: 23.304
Theoretical Density, T, (=∑M / ∑V)	62.478 lb/ft³		**Air Content, Air, [= (T – D)/T x 100%]**			18.371%
Measured Density, D	51 lb/ft³		**Air Content, Air, [= (27 – ∑V))/27 x 100%]**			13.689%
Total Aggregate Ratio*[2] *(=$V_{agg,SSD}$ / 27)	*50.22%*		***Slump, Slump flow, Spread*** *(as applicable)*			*1 in.*
EG+C Ratio*[3] *(=V_{EG+C} / $V_{agg,SSD}$)	*70%*					

Appendix A - Mixture Proportions and Primary Mixture Calculation

Note 1: Numbers shown below have been rounded to three decimal places, however actual values were used when calculating vales in order to ensure precision.
Note 2: All values are per cubic yard of concrete.

Cementitious Materials

$$\boldsymbol{Mass = given}$$

$$Mass_{portland\ cement} = 175\ lbs$$

$$Mass_{fly\ ash} = 100\ lbs$$

$$Mass_{matakaolin} = 50\ lbs$$

$$Mass_{VCAS} = 75\ lbs$$

$$Mass_{slag\ cement} = 50\ lbs$$

$$Mass_{silica\ fume} = 50\ lbs$$

$$\boldsymbol{\sum Mass_{cementitious} = cm = 500\ lbs}$$

$$\boldsymbol{Volume = \frac{mass}{specific\ gravity * 62.4\ lb/ft^3}}$$

$$Volume_{portland\ cement} = \frac{175}{3.15*62.4} = 0.890\ ft^3$$

$$Volume_{fly\ ash} = \frac{100}{2.30*62.4} = 0.697\ ft^3$$

$$Volume_{metakaolin} = \frac{50}{2.20*62.4} = 0.364\ ft^3$$

$$Volume_{VCAS} = \frac{75}{2.60*62.4} = 0.462\ ft^3$$

$$Volume_{slag\ cement} = \frac{50}{2.90*62.4} = 0.276\ ft^3$$

$$Volume_{silica\ fume} = \frac{50}{2.29*62.4} = 0.364\ ft^3$$

$$\boldsymbol{\sum Volume_{cementitious} = 2.690\ ft^3}$$

Fibers

$$\boldsymbol{Mass = given}$$

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

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

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

$$\boldsymbol{Volume = \frac{mass}{specific\ gravity * 62.4\ lb/ft^3}}$$

$$Volume_{micro\ fibers} = \frac{3.10}{0.91*62.4} = 0.055\ ft^3$$

$$Volume_{macro\ fibers} = \frac{4.00}{0.91*62.4} = 0.070\ ft^3$$

$$\boldsymbol{\sum Volume_{fibers} = 0.125\ ft^3}$$

Aggregates

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

$$Mass_{clay\ shale\ (fine)} = 68.424\ lbs$$

$$Mass_{clay\ shale\ (crushed\ fine)} = 45.135\ lbs$$

$$Mass_{clay\ shale\ (10\ mesh)} = 22.033\ lbs$$

$$Mass_{poraver\ (0.1-0.3)} = 12.735\ lbs$$

$$Mass_{poraver\ (0.25-0.5)} = 76.764\ lbs$$

$$Mass_{poraver\ (0.5-1.0)} = 109.782\ lbs$$

$$Mass_{poraver\ (1.0-2.0)} = 5.446\ lbs$$

$$\boldsymbol{\sum Mass_{aggregates} = 340.32\ lbs}$$

$$\boldsymbol{Volume = \frac{W_{SSD}}{specific\ gravity(SSD) * 62.4\ lb/ft^3}}$$

$$Volume_{clay\ shale\ (fine)} = \frac{68.424}{0.854*62.4} = 1.284\ ft^3$$

$$Volume_{clay\ shale\ (crushed\ fine)} = \frac{45.135}{0.845*62.4} = 0.856\ ft^3$$

$$Volume_{clay\ shale\ (10\ mesh)} = \frac{22.033}{0.825*62.4} = 0.428\ ft^3$$

$$Volume_{poraver\ (0.1-0.3)} = \frac{12.735}{0.9*62.4} = 0.227\ ft^3$$

$$Volume_{poraver\ (0.25-0.5)} = \frac{76.764}{0.68*62.4} = 1.809\ ft^3$$

$$Volume_{poraver\ (0.5-1.0)} = \frac{109.782}{0.47*62.4} = 3.743\ ft^3$$

$$Volume_{poraver\ (1.0-2.0)} = \frac{5.446}{0.41*62.4} = 0.213\ ft^3$$

$$\boldsymbol{\sum Volume_{aggregates} = 8.560\ ft^3}$$

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

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

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

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

$$SG_{SSD-poraver\ (0.1-0.3)} = 0.90$$

$$SG_{SSD-poraver\ (0.25-0.5)} = 0.68$$

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

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

$$Abs_{clay\ shale\ (crushed\ fine)} = 16.5\%$$

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

$$Abs_{poraver\ (0.1-0.3)} = 35.0\%$$

$$Abs_{poraver\ (0.25-0.5)} = 28.0\%$$

$SG_{SSD-poraver\ (0.5-1.0)} = 0.47$ $\quad$ $Abs_{poraver\ (0.5-1.0)} = 20.0\%$

$SG_{SSD-poraver\ (1.0-2.0)} = 0.41$ $\quad$ $Abs_{poraver\ (1.0-2.0)} = 20.0\%$

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

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

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

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

$SD_{OD-poraver\ (0.1-0.3)} = \frac{0.90}{1+0.350} = 0.667$

$SD_{OD-poraver\ (0.25-0.5)} = \frac{0.68}{1+0.280} = 0.531$

$SD_{OD-poraver\ (0.5-1.0)} = \frac{0.47}{1+0.200} = 0.392$

$SD_{OD-poraver\ (1.0-2.0)} = \frac{0.41}{1+0.200} = 0.342$

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

$W_{OD-clay\ shale\ (fine)} = 1.284 * 0.726 * 62.4 = 58.184\ lbs$

$W_{OD-clay\ shale\ (crushed\ fine)} = 0.856 * 0.725 * 62.4 = 38.725\ lbs$

$W_{OD-clay\ shale\ (10\ mesh)} = 0.428 * 0.722 * 62.4 = 19.286\ lbs$

$W_{OD-poraver\ (0.1-0.3)} = 0.227 * 0.667 * 62.4 = 9.448\ lbs$

$W_{OD-poraver\ (0.25-0.5)} = 1.809 * 0.531 * 62.4 = 59.940\ lbs$

$W_{OD-poraver\ (0.5-1.0)} = 3.743 * 0.392 * 62.4 = 91.557\ lbs$

$W_{OD-poraver\ (1.0-2.0)} = 0.213 * 0.342 * 62.4 = 4.546\ lbs$

$\boldsymbol{\sum W_{OD(aggregates)} = 282.667\ lbs}$

$\boldsymbol{Mass(W_{SSD}) = W_{OD} * (1 + ABS)}$

$W_{SSD-clay\ shale\ (fine)} = 58.184 * (1 + 0.176) = 68.406\ lbs$

$W_{SSD-clay\ shale\ (crushed\ fine)} = 38.725 * (1 + 0.165) = 45.115\ lbs$

$W_{SSD-clay\ shale\ (10\ mesh)} = 19.283 * (1 + 0.143) = 22.040\ lbs$

$W_{SSD-poraver\ (0.1-0.3)} = 9.448 * (1 + 0.35) = 12.755\ lbs$

$W_{SSD-poraver\ (0.25-0.5)} = 59.940 * (1 + 0.28) = 76.723\ lbs$

$W_{SSD-poraver\ (0.5-1.0)} = 91.557 * (1 + 0.20) = 109.868\ lbs$

$W_{SSD-poraver\ (1.0-2.0)} = 4.546 * (1 + 0.20) = 5.455\ lbs$

$\boldsymbol{\sum W_{SSD(aggregates)} = 340.362\ lbs}$

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

$MC_{clay\ shale\ (fine)} = 0.0\%$

$MC_{clay\ shale\ (crushed\ fine)} = 0.0\%$

$MC_{clay\ shale\ (10\ mesh)} = 0.0\%$

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

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

$$MC_{poraver\ (0.5-1.0)} = 0.5\%$$
$$MC_{poraver\ (1.0-2.0)} = 0.5\%$$

$$\boldsymbol{Mass\ at\ Stock\ Moisture\left(MC_{stk(aggregate)}\right) = W_{OD(agg)} * \left(1 + \frac{MC_{stk}}{100\%}\right)}$$
$$Mass_{stk-clay\ shale\ (fine)} = 58.184\left(1 + \frac{0}{100}\right) = 58.184\ lbs$$
$$Mass_{stk-clay\ shale\ (crushed\ fine)} = 38.725\left(1 + \frac{0}{100}\right) = 38.725\ lbs$$
$$Mass_{stk-clay\ shale\ (10\ mesh)} = 19.286\left(1 + \frac{0}{100}\right) = 19.286\ lbs$$
$$Mass_{stk-poraver\ (0.1-0.3)} = 9.448\left(1 + \frac{0.5}{100}\right) = 9.495\ lbs$$
$$Mass_{stk-poraver\ (0.25-0.5)} = 59.940\left(1 + \frac{0.5}{100}\right) = 60.249\ lbs$$
$$Mass_{stk-poraver\ (0.5-1.0)} = 91.557\left(1 + \frac{0.5}{100}\right) = 92.015\ lbs$$
$$Mass_{stk-poraver\ (1.0-2.0)} = 4.546\left(1 + \frac{0.5}{100}\right) = 4.569\ lbs$$

$$\boldsymbol{Total\ Moisture\ Contents(MC_{total}) = \frac{MC_{stk(agg)} - W_{OD(agg)}}{W_{OD(agg)}}}$$
$$MC_{total-clay\ shale\ (fine)} = \frac{58.184 - 58.184}{58.184} = 0.0\%$$
$$MC_{total-clay\ shale\ (crushed\ fine)} = \frac{38.725 - 38.725}{38.725} = 0.0\%$$
$$MC_{total-clay\ shale\ (10\ mesh)} = \frac{19.286 - 19.286}{19.286} = 0.0\%$$
$$MC_{total-poraver\ (0.1-0.3)} = \frac{9.495 - 9.448}{9.448} = 0.005\%$$
$$MC_{total-poraver\ (0.25-0.5)} = \frac{60.249 - 59.940}{59.940} = 0.005\%$$
$$MC_{total-poraver\ (0.5-1.0)} = \frac{92.015 - 91.557}{91.557} = 0.005\%$$
$$MC_{total-poraver\ (1.0-2.0)} = \frac{4.569 - 4.546}{4.546} = 0.005\%$$

$$\boldsymbol{Moisture\ Contents(MC_{free}) = MC_{Total} - Abs}$$
$$MC_{clay\ shale\ (fine)} = 0.0 - 17.6 = -17.6\%$$
$$MC_{clay\ shale\ (crushed\ fine)} = 0.0 - 16.5 = -16.5\%$$
$$MC_{clay\ shale\ (10\ mesh)} = 0.0 - 14.3 = -14.3\%$$
$$MC_{poraver\ (0.1-0.3)} = 0.005 - 35 = -34.995\%$$
$$MC_{poraver\ (0.25-0.5)} = 0.005 - 28 = -27.995\%$$
$$MC_{poraver\ (0.5-1.0)} = 0.005 - 20 = -19.995\%$$
$$MC_{poraver\ (1.0-2.0)} = 0.005 - 20 = -19.995\%$$

$$\boldsymbol{Free\ Water\ (w_{free}) = W_{OD} * \left(\frac{MC_{free}}{100\%}\right)}$$
$$w_{clay\ shale\ (fine)} = 58.184\left(\frac{-17.6}{100}\right) = -10.240\ lbs$$
$$w_{clay\ shale\ (crushed\ fine)} = 38.725\left(\frac{-16.5}{100}\right) = -6.390\ lbs$$
$$w_{clay\ shale\ (10\ mesh)} = 19.286\left(\frac{-14.3}{100}\right) = -2.758\ lbs$$

$$w_{poraver\ (0.1-0.3)} = 9.448\left(\frac{-34.995}{100}\right) = -3.306\ lbs$$
$$w_{poraver\ (0.25-0.5)} = 59.940\left(\frac{-27.995}{100}\right) = -16.780\ lbs$$
$$w_{poraver\ (0.5-1.0)} = 91.557\left(\frac{-19.995}{100}\right) = -18.307\ lbs$$
$$w_{poraver\ (1.0-2.0)} = 4.546\left(\frac{-19.995}{100}\right) = -0.909\ lbs$$
$$\boldsymbol{\sum w_{free} = -58.690\ lbs}$$

Admixtures

$$\boldsymbol{Dosage = given}$$
$$Dosage_{AEA\ 92} = 18.26\frac{fl\ oz}{cwt}$$
$$Dosage_{Plastol\ 6400} = 9.96\frac{fl\ oz}{cwt}$$

$$\boldsymbol{water\ content = 1 - \%\ solids}$$
$$\boldsymbol{water_{admixtures} = dosage\left(\frac{fl\ oz}{cwt}\right) * cwt\ of\ cm * water\ contenet\ (\%) * \frac{1\ gal}{128\ fl\ oz} * \frac{lb}{gal}\ of\ admixture}$$
$$water_{AEA\ 92} = 18.26 * 5.00 * (1 - 0.06) * \frac{1\ gal}{128\ fl\ oz} * 8.5\frac{lb}{gal} = 5.700\ lbs$$
$$water_{Pastol\ 6400} = 9.96 * 5.00 * (1 - 0.41) * \frac{1\ gal}{128\ fl\ oz} * 8.8\frac{lb}{gal} = 2.020\ lbs$$
$$\boldsymbol{\sum water_{admixtures} = 7.720\ lbs}$$

Solids

$$\boldsymbol{Mass = given}$$
$$Mass_{pigment} = 12.20\ lbs$$
$$Mass_{glass\ bubbles} = 24.36\ lbs$$
$$\boldsymbol{\sum Mass_{solids} = 36.56\ lbs}$$

$$\boldsymbol{Volume = \frac{mass}{specific\ gravity * 62.4\ lb/ft^3}}$$
$$Volume_{pigment} = \frac{12.20}{2.50 * 62.4} = 0.078\ ft^3$$
$$Volume_{glass\ bubbles} = \frac{24.36}{0.15 * 62.4} = 2.602\ ft^3$$
$$\boldsymbol{\sum Volume_{solids} = 2.690\ ft^3}$$

Water

$$\boldsymbol{Water = \frac{w}{cm} * cm}$$
$$Mass_{water} = 0.32 * 500 = 160\ lbs$$

$$\boldsymbol{Batch\ Water\ (w_{batch}) = w - \left(\sum w_{free} + \sum w_{admix}\right)}$$
$$w_{batch} = 160 - (-58.690 + 7.72) = 210.97\ lbs$$

$$\boldsymbol{Volume = \frac{mass}{specific\ gravity * 62.4\ lb/ft^3}}$$
$$Volume_{water} = \frac{160}{1 * 62.4} = 2.564\ ft^3$$

Concrete Analysis

Densities:

$$\sum Masses = Mass_{concrete} = 1{,}044.02\ lbs$$
$$\sum Volumes = Volume_{concrete} = 16.629\ ft^3$$
$$Theoretical\ Density(T) = 62.78\ lbs/ft^3$$

$Measure\ Density\ (D) = 60\ lbs/ft^3$

Air content:

$Air\ Content = \frac{T-D}{T} * 100\% = \frac{62.79-60}{62.79} = 0.0444 = 4.43\%$

$Air\ Content = \frac{27\ ft^3 - Volume_{concrete}}{27\ ft^3} * 100\% = \frac{27-2.564}{27} = 0.3841 = 38.41\%$

Important Ratio:

Cement/cementitious ratio: $\frac{c}{cm} = \frac{175\ lbs}{500\ lbs} = 0.35$

Water/cementitious ratio: $\frac{w}{cm} = \frac{160\ lbs}{500\ lbs} 0.32$

Water/cement ratio: $\frac{w}{c} = \frac{160\ lbs}{175\ lbs} = 0.914$

Aggregate Ratio Check

$Aggregate\ Ratio\ (\%) = \frac{volume_{total\ aggregate}}{27\ ft^3} * 100\% = \frac{8.56}{27} * 100 = 31.70\% > 25\%$

Slump

Measured at 1" plus or minus 0.

Internal stresses were computed by first developing a free body diagram (Figure 12).

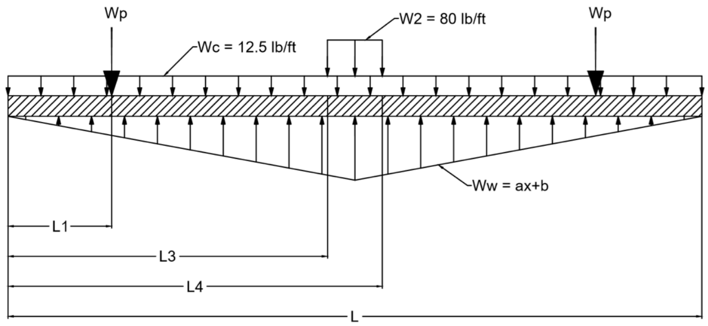


Figure 12. Full Free Body Diagram

For the loading condition provided in the prompt, the following assumptions were made:

$$W_c = 12.5\ lb/ft$$
$$W_2 = 80\ lb/ft$$
$$W_p = 200\ lbs$$
$$L = 20'2"\ (20.1667')$$
$$L_1 = 3ft$$
$$L_2 = 17'2"\ (17.1667')$$
$$L_3 = 7'7"\ (7.58')$$
$$L_4 = 12'7"\ (12.58')$$
$$W_w = ax + b$$

W_w, the distributed buoyant load, is assumed to be linear. The coefficient, a, was computed by setting the magnitude and location of the downward resultant force equal to the resultant of the buoyant force pushing upwards. This load was also constrained at the bow and stern to equal zero (which in turn forces b to equal 0. The following integrals compute the magnitude and centroid for the function:

$$R = \int_0^L [ax]dx = aL^2$$
$$\bar{x}R = \int_0^L \bar{x}[ax] = aL^3$$

Sum the vertical forces and moments from the FBD to compute the magnitude and location of the resultant buoyant force, then solve for a.

$$+\uparrow \sum F_y = R - W_c L - 2W_p - W_2(L_4 - L_3) = 0$$
$$R = 1053\ lbs$$
$$+(CW) \sum M_{bow} = \bar{x}R - 0.5W_c L^2 - W_p(L_1 + L_2) - 0.5LW_2(L_4 - L_3) = 0$$
$$\bar{x}R = 10{,}600\ ft - lb$$

Solve for a:

$R = aL^2$

$a = R/L^2 = 2.60$

Shear force and bending moment diagrams are computed from the FBD by taking three cuts (since the loading is symmetrical), then summing vertical forces and moment for each cut (Figure 13). Cut 1 was taken between the bow and first paddler load. Cut 2 was taken between the first paddler load and the cargo load distributed load. Cut 3 was taken inside of the cargo load before the midpoint of the canoe. Example calculations are shown for cut 3. The equations for the other cuts are computed in a similar manner, with the only difference being the reduction in loads as the cut are closer to the bow.

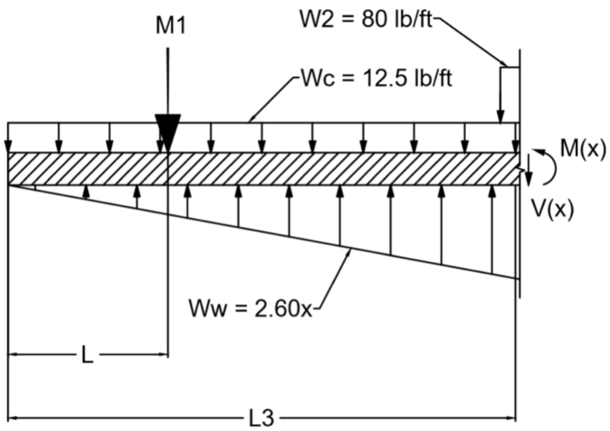


Figure 13. Free Body Diagram of Cut

$$\sum F_y = .5x * 2.60x - W_p - W_2 x - V(x_3) = 0$$
$$V(x_3) = 1.3x^2 - 92.5x - 200$$

$$\sum M = .5(x - L_3)W_2 + .5x(W_c) + (x - L_1)W_p - \frac{1}{3}x(.5W_w x) + M(x_3) = 0$$
$$M(x_3) = 0.43x^3 - 46.25x^2 - 200x + 600$$

x	$0 \le x \le L_1$	$L_1 \le x \le L_3$	$L_3 \le x \le L/2$
$V(x)$	$1.3x^2 - 12.5x$	$1.3x^2 - 12.5x - 200$	$1.3x^2 - 92.5x - 200$
$M(x)$	$0.43x^3 - 6.25x^2$	$0.43x^3 - 6.25x^2 - 200x + 600$	$0.43x^3 - 46.25x^2 - 200x + 600$

The following graphs were produced by using the equations found from the cuts.

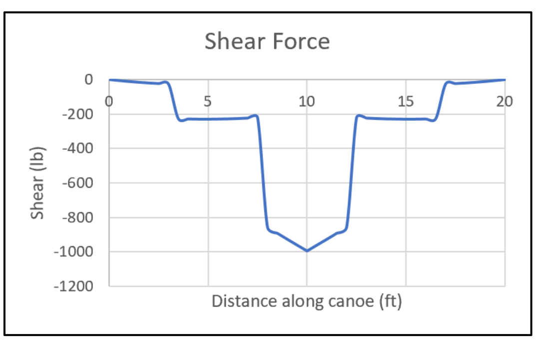


Figure 14. Shear Force Diagram

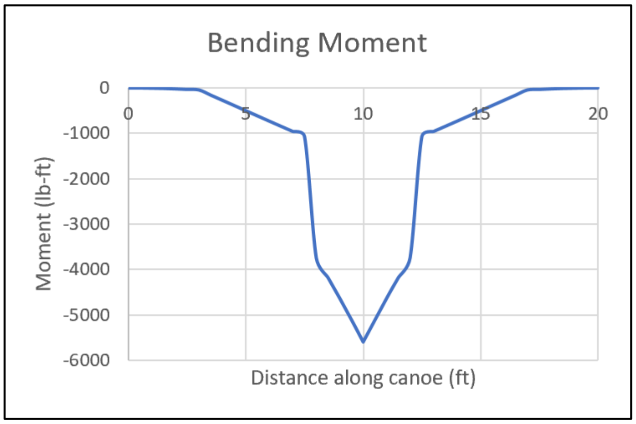


Figure 15. Bending Moment Diagram

Stress is computed by using the theory of simple bending, $\sigma = \frac{Mc}{I}$, where M is the max moment, c is the distance from the neutral axis to the extreme fiber, and I is the section moment of inertia. Since the moment diagram is negative, this means the belly of the canoe is in tension, and the top of the sidewalls are in compression.

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

Hull Thickness/Reinforcement Calculations

Thickness:

Layers

Three (3) structural layers at 3/16” each

Reinforcement

Two (2) layers of Carbon Fiber Mesh = (2)(0.026”) = 0.052”

Wall:

Total Wall Thickness: (3)(3/16”) + (0.052”) = 0.6145”

Total Reinforcement Thickness = 0.052”

Total Reinforcement Thickness/Total Wall Thickness = 0.0846 < 0.5 ***Acceptable Ratio***

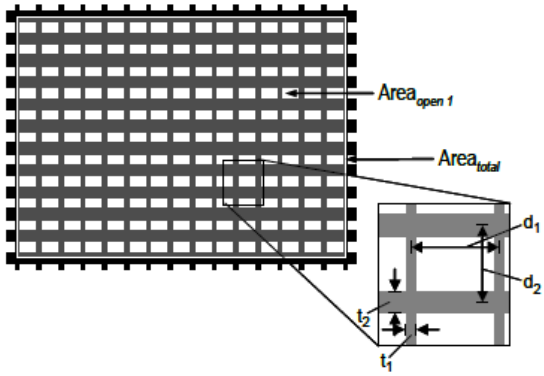
Bulkhead:

Total Wall Thickness: (3)(3/16”) + (0.052”) = 0.6145”

Total Reinforcement Thickness = 0.052”

Total Reinforcement Thickness/Total Wall Thickness = 0.0846 < 0.5 ***Acceptable Ratio***

Percent Open Area



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:

$$\boxed{\begin{gathered} d_1 = \text{aperature dimension} + 2(t_1/2) \\ d_2 = \text{aperature dimension} + 2(t_2/2) \\ \text{Length}_{\text{sample}} = n_1 d_1 \\ \text{Width}_{\text{sample}} = n_2 d_2 \\ \sum \text{Area}_{\text{open}} = n_1 \times n_2 \times \text{Area}_{\text{open 1}} \\ \text{Area}_{\text{total}} = \text{Length}_{\text{sample}} \times \text{Width}_{\text{sample}} \\ \text{POA} = \sum \text{Area}_{\text{open}} / \text{Area}_{\text{total}} \times 100\% \end{gathered}}$$

Carbon Fiber Mesh:

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

$$\text{Length}_{\text{sample}} = 15(3.5 \text{ mm}) = 52.5 \text{ mm}$$
$$\text{Width}_{\text{sample}} = 11(3.5 \text{ mm}) = 38.5 \text{ mm}$$
$$\sum \text{Area}_{\text{open}} = 15 \times 11 \times 5.0 \text{ mm}^2 = 825 \text{ mm}^2$$
$$\text{Area}_{\text{total}} = 52.5 \text{ mm} \times 38.5 \text{ mm} = 2970 \text{ mm}^2$$
$$\text{POA} = \frac{825 \text{ mm}^2}{2970 \text{ mm}^2} \times 100\% = 40.8\ \% > 40\% \rightarrow \textit{Compliant}$$

Appendix D - References

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Appendix E – Supporting Documentation

Pre-Qualification Form

Arizona State University
(school name)

We acknowledge that we have read the 2020 ASCE National 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 Conference and National Competitions as outlined in Section 2.0 and Attachment 1.	BJ KMW
The requirements for teams to qualify as a potential Wildcard team including scoring in the top 1/3 of all Annual Reports, submitting a Statement of Interest, and finish within the top 1/2 of our Conference Concrete Canoe Competition (Attachment 1)	BJ KMW
The eligibility requirements of registered participants (Section 2.0 and Attachment 1)	BJ KMW
The deadline for the submission of *Preliminary Project Delivery Schedule* and *Pre-Qualification Form* (uploaded to ASCE server) is November 1, 2019; 11:59 p.m. Eastern	BJ KMW
The last day to submit *ASCE Student Chapter Annual Reports* to be eligible for qualifying (so that they may be graded) is February 1, 2020	BJ KMW
The last day to submit *Request for Information* (RFI) to the CNCCC is January 15, 2020	BJ KMW
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.	BJ KMW
The submission date of *Technical Proposal* and *MTDS Addendum* for Conference Competition (hard copies to Host School and uploading of electronic copies to ASCE server) is Monday, February 17, 2020.	BJ KMW
The submission date of *Technical Proposal* and *MTDS Addendum* for National Competition (hard copies to ASCE and uploading of uploading of electronic copies to ASCE server) is May 19, 2020; 5:00 p.m. Eastern.	BJ KMW

Brielle Januszewski — 10/29/19
Project Manager (print name) — *(date)*

Brielle Januszewski
(signature)

Kristen M Ward — 10-30-2019
ASCE Student Chapter Faculty Advisor (print name) — *(date)*

Kristen Ward
(signature)

Appendix E – Supporting Documentation

Arizona State University
(school name)

In 150 words or less, provide a high-level overview of the team's Health & Safety (H&S) Program. If there is currently not one in place, what does the team envision their H&S program will entail?

The team's health and safety was created and is enforced by the project manager in conjunction with the ASU EH&S team. This includes long pants, close-toed shoes, face masks, and goggles utilization for all work done in the concrete and construction lab. All team leaders have completed requisite online and in-person training including fire safety, dust inhalation training, and hazardous waste disposal. The project manager also has a direct line of communication with the university lab manger and has weekly meetings with them to approve material acquisitions, project activities, and to update the health and safety guidelines depending on the phase the project is on and the materials being considered.

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?

For quality control, the mix design team has multiple tests, such as cylinder testing, slump testing, and buoyancy testing after every mix is made to ensure that each mix meets the requirements stipulated by the team. The construction team constantly tests the depth of concrete placed on the mold using tread-depth gauges and strips of shelf-liners to control the accuracy of concrete placement. For quality assurance, the team has started using KitchenAid mixers to achieve the same quality every time. The construction team has changed mold preparation procedures regarding the shaping of the bulkhead to ensure a final product that is consistent with the original design. The team has also implemented a new shelf-liner system to aid volunteers in placing the proper thickness of concrete. The team also hosts two pre-casting demonstrations to teach volunteers how to properly place concrete to minimize unevenness, slumping, and air pockets.

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 has completed multiple safety and testing trainings regarding using face masks, respirators, compression testing equipment, hazardous waste collection, and in sample preparation. The team is in constant communication with the EH&S team for the engineering school, meets with the EH&S team about once a week, has a dedicated Facilities Manager through ASCE, works with multiple professors for use of the machines and constantly ensures that the work is being conducted safely. The team has used a fume extractor, has updated procedures regarding ventilation, and prioritizes safety over efficiency.

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

Canoe Name: Legacy
Canoe Theme: National Parks/Wilderness

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

Yes, it was approved by the Faculty Advisor.

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

4

Provide an estimated project budget for the year (including materials, transportation, etc.). Base this on real costs (not costs provided in the Detailed Cost Assessment). List and approximate (percentage (%) of overall) anticipated financial sources for the upcoming year (University, material donations, sponsors, monetary donations, etc.)

The estimated project budget (including material acquisition, tools, transportation, and gear) is $5516.16. Anticipated financial sources are the university (66%), materials donations (10%), and sponsors (24%).

Acknowledgement of RFP Addendum(s)

RFP Addendum Acknowledgment Form

Arizona State University
(school name)

We acknowledge that we have received and acknowledge the following Addendums to the 2020 ASCE National Concrete Canoe Competition Request for Proposal (*initialed by team project manager and ASCE Faculty Advisor*):

Addendum No. 1: Presentation Q&A

This Addendum provides the Technical Presentation score card and a list of questions that the judges can use during the 10-minute Judge's question & answer period. In addition, a scorecard was provided.

Per Section 8.0 of the Request for Proposals (RFP), the presentation is limited to 3 minutes and will be cutoff at precisely 3 minutes by a signal. Also, per Section 8.0 of the RFP, the technical presentation "…should focus on the primary aspects of the design, construction, and technical capabilities. Briefly summarize the major aspects of the project, with the intent of demonstrating why your team, design, and prototype should be selected by the panel of judges for the standardized design (recall this is a hypothetical scenario to provide an end goal for the RFP and the competition)."

KMW BEJ

Addendum No. 2: Durability & Repairs

This Addendum provides information regarding how the durability of the canoe prototype is to be assessed, allowable repairs and materials, and forms including *Damage / Accident Report*, *Repair Procedure Report*, and *Reconstruction Request*.

KMW BEJ

Addendum No. 3: Detailed Cost Assessment

This Addendum provided a list of material costs for a variety of cementitious materials, pozzolans, admixtures, fibers, aggregates, and other constituents that were not presented in *Attachment 4: Detailed Cost Assessment* of the Request for Proposal. Teams were also advised that if they have products that were not given a specific price for, they should use their best judgement to use a price for a similar material in their Material Cost Estimate.

KMW BEJ

Brielle Januszewski — 2/13/20
Project Manager (print name) — *(date)*

Brielle Januszewski
(signature)

Kristen M Ward — 02/13/2020
ASCE Student Chapter Faculty Advisor (print name) — *(date)*

Kristen Ward
(signature)