University of Nevada, Reno

2022 Technical Report

Aune

February 18, 2022

Committee on Concrete Canoe Competitions
ASCE Student Services
1801 Alexander Bell Drive
Reston, VA 20191
Attn: 2021 Concrete Canoe Competition

Subject: Response to Request for Proposal -- 2021-2022 Concrete Canoe

Dear Committee on Concrete Canoe Competitions,

The Nevada Concrete Canoe Team (NCCT) is excited to present our project proposal for the 2021-2022 competition year. The NCCT has competed in the Concrete Canoe Competition for many years and is proud to present the culmination of our work during a year faced with the challenges caused by the ongoing COVID-19 pandemic. The team has thoroughly reviewed the *2021-2022 Request for Proposal*s (*RFP*) and has checked that the C4 that our submission complies with the rules and specifications. All registered participants listed below are qualified student members and Society Student Members of ASCE that meet all eligibility requirements detailed in Section 3.0 of the *2022 RFP*.

Participant	ASCE Society Member ID Number
Maya Abraham	000012298789
Michaela Bruns	000012287563
Robert Bush	000011944980
Annika Dixon	00001230057
Mason Loyd	000012282147
Arturo Medina	000011936223
Lucas Prichett	000012282153
Naomi Schlageter	000012282845
Alex Tang	000011695837
Emily Wolder	000011945005

Additionally, the NCCT hereby certifies that:

- The proposed hull design, concrete mixture design, reinforcement scheme, and construction of the prototype canoe has been performed in full compliance with the specifications outlined in the Request for Proposal.
- Material Technical Data Sheets (MTDS) and Safety Data Sheets (SDS) have been reviewed by the team.
- The team acknowledges receipt of the Request for Information (RFI) Summary and that their submissions comply with responses provided.
- The anticipated registered participants are qualified student members and Society Student Members of ASCE and meet all eligibility requirements.

The following signatures by the team captains and ASCE Student Chapter Faculty Advisor certify that the NCCT's 2022 submission *Azure* and the information presented in this *Project Proposal* and *MTDS Addendum* is true.

Sincerely,

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Table of Contents

Executive Summary

High in the Sierra Nevada region, where prairie meets meadow, the mountain bluebird can be spotted perched in low lying branches or even nesting in the cavities of the graceful aspen trees. The bright and brilliant blue of the mountain bluebird is seen as a sacred symbol to many Native American tribes. To the Pima tribe, the bluebird is a symbol of transformation and growth [1]. For the Navajo and Pueblo tribes, the bluebird's early morning song that signals daybreak has led them to associate it with the Sun [2]. It is from the stark blue color of Nevada's state bird and its symbolism that the NCCT's 2022 submission *Azure* derived its name.

The University of Nevada, Reno (UNR) is surrounded by vast wetlands and forests which provide refuge to hundreds of remarkable wildlife species of Northern Nevada [3]. This region is also home to the award-winning NCCT, which has a deeply rooted history of competing in the ASCE Concrete Canoe Competition. The team has involved itself with creating concrete canoes since the 1970s; however, the NCCT did not make a name for itself until the 2015-2016 project managers led the team to its first national competition with its submission *Euphoria* in 2006. For the next 15 years, the NCCT competed in the Mid-Pacific Region, one of the few regions to host international schools, and proved itself to be a top competitor with 11 national finishes and two national wins (*Argentum 2008* and *Alluvium 2014)*.

Azure's project team aimed to fly above the NCCT's high standards of quality (Table 1). This year, the team focused on further developing construction with a female form, organizational efforts to promote knowledge retention for future teams, developing new testing methods, and further pushing the bounds of the team's overall design process. Challenges due to supply chain delays were faced head-on, and project managers worked hard to ensure the team stayed on schedule despite extensive and continuous delays.

Table 1. Azure specifications.

Dimensions	
Colors	Black, Blue, Orange, White
Weight (estimated)	199 lbs.
Length (max)	21 ft.
Width (max)	25 in.
Depth (max)	12.3 in.
Thickness (avg.)	0.5 in.
Primary Reinforcement	
0.125 in. dia. Kevlar	
1.5 in. Carbon Fiber Mesh	
0.125 in. Steel Threaded Rod	
Secondary Reinforcement	
8 mm and 12 mm PVA Fibers	

The hull design team explored new ways to implement hull design mechanics beyond the traditional theoretical approach. The team experimented with field testing with fiberglass practice canoes cast using forms from previous years was to improve understanding of canoe hull performance. This hands-on approach gave the hull design team a look at the relationships between the different equations and characteristics of canoe.

The structural team experimented with naval architect software DELFTship™ to analyze hull design and meet new requirements from the *2022 RFP* [4], [5]. DELFTship™ was also helpful in exploring and understanding the NCCT's structural analysis worksheet that has been extensively used since 2008. The team was able to an optimized prestress system for a female form and provide accurate values for mix design requirements.

The construction team worked to implement the team's first prestress system in a female form; 2022 is only the second time the NCCT used this form type since its introduction in 2019. The lack of a prestress system in *Redacted* (2019) resulted in a canoe that did not meet serviceability standards. This year, the team also developed a streamlined construction process for a female form that would meet these standards and create a foundation on which future teams can develop.

The mix design team refined the structural mix to improve workability without sacrificing strength using an innovative testing method (Tables 2 and 3). Changes in rules and closure of the team's Haydite supplier led the team to explore new aggregates. The team also explored different methods to accelerate the mix design process and testing due to delays. The tests focused on creating batches that differ in ratios of cementitious material and aggregate gradation.

Table 2. Structural Mix Properties

Unit Weight Wet/Dry	70.1 lb/ft^3	67.5 lb/ft^3
7 Day Compressive Strength	2245 psi	
7 Day Tensile Strength	421 psi	
7 Day Composite Flexural Strength	551 psi	
Concrete Slump/Spread	¼ inch	
Air Content	6.6%	

Table 3. Patch Mix Properties

Unit Weight Wet/Dry	72.4 lb/ft^3	67.5 lb/ft^3
7 Day Compressive Strength	1442 psi	
7 Day Tensile Strength	291 psi	
7 Day Composite Flexural Strength	-	
Concrete Slump/Spread	3.0 inch	
Air Content	6.6%	

The team set a goal to be more environmentally conscious to set a better standard for future years. Project managers worked to reduce carbon footprint by reducing the number of miles generated by driving the NCCT trailer. Reducing waste was key to becoming more sustainable, so the team looked for ways to increase reusability during the project lifecycle.

Azure's project managers adapted and ensured the team remained on schedule despite the ongoing COVID-19 pandemic which caused extensive delays in material acquisition. Efficient scheduling and increased involvement of team managers was key to remaining on track. Despite these challenges, the NCCT was able to complete the project on schedule and under budget.

It is with pride that the NCCT continues its tradition in competing in the ASCE Concrete Canoe Competition throughout another challenging year and presents the Committee on Concrete Canoe Competitions with Nevada's newest addition to its fleet, *Azure*.

ASCE Student Chapter Profile

An integral part of the engineering community in Reno, Nevada, the American Society of Civil Engineers (ASCE) Student Chapter acts as the bridge between students at the University of Nevada, Reno (UNR) and those in the professional community. Established in the 1980s, the UNR ASCE Student Chapter provides its members opportunities to enhance their education and practice the professional skills necessary for their future careers. The University's Civil and Environmental Engineering program stands among the best in the country, with some of the program's 475 undergraduate and graduate students making up the student chapter.

The UNR ASCE Student Chapter is an active part of the Truckee Meadows Community, working with the Truckee Meadows Branch of the Younger Member Forum (YMF) to provide students the opportunity to engage with local engineering firms, practice professional interviewing skills, and meet some of the professionals that students may work with in the future in yearly events such as the Office Crawl. To celebrate the hard work of students and to express gratitude to the many firms and individuals who support the UNR ASCE Chapter, the ASCE Truckee Meadows Branch, in conjunction with the student chapter, hosts the annual ASCE Awards Banquet.

The Student Chapter also has demonstrated it competitiveness at the ASCE Concrete Canoe Competition, both at the regional and national level, with the NCCT placing first at nationals in 2014 with Alluvium, third in 2016 with Zephyr, and second at regionals in 2019 with its canoe Goldstrike. Student teams also compete annually in the Water Treatment, Geowall, and Sustainable Solutions events and achieve excellent results and high competency in these areas as well.

The UNR ASCE Student Chapter strives to give back to the community, particularly working towards helping the prominent homeless population by hosting canned food drives. Community outreach to schools promotes STEM education and pursuing a career in the field. The student chapter's involvement with Keep Truckee Meadows Beautiful is an example of how UNR ASCE shows its contribution to a greener planet, where students help maintain regional park grounds twice a semester.

Figure 1. UNR ASCE Student Chapter Summary.

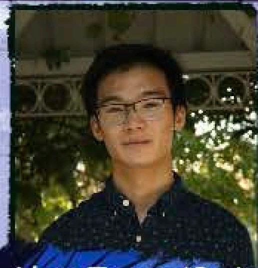
Key Team Members

Team Managers

Name	Role	Duties
Alex Tang (Sr.)	Project Manager	QA/QC, Fundraising, Budget Appropriation, Scheduling, Communication, Task Delegation, Project Proposal, Technical Presentation
Arturo Medina (Jr.)	Project Manager	QA/QC, Fundraising, Budget Appropriation, Scheduling, Communication, Task Delegation, Project Proposal, Technical Presentation
Mason Loyd (So.)	Assistant Project Manager	QA/QC, Communication, Environmental Health and Safety, Hull Design, Enhanced Focus Area Development
Lucas Pritchett (Fr.)	Construction Manager	Research, Held and oversaw quality of construction (QA/QC)
Aditya Prathap (Jr.)	Construction Manager	Research, Held and oversaw quality of construction (QA/QC)
Naomi Schlageter (So.)	Mix Design Manager	Research, development, testing of concrete design
Nura Tung (Jr.)	Design Manager	Artistic elements of proposal
Parker Allison (Sr.)/Payton Griffin (Sr.)	Structural Engineer	Structural analysis to determine concrete strength and reinforcement requirements
Colton Dodge (Sr.)	Paddling Coach	Develop skills of paddlers

Student Members

Construction	Maya Abraham (Fr.), Matthew Walker (Fr.), Vanessa Arias (So.), Christan Aguiar(So.), Zach Flowers (Jr.), Sam Triest (Sr.), Libby Elliott (Sr.), Robert Bush (Sr.)
Mix Design	Michaela Bruns (So.), Emily Wolder (Sr.), Erick Bandala(Sr.), Matthew Morrison (Sr.)
Design	Sarah Gu (Sr.), Parker Allison (Sr.), Amanda Singleton (Sr.)
Structural	Payton Griffin (Sr.), Parker Allison (Sr.)

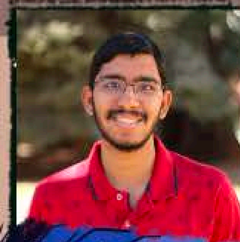


Alex Tang (Sr.)
Project Manager

Arturo Medina (Jr.)
Project Manager

Mason Loyd (So.)
Asst. Project Manager

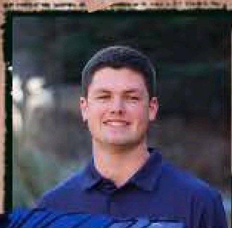
Lucas Pritchett (Fr.)
Construction Manager



Aditya Prathap (Jr.)
Construction Manager

Naomi Schlageter (So.)
Mix Design Manager

Nura Tung (Jr.)
Design Manager



Payton Griffin (Sr.)
Structural Engineer

Parker Allison (Sr.)
Structural Engineer

Colton Dodge (Sr.)
Paddling Coach

ADVISOR

Kelly Keselica

ASST. MEMBERS

Maya Abraham (Fr.), Matthew Walker (Fr.), Vanessa Arias (So.), Christian Aguiar (So.), Michaela Bruns (So.), Annika Dixon (So.), Zach Flowers (Jr.), Sam Triest (Sr.), Libby Elliott (Sr.), Rober Bush (Sr.), Emily Wolder (Sr.), Erick Bandala (Sr.), Matthew Morrison (Sr.), Sarah Gu (Sr.)

PADDLERS

Maya Abraham, Michaela Bruns, Robert Bush, Mason Loyd, Arturo Medina, Lucas Pritchett, Naomi Schlageter, Annika Dixon, Alex Tang, Emily Wolder

Hull Design

The goal for *Azure's* hull design was to create a canoe that was optimized for both sprint and slalom racing but could also see recreational use. Analysts decided to use *Goldstrike* (2019) and *Redacted* (2020) as baselines for the hull design.

Preliminary analysis began by comparing the performance between *Goldstrike* and *Redacted. Redacted* could not be used for analysis because of damages sustained from poor concrete curing due to the abrupt end of construction due to COVID-19. In order to compare the two canoes, fiberglass resin practice canoes were cast using the preserved forms. Field tests were conducted by the paddling and hull design team to compare empirical results with theoretical outputs of *Aquaholic*, a hull design spreadsheet developed by the NCCT, and knowledge from canoe design literature such as *The Shape of the Canoe* (Table 4) [6].

Table 4. Comparison of field results and Aquaholic outputs

Characteristic	Goldstrike	Redacted
Average 200-meter sprint	103 seconds	94 seconds
Average 180º turn time	13 seconds	8 seconds
Average Stability Rating (1-5)	1.2	4.8
Block Coefficient	0.56	0.60
Prismatic Coefficient	0.610	0.658
Section coefficient	0.909	0.913
Length	20.8 ft.	19 ft.
Beam (max)	26 in.	23 in.

The 200-meter sprint was used to compare the straight-line speed and tracking of the canoes. The 180º turn was used to compare maneuverability around a buoy. The stability rating was obtained from paddlers who rated each canoe's stability during the race from 1 to 5 (best to worse). The block coefficient, C_b, is a measure of hull fineness where a higher C_b would indicate a blocky hull and a lower indicates a fine V-shaped hull [6]. This was used to quantify tracking. The prismatic coefficient, C_p, is an indicator of a hull's wave-making resistance which is a cause of drag [6]. The section coefficient, C_x, was used to quantify maneuverability where a large value indicates a hard chine which is used to increase maneuverability [5], [7]. The differences between C_b, C_p, and C_x is displayed in Figure 2, where C_x and C_m are equivalent [7].

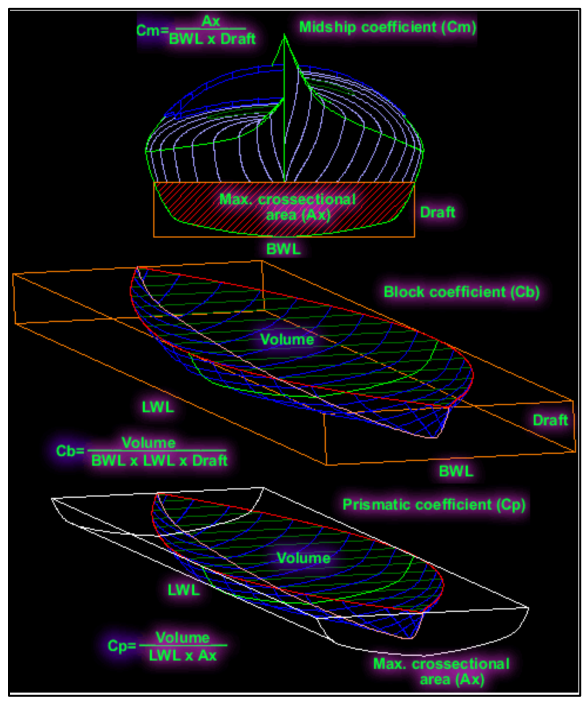


Figure 2. Definitions of Cb, Cp, and Cx [7]

The hull design team interpreted that *Goldstrike's* V-shaped stern and long length were ideal for tracking but made it difficult to maneuver, indicated by the 5 second difference in turn time. *Redacted*, being shorter, having rounded sections at the stern, and rectangular cross-sections at the middle provided it with exceptional maneuverability. Additionally, the higher C_p indicated *Redacted* experienced less wave-making resistance which allowed it to surpass *Goldstrike* in the 200-meter sprint [6], [8]. However, the combination of its cross-section shapes, smaller beam, and shorter length resulted in a reduced wetted surface area and subsequently stability issues. The stability issues and high maneuverability of *Redacted* caused paddlers to veer off course or capsize during testing. From this, the hull design team decided to focus on maintaining the tracking of *Goldstrike* and the maneuverability of *Redacted* without sacrificing stability.

The team first focused on increasing the wetted surface area of the hull to increase stability. The beam of *Azure* was increased from 23 in. to 25 in. A wider beam provides more stability because the center of buoyancy shifts to the bilge when a canoe begins to roll, and a righting moment is required to maintain stability to prevent capsizing [6], [9]. By increasing the distance from the center of buoyancy, the righting moment is increased. To further increase the wetted surface area, the overall length of the canoe was increased from 19 ft to 21 ft, which also benefitted in maximizing speed [10].

An increased length reduces maneuverability, so the rocker was increased at the bow and stern. Rocker is the curvature from bow to stern and is measured as the height from the base of the canoe. The hull design team studied the shape of kayaks designed for slalom races and found that rocker at both the bow and stern improved the ability for kayaks to maneuver [11]. The team inrceased the bow rocker from 3.5 in to 4.5 in and the stern rocker from 0.34 in to 2.6 in (Figures 3 and 4). To further increase the maneuverability, more U-shaped sections were used across the length of the hull.

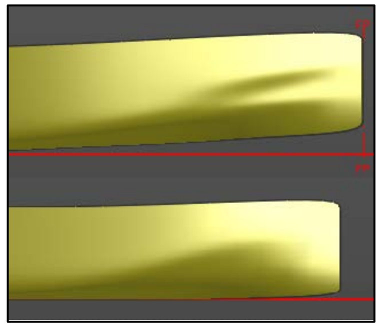


Figure 3. Azure stern (top) compared to Redacted stern (bottom).

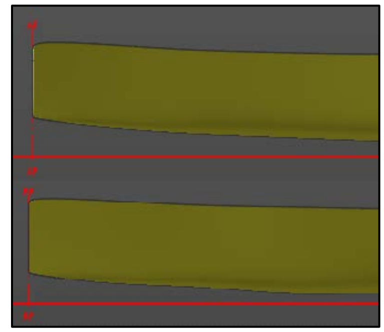


Figure 4. Azure bow (top) compared to Redacted bow (bottom).

Tracking was maintained by incorporating a V-shaped stern and asymmetric shape. A V-shaped stern acts as a keel in a canoe, which helps maintain course [12]. This was incorporated into the stern because combined with an asymmetric shape and widest beam behind the mid-point, the center of buoyancy is located in the back making the stern paddler in charge of steering. *Azure's* stern tied elements between *Goldstrike's* sharp-V-shaped and *Redacted's* U-shaped stern to maintain a balance between tracking and maneuverability (Figure 5).

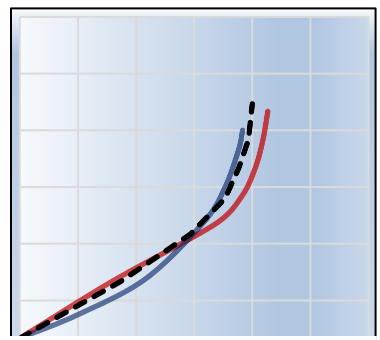


Figure 5. One-half stern profiles of Goldstrike (red), Redacted (blue), and Azure (black).

Comparison between Aquaholic results in Table 5 shows *Azure's* low C_b and high C_x which indicate improved tracking and maneuverability compared to *Redacted*. *Azure*'s larger C_p means it is expected to experience slightly more skin drag, or resistance, than *Redacted* but similar to *Goldstrike's* whose performance allowed the NCCT to take first in the 2019 competition races.

Table 5 Summary of Goldstrike, Redacted, and Azure.

Coefficient	Goldstrike	Redacted	Azure
C_b	0.56	0.60	0.55
C_x	0.909	0.913	0.927
C_p	0.610	0.658	0.590

Structural Analysis

The structural analysis team was tasked with providing the mix design team with concrete design requirements in order to produce a canoe that would meet the demands of the competition. Shear and moment diagrams were analyzed to determine maximum stresses to determine minimum concrete strength requirements (Table 6). The team also looked

Table 6. Summary of shear and moment values.

Loading Scenario	Max Shear	Max Moment
Male Tandem	211.0 lbs.	- 978.4 lb.-ft
Female Tandem	174.3 lbs.	- 844.8 lb.-ft
Four-person co-ed	150.3 lbs.	-887.5 lb.-ft
Simply Supported (both)	80 lbs.	457.43 lb.-ft

for ways to reduce the stresses and increase the overall strength and durability of the canoe by incorporating different reinforcements.

Using the NCCT structural analysis spreadsheet, the hull design was inputted as coordinate points. Each cross-section was graphed at one-foot intervals along the length of the canoe and values for area, centroid, and moment of inertia were calculated. Shear force and bending moment diagrams were analyzed for female and male tandem, four-person-co-ed, and simply supported right side up and upside down. For simplicity, the canoe was modeled as a 2D beam for all scenarios with a self-weight distributed load. Buoyant forces were assumed nonuniform for a more accurate analysis and were calculated at one-foot sections. For each tandem scenario, paddlers were placed 3 ft and 19 ft from the bow. The male loading case was evaluated as two 200 lb. point loads, and the female loading case was evaluated as two 160 lb. point loads. Four-person co-ed was evaluated as two 200 lb. point loads 3 ft and 15 ft from the bow and two 160 lb. point loads 7 ft and 19 ft from the bow. Simply supported cases represented two-person carry and display scenarios. The maximum negative moment was determined to be the male tandem loading case and the maximum positive moment the simply supported loading case.

Initial analysis required concrete to meet a minimum compressive strength of 262.6 psi and modulus of rupture of 411.45 psi. To reduce the demand, a prestress system was incorporated. The system also increased the strength, durability, lifespan, and serviceability of the canoe. Analysts determined that the system required 4,200 lbs. evenly distributed across 14 tendons. An assumed loss of 25 percent due to creep, elastic shortening, shrinkage, and relaxation in accordance with AASHTO LRFD Bridge Design Specification was accounted for [13]. To minimize stress at the gunwales during the races and chine during transportation, four tendons were pathed along the gunwales and three along the chine. After applying a factor of safety of 1.25 to compressive strength and 2.5 tensile strength, the structural analysts determined that a minimum of compressive strength of 884.2 psi and a modulus of rupture of 236.40 psi was required for the concrete. A larger factor of safety was applied in tension to account for concrete's weakness in tension.

Additional analysis determined the amount of foam required in the bulkheads, rib locations, and carbon-fiber grid reinforcement scheme. The amount of foam required was determined by using the self-weight of the canoe to determine the buoyant force required to maintain equilibrium about the canoe's center of gravity. Structural ribs were incorporated at paddler locations to prevent shear failure along the base of the canoe from paddler's knee pressure and to counteract the radial forces from the prestress system. A dual-layered carbon-fiber grid system served as primary reinforcement for the concrete mixture to provide bending resistance along the length of the canoe.

Mix Design

Due to difficulties in material procurement, staffing, and COVID-19 related issues, the mix design team faced many adversities in the design of a lightweight concrete mixture that was capable of meeting the structural and aesthetic requirements for *Azure*. To accommodate for these adversities, the mix design team implemented an accelerated testing method to simultaneously optimize the gradation of Utelite® and ratio of metakaolin to hydrated lime (MKL).

Goldstrike's mix served as a baseline for *Azure's* structural mix due it its proven strength at the 2019 competition and the environmentally sustainable supplementary cementitious materials (SCMs) and aggregates that were used. White Portland cement Type 1 was used as the primary source of strength in the mix and for aesthetic purposes. Metapor® Metakaolin and hydrated lime cement were used as sustainable, lightweight SCMs to reduce the amount of Portland cement used to 30%.

Poraver® Expanded Glass and Syntheon® Elemix™ were incorporated because of their low specific gravities (S.G). ranging from 0.04 to 0.85. To meet ASTM C330 aggregate requirements, the team incorporated Utelite® Structural Fines. Utelite® replaced Haydite, an ASTM C330 aggregate used in previous NCCT mix designs that is no longer commercially available. ASTM C127/C128 data from the *Goldstrike* team identified the specific gravities and absorptions of the aggregates retained on the No. 8, No. 16, No. 30, and No. 50 sieves [14], [15]. The mix team compared the S.G. and absorption of the two aggregates and found the differences were marginal (Table 7).

Table 7. S.G. and Absorptions of Utelite® and Haydite.

Aggregate	S.G.	Absorption
Utelite 8	1.44	18.8%
Utelite 16	1.61	16.3%
Utelite 30	1.59	17.2%
Utelite 50	1.60	17.9%
Haydite 8	1.50	19.5%
Haydite 16	1.51	20.9%
Haydite 30	1.57	19.5%

Nycon® PVA fibers at 8 mm and 12 mm strengthened the tensile capacity and improved the workability of the mix design. The benefit of using PVA fibers is because they disperse better and have low visibility in the final product. Q-Cel® 6019S, which passes through the No. 200 sieve, was used as a mineral filler because of its low S.G. of 0.14 and the significant compressive strength increase experienced after the 2016 NCCT researched and incorporated it in *Zephyr*, approximately 100 psi every two percent [16].

DARAVAIR® AT30 was reintroduced to lower the unit weight of the mix after being removed from NCCT mix designs in 2019. It was removed because of the adverse effects high dosages had on concrete finish and compressive strength [17]. The manufacturer recommended dosage is 3 fl. oz/cwt, and the *Azure* team used it at 6 fl. oz/cwt whereas past teams have used it from 14 to 20 fl. oz/cwt [18]. ADVA® Cast 575, a high range water reducer, reduced the water cement ratio from 0.45 to 0.43 and helped improve workability.

The design team worked to find the optimal ratio of MKL while simultaneously optimizing the mix's aggregate gradation to quickly develop a strong, lightweight concrete mix. Metakaolin is a pozzolanic SCM that can replace a portion of cement to achieve a low unit weight with its S.G. of 2.06 compared to Portland cement at 3.15. Metapor® Metakaolin specifically was used to reduce the team's carbon footprint since it is a byproduct of Poraver® Expanded Glass [19]. Metakaolin has a synergistic effect with hydrated lime where its high alumina content reacts with the calcium carbonate in the lime to improve the strength of concrete [20]. This effect was observed in *Goldstrike's* mix design which led them to increase their lime from 15 percent by mass to 30 percent.

Three different ratios of MKL were tested while maintaining a constant Portland cement at 30 percent by mass a baseline for strength. The three ratios used were *Goldstrike's* ratio (MKL-1.33:1), a 2:1 ratio (MKL-2:1), and a 4:1 ratio (MKL-4:1) both which are commonly used in researching the effects of MKL cement mixtures [20], [21]. Fiber and admixture content remained constant.

The mix design team created three different gradations of Elemix™, Poraver®, and Utelite® to test with the three different ratios of MKL (Table 8). Gradation 1 and 2 (G1 and G2) were designed to fit between the ASTM C33 upper and lower limits (dashed lines) for fine aggregates (Figure 6) [22]. G2 (blue) has a better fit compared to G1 (red) because it possesses higher proportions of Poraver® 0.1-0.3 mm and Utelite® 50. In order to counter the high specific gravities of the two aggregates, Elemix™ increased by 5 percent. Gradation 3 (G3, yellow) maintained the general the shape of the ASTM C33 limits but focused on attaining a low unit weight by excluding Poraver® 0.1 to 0.3 mm, using more Poraver®

ranging from 0.25 to 4 mm and limiting the amount of Utelite® 50. A total of nine different mix designs were created and tested for density (ASTM C138), compressive strength (ASTM C39), tensile strength (ASTM C496), and flexural strength (ASTM C78) [23], [24], [25], [26].

Results from testing are summarized in Table 9 and Figure 7. Seven-day test results were analyzed due to time constraints, and 28-day results were not predicted because the research supporting prediction equations were found to be designed for ordinary concrete mixes. The average density was smaller for G3 which can be attributed to the use of lower S.G. Poraver® sizes. Within G3, MKL-4:1 had the largest density while MKL-1.33:1 had the smallest. The trend of MKL-4:1 being denser than the other ratios was true for G1 but not G2. The mix team believed that the gradation had more of an influence on density than the ratio of MKL. The mix team also observed that the 7-day composite strength generally decreased as metakaolin replaced more lime. For G1-G3, the compressive strength of the MKL-4:1 mixtures was 200 psi to 400 psi lower than the MKL-1.33:1 mixtures. The tensile test results were inconclusive regarding the correlation between the change in MKL ratios. The flexural results exhibited the same properties as the compressive results. The flexural strength results evaluated were modified by a ratio of 0.75, an estimate for aggregates less than 9.5 mm, since ASTM C78 advises to apply a ratio of 0.86 to aggregates with a maximum aggregate size between 9.5 mm and 37.5 mm [26].

Table 8. Gradations 1-3 and their respective S.G. and aggregates by percent mass.

Aggregate	S.G.	G1	G2	G3
Elemix	0.04	27.0%	32.0%	26.0%
Poraver® 0.1-0.3 mm	0.85	5.0%	9.0%	-
Poraver® 0.25-0.5 mm	0.68	8.0%	-	5.0%
Poraver® 1-2 mm	0.41	-	9.0%	9.0%
Poraver® 2-4 mm	0.35	10.0%	-	10.0%
Utelite 8	1.44	8.0%	7.0%	8.0%
Utelite 16	1.61	15.0%	13.0%	15.0%
Utelite 30	1.59	22.0%	13.0%	20.0%
Utelite 50	1.60	5.0%	17.0%	7.0%

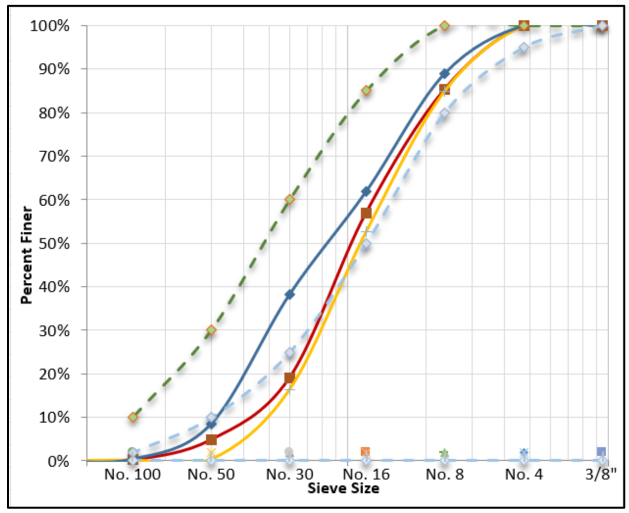


Figure 6. ASTM C33 gradation curves for Gradations 1, 2 and 3.

Table 9. Summary of test results for Gradations 1, 2, and 3 and their respective MKL ratios.

Mix ID	Density (lb/ft3)	Compression (psi)	Tension (psi)	Flexural (psi)	Adjusted Flexural (psi)
G1 MKL-1.33:1	80.1	1953	302	674	506
G1 MKL-2:1	84.4	2027	356	693	520
G1 MKL-4:1	86.5	1709	409	613	460
G2 MKL-1.33:1	86.3	1871	498	620	465
G2 MKL-2:1	74.9	1461	292	624	468
G2 MKL-4:1	80.9	1442	359	529	397
G3 MKL-1.33:1	72.4	2245	421	735	551
G3 MKHL-2:1	77.3	1327	367	395	297
G3 MKHL-4:1	86.3	1823	549	549	412

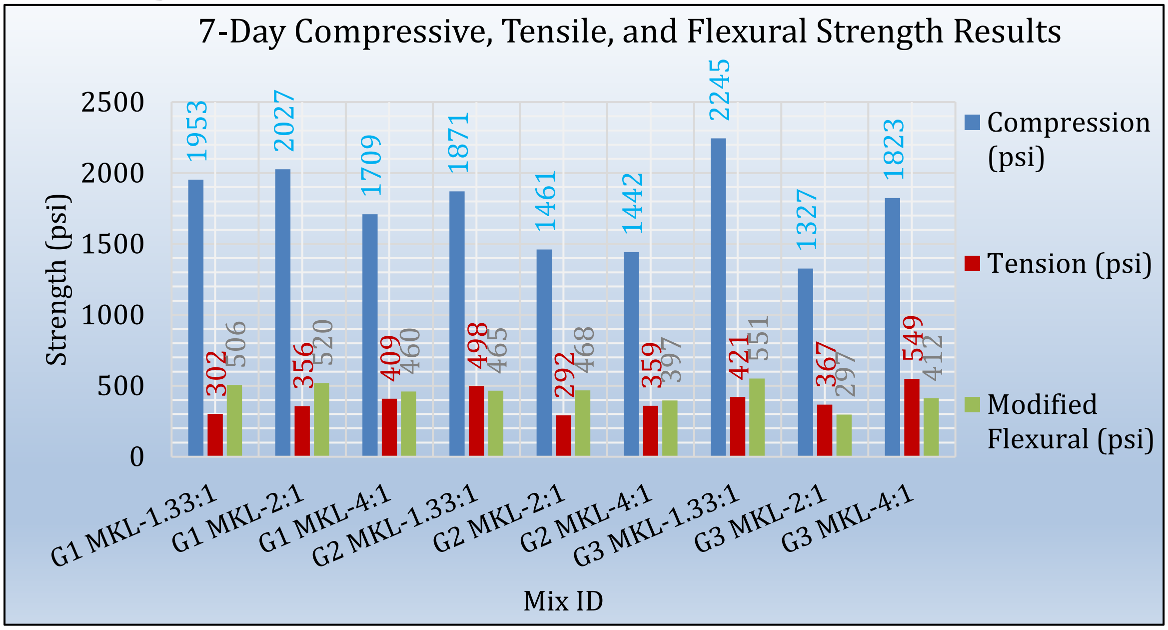


Figure 7. Comparative chart of 7-day compressive, tensile, and flexural strength results.

The team concluded that adding metakaolin and lime at a ratio larger than 2:1 oversaturates the mixture with metakaolin. Such mixtures are not provided enough lime for the metakaolin to react with, inhibiting its ability to reach the high compressive strength observed in the 1.33:1 ratio. The final mix selected for the structural concrete mixture was G3 with a MKL of 1.33:1 which is more than sufficient in meeting the demands outlined by the structural team (Table 10).

Table 10. Final mix selection properties vs. required properties.

	Required	Provided
Compressive	884.2 psi	2245 psi
Modulus of Rupture	236.40 psi	551 psi

Construction

The goal for construction was to streamline a construction process that revolved around using a female form which was first implemented by the team in 2020. Because 2020's team had difficulties in determining an effective method to install a prestress system, the construction and structural analysis teams were encouraged to incorporate it into *Azure*.

The team started by assembling the carbon fiber grid, structural ribs, and gunwale molds. Carbon fiber grids were tied together using fishing line to create a dual layer of reinforcement that would span between the bulkheads. Structural rib were estimated by reading measurements from *Aquaholic*. The gunwale molds were created by using halved polyvinyl chloride (PVC) pipes.

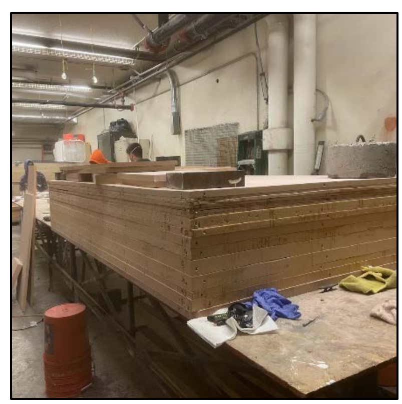


Figure 8. Construction foam blocks.

The team used Precision Board™ High-Density Urethane (PB-HDU) foam to construct the form. The HDU was arrived in sheets and was assembled into three blocks for computer numerical control (CNC) routing. Each block was bonded in order of lowest to highest density from the bottom up in order to provide a strong base to the form (Figure 8). Considerations were made for tendon pathing as lower density foam would not support the system. The team typically uses PB-Bond 240, an adhesive made for PB-HDU, but it did not come with the foam shipment [27]. The team typically uses PB-Bond

240, an adhesive made for PB-HDU, but it did not come with the foam shipment [27]. Instead, the team tested the effectiveness of fiberglass resin by bonding smaller foam stacks and evaluating its strength after the before using it on the form. Fiberglass was used because the team maintains a supply for practice boat repairs.

Form preparations began when the team received the female form from the CNC shop. Construction managers decided to use a female form because of the improved constructability and the reduced time in casting, approximately nine hours, compared to the male form. The form release system was first implemented by making cutouts at the top of the foam and inserting steel plates with steel rods threaded through the form and out the base (Figure 9). The rods were later used to pull the form off the canoe. Bondo® was used to patch the form. Four layers of fiberglass resin were applied to the form for to prevent the concrete from adhering to the form and to provide a smooth interior for canoe finishing. This was an increase from the two layers used on *Redacted's* form due to difficulties experienced with form removal. The surface of the form was sanded down to 800 grit and managers checked for imperfections. Finally, *Azure's* outer design was drawn on the surface before it was coated with form release wax.

Figure 9. Steel plate and rods inserted.

Figure 10. Prestress system testing.

After form preparation was completed, the prestress system was installed (Figure 10). Using coordinates from the structural analysis worksheet, 280 points were marked along the form. The points outlined the path for each of the 14 tendons. Screws were threaded through washers and installed at each of the 280 points. They served as depth indicators for casting and anchors for the tendons to prevent them from contracting to the center during the tensions process. The distance between the tendons and form was spaced 0.25 in apart to represent the first of two layers of concrete. Ferrules were used to bind the tendon together at the bow and stern. After tallying each screw, the tendons were jacked to the predetermined force of 300 pounds. Once the prestress system was in place, the canoe was ready for casting.

Construction managers instructed the team prior to casting day on how to pack concrete into the canoe using the cross section from 2020. Practicing would simulate the process and allow members to better understand the goals and how to achieve them. This helped prevent cold joints and reduced air voids due to improper casting technique. The mix managers prepared batches throughout the week prior to casting day to reduce the time between the supply and demand for concrete.

Casting the canoe began with members set at the bow and stern who worked their way towards the center. The pre-traced design guided members on how to cast the first layer. Managers were instructed to oversee that the design was casted accurately, members packed tightly, and that colors were not being mixed. Managers used spray bottles and a damp tarp to maintain moisture in the concrete to prevent early setting. After the first layer was cast, the dual layer of carbon fiber grid was gently rubbed into the first layer of concrete. A series of laminated inlays were set to create the inner design of *Azure*, and the second layer was cast. Bulkheads were cast with foam encased. Four ribs were cast at paddler locations with the second layer. The final step was adding the gunwales molds packed with concrete after the second layer. Wire was threaded through the gunwale mold, concrete, and form to hold it in place while the concrete cured.

For the next seven days, the canoe was manually watered as this was the most critical time frame to ensure the concrete was on the path to achieve maximum strength. A PVC frame supported a fitted plastic tarp to retain moisture combined with a cloth sheet maintained an ambient temperature of 70°F [28]. Members routinely soaked excess water with sponges to reduce time spent draining water before the wet sanding process began. After the seven days, an automatic watering system was set up to mist the canoe every six hours. During this period, members began a wet sanding process and using sponges to transfer excess water back into the watering system for reuse. Members were instructed to sand at one-foot sections to reveal screw heads. Once all 280 screws were identified, they were counted, removed, and counted again before releasing the tension system. At the end of the 28 days, the water was cured for disposal with the university's Environmental Health and Safety Administration approval.

The form was brought outside and carefully rolled upside down onto a wooden frame. The exposed rods were threaded through wooden beams and secured. Starting with the middle piece, members used the beams to slowly lift the form pieces. The beams allowed members to control the rate they lifted to reduce the moment created when removing the form. The canoe was moved into a cradle for finishing. The outside was patched and sanded to 1500 grit. The inside was patched and sanded to 400 grit, a lower grit to prevent paddlers from slipping. Adhesive lettering was placed, and the canoe was sealed and readied for the competition.

Quality Control and Quality Assurance

NCCT quality assurance and quality control (QA/QC) program featured the involvement of managers, recently retired project managers, alumni, and the team's faculty advisor. Project managers (PMs) setup meetings to develop an effective QA/QC plan that encompassed the entire project to produce a quality product.

The QA program was composed of planning, training, and clear communication. At the start of the project, project managers revised the plan for each stage of the project with past project leads and the faculty advisor to ensure its effectiveness. Managers reviewed the timeline of the project and were trained by past and presented project managers in their respective fields. This year, the NCCT experimented with giving younger members the opportunity to fulfil leadership roles. This required extensive training as their knowledge was not as extensive as Senior members. Specific training included reviewing the rules, construction practices, and ASTM standards and testing. A key aspect of training was the collaborative development of a team website which is further discussed in the Enhanced Focus Area [29]. Managers used the training to conduct testing of innovative ideas before implementing them into the product. Weekly meetings between PMs and managers were held to maintain project schedule and communication between the team. Alumni and faculty advisors served as knowledge bases, where advice was passed down to project managers.

The QC program primarily consisted of oversight and problem solving. PMs and managers served oversight roles where they inspected the work of members to produce a quality canoe that conforms to the RFP. Problems were identified and resolved quickly as managers were present during each project stage. Oversight played a role during testing to ensure tests were appropriately. This was integral in making sure new ideas and material were incorporated properly and safely without adverse effects onto the product. By having multiple layers of inspection and thorough testing, the NCCT QA/QC program is confident in developing a quality product.

Scope, Schedule, and Fee

The NCCT set goals to reduce the workload on PMs by creating task-specific divisions within the team led by managers that are trained at the beginning and throughout the year. PMs wanted to promote better transfer of knowledge between teams, so this year managers' responsibilities were increased. They were in charge of research, innovation, and leading meetings. This created an environment in which everyone is invested in the project and working together to achieve the same goal.

PMs generated a schedule for the year by identifying major milestones (Table 11). These tasks that summarized the time from *RFP* release to the regional competition. The project schedule was developed by categorizing milestones into independent categories either task-specific divisions. Specific tasks were added into each category to expand on the schedule. One month of float time was provided for tasks that would experience variable delays such as shipping or sourcing a new supplier. Critical path activities were identified as tasks that would delay the schedule if finished late.

Table 11. *List of 2022 Milestones.*

2022 Milestones
Rules Release
Fundraising Complete
Manager Training Complete
Hull Design Complete
Structural Analysis Complete
Form Preparations Complete
Mix Design Complete
Canoe Cast
Canoe Finish
Proposal Deliverables Complete

The biggest hurdles to the critical path were delays due to material procurement and COVID-19. Because shipping delays were out of the project manager's control, extra float time was considered for affected tasks. One affected task was the PB-HDU foam which arrived six weeks late. PMs adjusted the project timeline to allow as many form preparations tasks as possible to be completed while waiting for the shipment. A list of these tasks can be seen in Table 12, where an asterisk indicates that the task was originally planned to be finished after the foam was received. Completing these tasks accelerated the form preparation process and kept the team on track.

Table 12. Tasks adjusted to stay on schedule.

Tasks Completed Before Foam Acquisition
*Table Construction
*Carbon Fiber Grid Tying
*Structural Rib Fitting
Prestress System Finalized
*Bulkhead Foam Cut
*Gunwale Preparations

In order to determine the budget for the project, project managers evaluated budgets from previous years and adjusted for inflation. Fundraising through sponsorship from local companies was critical in allowing the team to compete. Letters were distributed in person, through email, and one-on-one meetings with different companies were arranged to discuss NCCT's project and history. The NCCT raised $18.6 thousand dollars for the competition year. A total of $11.2 thousand was allocated towards CNC routing, acquiring the docks, replacing tools, and ordering new material, leaving $7,600 for the next competition.

Sustainability

The NCCT incorporated the three pillars of sustainability - social, economic, and environmental - throughout the project lifecycle. The team believed that its contribution to sustainability was paramount in order to protect the surrounding ecosystems and wildlife that contribute to the beauty and culture of the Reno-Tahoe area.

Social efforts were made to maintain team involvement throughout the project within COVID-19 guidelines and restrictions. Weekly in-person meetings were held to update members about social events, scholarship opportunities, and internship opportunities. Members were encouraged to join the university's ASCE student chapter. A key social impact that affected the sustainability of the team was acquiring access to dock at the marina where the paddling team practices. This provided the opportunity to hold social events that promoted friendships within the team and allowed members to get the chance to paddle.

Maintaining relations with the NCCT sponsors worked to continue economic support, and engagement with new sponsors increased the team's financial stability. The team's existing inventory was carefully reused which saved money so it could be allocated to other aspects of the project that needed funding such as expediting shipping for material. Before new items were purchased, the item's cost-effectiveness was discussed in terms of practicality and functionality between current and past PMS. This was important to prevent unnecessary or expensive purchases.

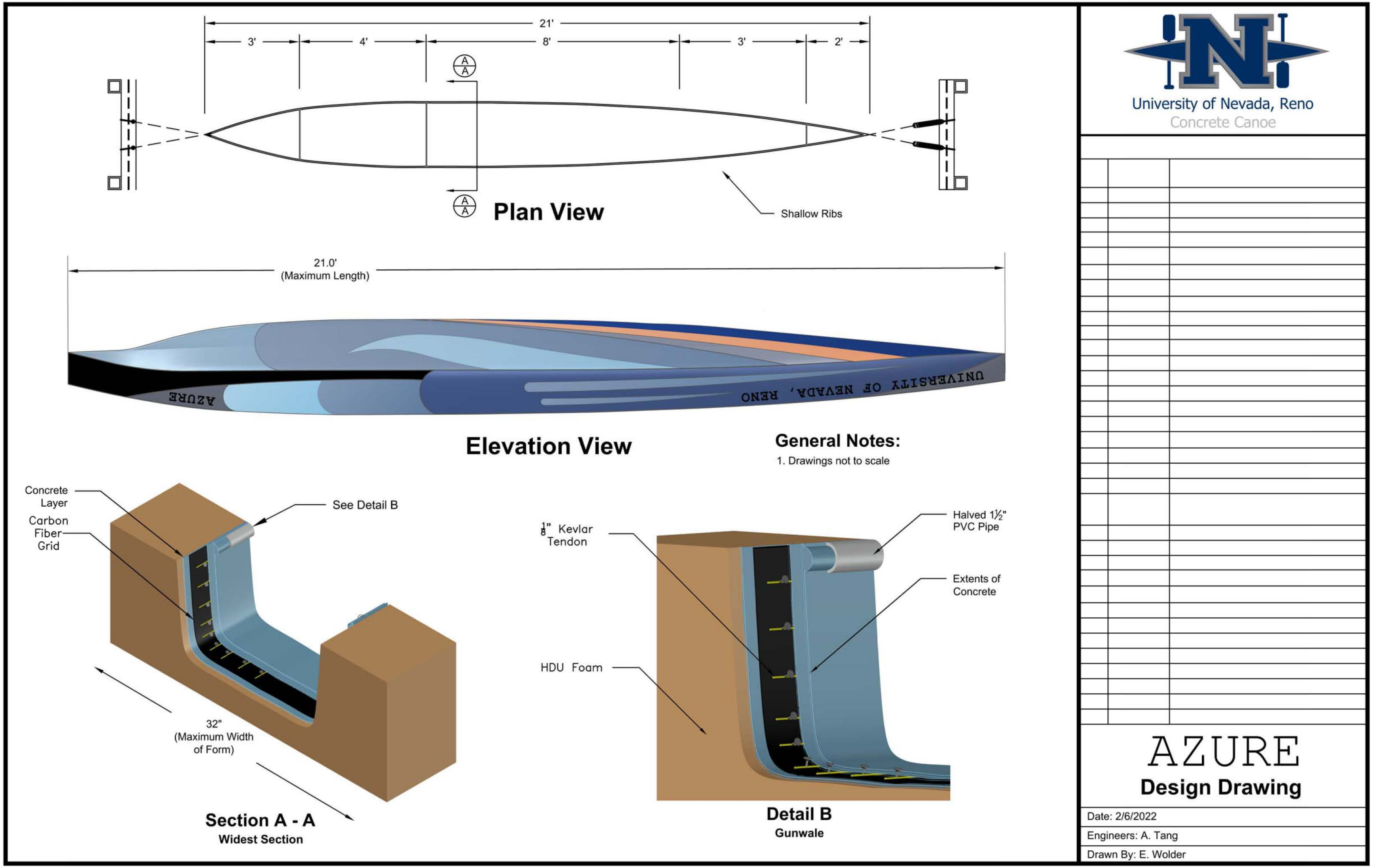
The environmental impact of the project was considered with recyclability, reusability, and reduction of carbon footprint in mind. Recyclability and reusability were achieved through the use of PB-HDU foam for the form. The HDU foam meets two green building standards: LEED, developed by the U.S. Green Building Council, and the National Green Building Standard [30]. PB-HDU foam is composed of 23.9% rapidly renewable materials and possesses a carbon balance of three-to-one (i.e., a carbon intake of 3 kg/m to a carbon output of 1 kg/m) [31]. The team reduced its carbon footprint by working with a CNC facility closer to Reno, Nevada. In past years, the team utilized a CNC facility in Los Angeles, California because it was the cheapest known option. This year, the NCCT reduced the miles driven by 500 using a facility located in Livermore, California. A facility in the city was not chosen due to scheduling conflicts with the few local companies who had the proper machine to CNC the form. Acquiring the docks also reduced the team's carbon footprint by not requiring paddlers to tow the trailer from the university to the marina every weekend for practice.

Health and Safety

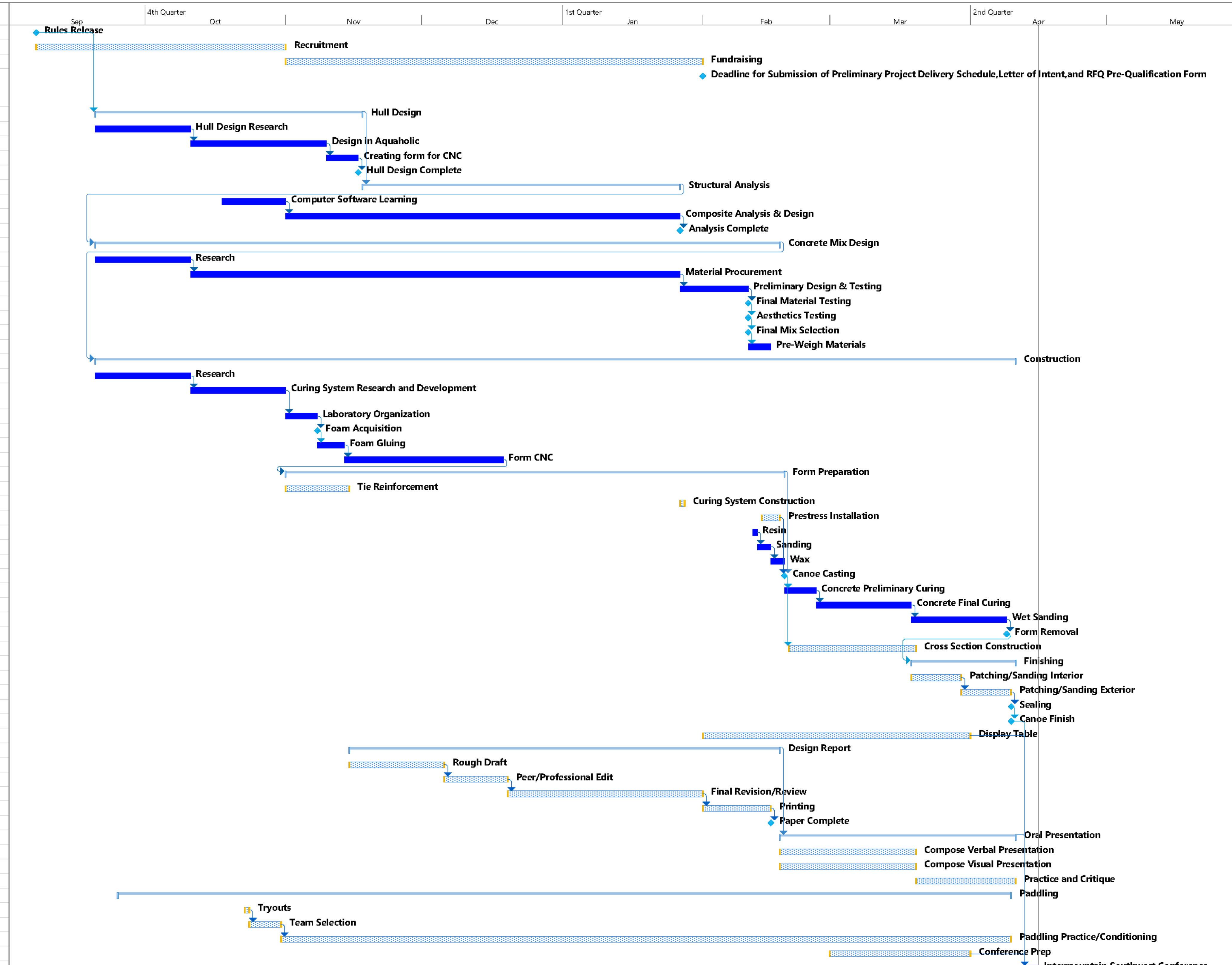
The health and safety of all involved team members was prioritized throughout the project life cycle. The ongoing COVID-19 pandemic only elevated the importance of health and safety to the team. PMs and the assistant PM were responsible for ensuring the entire team shared this value and worked together to create a safe working environment.

PMs began the year meeting with the University's Environmental Health & Safety (EH&S) administration to ensure that the workspace met their standards to maintain access. This included maintaining five feet from the fire riser system, having all buckets and waste bins labeled, and controlling the dust level. Standard operating procedures, documentation for all tools and material, and policies for working in the workspace were inventoried or created by the assistant PM and team members. Posters were created and displayed to outline important standards and policies. Construction and mix managers inventoried and documented all tools and material in the workspace. They worked with project managers to determine if the tool or material in question had reached its end-of-life use and needed to be replaced. During this time, training on how to handle tools and materials, the required PPE, and disposal was conducted. This training was passed down to student members.

Regarding COVID-19 policies, the University required vaccinations for all students enrolling in the Spring 2022 semester in August 2021, but this order was rescinded in December 2021 [32], [33]. PMs were under the impression that a majority of the team was vaccinated and felt safe to hold in-person meetings but maintained a mask requirement regardless of vaccination status. Due to the uncertainty of the virus and to ensure a safe and healthy team, PMs required exposed members to self-isolate follow university guidelines. These health and safety practices worked to prevent the spread of the virus amongst the team.


21'
3'
4'
8'
3'
2'
A A
A A
Plan View
Shallow Ribs
21.0'
(Maximum Length)
AZURE
UNIVERSITY OF NEVADA, RENO
Elevation View
General Notes:
1. Drawings not to scale
Concrete Layer
Carbon Fiber Grid
See Detail B
32" (Maximum Width of Form)
Section A - A
Widest Section
1/8" Kevlar Tendon
HDU Foam
Halved 1½" PVC Pipe
Extents of Concrete
Detail B
Gunwale
University of Nevada, Reno
Concrete Canoe
AZURE
Design Drawing
Date: 2/6/2022
Engineers: A. Tang
Drawn By: E. Wolder

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Rules Release**	**0 days**	**Tue 9/7/21**	**Tue 9/7/21**	
2	**Recruitment**	**55 days**	**Tue 9/7/21**	**Mon 11/1/21**	
3	**Fundraising**	**92 days**	**Mon 11/1/21**	**Tue 2/1/22**	
4	**Deadline for Submission of Preliminary Project Delivery Schedule, Letter of Intent, and RFQ**	0 days	Tue 2/1/22	Tue 2/1/22	
5	**Hull Design**	**59 days**	**Mon 9/20/21**	**Thu 11/18/21**	**1**
6	Hull Design Research	21 days	Mon 9/20/21	Mon 10/11/21	
7	Design in Aquaholic	30 days	Mon 10/11/21	Wed 11/10/21	6
8	Creating form for CNC	7 days	Wed 11/10/21	Wed 11/17/21	7
9	Hull Design Complete	0 days	Wed 11/17/21	Wed 11/17/21	8
10	**Structural Analysis**	**70 days**	**Thu 11/18/21**	**Thu 1/27/22**	**5**
11	Computer Software Learning	14 days	Mon 10/18/21	Mon 11/1/21	
12	Composite Analysis & Design	87 days	Mon 11/1/21	Thu 1/27/22	11
13	Analysis Complete	0 days	Thu 1/27/22	Thu 1/27/22	12
14	**Concrete Mix Design**	**151 days**	**Mon 9/20/21**	**Fri 2/18/22**	**10**
15	Research	21 days	Mon 9/20/21	Mon 10/11/21	
16	Material Procurement	108 days	Mon 10/11/21	Thu 1/27/22	15
17	Preliminary Design & Testing	15 days	Thu 1/27/22	Fri 2/11/22	16
18	Final Material Testing	0 days	Fri 2/11/22	Fri 2/11/22	17
19	Aesthetics Testing	0 days	Fri 2/11/22	Fri 2/11/22	18
20	Final Mix Selection	0 days	Fri 2/11/22	Fri 2/11/22	19
21	Pre-Weigh Materials	5 days	Fri 2/11/22	Wed 2/16/22	20
22	**Construction**	**203 days?**	**Mon 9/20/21**	**Mon 4/11/22**	**14**
23	Research	21 days	Mon 9/20/21	Mon 10/11/21	
24	Curing System Research and Development	21 days	Mon 10/11/21	Mon 11/1/21	23
25	Laboratory Organization	7 days	Mon 11/1/21	Mon 11/8/21	24
26	Foam Acquisition	0 days	Mon 11/8/21	Mon 11/8/21	25
27	Foam Gluing	6 days	Mon 11/8/21	Sun 11/14/21	26
28	Form CNC	35 days	Sun 11/14/21	Sun 12/19/21	27
29	**Form Preparation**	**110 days?**	**Mon 11/1/21**	**Sat 2/19/22**	**28**
30	Tie Reinforcement	14 days	Mon 11/1/21	Mon 11/15/21	
31	Curing System Construction	1 day	Thu 1/27/22	Fri 1/28/22	
32	Prestress Installation	4 days	Mon 2/14/22	Fri 2/18/22	
33	Resin	1 day	Sat 2/12/22	Sun 2/13/22	
34	Sanding	3 days	Sun 2/13/22	Wed 2/16/22	33
35	Wax	3 days	Wed 2/16/22	Sat 2/19/22	34
36	Canoe Casting	0 days	Sat 2/19/22	Sat 2/19/22	29,32
37	Concrete Preliminary Curing	7 days	Sat 2/19/22	Sat 2/26/22	36
38	Concrete Final Curing	21 days	Sat 2/26/22	Sat 3/19/22	37
39	Wet Sanding	21 days	Sat 3/19/22	Sat 4/9/22	38
40	Form Removal	0 days	Sat 4/9/22	Sat 4/9/22	39
41	Cross Section Construction	28 days	Sun 2/20/22	Sun 3/20/22	36
42	**Finishing**	**23 days**	**Sat 3/19/22**	**Mon 4/11/22**	**40**
43	Patching/Sanding Interior	11 days	Sat 3/19/22	Wed 3/30/22	
44	Patching/Sanding Exterior	11 days	Wed 3/30/22	Sun 4/10/22	43
45	Sealing	0 days	Sun 4/10/22	Sun 4/10/22	44
46	**Canoe Finish**	**0 days**	**Sun 4/10/22**	**Sun 4/10/22**	**45**
47	**Display Table**	**59 days**	**Tue 2/1/22**	**Fri 4/1/22**	
48	**Design Report**	**95 days**	**Mon 11/15/21**	**Fri 2/18/22**	
49	Rough Draft	21 days	Mon 11/15/21	Mon 12/6/21	
50	Peer/Professional Edit	14 days	Mon 12/6/21	Mon 12/20/21	49
51	Final Revision/Review	43 days	Mon 12/20/21	Tue 2/1/22	50
52	Printing	15 days	Tue 2/1/22	Wed 2/16/22	51
53	Paper Complete	0 days	Wed 2/16/22	Wed 2/16/22	52
54	**Oral Presentation**	**52 days**	**Fri 2/18/22**	**Mon 4/11/22**	**48**
55	Compose Verbal Presentation	30 days	Fri 2/18/22	Sun 3/20/22	
56	Compose Visual Presentation	30 days	Fri 2/18/22	Sun 3/20/22	
57	Practice and Critique	22 days	Sun 3/20/22	Mon 4/11/22	
58	**Paddling**	**197 days**	**Sat 9/25/21**	**Sun 4/10/22**	
59	Tryouts	1 day	Sat 10/23/21	Sun 10/24/21	
60	Team Selection	7 days	Sun 10/24/21	Sun 10/31/21	59
61	Paddling Practice/Conditioning	161 days	Sun 10/31/21	Sun 4/10/22	60
62	**Conference Prep**	**31 days**	**Tue 3/1/22**	**Fri 4/1/22**	
63	**Intermountain Southwest Conference**	**3 days**	**Wed 4/13/22**	**Sat 4/16/22**	**62,46,47,54**



Project: prelim sch 2021-22
Date: Wed 2/16/22

Critical Split | Planned Task | Summary | Critical Path | Milestone | Critical

Appendix A - Bibliography

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Appendix B - Mixture Proportions and Primary Mix Calculation

Structural Mix

CEMENTITIOUS MATERIALS				
Component	***Specific Gravity***	***Volume***	***Amount of CM***	
Portland Cement, Type I, (White)	3.15	*0.967 ft^3*	*189.62 lb/yd^3*	*Total cm (includes c)* ***632.07*** *lb/yd^3 c/cm ratio, by mass* ***0.3***
Metapor, Class N (Metakaolin)	2.06	*1.96 ft^3*	*252.83 lb/yd^3*	
Hydrated Lime Cement Type S	2.21	*1.37 ft^3*	*189.62 lb/yd^3*	

FIBERS				
Component	***Specific Gravity***	***Volume***	***Amount of Fibers***	
Nycon PVA (8mm)	1.3	*0.117 ft^3*	*9.52 lb/yd^3*	*Total Amount of Fibers* ***19.04*** *lb/yd^3*
Nycon PVA Fibers (12 mm)	1.3	*0.117 ft^3*	*9.52 lb/yd^3*	

AGGREGATES (EXCLUDING MINERAL FILLERS PASSING NO. 200 SIEVE)							
Aggregates	***ASTM C330 or RCA[1]***	***Abs (%)***	***SG_{OD}***	***SG_{SSD}***	***Base Quantity, W***		***Volume, $V_{agg, SSD}$***
					W_{OD}	***W_{SSD}***	
Elemix™	N	*6%*	0.04	0.042	*8.54 lb/yd^3*	*9.05 lb/yd^3*	*3.42 ft^3*
Poraver® Siscorspheres 0.25-0.5 mm	N	*15%*	0.68	0.782	*27.96 lb/yd^3*	*32.15 lb/yd^3*	*0.66 ft^3*
Poraver® Siscorspheres 1-2 mm	N	*7%*	0.41	0.439	*30.34 lb/yd^3*	*32.46 lb/yd^3*	*1.19 ft^3*
Poraver® Siscorspheres 2-4 mm	N	*7%*	0.35	0.375	*28.77 lb/yd^3*	*30.78 lb/yd^3*	*1.32 ft^3*
Utelite® 8	Y	*19%*	1.44	1.714	*94.72 lb/yd^3*	*112.72 lb/yd^3*	*1.05 ft^3*
Utelite® 16	Y	*16%*	1.61	1.868	*198.32 lb/yd^3*	*230.05 lb/yd^3*	*1.97 ft^3*
Utelite® 30	Y	*17%*	1.59	1.860	*261.48 lb/yd^3*	*305.93 lb/yd^3*	*2.64 ft^3*
Utelite® 50	Y	*18%*	1.60	1.888	*92.09 lb/yd^3*	*108.67 lb/yd^3*	*0.92 ft^3*

LIQUID ADMIXTURES					
Admixture	***lb/ US gal***	***Dosage (fl. oz / cwt)***	***% Solids***	***Amount of Water in Admixture***	
DARAVAIR®-AT30, *$admx_1$*	8.3	6	*5%*	*2.34 lb/yd^3*	Total Water from Liquid Admixtures, $\sum w_{admx}$ 16.84 lb/yd^3
ADVA® Cast 575, *$admx_2$*	8.9	55	*40%*	*14.50 lb/yd^3*	

SOLIDS (DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)				
Component	***Specific Gravity***	***Volume (ft^3)***	***Amount (lb/yd^3)***	
Direct™ Colors Powdered Pigment, *$S_{p\ admix}$*	1.27	*0.075 ft^3*	*5.98 lb/yd^3*	*Total Solids, S_{total}* *36.65 lb/yd^3*
Q-Cel® 6019S, *mf*	0.14	*3.511 ft^3*	*30.78 lb/yd^3*	

WATER			
	Amount		***Volume***
Water, *w, [$=\sum (w_{free} + w_{admx} + w_{batch})$]*	*w/c ratio, by mass* ***1.43*** *w/cm ratio, by mass* ***0.43***	*271.79 lb/yd^3*	*4.36 ft^3*
Total Free Water from All Aggregates, *$\sum w_{free}$*		*-120.4 lb/yd^3*	
Total Water from All Admixtures, *$\sum w_{admx}$*		*16.84 lb/yd^3*	
Batch Water, *w_{batch}*		*375.35 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*	*632.07 lb*	*19.04 lb*	*861.82 lb*	*36.65 lb*	*271.79 lb*	*$\sum$M:1821.37 lb*
Absolute Volume, *V*	*4.30 ft^3*	*0.23 ft^3*	*13.17 ft^3*	*3.59 ft^3*	*4.36 ft^3*	*$\sum$V:25.65 ft^3*
Theoretical Density, *T, (=$\sum M / \sum V$)*	*71.01 lb/ft^3*		***Air Content, Air,*** *[= (T – D)/T x 100%]*			*5.00%*
Measured Density, *D*	*67.46 lb/ft^3*		***Air Content, Air,*** *[= (27 – $\sum$V))/27 x 100%]*			*5.00%*
Total Aggregate Ratio[2] *(=$V_{agg,SSD}$/ 27)*	*49%*		***Slump, Slump flow, Spread*** *(as applicable)*			*1.00 in.*
C330+RCA Ratio[3] *(=$V_{C330+RCA}$ / $V_{agg,SSD}$)*	*50%*					

Patch Mix

Cementitious Materials				
Component	***Specific Gravity***	***Volume***	***Amount of CM***	
Portland Cement, Type I, (White)	3.15	*0.967 ft^3*	*189.62 lb/yd^3*	*Total cm (includes c)* ***632.07*** *lb/yd^3 c/cm ratio, by mass* ***0.3***
Metapor, Class N (Metakaolin)	2.06	*1.96 ft^3*	*252.83 lb/yd^3*	
Hydrated Lime Cement Type S	2.21	*1.37 ft^3*	*189.62 lb/yd^3*	
Nycon PVA Fibers (12 mm)	1.3	*0.117 ft^3*	*9.52 lb/yd^3*	

Aggregates (Excluding Mineral Fillers Passing No. 200 Sieve)							
Aggregates	***ASTM C330 or RCA[1]***	***Abs (%)***	***SG_{OD}***	***SG_{SSD}***	***Base Quantity, W***		***Volume, $V_{agg, SSD}$***
					W_{OD}	***W_{SSD}***	
Elemix™	N	*6%*	0.04	0.042	*10.51 lb/yd^3*	*11.14 lb/yd^3*	*4.211 ft^3*
Poraver® Siscorspheres 0.1-0.3 mm	N	*22%*	0.85	1.037	*62.9 lb/yd^3*	*76.74 lb/yd^3*	*1.186 ft^3*
Poraver® Siscorspheres 1-2 mm	N	*7%*	0.41	0.439	*30.34 lb/yd^3*	*32.46 lb/yd^3*	*1.186 ft^3*
Utelite® 8	Y	*19%*	1.44	1.714	*82.87 lb/yd^3*	*98.62 lb/yd^3*	*0.922 ft^3*
Utelite® 16	Y	*16%*	1.61	1.868	*171.89 lb/yd^3*	*199.39 lb/yd^3*	*1.711 ft^3*
Utelite® 30	Y	*17%*	1.59	1.860	*169.95 lb/yd^3*	*198.84 lb/yd^3*	*1.713 ft^3*
Utelite® 50	Y	*18%*	1.60	1.888	*223.65 lb/yd^3*	*263.91 lb/yd^3*	*2.240 ft^3*

Liquid Admixtures					
Admixture	***lb/ US gal***	***Dosage (fl. oz / cwt)***	***% Solids***	***Amount of Water in Admixture***	
DARAVAIR®-AT30, *$admx_1$*	8.3	6	*5%*	*2.34 lb/yd^3*	Total Water from Liquid Admixtures, $\sum w_{admx}$ 18.16 lb/yd^3
ADVA® Cast 575, *$admx_2$*	8.9	60	*40%*	*15.82 lb/yd^3*	

Solids (Dyes, Powdered Admixtures, and Mineral Fillers)				
Component	***Specific Gravity***	***Volume***	***Amount (lb/yd^3)***	
Direct™ Colors Powdered Pigment, *$S_{p\ admix}$*	1.27	*0.075 ft^3*	*5.98 lb/yd^3*	*Total Solids. S_{total}* *36.66 lb/yd^3*
Q-Cel® 6019S, *mf*	0.14	*3.512 ft^3*	*30.78 lb/yd^3*	

Water			
	Amount		***Volume***
Water, *w, [$=\sum (w_{free} + w_{admx} + w_{batch})$]*	*w/c ratio, by mass* ***1.43*** *w/cm ratio, by mass* ***0.43***	*271.79 lb/yd^3*	*4.36 ft^3*
Total Free Water from All Aggregates, *$\sum w_{free}$*		*-120.4 lb/yd^3*	
Total Water from All Admixtures, *$\sum w_{admx}$*		*16.84 lb/yd^3*	
Batch Water, *w_{batch}*		*375.35 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*	*632.07 lb*	*0 lb*	*861.82 lb*	*36.66 lb*	*271.79 lb*	*∑M: 1821.62 lb*
Absolute Volume, *V*	*4.30 ft^3*	*0 ft^3*	*13.17 ft^3*	*3.59 ft^3*	*4.36 ft^3*	*∑V:25.42 ft^3*

Theoretical Density, *T, ($=\sum M / \sum V$)*	*71.66 lb/ft^3*	***Air Content, Air,*** *[= (T – D)/T x 100%]*	*5.85%*
Measured Density, *D*	*67.47 lb/ft^3*	***Air Content, Air,*** *[= (27 – ∑V))/27 x 100%]*	*5.85%*
Total Aggregate Ratio[2] *($=V_{agg,SSD} / 27$)*	*49%*	***Slump, Slump flow, Spread*** *(as applicable)*	*3.00 in.*
C330+RCA Ratio[3] *($=V_{C330+RCA} / V_{agg,SSD}$)*	*50%*		

Structural Mix Calulations:

Step 1 Cementitious Materials

$$V_{cement} = \frac{M_{cement}}{SG_{cement} * 62.4 \frac{lb}{ft^3}}$$

Portland Cement, Type 2, (white)

$$V = \frac{189.62\ lb}{3.15 * 62.4 \frac{lb}{ft^3}} = 0.967\ ft^3$$

Metapor®, Class N (Metakaolin)

$$V = \frac{252.83\ lb}{2.06 * 62.4 \frac{lb}{ft^3}} = 1.96\ ft^3$$

Hydrated Lime, Type S

$$V = \frac{189.62\ lb}{2.21 * 62.4 \frac{lb}{ft^3}} = 1.37\ ft^3$$

$$\Sigma V_{cement} = 0.967\ ft^3 + 1.96\ ft^3 + 1.37\ ft^3 = 4.3$$

$$\Sigma M_{cement} = 189.62\ lb + 252.83\ lb + 189.62\ lb = 632.07\ lb$$

$$\frac{c}{cm} = \frac{189.62\ ft^3}{632.07\ ft^3} = 0.30$$

Step 2 Fibers

$$V_{fibers} = \frac{M_{fibers}}{SG_{fibers} * 62.4 \frac{lb}{ft^3}}$$

Nycon® PVA Fibers (8 mm)

$$V = \frac{9.52\ lb}{1.3 * 62.4 \frac{lb}{ft^3}} = 0.117\ ft^3$$

Nycon® PVA Fibers (12 mm)

$$V = \frac{9.52\ lb}{1.3 * 62.4 \frac{lb}{ft^3}} = 0.117\ ft^3$$

Step 3 Aggregates

$$V_{aggregates} = \frac{M_{aggregates(OD)}}{SG_{aggregates(OD)} * 62.4\ \frac{lb}{ft^3}} = \frac{M_{aggregates(ssd)}}{SG_{aggregates(ssd)} * 62.4\ \frac{lb}{ft^3}}$$

Elemix™

$$V = \frac{8.54\ lb}{0.040 * 62.4\ \frac{lb}{ft^3}} = \frac{9.05\ lb}{0.042 * 62.4\ \frac{lb}{ft^3}} = 3.42\ ft^3$$

Poraver® Siscorspheres 0.25-0.5 mm

$$V = \frac{27.96\ lb}{0.680 * 62.4\ \frac{lb}{ft^3}} = \frac{32.15\ lb}{0.782 * 62.4\ \frac{lb}{ft^3}} = 0.66\ ft^3$$

Poraver® Siscorspheres 1-2 mm

$$V = \frac{30.34\ lb}{0.410 * 62.4\ \frac{lb}{ft^3}} = \frac{32.46\ lb}{0.439 * 62.4\ \frac{lb}{ft^3}} = 1.19\ ft^3$$

Poraver® Siscorspheres 2-4

$$V = \frac{28.77\ lb}{0.350 * 62.4\ \frac{lb}{ft^3}} = \frac{30.78\ lb}{0.375 * 62.4\ \frac{lb}{ft^3}} = 1.32\ ft^3$$

Utelite® 8

$$V = \frac{94.72\ lb}{1.440 * 62.4\ \frac{lb}{ft^3}} = \frac{112.72\ lb}{1.714 * 62.4\ \frac{lb}{ft^3}} = 1.05\ ft^3$$

Utelite® 16

$$V = \frac{198.32\ lb}{1.610 * 62.4\ \frac{lb}{ft^3}} = \frac{230.05\ lb}{1.868 * 62.4\ \frac{lb}{ft^3}} = 1.97\ ft^3$$

Utelite® 30

$$V = \frac{261.48\ lb}{1.590 * 62.4\ \frac{lb}{ft^3}} = \frac{305.93\ lb}{01.860 * 62.4\ \frac{lb}{ft^3}} = 2.64\ ft^3$$

Utelite® 50

$$V = \frac{92.09\ lb}{1.600 * 62.4\ \frac{lb}{ft^3}} = \frac{108.67\ lb}{1.888 * 62.4\ \frac{lb}{ft^3}} = 0.92\ ft^3$$

$\Sigma\, V_{aggregates} = 3.42\ ft^3 + 0.66\ ft^3 + 1.19\ ft^3 + 1.32\ ft^3 + 1.05\ ft^3 + 1.97\ ft^3 + 2.64\ ft^3 + 0.92\ ft^3 = 13.17\ ft^3$

$\Sigma\, M_{aggregates} = 9.05\ lb + 32.15\ lb + 32.46\ lb + 30.78\ lb + 112.72\ lb + 230.05\ lb + 305.93\ lb + 108.67\ lb = 861.82\ lb$

$$V_{ASTM\ C330} = \frac{1.05\ ft^3 + 1.97\ ft^3 + 2.64\ ft^3 + 0.92\ ft^3}{13.17\ ft^3} * 100 = 50.00\%$$

$$Aggregate\ Ratio = \frac{13.17 ft^3}{27\ ft^3} * 100 = 49.00\%$$

Step 4 Admixtures

$$w_{admx} = \frac{dosage * cwt\ of\ cm * water\ content * 1\ gal * density(\frac{lb}{gal})}{128\ fl.oz.}$$

DARAVAIR®-AT30

$$w = \frac{\left(6\ \frac{fl.oz.}{cwt}\right) * (6.3207\ cwt) * \left[\frac{100-5}{100}\right] * 1\ gal * 8.3\ \frac{lb}{gal}}{128\ fl.oz.} = 2.34\ lb$$

ADVA® Cast

$$w = \frac{\left(55\ \frac{fl.oz.}{cwt}\right) * (6.3207\ cwt) * \left[\frac{100-40}{100}\right] * 1\ gal * 8.9\ \frac{lb}{gal}}{128\ fl.oz.} = 14.50\ lb$$

$\Sigma\, w_{admx} = 2.34\ lb + 14.5\ lb = 16.84\ lb$

Step 5 Solids

$$V_{solids(solids)} = \frac{M_{solids}}{SG_{solids} * 62.4\ \frac{lb}{ft^3}}$$

Direct™ Colors Powdered Pigment

$$V = \frac{5.98\ lb}{1.27 * 62.4\ \frac{lb}{ft^3}} = 0.075\ ft^3$$

Q-Cel® 6019S

$$V = \frac{30.68\ lb}{0.14 * 62.4\ \frac{lb}{ft^3}} = 3.512\ ft^3$$

$$\Sigma\, v_{Solids} = 0.075 ft^3\ + 14.5\ ft^3 = 14.575\ ft^3$$
$$\Sigma\, w_{admx} = 5.98\ lb + 30.68\ lb = 36.66\ lb$$

Step 6 Water

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

$$w_{batch} = w - (w_{free} + \Sigma\, w_{admx})$$

$$MC_{total} = \frac{W_{stk} - W_{OD}}{W_{OD}} * 100$$

$$MC_{free} = MC_{total} - Abs$$

$$w_{free} = W_{OD} * \frac{MC_{free}}{100\%}$$

MC_{total}	MC_{free}	w_{free}
Elemix $\frac{8.582 - 8.54}{8.54} * 100\% = 0.50\%$	$0.5\% - 6\% = -5.5\%$	$8.54 * \frac{-5.50\%}{100\%} = -0.47$
Siscor 0.25-0.5 mm $\frac{27.96 - 27.96}{27.96} * 100\% = 0.00\%$	$0.0\% - 15\% = -15.00\%$	$27.96 * \frac{-15.00\%}{100\%} = -4.197$
Siscor 1-2 mm $\frac{30.346 - 30.34}{30.34} * 100\% = 0.02\%$	$0.02\% - 7\% = -6.98\%$	$30.34 * \frac{-6.98\%}{100\%} = -2.12$
Siscor 2-4 mm $\frac{28.77 - 28.77}{28.77} * 100\% = 0.00\%$	$0.0\% - 7\% = -7.00\%$	$28.77 * \frac{-7.00\%}{100\%} = -2.02$
Utelite 8 $\frac{94.899 - 94.72}{94.72} * 100\% = 0.19\%$	$0.19\% - 19\% = -18.81\%$	$94.72 * \frac{-18.81\%}{100\%} = -17.816$
Utelite 16 $\frac{198.32 - 198.32}{198.32} * 100\% = 0.00\%$	$0.0\% - 16.3\% = -16.30\%$	$198.32 * \frac{-16.30\%}{100\%} = -32.328$
Utelite 30 $\frac{261.48 - 261.48}{261.48} * 100\% = 0.00\%$	$0.0\% - 17.2\% = -17.20\%$	$261.48 * \frac{-17.20\%}{100\%} = -44.97$
Utelite 50 $\frac{92.182 - 92.09}{92.09} * 100\% = 0.1\%$	$0.1\% - 18\% = -17.90\%$	$92.09 * \frac{-17.90\%}{100\%} = -16.48$

$$w = 0.43 * 632.07 \frac{lb}{yd^3} = 271.79 \frac{lb}{yd^3}$$

$$w_{free} = (-0.47 - 4.197 - 2.12 - 2.02 - 17.816 - 32.328 - 44.97 - 16.48)lb = -120.4 \text{ lb}$$

$$v_{water} = \frac{Amount}{1 * 62.4\frac{lb}{ft^3}} = \frac{271.79}{1 * 62.4\frac{lb}{ft^3}} = 4.36$$

$$w_{batch} = 271.79 - (-120.4 + 16.84) = 375.35\frac{lb}{yd^3}$$

Step 7 Densities, Air Content, Slump, and Ratios

$$M = Amnt_{cm+}Amnt_{fibers+}Amnt_{aggr.+}Amnt_{w+}Amnt_{solids}$$

$$V = V_{cm} += V_{fibers} + V_{aggr.} + V_w + V_{solids}$$

$$T = \frac{M}{V}$$

$$Air\ Content = \left(\frac{T - D}{T}\right) * 100\%$$

$$M = 632.07\ lb + 19.04\ lb + 861.82\ lb + 36.65\ lb + 271.79\ lb = 1821.37\ lb$$

$$V = 4.3\ ft^3 + 0.23ft^3 + 13.17ft^3 + 3.59ft^3 + 4.36\ ft^3 = 25.65ft^3$$

$$T = \frac{1821.37\ lb}{25.65ft^3} = 71.01\ lb/ft3$$

$$D = \frac{1821.37\ lb}{27.00ft^3} = 67.46\ lb/ft3$$

$$Air\ Content = \left(\frac{71.01\ \frac{lb}{ft^3} - 67.46\frac{lb}{ft^3}}{71.01\frac{lb}{ft^3}}\right) * 100\% = 5.00\%$$

$$Air\ Content = \left(\frac{27\ ft^3 - 25.65ft^3}{27ft^3}\right) * 100\% = 5.00\%$$

Appendix C - Structural & Freeboard Calculations

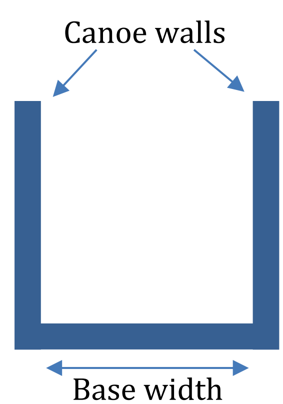
Variable	Definition	Units
L_{canoe}	Total length of the canoe	ft
$t_{concrete}$	Thickness of the concrete	in
A	Canoe cross-section area	ft^2
A_{sub}	Area of cross-section submerged	ft^2
b	Canoe base width	in
h	Canoe wall height	in
V	Shear value	lbs
w_{canoe}	Canoe weight	lbs
$w_{paddler}$	Paddler weight	lbs
$w_{buoyant}$	Buoyant weight	lbs
v_{sub}	Volume of displaced water	ft^3
$\rho_{concrete}$	Density of concrete	lb/ft^3
M	Moment	ft-lb
x	Distance from canoe end	in
S	Canoe support force	lb
i	Point on canoe	

Given:

$L_{canoe} = 21\,ft$

$t_{concrete} = 0.5\,in$

$A = t_{concrete} * b + 2 * b * h$



Shear Calculations

$$V = w_{buoyant} - w_{canoe} - w_{paddler}$$

$$w_{buoyant} = v_{sub} * 62.4\,\frac{lb}{ft^3}$$

$$v_{sub} = A_{sub} * x$$

$$w_{concrete} = A * \rho_{concrete} * x$$

Bending Moment calculations

$$M = V * \frac{X}{12\,\frac{in}{ft}}$$

Canoe Supports

$$V = S - w_{canoe}$$

$$M = M_{i-1} + V * X$$

SFD/BMD Example Calculations

1. Female Tandem

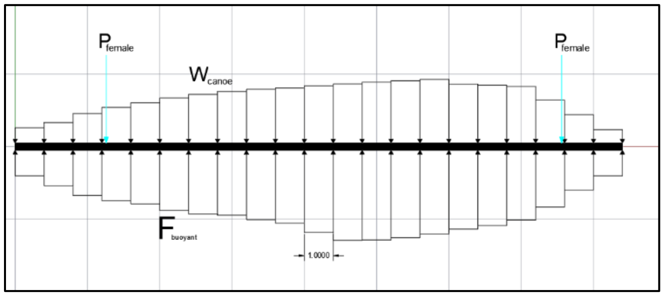
a. Assumptions:

   i. One 150-lb paddler located at 15% of canoe length & one 150-lb paddler located at 90% of canoe length analyzed as point loads

   ii. Canoe weight and length as previously defined

   iii. Canoe weight is assumed to act as constant distributed loads for each 1-foot interval of the canoe length

Free Body Diagram for Female Tandem Loading



b. Find: Shear Force and Bending Moment Diagrams & location of maximum Bending Moment

c. Solution:

Determine location where shear force equals zero

$$V = -P1 + \sum_{i=0}^{x\,ft.} \left(w_{buoyant_i} - w_{canoe_i}\right)\ lb$$

$$0 = -150\ lb + \sum_{i=0}^{x} ((A_{submerged_i} * x_i * 62.4\ \frac{lb}{ft^3}) - (A_i * x_i * \rho_{concrete}))$$

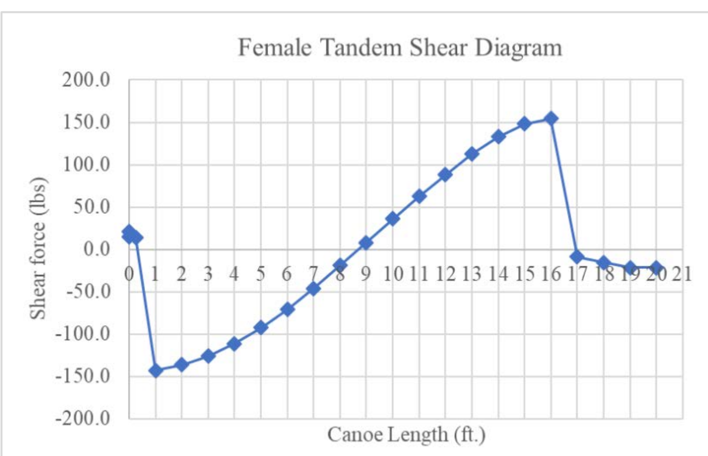
$$x = 10.5\ ft.$$

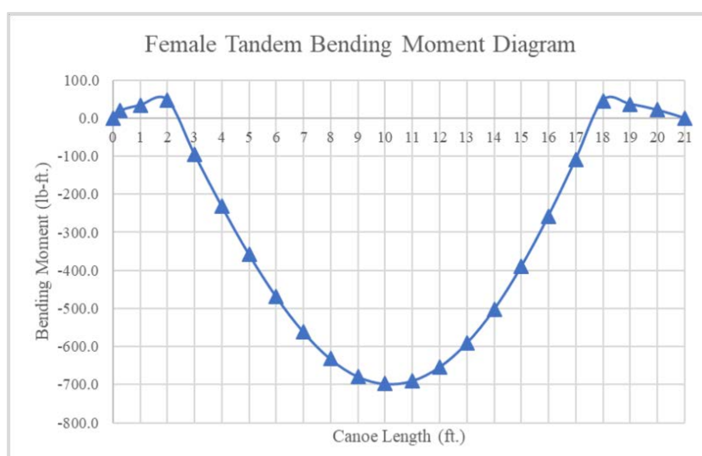
Determine Bending Moment @ L = 10.5 ft.

$$M = \int_0^{10.5\ ft} V(x)dx$$

$$M = \sum_{i=0}^{10.5\ ft} (x * V_i)$$

$$M_{max} = 697.4\ lb - ft$$





2. Male Tandem

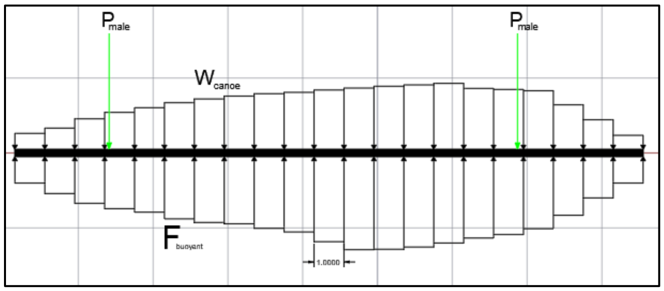
a. Assumptions:

   i. One 180-lb paddler located at 15% of canoe length & one 225-lb paddler located at 80% of canoe length analyzed as point loads

   ii. Canoe weight and length as previously defined

   iii. Canoe weight is assumed to act as constant distributed loads for each 1-foot interval of the canoe length

Free Body Diagram for Male Tandem Loading



b. Find: Shear Force and Bending Moment Diagrams & location of maximum Bending Moment

c. Solution:

Determine location where shear force equals zero

$$V = -P1 + \sum_{i=0}^{x\ ft.} \left(w_{buoyant_i} - w_{canoe_i}\right)\ lb$$

$$0 = -180\ lb + \sum_{i=0}^{x} ((A_{submerged_i} * x_i * 62.4\ \frac{lb}{ft^3}) - (A_i * x_i * \rho_{concrete}))$$

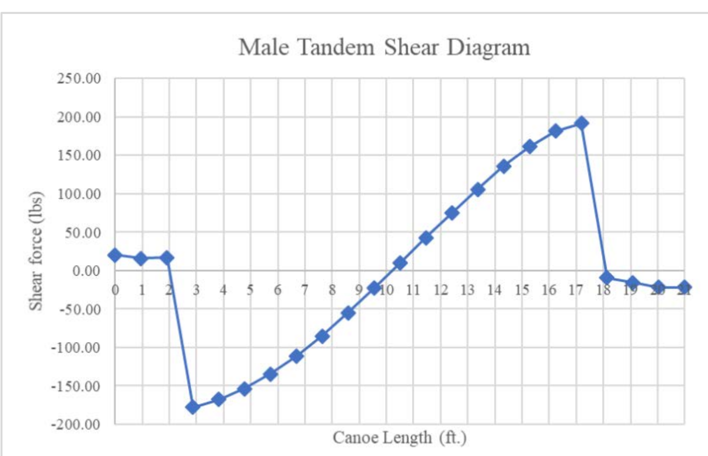
$$x = 9.45\ ft.$$

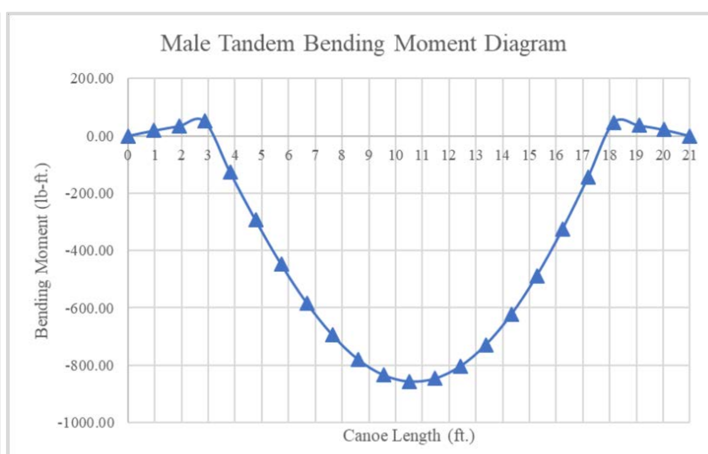
Determine Bending Moment @ L = 9.45 ft.

$$M = \int_0^{9.45\ ft} V(x)dx$$

$$M = \sum_{i=0}^{9.45\ ft} (x * V_i)$$

$$M_{max} = 856\ lb - ft$$





3. Four-person co-ed

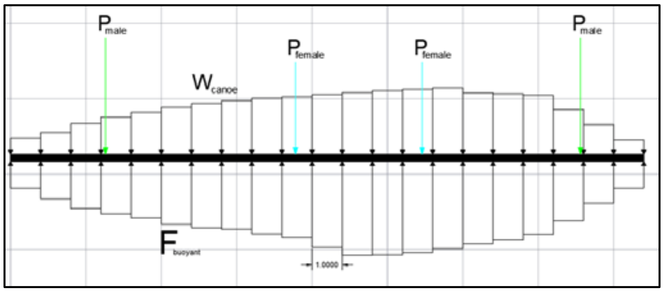
a. Assumptions:

i. Two 200-lb paddlers located at 15% & 90% of canoe length & two 150-lb paddlers located at 45% & 65% of canoe length analyzed as point loads

ii. Canoe weight and length as previously defined

iii. Canoe weight is assumed to act as constant distributed loads for each 1-foot interval of the canoe length

Free Body Diagram for Four-person Co-ed Loading



b. Find: Shear Force and Bending Moment Diagrams & location of maximum Bending Moment

c. Solution:

Determine location where shear force equals zero

$$V = -P1 - P2 + \sum_{i=0}^{x\,ft.} \left(w_{buoyant_i} - w_{canoe_i}\right)\ lb$$

$$0 = -200\ lb - 150\ lb + \sum_{i=0}^{x} ((A_{submerged_i} * x_i * 62.4\ \frac{lb}{ft^3}) - (A_i * x_i * \rho_{concrete}))$$

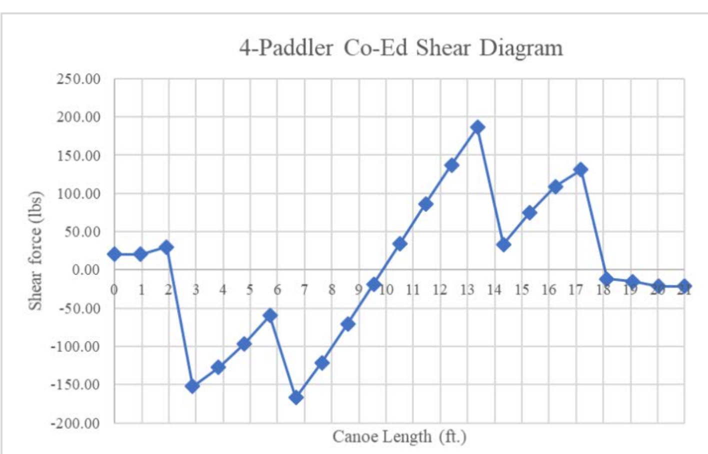
$$x = 10.5\ ft.$$

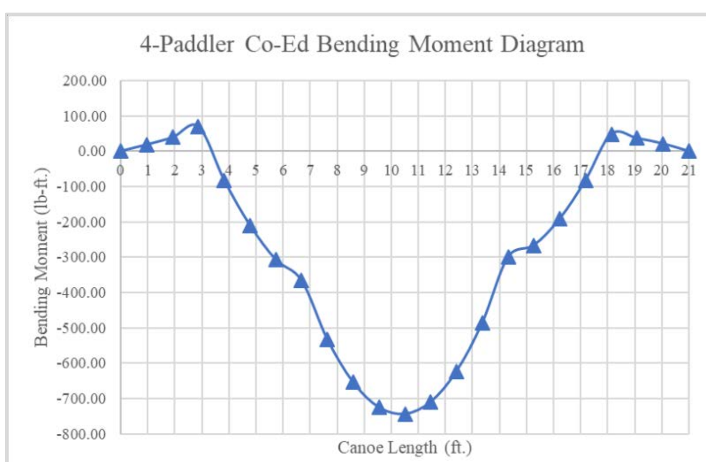
Determine Bending Moment @ L = 11.025 ft.

$$M = \int_0^{11.025\,ft} V(x)dx$$

$$M = \sum_{i=0}^{11.025\,ft} (x * V_i)$$

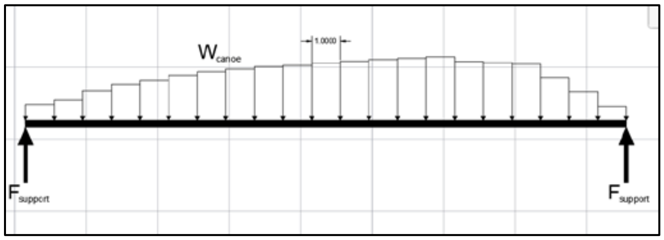
$$M_{max} = 743\ lb - ft$$





4. **Simply-Supported**
   a. Assumptions:
      i. Canoe weight is only load accounted for
      ii. Supports located at extreme ends of canoe
      iii. Canoe weight is assumed to act as constant distributed loads for each 1-foot interval of the canoe length

Free Body Diagram for Simply Supported Beam



   b. Find: Shear Force and Bending Moment Diagrams & location of maximum Bending Moment
   c. Solution:

Determine location where shear force equals zero

$$V = \sum_{i=0}^{x\,ft.} \left(-w_{canoe_i}\right)\ lb$$

$$0 = \sum_{i=0}^{x} -(A_i * x_i * \rho_{concrete})$$

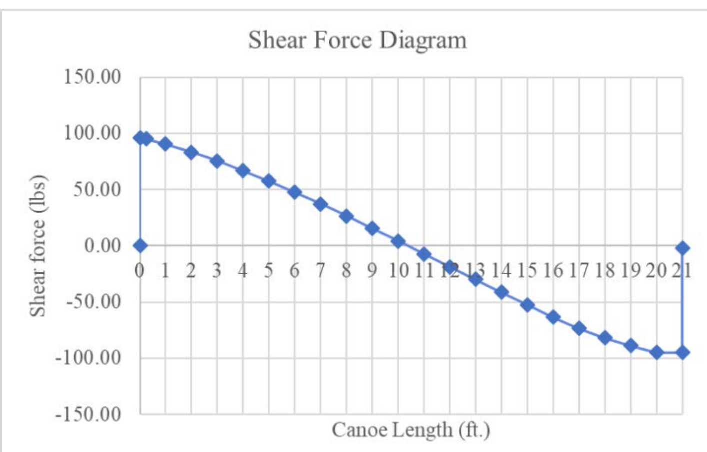
$$x = 11.0\ ft.$$

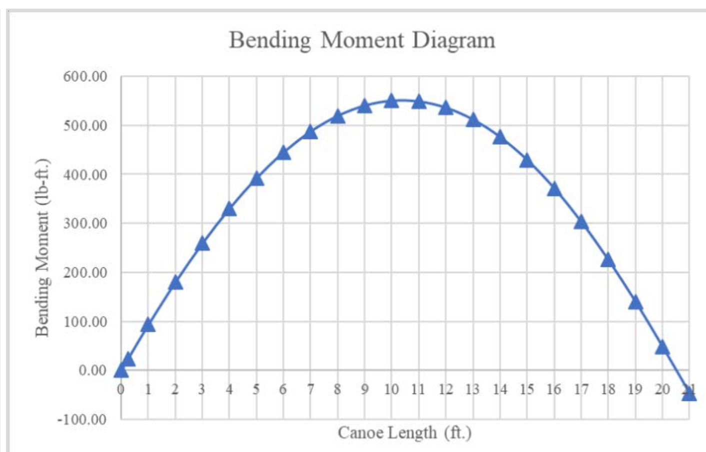
Determine Bending Moment @ L = 11 ft.

$$M = \int_0^{11.0\,ft} V(x)dx$$

$$M = \sum_{i=0}^{11.0\,ft} (x * V_i)$$

$$M_{max} = 457\ lb - ft$$





Summary of Load Cases and Magnitudes

Load Case	Female Tandem	Male Tandem	Four Person Co-ed	Simply Supported
Moment (+)	48 lb-ft	17 lb-ft	70 lb-ft	549 lb-ft
Location (ft.)	2.86 ft	2 ft	3.82 ft	11 ft
Moment (-)	-697 lb-ft	-857 lb-ft	-743 lb-ft	-47 lb-ft
Location (ft.)	10.5 ft	9.45 ft	10.5 ft	21 ft

Freeboard Calculation

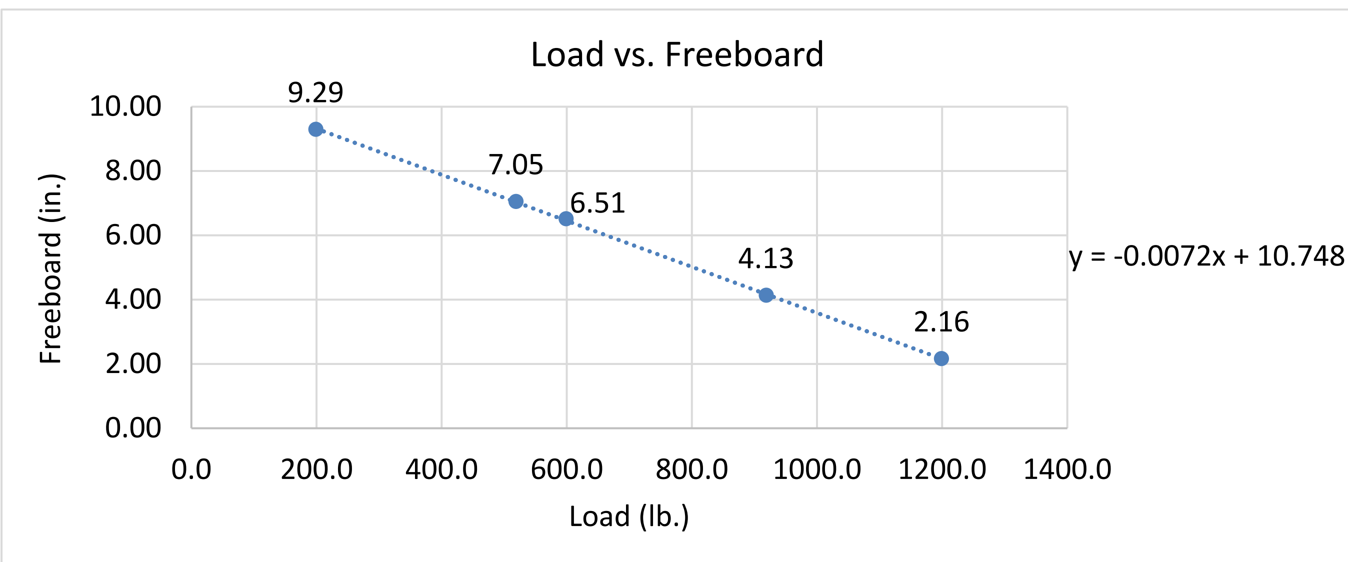
Freeboard values were obtained by using *Aquaholic* which plots cross sections of the canoe at one-foot intervals. Areas and volumes for each cross-section are determined areas between two curves which are evaluated to get the cross-sectional area of a given cross section interval.

Aquaholic utilizes a macro to take an initial waterline location guess and iterates the proper location. The program assumes that the buoyant force is equal to the displaced volume times the density of water (Archimedes' Principle). *Aquaholic* adjusts the waterline at each cross section until the resultant buoyant force is equal to the resultant paddler and canoe self-weight forces. The average across each cross-section is the overall waterline for a given scenario.

Freeboard and draught values for the lowest section of the canoe, 4 ft from the bow, are as shown:

Summary of load, freeboard, and draught values.

Scenario	Load (lb.)	Freeboard (in.)	Draught (in.)	Check Height @ 4 ft from bow(in.)
Self-weight	199.0	9.29	3.01	12.30
Female Tandem	519.0	7.05	5.25	12.30
Male Tandem	599.0	6.51	5.79	12.30
Co-ed	919.0	4.13	8.17	12.30
+1,000 lbs.	1199.0	2.16	10.14	12.30



Appendix D - Hull Thickness, Reinforcement & Percent Open Area Calculations

Summary of Reinforcement Thickness:

Reinforcement Material	Material Thickness (in.)
Carbon Fiber	0.035
Kevlar Tendons	0.125
Threaded Rod	0.375
Ferrule	0.094

<u>Section A: Standard Canoe Wall, Typical</u>

Minimum Concrete Wall Thickness: 0.5 in.

$$\frac{t_{\text{Reinforcement}}}{t_{\text{Concrete}}} = \frac{t_{tendon} + 2 \cdot t_{carbonfiber}}{t_{Concrete}} = \frac{0.125 + 2 \cdot 0.035}{0.5} = 39\% \leq 50\%$$

<u>Section B: Rib Location</u>

Minimum Concrete Wall Thickness: 1.5 in.

$$\frac{t_{\text{Reinforcement}}}{t_{\text{Concrete}}} = \frac{t_{tendon} + 2 \cdot t_{carbonfiber} + t_{threadedrod}}{t_{Concrete}} = \frac{0.125 + 2 \cdot 0.035 + 0.375}{1.5} = 38\% \leq 50\%$$

<u>Section C: Bulkhead</u>

Minimum Concrete Wall Thickness: 1.0 in.

$$\frac{t_{\text{Reinforcement}}}{t_{\text{Concrete}}} = \frac{2 \cdot t_{tendon}}{t_{Concrete}} = \frac{2 \cdot 0.125}{1.0} = 25\% \leq 50\%$$

<u>Section D: Anchorage Zone</u>

Minimum Concrete Wall Thickness: 1.0 in.

$$\frac{t_{\text{Reinforcement}}}{t_{\text{Concrete}}} = \frac{2 \cdot t_{tendon} + t_{ferrule}}{t_{Concrete}} = \frac{2 \cdot 0.125 + 0.094}{1.0} = 34.4\% \leq 50\%$$

General Note: Reinforcement thicknesses are determined based upon guidelines givein in Exhibit 5 of the 2022 ASCE National Conrete Canoe Competition Rules and Regulations.

Percent Open Area Calculations: Carbon Fiber Grid

Variable	Definition	Carbon Fiber Grid Parameters
$\boldsymbol{N_1}$	Number of apertures along sample length	6
$\boldsymbol{N_2}$	Number of apertures along sample length	7
$\boldsymbol{aperture_1}$	Spacing of reinforcement (center-to-center) along sample length	1.5 in.
$\boldsymbol{aperture_2}$	Spacing of reinforcement (center-to-center) along sample length	1.5 in.
$\boldsymbol{T_1}$	Thickness of reinforcement along sample length	0.15 in.
$\boldsymbol{T_2}$	Thickness of reinforcement along sample width	0.15 in.

Carbon Fiber Grid Reinforcement

$$d_1 = \text{aperture}_1 + 2 \cdot \left(\frac{t_1}{2}\right) = 1.5\ in. + 2 \cdot \left(\frac{0.15\ in.}{2}\right) = 1.65\ in.$$

$$d_2 = \text{aperture}_2 + 2 \cdot \left(\frac{t_2}{2}\right) = 1.5\ in. + 2 \cdot \left(\frac{0.15\ in.}{2}\right) = 1.65\ in.$$

$$Length = n_1 \cdot d_1 = 6 \cdot 1.65\ in. = 9.9\ in.$$

$$Width = n_2 \cdot d_2 = 7 \cdot 1.65\ in. = 11.55\ in.$$

$$\Sigma Area_{open} = n_1 \cdot n_2 \cdot aperture_1 \cdot aperture_2 = 6 \cdot 7 \cdot 1.5\ inch \cdot 1.5\ inch = 94.5\ in^2$$

$$\Sigma Area_{total} = Length \cdot Width = 9.9\ inch \cdot 11.55\ inch = 114.345\ in.^2$$

$$POA = \frac{\Sigma Area_{open}}{\Sigma Area_{total}} = \frac{94.5\ in.^2}{114.345\ in.^2} = 82.6\%\ (> 40\%\ min)$$

O.K.

Appendix E - Detailed Fee Estimate

Labor Costs

Direct Labor Costs and Hours Estimate													
Role	RLR	HRS per task										HRS	RLR*HRS
		A	B	C	D	E	F	G	H	I	J		
Principal Design Engineer	$50.00	80	28	21	31	32	37	38	28	26	11	332	$16,600.00
Design Manager	$45.00	19	32	11	46	17	44	23	30	20	15	257	$11,565.00
Project Construction Manager	$40.00	48	-	8	-	30	55	5	5	5	20	176	$7,040.00
Construction Superintendent	$40.00	65	-	8	-	41	75	-	-	-	30	219	$8,760.00
Project Design Engineer	$35.00	-	40	41	50	48	73	32	31	26	20	361	$12,635.00
Quality Manager	$35.00	41	6	6	33	26	56	10	10	10	10	208	$7,280.00
Graduate Field Engineer	$25.00	9	6	5	5	5	5	10	5	10	5	65	$1,625.00
Technician/Drafter	$20.00	-	10	5	5	-	-	5	5	10	10	50	$1,000.00
Laborer/Technician	$25.00	-	-	-	72	87	135	-	-	-	87	381	$9,525.00
Clerk/Office Admin	$15.00	25	-	-	-	-	-	-	-	-	-	25	$375.00
Total		**287**	**122**	**105**	**242**	**286**	**480**	**123**	**114**	**107**	**208**	**2074**	**$76,405.00**

Task	Symbol
Project Management	A
Hull Design	B
Structural Analysis	C
Mixture Design	D
Mold Construction	E
Canoe Construction	F
Project Proposal	G
Enhanced Focus Area Report	H
Presentation	I
Display	J

Total hours	2074
Direct Employee Costs, DEC	1.5
Indirect Employee Costs, IEC	1.3
Profit Multiplier, P	18.0%
Direct Labor, DL = [Σ(RLR×HRS)]× (DEC + IEC)× (1+P)	$252,442.12

- RLR = Raw Labor Rates
- HRS = Labor Hours

Material Costs					
Construction					
Material	**Unit Price**	**Unit**	**Units**	**Cost**	**Source**
1/8" Kevlar Cord	$0.29	ft	228.0	$66.12	US Netting
Carbon fiber grid	$16.50	ft	40.0	$660.00	Fishstone
3/8" Rebar	$1.33	ft	12.0	$15.92	Home depot
Sealer	$0.39	ft2	200.0	$78.00	WR Meadows
Polyvinyl Chorlide Pipe	$3.63	ft	40.0	$145.20	Valencia Pipe Co.
EPS Foam	$7.09	ft3	2.0	$14.18	Insulfoam
Concrete					
Material	**Unit Price**	**Unit**	**Units**	**Cost**	**Source**
Portland Cement White Type I	$0.43	lb	28.0	$12.10	Lehigh Hanson
Metapor® Metakaolin	$0.43	lb	20.0	$8.60	Poraver®
Hydrated Lime, Type S	$0.15	lb	28.0	$4.20	Graymont
Poraver® Siscorspheres	$0.25	lb	50.0	$12.50	Poraver®
Elemix™	$2.75	lb	3.0	$8.25	Syntheon®
Expanded Shale	$0.34	lb	20.0	$6.80	Utelite®
Poylvinyl Alcohol Fibers	$1.05	lb	4.4	$726.97	Nycon®
Q-Cel® 6019S	$0.18	lb	12.6	$2.27	Potters Industries Inc.
Pigment	$5.00	lb	2.0	$172.90	Direct™ Colors
ADVA®Cast 575	$8.35	gal	0.8	$6.43	GCP Applied Technologies
DARAVAIR®-AT30	$9.00	gal	0.4	$3.24	GCP Applied Technologies
Total Materials Cost, MC				$1,943.67	
Direct Labor Expenses, DE				$1,600.00	
Markup, M				10.0%	
Expenses, E = [ΣMC + ΣDE]*(1+M),				$3,898.04	
Direct Labor Costs, DL				$252,442.12	
Lump sum fee for mold construction				$6,000.00	
Shipping costs of the canoe via truck rental (from reno, nv to Ruston, LA)				$1,223.00	
Grand total				$263,563.16	

Appendix F - Supporting Documentation

Material Technical Data Sheets (MTDS)

Product Name	Type	ASTM	Link
Construction			
Carbon Fiber Reinforcing CT275 C-Grid	Primary reinforcement	No Standard	https://concretecountertopsupply.com/Item/Cgrid
KR12S-18-600 Kevlar Cord	Primary reinforcement	No Standard	https://www.usnetting.com/rope/kevlar/
Fishing Line	Reinforcing Material	No Standard	https://ger-line.com/monofilament/
Threaded Rod	Reinforcing Material	No Standard	https://marineboltsupply.com/stainless-information
Aluminum Ferrule	Reinforcing Material	No Standard	https://www.homedepot.com/p/Everbilt-1-8-in-Aluminum-Ferrule-and-Stop-Set-43254/205887928
EPS Foam	Floatation	No Standard	https://images.thdstatic.com/catalog/pdfImages/9e/9e0913b9-f642-4641-bb95-dd5b6699b6ca.pdf
VOCOMP®-25	Sealer	C1315	https://www.wrmeadows.com/vocomp-25-concrete-curing-sealing-compound/
Cementitious			
White Portland Cement Type 1	Cement	C595	https://www.lehighwhitecement.com/wp-content/uploads/2019/01/specsheet.pdf
Metapor® Metakaolin Class N	Cementitious Material	C618 Type N	https://www.poraver.com/wp-content/uploads/2018/11/181031_TDS_Metapor_PNA.pdf
Super Limoid® Hydrated Lime Type S	Cementitious Material	C207 Type S	https://www.graymont.com/sites/default/files/pdf/superlimoid_s_brochure_5-01.pdf
Aggregate			
Elemix™	Aggregate	N/A	Manufacturer website no longer available
Poraver® Siscorspheres	Aggregate	N/A	https://www.poraver.com/wp-content/uploads/2019/12/191202_TDS_Poraver_PNA_8grains_EN_DE.pdf
Utelite® Expanded Shale	Aggregate	C330	https://www.utelite.com/products/utelite-fines-expanded-shale/
Solids			
DCI-Concrete Pigment	Aesthetics	C979	https://directcolors.com/diy/data-sheets/

PVA (Polyvinyl Alcohol Fibers)	Secondary Reinforcement	C1116	https://cdn.shopify.com/s/files/1/0088/0764/5299/files/NyconPVARECS15Sheet042015.pdf?7980
Q-Cel® 6019S Hollowed Engineered Glass Microspheres	Mineral Filler	No Standard	https://www.pqcorp.com/docs/default-source/recommended-literature/potters/q-cell/hollow-microspheres-chart-08-2013.pdf?sfvrsn=a06644e0_3
Admixtures			
ADVA® Cast 575	High Range Water Reducer	C494	https://gcpat.com/en/solutions/products/adva-cast-high-range-water-reducers/adva-cast-575
DARAVAIR®-AT30	Air Entrainer	C260	https://gcpat.com/en/solutions/products/daravair-at30

Pre-Qualification Form (Page 2 of X)

_ University of Nevada, Reno
(school name)

As of the date of issuance of this Request for Proposal, what is the status of your school/ university's 2021-22 classroom instruction (in-person, remote, hybrid)? What is anticipated after Thanksgiving and winter holiday break? If in-person or hybrid, do you have access to laboratory space or other facilities outside of classes?

The University of Nevada, Reno (UNR) is proceeding with in-person classes for the 2021-2022 school year. After Thanksgiving and winter holiday break, class is anticipated to resume in-person. The Nevada Concrete Canoe Team (NCCT) has access to laboratory space and our workspace outside of classes.

In 250 words or less, provide a high-level overview of the team's Health & Safety {H&S) Program. If there is currently not one in place, what does the team envision their H&S program will entail? Include a discussion on the impact of COVID-19 on the team's ability to perform work and what plans would be implemented assuming work could be performed.

The NCCT has the following H&S Program in place:

1. Safety
   All members are required to wear PPE, including long-sleeved shirts, pants, closed toed shoes, gloves, and N-95 masks. The NCCT works closely with the university's Environmental Health & Safety (EH&S) Office to ensure proper safety measures are in place. The NCCT abides by strict policies in regard to proper use and storage of chemicals and tools. Standard operating procedures and safety manuals for the chemicals and tools in the work space are provided.

2. Workday Overview
   Before a workday, a briefing will be held by the EH&S Officer and Construction Manager to familiarize members on the workday's goals, proper construction techniques, chemical management, and safety concerns. Additionally, a review of all tools, chemicals, material, and equipment including the proper safety protocols to abide will be made.

3. Cleaning
   After each workday, cleaning of the workspace and tools is required. Brooms, wash cloths, and mops are provided. All tools, material, and chemicals are to be returned to its proper storage bin or locker.

4. COVID-19
   Face coverings are required to be worn at all times. Members who have symptoms of or test positive for COVID-19 must report to the EH&S Officer and may not participate on the NCCT until a negative test is provided. All team members will be notified if someone was affected by COVID-19. UNR is requiring all students to be vaccinated to enroll in the spring 2022 semester. By then, all team members will be vaccinated.

In 150 words or less, provide a high-level overview of the team's current QA/QC Program. If there is currently not one in place, what does the team envision their QA/QC program will entail?

The NCCT has the current QA/QC program in place:

1. Scheduling
Team managers will meet weekly to discuss deadlines and important dates regarding the project delivery schedule. Updates regarding project delivery and modifications to deadlines to account for delays will also happen during these meetings.

2. Preparations
Before each workday, a meeting will be held with the managers of the project. The meeting entails reviewing proper construction and mix techniques, safety concerns and protocols, and any problems that may occur during the workday.

3. Oversight
Past project managers and a trained Construction Manager will provide active oversight for each workday. Together, they will ensure all members are performing proper construction techniques, quality work is being produced, and any errors are resolved such that the overall quality is not diminished.

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, all relevant team members will receive training from the laboratory before any construction or mix design begins.

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

Mountain bluebird, the state bird of Nevada.

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

Yes. There will be no issues with the theme so long we provide our own art or get permission/cite from the necessary parties.

The core project team is made up of 10 *number of people.*

Nevada Concrete Canoe Team
University of Nevada, Reno
1664 N Virginia St
Reno, NV 89557

October 21, 2021

ASCE Student Services
1801 Alexander Bell Drive
Reston, VA 20191

Dear ASCE Concrete Canoe Competition Committee,

The University of Nevada, Reno Concrete Canoe Team (NCCT) hereby acknowledges the receipt of the 2022 American Society of Civil Engineers (ASCE) Committee on Concrete Canoe Competitions (C4) Request for Proposal (RFP). We certify that our 2022 project proposal and enhanced focus area report will be completed and submitted in compliance with the rules and regulations detailed in the 2022 RFP. We also understand the eligibility requirements set forth by the C4 and ensure that all registered participants for both the ASCE Student Symposia Concrete Canoe Competition and the Society-wide Competition will meet the requirements. The NCCT understands the use of the submission platform "Cerberus Web Client" and acknowledges the deadlines of submissions outlined in Exhibit 1 of the RFP.

Sincerely,

10/21/2021
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2020-2021 Project Manager
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