Ponderosa Pinecones

2022 Concrete Canoe

Technical Proposal

Northern Arizona University

February 18, 2021

Dear Committee on Concrete Canoe Competitions,

Attached to this letter is the Technical Proposal from the 2021-2022 Northern Arizona University Concrete Canoe Team. This document is the response to the Request for Proposal for the concrete canoe design. The attached Technical Proposal displays the developed design from the Northern Arizona University Team. The proposal hull design, concrete mixture design, and the reinforcement scheme are in full compliance with the specifications outlined in the Request for Proposal. All relevant Material Data Sheets and Safety Data Sheets for materials proposed for the construction of the canoe have been reviewed by the team. The team is in receipt of the Request for Information Summary and this submission complies with the RFI responses provided. The registered participants are qualified student members and Society Student Members of ASCE and meet all eligibility requirements. The registered participants are as follows:

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Please contact the Project Manager, Hunter Kassens, if there are any questions or comments

Regards,
Northern Arizona University 2021-2022 Concrete Canoe Team

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1.0 Executive Summary

This year's canoe from Northern Arizona University' Concrete Canoe Team, the Ponderosa Pinecones (or just Pinecones), is inspired in part by the nature surrounding Flagstaff, Arizona. Unlike the majority of Arizona, Flagstaff is a small mountain town in the Coconino National Forest, a stark contrast to the desert that most of Arizona is known for. The town is filled with the iconic Ponderosa pine trees and, of course, their pinecones. The large part of the choice of the team's name was a particular professor that we all had as underclassmen at Northern Arizona University. The professor made an analogy to all of us young engineers being pinecones. As pinecones fall from the tree in a storm, take time to dry out, and finally open up, students leave home to come to college, take time to learn the principles of engineering, and then open the door to a career.

In recent years, the NAU concrete canoe teams have continued to improve and are on an upward trend, so we have set out to continue this. The placements have been 3rd (Ponderosa, 2021), 9th (Agassiz, 2020), and 11th (VolCanoe, 2019), respectively. This year we set out with a goal of again placing in the top 3 for the concrete canoe competition at ISWC this year. To do this, we decided early on to build-on and improve the work and design of previous NAU teams in many different facets.

One notable way in which we have accomplished this was by using recycled concrete in our mix design. The recycled concrete comes for the Agassiz canoe. This canoe was found to have one of the lowest densities of the NAU canoes that was available to us, and thus, it was chosen to be used for our recycled concrete aggregate. This not only increases the sustainability of the canoe through recycling, but it also allows for a much lighter mix design than last year's team, Ponderosa. Ponderosa used entirely Utelite to comply with the C4 regulation of having 50% C330 aggregate, but instead, we supplemented this with 25.4% recycled concrete. This creates a lighter mix since the recycled concrete had a unit weight of 56 lb/ft^3 [1]. The properties of our final mix can be seen in Table 1-1.

Table 1-1: Concrete Properties

Concrete Properties		
Property	Mix Value	Units
Wet Density	76.3	pcf
Dry Density	74	pcf
Compressive Strength (14-day)	1190	psi
Tensile Strength	180	psi
Composite Flexural Strength	150	psi
Slump	2	inch
Air Content	2.1	%

In terms of the hull design, the Pinecones have decided to go with a symmetrical canoe, contrary to the design of Ponderosa who had an asymmetrical hull design. This goes back to a similar design as Agassiz. This symmetrical design allows for an easier hull design and construction process since not all parts of the design are unique. The specifications of the hull design can be seen in Table 1-2.

Table 1-2: Canoe Characteristics

Pinecone Canoe Characteristics		
Property	Value	Units
Length	217	inch
Width	27.5	inch
Depth	14.2	inch
Thickness	0.5	inch
Weight		pounds

Lastly, an over arching objective of the Pinecones was to work closely with mentees in order to educate them on the intricacies of designing and constructing a concrete canoe. This is a large part of the sustainability of NAU's Concrete Canoe Club. Passed down knowledge is vital for the school's continued success in the ASCE Concrete Canoe Competition.

2.0 Project Delivery Team

2.1 ASCE Student Chapter Profile

The goal of Northern Arizona University's (NAU) ASCE Student Chapter is to increase a student's professional and personal networks. In previous years, the chapter has facilitated intramural sporting events for chapter members to encourage a team-building environment. In recent history, the ASCE Student Chapter has organized events such as hiking, bowling, tailgating, and meal nights with members to provide an environment that students can easily make friends and expand their personal networks. The ASCE Student Chapter will also coordinate community service and volunteer activities in order to give students the opportunity to give back to the Flagstaff community. These have included trash-pickups along local roads and repairing and restoring land after summer floods.

General meetings are held biweekly and usually consist of presentations given by professionals at various companies, giving students the opportunity to expand their professional networks. Professionals on anything from technical engineering work to their personal experiences throughout their career. Students are encouraged to bring resumes to these general meetings so that they can build relationships with professionals. To ensure students feel comfortable bringing their resumes to company presentations, the chapter holds bi-monthly general meetings as resume builders. This way, students can receive help from faculty, professionals, and peers in a relaxed environment.

The NAU ASCE Student Chapter also focuses on underclassmen outreach. Every semester, upperclassmen in the club will go give presentations to underclassmen engineering classes to encourage the engagement and growth of younger students. All underclassmen members of the chapter will receive an upperclassmen mentor in order to help guide and advise on career paths, professional development, and classes. This helps to provide a supportive and engaged community for all members of the club.

2.2 Key Team Members

The key members of the team consisted of Hunter Kassens, Cole Robertson, Hannah Thelen, Eric Moore, and Steven Procaccio.

Hunter Kassens is the Project Manager. Hunter's responsibilities are to manage the project schedule, budget, deliverables, and to fundraise. Although these are Hunter's primary tasks, Hunter also assists all other team members in completing and overseeing their tasks.

Cole Robertson is the Mix Design Manager. Cole is responsible for doing material research, concrete mix design, material procurement, and concrete testing. Although Cole oversees these areas, other team members assist in these areas to provide the manpower that is necessary for mixing, testing, and material procurement.

Hannah Thelen is the Quality Control and Quality Assurance Manager. Hannah is responsible for assuring quality of all of deliverables as well as the quality of the construction of the canoe. Hannah also ensures that all elements of the project are following the rules and regulations set forth in the Request for Proposal.

Eric Moore is the Structural Design Manager. Eric's primary responsibilities are completing structural calculations and designing the reinforcement layout. Eric will ensure that the canoe's design will endure all necessary load combinations.

Steven Procaccio is the Hull Design Manager. Steven is responsible for researching and designing the hull of the canoe and procurement of the mold for the construction of the canoe. Steven will design the canoe and provide construction drawings via SolidWorks.

2.3 Organizational Chart

3.0 Technical Approach

3.1 Hull Design

The main goal of this year's hull design was to provide a maneuverable canoe that could stay competitive with a moderately heavy mix design. After rigorous paddling practice throughout last fall utilizing canoes from past years, a design baseline was established based upon desired characteristics from past canoes. After testing remaining canoes from the past 5 canoe teams, the 2019 NAU Concrete Canoe, Agassiz, stood out with its excellent handling and maneuverability despite the canoe being relatively heavy [1]. Coincidentally, this canoe was never raced in conference or tested on the water prior to last year. Therefore, it was determined that with the materials available to us and the estimated final mix design unit weight, designing this year's canoe with a similar style of hull design would be the most beneficial way for this year's team to stay competitive in the competition races at ISWS. A symmetrical design was chosen over an asymmetrical design, after thorough research and testing was procured. It was decided that a symmetrical design with predictable handling was more desired over the enhanced forward speed and glide of the other potential design, a swede form asymmetrical canoe. A symmetrical design would also improve the efficiency and simplicity of the mold procurement in the construction process.

With a final mix unit weight prediction of 70 lb./ft^3, the dimensions of the Pinecones canoe were scaled down from the 2020 team's design (Ponderosa), which was scaled up in length and width to aid in buoyancy with a heavier mix at 94 lb./ft^3 [2]. A scale down of dimensions not only improves performance and maneuverability within a tight turning radius, but also requires less materials to construct. The canoe will sit lower in the water with a shorter length but will displace the same amount of water as a longer canoe would. This causes maneuverability around corners to be an issue due to the force of buoyancy on the canoe walls. This is offset by a shallow curve to the bottom of the canoe. The shallow curve will displace more water than a shallow-v design. This will be necessary for the heavier mix compared to previous years.

Maneuverability is the focus of this year's canoe design, as the canoe must be accessible to paddlers of any skill level. The lakes are frozen for most of the academic year in Flagstaff, therefore paddling practice is not easily accessible during the winter months. Notable dimensions of the Ponderosa Pinecones canoe include a length of 217 inches- which is equivalent to 18.1 ft, a thickness of 0.5 inches, a maximum height of 14.2 inches, and a maximum width of 27.52 inches. This can be found in Section 4.0. The calculated freeboard for the Pinecones canoe is 9.17 inches for the male two-person loading case, 9.72 inches for the female two-person loading case, and 6.8 inches for the four-person loading case. Two layers of bi-directional carbon grid were added to the gunwale to provide reinforcement strength to the canoe. 3-foot foam bulkheads were added to each end of the canoe to help with floatation and to pass the swamp test during competition. These bulk heads are larger than Agassiz since the mix is not as light as before.

3.2 Structural Design

The structural analysis of the canoe began with specifying goals for the various properties of the concrete mix that would optimize the performance and strength of the design. The goal of the analysis was to determine the compressive strength necessary for the final concrete mix in order to ensure the final product is structurally sound, while keeping the mix as close to the unit weight of water as possible to keep its' buoyancy. The structural analysis included: the requirements of the mix design, determining the reinforcement to be used in the hull, and additional analysis to determine what loadings and stresses the canoe could withstand.

The first step was to determine the mesh reinforcement to be used in the hull in between the layers of concrete. The team had to choose between carbon fiber and basalt mesh. The team had access to both materials, the basalt mesh from previous years teams, and received bi-directional carbon grid as a donation. Based on the factors of cost, sustainability, constructability, and effectiveness, the bi-directional carbon grid reinforcement was chosen. This was based on its high strength, availability, and a greater flexibility to fit various shapes.

Once the reinforcement was determined, the canoe was analyzed according to the load scenarios required by the Committee on the Concrete Canoe Competition. These loadings were a two-person loading with female paddlers, a two-person loading with male paddlers, and a four-person loading. These scenarios represent the loadings that the canoe during the races at the conference competition. The canoe was assumed to be a uniform concrete beam with straight edges and 90-degree corners to calculate the shear and moment along the length. In addition to the loadings from the paddlers, the canoe will be subject to loadings from the buoyancy force pushing up on it, and the self-weight of the canoe itself. The self-weight was calculated using the unit weight of the concrete mix and the volume of the hull, found using SolidWorks software. This was determined to be 12.9 lb/ft, resulting in a 232.2 lb force, assumed to be uniformly distributed along the entire length of the canoe.

The two-person female tandem loading included two 150-lb point forces acting at 15% and 85% of the canoe length. These loadings combined with the self-weight resulted in a 532-pound acting downward on the canoe. The buoyancy force acting upwards on the canoe was determined based on the depth in the water, the volume displaced by the canoe, the density of water, and the force of gravity. This force was calculated to be 31.5 lb./ft, and a uniform loading across the length of the canoe because the loading inside the canoe is evenly distributed.

The two-person male tandem loading included two 185-lb point forces acting at 15% and 85% of the canoe length. These loadings combined with the self-weight resulted in a 602-pound acting downward on the canoe. The buoyancy force acting upwards on the canoe was determined based on the depth in the water, the volume displaced by the canoe, the density of water, and the force of gravity. This force was calculated to be 35.16 lb/ft, and a uniform loading across the length of the canoe because the loading inside the canoe is evenly distributed.

The four-person loading included two 150-lb point forces acting at 15% and 85% of the canoe length, and two 185-lb point forces acting at 35% and 65% of the canoe length. These loadings combined with the self-weight resulted in a 902-pound acting downward on the canoe. The buoyancy force acting upwards on the canoe was determined based on the depth in the water, the volume displaced by the canoe, the density of water, and the force of gravity. This force was calculated to be 51.83 lb/ft, and a uniform loading across the length of the canoe because the loading inside the canoe is evenly distributed.

Using the free-body diagrams for the three loading scenarios, Microsoft Excel was used to construct the shear force and bending moment diagrams for each. The table showing the maximum bending moment for each loading scenario can be seen in Appendix C.

3.3 Mix Design

The overall goal of mix design is to create a unique and advantageous concrete mixture that utilizes 2022 ASCE Concrete Canoe Competition Request for Proposal approved materials and follows all given competition rules. The focus of this year's mix design was to create a workable, lightweight, and strong concrete mix while utilizing recycled aggregate. The first step that was taken for mix design was to create last year's NAU team (Ponderosa's) mix design. This mix focused on using a simple mix recipe with only 2 main aggregates, Perlite and Utelite [2]. With this baseline mix design, we started doing iterative testing to determine our final structural mix design.

A significant difference between our mix and the Ponderosa' mix is that instead of using only C330 commercially available aggregate to meet the 50% minimum by volume of the total mix, we used recycled concrete primarily [3]. This allowed our final structural mix to use 35.3% of the total volume of aggregates in the form of recycled aggregate. This recycled aggregate was acquired by crushing previous teams' canoes. The specific gravity of the recycled aggregate, which is the only non-commercially available material used, was found using and following C127 testing procedures [4].

As mentioned above this year's Committee on the Concrete Canoe Competition (C4) rule set allowed for a mix of C330 aggregates and recycled aggregates to meet the 50% minimum total aggregate volume [5]. This allowed our mix design to incorporate recycled aggregate acquired from previous years canoes to make up a bulk of our structural aggregate. Recycled aggregate has a much smaller specific gravity than Utelite (which was what we used for our C330). The specific gravity of the recycled aggregate that we used was found to be 0.90 compared to 1.55 of Utelite. Utelite was chosen to be our ASTM C330 compliant aggregate because it has a low specific gravity when compared to other aggregates in the same category, it provides the strenth needed for our mix, and the aggregate was donated which saved costs for the team. It is important to note that the team used two different gradations of Utelite (10 mesh and crushed fines) to provide different sizes of aggregate in each mix.

There were three other aggregates that were evaluated for use in this year's canoe. The other aggregates used to fill the remaining aggregate volume that were considered were Ultra-lightweight Foamed Glass Aggregate (UL-FGA), Expanded Perlite, and Poraver of various sizes. Poraver is a lightweight aggregate that is made from recycled glass and is in the shape of a bead. Poraver has a specific gravity of 0.4-0.8 depending on the size and allows for good interlocking of concrete as the bead shape is good for concrete cohesion. Poraver was not selected for our mix design as the material was sold out and not obtainable and thus was decided to be unsustainable and ineffective for this project.

UL-FGA was procured via donation from a company called Aero Aggregates. UL-FGA is a 100% recycled aggregate that has high permeability, low specific gravity (0.78), and a high frictional surface for cohesion. This material was used in the team's mix design as a result of the lightweight yet strong material properties that the material provides.

Perlite was the other aggregate that was used in this years mix design. Perlite was chosen for our mix design because of its ultra-lightweight property. Perlite is also a ASTM C332 compliant aggregate for insulting concrete which shows the materials ability to work as an aggregate in concrete. Perlite has a specific gravity of 0.27 which allows perlite to be used to take up volume while adding minimal weight. Perlite has little structural additions and is mainly used in the mix as a lightweight fill material.

The three cementitious materials that were considered and used for this years mix design was Type 1 Portland cement, silica fume, and Class-C Fly Ash. All three of these cementitious materials were procured from an Arizona based material company named SRMG.

Type 1 Portland cement works as the primary reactant for the teams mix. Type 1 Portland cement has a specific gravity of 3.15 and is readily available and has excellent bonding strength for increased tensile and compressive strength.

Type-C Fly Ash was used to replace roughly 20% of the amount of type 1 Portland Cement. Type-C Fly Ash was chosen to be a supplement to cement as this material has decreased permeability and water demand. In addition, the particles are more spherical shaped by nature which helps with cohesion as well as type-C fly ash has a specific gravity of 2.5 which is less than that of Portland cement.

The last cementitious material that was used in our mix design was silica fume. This material was also soured locally through SRMG. Silica fume was selected for use in our mix design as silica fume which is a pozzolan increases permeability and workability of concrete. Silica fume achieves this as the materials particle sizes are roughly 100 times smaller than that of Portland cement. This allows the silica fume to act as a filler for our concrete and increase the compaction of our mix design.

A water to cementitious ratio of 0.4 was decided upon for this years mix design. This ratio was determined through 4 rounds of iterative testing with ratios between 0.3 and 0.5.

Several addmixtures were considered for use in the construction of this years concrete canoe. 5 admixtures were considered including: MasterGlenium® 7500, Masterset® DELVO, MasterAir® AE 90, MasterLife® SRE-35, MasterMatrix® VMA 362, and MasterAir® AE 90 were not used as it was decided through talks with previous teams early in the project that an air-entrainer and a viscosity increaser was not needed. So the final 3 admixtures that were choosen to be used for this project were MasterGlenium® 7500, Masterset® DELVO, and MasterLife® SRE-35. It is important to note that all three admixtures used meet ASTM C494 requirements.

MasterGlenium® 7500 is a high-range water reducer that allows the team to reduce the water to cement ratio and thus reduces the unit weight of the concrete. MasterLife® SRE-35 is an admixture that will reduce shrinkage and cracking of the concrete once placed which will increase the water-tight ability of the team's canoe. Lastly, Masterset® DELVO is a retarding admixture. Delvo provides the team more working time before the concrete starts to set and harden which will be a key fator in effective placement of the canoe.

The last material used in the mix design is secondary reinforcement. This secondary reinforcement takes the place of PVA-15 8mm reinforcing fibers that were provided from the previous years team (Pondersoa). The polyvinyl fibers bond with the concrete and add significant strength, and reduce shrinkage by creating a molecular bond with the concrete during mixing.

Using all the materials mentioned above the Ponderosa Pinecone team created 21 independent mixes that were tested and analyzed before coming to the final mix design. The main testing procedures for each test was for tensile and compressive strengths which complied with ASTM C496 and C39. In addition, unit weights, workability, and consolidation were all important factors that went into analyzing each design.

Previous team members, research essays, books, NAU grading instructors and technical advisors were heavily relied upon when creating initial and integrative mixes as well as the mix spreadsheet. A key roadblock that was overcame in the mix design process was with the quantity of concrete that was being made. During the middle part of mix design testing mixes would only make 50% of what it should. It was established that the specific gravities of some materials were wrong. Western Technologies in Flagstaff, Arizona tested three of our aggregates and were able to provide accurate specific gravity data that was then used to more correctly and accurately create mixes.

Ultimately, the mix that can be found in appendix B was chosen to be the teams final mix design. The mix was chosen because it most reflected the team's goals. The mix was in the target compressive strength and tensile strength over (1000 psi and 100 psi respectively), had a unit weight of around 75 lbs/ft^3, was workable (slump of 1/2"), and was sourced with sustainable materials.

3.4 Construction Process

A mold was constructed by utilizing SolidWorks drawing features which was then outsourced after completion to be fabricated. The material used for the construction of the mold was a 1.5 lb./ft^3 density EPS foam block that was cut using a Computer Numeric Routing (CNC) machine provided by F3 Online in Palm Springs, California. Use of a CNC allows for more accurate cutting and shaping not possible by hand. 1.5 lb./ft^3 density foam was chosen for its ability to shape with sufficient rigidity to handle the demand of concrete pouring. A female mold was selected for its ability to shrink into the concrete and to retain moisture in the concrete during the curing process. The mold was made by creating 60 cross-sections, gluing the cross-sections together, and sanding down any imperfections to match the design needed. Since the design was symmetrical, 30 cross-sections were designed with each cross-section duplicated to complete the mold. This decreases the time needed to machine and design the mold, requiring less work for the manufacturer and designer. The mold was assembled on a sturdy construction table that was assembled by a past NAU team. This increases the sustainability of the construction process and removes the need for a new one to be built each year. A liquidized rubber was then added to the mold to separate the foam from the releasing agent. The team decided that Vaseline would be the most effective releasing agent, as it has been a cost effective and reliable releasing agent for past NAU teams.

The team decided to go with a two-level layering scheme with the layers at ¼" with the bi-directional carbon grid reinforcement in between. The concrete mix was uniform throughout each layer with no differentiation. This has shown to be a sufficient layering scheme used with past teams, providing adequate strength for transportation and races.

The day before construction, the dry materials of the concrete mixture were batched out to make the construction process more efficient on the day of construction. The aggregates were hydrated according to their absorption values. This process allowed for efficiency and simplicity on construction day.

On the construction day, the mix design team began mixing the concrete mixture, while the placement team prepared the mold with the release agent. A concrete drum mixer was used to mix aggregates with cement, water, admixtures, and fibers. A drill with a paddle blade was also utilized to remix concrete sitting out for more than 10-15 minutes. This is necessary as the admixtures change the viscosity of the concrete. Once the mix was prepared and the mold was ready, the concrete placement was started. The concrete placement began on the belly of the canoe and was pulled up onto the sides of the canoe. The first layer was placed while the Quality Control Manager checked the thickness of the concrete along the bottom and sides. Since the first layer placed was the outside layer of the canoe, the first layer had a goal thickness of ¼”. This was verified using toothpicks marked at ¼ “. Once the goal thickness of ¼” was reached for the first layer, the bi-directional carbon grid reinforcement was laid along the gunwale. The reinforcement was pre-cut into 6 3-foot strips, overlapping 2” at each connection to increase the constructability of the applied grid. While this took place, the concrete for the second layer was mixed. Once the reinforcement was applied, the second layer of concrete was placed, utilizing the same method as the first layer. The thickness was then checked utilizing toothpicks marked at 1/2”. Throughout the placement, concrete was kept wet by using a spray bottle. The Quality Control Manager ensured that concrete remained hydrated before curing was to commence so that no cold joints were created.

After all the concrete had been placed in the mold, a curing chamber was constructed over the canoe using PVC (Polyvinyl Chloride) pipes and plastic sheeting. The chamber was built directly over the canoe and mold, so it would not need to be moved. Multiple humidifiers were placed into the canoe to keep the concrete hydrated. The chamber was kept above 95% humidity for the first 14 days, a process also known as wet curing. After 14 days, the mold was removed, and the canoe continued to cure in a humid room for another 7 days. The transportation stand was used to support the canoe after it was removed from the mold. At this stage, 3-foot bulkheads were cut and trimmed from EPS and placed at each end of the canoe. ½” of concrete as applied to cover the bulkheads. Thickness was verified with pre-marked toothpicks. The canoe then dry-cured for the last 7 days. The canoe was wet sanded on the inside and outside to create a smooth finish. To complete the construction process, two coats of sealant were applied, with the application of stickers denoting "Northern Arizona University” and “Ponderosa Pinecone” applied in between coats.

3.5 Scope, Schedule, and Fees

The process of creating the canoe was planned out utilizing a general scope created by the team. The scope consists of eight major tasks, with subtasks falling beneath them. The tasks in order are Enhanced Focus Areas, Mix Design, Hull Design, Reinforcement, Construction, General Conference Deliverables, Project Management, and Impacts. The scope of the project allowed for the team to understand all major duties for the project, and how they impact one another.

The work and progress of the project is overseen by the Project Manager and the Quality Assurance/Quality Control Manager. These leads are tasked with ensuring that the team stays on task by completing work efficiently and effectively. The Mix Design, Hull Design, and Structural Design Managers are to keep track of work done for their individual tasks to confirm items are completed by specified due dates.

The Project Manager and Quality Assurance/Quality Control Manager are also responsible for the budget and financial aspects of the project. They are to closely consider the schedule of the project, to ensure that the other three managers on the team have the resources they need, when they need them. In order to do this effectively, the team is to have great communication. The Mix Design Manager is to inform the Project and QA/QC Managers when supplies are low or out, so that they can continue their work.

As the Project and QA/QC Managers are in charge of the budget, they also work with NAU’s ASCE student chapter treasurer to know where funds are to go when accepted, and how to spend the funds. This is greatly important when gathering materials for the project. Materials are to typically be amassed through utilizing donation money and contacting companies for general donations of mix, structural, and mold materials.

There are a few major milestone activities for this project, as determined by the project team. These milestones include designing canoe, creating a workable final mix, acquire a mold, placing concrete mix and reinforcement with mold, produce the ASCE Concrete Canoe conference proposal, and take part in various competitions at the regional conference.

The design of the canoe takes the given regulations by the C4 Competition rules, general team expectations, and computer aided design programs into consideration. The design of the canoe was determined to be a major milestone as it is one of the major tasks that the team will be scored on. The competition rules control over some attributes of the designs such as the dimensions. If the design of the canoe takes more time than expected, this could hinder the timeline expected for acquiring a mold. The completion of this milestone was determined, and given buffer room, so that it would not greatly influence further tasks.

The creation of a mix is also a milestone activity, as the team will have to do great research and testing to determine was is best considering rules and team manager expectations. Also, once this step is completed, other major steps in this project can take place, such as the pouring of the canoe with the mold.

Acquiring a mold is a milestone, as in order to do so research concerning female or male molds, type of mold materials, and mold manufacturers must be considered. This will take the team a decent amount of time, and they must work together to contact companies and be able to fund this part of the project. The placing of concrete mix and reinforcement materials with the mold is a major milestone as a team of people is needed to assist in the construction. Once cured, this signifies the completion of the physical components of the project.

With the ASCE Concrete Canoe Competition considered, there are also major milestones associated with it. These major milestones are producing the ASCE Concrete Canoe conference proposal and competing at conferences. These are major milestones as many parts of the project lead up to these, and upon conclusion, the general project can be considered to be complete.

Many of the covered major milestones can also pose as hurdles that influenced the planning process. These hurdles were considered, and the planning process was created intricately. To avoid hurdles, the team decided it to be best to complete tasks as early and diligently as possible, and to allow for some buffer time between the task itself and the task it could delay. In order to keep the project going, tasks such as these were staggered and worked on generally simultaneously, to allow for some time disparities.

3.6 Quality Control/Assurance

The quality control and quality assurance practices taken through the course of this project allowed for the product to be of highest standards. The practices were considered throughout the progression of the project. The applicability of the quality control and quality assurance practices can be discussed further in relation to concrete mixing and concrete placement during construction of the canoe prototype. The goal of the quality control and quality assurance practices are to mitigate risks throughout the project.

A practice that has been consistent for the team in regard to concrete mixing, is having weekly team meetings to discuss expectations and goals. Conversations surrounding expectations and goals are vital to mixing, as the team decides what materials would be best to try out in testing, and what consistency of mix is applicable to the project. These meetings were hosted by the Mix Design Manager, where discussions of mix compliancy considering the RFP was considered.

As outlined previously, there were also steps taken to ensure that the concrete placement during construction of the canoe prototype was done with great work. This task has many parts to it, and therefore there are many precautions to take to ensure upmost standards. The first to consider for construction was the mold.

There are many directions to go when choosing a mold. This includes different materials, shapes, how it is cut/built, if it is female or male, and more. The team chose to use a female foam mold, due to research and NAU teams having success with them in the past. Foam molds prove to be relatively easy to work with, and easy to acquire. Foam molds can also be cut to high accuracy, meaning that the mold will carry high resemblance to the planned design of the canoe.

The excretion of the canoe from the mold was also to be considered. The concrete on the mold would likely get stuck, creating a rough and unworkable mess. Different lubricating and lifting agents had to be considered in relation to this. The team tested various materials, and decided upon Vaseline as the top choice. This also considered previous teams experience with Vaseline, as well as the material being readily available and relatively low in cost.

Once the concrete is being poured or placed in the mold, it needed to have uniform thickness throughout the product. To do this, the team decided it would be best to use pre-marked toothpicks with a specific depth, and using those as a guide for how thick to pour the concrete.

To guide future NAU teams in the future, the team is taking notes and recording data for all things that did and did not work in relation to quality control. Along with this, the team is utilizing the already established concrete canoe mentee program and allowing them to learn along with the team.

3.7 Sustainability

The project addressed the subject of sustainability primarily through the use of recycled concrete in our mix. The recycled concrete was from a concrete canoe that was made by the NAU concrete canoe team from 2019-2020. Instead of being stored at NAU's facilities and wasting away, this canoe was crushed to be used as aggregate for a new product. This recycled concrete replaces aggregate which would have been mined. This allows for less of the environment to be disturbed for mining purposes.

Another way in which we increased the sustainability of our canoe was through the use of locally sourced material. Most of the materials that were used in the mix were sourced in Arizona. One of our main aggregates, Utelite, was not sourced in Arizona but in the neighboring state Utah [6]. Materials sourced from in-state or nearby states allow for a smaller carbon footprint due to less and shorter shipping. Perlite, another primary aggregate used, is known as Generally Recognized as Safe (GRAS) by the US Food and Drug Administration FDA [7]. This means that perlite is safe for the environment if there was any perlite that may have made it into the environment from the construction of our canoe.

The last area of sustainability was through our mentee program. Through our mentee program, future teams are allowed to learn proper practices and training. Also, the money fundraised by our team will be reinvested into the concrete canoe program. This will be done through the investment of excess funds in new equipment for construction and testing. This will allow a cycle to continue for teams to continue investing funds in the improvement of mentees and equipment.

3.8 Health and Safety

Northern Arizona University's College of Engineering is primarily concerned with the safety of students and faculty when using labs since there is possible harm due to material, chemicals, or tools. Before lab use was granted to the Pinecones, a safety binder was complied. This binder includes all material and safety data sheets for chemicals and materials that were stored at the Concrete Canoe Lab and safety precautions and practices for all the tools. In addition, a list of contacts is included in the binder in case of various emergencies that may occur. Once the binder was assembled, a couple of meeting were held with faculty and the lab manager in order to review the binder and address all hazards concerning the project.

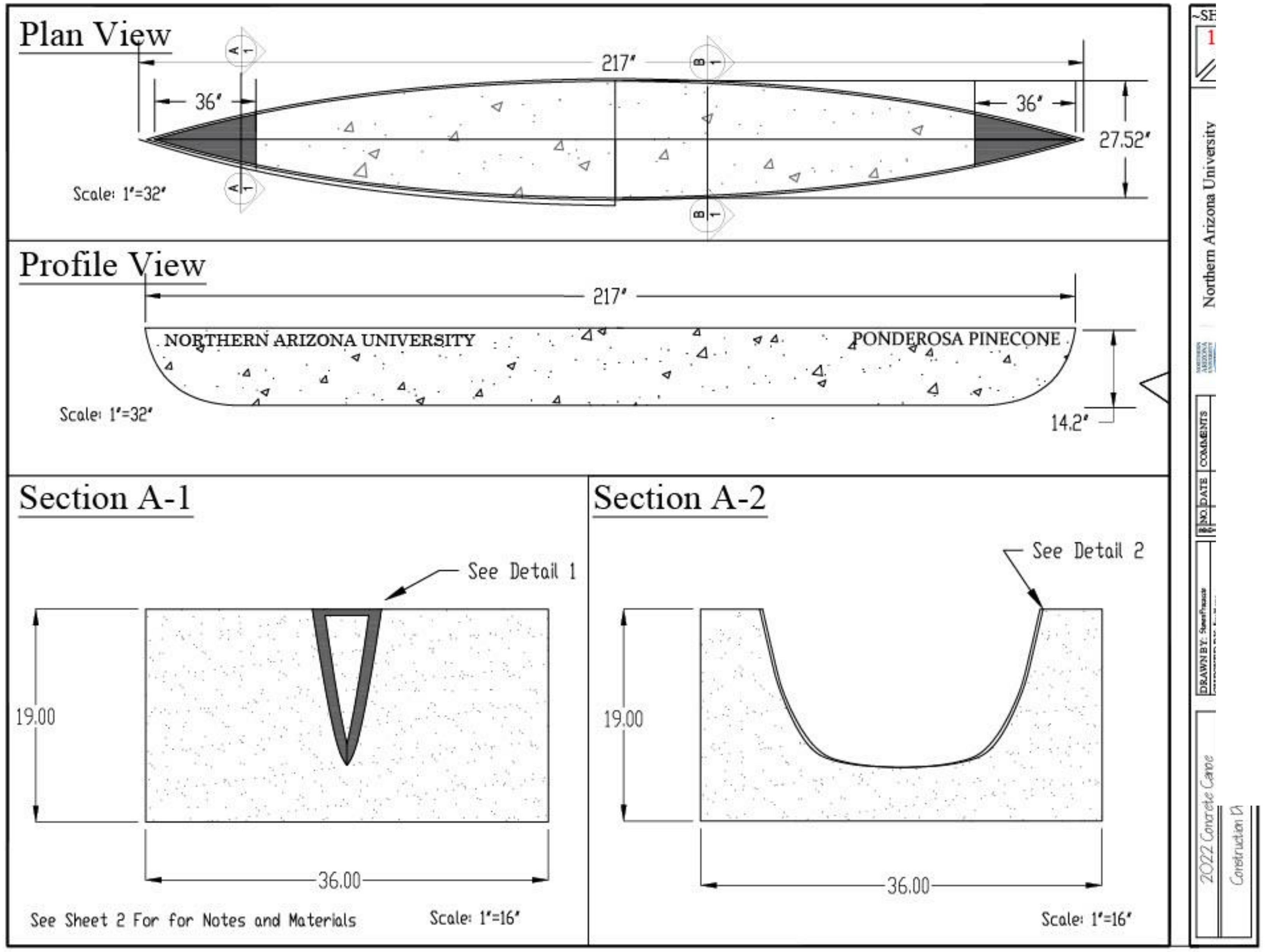
A safety waiver was signed before the assistance of any mentees was accepted. This ensured that mentees were educated on the hazards of the project.

During material testing, all members of the team present had on dust masks, safety glasses, and gloves as applicable. This was especially necessary when dealing with material that contained small dust particles, like UL-FGA.

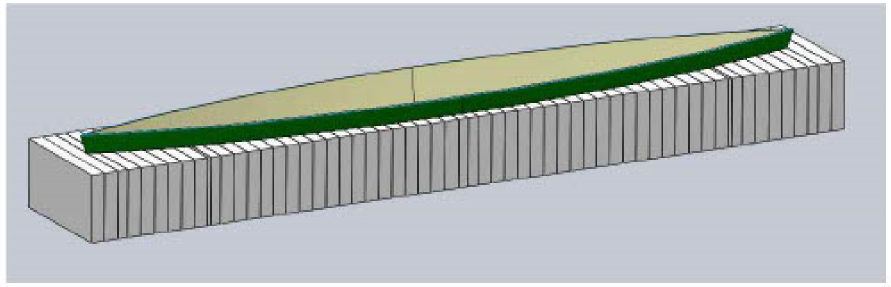
During construction of the canoe, a few different safety measures were implemented. This included an education of all mentees on the proper use of any tools that were being used, limiting the use of power tools to core team members, and requiring those mixing concrete to wear safety glasses, dust masks, and gloves.

Due to the effects of COVID, the team had a cautious approach to the testing and construction phases of the project. This included team members and mentees getting tested and staying at home if there was contact with anyone with COVID. After test result came back, given that the person had a negative result, the person was allowed to rejoin in-person team activities. In addition, all team members wore masks when at in-person activities. Although activities in-person are unavoidable for testing and construction, any activities were limited to 10 people. This allowed for limited exposure especially during construction.

4.0 Construction Drawings and Specifications



Isometric View



Not to Scale

Notes

1. A two-lever layering scheme will be utilized for concrete placement, with two layers of concrete mix at a thickness of ¼" each, with bi-directional carbon grid in between.
2. Section A-1 represents the first 36" of the canoe on the bow and stern.
3. Section B-1 represents the interior of the canoe between the bulkheads.
4. Mold is displayed with section cuts to display construction methods.
5. Mold is split into 4" sections for constructability purposes.
6. Liquidized rubber is applied to the mold for protection.
7. Retarder Admixture is added to the concrete mix to decrease set time and reduce risk of delaminating in between layers.

Detail 1

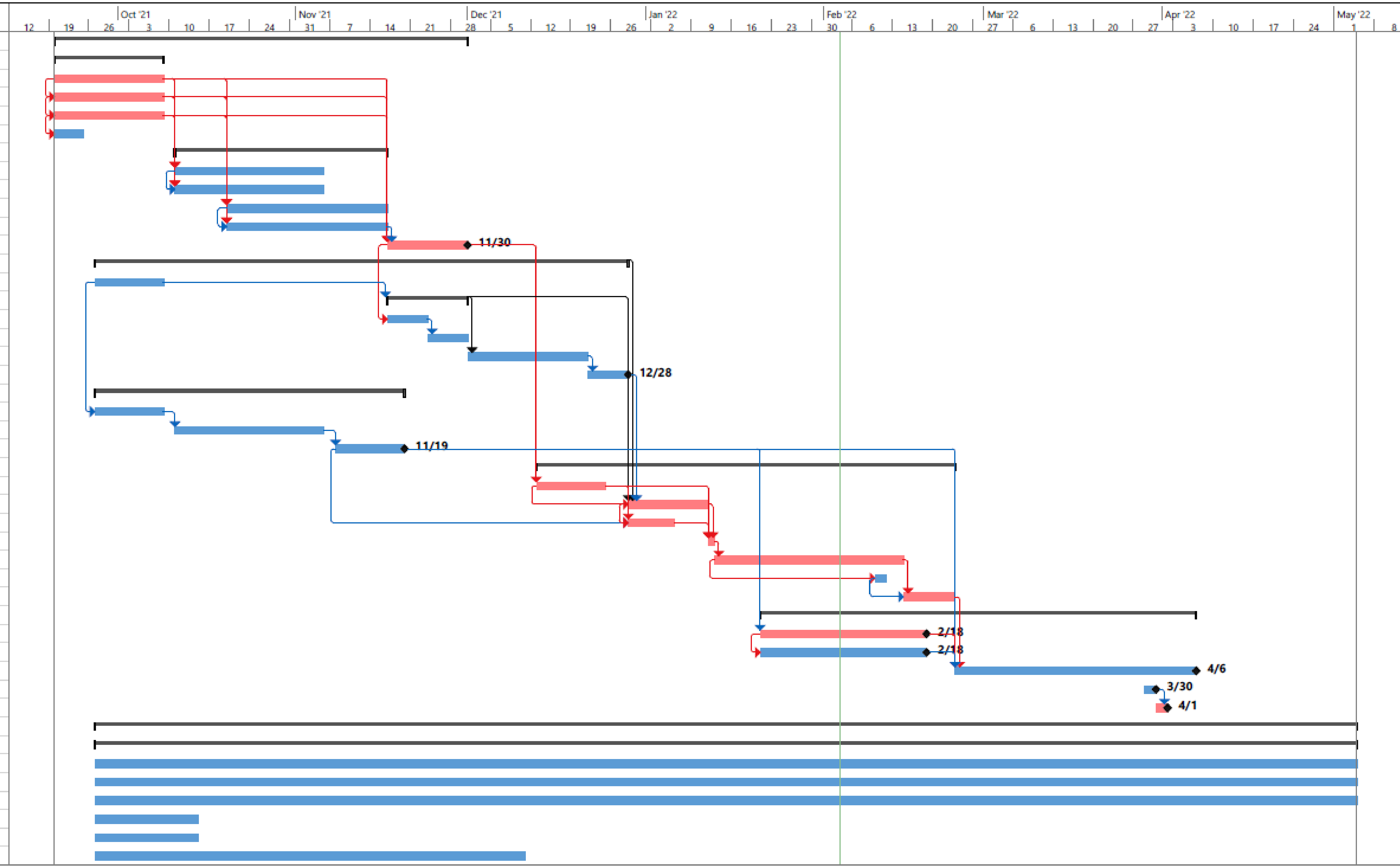
Detail 2

Bill of Materials

Material	Weight
Utelite Crushed Fines	15.57 lbs.
Utelite 10mesh	15.57 lbs.
Recycled Aggregate	41.35 lbs.
UL-FGA	20.41 lbs.
No. 6- Expanded Perlite	10.2 lbs.
Delvo	0.16 lbs.
Type I/II/V Cement	46.19 lbs.
Class C Fly Ash	12.89 lbs.
Silica Fume	4.3 lbs.
Glenium 7500	0.49 lbs.
SRA-35	0.04 lbs.
SSD Water	24.17 lbs.
Water for CM Hydration	25.35 lbs.
Fiber Mesh	0.11 lbs.

5.0 Project Schedule

ID	Task Name	Duration
1	**Task 1: Mix Design**	**52 days**
2	**Task 1.1: Mix Design Research**	**15 days**
3	Task 1.1.1: Cementitious Materials	15 days
4	Task 1.1.2: Aggregates	15 days
5	Task 1.1.3: Admixtures	15 days
6	Task 1.2: Develop an Initial Mix Design	5 days
7	**Task 1.3: Mix Design Testing**	**27 days**
8	Task 1.3.1: Slump Test	20 days
9	Task 1.3.2: Unit Weight of Mix	20 days
10	Task 1.3.3: Compressive Strength	20 days
11	Task 1.3.4: Tensile Strength	20 days
12	Task 1.4: Final Mix Design	10 days
13	**Task 2: Hull Design**	**67 days**
14	**Task 2.1: Hull Design Research**	10 days
15	**Task 2.2: Software Modeling**	**10 days**
16	Task 2.2.1: Solidworks	5 days
17	Task 2.2.2: MaxSurf	5 days
18	**Task 2.3: Structural Analysis**	15 days
19	**Task 2.4: Final Hull Design**	5 days
20	**Task 3: Reinforcement**	**40 days**
21	**Task 3.1: Research**	10 days
22	**Task 3.2: Analysis and Testing**	20 days
23	**Task 3.3: Final Reinforcement Design**	10 days
24	**Task 4: Construction**	**53 days**
25	**Task 4.1: Mold Procurement**	10 days
26	**Task 4.2: Cure Chamber Procurement**	10 days
27	**Task 4.3: Reinforcment Placement**	6 days
28	**Task 4.4: Concrete Pours**	1 day
29	**Task 4.5: Curing and Removal from Mold**	23 days
30	**Task 4.6: Aesthetics**	2 days
31	**Task 4.7: Stand**	7 days
32	**Task 5: Society Wide Deliverables**	**54 days**
33	**Task 5.1: Conference Technical Proposal**	21 days
34	**Task 5.2: Enhanced Focus Areas Report**	21 days
35	**Task 5.3: Conference Presentation**	30 days
36	**Task 5.4: Transport of Canoe**	2 days
37	**Task 5.5: Race Canoe**	2 days
38	**Task 6: Project Management**	**158 days**
39	**Task 6.1: Project Meetings**	**158 days**
40	Task 6.1.1: Team Meetings	158 days
41	Task 6.1.2: Grading Instructor/Technical Advisor Meet	158 days
42	Task 6.1.3: Client Meetings	158 days
43	**Task 6.2: Budget**	14 days
44	**Task 6.3: Schedule**	14 days
45	**Task 6.4: Fundraising**	55 days



Appendix A – Bibliography

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[13] T. U. o. Memphis, "Fly Ash, Slag, Silica Fume, and natural pozzolans".

Appendix B – Mixture Proportions and Primary Mixture Calculations

Cementitious Materials				
Component	***Specific Gravity***	***Volume (ft^3)***	***Amount of CM (lb/yd^3)***	
Type 1 White Cement, cm_1	*3.15*	*2.19*	*430*	*Total cm (includes c)* ***590 lb/yd^3*** *c/cm ratio, by mass* ***0.73***
Fly Ash - Type C, cm_2	*2.5*	*0.77*	*120*	
Silica Flume, cm_3	*2.25*	*0.28*	*40*	

Fibers				
Component	***Specific Gravity***	***Volume (ft^3)***	***Amount of Fibers (lb/yd^3)***	
PVA RECS15 8mm, f_1	*1.31*	*0.012*	*1*	*Total Amount of Fibers* ***1 lb/yd^3***

Aggregates (Excluding Material Fillers Passing No. 200 Sieve)							
Aggregates	***ASTM C330 or RCA***	***Abs (%)***	***SG_{OD}***	***SG_{SSD}***	***Base Quanity, W (lb/yd^3)***		***Volume, $V_{agg,SSD}$***
					W_{OD}	***W_{SSD}***	
Utelite Crushed Fines, agg_1	*Yes*	*18*	*1.55*	*1.83*	*145*	*171*	*1.5*
Utelite Fines, agg_2	*Yes*	*18*	*1.55*	*1.83*	*145*	*171*	*1.5*
Recycled Aggregate, agg_3	*Yes*	*20*	*0.90*	*1.08*	*385*	*462*	*6.86*
No. 6 - Expanded Perlite, agg_4	*No*	*70*	*0.27*	*0.73*	*95*	*162*	*5.64*
UL-FGA, agg_5	*No*	*64*	*0.38*	*0.62*	*190*	*224*	*3.9*

Liquid Admixtures					
Admixture	***lb / US gal***	***Dosage (fl. oz / cwt)***	***% Solids***	***Amount of Water in Admixture (lb/yd^3)***	
MasterGlenium 7500, ad	*8.77*	*13*	*14*	*4.52*	*Total Water from Liquid Admixtures, $S_{W_{admx}}$* ***6.42 lb/yd^3***
MasterSet Delvo	*8.92*	*5*	*26*	*1.52*	
MasterLife SRA-35	*8.26*	*5*	*80*	*0.38*	

Solids				
Component	***Specific Gravity***	***Volume (ft^3)***	***Amount (lb/yd^3)***	
Solid Component of Liquid Dye, S_{ld}	*n/a*	*0*	*0*	*Total Solids, S_{total}* ***0 lb/yd^3***
Powdered Admixture, $S_{p\ admix}$	*n/a*	*0*	*0*	
Material Filler (Passing No. 200 Sieve), mf	*n/a*	*0*	*0*	

Water			
	Amount (lb/yd^3)		***Volume (ft^3)***
Water, w	*w/c ratio, by mass* ***0.55*** *w/cm ratio, by mass* ***0.4***	*236*	*3.78*
Total Free Water from All Aggregates		*-225.12*	
Total Water from All Admixtures		*6.42*	
Batch Water, w_{Batch}		*454.7*	

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)	*590*	*1*	*1189.9*	*0*	*236*	*2016.9*
Absolute Volume, V (ft^3)	*3.24*	*0.012*	*19.40*	*0*	*3.78*	*26.43*
Theoretical Density, T (= SM / SV) (lb/ft^3)	*76.3*		***Air Content, Air [= (T-D)/T x 100%]***			*2.1%*
Measured Density, D (lb/ft^3)	*74.7*		***Air Content, Air [= (27 - SV)/27 x 100%]***			*2.1%*
Total Aggregate Ratio (= $V_{agg,\ SSD}$ /27)	*71.9%*		***Slump, Slump Flow, Spread (in)***			*1/2*
C330+RCS Ratio (= $V_{C330+RCA}$ / $V_{agg,\ SSD}$)	*50.8%*					

Aggregates:

Perlite:

$$W_{od} = 95\ lbs$$
$$W_{ssd} = 161.5\ lbs$$

$$ABS = \left(\frac{W_{ssd} - W_{od}}{W_{od}}\right) * 100\%$$
$$ABS = \left(\frac{161.5 - 95}{95}\right) * 100\% = 70\%$$
$$W_{stk} = W_{od} + (W_{od} * .5\%)$$
$$W_{stk} = 95 + (95 * 0.005) = 95.48\ lbs$$
$$MC_{total} = \left(\frac{W_{stk} - W_{od}}{W_{od}}\right) * 100\%$$
$$MC_{total} = \left(\frac{95.48 - 95}{95}\right) * 100\% = 0.5\%$$
$$MC_{free} = MC_{total} - ABS$$
$$MC_{free} = 0.5\% - 70\% = -69.5\%$$
$$W_{ssd} = \left(1 + \left(\frac{ABS}{100\%}\right)\right) * W_{od}$$
$$W_{ssd} = \left(1 + \left(\frac{70\%}{100\%}\right)\right) * 95 = 161.5\ lbs$$
$$W_{free} = W_{od} * (\frac{MC_{free}}{100\%})$$
$$W_{free} = 95 * \left(-\frac{69.5\%}{100\%}\right) = -66.03\ lbs$$
$$W_{stk} = W_{ssd} + W_{free}$$
$$W_{stk} = 161.5 + (-66.03) = 95.47\ lbs$$

Utelite Fines:
$$W_{od} = 145\ lbs$$
$$W_{ssd} = 171.1\ lbs$$
$$ABS = \left(\frac{W_{ssd} - W_{od}}{W_{od}}\right) * 100\%$$
$$ABS = \left(\frac{171.1 - 145}{145}\right) * 100\% = 18\%$$
$$W_{stk} = W_{od} + (W_{od} * .5\%)$$
$$W_{stk} = 145 + (145 * 0.005) = 145.725\ lbs$$
$$MC_{total} = \left(\frac{W_{stk} - W_{od}}{W_{od}}\right) * 100\%$$
$$MC_{total} = \left(\frac{145.725 - 145}{145}\right) * 100\% = 0.5\%$$
$$MC_{free} = MC_{total} - ABS$$
$$MC_{free} = 0.5\% - 18\% = -17.5\%$$
$$W_{ssd} = \left(1 + \left(\frac{ABS}{100\%}\right)\right) * W_{od}$$
$$W_{ssd} = \left(1 + \left(\frac{18\%}{100\%}\right)\right) * 145 = 171.1\ lbs$$
$$W_{free} = W_{od} * (\frac{MC_{free}}{100\%})$$
$$W_{free} = 145 * \left(-\frac{17.5\%}{100\%}\right) = -25.38\ lbs$$
$$W_{stk} = W_{ssd} + W_{free}$$
$$W_{stk} = 171.1 + (-25.38) = 145.73\ lbs$$

Recycled Aggregate:
$$W_{od} = 385\ lbs$$
$$W_{ssd} = 462\ lbs$$
$$ABS = \left(\frac{W_{ssd} - W_{od}}{W_{od}}\right) * 100\%$$
$$ABS = \left(\frac{462 - 385}{385}\right) * 100\% = 20\%$$
$$W_{stk} = W_{od} + (W_{od} * .5\%)$$
$$W_{stk} = 385 + (385 * 0.005) = 386.93\ lbs$$
$$MC_{total} = \left(\frac{W_{stk} - W_{od}}{W_{od}}\right) * 100\%$$
$$MC_{total} = \left(\frac{386.93 - 385}{385}\right) * 100\% = 0.5\%$$
$$MC_{free} = MC_{total} - ABS$$
$$MC_{free} = 0.5\% - 20\% = -19.5\%$$
$$W_{ssd} = \left(1 + \left(\frac{ABS}{100\%}\right)\right) * W_{od}$$
$$W_{ssd} = \left(1 + \left(\frac{20\%}{100\%}\right)\right) * 385 = 462\ lbs$$
$$W_{free} = W_{od} * (\frac{MC_{free}}{100\%})$$
$$W_{free} = 385 * \left(-\frac{19.5\%}{100\%}\right) = -75.08\ lbs$$
$$W_{stk} = W_{ssd} + W_{free}$$
$$W_{stk} = 462 + (-75.08) = 386.92\ lbs$$

Expanded Glass:
$$W_{od} = 190\ lbs$$
$$W_{ssd} = 224.2\ lbs$$
$$ABS = \left(\frac{W_{ssd} - W_{od}}{W_{od}}\right) * 100\%$$
$$ABS = \left(\frac{224.2 - 190}{190}\right) * 100\% = 18\%$$
$$W_{stk} = W_{od} + (W_{od} * .5\%)$$
$$W_{stk} = 190 + (190 * 0.005) = 190.95\ lbs$$
$$MC_{total} = \left(\frac{W_{stk} - W_{od}}{W_{od}}\right) * 100\%$$
$$MC_{total} = \left(\frac{190.95 - 190}{190}\right) * 100\% = 0.5\%$$
$$MC_{free} = MC_{total} - ABS$$
$$MC_{free} = 0.5\% - 18\% = -17.5\%$$
$$W_{ssd} = \left(1 + \left(\frac{ABS}{100\%}\right)\right) * W_{od}$$
$$W_{ssd} = \left(1 + \left(\frac{18\%}{100\%}\right)\right) * 385 = 224.2\ lbs$$
$$W_{free} = W_{od} * (\frac{MC_{free}}{100\%})$$

$$W_{free} = 190 * \left(-\frac{17.5\%}{100\%}\right) = -33.25\ lbs$$
$$W_{stk} = W_{ssd} + W_{free}$$
$$W_{stk} = 224.2 + (-33.25) = 190.95\ lbs$$

Utelite Crushed Fines:

$$W_{od} = 145\ lbs$$
$$W_{ssd} = 171.1\ lbs$$
$$ABS = \left(\frac{W_{ssd} - W_{od}}{W_{od}}\right) * 100\%$$
$$ABS = \left(\frac{171.1 - 145}{145}\right) * 100\% = 18\%$$
$$W_{stk} = W_{od} + (W_{od} * .5\%)$$
$$W_{stk} = 145 + (145 * 0.005) = 145.73\ lbs$$
$$MC_{total} = \left(\frac{W_{stk} - W_{od}}{W_{od}}\right) * 100\%$$
$$MC_{total} = \left(\frac{145.73 - 145}{145}\right) * 100\% = 0.5\%$$
$$MC_{free} = MC_{total} - ABS$$
$$MC_{free} = 0.5\% - 18\% = -17.5\%$$
$$W_{ssd} = \left(1 + \left(\frac{ABS}{100\%}\right)\right) * W_{od}$$
$$W_{ssd} = \left(1 + \left(\frac{18\%}{100\%}\right)\right) * 145 = 171.1\ lbs$$
$$W_{free} = W_{od} * \left(\frac{MC_{free}}{100\%}\right)$$
$$W_{free} = 145 * \left(-\frac{17.5\%}{100\%}\right) = -25.38\ lbs$$
$$W_{stk} = W_{ssd} + W_{free}$$
$$W_{stk} = 171.1 + (-25.38) = 145.73\ lbs$$

Water in Cementitious Materials:

$$W = \frac{W}{cm} * cm$$
$$W = 0.4 * 590 = 236\ lbs$$

Cementitious Materials:

Type 1 Cement:

$$W_{OD} = 430\ lbs$$
$$SG_{cement} = 3.15$$
$$V_{cement} = \frac{W_{OD}}{SG_{cement} * 62.4}$$
$$V_{Cement} = \frac{430}{3.15 * 62.4} = 2.19\ ft^3$$

Fly Ash – Type C:

$$W_{OD} = 120\ lbs$$
$$SG_{Fly\ Ash} = 2.50$$
$$V_{Fly\ Ash} = \frac{W_{OD}}{SG_{Fly\ Ash} * 62.4}$$
$$V_{Fly\ Ash} = \frac{120}{2.5 * 62.4} = 0.77\ ft^3$$

Silica Fume:

$$W_{OD} = 40\ lbs$$
$$SG_{Silica\ Fume} = 2.25$$
$$V_{Silica\ Fume} = \frac{W_{OD}}{SG_{Silica\ Fume} * 62.4}$$
$$V_{Silica\ Fume} = \frac{40}{2.25 * 62.4} = 0.29\ ft^3$$

Admixtures:

$$CWT\ (mix) = \frac{cm}{100} lb$$
$$CWT = \frac{590}{100} = 5.9$$

High Range Water Reducer:

$$w_{admx} = \#\frac{fl\ oz}{cwt} * CWT * water\ content * \frac{1\ gal}{128\ fl} * \frac{lb}{gal} of\ admixture$$

$w_{admx} = 13 \frac{fl\,oz}{cwt} * 5.9 * 86\% * \frac{1gal}{128\,fl} * 8.77\ lb/gal$ = 4.52 lbs

Set Retarder:

$$w_{admx} = \# \frac{fl\ oz}{cwt} * CWT * water\ content * \frac{1\ gal}{128\ fl} * \frac{lb}{gal} of\ admixture$$

$w_{admx} = 5.0 \frac{fl\,oz}{cwt} * 5.9 * 74\% * \frac{1gal}{128\,fl} * 8.92\ lb/gal$ = 1.52 lbs

Shrinkage Factor:

$$w_{admx} = \# \frac{fl\ oz}{cwt} * CWT * water\ content * \frac{1\ gal}{128\ fl} * \frac{lb}{gal} of\ admixture$$

$w_{admx} = 5.0 \frac{fl\,oz}{cwt} * 5.9 * 20\% * \frac{1gal}{128\,fl} * 8.26\ lb/gal$ = 0.38 lbs

Water in Mix:

$$W = 236\ lbs$$
$$w_{free} = -225.12\ lbs$$
$$\sum w_{admx} = 6.42\ lbs$$
$$w_{batch} = W - (w_{free} + \sum w_{admx})$$
$$w_{batch} = 236 - (-225.12 + 6.42) = 454.70\ lbs$$

$$Volume_{\ Water} = \frac{Mass_{Water}}{62.4}$$
$$Volume_{Water} = \frac{236}{62.4} = 3.78\ ft^3$$

Densities, Air Content, Slump, and Ratios

Mass of Concrete:

$$M_{Concrete} = Ammount_{cm} + Amount_{fibers} + Amount_{aggregates} + Amount_{water} + Amount_{solids}$$
$$M_{conrete} = 590 + 1 + 1189.9 + 236 + 0 = 2016.9\ lbs$$

Volume of Concrete:

$$V_{Concrete} = Volume_{cm} + Volume_{fibers} + Volume_{aggregates} + Volume_{water} + Volume_{solids}$$
$$V_{conrete} = 3.24 + 0.012 + 19.40 + 0 + 3.78 = 26.43\ ft^3$$

Theoretical Density:

$$T_{Concrete} = M_{concrete}/V_{Concrete}$$
$$T_{concrete} = \frac{2016.9}{26.43} = 76.31 \frac{lb}{ft^3}$$

Air Content:

$$D_{Concrete} = 74.40\ lb/ft^3$$
$$Air\ Content = \frac{T_{Concrete} - D_{Concrete}}{T_{Concrete} * 100}$$
$$Air\ Content = \frac{76.31 - 74.40}{74.40 * 100} = 2.10\%$$
$$Air\ Content = \frac{27 - V_{Concrete}}{27} * 100$$
$$Air\ content = \left(\frac{27 - 26.43}{27}\right) * 100 = 2.10\%$$
$$2.10\% = 2.10\% = GOOD$$

Cement to Cementitious Materials Ratio:

$$\frac{c}{cm} = \frac{cement}{cementitious\ materials}$$
$$\frac{c}{cm} = \frac{430}{590} = 0.73$$

Water to Cementitious Material Ratio

$$\frac{w}{cm} = \frac{water}{cementitious\ materials}$$
$$\frac{w}{cm} = \frac{236}{590} = 0.40$$

Aggregate to Concrete Ratio

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

C330+RCA to Total Aggregate Ratio

$$Aggregate\ Ratio\ (\%) = \frac{V_{C330+RCA}}{V_{Aggregate}} * 100\%$$
$$Aggregate\ ratio\ (\%) = \frac{9.86}{19.40} * 1005 = 50.82\%$$

$50.82\% > 50\% = GOOD$

Appendix C – Structural & Freeboard Calculations

Moment Calculations

Female Tandem

$$Moment(M) = \left[\frac{1}{2}(F - S)(x^2)\right] - [F_R(x)] + c = [8.335(9^2)] - [149.97(9)] + 404.919 = -269.676$$

Male Tandem

$$Moment(M) = \left[\frac{1}{2}(F - S)(x^2)\right] - [F_R(x)] + c = [10.165(9^2)] - [182.97(9)] + 494.019 = -329.346$$

Four Person

$$Moment(M) = \left[\frac{1}{2}(F - S)(x^2)\right] - [F_R(x)] + c = [18.5(6.3^2)] - [148(6.3)] + 405 = 206.865$$

Simply Supported - Right Side Up

$$Moment(M) = \left[-\frac{1}{2}(S)(x^2)\right] + \left[\frac{1}{2}F_R(x)\right] = [-7.415(9^2)] + [133.5(9)] = 600.615$$

Simply Supported - Upside Down

$$Moment(M) = \left[-\frac{1}{2}(S)(x^2)\right] + \left[\frac{1}{2}F_R(x)\right] = [-7.415(9^2)] + [133.5(9)] = 600.615$$

Variables:

F = Buoyancy force (lb/ft)
S = Self-weight (lb/ft)
F_R = Resultant Force (lb)
X = distance (ft)

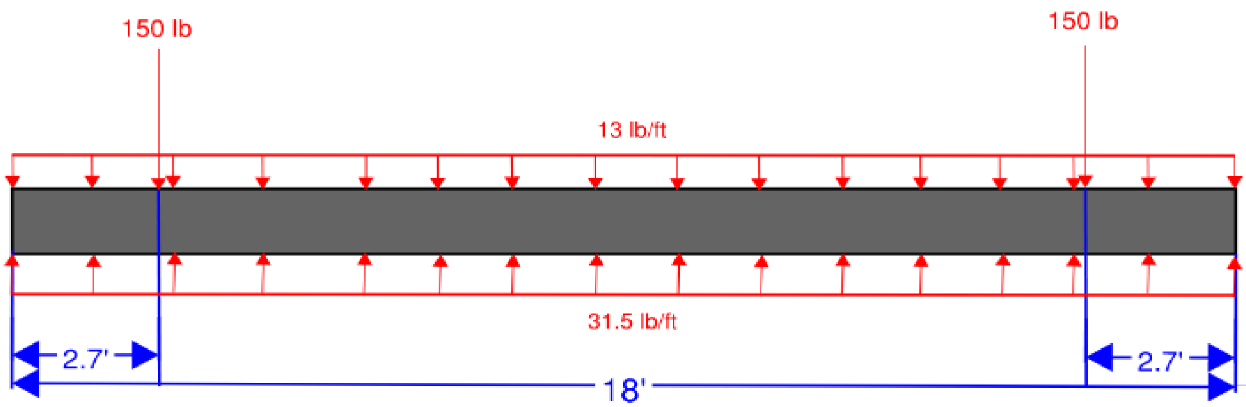


Figure 1. Female Tandem FBD

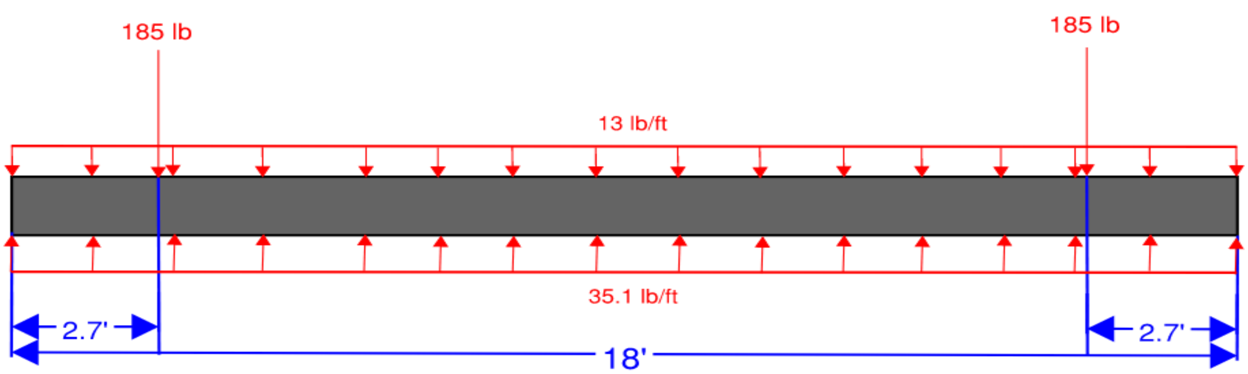


Figure 2. Male Tandem FBD

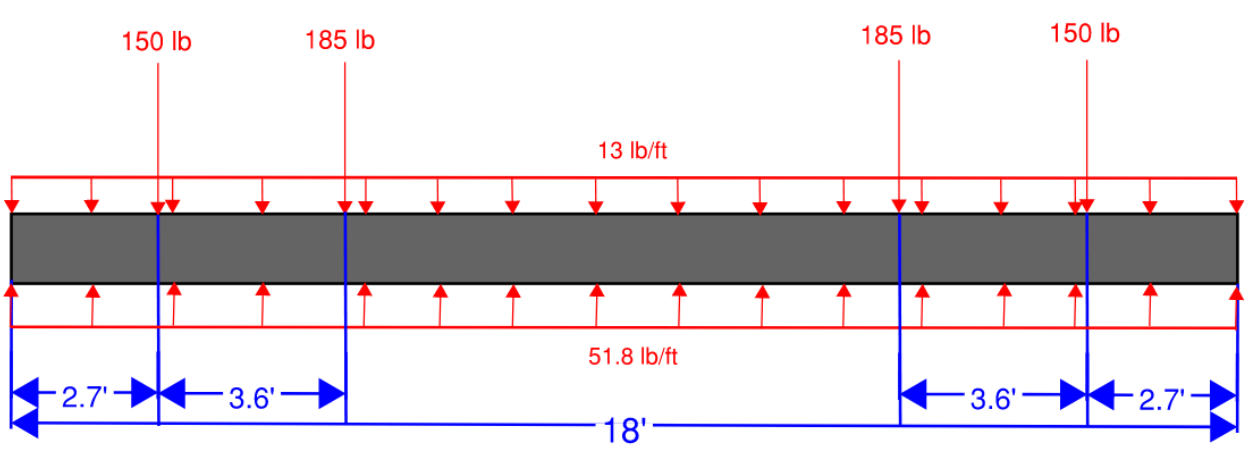


Figure 3. Four Person FBD

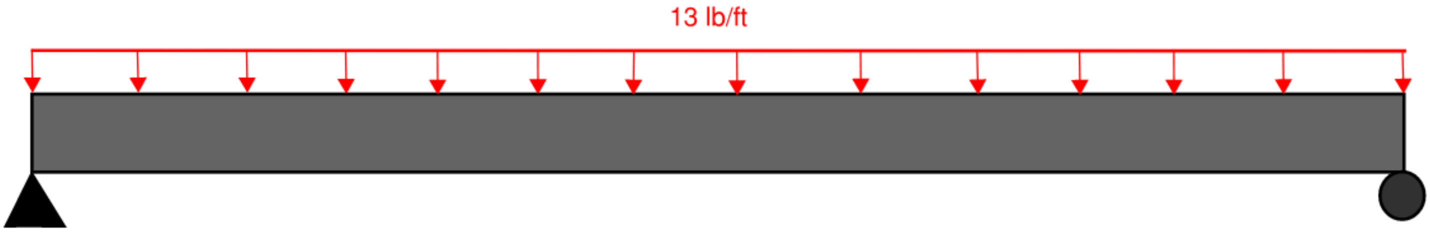
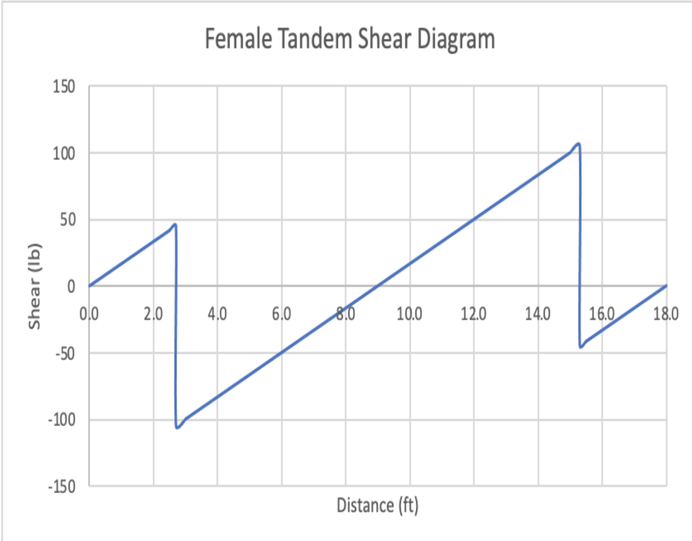


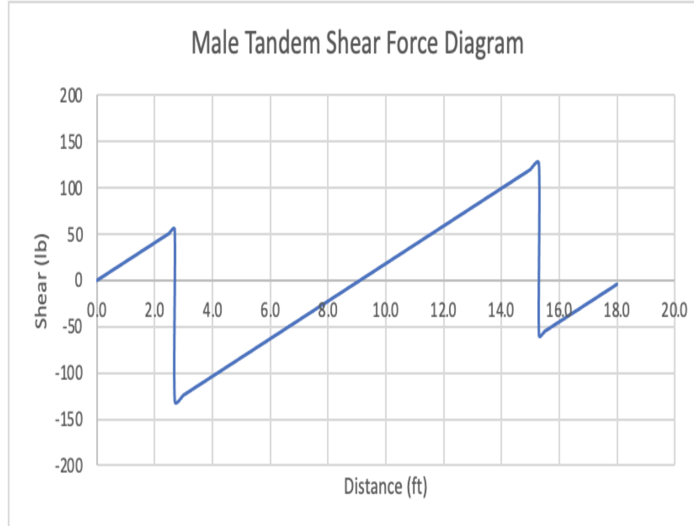
Figure 4. Simply Supported FBD

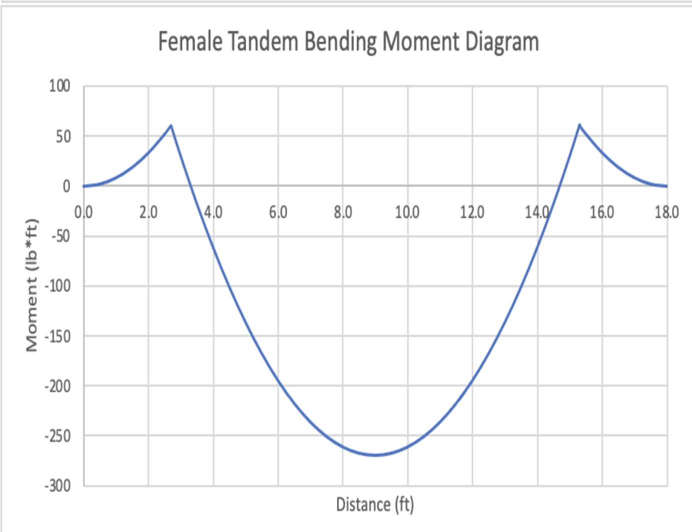
Moment Summary Table

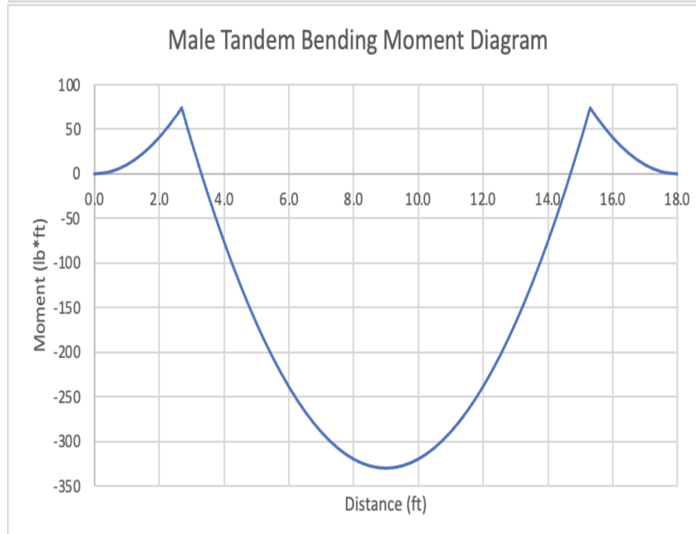
Load Case	Positive Moment Magnitude (lb*ft.)	Positive Moment Location (ft.)	Negative Moment Magnitude (lb*ft.)	Negative Moment Location (ft.)
Female Tandem	60.76	2.7, 15.3	-269.676	9
Male Tandem	74.1	2.7, 15.4	-329.346	9
4 Person	206.865	6.3,11.7	N/A	N/A
Simply Supported (right side up)	607.5	9	N/A	N/A
Simply Supported (upside down)	607.5	9	N/A	N/A

Female Tandem Loading

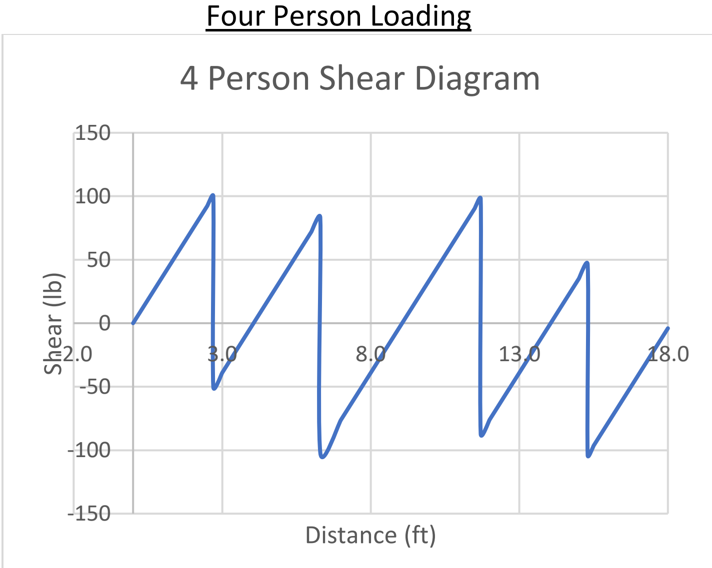


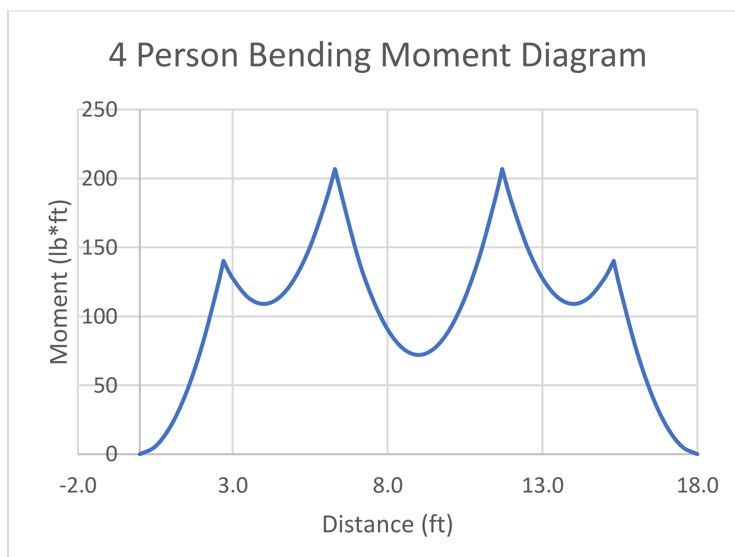






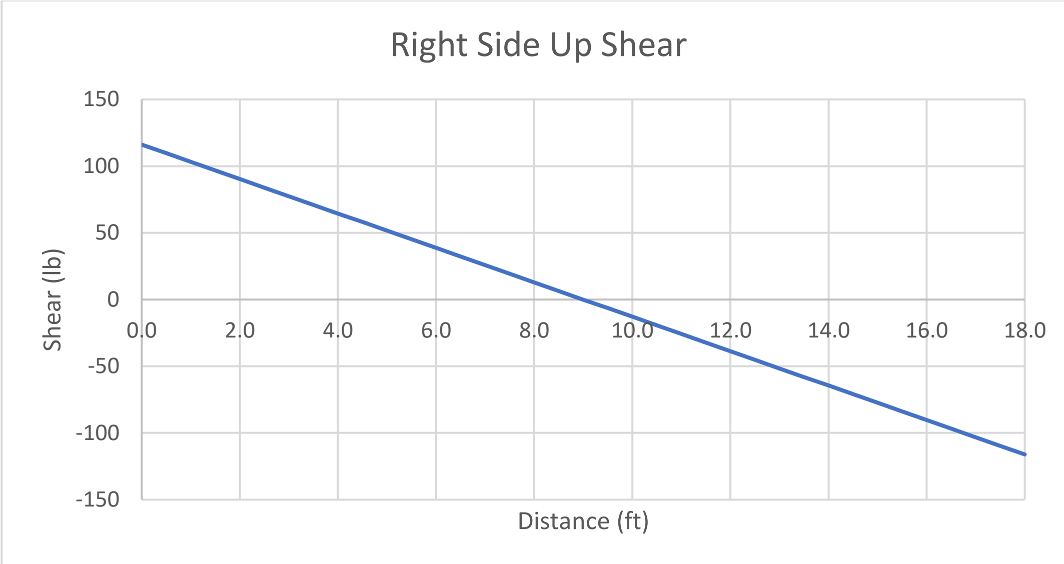
<u>Four Person Loading</u>

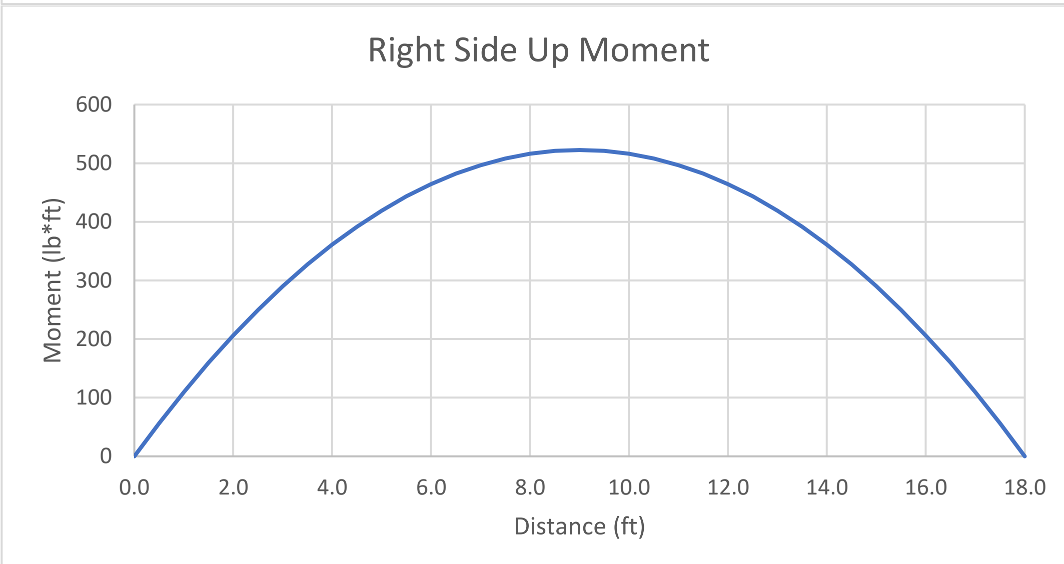




<u>Male Tandem Loading</u>

<u>Simply Supported</u> (right side up is the same as upside down)


Right Side Up Shear
Shear (lb)
150
100
50
0
-50
-100
-150
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
Distance (ft)


Right Side Up Moment
Moment (lb*ft)
600
500
400
300
200
100
0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
Distance (ft)

Freeboard (Two-Person, Four-Person, and Function of Load)

Two-Person

Female Tandem

$$Volume\ Displacement\ V_D = \frac{\Sigma F_y(lb)}{\gamma_w(\frac{lb}{ft^3})} = \frac{(150+150+232.2)}{62.4} = 8.52\ ft^3$$

Draught $D = \frac{V_D(ft^3)}{L(ft)*W(ft)} = \frac{8.52}{17.7*2.3*0.6} = 0.35\ ft = 10in$

Freeboard FB = $H(ft) - D(ft) = 1.18 - 0.37 = 0.81\ ft = 9.72in$

Male Tandem

$$Volume\ Displacement\ V_D = \frac{\Sigma F_y(lb)}{\gamma_w(\frac{lb}{ft^3})} = \frac{(185+185+232.2)}{62.4} = 9.65\ ft^3$$

Draught $D = \frac{V_D(ft^3)}{L(ft)*W(ft)} = \frac{9.65}{17.7*2.3*0.6} = 0.39\ ft = 4.76in$

Freeboard FB = $H(ft) - D(ft) = 1.18 - 0.42 = 0.79\ ft = 9.44in$

Four-Person

$$Volume\ Displacement\ V_D = \frac{\Sigma F_y(lb)}{\gamma_w(\frac{lb}{ft^3})} = \frac{(185+185+150+150+232.2)}{62.4} = 14.46ft$$

$$Draught\ D = \frac{V_D(ft^3)}{L(ft)*W(ft)} = \frac{14.46}{17.7*2.3*0.6} = 0.59ft = 7.12in$$

$$FreeBoard\ FB = H(ft) - D(ft) = 1.18 - 0.62 = 0.59ft = 7.07in$$

Function of Load

Freeboard FB = $H(ft)$ - $\frac{F_y(lb) / \gamma_w(\frac{lb}{ft^3})}{L(ft)*W(ft)*0.6} = 1.18 - \frac{F_y(lb)/62.4}{24.426} = 1.18 - \frac{F_y(lb)}{1524.1824}$

Self-weight

Freeboard FB = $H(ft) - \frac{F_y(lb)}{1524.1824} = 1.18 - \frac{232.2}{1524.1824} = 1.03ft. = 12.33in$

Self-weight + 1000lbs.

Freeboard FB = $H(ft) - \frac{F_y(lb)}{1524.1824} = 1.18 - \frac{1232.2}{1524.1824} = 0.37ft. = 4.46in$

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

<u>Hull Thickness</u>
Total Thickness of Canoe = 0.5 inches
Reinforcement (Carbon Fiber) Thickness = 0.0017 inches
Layers of Reinforcement = 2

<u>Calculations</u>

Total Reinforcement Thickness

$$Total\ Reinforcment\ Thickness = Reinforcement\ Thickness * \ Layers\ of\ Reinforcement$$
$$0.0017 * 2 = 0.0034$$

Composite Thickness Ratio

$$Composite\ Thickness = \frac{Total\ Reinforcement\ Thickness}{Total\ Thickness\ of\ Canoe}$$
$$\frac{0.0034}{0.5} = 0.0068$$

Composite Ratio = 0.68% $<$ 50% = Compliant

<u>Percent Open Area Calculation</u>

Open Area Calculation

$$\sum Area_{Open} = n_1 * n_2 * Area_{Aperture}$$

Total Area Equation

$$Area_{Open} = Lemgth_{Sample} * Width\ _{Sample}$$

Percent Open Area Equation

$$P.O.A. = \frac{\sum Area_{Open}}{Area_{Total}}$$

Variables:
t_1 = Thickness of reinforcement along sample length
t_2 = Thickness of reinforcement along sample width
d_1 = Spacing of reinforcement (center to center) along sample width + $\left(2 * \frac{t_1}{2}\right)$
d_2 = Thickness of reinforcement (center to center) along sample width + $\left(2 * \frac{t_2}{2}\right)$
n_1 = Number of Apertures along sample length
n_2 = Number of Apertures along sample width
$Area_{Aperture}$ = Area of single Aperture

Table 2. Percent Open Area Calculation Results

Variable	Quantity
d_1 (mm)	30.1
d_2 (mm)	30.6
t_1 (mm)	5.6
t_2 (mm)	3.9
n_1	6
n_2	6
Length (mm)	180.6
Width (mm)	183.6
$\sum Area_{Open}$ (mm)	22500
$Area_{Total}$ (mm)	33158.16
POA>40%	67.9

Appendix E – Detailed Fee Estimate

Task	PDE	DM	PCM	CS	PE	QM	EIT	TD	LT	OA	OC
Task 1: Enhanced Focus Area	4	4	4	0	4	4	4	4	4	0	0
Task 2: Mix Design	8	52	0	4	28	50	64	2	82	0	0
Task 3: Hull Design	6	10	4	0	8	12	8	34	9	0	0
Task 4: Reinforcement	11	24	8	0	0	10	8	10	10	0	0
Task 5: Construction	6	10	11	9	8	4	24	2	2	0	4
Task 6: Project Management	41	9	9	9	9	9	9	9	9	27	8
Total (hours - EA)	116	255	59	39	123	209	265	141	269	27	16
Project Total (hours)	1519										

Engineering Services Cost Estimate				
Description	**QTY**	**Unit of Measure**	**Rate (USD/UM)**	**Cost**
PERSONNEL (direct employee costs + indirect employee costs)				
Principal Design Engineer	116	HR	$ 50.00	$ 5,800.00
Design Manager	255	HR	$ 45.00	$ 11,475.00
Project Construction Manager	59	HR	$ 40.00	$ 2,360.00
Construction Superintendent	39	HR	$ 40.00	$ 1,560.00
Project Design Engineer (P.E.)	123	HR	$ 35.00	$ 4,305.00
Quality Manager	209	HR	$ 35.00	$ 7,315.00
Graduate Field Engineer (E.I.T.)	265	HR	$ 25.00	$ 6,625.00
Technician/Drafter	141	HR	$ 20.00	$ 2,820.00
Laborer/Technician	269	HR	$ 25.00	$ 6,725.00
Clerk/Office Admin	27	HR	$ 15.00	$ 405.00
Outside Consultant	16	HR	$ 200.00	$ 3,200.00
	1519	**Personnel Total**		$ 52,590.00
Shipping Cost				
Shipping Cost from Flagstaff, AZ to Ruston, LA				
UHAUL 26' Truck	1	LS	$ 1,400.00	$ 1,400.00
Materials				
Cementious Materials	10	CF	$ 10.00	$ 100.00
Reinforcement	15	SY	$ 14.00	$ 210.00
Admixtures	2	Gal	$ 12.00	$ 24.00
Aggregates	2	CF	$ 15.00	$ 15.00
Mold	1	LS	$ 1,000.00	$ 1,000.00
			Materials Total	$ 1,349.00
			Project Total	$ 55,339.00

Appendix F – Supporting Documentation

Pre-Qualification Form (Page 1 of 1)

Northern Arizona University
(school name)

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

The requirements of all teams to qualify as a participant in the ASCE Student Symposium and Society-wide Competitions as outlined in Section 3.0 and Exhibit 3.	HK / ML
The eligibility requirements of registered participants (Section 3.0 and Exhibit 3)	HK / ML
The deadline for the submission of *Letter of Intent, Preliminary Project Delivery Schedule and Pre-Qualification Form* (uploaded to ASCE server) is November 5, 2021; 5:00 p.m. Eastern	HK / ML
The last day to submit *ASCE Student Chapter Annual Reports* to be eligible for qualifying (so that they may be graded) is February 1, 2022	HK / ML
The last day to submit *Request for Information* (RFI) to the C4 is January 22, 2022	HK / ML
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.	HK / ML
The submission date of *Project Proposal, Enhanced Focus Area Report*, and *MTDS Addendum* for the Student Symposium Competition (hard copies to Host School and uploading of electronic copies to ASCE server) is Friday, February 18, 2022.	HK / ML
The submission date of *Project Proposal, Enhanced Focus Area Report*, and *MTDS Addendum* for Society-wide Final Competition (hard copies to ASCE and uploading of uploading of electronic copies to ASCE server) is May 10, 2022; 5:00 p.m. Eastern.	HK / ML

Hunter Kassens — 11/4/21
Team Captain — *(date)*

MARK LAMER — 11/04/21
ASCE Student Chapter Faculty Advisor — *(date)*

[signature]
(signature)

[signature]
(signature)

Pre-Qualification Form (Page 2 of 2)

Northern Arizona University
(school name)

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

At Northern Arizona University, the classes are fully in-person. After Thanksgiving and winter holiday break, classes will continue being fully in-person. Here, at NAU, we do have laboratory access/space outside of class.

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

The team is following all NAU recommendations for COVID-19 prevention. Only necessary team members are present while performing lab work, and the lab is properly disinfected prior to work. For general lab safety, the team created a safety binder in order to gain NAU lab access. This binder contains emergency contacts for each team member as well as an emergency response plan in case of an injury on-site. There are also safety documents such as material data sheets and safety trainings. There is a project activity log to track the work done throughout the course of the project. This project safety binder has been approved and vetted by NAU Environmental Health and Safety.

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 team's QA/QC program reviews all submissions and lab activities to ensure they meet the standard practices. The team assigned a student QA/QC director that is responsible for the review of these tasks. Prior to lab work and deliverable submissions, approval from the ASCE Faculty Advisor is required. Any lab testing performed follows proper ASTM standards and NAU Health and Safety protocols. The work is also checked by the student QA/QC director to ensure it adheres to the guidelines set by C4 in the RFP.

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?

Each team member has reviewed the University safety policies regarding material research, material lab testing, and construction. Each team member has current certification for the following NAU trainings: Field Safety, Chemical Hygiene, and Safe Return to Campus (COVID-19). Lab testing will follow ASTM Standards. The conference this upming spring will be held in-person, therefore team members driving to the competition will complete he Defensice Driving Training Course administered by NAU.

Pre-Qualification Form (Page 2 of 3)

Northern Arizona University
(school name)

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.

This year's canoe name and theme is Ponderosa Pinecones. This is a representation of Flagstaff, Arizona, which is located in the largest continuous Ponderosa Pine forest in the world.

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

The theme has been discussed with the team's Faculty Advisor about potential Trademark or Copyright issues.

The core project team is made up of__5_number of people.