VolCanoe

2019 Concrete Canoe Design Report

Northern Arizona University

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Executive Summary

Desert, cacti, and 100-degree weather are the general public's idea of life in Arizona. Yet, Flagstaff, in the heart of Northern Arizona, is the home to the largest contiguous Ponderosa Pine forest, capable of producing approximately 36 inches of snow in one day. The drastic change in scenery surrounding Flagstaff can largely be attributed to the historic volcanic activity in Northern Arizona. The San Francisco Peaks, Mount Elden, and Sunset Crater are a few of the 600 volcanos which make activities such as hiking, snowboarding, high elevation star gazing, and sight-seeing possible in Flagstaff (USGS 2001). Northern Arizona University (NAU) selected a volcano theme for the National Concrete Canoe Competition (NCCC), branding it as *VolCanoe*. The team felt a volcano theme would fully encompass and highlight the reasons Flagstaff and NAU are unique.

For many, volcanos symbolize upward challenges and the value beyond merely a destination, but also within the journey. *VolCanoe* aims to adopt the same methodology when competing at the 2019 Pacific South West Conference (PSWC). The team aims to gain valuable experience and learning opportunities at every step within the project.

In recent history, NAU's *Canoopa* (2018), *Paddlegonia* (2017), and *Polaris* (2016) regionally placed 11th, 8th, and 6th, respectfully. Understanding the journey to the top will be difficult, *VolCanoe* seeks to be encouraged by the long trail ahead, identifying and celebrating the milestones achieved and lessons learned along the way. Unsatisfied with conference outcomes in previous years, *VolCanoe* identified areas of improvement and executed innovative solutions within each major category for the NCCC.

Compared to *Canoopa*, *VolCanoe* increased maneuverability by decreasing the length by 15 percent and thickness of the canoe by 40 percent, eased constructability by eliminating the need for post tensioning reinforcement, increased compressive strength by a factor of two, increased flexural strength by a factor of three, and redesigned the curing chamber to increase efficiency. Support for NAU's canoe team and general awareness for the American Society of Civil Engineers (ASCE) was gained and shown through a substantial increase in donated materials and mentee involvement. Notably, a female mold was constructed for the first time in five years, natural occurring aggregates including recycled glass and expanded polystyrene (EPS) foam were introduced to the mix design, and a practice canoe was constructed for the first time in history at NAU. Table 1 summarizes the innovative features *VolCanoe* implemented. *VolCanoe's* general properties and concrete mix properties are found in Table 2 and 3 respectively.

Table 1: Innovative Features

Task	Notable Feature
Hull Design	Decreased length by 15% and thickness by 40%; implemented first female mold at NAU since 2014
Structural Analysis	Eliminated need for post tensioning
Mixture Design	Doubled structural mix compressive strength; tripled structural mix flexural strength
Construction	Practice canoe implemented; new and improved curing chamber constructed
Project Management	Increased amount of donated materials by $1,221; increased mentee involvement by 60%
Sustainability	Recycled foam glass aggregate, basalt reinforcement mesh, recycled EPS foam, natural pumice, and shale incorporated into mix design

Table 2: *VolCanoe* General Properties

Hull Dimensions	
Maximum Length	219 in
Maximum Width	33 in
Maximum Depth	16 in
Average Thickness	0.75 in
Estimated Weight	300 lbs
Reinforcement	
Primary	Basalt Mesh
Secondary	8mm PVA Fibers and MasterFiber MAC Matrix Fibers
Color	
Interior Finishing Mix	Red
Structural Mix	N/A
Exterior Finishing Mix	Black

Table 3: *VolCanoe* Concrete Properties

Mixes	Finishing	Structural
Wet Unit Weight	59.4 pcf	63.7 pcf
Oven-Dry Unit Weight	47 pcf	53 pcf
28-Day Compressive Strength	1,950 psi	2,080 psi
28-Day Tensile Strength	270 psi	300 psi
28-Day Flexural Strength	1,330 psi	1,500 psi
Concrete Air Content	10.0%	9.1%

Hull Design and Structural Analysis

Hull Design

The NAU concrete canoe team had four goals to improve on the previous year's canoe hull design. The first goal was to lighten the canoe, the second goal was to increase maneuverability of the canoe, the third goal was to maintain the stability of the canoe, and the fourth goal was to minimize the size of the canoe while still maintaining adequate buoyancy. After researching canoe designs the team decided to go with a shallow-V hull design.

The team discovered the shallow-V hull design was the best compromise between maneuverability and stability, based on comments from past paddlers and team members that had worked on previous canoes. The "V" portion at the bottom is made up of a 15-degree chime. The team built a rocker into the canoe to help the canoe handle small waves smoothly. The rocker extends approximately 2 feet from either end of the canoe and has a radius of 2.74 feet. The radius was selected from commercially available canoe model measurements that the team felt would make a good model. The team decided on an overall length of 18 feet. The length was decreased in comparison to *Canoopa's* previous length of 21 feet because last year's design was harder to maneuver in the water by previous paddlers. Paddlers mentioned that the canoe took more strength and effort to rotate about a fixed point because of the length of the canoe. The team determined that shortening the canoe by three feet would improve the maneuverability of *VolCanoe* in the water by the paddlers, while maintaining the excellent buoyancy of *Canoopa*. This was determined by analyzing the weight of the canoe in relation to the length, the strength of paddlers, and the ability of previous paddlers to turn the canoe sharply around a fixed point.

The width of the canoe was decided upon to minimize weight and volume while maximizing comfort, as previous paddlers commented on an excessively narrow canoe making paddling uncomfortable and more difficult than necessary. The width of 33 inches was decided upon after taking measurements of the width of most paddlers' comfortable kneeling stance. The walls of the canoe were flared out with a 6.25 percent slope to accommodate construction of the canoe. The slope would also help resist tipping for inexperienced paddlers, as the hull design would provide more stability than *Canoopa's* flat-bottom design. The sloped walls provided one inch of additional surface area for the paddler to gather stability with their body, while still providing paddlers access to the water. Figure 1 at the top right shows the 3D model of *VolCanoe* created on SolidWorks® (2018).

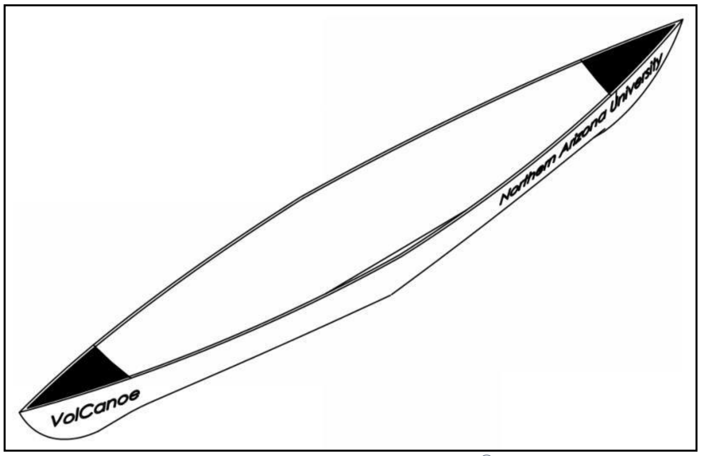


Figure 1: *VolCanoe* 3D Hull Model (SolidWorks® 2018)

Structural Analysis

The structural analysis for *VolCanoe* consists of a primary goal of justifying the elimination and use of post tensioning cable reinforcement and the adoption of only one encompassing layer of mesh reinforcement. *Paddlegonia* and *Canoopa* both integrated post tensioning cables and two encompassing layers of mesh reinforcement, creating difficulties in ensuring the thickness' quality assurance. As a result, the canoes' actual thickness resulted in nearly a triple and double respective increase compared to the desired thickness. Consequently, the overall weight and volume were also larger than anticipated. The secondary goals of the analysis include resulting accurate stress values obtained from shear and moment diagrams and calculating nominal shear for an area simulating a male paddler's knee to govern concrete strengths for mix design.

The team analyzed 36 half-foot cross sections for the entire length of the canoe. Longitudinal shear and moment equations were inputted into Microsoft® Excel (2016) and plotted into a diagram. The loading cases that were considered were the 2-person

Hull Design and Structural Analysis

male/female races and 4-person coed races. *VolCanoe* was simplified as a uniform beam with a conservative weight of 300 pounds. The buoyancy force was represented as a linearly distributed load that is equal and opposite to the total weight of the system of the loading case being analyzed. The paddlers for the 2-person and the 4-person races were assumed as a conservative 180 pound point load placed along the length of the canoe. An example of the 4-person loading scenario is shown in Figure 2.

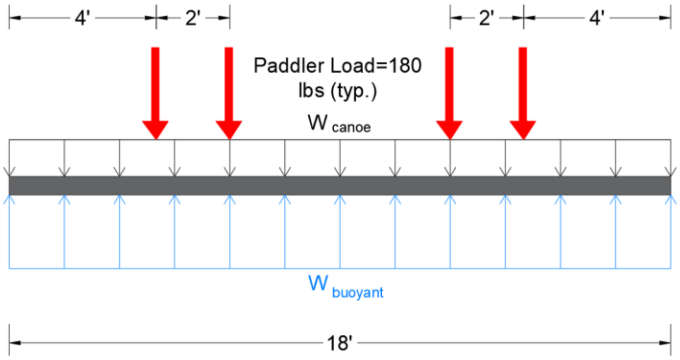


Figure 2: Simplified Beam Analysis of 4-Person Racing Scenario

Various placement scenarios of the paddlers were considered before finalizing each paddler's location during racing. The team determined the most conservative analysis occurs when the paddlers are positioned 6 feet from the bow and stern of the canoe for the 2-person race. Paddlers will be placed at 3 feet intervals from the center of the canoe to the bow or stern for the 4-person races. The moment diagram for each scenario can be seen in Figure 3 below.

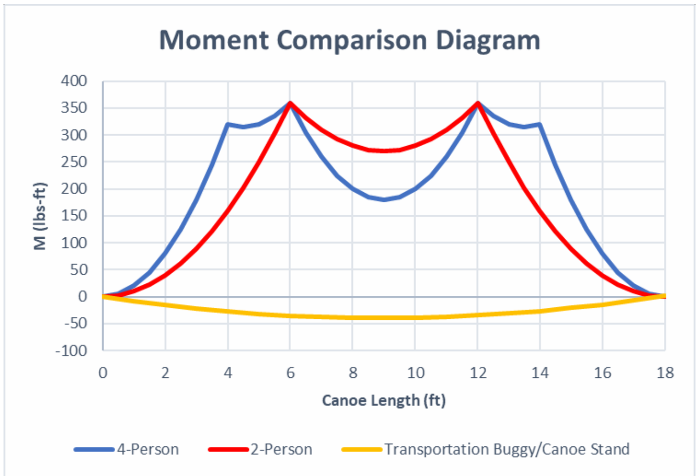


Figure 3: Comparison of Loading Scenarios

The maximum tensile and compressive stresses are analyzed as a simplified conservative cross section comprised of three rectangles arranged into a "U-shape" due to the complexity of *VolCanoe's* cross sectional curves. The compressive and tensile stresses are calculated using the location of the centroid of the simplified cross section, moment of inertia, and the maximum moment calculated from all loading cases. The results of the stresses for all loading cases are organized into Table 4 shown below.

Table 4: Structural Analysis Results

Loading Case	2-Person Race	4-Person Race	Transportation/ Canoe Stand
Maximum Moment	4,320 lb-in	4,320 lb-in	472 lb-in
Compressive Stress	38.5 psi	38.5 psi	4.2 psi
Tensile Stress	20.2 psi	20.2 psi	2.2 psi

The nominal shear was analyzed as a 4 inch by 4 inch area with a thickness of ⅝ inch for a two-way slab to mimic a 200 pound male paddler's knee during racing. The equation for nominal shear is governed by the American Concrete Institute (ACI 318-14) Building Code. The compressive strength of our concrete cylinders is used in this calculation as well as a lightweight concrete factor. This value was calculated to be 1,095.5 pounds without regards to the layers of mesh reinforcement.

The values obtained from the compressive stress, tensile stress, and nominal shear justifies the exclusion of post tensioning reinforcement from *VolCanoe's* design. To air on the side of precaution, the team decided to design concrete mixes that would account for the absence of post tensioning. To achieve this goal, the team introduced innovative and stronger volcanic aggregates that have not been used before in previous NAU concrete canoe teams.

Development and Testing

The primary goals of *VolCanoe's* development and testing are to develop several mixes that reduce the overall weight of the canoe and improve concrete strength. To accomplish these goals, the mix team tested a variety of new materials and admixtures. Notable achievements for NAU Concrete Canoe teams within the last three years, *Paddlegonia* produced the greatest concrete strengths and *Canoopa* produced lighter oven-dry unit weights. As such, a baseline concrete mix was implemented using the same materials as *Paddlegonia* and *Canoopa*. After testing commenced, procurement of half inch pumice aggregate was available through Arrow Redi, a local cement plant. Pumice aggregate was procured because it was discovered that the smaller particle sizes of Poraver® utilized in *Paddlegonia* and *Canoopa* were not compliant with the 2019 NCCC Rules and Regulations (ASCE 2019). As a result, the pumice from Arrow Redi Cement Plant was crushed down to a quarter inch, an eighth of an inch, and fine sand at FNF Construction in Tempe, Arizona. Once the material was sieved and washed, the material was implemented into the mix. Pumice allows the mix to have better gradation than in previous years, which allows for better cement to aggregate bonding. The improved bonding strength improves load transfers from the cement to the aggregate.

The cementitious baseline mix is comprised of a mixture of *Paddlegonia* and *Canoopa*. The cementitious baseline mix consists of 65 percent Type 1 Portland cement, 14 percent natural pozzolan, and 21 percent of Class F fly ash. The inclusion of fly ash and natural pozzolan allows the concrete mix to utilize 36 percent less Portland cement, which ultimately produces a lighter oven-dry unit weight. The aggregate baseline consists of Trinity expanded clay shale, Poraver®, and pumice. Other baseline materials include a high-range water reducer, a shrinkage reducer, an air-entrainer, a retarder, MasterFiber® 100, and water. Due to the complexity of the mix, only one material was altered and tested at a time. Multiple samples from each mix were tested in accordance with ASTM C109 and ASTM C496 to ensure accurate results. Final compressive results were tested according to ASTM C39. The standardized testing process, coupled with careful quality control, led to the efficient testing of concrete mixes. To ensure safety, captains wore gloves, particle masks, and safety glasses whenever batching and testing concrete (ASTM C109, ASTM C39).

Figure 4: Sieving Crushed Pumice Aggregate

Secondary goals of *VolCanoe* are to improve the durability of the canoe, improve concrete workability, and reinforce green building principles and sustainability. This is accomplished by incorporating Ultra-Lightweight Foamed Recycled Glass (UL-FGA) from Aeroaggregates®, expanded shale from Utelite Corporation, and EPS foam beads from EnStyro. These innovative aggregates improve concrete strength, dry-unit weight, workability, and promote green and sustainable building as UL-FGA and EPS foam are recycled materials. Additionally, Utelite's expanded shale is a natural material and can be used as a biodegradable backfill for plants. It is important to note that UL-FGA is also 85-90 percent lighter than other quarried aggregates, resulting in a lighter oven-dry unit weight. Additionally, the incorporation of polymers and latex admixtures increase the strength of concrete. Modifier A™/NA from Trinseo, as well as Rovene 4040 and Tylac 4193 from Mallard Creek Polymers are incorporated to the mix in order to improve bonding between cement and aggregates, which also improvs the strength and durability of the concrete. In addition, MasterFiber® MAC Matrix fibers from BASF and 8 mm PVA fibers were tested in mixes and produced favorable results in strength and durability. A crystalline waterproofing powder (MasterLife® D300) from BASF is also added to the mix in order to prevent capillary action in the

Development and Testing

pores of the pumice and recycled glass aggregates.

These materials and admixtures are used in the structural and finishing layers of the canoe in order to provide additional strength and durability to the canoe.

Prior to the baseline mix design, research on different materials and previous successful canoe mix designs was performed to ensure that a quality mix can be created. After each mix, 7-day samples are tested to determine if the desired compressive strength and unit weight are met per ASTM C19 and ASTM C138. If the 7-day samples met the desired properties, a tensile test and final compression test were completed at 21 and 28 days. If the mix did not meet expectations at 7 days, the mix is modified. As with *Canoopa*, *VolCanoe* developed a unit weight calculator in Microsoft Excel to determine the dry unit weight before trial mixing. This aided in refining the mix design. The ASTM C330 compliant aggregates used in each mix design are Poraver®, pumice, and Utelite material.

The chosen admixtures are added to help improve the workability of the concrete to ease constructability, improve bonding and adhesion of cement to the aggregates, and improve the strength of the concrete. The water reducer is used to create a mix with a low slump (ASTM C143). Low slumps allowed for easier placement on the canoe mold. In order to refine slump issues, the volume of the water reducer increased to allow for better workability. The water reducer was increased rather than increasing the cement ratio to avoid making the canoe heavier. The shrinkage reducer is used to prevent shrinkage cracks from appearing on the canoe during the curing process. Shrinkage reducer also aids in keeping the concrete durable and maintain strength as less voids are present in the concrete. A set retarder is used to allow the team more time to place the concrete in case delays persist in placing the various layers on the mold. The team eliminated air-entrainer in the mix, similar to *Canoopa*, because batch trials yielded low unit weights and the team did not want to lose additional strength in the concrete. *VolCanoe's* weakest mix has a compressive strength of 1,950 pounds per square inch (psi) and a tensile strength of 270 psi (ASTM C496). These strengths exceed the structural analysis requirements of 134.8 psi compressive strength and 202.1 psi tensile strength.

Aggregate proportion is an important detail of the mix because the team opted for maximum cement to aggregate bonding for maximum load transfer from the cement to the aggregates. As a result, many different aggregate proportions are considered and tested. At first, 59 percent by volume of aggregates are composed of EPS foam, 6 percent by volume of total aggregate is composed of the various pumice particle sizes seen in Table 5, 19 percent by volume of total aggregate is composed of the various UL-FGA particle sizes seen in Table 5, and 17 percent by volume of total aggregate is composed of Poraver®. This initial mix provided a dry unit weight range between 47-60 pounds per cubic foot (lb/ft^3) and compressive strengths around 1,300 psi. While the unit weight and strength values are acceptable, the tensile strength for this mix is below 200 psi which is not a desirable strength for the mix design team as it did not meet minimum strengths according to our structural analysis. To increase the tensile strength of the mix, additional aggregate sources need to be introduced to the mix. At this point, Utelite expanded shale is introduced to the mixes in order to increase tensile strength. The team tested Utelite in compression samples and found that concrete containing Utelite is 51 percent stronger in tension than without the aggregate. In addition, the team discovered that Utelite expanded shale is also 46 percent stronger in compression than that of *Canoopa's* mix with Trinity #1 sand. This data, coupled with Utelite's sustainability as a biodegradable backfill for plants, led the team to use Utelite in the structural and finishing mixes as an ASTM C330 aggregate. After additional testing and the refinement of minor aggregate proportions, the desired properties of the concrete is achieved. The dry unit weights ranged between 45-55 pcf, the compressive and flexural strengths are between 1,300-1,500 psi, and the tensile strength is between 250 psi and 350 psi. The properties of the aggregate are shown on the next page in Table 5. Two final mixes were chosen after testing 24 different mix designs for compressive strength, tensile strength, and slump. The components of each mix can be seen in Appendix B. Aggregate proportion properties of each mix can be seen in Table 5.

Development and Testing

Table 5: Finishing Mix Aggregate Proportions

Aggregate	Specific Gravity	Absorption (%)
Poraver® 1.0-2.0 mm	0.40	20.0
Pumice 4.76-6.35 mm	2.35	65.0
Pumice 2.89-3.36 mm	2.35	65.0
Pumice 0.07-0.84 mm	2.35	65.0
AeroAggregate UL-FGA 4.76-6.35 mm	0.38	64.0
AeroAggregate UL-FGA 2.89-3.36 mm	0.38	64.0
AeroAggregate UL-FGA 0.07-0.84 mm	0.38	64.0
EnStyro EPS Foam Beads 2.89-3.36 mm	0.01	4.0
Utelite Fines 0.84-4.76 mm	1.62	18.9
Utelite #10 Mesh 0.07-0.30 mm	1.62	18.9

The pumice aggregate, the Poraver®, and the Utelite expanded shale are ASTM C330 compliant and help achieve the 25% aggregate by volume regulation. The remaining volume of each mix is compressed of the solids from admixtures, fibers, cementitious materials, and non-ASTM C330 aggregates. Although the mixes have similar proportions of material, the greatest difference is the proportion of the different sizes of larger aggregate (2.38 mm - 6.35 mm). The finishing mix incorporates a larger percentage of finer sized aggregates, while the structural mix utilizes a greater percentage of larger aggregate sizes and Utelite material.

Curing

After establishing *VolCanoe's* mix, the team focused on creating a curing process that would allow the concrete to reach its highest possible strength and reduce the canoe's weight. The curing process began with a 3-hour heated dry cure. Afterwords, the canoe wet cured for 14 days in a controlled curing chamber with a temperature of 73°F (ASTM C192) and 98 percent humidity to reduce the free water on the concrete surface. This allows the concrete to harden and hydrate at a controlled rate. This process of applying moisture and heat in a controlled environment reduces the probability of micro-cracks forming on the surface of the concrete. Finally, the canoe dry cured for seven days at 80° F to remove the remaining moisture from the canoe. This 28-day curing procedure was implemented in order to minimize failure and cracks due to rapid drying shrinkage and create the lightest canoe possible. This curing process resulted in a low unit weight and high compressive, flexural, and tensile strengths.

Reinforcement

The team decided the primary reinforcement will be mesh for *VolCanoe*. The team needed a reinforcement scheme strong enough to eliminate the need for post-tensioning cables as it increases wall thickness. Three mesh reinforcements were considered, fiberglass mesh, carbon fiber mesh, and basalt mesh. Carbon fiber mesh had the highest tensile strength, but was the most expensive option. Basalt mesh had tensile strengths lower than carbon fiber, but higher than fiberglass mesh, as well as greater flexural resistance than carbon fiber mesh and fiberglass mesh. Flexural and shear strength are the most critical factors, and basalt mesh performed the best and it is cost effective for the team. Two layers of mesh were utilized in the canoe. The first layer is a 5 inch wide spine that runs the entire length of *VolCanoe.* This layer's primary function is to resist the flexural loads during racing conditions. The second layer resists nominal shear forces and is composed of basalt mesh sections that spans across the inner cross section, overlapped 4 inches between sections. The Basalt mesh has a percent open area of 67.9 percent and the total thickness of the reinforcement layers is 10.67 percent of the hull thickness.

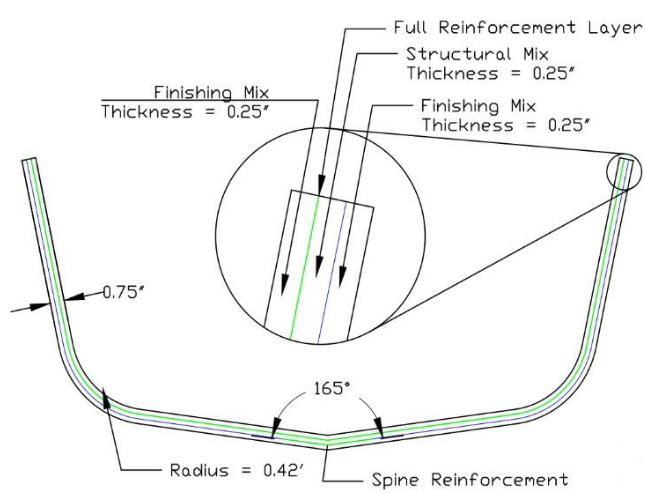


Figure 5: *VolCanoe* Cross-Section

Construction

The primary goal for the construction process was to successfully implement quality control measures to ensure the intended design was carried out as closely as possible throughout fabrication. Previous concrete canoe teams have suggested concrete placement was problematic and thickness was difficult to gage when using a male mold. Additionally, sanding the exterior of the canoe was extremely time consuming and not ideal for the overall aesthetics of the canoe. As such, *VolCanoe* implemented a female mold for the first time since 2014's *Spirit*. The mold was designed in SolidWorks® (2018) to be 18 feet in length, 33 inches at the maximum width, and 16 inches at the maximum height.

To construct the mold, 92 cross sections of the SolidWorks® (2018) model were sent to *XY Corp* for fabrication into Styrofoam cross sections. The material of the mold was chosen to be Styrofoam because it was the most economical material which could be fabricated via a Computer Numeric Control (CNC) machine. The mold's cross sections were fabricated utilizing a CNC machine because it was the most accessible fabrication option which provided the greatest accuracy. The thickness of the cross sections varied depending on how drastically the canoe's slope changed throughout the body of the canoe. The ends of the canoe were printed into one-inch cross sections, while the body of the canoe printed into four-inch cross sections. For *Canoopa*, the cross sections of the male mold were held together by a single steel rod running through the middle of the mold. This method was unfeasible for a female mold. Instead, the cross sections' corners were drilled into and four steel rods were run through the mold. In addition, the cross sections were coated in heavy duty glue. Once all the cross sections were glued and run through the steel rods, the rods were tightened to compress the cross sections together and keep them as flush as possible (Figure 6). Once the glue was left to dry for 24 hours, the mold was shadow sanded (Figure 7) and sealed after the cross sections were assembled to provide the smoothest surface for concrete placement. This also prevented any seepage of material into the mold (Figure 8).

Figure 6: Mold Construction in Progress

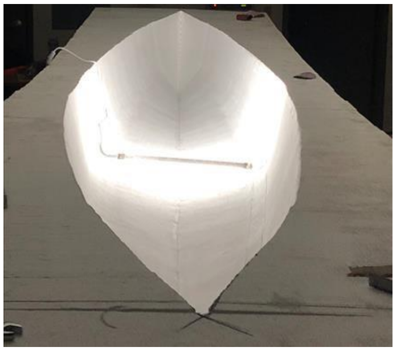


Figure 7: Shadow Sanding of Mold

Figure 8: Flex Seal Applied on Mold

Additional quality control measures were taken to improve the concrete mixing process and ultimately increase consistency in results. All mixing was conducted by weighing materials on a scale and then mixing batches in 5-gallon buckets with a power drill and a mixing attachment. Batches were mixed in 5-gallon buckets with power tools instead of hand mixing in tubs because losses were comparable, while the amount of time it took to mix was reduced drastically. As well, a power drill was used to mix batches because it allowed for uniform mixing of aggregates, fibers, admixtures, water, and cementitious materials. The mixing procedure included separating the aggregate and MasterFiber® MAC Matrix fibers from the cementitious material at the beginning of the mix process to allow for the proper aggregate water to be added. Water was added to the aggregate first to allow the aggregate to absorb the necessary water and allow for more free water to be added to the cementitious materials. Free water is the water that is added to allow for the hydration process to commence. The

Construction

cementitious materials were then mixed together and added into the mix with water added shortly after. Admixtures such as set retarder, shrinkage reducer, water reducer, polymers, and latex were then added to the mix at the same time as the free water was introduced. For the colored mixes, a pigmented admixture was added at this point along with the rest of the additional water. Finally, the 8 millimeter PVA fibers were added to reduce the cracking and add durability to the concrete. The 8 mm PVA fibers were added last to the mix in order to reduce clumping of the fibers and ensuring their distribution throughout the mixture. Lastly, to achieve the desired consistency of the concrete, the concrete was mixed via drum mixers. The mixing procedure was found to be effective and produce concrete that was homogeneous with minimal clumps of fiber or cement.

Once the concrete was properly mixed, the concrete was hand placed onto the female mold. The mold had 1/8th inch rubber thickness gauges nailed every 6 inches. The exterior black, finishing layer of concrete was placed to be flush with the thickness gauges. Once the thickness gauges were removed and replaced with concrete (Figure 9), the first layer was checked by our quality control team. The quality control team would check the thickness of the canoe using nails which were painted different colors at each 1/8th of an inch interval. The nails were an additional quality control measure implemented to ensure the areas in between the rubber gauges were a uniform thickness. While the rubber thickness gauges allowed the team to check each layer's thickness was an eighth of an inch, the painted nails also provided a means to check the overall thickness of the canoe after each layer was placed. Following, an additional 1/8th layer of exterior black, finishing layer was placed before placing the basalt mesh reinforcement spine in the canoe and 1/4th inch of structural concrete (Figure 10). Lastly, the final basalt mesh reinforcement was placed throughout the body of the canoe and covered by two, 1/8th inch interior red, finishing layers (Figure 11). The 1/8th inch rubber thickness gauges and painted nails were utilized for each layer mentioned.


Figure 9: Exterior Finishing


Figure 10: Placement of Spine and Structural Layer


Figure 11: Body Reinforcement and Interior Finishing Layer

Once the final finishing layer of concrete was placed, the curing chamber was assembled through one inch polyvinyl chloride (PVC) pipes, elbow and tee connections, plastic, duct tape, Velcro, and humidifiers, shown in Figure 12 below. Four humidifiers were placed on each corner of the mold. The plastic covered the PVC pipe and was taped onto the concrete floor, and Velcro was used to create a door to enter the curing chamber.

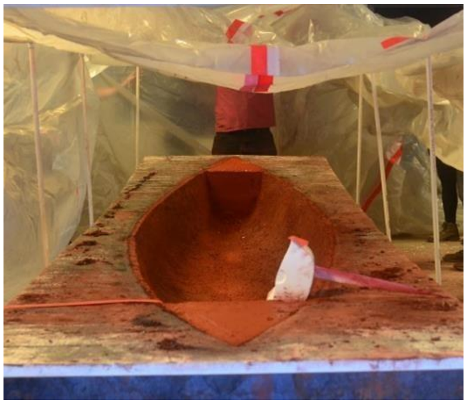


Figure 12: Construction of Curing Chamber

Project and Quality Management

After consulting with technical advisors and previous concrete canoe participants, the three main goals for *VolCanoe's* Project Management were established: increase sponsor funding and donated materials, expand community involvement, and establish a feasible project schedule.

Sponsor funding was successfully increased by implementing diverse fundraising and resource allocation techniques. First, team captains established a professional template used to increase sponsorship awareness. The template was then presented and distributed at NAU ASCE meetings to student members who were willing to reach out to family members and/or companies who they believe may be interested in sponsorship. Fundraisers at local restaurants were created to expand community awareness while also creating fundraising opportunities. Community awareness was further achieved by setting up informational booths at each fundraising event displaying *Canooopa's* cross section. *VolCanoe's* captains also volunteered to speak in a local kindergarten fieldtrip through the NAU engineering department. In Figure 13, *VolCanoe's* mix design captain prepares to demonstrate to kindergarteners the difference between a concrete cylinder that floats and one that does not.

Figure 13: Kindergarteners' Fieldtrip to NAU

Further, budget management was achieved by monitoring funds closely via a Microsoft® Excel spreadsheet which clearly identified the budget's progress throughout the project, marking all donations and expenditures. The budget was addressed at each team meeting, and receipts were updated onto the Microsoft® Excel spreadsheet weekly, ensuring the project's available funds were not exceeded. The total budget was determined to be $6,500. However, the project's total cost was estimated at $6,180, as seen in Figure 14.

Figure 14: Summary of Project Cost

VolCanoe was able to stay within budget by emphasizing resource management. Resource management included creating connections with vendors to increase the amount of donated materials available for the mix design and construction. As a result, the team received approximately $1,230 worth of donated materials, seen in Table 6. Similarly, Table 7 breaks down the monetary value of purchased materials. By decreasing the amount of purchased materials, the team was able to allocate fundraised funds towards the construction of a practice canoe.

Table 6: Monetary Value of Donated Material

Material	Quantity	Unit Cost	Total Cost
Gray Portland Cement Type I	188.00 lbs	$0.20/lbs	$37.60
1/2" Pumice Aggregate	21.00 ft^3	$12.00/$ft^3$	$252.00
MasterGlenium 7500	1.00 gal	$25.00/gal	$25.00
MasterColor Black	1.00 gal	$25.00/gal	$25.00
MasterColor Red	1.00 gal	$25.00/gal	$25.00
MasterFiber MAC Matrix	9.00 lbs	$12.00/lbs	$108.00
Sealant	5.00 gal	$12.50/gal	$62.50
MasterLife D300	25.00 lbs	$5.00/lbs	$125.00
Modified A/NA Latex	1.00 gal	$15.00/gal	$15.00
Tylac 4193	1.00 gal	$15.00/gal	$15.00
Rovene 4040	1.00 gal	$15.00/gal	$15.00
Ultra-Lightweight Foamed Recycled Glass Aggregate	21.00 ft^3	$15.00/$ft^3$	$315.00
Material Crushing	42.00 ft^3	$5.00/$ft^3$	$210.00
Total Value for Materials			**$1,230**

Project and Quality Management

Table 7: Monetary Value of Purchased Materials			
Material	**Quantity**	**Unit Cost**	**Total Cost**
Threaded Rod , Washers, Nuts	Varies	Varies	$100
Screws, Wood, Flex Seal, PVC Pipe	Varies	Varies	$250.00
Poraver 1.0-2.0 mm	38 lbs	$0.70/lbs	$27.00
Mold Fabrication	2 molds	Varies	$1,800.00
Basalt Reinforcing Mesh	225 m^2	$2.00/$m^2$	$450.00
Poraver 1-2 mm	58 lbs	$1.00/lbs	$58.00
Pumice Samples	8 lbs	Varies	$65.00
Total Value for Purchased Materials			**$2,750**

Further, to gain economic sustainability, post tensioning was eliminated. The materials chosen for the mix design and reinforcement took both economic and environmental sustainability into consideration through the use of basalt mesh reinforcement, recycled foam glass aggregate, recycled EPS foam, natural pumice, and shale in the mix design.

Before implementing scheduling, the scope of the project was established by clearly identifying the major tasks and subtasks encompassing the project. The scope was created after a thorough review of the NCCC 2019 rules during bi-weekly team meetings beginning in early September. Additionally, a Quality Control and Assurance (QC/QA) role was established between the team to ensure the scope was accurately and completely understood. Risk management was largely focused on the quality control during construction. To mitigate the risks associated with construction, a half-sized practice canoe was constructed to identify potential errors in the final canoe's construction. The total hours allocated for each major milestone are summarized in Figure 15.

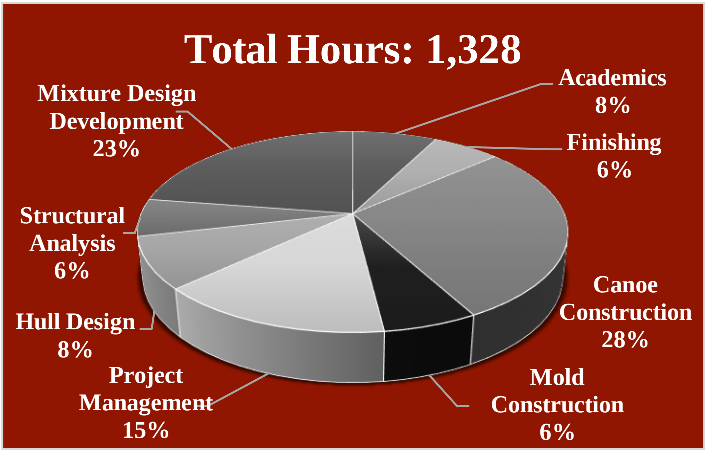


Figure 15: Total Hours Allocated

After establishing ambitious milestones and assessing feasibility, the preliminary schedule was created. Ultimately, *VolCanoe's* goal was to complete pour day as early as possible. However, pour day was delayed by about a month primarily due to unforeseen challenges in mold fabrication and mixture design. NAU had difficulty finding a vendor who would be willing to CNC the canoe's female mold within the budget's limits and within reasonable proximity to Flagstaff. Once a vendor was established in Palm Springs, California, additional safety measures had to be taken before the mold could be transported. Safety measures included certifying drivers through NAU, taking a defensive driver course, and filling out proper documentation to access NAU vehicles.

The final mix design was delayed approximately two months due to an underestimation of materials needed for the final canoe. The material was ordered using the volume provided from the SolidWorks® (2018) model with a 20 percent factor of safety. After the construction of the practice canoe, the volume of concrete used was larger than the value calculated via SolidWorks® (2018). Consulting with previous NAU canoe teams, it was determined a 40 percent factor of safety was necessary when using the volume provided by SolidWorks® (2018). As a result, the mix design had to be redesigned to ensure the remaining material available would be sufficient for the volume of the final canoe and cross section. Because *VolCanoe's* preliminary schedule was aggressive, a 28-day cure for the final canoe will still be met. Table 8 summarizes VolCanoe's milestones and their variance with respect to the end dates established from the preliminary schedule to the final schedule.

Table 8: Project Milestones		
Milestone	**Schedule Variance**	**Reason**
Mix Design	-51 days	Material procurement
Reinforcement Design	+3 days	N/A
Hull Design	-38 days	Changes in desired volume
Construction	-27 days	Mold fabrication
Competition	N/A	N/A

Organization Chart

Captain

Virgilio Bareng (Sr)

Structural Lead

Lead for the structural analysis, assisted with reinforcement and hull design plan, construction plan, paddling captain, and assisted with other tasks as needed.

Captain

Ernesto Mauricio (Sr)

Mix Design Lead

Lead the design of concrete mixtures, procured and tested aggregates, tested admixture compatibility with mix designs, and assisted with other tasks as needed.

Allyson Marnocha (Sr)

Project Manager

Lead for team and project scheduling, graphic design, fundraising, finances, and assisted in other tasks as needed.

2018-2019 Mentees

Kylie Dykstra (Sr.)
Maxx Townsend (Sr.)
Celine Bannourah (Jr.)
Nick Campbell (Jr.)
Sam Cole (Jr.)
Ally Fedor (Jr.)
Logan Grijalva (Jr.)
Stephan Henderson (Jr.)
Kristen Rassmussen (Jr.)
Conrad Senior (Jr.)
Carl Wilson (Jr.)
Russell Collins (So.)
Marie Cook (So.)
Hannah Fischer (So.)
Stephanie Seymour (So.)
Ryan Wassenburg (So.)

Trevor Mahoney (Sr)

Reinforcement Lead

Lead the design and draft of canoe mold, designed and tested reinforcement plan, drafted final construction drawing, mold construction, and assisted with other tasks as needed.

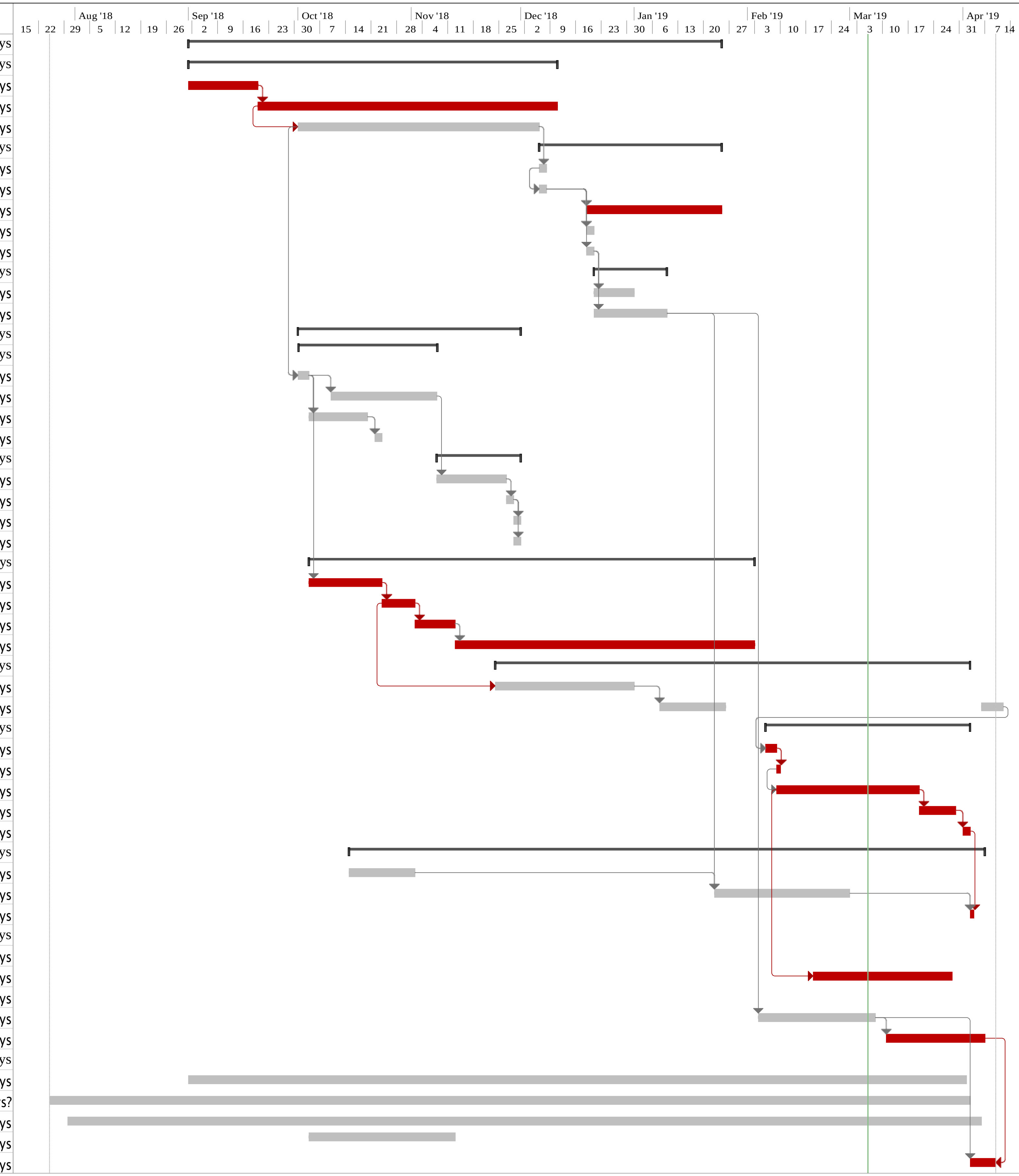
Jennifer Chavez (Sr)

Quality Assurance/Control

Lead for the quality assurance and control of construction, head editor, ensured all deliverables follow the 2018 NCCC Rules and Regulations, and assisted with other tasks as needed.

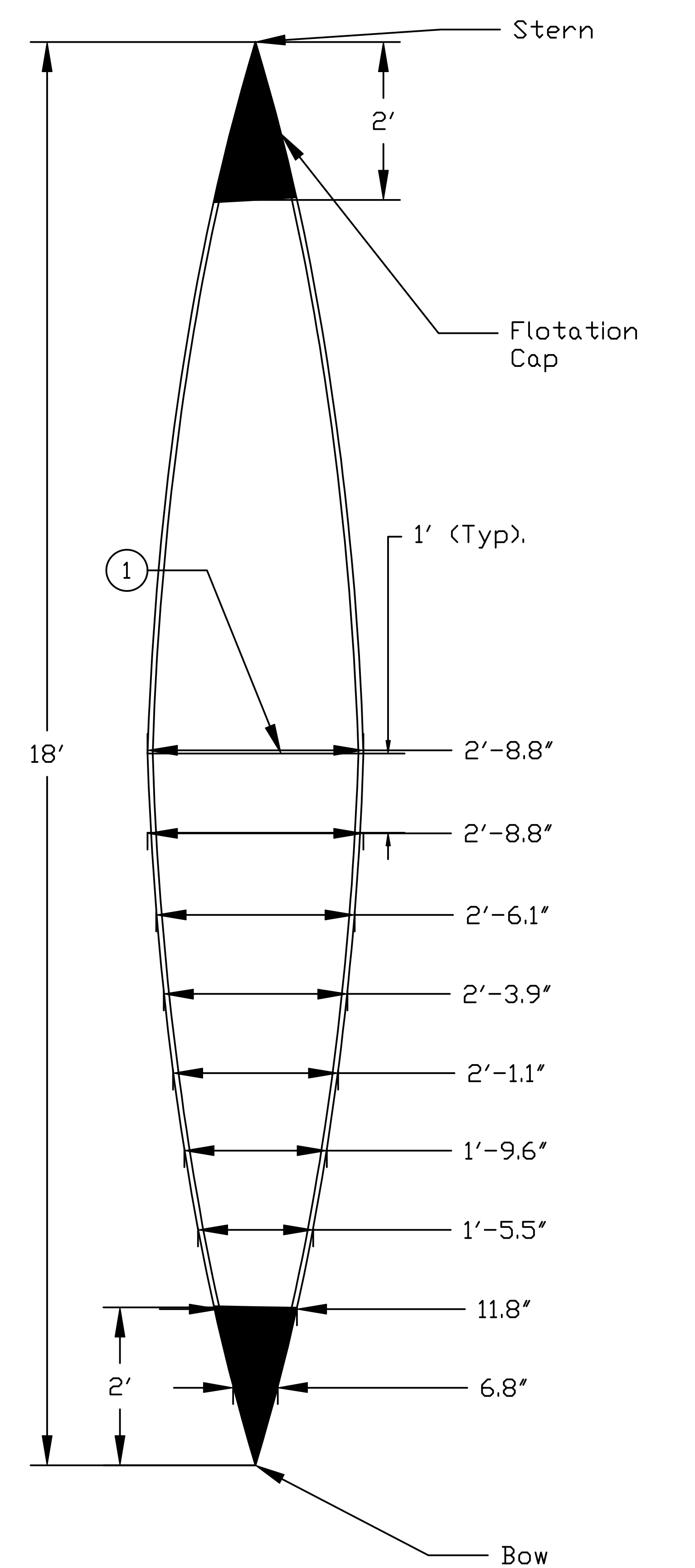
ASCE registered participant — Current Paddler — # of years on previous NAU Canoe teams

ID	Task Name	Duration	Start	Finish	Predecessors	Total Slack
1	Task 1.0: Mix Design	108 days	Sat 9/1/18	Thu 1/24/19		0 days
2	1.1 Material Research	74 days	Sat 9/1/18	Mon 12/10/18		0 days
3	1.1.1 Aggregates	14 days	Sat 9/1/18	Wed 9/19/18		0 days
4	1.1.2 Material Procurement	60 days	Thu 9/20/18	Mon 12/10/18	3	0 days
5	1.1.3 Develop Initial Mix Design	50 days	Mon 10/1/18	Wed 12/5/18	4SS+7 days	0 days
6	1.2 Concrete Testing	37 days	Thu 12/6/18	Thu 1/24/19		0 days
7	1.2.1 Slump Test	2 days	Thu 12/6/18	Fri 12/7/18	5	0 days
8	1.2.2 Cylinder Sample Collection	2 days	Thu 12/6/18	Fri 12/7/18	7SS	0 days
9	1.2.3 Compressive Strength Test	28 days	Wed 12/19/18	Thu 1/24/19	8FS+7 days	0 days
10	1.2.4 Split Tensile Strength Test	2 days	Wed 12/19/18	Thu 12/20/18	8FS+7 days	0 days
11	1.2.5 Dry Unit Weight	2 days	Wed 12/19/18	Thu 12/20/18	8FS+7 days	0 days
12	1.3 Refining Initial Mix Design	14 days	Fri 12/21/18	Wed 1/9/19		0 days
13	1.3.1 Creating Decision Matrix for Mix Design	7 days	Fri 12/21/18	Mon 12/31/18	11	0 days
14	1.3.2 Finalizing Competition Mix Deliverables	14 days	Fri 12/21/18	Wed 1/9/19	11	0 days
15	Task 2.0: Reinforcement Design	46 days	Mon 10/1/18	Fri 11/30/18		0 days
16	2.1 Testing of Reinforcement Materials	28 days	Mon 10/1/18	Wed 11/7/18		0 days
17	2.1.1 Thickness	3 days	Mon 10/1/18	Wed 10/3/18	5SS	0 days
18	2.1.2 Mechanical Bonding Test	21 days	Wed 10/10/18	Wed 11/7/18	17FS+3 days	0 days
19	2.1.3 Determine Percent Open Area	12 days	Thu 10/4/18	Fri 10/19/18	17	0 days
20	2.2 Reinforcement Selection	2 days	Mon 10/22/18	Tue 10/23/18	19	0 days
21	2.3 Concrete Pre-Stressing Assessment	18 days	Thu 11/8/18	Fri 11/30/18		0 days
22	2.3.1 Reinforcement Strength	14 days	Thu 11/8/18	Mon 11/26/18	18	0 days
23	2.3.2 Risk/Benefit Analysis	2 days	Tue 11/27/18	Wed 11/28/18	22	0 days
24	2.3.3 Determining Pre-Stressing Arrangement and Forces	2 days	Thu 11/29/18	Fri 11/30/18	23	0 days
25	2.4 Reinforcing Mix Materials	2 days	Thu 11/29/18	Fri 11/30/18	23	0 days
26	Task 3.0: Hull Design	92 days	Thu 10/4/18	Sat 2/2/19		0 days
27	3.1 Draft Hull in SolidWorks	14 days	Thu 10/4/18	Tue 10/23/18	17	0 days
28	3.2 Structural Analysis	7 days	Wed 10/24/18	Thu 11/1/18	27	0 days
29	3.3 Mold Design	7 days	Fri 11/2/18	Mon 11/12/18	28	0 days
30	3.4 Mold Procurement	64 days	Tue 11/13/18	Sat 2/2/19	29	0 days
31	Task 4.0: Construction	98 days	Sat 11/24/18	Tue 4/2/19		5 days
32	4.1 Construction Table	28 days	Sat 11/24/18	Mon 12/31/18	28SS	0 days
33	4.2 Practice Canoe	20 days	Tue 1/8/19	Thu 4/11/19	32	0 days
34	4.3 Final Canoe	41 days	Wed 2/6/19	Tue 4/2/19		5 days
35	4.3.1 Material Set Up	3 days	Wed 2/6/19	Fri 2/8/19	33FS+19 days	0 days
36	4.3.2 Placement	1 day	Sat 2/9/19	Sat 2/9/19	35	0 days
37	4.3.3 Curing	28 days	Sat 2/9/19	Tue 3/19/19	36SS	0 days
38	4.3.4 Finishing	8 days	Wed 3/20/19	Fri 3/29/19	37	5 days
39	4.3.5 Lettering	2 days	Mon 4/1/19	Tue 4/2/19	38	5 days
40	Task 5.0: Competition Deliverables	132 days	Mon 10/15/18	Sat 4/6/19		2 days
41	5.1 Acknowledgment Form and Preliminary Schedule	14 days	Mon 10/15/18	Thu 11/1/18		0 days
42	5.2 Project Overview and Technical Addendum	30 days	Wed 1/23/19	Thu 2/28/19	41,14	0 days
43	5.3 Transportation	1 day	Wed 4/3/19	Wed 4/3/19	42FS+20 days,39	5 days
44	5.4 Aesthetics	33 days	Tue 2/19/19	Thu 4/4/19		4 days
45	5.4.1 Canoe Stand	12 days	Wed 3/20/19	Thu 4/4/19	37	4 days
46	5.4.2 Cutaway Section	28 days	Tue 2/19/19	Thu 3/28/19	37SS+7 days	9 days
47	5.4.3 Tabletop Display	9 days	Mon 3/25/19	Thu 4/4/19	45SS+3 days	4 days
48	5.5 Design Paper	25 days	Mon 2/4/19	Thu 3/7/19	14	3 days
49	5.6 Oral Presentation	21 days	Mon 3/11/19	Sat 4/6/19	48	2 days
50	Task 6.0: Project Management	191 days	Wed 7/25/18	Sat 4/6/19		2 days
51	6.1 Fundraising	158 days	Sat 9/1/18	Mon 4/1/19		7 days
52	6.2 Meetings	187 days?	Wed 7/25/18	Tue 4/2/19		6 days?
53	6.3 Schedule Management	187 days	Mon 7/30/18	Fri 4/5/19		3 days
54	6.4 Safety Training	28 days	Thu 10/4/18	Mon 11/12/18		0 days
55	Task 7.0: Attend PSWC at Cal Poly SLO	6 days	Wed 4/3/19	Tue 4/9/19	48,49FF	0 days



Project: Critical Path Schedule
Date: Wed 3/6/19

Task | Summary | Project Summary | Critical



Plan View
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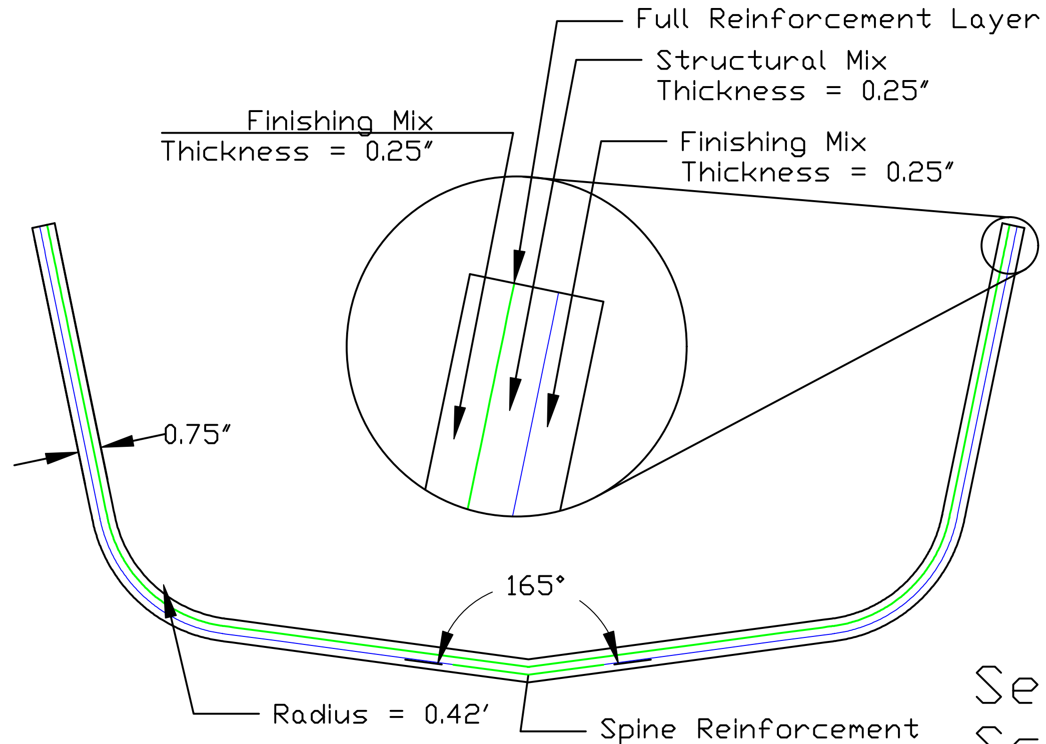
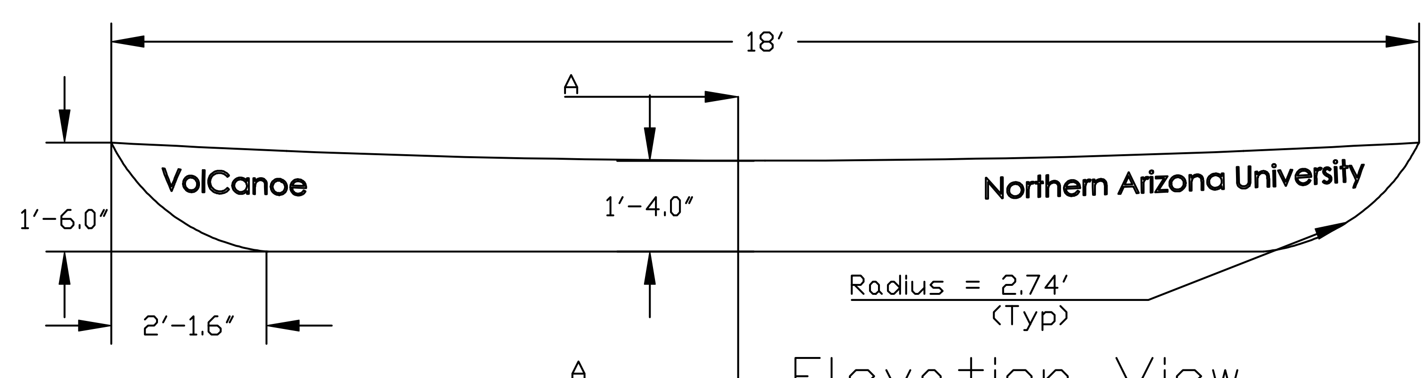
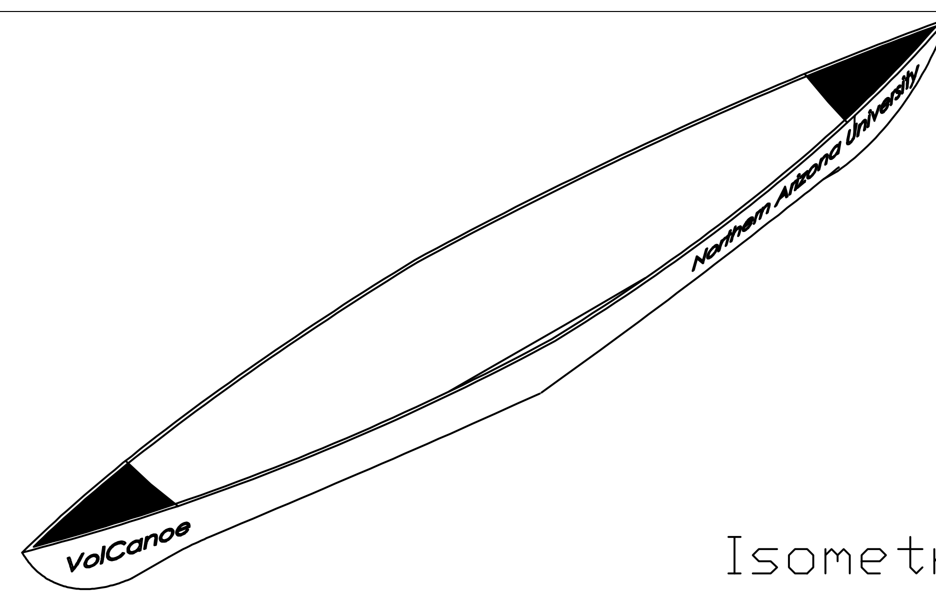


Section A-A
Scale: 1″ =6″



Elevation View
Scale: 1″=30″



Isometric View
Scale 1″=30″

Bill of Materials

127.7 lbs	Portland Type 1
35.5 lbs	SRMG Natural Pozzalan
3.19 lbs	BASF MasterLIfe® 300D
1.28 lbs	Nycon PVA Fiber 8mm
2.03 lbs	MasterFiber® MAC Matrix
2.53 lbs	Poraver® 1.0-2.0mm
11.7 lbs	Pumice 4.76-6.35mm
1.09 lbs	Pumice 2.89-3.36mm
16.9 lbs	Pumice 0.07-0.84mm
4.31 lbs	AeroAggregate UL-FGA 4.76-6.35mm
5.32 lbs	AeroAggregate UL-FGA 2.89-3.36mm
11.7 lbs	AeroAggregate UL-FGA 0.07-0.84mm
1.09 lbs	Enstyro EPS Foam Beads 2.89-3.36mm
16.9 lbs	Utelite Fines 0.84-4.76mm
15.9 lbs	Utelite #10 Mesh 0.070.30mm
0.88 lbs	Mallard Creek Polymers Rovene 4040
0.87 lbs	Mallard Creek Polymers Rovene 4193
0.91 lbs	Trinseo Modified A/NA
0.65 lbs	MasterSet Delvo
1.04 lbs	MasterGlenium 7500
0.49 lbs	MasterLife SRA 20
3.12 lbs	MasterColor Black
66.75 lbs	Water
59 SQ. FT.	Baslt Mesh
0.5 gal	Arizona Seal Sealent

~SHEET~ 1 OF 1

Northern Arizona University
Department of Civil Engineering, Construction Management and Environmental Engineering

NO.	DATE	COMMENTS

DRAWN BY:
CHECKED BY:
DATE:
SCALE:

VolCanoe
Construction Drawings

Appendix A – References

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Appendix A - References

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Appendix B – Mixture Proportion

MIXTURE DESIGNATION: FINISHING MIX

CEMENTITIOUS MATERIALS

Component	Specific Gravity	Volume (ft^3)	Amount of CM (mass/volume) (lb/yd^3)	
Cement, Gray Portland Type 1	3.15	2.56	504.00	Total Amount of cementitious materials 656.60 lb/yd^3 c/cm ratio 0.77
SRMG Natural Pozzolan	2.50	0.90	140.00	
BASF MasterLife 300D	2.10	0.10	12.60	

FIBERS

Component	Specific Gravity	Volume (ft^3)	Amount of Fibers (mass/volume) (lb/yd^3)	
PVA Fiber 8mm	1.30	0.06	4.75	Total Amount of Fibers 12.75 lb/yd^3
Fiber 2	0.91	0.14	8.00	

AGGREGATES

Aggregates	ASTM C330*	Abs (%)	SG_{OD}	SG_{SSD}	Base Quantity (lb/yd^3)		Volume (ft^3)
					OD	SSD	
Poraver® 1.0-2.0 mm*	Yes	20.00	0.34	0.40	115.00	138.00	5.53
Pumice 4.76-6.35 mm*	Yes	65.00	1.42	2.35	30.00	49.50	0.34
Pumice 2.89-3.36 mm*	Yes	65.00	1.42	2.35	10.00	16.50	0.11
Pumice 0.07-0.84 mm*	Yes	65.00	1.42	2.35	45.00	74.25	0.51
AeroAggregate UL-FGA 4.76-6.35mm	No	64.00	0.23	0.38	15.00	24.60	1.04
AeroAggregate UL-FGA 2.89-3.36mm	No	64.00	0.23	0.38	20.00	32.80	1.38
AeroAggregate UL-FGA 0.07-0.84mm	No	64.00	0.23	0.38	50.00	82.00	3.46
EnStyro EPS Foam Beads 2.89-3.36mm	No	4.00	0.01	0.01	4.25	4.42	6.44
Utelite Fines 0.84-4.76 mm*	Yes	18.90	1.36	1.62	65.00	77.29	0.76
Utelite #10 Mesh 0.07-0.30 mm*	Yes	18.90	1.36	1.62	60.00	71.34	0.71

ADMIXTURES

Admixture	lb/gal	Dosage (fl. oz / cwt)	% Solids	Amount of Water in Admixture (lb/yd^3)	
Mallard Creek Polymers Rovene 4040	8.42	5.00	14.00	2.19	Total Water from Admixtures, $\sum w_{admx}$ 38.38 lb/yd^3
Mallard Creek Polymers Rovene 4193	8.39	12.00	26.00	4.12	
Trinseo A/NA	8.76	8.00	51.00	1.69	
MasterSet Delvo	9.93	8.00	52.00	1.65	
MasterGlenium 7500	9.05	8.00	47.90	1.87	
MasterLife SRA 20	7.59	5.00	80.00	0.39	
MasterColor Black	15.00	40.00	14.00	26.47	

SOLIDS (LATEX, DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)

Component	Specific Gravity	Volume (ft^3)	Amount (mass/volume) (lb/yd^3)	
Trinseo A/NA	1.05	0.03	1.72	Total Solids from Admixtures 9.58 lb/yd^3
Mallard Creek Polymers Rovene 4040	1.01	0.03	1.76	
Mallard Creek Polymers Rovene 4193	1.01	0.03	1.79	

MasterColor Black	1.80	0.04	4.31	

Water

		Amount (mass/volume) (lb/yd^3)	Volume (ft^3)
Water, lb/yd^3		w: 262.64	4.21
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -149.70	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: 38.38	
Batch Water, lb/yd^3		w_{batch}: 151.36	

Densities, Air Content, Ratios and Slump

	cm	fibers	aggregates	solids	water	Total
Mass of Concrete, M, (lb)	656.60	12.75	454.25	9.58	262.64	∑M:1,401.07
Absolute Volume of Concrete, V, (ft^3)	3.56	0.20	16.20	0.13	4.21	∑V:24.31
Theoretical Density, T, (=∑M / ∑V)	57.63 lb/ft^3		Air Content [= (T – D)/T x 100%]			9.97%
Measured Density, D	56.52 lb/ft^3		Slump, Slump flow			5.50 in.
water/cement ratio, w/c:	0.52		water/cementitious material ratio, w/cm:			0.40

* Indicate if aggregate, other than manufactured glass microspheres and/or cenospheres, is compliant with ASTM C330.

MIXTURE DESIGNATION: STRUCTURAL MIX

CEMENTITIOUS MATERIALS				
Component	Specific Gravity	Volume (ft^3)	Amount of CM (mass/volume) (lb/yd^3)	
Cement, Gray Portland Type 1	3.15	2.56	504.00	Total Amount of cementitious materials 656.60 lb/yd^3 c/cm ratio 0.77
SRMG Natural Pozzolan	2.50	0.90	140.00	
BASF MasterLife 300D	2.10	0.10	12.60	

FIBERS				
Component	Specific Gravity	Volume (ft^3)	Amount of Fibers (mass/volume) (lb/yd^3)	
PVA Fiber 8mm	1.30	0.07	6.00	Total Amount of Fibers 14.00 lb/yd^3
Fiber 2	0.91	0.14	8.00	

AGGREGATES							
Aggregates	ASTM C330 *	Abs (%)	SG_{OD}	SG_{SSD}	Base Quantity (lb/yd^3) OD	Base Quantity (lb/yd^3) SSD	Volume (ft^3)
Poraver® 1.0-2.0 mm*	Yes	20.00	0.34	0.40	105.00	126.00	5.05
Pumice 4.76-6.35 mm*	Yes	65.00	1.42	2.35	60.00	99.00	0.68
Pumice 2.89-3.36 mm*	Yes	65.00	1.42	2.35	10.00	16.50	0.11
Pumice 0.07-0.84 mm*	Yes	65.00	1.42	2.35	50.00	82.50	0.56
AeroAggregate UL-FGA 4.76-6.35mm	No	64.00	0.23	0.38	25.00	41.00	1.73
AeroAggregate UL-FGA 2.89-3.36mm	No	64.00	0.23	0.38	25.00	41.00	1.73
AeroAggregate UL-FGA 0.07-0.84mm	No	64.00	0.23	0.38	30.00	49.20	2.07
EnStyro EPS Foam Beads 2.89-3.36mm	No	4.00	0.01	0.01	4.50	4.68	6.82
Utelite Fines 0.84-4.76 mm*	Yes	18.90	1.36	1.62	75.00	89.18	0.88
Utelite #10 Mesh 0.07-0.30 mm*	Yes	18.90	1.36	1.62	75.00	89.18	0.88

ADMIXTURES					
Admixture	lb/gal	Dosage (fl. oz / cwt)	% Solids	Amount of Water in Admixture (lb/yd^3)	
Mallard Creek Polymers Rovene 4040	8.42	5.00	14.00	2.19	Total Water from Admixtures, $\sum w_{admx}$ 11.92 lb/yd^3
Mallard Creek Polymers Rovene 4193	8.39	12.00	26.00	4.12	
Trinseo A/NA	8.76	8.00	51.00	1.69	
MasterSet Delvo	9.93	8.00	52.00	1.65	
MasterGlenium 7500	9.05	8.00	47.90	1.87	
MasterLife SRA 20	7.59	5.00	80.00	0.39	

SOLIDS (LATEX, DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)				
Component	Specific Gravity	Volume (ft^3)	Amount (mass/volume) (lb/yd^3)	
Trinseo A/NA	1.05	0.03	1.72	Total Solids from Admixtures 5.27 lb/yd^3
Mallard Creek Polymers Rovene 4040	1.01	0.03	1.76	
Mallard Creek Polymers Rovene 4193	1.01	0.03	1.79	

WATER			
	Amount (mass/volume) (lb/yd^3)		Volume (ft^3)
Water, lb/yd^3		w: 262.64	4.21
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -170.03	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: 11.92	
Batch Water, lb/yd^3		w_{batch}: 109.31	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP						
	cm	fibers	aggregates	solids	water	Total
Mass of Concrete, M, (lb)	656.60	14.00	499.50	5.27	262.64	∑M:1,438.01
Absolute Volume of Concrete, V, (ft^3)	3.56	0.21	16.44	0.12	4.21	∑V:24.54
Theoretical Density, T, (=∑M / ∑V)	56.30 lb/ft^3		Air Content [= (T – D)/T x 100%]			13.05%
Measured Density, D	59.64 lb/ft^3		Slump, Slump flow			5.00 in.
water/cement ratio, w/c:	0.52		water/cementitious material ratio, w/cm:			0.40

* Indicate if aggregate, other than manufactured glass microspheres and/or cenospheres, is compliant with ASTM C330.

Cementitious Materials:

Mass = Given

$Mass_{Type\ 1\ Portland\ Cement}$ = 504.00 lbs

$Mass_{Class\ N\ Natural\ pozzolan}$ = 140.00 lbs

$Mass_{MasterLife^{®}\ D300}$ = 12.60 lbs

$\sum Mass_{Cementitious}$ = 656.60 lbs

$$\textbf{Volume} = \frac{Mass}{Specific\ Gravity\ x\ 62.4\ lbs/ft^3}$$

$$Volume_{Type\ 1\ Portland\ Cement} = \frac{504.00\ lbs}{3.15\ x\ 62.4\ lbs/ft^3} = 2.56\ ft^3$$

$$Volume_{Class\ N\ Natural\ pozzolan} = \frac{5140.00\ lbs}{2.50\ x\ 62.4\ lbs/ft^3} = 0.79\ ft^3$$

$$Volume_{MasterLife^{®}\ D300} = \frac{12.60\ lbs}{2.10\ x\ 62.4\ lbs/ft^3} = 0.10\ ft^3$$

$\sum Volume_{Cementitious} = 3.45\ ft^3$

Fibers:

Mass = Given

$Mass_{8mm\ PVA}$ = 4.75 lbs

$Mass_{MasterFiber^{®}\ MAC360}$= 8.00 lbs

$\sum Mass_{Fibers}$ = 12.75 lbs

$$\textbf{Volume} = \frac{Mass}{Specific\ Gravity\ x\ 62.4\ lbs/ft^3}$$

$$Volume_{8mm\ PVA} = \frac{4.75\ lbs}{1.30\ x\ 62.4\ lbs/ft^3} = 0.06\ ft^3$$

$$Volume_{MasterFiber^{®}\ MAC360} = \frac{8.00\ lbs}{0.91\ x\ 62.4\ lbs/ft^3} = 0.14\ ft^3$$

$\sum Volume_{Fibers} = 0.2\ ft^3$

Aggregates:

Mass (W_{SSD}) = Given

Mass$_{Poraver^{®} 1.0\text{-}2.0mm}$= 138.00 lbs

Mass$_{Pumice\ 4.76\text{-}6.35mm}$= 49.50 lbs

Mass$_{Pumice\ 2.38\text{-}3.36mm}$ = 16.50 lbs

Mass$_{Pumice\ 0.07\text{-}0.84mm}$ = 74.25 lbs

Mass$_{Aeroaggregate\ Recycled\ Foam\ Glass\ 4.76\text{-}6.35mm}$ = 24.60 lbs

Mass$_{Aeroaggregate\ Recycled\ Foam\ Glass\ 2.38\text{-}3.36mm}$ = 32.80 lbs

Mass$_{Aeroaggregate\ Recycled\ Foam\ Glass\ 0.07\text{-}0.84mm}$ = 82.00 lbs

Mass$_{EPS\ Foam\ 2.38\text{-}4.76mm}$ = 4.42 lbs

Mass$_{Utelite\ Fines\ 0.84\text{-}4.76mm}$ = 77.29 lbs

Mass$_{Utelite\ \#10\ Mesh\ 0.07\text{-}0.30mm}$ = 71.34 lbs

∑Mass$_{Aggregates}$ = 570.70 lbs

Volume = $\frac{W_{SSD}}{Specific\ Gravity\ x\ 62.4\ lbs/ft^3}$

Volume$_{Poraver^{®} 1.0\text{-}2.0mm}$= $\frac{138\ lbs}{0.40\ x\ 62.4\ lbs/ft^3}$ = 5.53 ft^3

Volume$_{Pumice\ 4.76\text{-}6.35mm}$= $\frac{30.00\ lbs}{2.35x\ 62.4\ lbs/ft^3}$ = 0.34 ft^3

Volume$_{Pumice\ 2.38\text{-}3.36mm}$ = $\frac{10.00\ lbs}{2.35\ x\ 62.4\ lbs/ft^3}$ = 0.11 ft^3

Volume$_{Pumice\ 0.07\text{-}0.84mm}$ = $\frac{45.00\ lbs}{2.35\ x\ 62.4\ lbs/ft^3}$ = 0.51 ft^3

Volume$_{Aeroaggregate\ Recycled\ Foam\ Glass\ 4.76\text{-}6.35mm}$ = $\frac{15.00\ lbs}{0.36\ x\ 62.4\ lbs/ft^3}$ = 1.04 ft^3

Volume$_{Aeroaggregate\ Recycled\ Foam\ Glass\ 2.38\text{-}3.36mm}$ = $\frac{20.00\ lbs}{0.36\ x\ 62.4\ lbs/ft^3}$ = 1.38 ft^3

Volume$_{Aeroaggregate\ Recycled\ Foam\ Glass\ 0.07\text{-}0.84mm}$ = $\frac{50.00\ lbs}{0.36\ x\ 62.4\ lbs/ft^3}$ = 3.46 ft^3

$\text{Volume}_{\text{EPS Foam 2.38-4.76mm}} = \frac{4.25\ lbs}{0.01\ x\ 62.4\ lbs/ft^3} = 6.44\ \text{ft}^3$

$\text{Volume}_{\text{Utelite Fines 0.84-4.76mm}} = \frac{65.00\ lbs}{1.62\ x\ 62.4\ lbs/ft^3} = 0.76\ \text{ft}^3$

$\text{Volume}_{\text{Utelite \#10 Mesh 0.07-0.30mm}} = \frac{60.00\ lbs}{1.62\ x\ 62.4\ lbs/ft^3} = 0.71\ \text{ft}^3$

$\boldsymbol{\sum \text{Volume}_{\text{Aggregates(SSD)}} = 20.27\ \text{ft}^3}$

Mass (W_{OD}) = Given

$\text{Mass}_{\text{Poraver}^{®}\text{1.0-2.0mm}} = 115.00\ \text{lbs}$

$\text{Mass}_{\text{Pumice 4.76-6.35mm}} = 30.00\ \text{lbs}$

$\text{Mass}_{\text{Pumice 2.38-3.36mm}} = 10.00\ \text{lbs}$

$\text{Mass}_{\text{Pumice 0.07-0.84mm}} = 45.00\ \text{lbs}$

$\text{Mass}_{\text{Aeroaggregate Recycled Foam Glass 4.76-6.35mm}} = 15.00\ \text{lbs}$

$\text{Mass}_{\text{Aeroaggregate Recycled Foam Glass 2.38-3.36mm}} = 20.00\ \text{lbs}$

$\text{Mass}_{\text{Aeroaggregate Recycled Foam Glass 0.07-0.84mm}} = 50.00\ \text{lbs}$

$\text{Mass}_{\text{EPS Foam 2.38-4.76mm}} = 4.25\ \text{lbs}$

$\text{Mass}_{\text{Utelite Fines 0.84-4.76mm}} = 65.00\ \text{lbs}$

$\text{Mass}_{\text{Utelite \#10 Mesh 0.07-0.30mm}} = 60.00\ \text{lbs}$

$\boldsymbol{\sum \text{Mass}_{\text{Aggregates(OD)}} = 414.25\ \text{lbs}}$

Absorbance (Abs) $= \frac{W_{SSD} - W_{OD}}{W_{OD}} * 100\%$

$\text{Abs}_{\text{Poraver}^{®}\text{1.0-2.0mm}} = \frac{138.00l\ bs - 115.00\ lbs}{115.00\ lbs} * 100\% = 20.00\%$

$\text{Abs}_{\text{Pumice 4.76-6.35mm}} = \frac{49.50\ lbs - 30.00\ lbs}{30.00\ lbs} * 100\% = 65.00\%$

$\text{Abs}_{\text{Pumice 2.38-3.36mm}} = \frac{16.50\ lbs - 10.00\ lbs}{10.00\ lbs} * 100\% = 65.00\%$

$W_{Pumice\ 4.76\text{-}6.35mm} = 30.00\ lbs * (1 + \frac{6.50\%}{100\%}) = 31.95$ lbs

$W_{Pumice\ 2.38\text{-}3.36mm} = 10.00\ lbs * (1 + \frac{6.50\%}{100\%}) = 10.65$ lbs

$W_{Pumice\ 0.07\text{-}0.84mm} = 45.00\ lbs * (1 + \frac{6.50\%}{100\%}) = 47.93$ lbs

$W_{Aeroaggregate\ Recycled\ Foam\ Glass\ 4.76\text{-}6.35mm} = 15.00\ lbs * (1 + \frac{1.00\%}{100\%}) = 15.15$ lbs

$W_{Aeroaggregate\ Recycled\ Foam\ Glass\ 2.38\text{-}3.36mm} = 20.00\ lbs * (1 + \frac{1.00\%}{100\%}) = 20.20$ lbs

$W_{Aeroaggregate\ Recycled\ Foam\ Glass\ 0.07\text{-}0.84mm} = 50.00\ lbs * (1 + \frac{1.00\%}{100\%}) = 50.50$ lbs

$W_{EPS\ Foam\ 2.38\text{-}4.76mm} = 4.25\ lbs * (1 + \frac{0.50\%}{100\%}) = 4.27$ lbs

$W_{Utelite\ Fines\ 0.84\text{-}4.76mm} = 65.00\ lbs * (1 + \frac{4.60\%}{100\%}) = 67.99$ lbs

$W_{Utelite\ \#10\ Mesh\ 0.07\text{-}0.30mm} = 60.00\ lbs * (1 + \frac{4.60\%}{100\%}) = 62.76$ lbs

Moisture Content (MC_{free}) = MC_{Total} -Abs

$MC_{Poraver^{®}\ 1.0\text{-}2.0mm} = 0.50\% - 20.00\% = -19.50\%$

$MC_{Pumice\ 4.76\text{-}6.35mm} = 6.50\% - 65.00\% = -59.50\%$

$MC_{Pumice\ 2.38\text{-}3.36mm} = 6.50\% - 65.00\% = -59.50\%$

$MC_{Pumice\ 0.07\text{-}0.84mm} = 6.50\% - 65.00\% = -59.50\%$

$MC_{Aeroaggregate\ Recycled\ Foam\ Glass\ 4.76\text{-}6.35mm} = 1.00\% - 64.00\% = -63.00\%$

$MC_{Aeroaggregate\ Recycled\ Foam\ Glass\ 2.38\text{-}3.36mm} = 1.00\% - 64.00\% = -63.00\%$

$MC_{Aeroaggregate\ Recycled\ Foam\ Glass\ 0.07\text{-}0.84mm} = 1.00\% - 64.00\% = -63.00\%$

$MC_{EPS\ Foam\ 2.38\text{-}4.76mm} = 0.50\% - 4.00\% = -3.50\%$

$MC_{Utelite\ Fines\ 0.84\text{-}4.76mm} = 4.60\% - 18.90\% = -18.40\%$

$MC_{Utelite\ \#10\ Mesh\ 0.07\text{-}0.30mm} = 4.60\% - 18.90\% = -18.40\%$

Free Water (w_{free}) $= W_{OD} * (\frac{MC_{free}}{100\%})$

$W_{Poraver^{®} 1.0\text{-}2.0mm} = 115.00\ lbs * (\frac{-19.50\%}{100\%})$ = -22.43 lbs

$W_{Pumice\ 4.76\text{-}6.35mm} = 30.00\ lbs * (1 + \frac{-59.50\%}{100\%})$ = -17.85 lbs

$W_{Pumice\ 2.38\text{-}3.36mm} = 10.00\ lbs * (1 + \frac{-59.50\%}{100\%})$ = -5.95 lbs

$W_{Pumice\ 0.07\text{-}0.84mm} = 45.00\ lbs * (1 + \frac{-59.50\%}{100\%})$ = -26.78 lbs

$W_{Aeroaggregate\ Recycled\ Foam\ Glass\ 4.76\text{-}6.35mm} = 15.00\ lbs * (1 + \frac{-6\ \ .00\%}{100\%})$ = -9.45 lbs

$W_{Aeroaggregate\ Recycled\ Foam\ Glass\ 2.38\text{-}3.36mm} = 20.00\ lbs * (1 + \frac{-63.00\%}{100\%})$ = -12.60 lbs

$W_{Aeroaggregate\ Recycled\ Foam\ Glass\ 0.07\text{-}0.84mm} = 50.00\ lbs * (1 + \frac{-63.00\%}{100\%})$ = -31.50 lbs

$W_{EPS\ Foam\ 2.38\text{-}4.76mm} = 4.25\ lbs * (1 + \frac{-3.50\%}{100\%})$ = -0.15 lbs

$W_{Utelite\ Fines\ 0.84\text{-}4.76mm} = 65.00\ lbs * (1 + \frac{-1\ \ .40\%}{100\%})$ = -11.96 lbs

$W_{Utelite\ \#10\ Mesh\ 0.07\text{-}0.30mm} = 60.00\ lbs * (1 + \frac{-18.40\%}{100\%})$ = -11.04 lbs

$\sum W_{free}$ = -149.70 lbs

Admixtures:

Dosage = Given

$Dosage_{MasterSet\ Delvo} = 5\ \frac{fl\ oz}{cwt}$

$Dosage_{MasterGlenium\ 7500} = 8\ \frac{fl\ oz}{cwt}$

$Dosage_{Rovene\ 4040} = 8\ \frac{fl\ oz}{cwt}$

$Dosage_{Tylac\ 4193} = 8\ \frac{fl\ oz}{cwt}$

$Dosage_{Trinseo\ AN^{TM}/A} = 8\ \frac{fl\ oz}{cwt}$

$\text{Dosage}_{\text{MasterLife SRA 035}} = 5\,\frac{fl\,oz}{cwt}$

$\text{Dosage}_{\text{MasterColor Black}} = 40\,\frac{fl\,oz}{cwt}$

Mass of Water from Admixtures:

$$\mathbf{W_{admix}} = \mathbf{dosage}\left(\frac{fl\,oz}{cwt}\right) * \mathbf{cwt\ of\ cm} * \mathbf{water\ content}\,(\%) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * \left(\frac{lbs}{gal}\ \mathbf{of\ admix.}\right)$$

$$W_{\text{MasterSet Delvo}} = 5\left(\frac{fl\,oz}{cwt}\right) * \frac{656.60\,\frac{lbs}{yd^3}}{100} * (100.00\% - 14.00\%) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * 9.93\left(\frac{lbs}{gal}\ of\ admix.\right) = 2.19\text{ lbs}$$

$$W_{\text{MasterGlenium 7500}} = 8\left(\frac{fl\,oz}{cwt}\right) * \frac{656.60\,\frac{lbs}{yd^3}}{100} * (100.00\% - 26.00\%) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * 9.05\left(\frac{lbs}{gal}\ of\ admix.\right) = 2.75\text{ lbs}$$

$$W_{\text{MasterLife SRA 20}} = 5\left(\frac{fl\,oz}{cwt}\right) * \frac{656.60\,\frac{lbs}{yd^3}}{100} * (100.00\% - 8.00\%) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * 7.59\left(\frac{lbs}{gal}\ of\ admix.\right) = 1.79\text{ lbs}$$

$\mathbf{\sum MassWater_{admixtures} = 38.42\ lbs}$

Mass of Solids from Admixtures:

$$W_{\text{Rovene 4040}} = 8\left(\frac{fl\,oz}{cwt}\right) * \frac{656.60\,\frac{lbs}{yd^3}}{100} * (51.00\%) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * 8.42\left(\frac{lbs}{gal}\ of\ admix.\right) = 1.76\text{ lbs}$$

$$W_{\text{Tylac 4193}} = 8\left(\frac{fl\,oz}{cwt}\right) * \frac{656.60\,\frac{lbs}{yd^3}}{100} * (52.00\%) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * 8.39\left(\frac{lbs}{gal}\ of\ admix.\right) = 1.79\text{ lbs}$$

$$W_{\text{Trinseo AN}^{\text{TM}}\text{/A}} = 8\left(\frac{fl\,oz}{cwt}\right) * \frac{656.60\,\frac{lbs}{yd^3}}{100} * (47.90\%) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * 8.76\left(\frac{lbs}{gal}\ of\ admix.\right) = 1.72\text{ lbs}$$

$$W_{\text{MasterColor Black}} = 40\left(\frac{fl\,oz}{cwt}\right) * \frac{656.60\,\frac{lbs}{yd^3}}{100} * (14.00\%) * \left(\frac{1\,gal}{128\,fl\,oz}\right) * 15\left(\frac{lbs}{gal}\ of\ admix.\right) = 4.31\text{ lbs}$$

$\mathbf{\sum MassSolids_{admixtures} = 9.58\ lbs}$

Volume of Solids from Admixtures:

$$\textbf{Volume}_{\textbf{admixture}} = \frac{Mass_{admix}\,(lbs)}{Specific\ Gravity\ x\ 62.4\,\frac{lbs}{yd^3}}$$

$$\text{Volume}_{\text{Rovene 4040}} = \frac{1.76\ (lbs)}{1.009\ x\ 62.4\,\frac{lbs}{yd^3}} = 0.03\ \text{ft}^3$$

$$\text{Volume}_{\text{tylac 4193}} = \frac{1.79\ (lbs)}{1.005\ x\ 62.4\,\frac{lbs}{yd^3}} = 0.03\ \text{ft}^3$$

$$\text{Volume}_{\text{Trinseo AN}^{\text{TM}}\text{/A}} = \frac{1.72\ (lbs)}{1.050\ x\ 62.4\,\frac{lbs}{yd^3}} = 0.03\ \text{ft}^3$$

$$\text{Volume}_{\text{MasterColor Black}} = \frac{4.31\ \ (lbs)}{1.797\ x\ 62.4\,\frac{lbs}{yd^3}} = 0.04\ \text{ft}^3$$

$$\sum \textbf{VolumeSolids}_{\textbf{admixtures}} = \textbf{0.12 ft}^3$$

Water:

$$\textbf{Mass}_{\textbf{Water}} = \frac{w}{cm} * cm$$

$$\text{Mass}_{\text{water}} = 0.40 * 656.60\ lbs = 262.64\ \text{lbs}$$

$$\textbf{Batch Water (W}_{\textbf{batch}}\textbf{) = w+ (}\sum \textbf{W}_{\textbf{free}} + \sum \textbf{W}_{\textbf{admix}}\textbf{)}$$

$$\text{W}_{\text{batch}} = 262.64\ \text{lbs} + (-149.70\ \text{lbs} + 38.42\ \text{lbs}) = 151.36\ \text{lbs}$$

$$\textbf{Volume Water} = \frac{Mass_{Water}}{Specific\ Gravity\ x\ 62.4\,\frac{lbs}{yd^3}}$$

$$\text{Volume Water} = \frac{262.64\ lbs}{1.00\ x\ 62.4\,\frac{lbs}{yd^3}} = 4.21\ \text{ft}^3$$

Concrete Analysis:

Densities:

$$\sum \textbf{Masses} = \textbf{Mass}_{\textbf{Concrete}} = \textbf{1,388.60 lbs}$$

$$\sum \textbf{Volumes} = \textbf{Volume}_{\textbf{Concrete}} = \textbf{24.20 ft}^3$$

$$\textbf{Theoretical Desnity (T)} = \frac{\text{MassConcrete}}{\text{VolumeConcrete}} = \frac{1{,}388.60\ lbs}{24.20\ ft^3} = 57.38\,\frac{lbs}{yd^3}$$

$$\textbf{Measured Density (D)} = 51.43\,\frac{lbs}{yd^3}$$

$$\textbf{Air Content} = \frac{T(\frac{lbs}{yd^3}) - D(\frac{lbs}{yd^3})}{T(\frac{lbs}{yd^3})} * 100\% = \frac{57.38(\frac{lbs}{yd^3}) - 51.43(\frac{lbs}{yd^3})}{57.38(\frac{lbs}{yd^3})} * 100\% = 10.37\%$$

$$\text{Air Content} = \frac{27\,ft^3 - Volume_{Concrete}(\frac{lbs}{yd^3})}{27\,ft^3} * 100\% = \frac{27\,ft^3 - 24.20\,ft^3}{27\,ft^3} * 100\% = 10.37\%$$

Important Ratios:

Cement/Cementitious Material: $\frac{c}{cm} = \frac{504.00\,lbs}{656.60\,lbs} = 0.77$

Water/Cement: $\frac{w}{c} = \frac{262.64\,lbs}{504.00\,lbs} = 0.52$

Water/ Cementitious Material: $\frac{w}{cm} = \frac{262.64\,lbs}{656.60\,lbs} = 0.40$

Aggregate Ratio Check:

$$\text{Aggregate Ratio (\%)} = \frac{Volume_{Total\ Aggregate}(ft^3)}{27\,ft^3} * 100\%$$

$$\text{Aggregate Ratio (\%)} = \frac{20.27\,ft^3}{27\,ft^3} * 100\% = 75.07\% > 25\% \therefore$$ Compliant

ASTM C330 Aggregate Ratio Check:

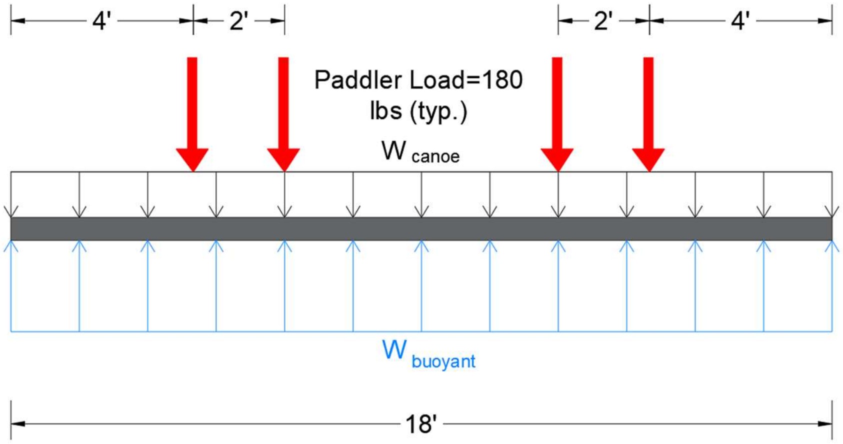
$$V_{ASTM\ C330}\ (\%) = \frac{Volume_{ASTM\ C330\ Aggregate}(ft^3)}{Volume_{Total\ Aggregate}(ft^3)} * 100\%$$

$$\text{Aggregate Ratio (\%)} = \frac{7.96\,ft^3}{20.27\,ft^3} * 100\% = 39.27\% > 25\% \therefore$$ Compliant

Appendix C – Example Structural Calculations

Known Values:

The 4-Person racing scenario is considered for the sample 2D structural calculations which include two male and two female paddlers represented as 180lb point loads along *VolCanoe's* length of 18ft. Other values included into the analysis are shown under "Properties" to the right below.



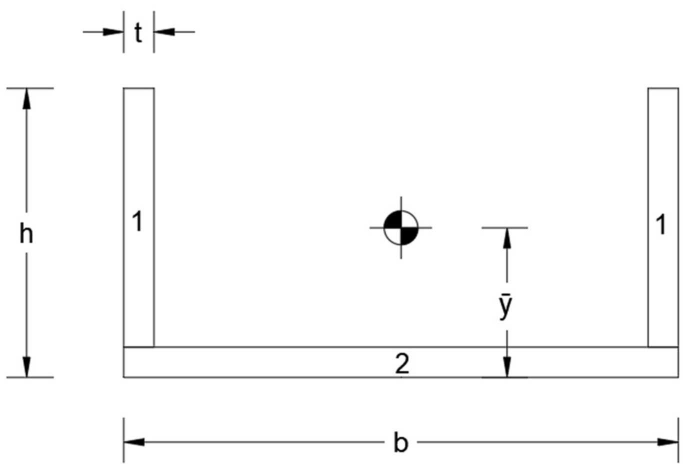
Properties:

- *VolCanoe* length = 18 ft
- *VolCanoe* density = 59 pcf
- *VolCanoe* weight = 300 lbs
- *VolCanoe* thickness = 5/8 in

Assumptions:

1. *VolCanoe* is simplified into a beam.
2. The self-weight and the buoyant force of *VolCanoe* is represented as a uniformly distributed load.
3. Mesh reinforcement is neglected.
4. Cross-section is simplified to a "U-shape" comprised of three rectangles.

Centroid Calculation:



$$\bar{y} = \frac{\Sigma y_i A_i}{\Sigma A_i} = \frac{2(y_1 b_1 h_1) + (y_2 b_2 h_2)}{(b_1 h_1) + (b_2 h_2)} = \frac{2(8.375in)(0.75in)(15.25in) + (0.375in)(33in)(0.75in)}{2(0.75in)(15.25in) + (33in)(0.75in)}$$

ȳ = 4.22 in

Moment of Inertia Calculations:

$I_{xi} = \frac{b_i h_i^3}{12} = 2\left[\frac{b_1 h_1^3}{12}\right] = 2\left[\frac{(0.75in)(15.25i\ ^3)}{12}\right]$ **I_{x1} = 443.32 in^4**

$I_{xi} = \frac{b_i h_i^3}{12} = \frac{b_2 h_2^3}{12} = \frac{(33in)(0.75in^3)}{12}$ **I_{x2} = 1.16 in^4**

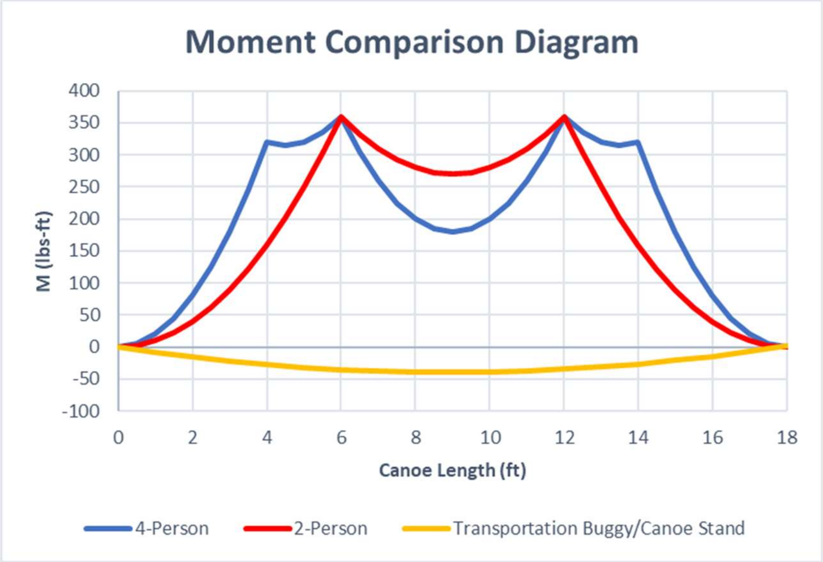
$I_x = I_{x1} + I_{x2} = 443.32in^4 + 1.16in^4$ **I_x = 444.48 in^4**

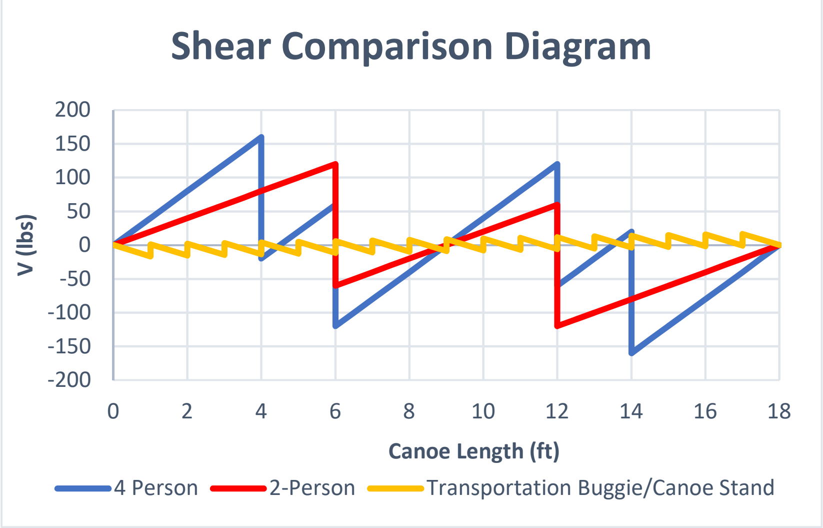
$$I_{xx} = I_x + \Sigma \bar{y}_i^2 A_i = I_x + \left[2\left(\bar{y}_1^2 b_1 h_1\right) + \left(\bar{y}_2^2 b_2 h_2\right)\right]$$
$$= 444.48in + [2(4.155in^2)(0.7in)(15.25in) + (-3.845in^2)(33in)(0.75in)]$$

I_{xx} = 1178.97 in^4

Calculating Moment Equations:

An example of the moment scenario is shown with the 4-Person race below.





Calculating Compressive and Tensile Stresses:

The maximum moment used for the calculation occurs during the 4-Perosn race scenario.
M_{max} = 360 lb-ft = 4320 lb-in

$$y_t = h - \bar{y}$$

$$\sigma_t = \frac{M_{max} y_t}{I_{xx}}$$

$$\sigma_t = \frac{(4320lb - in)(16in - 5.50in)}{1178.97in^4}$$

σ_t = - 38.47 psi

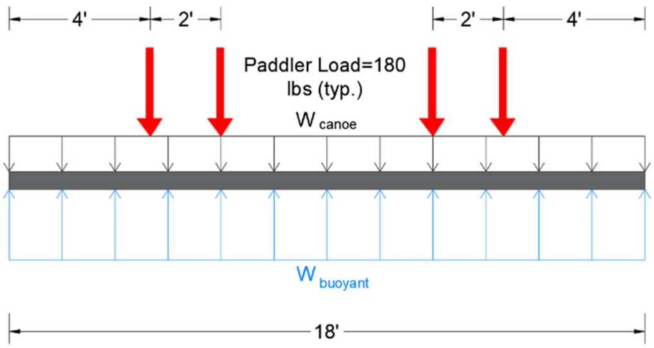
$$y_b = \bar{y}$$

$$\sigma_b = \frac{M_{max} y_b}{I_{xx}}$$

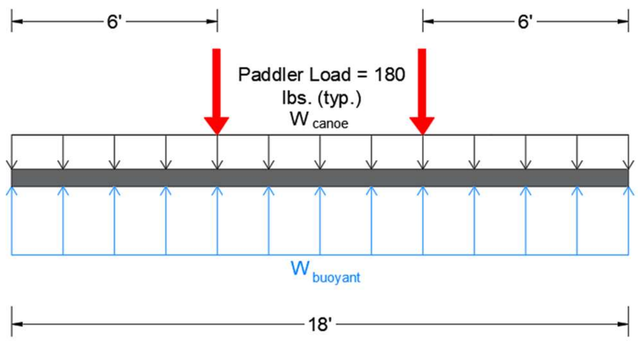
$$\sigma_b = \frac{(4320lb - in)(5.50in)}{1178.97in^4}$$

σ_b = 20.15 psi

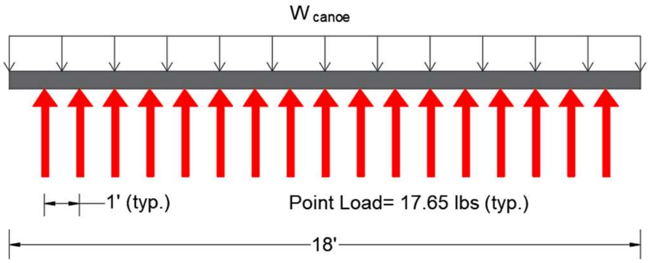
All Loading Scenarios:



4-Person Races



2-Person Races



Transportation/Canoe Stand

Summary of Structural Analysis:

Table 4: Structural Analysis Results

Loading Case	2-Person Race	4-Person Race	Transportation/ Canoe Stand
Maximum Moment	4,320 lb-in	4,320 lb-in	472 lb-in
Compressive Stress	38.5 psi	38.5 psi	4.2 psi
Tensile Stress	20.2 psi	20.2 psi	2.2 psi

Percent Open Area Calculations:

t_1= 5.6mm

t_2= 5.6mm

d_1= 24.9+ $2 * \frac{t_1}{2}$ = **24.9+ 2** $* \frac{\mathbf{5.6}}{\mathbf{2}}$ **= 30.1mm**

d_2 = 26.7 + $2 * \frac{t_2}{2}$ **= 26.7 + 2** $* \frac{\mathbf{3.9}}{\mathbf{2}}$ **= 30.6mm**

n_1= 6

n_2= 6

$Area_{open1}$= 25mm^2

$\boldsymbol{Area_{open}} = n_1 * n_2 * Area_{open1}$ = 6*6*25mm^2 **= 22500mm^2**

$\boldsymbol{Area_{total}} = Length_{sample} * Width_{sample}$ = 180.6mm*183.6mm = **33158.16mm^2**

$\boldsymbol{POA} = \frac{Area_{open}}{Area_{total}}$*100% = $\frac{22500}{33158.16}$*100% = **67.9%**

Thickness Calculations:

The wall thickness is 0.75”. Each layer of reinforcement is 0.04” thick. There are two layers of reinforcement in the canoe. So, $\mathbf{0.08"}/_{\mathbf{0.75}} * \mathbf{100\%} = \mathbf{10.67\%}$ of the hull thickness is reinforcement.