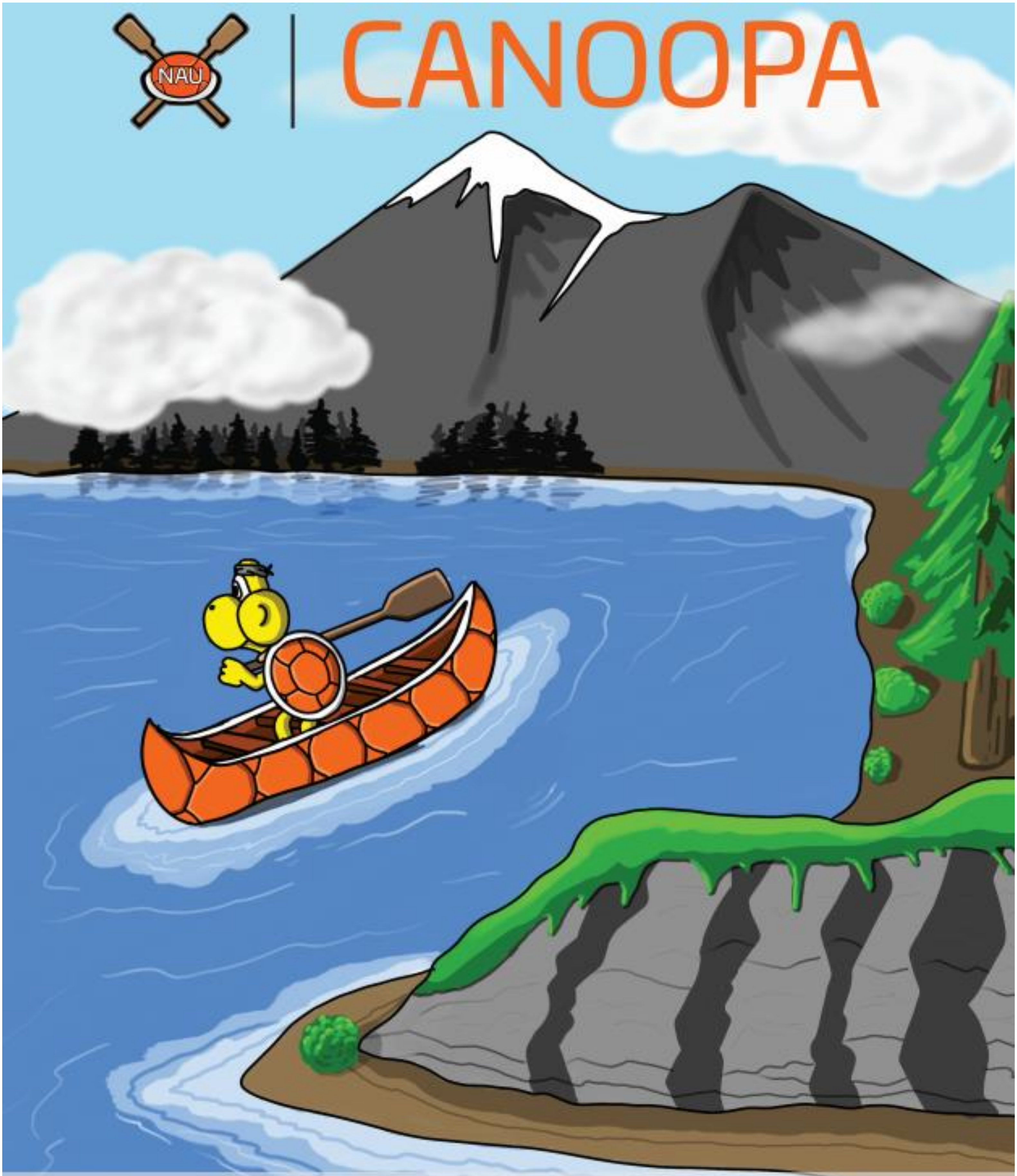
CANOOPA



Northern Arizona University

Concrete Canoe Design Report 2018

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EXECUTIVE SUMMARY

There is no better feeling than successfully finishing a competition and winning first place. There are hundreds of ways for this to occur and one of these is through the act of playing video games. Since the early 1970s, video games have been a growing form of entertainment. Genres vary from fun and sporty to strategic and competitive. One particular game that combines all four is Mario Kart. Northern Arizona University (NAU) selected Mario Kart as their theme for the 2018 concrete canoe, branding it as *Canoopa*. Mario Kart incorporates the idea of having fun while striving to be the best, as will the *Canoopa* team. The famously known video game contains diverse tracks players' race on. NAU students experience a similar terrain when hiking the beautiful trails around Northern Arizona. *Canoopa* was inspired by Mario Kart's "Koopa Troopa". The "Koopa Troopa" is known for being competitive through defending himself with his turtle shell. *Canoopa's* design incorporated the turtle shell to portray this character's spirit for NAU's concrete canoe team at the Pacific Southwest Competition (PSWC) in Tempe, Arizona.

Table 1: Canoopa Properties

Hull Dimensions	
Maximum Length	258 in
Maximum Width	26 in
Maximum Depth	15 in
Average Thickness	1.25 in
Estimated Weight	300 lb
Reinforcement	
Primary	SpiderLath Fiberglass
	Steel Post-Tensioning Cable
Secondary	MasterFiber M 100
Color	
BASF MasterColor	Light Red
	Yellow

NAU, founded in 1899, is located in Flagstaff, Arizona. The university started with the primary focus on education majors, but has grown significantly since with currently 90 areas of study including Civil and Environmental Engineering. NAU adopted the American Society of Civil Engineers (ASCE) as a student affiliated organization to allow students interested in Civil and Environmental Engineering to gain insight on the profession. The NAU ASCE chapter has been competing in PSWC since 1977. Last year's canoe, *Paddlegonia*, placed 8th overall, *Polaris* of 2016 placed 6th, and in 2015, *Dreadnoughtus* placed 3rd.

The structural design and mold used for *Canoopa* differed in design from previous years'. The 2018 concrete canoe design incorporated a tumblehome shape. A tumblehome shape is where the canoe's max width is in the middle of its walls. This design was used to improve the balance and race-ability of the canoe. The final properties of *Canoopa* are displayed in Table 1. *Paddlegonia's* mix tables served as a starting point for *Canoopa's* mix design. The *Canoopa* team's main goal was to create a lightweight mix with an equal percentage of Class C Fly Ash and cement. By using an equal percentage of Class C Fly Ash and cement, the *Canoopa* team reduced the overall weight of the canoe. *Paddlegonia* used a ratio of 70/30 of cement and Class F Fly Ash. Class C Fly Ash was incorporated into the mix design for *Canoopa* to improve the cementitious properties. The next important aspect to the final product was to incorporate aesthetics into the mix design. *Canoopa* members used White Portland cement instead of Gray Portland cement in their mix design to improve the color quality. The White Portland cement helped create a vibrant orange color for the finishing mix and a white color for the structural mix 1. The final mix properties for the *Canoopa* canoe are displayed in Table 2.

Table 2: Canoopa Concrete Properties

Finishing Mix	
Wet Unit Weight	65.85 lb/ft^3
Oven-Dry Unit Weight	59.15 lb/ft^3
28-Day Compressive Strength	1900 psi
28-Day Tensile Strength	350 psi
28-Day Flexural Strength	915 psi
Concrete Air Content	11.30%
Structural Mix #1	
Wet Unit Weight	68.37 lb/ft^3
Oven-Dry Unit Weight	61.34 lb/ft^3
28-Day Compressive Strength	1600 psi
28-Day Tensile Strength	375 psi
28-Day Flexural Strength	835 psi
Concrete Air Content	9.92%
Structural Mix #2	
Wet Unit Weight	65.01 lb/ft^3
Oven-Dry Unit Weight	56.12 lb/ft^3
28-Day Compressive Strength	1100
28-Day Tensile Strength	315
28-Day Flexural Strength	780 psi
Concrete Air Content	12.39%

PROJECT AND QUALITY MANAGEMENT

The project management for *Canoopa* began by meeting with *Paddlegonia*'s team at Northern Arizona University. *Paddlegonia* teammates advised the *Canoopa* members based on their experience with the canoe in 2017. This knowledge aided *Canoopa* members in the establishment of the milestone activities shown in Table 3. These milestones were achieved through effective communication, planning, and execution. The preliminary schedule associated with the milestones depicted in Table 3 varied from the actual schedule due to reasoning provided in the right hand column of the table. The scope of project was completed through continuous communication amongst the team. All decisions regarding the design of *Canoopa* were determined unanimously ensuring all members' opinions were addressed and noted. The simplified critical path for *Canoopa* is outlined in Figure 1. This path was determined based on the tasks required to meet the project milestones. The breakdown of person hours associated with these major tasks is displayed in Figure 2.

Table 3:Project Milestones

Milestone	Schedule Variance	Reason
ASCE NCCC Rule Review	None	Not Applicable
Mix Design	58 days	Compression machine broke
Reinforcement Selection	28 days	The mix was not complete on time
Structural Analysis	85 days	Delay of funding for software
Canoe Construction Day	None	Not Applicable
Canoe Finishing	None	Not Applicable
Attend ASCE PSWC	None	Not Applicable

The continuity meeting with *Paddlegonia's* captains established contacts for material donations from Badische Anilin und Soda Fabrik (BASF), CEMEX, Salt River Materials, and Trinity lightweight. Table 4 contains the monetary values of the material donated from these companies. This material was used for the design, testing, and construction of *Canoopa*. Other materials required for *Canoopa* were purchased through monetary donations obtained through GoFundMe. The monetary value of purchased materials are displayed in Table 5. The material procurement was impacted by Flagstaff's limited access to commercially available material. Material was transported to Flagstaff through means of shipping from companies located in Phoenix. *Canoopa* team members also traveled down to Phoenix for collection. *Canoopa* used local companies whenever possible to reduce the environmental impact associated with the canoe by minimizing resources used for transportation. Using local companies helped sustain the economy in Flagstaff as well. Companies who donated materials are advertised using team t-shirts to assist promotion of their firms.

The quality assurance/quality control (QA/QC) began with the team reviewing the 2018 National Concrete Canoe Competition (NCCC) rules and regulations. This review allowed all members to understand the requirements for compliance of materials, testing methods, documentation, and construction. The QA/QC review assisted with material procurement to ensure the properties of the canoe met the American Standard Testing Materials (ASTM) standards. Documentation of design trials pertaining to each component of the canoe was essential for compliance review against NCCC rules. Calculations for the design of *Canoopa* were reviewed by each member of the team to verify accuracy. *Canoopa* teammates invited their mentees to meetings involved in the design and construction of the canoe. This incorporation encouraged interest in the concrete canoe at NAU. NAU ASCE benefits from this program as it establishes social growth. All members and volunteers for *Canoopa* were required to obtain field safety training and lab safety training certifications through NAU. The material testing associated with the mix design, reinforcement design, and construction of the canoe was conducted according to the Occupational Safety and Health Administration (OSHA) training standards referenced in the field and lab safety trainings. These trainings were followed throughout the testing and construction of *Canoopa*. Risk management for *Canoopa* included increasing average canoe wall thickness to incorporate a post-tensioning reinforcement system. The increased wall thickness raised the overall weight of the canoe, however these negative effects were offset by the increased compressive strength.

PROJECT AND QUALITY MANAGEMENT

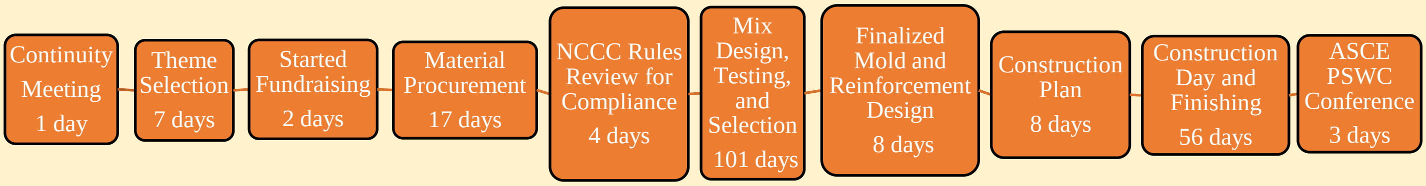


Figure 1: Simplified Critical Path

Note: The network displayed in this figure represents the simplified version of the tasks and durations of the tasks required to complete this project.

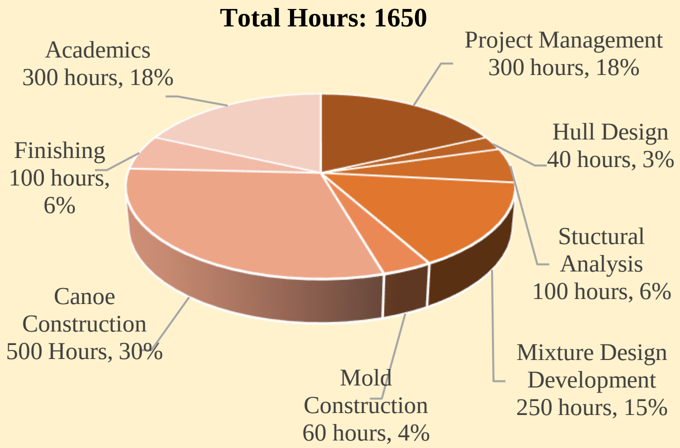


Figure 2: Person Hour Breakdown

Note: These values are approximated.

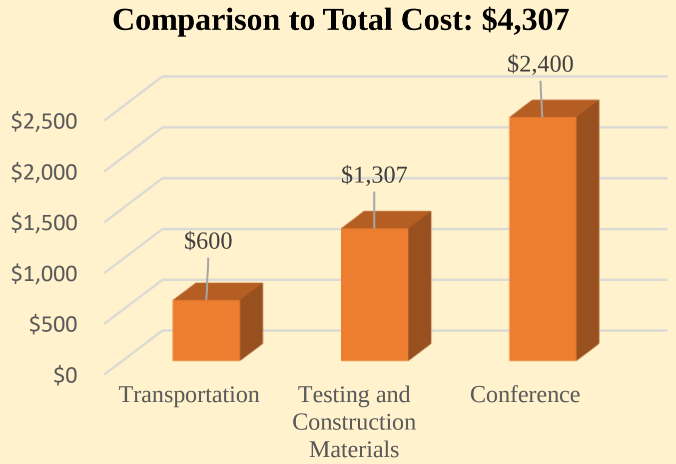


Figure 3: Overall Budget Allocation

Note: This is an estimated budget including the fees for 10 registered participants. The transportation costs included van rental and gas for conference and material procurement.

Table 5: Monetary Value of Donated Material

Material	Unit Cost	Total Cost	Distributor
Gray Portland Cement Type I	$0.05/lb	$10.00	CEMEX
Fly Ash, Class C	$0.02/lb	$4.00	Salt River Materials
Fly Ash, Class F	$0.02/lb	$4.00	CEMEX
Trinity Lightweight #1 Sand	$0.05/lb	$7.50	Trinity Lightweight
MasterSet Delvo	$1.39/lb	$6.95	BASF
MasterGlenium 7500	$1.78/lb	$8.90	BASF
MasterLife SRA 20	$4.31/lb	$4.31	BASF
MasterColor	$6.00/lb	$66.00	BASF
MasterFiber M100 Microfibers	$8.15/lb	$16.30	BASF
Natural Blended Pozzolan	$0.02/lb	$4.00	Salt River Materials
Total Value of Donated Materials			**$131.96**

Table 4: Monetary Value of Purchased Materials

Material	Unit Cost	Total Cost	Distributor
Arizona Seal	$0.75/gallon	$50	WR Meadows Sealtight
Bolts, Crimps, and Screws	Varies	$20.00	Home Depot
Poraver 0.1-0.3 mm	$1/lb	$147.00	North American Composites
Poraver 0.25-0.5 mm	$1/lb	$114.00	North American Composites
Poraver 0.5-1 mm	$1/lb	$66.00	North American Composites
Poraver 1-2 mm	$1/lb	$54.00	North American Composites
SpiderLath Fiberglass Mesh	$0.77/ft^2	$75.00	SpiderLath
Styrofoam for Mold	$28/sheet	$280.00	Sterling Steel & Foam
Turnbuckle	$2.56/each	$2.56	Home Depot
Wood for the Curing Chamber	$1.98/board	$19.80	Home Depot
White Portland Cement Type I	$50/bag	$100.00	Lehigh White Cement
Vinyl Lettering	$5.63	$180.00	Custom Vinyl Lettering
1/16" Galvanized Steel Cable	$0.26/ft	$40.00	Home Depot
1/8" Nylon Tubing	$9/50 ft	$27.00	Grainger
Total Value for Purchased Materials			**$1,175**

ORGANIZATION CHART

Team Captain

Branden Peterson (Senior)
Mix Design Lead

Designed and tested concrete mixes, refined mix design based on testing, assisted in reinforcement design and construction plan.

Team Captain

Joshua Leon (Senior)
Reinforcement Lead

Designed and tested reinforcement plan, paddling captain, assisted in the mix design and construction plan.

Katlynn Adams (Senior)
Project Manager

Lead team scheduling, material procurement, graphic design, finances and fundraising. Assisted in other tasks as needed.

Gina Boschetto (Senior)
Quality Assurance/Control

Developed and executed QA/QC strategies, ensured all deliverables met 2018 NCCC rules and regulations, head editor.

Zach Radovich (Senior)
Structural Lead

Designed and drafted tumblehome canoe mold, conducted structural calculations, drafted the construction drawing.

Mentees	
Russell Collins (Fr.)	Kylie Dykstra (Jr.)
Marie Cook (Fr.)	Ally Marnocha (Jr.)
Sam Cole (So.)	Cyrus Withers (Jr)
Conrad Senior (So.)	Darren Mack (Jr.)
Logan Grijalva (So.)	Virg Bareng (Jr.)

Paddlers	
Females:	**Males:**
Marie Cook	Virg Bareng
Kylie Dykstra	Logan Grijalva
Paxson Lowther	Joshua Leon
Ally Marnocha	Branden Peterson

In previous years, the NAU concrete canoe designs have focused on speed and tracking of the canoe resulting in a decrease in stability and paddling efficiency. This was a problem for NAU's 2017 canoe. *Paddlegonia* was also heavy, adding to the difficulties of paddling. These issues were confirmed by complaints from the paddlers that *Paddlegonia* felt unstable, causing the paddlers to be less efficient. This resulted in the canoe being unable to achieve its goals. These issues influenced the 2018 NAU concrete canoe team to take a new design approach from previous years for *Canoopa*.

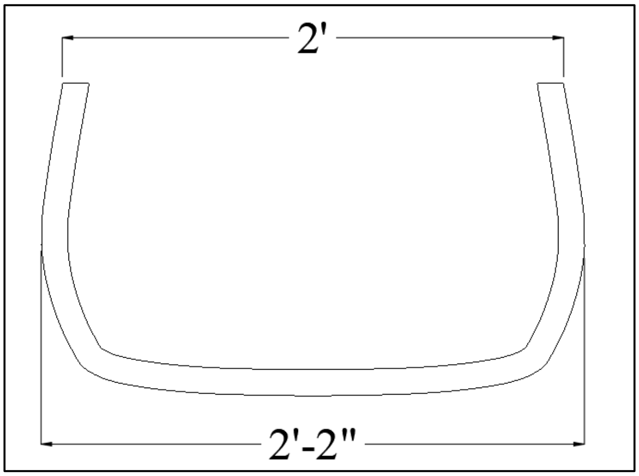


Figure 4: Tumblehome Cross Section

The primary design goal for *Canoopa* was to design a canoe that balanced speed and stability instead of maximizing one over the other. Research conducted helped find design characteristics that would fit these criteria. This research included reading the hull design section of design reports from previous years. The dimensions of the canoe were selected to comply with the 2018 NCCC Rules and Regulations while integrating similar properties of previous years' canoes.

The final shape chosen for *Canoopa* incorporates a tumblehome design. The tumblehome design was determined to have the desired shape with the widest section of the canoe located at the waterline instead of at the gunwale. This shape makes *Canoopa* easier to paddle than other canoes since the paddlers do not have to reach as far; this also will allow them to generate more force with each stroke. *Canoopa* utilized a moderate tumblehome with a maximum gunwale width of 24 in. and a maximum canoe width of 26 in. These dimensions were determined to provide the paddling benefits of a tumblehome while also displacing more water than a more drastic design. An example cross-section of *Canoopa* that displays the tumblehome of the canoe are in Figure 4.

The canoe has a V-shape at the bow and stern and has a flat-bottom design in between. The flat-bottom in the middle of the canoe was chosen to increase the surface area at the bottom of the canoe making it more stable and increasing its flotation. While the increased surface area will create more drag on the canoe, the increased stability will allow the paddlers to make up for it in efficiency. The V-shaped bow and stern were designed to cut through the water to improve the canoes performance the races. A 3D rendering of the canoe can be seen in Figure 5. Due to *Canoopa's* three concrete mixes having dry unit weights of 59.15, 61.34, and 56.12 lbs/ft3 respectively, bulkheads were not necessary to ensure the flotation of the canoe. However, it was determined that the bow and stern bulkheads of 18 in. were necessary to provide a factor of safety for the canoe during the flotation test where the concrete will not be in optimal dry conditions.

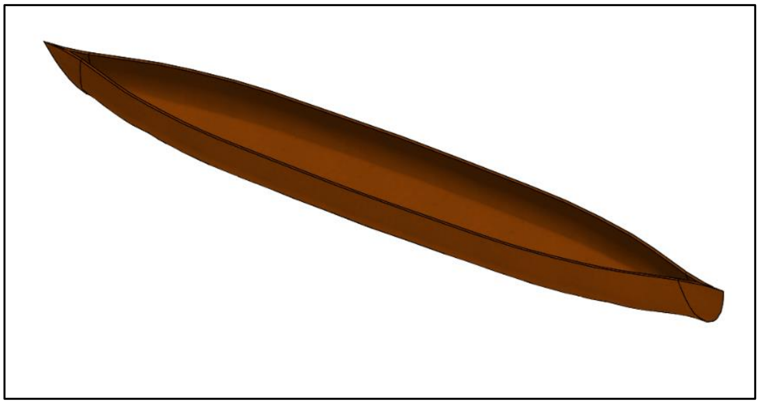


Figure 5: 3D Model of Mold

HULL DESIGN AND STRUCTURAL ANALYSIS

To model the canoe and complete the structural analysis, cross sections were created every 3 in. along the entire length of the canoe. The resulting 84 canoe cross sections were analyzed as parabolic shapes. The centroid and moment of inertia were determined for each cross section to calculate the longitudinal shear compression and tension stresses of the canoe.

The longitudinal shear and moment were calculated for three different loading conditions. These loading conditions were based on the 2-men, 2-women, and 4-person coed races that will take place during the competition. The loads used for this analysis were a 250 lb point load for a man, a 150 lb point load for a woman, a 9.53 lb/ft uniformly distributed load for the weight of the canoe and a uniformly distributed load for the water that changed based on the loading of the canoe. The loads for the men and women were based on the maximum weight of the paddlers and the weight of the canoe was approximated from the unit weight of the concrete mixes and the quantities in which each was used.

This resulted in a maximum shear of 156.98 lbs and a maximum moment of 343.75 ft-lb. A comparison of the shear and moments for each scenario were modeled in Microsoft Excel and the results were graphed and are illustrated in Figure 6. The shear diagram assisted in determining a maximum shear stress of 6.64 psi and the moment diagram helped determine a maximum compressive stress of 51.03 psi. and maximum tensile stress of 24.73 psi.

To prevent flexural failure and reduce cracking, six post-tensioning wires were placed about the geometric center of the canoe. It was determined that a maximum of 80 pounds of tension would be applied to each wired; based on the strength of the concrete, expected loads on the canoe, and the constructability of the post-tensioning system. Post-tensioning losses were taken into account including: curvature friction losses, anchorage losses, wobble losses, and elastic shortening. It was calculated that 35% of the post-tensioning was lost resulting in 52 pounds of tension in each wire.

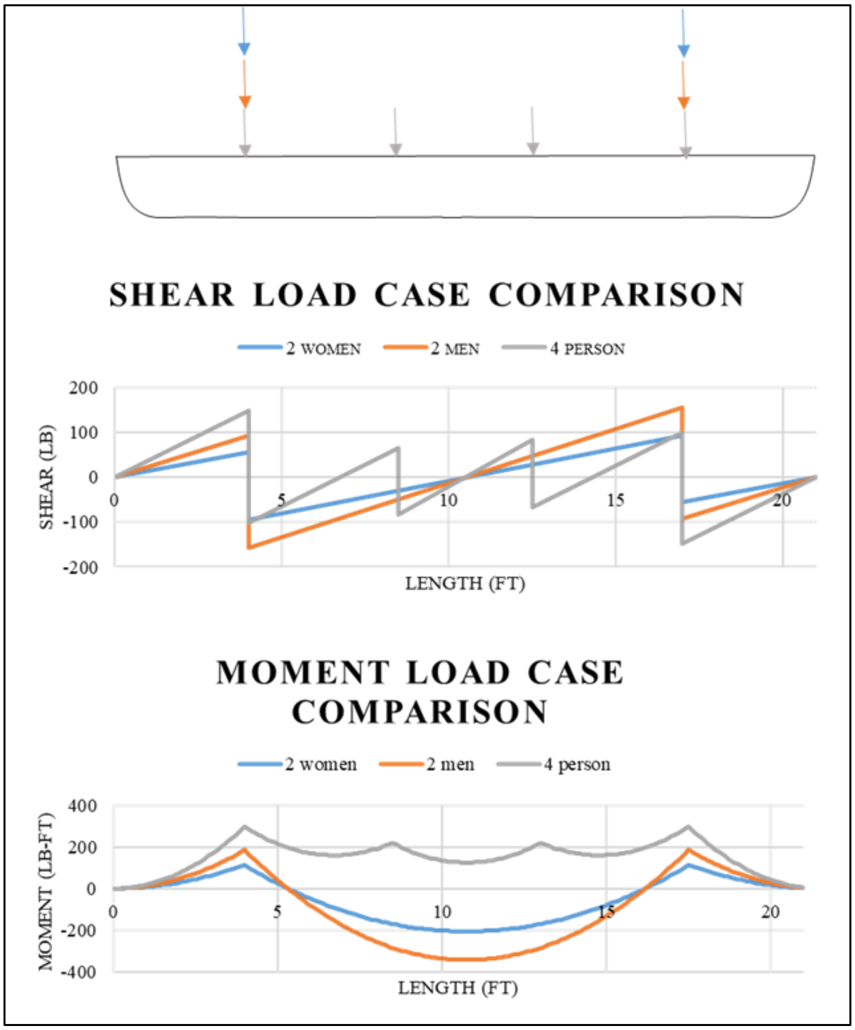


Figure 6: Shear and Moment Comparison

DEVELOPMENT AND TESTING

The primary goal of *Canoopa* was to focus on designing a lighter canoe. A baseline concrete mix was implemented using the same materials as *Paddlegonia,* but with a higher aggregate percentage. After testing had commenced, procurement of Class C Fly Ash was available through Salt River Materials Group. Once this material was obtained, it was implemented into the mix and produced more favorable results than the Class F Fly Ash. The cementitious properties of Class C Fly Ash allowed the mix to have a 50/50 cement to fly ash ratio compared to last year's canoe *Paddlegonia* of a 70/30 ratio. Class C Fly Ash has a smaller specific gravity than Class F Fly Ash; increasing its proportion in the mix design resulted in a lighter unit weight.

A secondary goal for the *Canoopa* team was to improve the aesthetics of the canoe in comparison to *Polaris* and *Paddlegonia*. This was done by incorporating a White Portland cement instead of Gray Portland to have better base for colored admixtures. Another material change to improve the coloring of *Canoopa* was changing the Class C Fly Ash that had a green tone to a white blended natural pozzolan; a mixture of Class F Fly Ash and Portland cement. This material was used in structural layer 1 to produce a white color on the inside of the canoe. Both the Class C Fly Ash and blended natural pozzolan were donated by Salt River Materials Group in Phoenix resulting in excellent choices for the budget, sustainability, and schedule.

Prior to the baseline mix design, research on different materials and previous successful canoe mix designs was performed to ensure that a quality mix was made to complete the mix design process on time. After each mix, testing was done for 7-day samples to determine if the desired compressive strength and unit weight were met (ASTM C19 and ASTM C138). If the 7-day samples met the desired properties then a tensile test and final compression test were completed at 14 and 28 days respectively. If not, the mix was modified to meet the desired properties. This year, a unit weight calculator was developed in Microsoft Excel to determine if a desirable wet unit weight for a concrete mix was expected within an error range of +/- 3%. This aided in refining the mix design. The lightweight aggregates in each mix varied in the proportions of Poraver sizes. These sizes included 0.1-0.3 mm, 0.25-0.5 mm, 0.5-1 mm, and 1-2 mm. The 1-2 mm grain size was not used in the finishing mix to allow for a smoother finish. The ASTM C330 compliant aggregate used in each mix design was Trinity #1 sand.

Another goal was to improve the quality control throughout the concrete mixing process to improve the ability to have repeatable results. All mixing was done by hand mixing in large tubs. Tubs were used instead of machine mixers since each batch resulted in approximately 0.25 ft^3. Small batches such as these would result in the loss of fine aggregate if a machine mixer was used as noted by previous teams. Using mixing tubs allowed the mix captain to verify that all the materials were being mixed properly. The mixing procedure included separating the aggregate and 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 mix. Free water is the water that is added to allow for the hydration process to commence. Admixtures such as set retarder and shrinkage reducer were also added at this stage of the mixing process. The cementitious materials were then mixed together and added into the mix with water added shortly after. For the colored mixes, a pigmented admixture was added at this point along with the rest of the additional water. At this point fibers were added to reduce the cracking and add durability to the concrete. Finally, water reducer was added since the manufacturer suggests adding it at the very end to produce the best results. This mixing procedure was found to work very well and produce concrete that was uniform with minimal clumps.

Aggregate proportion was an important detail of the mix so there were many different aggregate proportions that were considered and tested. At first 35% Trinity #1 sand and 50% of the larger Poraver aggregate size (.5-1 mm and 1-2 mm) by volume were used in terms of total aggregate used. This lead to a dry unit weight of 65-70 lb/ft3 and strengths around 2500 psi. While these were acceptable strengths, the larger unit weights were not desirable to achieve the primary goal of the mix design. To reduce the unit weight of the mix, it was determined the quantity of Trinity #1 should be reduced smaller grain sizes should be added to the mix. Since the smaller grain sizes of Poraver have higher specific gravities than the larger sizes, less cementitious material was used to keep the unit weight low since the cementitious material have a much larger specific gravity than the aggregates. After testing, it was identified that the wanted properties of the concrete had been reached. The dry unit weights were 55-60 lb/ft^3 while the strengths were between 1500 psi and 2000 psi. The properties of the aggregate are shown below in Table 6.

Table 6: Aggregate Proportions

Aggregate Name	Specific Gravity	Absorption (%)	Particle Size (mm)
Trinity #1 Sand	1.74	24	2.36-4.5
Poraver (0.1-0.3)	0.95	35	0.1-0.3
Poraver (0.25-0.5)	0.7	21	0.25-0.5
Poraver (0.5-1)	0.5	18	0.5-1
Poraver (1-2)	0.4	19	1.0-2.0

Three final mixes were chosen after testing 30 different mix designs for compressive strength, tensile strength, and slump. These mixes were comprised of White Portland cement, Class C Fly Ash/natural blended pozzolan, Trinity #1 sand, Poraver aggregates, coloring admixture, water reducer, shrinkage reducer, and set retarder was selected. The Finishing Mix is composed of 12% cementitious material, 59% aggregate, 18% water, and 11% air. Structural Mix #1 contains 13% cementitious material, 57% cementitious material, 20% water, and 10% air. Structural Mix #2 is comprised of 13% cementitious material, 59% aggregate, 18% water, and 11% air. In every mix approximately 25% of the aggregate by volume was ASTM C330 compliant from the Trinity #1 sand. The remaining volume of each mix was comprised of the solids provided from the admixtures as well as fibers. While the mixes had similar proportions of material, the biggest differences between them was the proportion of the different sizes of Poraver as well as the usage of either Class C Fly Ash or the natural blended pozzolan. The finishing mix incorporated Class C Fly Ash with a larger percentage of smaller sized Poraver, which lead to a higher compressive strength since the smaller aggregate sizes have greater compressive strengths. Structural Mix #1 utilized the natural blended pozzolan which lead to a greater strength than the Structural Mix #2 that contained Class C Fly Ash due to the fact that the natural blended pozzolan has better binding properties than the Class C Fly Ash.

The main purpose of the admixtures was to help improve the workability of the concrete for when the canoe was casted. The water reducer was used to create a drier mix with a low slump (ASTM C143) to allow for easier placing onto a canoe with a tumblehome shape. It was realized that when earlier mixes were placed they was tough to trowel and smooth out. More water reducer was added to the mix to allow for better workability without making the concrete weaker by adding water. Shrinkage reducer was used to prevent shrinkage cracks from appearing on the canoe since when concrete dries the cement shrinks which causes cracks and reduces the durability and strength of the concrete. Set retarder was used to allow the team more time to place the concrete on pour day in case there were problems with placing and there would be time delays. *Paddlegonia* also used air entrainer in their mix, but the team decided against that this year since the concrete already had low unit weights and the team also did not want to lose any more strength. *Canoopa's* weakest mix resulted in a compressive strength of 1100 psi, a tensile strength of 315 psi (ASTM C496), and a flexural strength of 785 psi

(ASTM C78). These strengths all exceed the structural analysis requirements of 38.91 psi, 23.11 psi and 38.91 psi, respectively.

The primary goal for reinforcement is to increase concrete strength, reduce major fractures, and save on construction costs. The primary reinforcement used in *Paddlegonia* influenced the reinforcement for *Canoopa,* due to prior results in percent open area, tensile strength, and minimal cost. SpiderLath Fiberglass Lath System provided a high tensile strength and large percent open area (POA), which are primary considerations for finalizing the reinforcement design. To improve cost efficiency leftover mesh from *Paddlegonia* was used alongside new mesh. To ensure that the properties of the two meshes were similar, the POA and tensile strength of both were tested.

The POA from the mesh for *Paddlegonia* was calculated to be 63.24%, the POA of the new supply of mesh was calculated at 62.98%; a 0.26% difference between the two. The tensile strength of the mesh was tested by measuring three strands from last year's mesh and three strands of the purchased mesh for six strands tested. The tensile strength of a single strand of mesh was tested by attaching a five-gallon bucket to the strand and connecting the dead end of the strand to a stationary piece of lumber elevated 4 ft off the ground. The bucket was gradually filled with water until failure, and the remaining water was measured to determine the force applied to the strand at failure. The average tensile strength from the previous material was 28.65 lb and the new material was 27.79 lb: a 0.86 lb difference. Based on the minimal differences in POA and tensile strength, it was determined that both the new and old mesh could be used.

To test the bonding between the concrete mix and mesh, three 4 in. x 12 in. x 0.5 in. sample beams were created. These were made to determine the required overlap for two sections of mesh with 2, 4, and 6 in. overlaps for each of the sample beams. After 14 days of curing, an instantaneous force was applied at the center of the beam. Upon failure, the beams were analyzed to determine the adequacy of the binding and how well the overlap held the sample together. Each sample bonded with the concrete. The three overlap lengths all kept the beam together; however, it was decided that the 6 in. overlap would be used to increase the factor of safety.

The final reinforcement design was comprised of 11, 2 ft x 4 ft segments of mesh along the span of the canoe with 6 in. of overlap between segments. This mesh was placed in between the two structural layers of concrete. A 5 in. x 2 ft, long strip of mesh was placed along the keel after the second structural concrete layer to add additional reinforcement. This was to aid the distribution of the loading along the hull, where the majority of loading will occur.

Post-tensioned steel cables were utilized to add compressive strength to the canoe. Post-tensioning was selected over pre-tensioning based on its constructability and lower risk of canoe damage. The cables used in *Canoopa* were 1/16 in. diameter galvanized steel cables encased in a ⅛ in. clear nylon tubing. The tubing provided a protective boundary for the surrounding concrete while the cables were tensioned. The cables were placed in respect to the geometric center of the canoe; fours strands along the walls of the canoe and two along the bottom hull, for six cables. These cables were vertically spaced 6 to 7 in. to minimize bending moment forces that could potentially crack the walls and bottom corners of the hull. The canoe was cured for 14 days before the tensioning the cables. The cables were post-tensioned to 80 lbs by anchoring one end of the cable and connecting the other to a strain force gauge and a turnbuckle attached to a secure wooden mount.

CONSTRUCTION

The primary goal for the construction process was to create a mold that could be constructed quickly and efficiently. The mold was made with 8 ft x 4 ft x 3 in. foam sheets that were cut to the design shape of *Canoopa* using a Computer Numerical Control (CNC) router. A total of eight sheets were used to obtain 84 cross-sections for the 21 ft tumblehome design. This method was more efficient than cutting the mold by hand and aided the construction process by keeping the canoe consistent with precise cross-section cuts. Each cross section was numbered and organized which reduced the construction time by two weeks and allowed the team to use less foam in comparison to *Paddlegonia*. A 2 in. x 2 in. steel rod was skewered through the center of 8 cross-section pieces, with 2 in. of steel protruding out of one end to connect to the rest of the mold to keep the cross-sections stable and in succession. Figure 7 displays the process of constructing the mold while Figure 8 shows the final mold. The foam configuration was then shrink wrapped to prevent the concrete from bonding to the foam mold.

Figure 7: Mold Assembly

After the mold was constructed, it was placed on a 3 in. x 24 in. wooden platform to prepare for pour day. This platform served as the work surface for the canoe construction. A plastic tarp was placed along the length the surface to prevent the concrete from the canoe from binding to it. To complete the preparation of the construction table, a detachable curing chamber was created using 22, 1.5 ft tall wooden planks. These planks were attached to the side of the construction table in sets of two with 11 horizontal planks connecting the pairs at the top. These planks supported the tarp that went over the curing chamber. Once the construction of the curing chamber was completed, it was removed from the construction table until the construction of the canoe was completed.

The NAU concrete canoe team batched and staged their materials a week prior to construction. Required batching volumes were determined based off the mix design proportions and their construction plan. Other steps taken for preparation included safety training for the members and the mentees. All participants were required to refresh their knowledge on safety training methods. Troweling was the selected method for application of the concrete on *Canoopa*. This method was chosen to create a smooth consistent surface and reduce material waste. The NAU concrete canoe team trained a week before their pour day to properly achieve placement methods.

Canoopa's pour day was on February 17th, 2018. Preparation started with team members ensuring all stations were cleaned and clear of possible safety hazards. Following that, the pre-batched materials were brought to the mixing station where members used tubs to hand mix the concrete. The concrete was applied immediately after preparation using the troweling method. Three layers were applied to the mold: the structural mix #1, the structural mix #2, and the third being the finishing mix.

Figure 8: Completed Mold

After the first layer of concrete was applied, reinforcement was placed onto the canoe. There were 11, 4 ft x 2 ft mesh reinforcement sheets used with an overlap of 6 in. per sheet. The second layer of concrete was applied over the mesh to secure it within the canoe. The next layer of the canoe contained six steel cables encased in plastic tubing aligned on both sides of the canoe. The steel cables used for the second layer of reinforcement were exposed at the bow and the stern to prepare for post-tensioning. Toothpicks were used to hold the wires in the desired position to ensure accuracy of placement. One layer of mesh was added to the keel of the canoe, spanning its full length with 11, 2 ft x 5 in. sheets of mesh. After proper placement of the cables and mesh, the finishing layer of concrete was applied to *Canoopa*.

Figure 9: Canoe Imprint

When the canoe was fully constructed, the curing chamber was reassembled. Humidifiers were placed at both ends of the chamber to ensure a proper 28 day cure. To maintain consistent curing conditions the humidifiers were refilled every 12 hours. Two weeks after the concrete was placed onto the mold, the cables were post-tensioned. Each cable was anchored into the concrete at one end and a force of 80 lbs was applied to the other. After the tensioning was completed, the finishing mix was used to cover the cables. At a 21 day cure, the canoe was flipped over and the Styrofoam mold was removed with a hot knife.

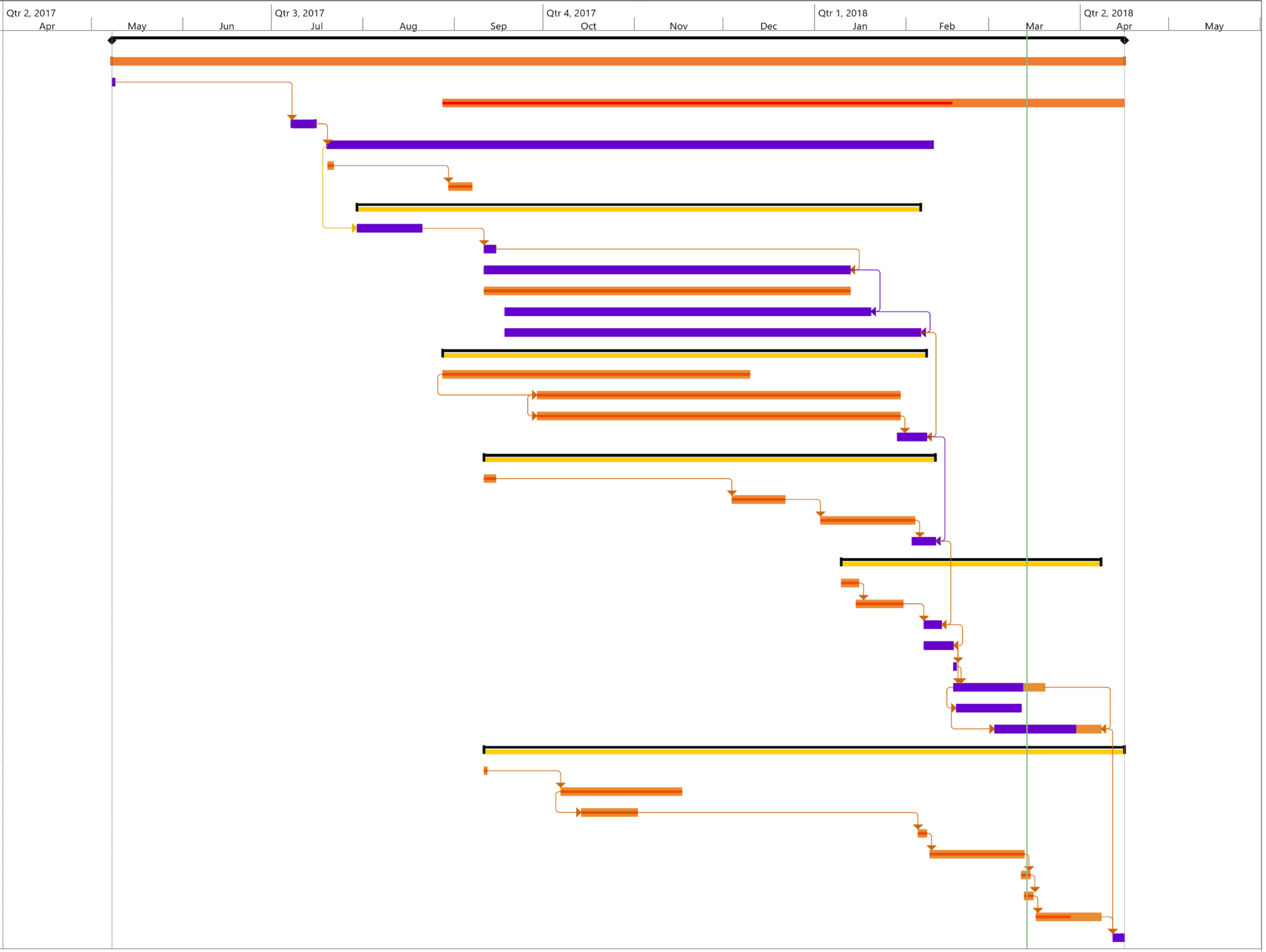
The construction process of the canoe required a method for QA/QC. This was implemented through the use of toothpicks labeled with 3 different measurements: 0.417 in., 0.833 in., and 1.25 in. These toothpicks assisted with ensuring the thickness of the concrete remained constant. All layers were designed to be 0.417 in. for a total thickness of 1.25 in. *Canoopa* was designed by NAU students to represent a turtle shell relating to their selected theme. Incorporating this design was completed by 3D printing a tool for imprinting as displayed in Figure 9. Team members used this tool after the finalized concrete layer was placed. Using this imprint created the turtle-like design as shown in Figure 10.

Figure 10: Canoe Aesthetics

When the curing for *Canoopa* was complete, the members met to finish their product by sanding, polishing, and sealing. Sanding blocks were used to provide consistent sanding over a large surface area and hand sanders were used to detail the turtle shell imprints. The canoe was then polished to create a smoother appearance. Once the polish dried, Arizona Seal was applied to the canoe. Lettering for the school name and canoe name were added to each side of the canoe. All applicants and letting used followed the 2018 NCCC Rules and Regulations and are commercially available

PROJECT SCHEDULE

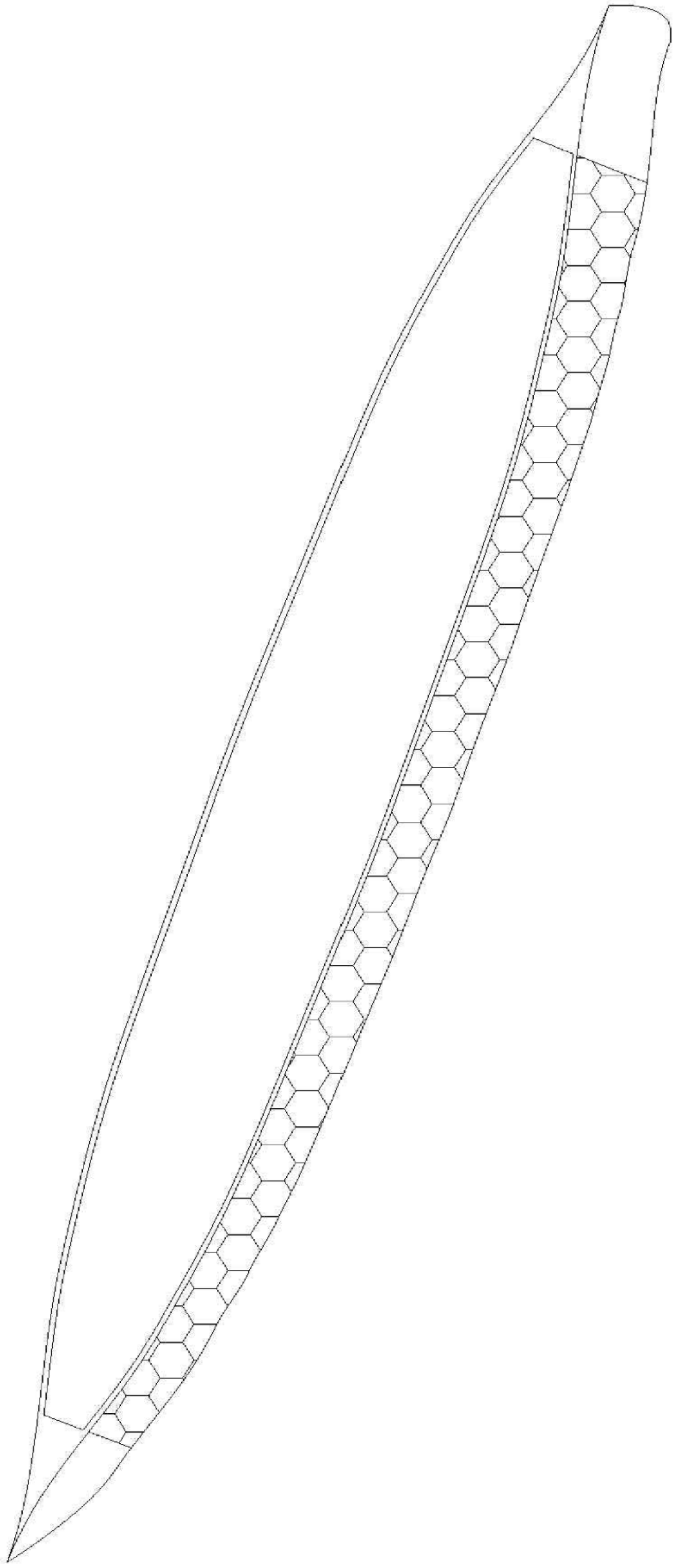
ID	ℹ	Task Mode	Task Name	Duration
1		⇨	**1.0 Project Management**	**245 days**
2		📌	1.1 Team Meetings	246 days
3	✓	📌	1.1.1 Continuity Meeting	1 day
4		📌	1.1.2 Weekly Team Meetings	166 days
5	✓	📌	1.2 Theme Selection	7 days
6	✓	📌	1.3 Fundraising	147 days
7	✓	📌	1.3.1 Set Up GoFundMe	2 days
8	✓	📌	1.4 Safety Training	6 days
9	✓	📌	**2.0 Mix Design**	**137 days**
10	✓	📌	2.1 Research and Material Procurement	17 days
11	✓	📌	2.2 Rule Review for Compliance	4 days
12	✓	⇨	2.3 Developing a Mix	90 days
13	✓	⇨	2.4 Incorporating Color into Mix	90 days
14	✓	⇨	2.5 Testing	90 days
15	✓	📌	2.6 Refining Mix	101 days
16	✓	📌	**3.0 Structural Analysis**	**118 days**
17	✓	📌	3.1 Research Shape Design	76 days
18	✓	📌	3.2 Create Hull Design	87 days
19	✓	📌	3.3 Determine Shape	87 days
20	✓	📌	3.4 Finalized Mold Design	8 days
21	✓	📌	**4.0 Reinforcement**	**111 days**
22	✓	📌	4.1 Rule Review for Compliance	4 days
23	✓	📌	4.2 Research and Material Procurement	14 days
24	✓	📌	4.3 Testing Materials	24 days
25	✓	📌	4.4 Reinforcement Selection	7 days
26		📌	**5.0 Construction**	**64 days**
27	✓	📌	5.1 Calculate Quantities for Pour Day	4 days
28	✓	📌	5.2 Material Procurement for Construction	12 days
29	✓	📌	5.3 Mold Construction	4 days
30	✓	📌	5.4 Construction Planning	8 days
31	✓	📌	5.5 Pour Day	1 day
32		📌	5.6 28 Day Cure	22 days
33	✓	📌	5.7 Construction Drawing	17 days
34		📌	5.8 Finishing	27 days
35		📌	**6.0 Competition**	**156 days**
36	✓	📌	6.1 Rules and Regulations Released	1 day
37	✓	📌	6.2 Preliminary Schedule	30 days
38	✓	⇨	6.3 Acknowledgement Form	13 days
39	✓	📌	6.4 Outline of Final Design Paper	3 days
40	✓	📌	6.5 Rough Draft for Review	22 days
41	✓	⇨	6.6 Final ASCE Design Paper	3 days
42	✓	📌	6.7 Technical Addendum	3 days
43		📌	6.8 Display for PSWC	17 days
44		📌	6.9 PSWC	3 days



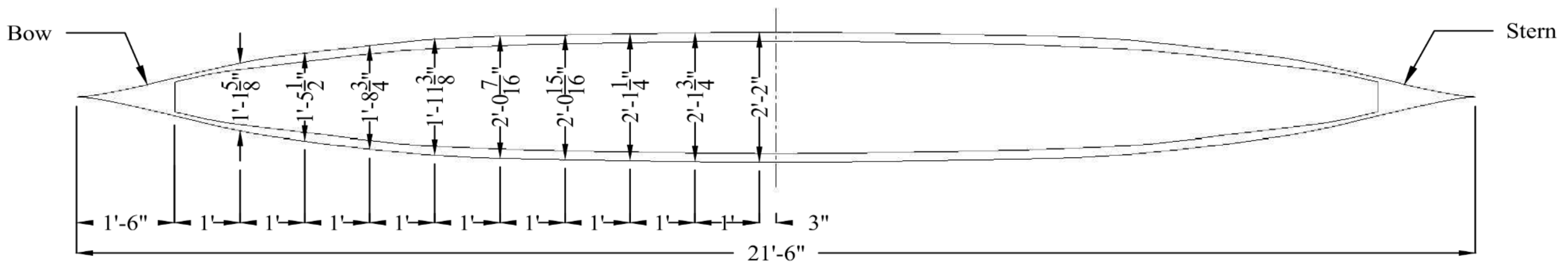
Project: Simple Project Plan
Date: Wed 3/14/18

Task	▬	Project Summary	▬	Manual Task	▬	Start-only	[	Deadline	⇩	Critical	▬
Split	┈	Inactive Task	▭	Duration-only	▬	Finish-only	]	Path Successor Milestone Task	◆	Critical Split	┈
Milestone	◆	Inactive Milestone	◇	Manual Summary Rollup	▬	External Tasks	▬	Path Successor Summary Task	▬	Progress	─
Summary	▬	Inactive Summary	▭	Manual Summary	▬	External Milestone	◆	Path Successor Normal Task	▬	Manual Progress	─

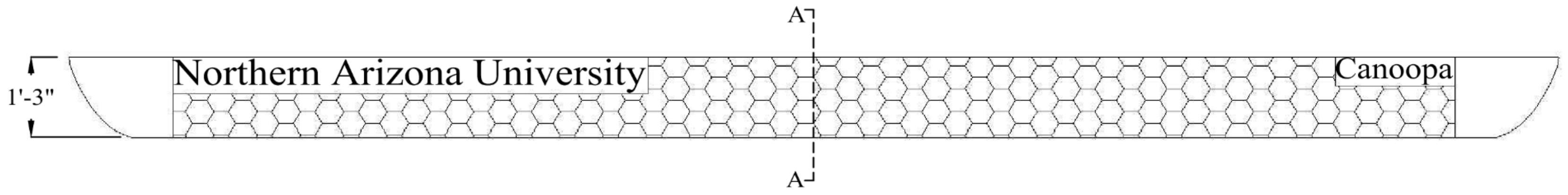
CONSTRUCTION DRAWING



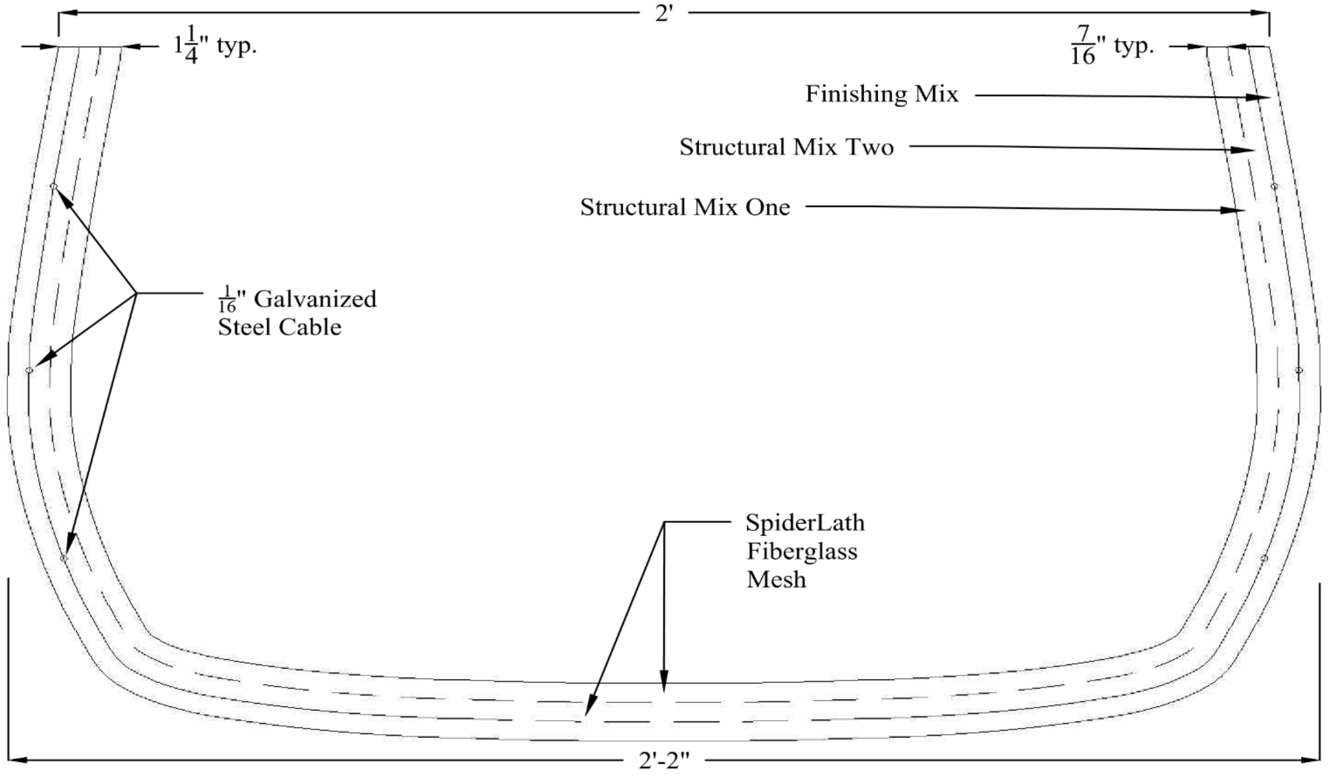
Isometric View
Scale: 1":20"



Plan View
Scale 1":30"



Elevation View
Scale 1":30"



Section A-A Cross-Section
Scale 1":4"

Bill of Materials:

Item No.	Item Description	Quantity	Unit
Concrete Constituents			
1	Lehigh White Portland Type 1 Cement	52.97	LB
2	Salt River Class C Fly Ash	33.63	LB
3	Salt River Blended Natural Pozzolan	22.32	LB
4	Trinity Lightweight Aggrigate #1 Sand	83.13	LB
5	Poraver .1-.3mm	34.33	LB
6	Poraver 0.25-0.5mm	28.48	LB
7	Poraver 0.5-1.0mm	21.04	LB
8	Poraver 1.0-2.0mm	9.77	LB
9	BASF MasterGlenium 7500	1.58	LB
10	Master Set Delvo	0.378	LB
11	Master Life SRA 20	0.306	LB
12	BASF MasterColor (Light Red and Yellow)	9.68	LB
Reinforcement/ Post Tensioning			
13	SpiderLath Fiberglass Mesh	85	FT^2
14	3/4" BASF MasterFiber M 100 Fibers	0.109	LB
15	1/16" Galvanized Steel Cable	102	LF
16	1/8" Parflex Nylon Tubing	102	LF
17	13/64" Zinc-plated Copper Button Stops	12	EA
18	1/8" x 1/8" x 1" Steel Bearing Plates	12	EA
Mold			
19	4' x 8' x3" R-Tech Foam Sheets	8	EA
20	Uline Plastic Shrink Wrap	100	FT^2
21	2"x2" Steal Rod	20	FT
Strongback			
22	Wooden Alignment	1	EA
23	Rotating Steel Plate	4	EA
24	1/2" Bolt	2	EA
25	3/8" Bolt	2	EA
26	Wood 2x4	120	LF
27	Wood 2x6	64	LF
Finishing			
28	Arizona Seal	2	GAL

Revised By:

Rev. No.	Date	Rev. Details

Canoopa

Address:
Engineering Bldg, 2112 S Huffer Ln,
Flagstaff, AZ 86011

Northern Arizona University

Concrete Canoe:
Construction Plan

Drawn By: ZNR
Date Drawn: 2/26/18
Reviewed By:
Date Reviewed:

Sheet:
1
Of: 1

APPENDIX A: REFERENCES

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APPENDIX B: MIXTURE PROPORTIONS

Mixture Designation: Structural Mix #1

Cementitious Materials

Component	**Specific Gravity**	**Volume (ft^3)**	**Amount of CM (mass/volume) (lb/yd^3)**	
Cement, Type 1 White Portland (ASTM C 150)	3.15	1.56	*309.9*	*Total Amount of cementitious materials ___619.8____ lb/yd^3 c/cm ratio ____.5___*
Natural Blended Pozzolan	2.85	1.74	309.9	

Fibers

Component	**Specific Gravity**	**Volume (ft^3)**	**Amount of Fibers (mass/volume) (lb/yd^3)**	
MasterFiber M 100	.91	.0096	.545	*Total Amount of Fibers ___.545__ lb/yd^3*

Aggregates

Aggregates	**ASTM C330***	**Abs (%)**	**SG_{OD}**	**SG_{SSD}**	**Base Quantity (lb/yd^3)**		**Volume (ft^3)**
					OD	**SSD**	
Trinity #1 Sand	Y	24	1.4	1.74	*338.96*	420.31	3.88
Poraver (.1-.3)	N	35	.704	.95	*119.49*	161.31	2.72
Poraver (.25-.5)	N	21	.58	.7	*133.55*	161.6	3.69
Poraver (.5-1)	N	18	.42	.5	*31.18*	36.79	1.19
Poraver (1-2)	N	19	.34	.4	*84.23*	100.23	3.97

Admixtures

Admixture	**lb/gal**	**Dosage (fl. oz / cwt)**	**% Solids**	**Amount of Water in Admixture (lb/yd^3)**	
Water Reducer	*9.9*	*17.31*	*26*	*6.15*	*Total Water from Admixtures, $\sum w_{admx}$ ___7.77___ lb/yd^3*
Shrinkage Reducer	*9.1*	*3.25*	*80*	*.286*	
Set Retarder	*7.6*	*4.19*	*14*	*1.33*	

Solids (Latex, Dyes and Powdered Admixtures Only)

Component	**Specific Gravity**	**Volume (ft^3)**	**Amount (mass/volume) (lb/yd^3)**	
N/A	*N/A*	*N/A*	*N/A*	*Total Solids from Admixtures ___N/A____ lb/yd^3*

Water

	Amount (mass/volume) (lb/yd^3)		**Volume (ft^3)**
Water, lb/yd^3		w: 347.11	*5.56*
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -164.21	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: *7.82*	
Batch Water, lb/yd^3		w_{batch}: 503.5	

Densities, Air Content, Ratios and Slump

	cm	**fibers**	**aggregates**	**solids**	**water**	**Total**
Mass of Concrete, M, (lb)	619.84	.545	880.24	3.58	347.11	*$\sum M$:1851.32*
Absolute Volume of Concrete, V, (ft^3)	3.3	.0096	15.45	.169	5.56	*$\sum V$:24.49*
Theoretical Density, T, *(=$\sum M$ / $\sum V$)*	*75.59 lb/ft^3*		**Air Content** *[= (T – D)/T x 100%]*			*9.55 %*
Measured Density, D	*68.37 lb/ft^3*		**Slump, Slump flow**			*1 in.*
water/cement ratio, w/c:	1.12		**water/cementitious material ratio, w/cm:**			.56

MIXTURE DESIGNATION: STRUCTURAL MIX #2

CEMENTITIOUS MATERIALS

Component	**Specific Gravity**	**Volume (ft^3)**	**Amount of CM (mass/volume) (lb/yd^3)**	
Cement, Type 1 White Portland (ASTM C 150)	3.15	1.21	*238.62*	*Total Amount of cementitious materials ____548.83___ lb/yd^3 c/cm ratio ___.43____*
Class C Fly Ash	2.21	2.24	*310.21*	

FIBERS

Component	**Specific Gravity**	**Volume (ft^3)**	**Amount of Fibers (mass/volume) (lb/yd^3)**	
MasterFiber M 100	.91	.009	*.52*	*Total Amount of Fibers ______.52_ lb/yd^3*

AGGREGATES

Aggregates	**ASTM C330***	**Abs (%)**	**SG$_{OD}$**	**SG$_{SSD}$**	**Base Quantity (lb/yd^3)**		**Volume (ft^3)**
					OD	**SSD**	
Trinity #1 Sand	Y	24	1.4	1.74	*347.69*	431.14	3.98
Poraver (.1-.3)	N	35	.704	.95	*132.67*	179.1	3.02
Poraver (.25-.5)	N	21	.58	.7	*118.71*	143.64	3.28
Poraver (.5-1)	N	18	.42	.5	*80.2*	94.64	3.06
Poraver (1-2)	N	19	.34	.4	*53.68*	63.88	2.53

ADMIXTURES

Admixture	**lb/gal**	**Dosage (fl. oz / cwt)**	**% Solids**	**Amount of Water in Admixture (lb/yd^3)**	
WATER REDUCER	*9.9*	*20.45*	*26*	*6.42*	*Total Water from Admixtures, $\sum w_{admx}$ ___8.11___ lb/yd^3*
SHRINKAGE REDUCER	*9.1*	*3.84*	*80*	*.3*	
Set Retarder	*7.6*	*4.95*	*14*	*1.39*	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES ONLY)

Component	**Specific Gravity**	**Volume (ft^3)**	**Amount (mass/volume) (lb/yd^3)**	
N/A	*N/A*	*N/A*	*N/A*	*N/A*

WATER

	Amount (mass/volume) (lb/yd^3)		**Volume (ft^3)**
Water, lb/yd^3		w: 295.05	*4.72*
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -170.57	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: 8.11	
Batch Water, lb/yd^3		w_{batch}: 457.51	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	**fibers**	**aggregates**	**solids**	**water**	**Total**
Mass of Concrete, M, (lb)	548.83	.52	912.4	3.39	295.05	*$\sum M$: 1760.19*
Absolute Volume of Concrete, V, (ft^3)	3.45	.009	15.87	.053	4.72	*$\sum V$: 24.1*
Theoretical Density, T, *$(=\sum M / \sum V)$*	*73.04 lb/ft^3*		**Air Content** *[= (T – D)/T x 100%]*			*10.99 %*
Measured Density, D	*65.01 lb/ft^3*		**Slump, Slump flow**			*1 in.*
water/cement ratio, w/c:	1.24		**water/cementitious material ratio, w/cm:**			.54

APPENDIX B: MIXTURE PROPORTIONS

MIXTURE DESIGNATION: FINISHING MIX

CEMENTITIOUS MATERIALS

Component	**Specific Gravity**	**Volume (ft^3)**	**Amount of CM (mass/volume) (lb/yd^3)**	
Cement, Type 1 White Portland (ASTM C150)	3.15	1.31	*257.34*	*Total Amount of cementitious materials* *_____**514.68**__ lb/yd^3* *c/cm ratio* *___**.5**____*
Class C Fly Ash	2.21	1.87	*257.34*	

FIBERS

Component	**Specific Gravity**	**Volume (ft^3)**	**Amount of Fibers (mass/volume) (lb/yd^3)**	
MasterFiber M 100	.91	.011	*.596*	*Total Amount of Fibers* *____.596__ lb/yd^3*

AGGREGATES

Aggregates	**ASTM C330***	**Abs (%)**	**SG$_{OD}$**	**SG$_{SSD}$**	**Base Quantity (lb/yd^3)**		**Volume (ft^3)**
					OD	**SSD**	
Trinity #1 Sand	Y	24	1.4	1.74	*351.19*	435.48	4.02
Poraver (.1-.3)	N	35	.704	.95	*140.57*	189.77	3.2
Poraver (.25-.5)	N	21	.58	.7	*112.2*	135.76	3.1
Poraver (.5-1)	N	18	.42	.5	*153.75*	181.43	5.73

ADMIXTURES

Admixture	**lb/gal**	**Dosage (fl. oz / cwt)**	**% Solids**	**Amount of Water in Admixture (lb/yd^3)**	
WATER REDUCER	*9.9*	*29.3*	*26*	*8.63*	*Total Water from Admixtures, $\sum w_{admx}$* *___**72.65**____ lb/yd^3*
SHRINKAGE REDUCER	*9.1*	*5.62*	*80*	*.41*	
Set Retarder	*7.6*	*7.26*	*14*	*1.91*	
MasterColor	*16.7*	*176.7*	*48*	*61.7*	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES ONLY)

Component	**Specific Gravity**	**Volume (ft^3)**	**Amount (mass/volume) (lb/yd^3)**	
N/A	*N/A*	*N/A*	*N/A*	*N/A*

WATER

	Amount (mass/volume) (lb/yd^3)		**Volume (ft^3)**
Water, lb/yd^3		*w*: 299.57	*4.8*
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -175.41	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: *72.65*	
Batch Water, lb/yd^3		w_{batch}: 402.33	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	**fibers**	**aggregates**	**solids**	**water**	**Total**
Mass of Concrete, M, (lb)	514.68	.596	942.44	61.58	299.57	*$\sum M$: 1818.87*
Absolute Volume of Concrete, V, (ft^3)	3.18	.011	16.05	.52	4.8	*$\sum V$: 24.56*
Theoretical Density, T, *(=$\sum M / \sum V$)*	*74.06 lb/ft^3*		**Air Content** *[= (T – D)/T x 100%]*			*11.08 %*
Measured Density, D	*65.85 lb/ft^3*		**Slump, Slump flow**			*1 in.*
water/cement ratio, w/c:	.921		**water/cementitious material ratio, w/cm:**			.461

APPENDIX B: MIXTURE PROPORTIONS

White Portland Cement Type 1: 309.92 lb, SG= 3.15

Natural Blended Pozzolan: 309.92 lb, SG= 2.85

MasterFiber M: .545 lb, SG=. 91

w/cm ratio: .56

Admixtures:

Water Reducer: 17.31 fl oz/cwt (26% solids by weight, 9.9 lb/gal)

Shrinkage Reducer: 3.25 fl oz/cwt (80% solids by weight, 9.1 lb/gal)

Set Retarder: 4.19 fl oz/cwt (14% solids bys weight, 7.6 lb/gal)

Measured Wet Unit Weight: 68.37 lb/ft^3

Mass of Cementitious Materials, Fibers, and Water

Mass$_{\text{White Portland Cement}}$= 309.92 lb

Mass$_{\text{Natural Blended Pozzolan}}$= 309.92 lb

Mass$_{\text{cm}}$= Mass$_{\text{White Portland Cement}}$ + Mass$_{\text{Natural Blended Pozzolan}}$= 619.84 lb

Mass$_{\text{MasterFiber M}}$= .545 lb

Mass$_{\text{water}}$= w/cm*Mass$_{\text{cm}}$

Mass$_{\text{water}}$= .56*619.84 lb= 347.11 lb

Volume of Cementitious Materials, Fibers, Solids, and Water

Absolute Volume= $\frac{Mass}{SG*62.4}$

Volume$_{\text{White Portland Cement}}$= 309.92/(3.15*62.4)= 1.56 ft^3

Volume$_{\text{Natural Blended Pozzolan}}$= 309.92/(2.85*62.4)= 1.74 ft^3

Volume$_{\text{cm}}$= Volume$_{\text{White Portland Cement}}$ + Volume$_{\text{Natural Blended Pozzolan}}$= 3.3 ft^3

Volume$_{\text{fibers}}$= .545/(.91*62.4)= .0096 ft^3

Volume$_{\text{water}}$= 347.11/(1*62.4)= 5.56 ft^3

Water from Admixtures

Water in admixture= dosage*cwt of cm*water content*(1 gal/128 fl oz)*(lb/gal of admixture)

From Water Reducer

[(17.31 fl oz/cwt)*(619.84 lb/yd^3/100)]*[(100%-26% solids)/100]*(1 gal/128 fl oz)*(9.1 lb/gal)= 6.15 lb

From Shrinkage Reducer

[(3.25 fl oz/cwt)*(619.84 lb/yd^3/100)]*[(100%-80% solids)/100]*(1 gal/128 fl oz)*(9.1 lb/gal)= 0.286 lb

From Set Retarder

[(4.19 fl oz/cwt)*(619.84/yd^3/100]*[(100%-14% solids)/100]*(1 gal/128 fl oz)*(7.6 lb/gal)= 1.33 lb

Water$_{\text{admixtures}}$= Water$_{\text{Water Reducer}}$ + Water$_{\text{Shrinkage Reducer}}$ + Water$_{\text{Set Retarder}}$= 7.77 lb

Solids From Admixtures

Mass$_{\text{Water Reducer}}$= 7.93 lb

Mass$_{\text{Shrinkage Reducer}}$= 1.49 lb

Mass$_{\text{Set Retarder}}$= 1.92 lb

From Water Reducer

Mass$_{\text{Water Reducer}}$ – Mass$_{\text{Water Reducer from Water}}$= 1.78 lb

From Shrinkage Reducer

Mass$_{\text{Shrinkage Reducer}}$ – Mass$_{\text{Shrinkage Reducer from Water}}$= 1.21 lb

From Set Retarder

Mass$_{\text{Set Retarder}}$ – Mass$_{\text{Set Retarder from Water}}$= 0.59 lb

Volume of Solids from Admixtures

Water Reducer= 7.93/(1.085*62.4)= 0.117 ft^3

Shrinkage Reducer= 1.49/(.91*62.4)= 0.026 ft^3

Set Retarder= 1.92/(1.19*62.4)= 0.026 ft^3

Solid Admixtures: Volume$_{\text{Water Reducer}}$ + Volume$_{\text{Set Retarder}}$ + Volume$_{\text{Shrinkage Reducer}}$= .169 ft^3

Volume of Aggregates

Mass$_{\text{Trinity \#1 Sand}}$= 421.5 lb

Mass$_{\text{Poraver (.1-.3)}}$= 161.16 lb

Mass$_{\text{Poraver (.25-.5)}}$= 161.16 lb

Mass$_{\text{Poraver (.5-1)}}$= 37.19 lb

Mass$_{\text{Poraver (1-2)}}$= 99.18 lb

Volume$_{\text{Trinity \#1 Sand}}$= 421.5/(62.4*1.74)= 3.88 ft^3

Volume$_{\text{Poraver (.1-.3)}}$= 161.16/(62.4*.95)= 2.72 ft^3

Volume$_{\text{Poraver (.25-.5)}}$= 161.16/(62.4*.7)= 3.69 ft^3

$\text{Volume}_{\text{Poraver (.5-1)}}$= 37.19/(.5*62.4)= 1.19 ft^3

$\text{Volume}_{\text{Poraver (1-2)}}$= 99.18/(.4*62.4)= 3.97 ft^3

$\text{Volume}_{\text{Total}}$= $\text{Volume}_{\text{Trinity \#1 Sand}}$ + $\text{Volume}_{\text{Poraver (.1-.3)}}$ + $\text{Volume}_{\text{Poraver (.25-.5)}}$ + $\text{Volume}_{\text{Poraver (.5-1)}}$ + $\text{Volume}_{\text{Poraver (1-2)}}$= 15.45 ft^3

Aggregate - Concrete Ratio (Volumetric)

Aggregate Ratio (%)= 15.45 ft^3/27 * 100%= 57.22% > 25% Acceptable

ASTM C330 Aggregate Ratio (Volumetric)

$\text{Volume}_{\text{Trinity \#1 Sand}}$= 3.88 ft^3

% $\text{Volume}_{\text{ASTM C330}}$= $\text{Volume}_{\text{ASTM C330}}$/$\text{Volume}_{\text{Aggregates}}$*100= 3.88 ft^3/15.45 ft^3= 25.11% > 25% Acceptable

Mass of Aggregates

Trinity #1 Sand	SG_{SSD}= 1.74	Abs= 24%
Poraver (.1-.3)	SG_{SSD}= .95	Abs= 35%
Poraver (.25-.5)	SG_{SSD}= .7	Abs= 21%
Poraver (.5-1)	SG_{SSD}= .5	Abs= 18%
Poraver (1-2)	SG_{SSD}= .4	Abs= 19%

Oven-Dry Specific Gravity

SG_{OD}= SG_{SSD}/(1+(Abs/100%))

Trinity #1 Sand

1.74/(1+(24/100))= 1.4

Poraver (.1-.3)

.95/(1+(35/100))= 0.704

Poraver (.25-.5)

.7/(1+(21/100))= 0.58

Poraver (.5-1)

.5/(1+(18/100))= 0.42

Poraver (1-2)

.4/(1+(19/100))= 0.34

APPENDIX B: MIXTURE PROPORTIONS

Base Quantity of Aggregates

W_{OD}= Volume $_{\text{Aggregate A}}$ * SG $_{\text{OD, Aggregate A}}$ * 62.4

Trinity #1 Sand

3.88*1.4*62.4= 338.96 lb

Poraver (.1-.3)

2.72*.704*62.4= 119.49 lb

Poraver (.25-.5)

3.69*.58*62.4= 133.55 lb

Poraver (.5-1)

1.19*.42*62.4= 31.18 lb

Poraver (1-2)

3.97*.34*62.4= 84.23 lb

Base Quantity of Aggregates (Saturated Surface Dry)

W_{SSD}=W_{OD}*(1+Abs/100)

Trinity #1 Sand

338.96*(1+(24/100))=421.5 lb

Poraver (.1-.3)

119.49*(1+(35/100))=161.16 lb

Poraver (.25-.5)

133.55*(1+(21/100))= 161.16 lb

Poraver (.5-1)

31.18*(1+(18/100))= 36.19 lb

Poraver (1-2)

84.23*(1+(19/100))= 99.18 lb

Check Aggregate Volumes

Trinity #1 Sand

421.5/(62.4*1.74)= 3.88 ft^3 =338.96/(62.4*1.4)

Poraver (.1-.3)

161.16/(62.4*.95)= 2.72 ft^3 =119.49/(62.4*.704)

Poraver (.25-.5)

161.16/(62.4*.7)= 3.69 ft^3 =133.55/(62.4*.58)

Poraver (.5-1)

37.19/(62.4*.5)= 1.19 ft^3 =31.18/(62.4*.42)

Poraver (1-2)

99.18/(62.4*.4)= 3.97 ft^3 =84.23/(62.4*.34)

Free Water from Aggregates

Assumptions

1. Poraver assumed MC_{stk}= .5%
2. Sand assumed Mc_{stk}= 2%

Mass, In Stock Moisture Content Condition

$W_{stk}= W_{OD}(1+MC_{stk}/100)$

Trinity #1 Sand

338.96*(1+(2/100))= 345.74 lb

Poraver (.1-.3)

119.49*(1+(.5/100))= 120.09 lb

Poraver (.25-.5)

133.55(1+(.5/100))= 134.22 lb

Poraver (.5-1)

31.18*(1+(.5/100))= 31.34 lb

Poraver (1-2)

84.23*(1+(.5/100))= 84.65 lb

Total Moisture Content

$MC_{total}= [(W_{stk}-W_{OD})/W_{OD}]*100$

Trinity #1 Sand

[(346.74-338.96)/338.96]*100= 2%

Poraver (.1-.3)

[(120.09-119.49)/119.49]*100= 0.5%

Poraver (.25-.5)

[(134.22-133.55)/133.55]*100= 0.5%

Poraver (.5-1)

[(31.34-31.18)/31.18]*100= 0.5%

Poraver (1-2)

[(84.65-84.23)/84.23]*100= 0.5%

Free Moisture Content

$MC_{free} = MC_{total} – A$

Trinity Sand #1

2 - 24= -22%

Poraver (.1-.3)

.5 - 35= -34.5%

Poraver (.25-.5)

.5 – 21= -20.5%

Poraver (.5-1)

.5 – 18= -17.5%

Poraver (1-2)

.5 – 19= -18.5%

Mass, In Stock Moisture Content Condition

$W_{free} = W_{OD}*(MC_{free}/100)$

Trinity #1 Sand

338.96*(-22/100)= -74.57 lb

Poraver (.1-.3)

119.49*(-34.5/100)= -41.22 lb

Poraver (.25-.5)

133.55*(-20.5/100)= -27.38 lb

Poraver (.5-1)

31.18*(-17.5/100)= -5.46 lb

Poraver (1-2)

84.23*(-18.5/100)= -15.58 lb

Total= (-74.57+-41.22+-27.38+-5.46+-15.58) lb= -164.21 lb

Batch Water

$W_{batch}= W – (W_{free}+\sum W_{admix})$

347.11 – (-164.21 lb +7.82 lb)= 503.5 lb

Mass of Aggregates

$\sum W_{Aggregate\ SSD}$= (420.31+161.31+161.6+36.79+100.23) lb= 880.24 lb

Mass of Concrete

$\sum M= M_{cm} + M_{fibers} + M_{aggregates} + M_{solids} + M_{water}$= (619.84+.545+880.24+3.58+347.11) lb= 1851.32 lb

Absolute Volume of Concrete

$\sum V= V_{cm} + V_{fibers} + V_{aggregates} + V_{solids} + V_{water}$= (3.3+.0096+15.45+.169+5.56) ft^3= 24.49 ft^3

Theoretical Density

T= ∑M/∑V

T= 1851.32 lb/24.49 ft^3= 75.59 lb/ft^3

Measured Density

D= 68.37 lb/ft^3

Air Content

Air Content= [(T – D)/T]*100= [(75.59 – 68.37)/75.59]*100= 9.55%

Air Content Check

Air Content= [(27-V)/27]*100= [(27 – 24.49)/27]*100= 9.3%

Cement – Cementitious Materials Ratio

c/cm= 309.92/619.84= .5

Water – Cementitious Materials Ratio

w/cm= 347.11/619.84= .56

Water – Cement Ratio

w/c= 347.11/309.92= 1.12

Slump

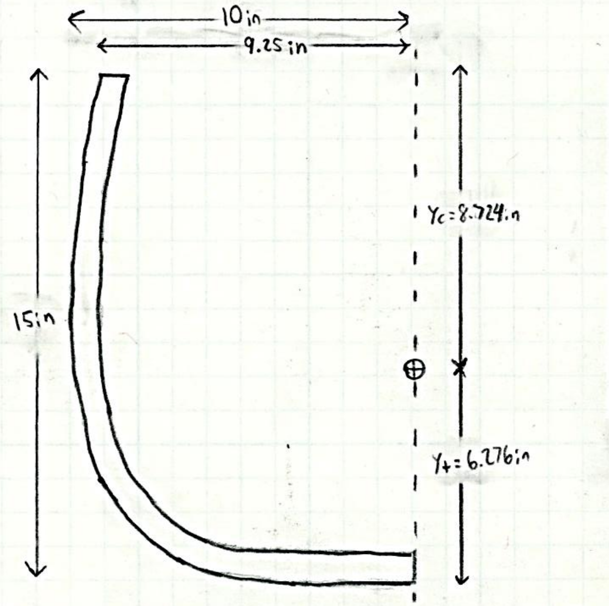
Slump= 1”

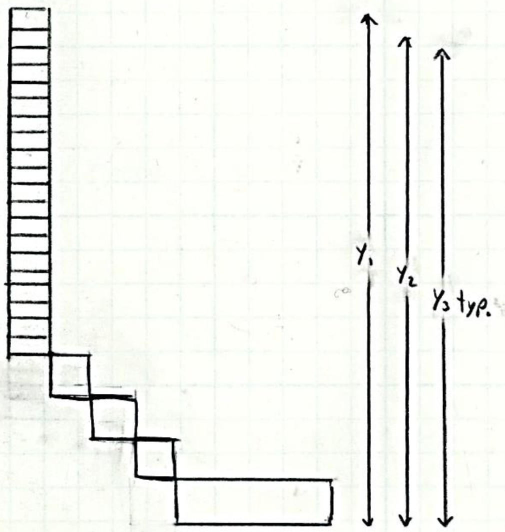
Cross- Section Analysis 4.3ft from bow

Assumptions: Hull cross-section is broken up into 0.5in x 1.25in, 1.25in x 1.25in, and 1.25in X4.5in rectangles

Hull is Symmetric about y-axis

Equations: $\bar{y} = \frac{\Sigma Ay}{\Sigma A}$ $I_{cx} = \frac{bh^3}{12}$ $d_y = \bar{Y} - Y$ $I_x = \Sigma(I_{cx} + d_y^2 A)$





Y- Values

$Y_1 = 14.75in$
$Y_2 = 14.25in$
$Y_3 = 13.75in$
$Y_4 = 13.25in$
$Y_5 = 12.75in$
$Y_6 = 12.25in$
$Y_7 = 11.75in$
$Y_8 = 11.25in$
$Y_9 = 10.75in$
$Y_{10} = 10.25in$
$Y_{11} = 9.75in$
$Y_{12} = 9.25in$
$Y_{13} = 8.75in$
$Y_{14} = 8.25in$
$Y_{15} = 7.75in$
$Y_{16} = 7.25in$
$Y_{17} = 6.75in$
$Y_{18} = 6.25in$
$Y_{19} = 5.75in$
$Y_{20} = 5.25in$
$Y_{21} = 4.375in$
$Y_{22} = 3.125in$
$Y_{23} = 1.875in$
$Y_{24} = 0.625in$

$A(1:20) = (0.5in)(1.25in) = 0.625in^2$

$A(21:23) = (1.25in)(1.25in) = 1.5625in^2$

$A(24) = (1.25in)(4.5in) = 5.625in^2$

$$\bar{y} = \frac{[A(1:20)(Y_1+Y_2+Y_3+\dots+Y_{20})] + [A(21:23)(Y_{21}+Y_{22}+Y_{23})] + [A(24)(Y_{24})]}{[(20)(A(1:20))]+[(3)(A(21:23))] + A(24)} = 6.276in$$

$Y_t = \bar{Y} = 6.276in$ $Y_c = Y - Y_t = 15in - 6.276in = 8.724in$

$$I_{cx}(1:20) = \frac{(1.25in)(0.5in)^3}{12} = 0.013in^4$$

$$I_{cx}(21:23) = \frac{(1.25in)(1.25in)^3}{12} = 0.203in^4$$

$$I_{cx}(24) = \frac{(4.5in)(1.25in)^3}{12} = 0.732in^4$$

$$I_x = (2)[20[I_{cx}(1:20)) + (2)(I_{cx}(21:22)) + I_{cx}(24) + (\bar{Y}-Y)^2(A))]$$

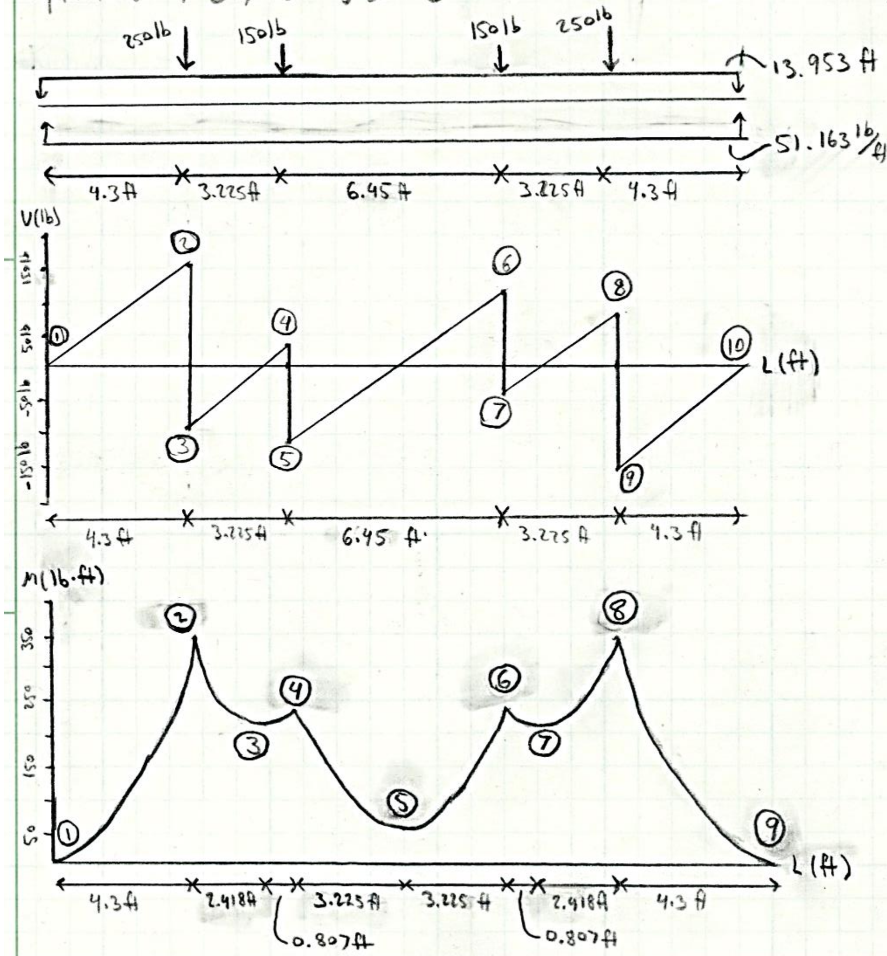
$$= 1019.822in^3$$

APPENDIX C: EXAMPLE STRUCTURAL CALCULATION

Longitudinal Loading

Assumptions: Paddlers are point loads, Canoe weight and buoyant forces are uniformly distributed, males = 250 lb, females = 150 lb, Canoe = 300 lb

Equations: $+\uparrow \Sigma F_y = 0$ $\circlearrowleft \Sigma M = 0$ $\tau = V/A$ $\sigma_c = \frac{My_c}{I_x}$ $\sigma_t = \frac{My_t}{I_x}$



$w_c = \frac{300\text{ lb}}{21.5\text{ ft}} = 13.953\text{ lb/ft}$ $+\uparrow \Sigma F_y = 0 = (2)(250\text{ lb}) + (2)(150\text{ lb}) + 300\text{ lb} + W_b(21.5\text{ ft})$

$\Rightarrow W_b = 51.163\text{ lb/ft}$

Shear

① 0 lb

② (51.163 lb/ft − 13.953 lb/ft)(4.3 ft) = 160 lb

③ 160 lb − 250 lb = −90 lb

④ −90 lb + (51.163 lb/ft − 13.953 lb/ft)(3.225 ft) = 30 lb

⑤ 30 lb − 150 lb = −120 lb

⑥ −120 lb + (51.163 lb/ft − 13.953 lb/ft)(6.45 ft) = 120 lb

⑦ 120 lb − 150 lb = −30 lb

⑧ −30 lb + (51.163 lb/ft − 13.953)(3.225 ft) = 90 lb

⑨ 90 lb − 250 lb = −160 lb

⑩ −160 lb + (51.163 lb/ft − 13.953 lb/ft)(4.3 ft) = 0 lb

Moment

① 0 lb·ft

② (½)(4.3 ft)(160 lb) = 344 lb·ft

③ (344 lb·ft) − (½)(2.418 ft)(90 lb) = 235.19 lb·ft

④ (235.19 lb·ft) + (½)(0.807 ft)(30 lb) = 247.30 lb·ft

⑤ (247.30 lb·ft) − (½)(3.225 ft)(120 lb) = 53.8 lb·ft

⑥ (53.8 lb·ft) + (½)(3.225 ft)(120 lb) = 247.30 lb·ft

⑦ (247.30 lb·ft) − (½)(0.807 ft)(30 lb) = 235.19 lb·ft

⑧ (235.19 lb·ft) + (½)(2.418 ft)(90 lb) = 344 lb·ft

⑨ (344 lb·ft) − (½)(4.3 ft)(160 lb) = 0

Stresses

$\tau = \frac{160\text{ lb}}{22.81\text{ in}^2} = 7.01\text{ psi}$

$\sigma_c = \frac{(344\text{ lb·ft})(12\text{ in/ft})(8.724\text{ in})}{1019.822\text{ in}^4} = 35.31\text{ psi}$

$\sigma_t = \frac{(344\text{ lb·ft})(12\text{ in/ft})(6.276\text{ in})}{1019.822\text{ in}^4} = 25.40\text{ psi}$

APPENDIX C: EXAMPLE STRUCTURAL CALCULATION

Structural Analysis Results

Load condition	Shear (lb)	Moment (lb*ft)	Shear Stress τ (psi)	Compression Stress σ_C (psi)	Tensile Stress σ_T (psi)
2-Women	94.16	206.25	4.13	23.34	13.87
2-Men	156.98	343.75	6.88	38.91	23.11
4-Person	148.84	297.68	6.53	30.25	21.76
Conference Scenario	160	344	7.01	35.31	21.4

APPENDIX D: HULL ANALYSIS/REINFORCEMENT & OPEN AREA CALCULATION

Determine: Reinforcement thickness in all hull locations must be less than 50%

Thickness of SpiderLath Fiberglass (T_{mesh}) = 0.0312 inches

Thickness of Post-Tensioned Cables ($T_{post\text{-}tensioning}$) = 0.125 inches (0.0625 steel wire enclosed in 0.125 nylon tube)

1. Walls of Canoe

Hull Thickness = 1.25 inches

T_{mesh} (1 layer) = 0.0312 inches x 1 layer = 0.0312 inches

$T_{post\text{-}tensioning}$ = 0.125 inches

$$\boldsymbol{Percent\ T_{Reinforcement} = \frac{0.0312 + 0.125}{1.25} * 100\% = 12.5\% < 50\%, Approved}$$

2. Keels, including 6 inch overlaps

Hull Thickness = 1.25 inches

T_{mesh} (3 layers) = 0.0312 inches x 3 layer = 0.064inches

$T_{post\text{-}tensioning}$ = 0.125 inches

$$\boldsymbol{Percent\ T_{Reinforcement} = \frac{0.0624 + 0.125}{1.25} * 100\% = 17.5\% < 50\%, Approved}$$

3. Gunwales, including 6 inch overlaps

Hull Thickness = 1.25 inches

T_{mesh} (1 layers) = 0.0312 inches x 1 layer = 0.0312 inches

Post Tensioning Not present in Gunwale

$$\boldsymbol{Percent\ T_{Reinforcement} = \frac{0.0312}{1.25} * 100\% = 2.5\% < 50\%, Approved}$$

4. Post Tensioning System, excluding Washer Anchors

Hull Thickness = 1.25 inches

$T_{post\text{-}tensioning}$ = 0.125 inches

$$\boldsymbol{Percent\ T_{Reinforcement} = \frac{0.125}{1.25} * 100\% = 10\% < 50\%, Approved}$$

5. Post Tensioning System, Including Washer Anchors

Hull Thickness = 1.25 inches

Flat Washer = 0.49 inches

$T_{post\text{-}tensioning}$ = 0.125 inches

$$\boldsymbol{Percent\ T_{Reinforcement} = \frac{0.49 + 0.125}{1.25} * 100\% = 49.2\% < 50\%, Approved}$$

APPENDIX D: HULL ANALYSIS/REINFORCEMENT & OPEN AREA CALCULATION

Calculations for Percent Open Area (POA) of Reinforcement

Equations:

$$POA = \frac{\sum Area_{Open}}{Area_{Total}} * \ 100\%$$

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

$$d_1 = aperture\ dimension + 2({}^{t_1}/_2)$$

$$d_2 = aperture\ dimension + 2({}^{t_2}/_2)$$

$$L_{sample} = n_1 * d_1$$

$$W_{sample} = n_2 * d_2$$

$$Area_{Total} = L_{sample} * W_{sample}$$

Variables:

n_1 = number of apertures along sample length

d_1 = spacing of reinforcement along length (center-to-center)

t_1 = thickness along length

L_{sample} = length of sample

n_2 = number of apertures along sample width

d_2 = spacing of reinforcement along width (center-to-center)

t_2 = thickness along width

W_{sample} = width of sample

Measured/Calculated/Given Data:

Aperture dimensions = 0.25 in. (Determined from Data Sheet)

t_1 = 0.0410 t_2 = 0.0910

$n_1 = n_2 = 12$

d_1 = aperture dimension + $2(t_1/2) = 0.25 + 2(0.041/2) = 0.291$

d_2 = aperture dimension + $2(t_2/2) = 0.25 + 2(0.091/2) = 0.341$

$L_{sample} = n_1 * d_1 = 12*0.291 = 3.492$ in. $W_{sample} = n_2 * d_2 = 12*0.341 = 4.092$ in.

Determine the POA of mesh reinforcement, must be greater than 40%

Solution:

$\sum Area_{Open} = n_1 * n_2 * Area_{Open}$ = (12 * 12 * (0.25in. * 0.25in.)) = **9 in.^{2}**

$Area_{Total} = L_{sample} * W_{sample}$ = 3.492 in. * 4.092 in. = **14.29 in.^{2}**

$$POA = \frac{\sum Area_{Open}}{Area_{Total}} * \ 100\% = \frac{9}{14.29} * 100 = \mathbf{62.98\ \% > 40\%, \mathit{Approved}}$$