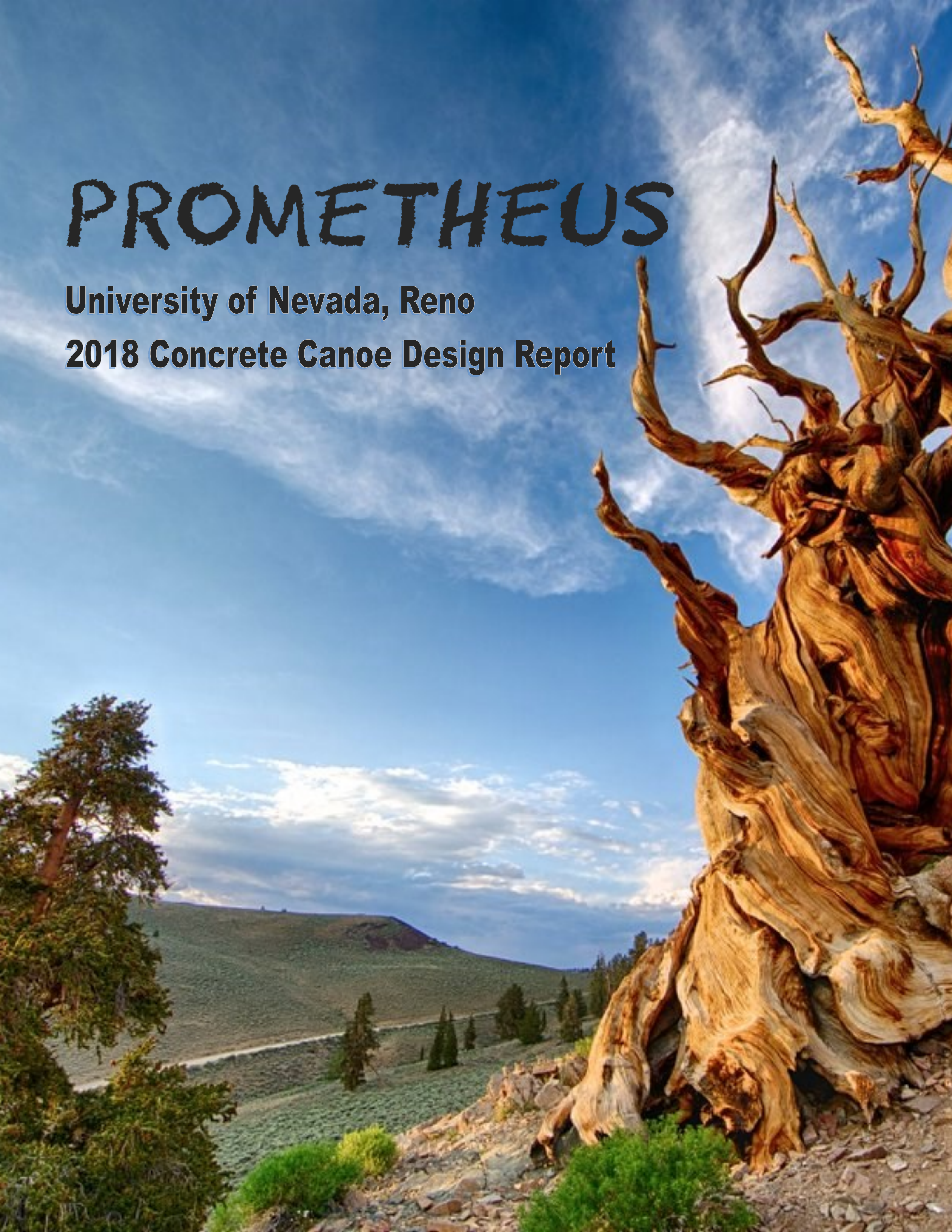
PROMETHEUS

University of Nevada, Reno

2018 Concrete Canoe Design Report



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Executive Summary

For thousands of years, the resilient bristlecone pine trees have resided in the harsh Nevada wilderness, recording the natural history of the region. In an attempt to extract a small sample, researchers inadvertently cut down the oldest amongst them, Prometheus. The calamity revealed a detailed record on climate and glacial pattern hidden within the growth rings (National Park Service). Prometheus' impartment of knowledge through the years reflects the practice of sharing knowledge each year that grants the success of University of Nevada, Reno's 2018 Concrete Canoe Team. Each year, the Nevada Concrete Canoe Team (NCCT) leaders strive to learn from previous experiences and build upon the methods and pass on knowledge to forthcoming teams. The NCCT provides an encouraging environment for young engineers to test and further seek knowledge, building upon the legacy set by previous years.

Located in northern Nevada, the University is comprised of over 22,000 undergraduate students, 392 of which embody the department of Civil and Environmental Engineering (UNR 2018). The NCCT is comprised 27 members with a diverse background amongst the engineering fields. For the past 13 years, the team has competed alongside universities from northern California and China in the Mid-Pacific Conference (Mid-Pac). The NCCT has a history being a strong competitor at both the regional and the national levels, most recently competing with *Incendium* (3rd at regionals, 2017), *Zephyr* (3rd at nationals, 2016), and *Aquatone* (6th at nationals, 2015).

The concrete casting process has become more demanding in recent years due to the required use of pigmented concrete for aesthetic design in 2016. The man- hours required to complete casting has increased tremendously since the implementation. Casting times ranged between 11 and 14 hours prior to the alteration and in more recent years, the process extended to 19 hours for *Zephyr* 12 hours for *Incendium* with a team of 20 and 30 members respectively. This year, an intricate branch design consisting of many fine lines between colors coupled with difficulty working with the required ASTM C330 aggregate resulted in a demand for more man-hours. Project leaders implemented a rotating schedule during casting day to improve casting quality. A total of 300 man hours were dedicated to the project. Physical canoe properties and selected reinforcements are summarized in Table 1. The structural mix selected for *Prometheus* achieved the density and strength needed for it with stand the trails of competition. The mix design team sought out a new ASTM C330 aggregate that was less dense and finer than the material used previously. The inclusion of a new polymer-modifying admixture helped create a strong concrete, capable of facing the rigors of competition.

Table 1: Dimensions and reinforcement

Dimensions	
Colors	Red Brown, Light Brown, Brown, Green
Weight*	210 lb
Length (max)	21 ft.
Width (max)	27.5 in.
Depth (max)	13.5 in.
Thickness (avg.)	0.5 in.
Reinforcement (Primary)	
0.125 in. dia. Kevlar® Cable	
1.5 in. Carbon Fiber Mesh	
0.25 in. Steel all Thread	
0.5 in. Galvanized Steel All Hardwear Cloth	
Reinforcement (Secondary)	
8 mm and 12 mm PVA Fibers	

***Estimated overall weight**

Table 2: Concrete properties used for *Prometheus*

Mix ID	Unit Weight Wet/Dry (pcf)	28 Day Compressive Strength (psi)	28 Day Composite Flexural Strength (psi)	14 Day Tensile Strength (psi)*	Air Content (%)
Structural	59.5/57	1470	1250	290	8.3
Patch	65/63	2010	N/A	220	8.1
Interior Patch	57.1/55	990	N/A	170	10.2

***(ASTM C496/C496M-11)**

Project and Quality Management

Project managers for the NCCT began the season with member recruitment. Member retention from the 2017 team was roughly 50 percent. While retention exceeded the previous year, the management team identified recruitment as a high priority and strove to increase membership for the upcoming year and project managers promoted outreach to engineering classes and at school club fairs. Using effective recruitment measures, managers enlisted 15 new members.

The project managers assigned all team members to committees based upon skill and interest. The division allowed for more efficient allocation of human resources. The five committees included mix design, construction, aesthetics, safety, and paddling. Project managers appointed experienced division managers to oversee each committee with the exception of the paddling committee, which was led by returning team coaches. Division managers ensured proper training of all new members and coordinated weekly tasks for their respective committees. Delegation allowed project managers to focus on hull design and mix design. The management team closely monitored the progress of each division through periodic inspection of work completed and weekly meetings with group leaders.

Managers constructed an efficient yet reasonable schedule using the critical path method. With the aid of division leaders and reference to past project schedules, managers determined major project milestones and designated appropriate time frames for each task. A breakdown of the man-hours allocated to each major task is depicted in Figure 1.

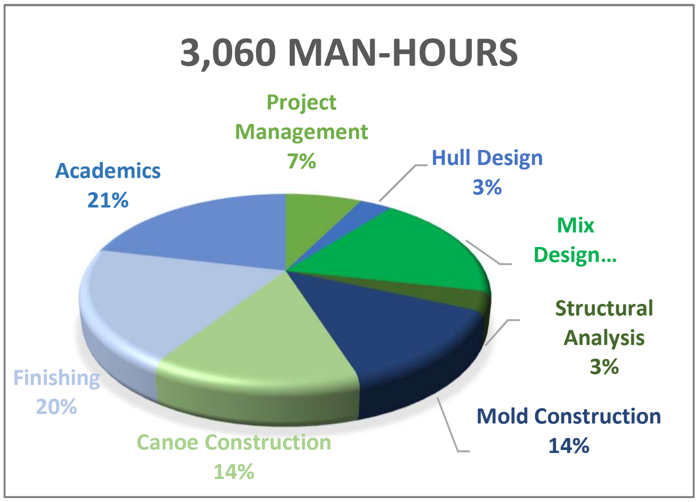


Figure 1: Breakdown of Man-Hours

Project managers worked to create a schedule that was efficient and fast paced yet left additional time for the possibility of delays. The selected method in scheduling proved useful, when milestones were delayed due to project complications. Complications included improper application of Duratec™ primer during form construction and Kevlar® tendon malfunctions. These two obstacles resulted in a delayed casting day. Managers applied appropriate time constraints to each milestone and used the Mid-Pac as the deadline, working backwards to determine the dates at which each task was completed.

Keeping financial sustainability in mind, managers implemented fundraising and cost-effective practices throughout the design and construction process to ensure all expenditures could be covered while maintaining a healthy budget for future years. One of the largest cost-saving tactics involved the form's acquisition and labor. In previous years, the NCCT received a foam donation that was shipped to Reno from Southern California. The form was then glued and transported back to Southern California where a computer numerical control (CNC) machine. This year, the team was able to reduce costs by roughly $1000 by traveling to the foam donor's facility, also in Southern California, in a single trip. The team also raised funds by reaching out to local companies for monetary and material donations, which were major funding sources throughout the year.

Throughout the design and construction of Prometheus, the project managers worked diligently to maintain compliance with the Concrete National Concrete Canoe (CNCCC) rules and proper safety measures. Quality control was carried out by the project managers and consisted of properly training new members, verifying material properties, monitoring design calculations, and performing inspections on casting day. Quality assurance was performed by the project managers and consisted of adhering to the OSHA standards, testing members on mix and construction methods learned, reviewing tasks finished by the team, and inspecting calculations.

Early in the year, the project managers met with the university's industrial hygienist and director of the Environmental Health and Safety to discuss safety procedures required by the new OSHA standards. The meeting was organized to identify potential health concerns associated with construction. The team was provided with important information on lowering the amount of silica in the air, safely removing concrete dust, and determining the appropriate type of safety mask. Project managers required the mix design team to be fit tested for safety mask, due to the potentially high exposure to silica, found in cementitious materials during trial batching. Additionally, each member on the team was required to attend a 30 minute safety training, conducted by the project managers. This meeting informed members of the eye wash station, the location of the first aid kit, fire and how to properly wear required safety gear.

In order to reduce the computational errors, the structural and mix design calculations were initially performed in Microsoft Excel. Project managers compared the calculations of the mix design in the excel file to the required mix design sheet in Appendix B. This verified the final mix complied with CNCCC standards. Furthermore, the project managers assigned the safety manager to ensure all construction materials met the requirements set in the CNCCC rules. The safety manager completed this throughout the mix and construction process.

The project managers spent 25 hours training the team to increase the quality and efficiency of tasks completed. Training sessions took place prior to newly tasks assigned task. Managers explained the required safety gear and hazards, potential areas for failure, and the expected final results. After each training session, the team was verbally tested to provide assurance that they understood the presented task. Project managers also required members to practice packing a 12 in. x 12 in. x 0.5 in. beam with carbon fiber mesh prior to casting day. This practice provided the members with the experience needed to ensure the proper canoe casting process. Properly training team members on accurately placing the canoe reinforcement onto the form was given high priority. The location and the pre-tensioning of each tendon, along with tying the carbon fiber mesh to the unique shape of the hull was vital to ensuring the strength properties of the canoe. Sufficient time would be required for it the reinforcement to be correctly complete. Project managers decided to delay casting day two weeks to focus on form preparation. The additional time allowed for the pre-tensioning to meet the design specifications and the carbon fiber mesh to be correctly tied to the form.

Quality control testing during concrete mix trial batching included calculating the volume and the tested relative yield, of each mix in order to determine that 70 structural mixes would be required for casting day. The mixes were weighed in 0.1 ft^3 batches to ensure quality control. The decreased quantity allowed the contents of the mix to be equally distributed and decreased amount of the wasted material on casting day. In order to verify the quality of the concrete mixed on casting day, the mix design team recorded the unit weight (ASTM C138/C138M-16a) of every five mixes produced. In addition, sixteen 2 in. x 4 in. cylinders (ASTM C39/C39M-16b) were packed at random on casting day. Half of the cylinders were cured with the canoe, while the remaining were cured in a controlled the wet room on campus. The cylinders were broken at day 7, 14, 21, and 28 to confirm the strengths of the concrete on casting day followed the strength trends during development and testing.

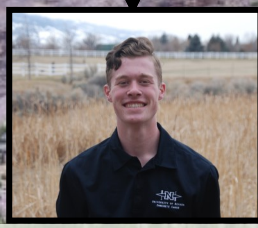
Organization Chart


Zachary Stock (Jr.) & Meghan Brock (Jr.)
Project Manager

Directed all project task and oversaw quality control practices. Responsible for budget appropriation, schedule formation, and task delegation

Lauren Mazurowski (Jr.)
Safety Manager

Updated SDS binder, implemented safety techniques, and worked with EH&S for compliance with all in-spections.



Owen Wurgler (Fr.)
Mix Design Manager

Directed mix design members in product research, material procurement, trial batching, and testing.

Greg Billingsly (Fr.)
Junior Mix Design Manager

Assistants

Dallas Babcock (Jr.)
Katie Kramer (Sr.)
Jillian Tobin (So.)

Ian Meyer (So.)
Construction Manager

Directed construction from form preparation, concrete casting, and canoe finishing

Carmen Bushorn (Fr.)
Junior Construction Manager

Assistants

Ilonna Biondo (Fr.)
Ryen Blair (Sr.)
Bethany Calvert (Fr.)
Alex Hansen (Sr,)
Sam Jones (So.)
Justin Jumper (Fr.)
Samantha Morales (So.)
Lynndie Munson (Jr.)
Alex Poroli (So.)
Gunner Scott (Sr.)
Jared Stimac (Sr.)
Claria Schwab (So.)
Kayla Tam (Jr.)
Aiden Tronnes (Fr.)

Lilly Raymond (Fr.)
Aesthetics Manager

Conceptualized artwork for project including canoe graphics, display, and canoe stand

Assistants

Erika Bolen (So.)
Katie Kramer (Sr.)
Emily McKenzie (Fr.)

Paddlers

Meghan Brock (Jr.)
Bethany Calvert (Fr.)
Lauren Mazurowsk (Jr.)
Emily McKenzie (Fr.)
Jillian Tobin (So.)
Greg Billingsly (Fr.)
Ian Meyer (So.)
Gunner Scott (Sr.)
Jared Stimac (Sr.)
Zachary Stock (Jr.)

Hull Design and Structural Analysis

The design team's goal for the hull design of *Prometheus* was to maintain a comfortable level of paddler stability while maintaining favorable straight-line speed and turning characteristics. To determine an optimum shape for *Prometheus,* the design engineers relied on the properties and characteristics of different hull geometries and used hull designs from previous years as references.

Performance characteristics such as straight-line speed, freeboard and turning speeds were calculated in a spreadsheet created by the 2008 NCCT. The sheet took into account the dimensions of cross-section shapes along each 1-foot interval of the canoe. The calculated performance statistics were used to compare dimensional properties of *Prometheus* against hull designs from previous years. After receiving input from previous paddlers, the design engineers concluded that the precise paddling skill demanded by the 2016 canoe, *Zephyr,* limited performance during races, and it was rejected from consideration (NCCT 2016).

Designers used *Incendium's* shape as a baseline for *Prometheus'* design. The team began analyzing various waterline lengths and ultimately decided a length of 21.5 ft. aligned with the design team's performance goals. Increasing the waterline length of the canoe increased the frictional drag yet decreased the wave-making resistance. Wave-making resistance is the energy required to displace water along the sides of the hull, and its decrease occurred because of gradual changes in profile along the length of the canoe. The decrease in total drag forces shows a positive correlation with straight-line speeds (Winters 2005).

Designers moved the largest beam width closer to the stern, at stations 10, 11, and 12 decreasing wave-making resistance and in turn increased straight-line speed. Similar to *Incendium*, the prominent keel enhanced tracking performance (NCCT 2017). The waterline length, large beam width, and hard chines preserved a comfortable freeboard which increased paddler stability in the water. Managers obtained values for maneuverability and drag using their spreadsheet and are denoted in Table 3.

By increasing the length of the *Incendium* and reinforcing a more gradual change in beam width, the total drag of *Prometheus* decreased by 6%. Increasing the length by 6 in. increased the turning resistance caused by a turning moment and ultimately increased the 180-degree turning time by 3%. The turning moment of the canoe corresponds to the amount of energy required to begin rotating the canoe. A boat sitting higher in the water has a reduced wetted surface area, and a subsequent reduction in the turning moment resistance. A reduction in turning resistance decreases the turning time (t) which was calculated in seconds using Equation 1:

$$t = \sqrt{\sum Ad * (1 + sin\theta)} \qquad \text{Eqn. (1)}$$

where A is wetted profile area of each 1-foot interval, d is the distance from the center of turning, and θ is the angle of the keel in degrees. The calculated results were cross referenced with recorded turning times. Tests produced a strong correlation between calculated and recorded times, with an average error of +/- 10%.

Table 3: Comparison of Past Three Canoes

Canoe Name	Lowest Freeboard (in)	Total Drag (lb)	180° Turn Time (sec)
Zephyr	5.54	24.1	6.06
Incendium	8.03	25.4	6.10
Prometheus	6.61	24.0	6.3

After finalizing *Prometheus*' hull design, managers began the structural analysis by inputting the geometry of the canoe into the team's structural analysis spreadsheet. Next, preliminary properties such as approximate unit weight of the concrete and assumed paddler load locations were incorporated. The spreadsheet uses the properties described above to find the moment of inertia, centroid, and cross-sectional areas of each 1-foot cross section of the canoe.

Once the initial properties were inputted, the spreadsheet created by the 2008 NCCT used a two-dimensional model of a simply-supported beam to analyze the canoe. The program analyzed four separate loading cases: two-person transportation, display, men's sprint, and coed as simply supported beams. Free body diagrams of each loading case are shown in Figure 2. The simply-supported model required paddler weights, self-weights, and the resulting buoyancy forces to remain in static equilibrium. The canoe's longitudinal asymmetrical profile resulted in an eccentricity between the center of gravity and the center of buoyancy, resulting in instability of the canoe within the water. The structural analysts calculated the angle with the waterline at which the canoe experiences no residual moment; this rotation is known as the pitching angle. The structural analysis program iterates an assumed waterline and pitching angle to determine buoyancy force distribution along the hull and satisfy static equilibrium for two-paddler and four-paddler load cases.

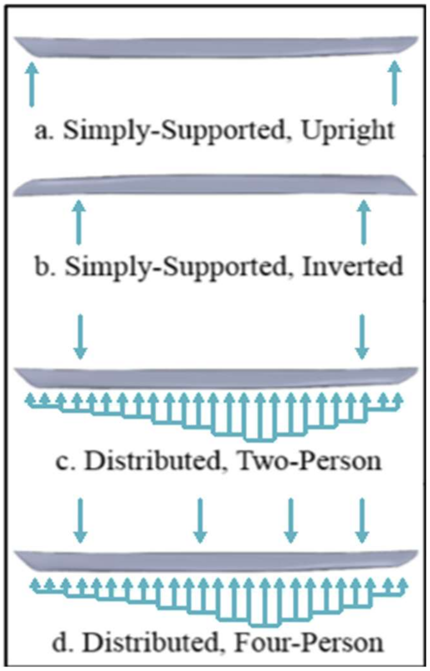


Figure 2: Loading Cases

The structural analysts designed a pre-stress system to ensure the stresses put on the canoe remain within the serviceable limits of the concrete during four desired loading cases. The system consisted of sixteen Kevlar® tendons, each carrying a tensile load of 275 pounds, totaling 4,400 pounds of tensile pre-stress. The individual load was reduced because in previous years high tensile loads resulted in constructability issues and were difficult to achieve. Engineers placed four tendon groups running along the gunwale of the canoe to counteract flexural tensile stresses due to the paddler loading cases. An additional four tendon groups were placed at the bottom and chine to counteract the groups' flexural stresses caused by the tendons near the gunwale.

The spreadsheet determined an optimal tendon path placement for each group and calculated the stresses and moments induced at each individual cross section using the combination of applied, resultant, and pre-stress loads at each 1-ft interval along the canoe. This spreadsheet assumed a conservative amount of losses in the pre-stress system of 25% in accordance with AASHTO LRFD Bridge Design Specification (AASHTO 2016). The calculation includes losses due to relaxation, creep, elastic shortening, and shrinkage in the concrete. Each individual stress due to the assumed loading cases was tabulated along the length of the canoe to determine the minimum required concrete strength. These values were calculated to ensure the maximum stresses at any point along the canoe did not exceed the serviceable strength limit of the concrete.

As a factor of safety, the team applied secondary reinforcement systems to the design. Two layers of carbon-fiber mesh encased in concrete were placed along the length of the boat to increase flexural stiffness and shear capacity. Four ribs were incorporated into the design scheme at approximate paddler locations. The addition of carbon-fiber increased the composite flexural strength of the concrete, and ribs added stiffness along the canoe to counteract the large radial forces from the pre-stress system acting inwards. The resultant minimum required compressive strength of the concrete for *Prometheus* was 1053psi and the minimum required modulus of rupture was 262psi.

Development and Testing

The mix design team managed the research and development of a resilient, lightweight concrete mix, capable of meeting the structural analysis requirements for *Prometheus.* Due to failing the flotation test in the previous year, the team's primary goal was to increase the safety factor for buoyancy. The team aimed to design a structural mix with a unit weight less than 58 pcf, significantly increasing the safety factor from *Incendium.* To achieve this goal, the mix design team decided that time must be allocated towards the research and testing of new materials, in order to improve unit weight and strength of the concrete. Through extensive research and adhering to ASTM test procedures, managers evaluated the individual and composite properties of the concrete, resulting in the construction of a competitive final product.

Incendium's structural mix served as a foundation for *Prometheus,* due to its carefully constructed aggregate gradation that provided its strength and buoyancy. Type 1 white portland cement, vitreous calcium aluminosilicate (VCAS^{TM}), grounded-granulated blast furnace slag (GGBFS), and Hydrated Lime Type S made up the cementitious materials. The aggregate gradation consisted of recycled glass Poraver® Siscorspheres ranging in size from 0.1 to 4 mm in diameter, engineered polymeric spheres Syntheon® Elemix^{TM}, Q-Cel® 6019S, and Cinder Sand (ASTM C330) retained on the #4 and #8 sieves. Polyvinyl alcohol (PVA) fibers were added at 0.87 percent by volume to increase the flexural strength. Admixtures consisted of ADVA® Cast 575, a high range water reducer (HRWR), which improved the workability of the concrete, V-MAR® F100, a viscosity modifier that stabilized the mix constituents, and Hycrete® X1002, a permeability-reducer that decreased moisture absorption. In order to achieve an air content of 16 percent, Daravair® AT30, an air entraining admixture (AEA), was incorporated. Following the initial trail batch of this mix, the design team performed compressive strength tests on 2 in. x 4 in. cylindrical samples at 7, 14, and 28 day intervals and found a 28-day compressive strength of 1200 psi (ASTM C39) and a dry unit weight of 59.3 pcf (ASTM C138).

The mix design team concluded that Cinder Sand's high specific gravity would not allow the team to achieve its primary goal. So the team decided to explore other possible ASTM C330 compliant structural lightweight aggregates that meet the requirements set by the CNCCC. After investigating several, the mix design team decided upon Haydite, an aggregate made from expanded shale, clay, and slate. The team performed a sieve analysis on the aggregate, collecting the retained material on the #8, #16, and #30 sieves (ASTM C136). This allowed the mix design team to have better control over the amount of each particle size to contribute to the mix designs. The sieved out material was sent to a local testing firm to perform the specific gravity and absorption test (ASTM C127). Haydite proved to have a lower specific gravity than Cinder Sand, allowing the team to select finer sizes than in the previous year (Table 4). This provided a finer aggregate gradation, making it easier for packing between the reinforcement.

Aggregate	Seive Size	SG_{SSD}	Abs (%)
Cinder Sand	#4	1.93	14.2
	#8	1.98	16.1
	#16	2.18	13.6
Haydite	#8	1.79	19.5
	#16	1.83	20.9
	#30	1.88	19.5

Table 4: Absorption and specific gravity of each selected size of Cinder Sand and

Additional non-ASTM C330 aggregates were researched as well by the mix design team. The team came across an eco-friendly material made from dry silica particulate called Lumira® Aerogel. Its low specific gravity of 0.15, and particle size ranging from 0.15-0.42 mm, made it ideal for replacing Poraver® Siscorspheres 0.25-0.5 mm. The mix managers tested it at 5 percent by volume. And concluded it had little effect on the concrete, only slightly lowering the density. The team then decided to increase the amount to 10 percent by volume, achieving a unit weight of 58.6 pcf. Unfortunately, the high cost of material, lead the mix design managers to conduct further research, excluding it from the final mix design.

The mix design team decided to adjust the aggregate gradation with the introduction of the new ASTM C330 material, Haydite. The material retained on the #8 and #16 sieves were incorporated into the structural mix design. The newly constructed gradation gap consisted of Haydite at 25 percent by volume, Elemix™ at 15 percent by volume, Q-cel at 5 percent by volume, and Poraver® Siscorspheres sizes at 2-4 mm, 0.5-0.1 mm, and 0.25-0.5 mm at 30, 15, and 5 percent by volume, respectively. This produced a mix with a wet unit weight of 57.7 pcf, along with a 28 day compressive strength of 1030 psi and a modulus rupture of 210 psi. The mix design team concluded that having high percent by volume of aggregate retained on the #8 sieve (2.38 mm) resulted in a weak aggregate interlock. Based research from *Zephry's*, the mix design team increased the amount of Q-Cel® 6019S and reduce the amount of Poraver® Siscorspheres 2-4mm. The increase in Q-Cel® 6019S would result in an increase in the compressive strength of the mix with a decrease the air content (NCCT 2016). This aggregate gradation improved the compressive strength by 20 percent and increased the unit weight by 5 percent. The team determined that in order to meet the strength requirements, they had to accept a higher density.

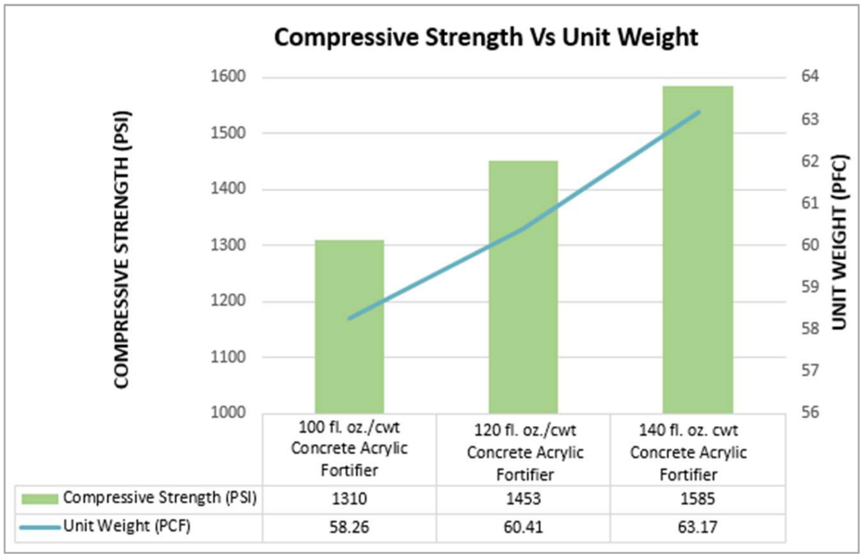


Figure 3: Compressive Strength vs. Unit Weight for QUIKRETE® Concrete Acrylic Fortifier

A latex polymer modifier, QUIKRETE® Concrete Acrylic Fortifier, was added to the mix design to increase the bond between the cementitious material and the aggregate. The goal of using this admixture was to increase the concrete's strength properties of *Prometheus.* The initial dosage was based upon a similar latex polymer modifier used in *Aquatone*, at 90 fl. oz./cwt (NCCT 2015). To meet the strength requirements needed, the team experimented with increasing the dosage. Through experimentation, it was discovered that increasing the QUIKRETE® Concrete Acrylic Fortifier would increase the strength and density of the concrete. In order to verify this relationship, three batches of the same concrete with different dosages of the QUIKRETE® Concrete Acrylic Fortifier were mixed and tested. The results from this testing are shown in figure 3.The design managers concluded that a dosage of 120 fl. oz./cwt would provide a sufficient relationship between unit weight and compressive strength.

The development process continued, admixture dosages were adjusted to optimize the properties of the concrete. The mix design team decided to decrease the dosage of Hycrete® X1002, due to the inclusion of the QUIKRETE® Concrete Acrylic Fortifier also contributing to water resistance. This reduction did not seem to negatively impact the mix, likely because both admixtures exhibit properties of decreasing moisture absorption. Based on previous Nevada canoe teams, the mix design team concluded that admixture dosages above the manufacturer's recommendation were necessary for many of the admixtures used to achieve a high strength, workable, and light weight concrete. Consultation with alumni verified that the use of increased dosages in these cases did not adversely affect the

Admixture	Type	Recommended Dosage (fl. oz./cwt)	Actual Dosage (fl. oz./cwt)
ADVA® Cast 575	HRWR	2-10 fl. oz./cwt	45 fl. oz./cwt
Hycrete® X1002	PRAH	34 fl. oz./cwt	20 fl. oz./cwt
Daravair® AT30	AEA	0.25-3 fl. oz./cwt	14 fl. oz./cwt
V-MAR® F100	VMA	3-12 fl. oz./cwt	35 fl. oz./cwt
QUIKRETE® Concrete Acrylic Fortifier	PMA	N/A	120 fl. oz./cwt
Hydrated Lime	S	N/A	53 g

Table 5: Admixture dosages

concrete properties and none were observed during trail batching. Table 5 summarizes the final admixture dosages used in the structural mix. After a final selection of aggregate and admixture proportions, the team created a final structural mix with a dry unit weight of 57 pcf and an air content of 8.3 %.

The structural analysis determined that the concrete required a minimum modulus of rupture of 260 psi. The final structural mix exceeded this requirement, with a 28 day modulus of rupture of 310 psi (ASTM C78/C78-16b). Based on its low density and high modulus of elasticity shown in previous years, carbon fiber mesh was chosen as the primary reinforcement for *Prometheus*. The 1.5 in. x 1.5 in. openings in the carbon fiber mesh resulted in an 86.6 percent open area. This provided sufficient amount of space, ensuring a quality casting of the canoe. To further increase the composite flexural strength of the concrete, the carbon fiber mesh applied in two layers. Combined with the two layers of carbon fiber reinforcement, the structural mix acquired a composite flexural strength of 1250 psi. The final test results along with the required strengths are illustrated in Table 6. These results assured the project managers that *Prometheus* would be able to withstand the rigors faced in competition. In addition to carbon fiber mesh, the canoe was pretensioned using Kevlar® synthetic fiber rope. The pretensioned cables put the canoe in a state of compression, improving the structural strength. Kevlar® rope was selected due to its lightweight properties and ability to withstand high tensile loads. Tests from *Zephyr* proved that concrete could adhere to Kevlar®, while still being able to withstand the tensile loads applied (NCCT 2016).

Property	Analysis Requirements	Actual Results
Compressive Strength (psi)	1100	1470
Modulus of Rupture (psi)	260	310
Composite Flexural Strength (psi)	N/A	1250

Table 6: Final Concrete Properties

Although the structural mix for *Prometheus* was lighter than the previous year, the mix design team still felt it was necessary to replace the concrete inside the bulkheads with foam to maintain a reasonable safety factor. The team determined that 10 pcf foam left over from the form would be sufficient in increasing the buoyancy. In order to meet the required strengths, the foam was layered, with concrete carefully placed in between each layer. This combined with a layer of concrete on the outside gave the bulkheads the strength to withstand any expected loads or impacts.

The design team developed a patch mix to fill in surface imperfections, while maintaining pigment consistency of the structural mix. The water-to-cementitious material ratio was increased from 0.4 to 0.45 to create a more workable mix. Aggregate sizes were reduced to create a mix that could easily be applied to smoothing over surface imperfections. The largest aggregate selected was Haydite, retained on the #16 (1.19 mm) sieve. This size was selected because of its low specific gravity of 1.51 along with being small enough to fill surface voids.

In previous years, upon the removal of canoe from the male form, the inside of the canoe was coated with a thin layer of patch mix. This served to smooth over any imperfections and voids, as well as to provide aesthetic appeal. Last year required a significant amount of mix to be used on the interior, as there were many voids upon removal from the form. Worried that the higher density of the patch mix would significantly increase the overall weight of the canoe if used for the interior, the design managers created a low density interior patch mix, suited for the inside of the canoe. In order to still meet the CNCCC standards and have a low unit weight, large amounts of Elemix™ at 25 percent by volume were used in the mix. This achieved a mix with unit weight of 59.9 pcf and a low compressive strength of 990 psi. Concerned about its low strength, the mix design team decided to use the patch mix to fill in the major voids along the interior and use the interior patch to cover the rest of the interior. *Prometheus's* mix design team strategically developed a light weight concrete, while meeting the design requirements and maintaining sustainability, to achieve a competitive final product.

Construction

Project managers created a construction schedule that reflected milestones for task completion. The relaxed construction schedule ensured that there was a sufficient amount of time to complete tasks in an efficient yet careful manner. Despite multiple delays throughout the construction process and a two-week discrepancy between preliminary and actual casting day, the team was still able to complete the canoe finishing processes in the nine weeks leading up to the competition. The team incorporated new construction techniques into the preexisting procedures in order to increase efficiency and quality of work conducted.

A 10 pcf polyurethane foam mold was used as a male mold form for *Prometheus*. Foam procurement was delayed by two weeks due to scheduling conflicts between material donors and team members. The team designed the form in three sections, created a center key piece using angled cuts along three different sections of the form. These three sections were cut into the desired shape using CNC machine. This would aid in future form removal after completion of the curing process. When the form arrived at the team's workspace, members carefully arranged each section on to the work table, ensuring it was properly centered and secured to the table.

Once division managers and project managers inspected and assured the alignment and centering of the form was completed correctly, the team attentively sanded the angular edges of the foam with 120 grit sand paper to create the desired smooth and rounded shape of the canoe. The unsmoothed edges of the form can be seen in figure 4.The team then measured the bulkheads and rib locations in preparation of secondary reinforcement. The members of the construction division removed the bulkheads fifteen inches from the bow and eighteen inches from the stern and cut the four ribs at four and a quarter feet interval along the form. Members then cut half inch deep rectangles in the form centerpiece to place four metal plates and threaded rods to aid in form removal. Team members then filled large holes and cuts with Bondo® body filler and allowed it to set for two days. Once the filler was completely hardened, team members sanded the sharp edges of the newly cut bulkheads and ribs and the surfaces that had been filled with Bondo®.

Figure 4:CNC machine cutting polyurethane foam

After the group effort of shaping the delicate features of the form, the construction manager and project managers applied six coats of Duratec™ industrial primer to create a smooth surface that the concrete would not bond to the form. After application of the primer, the management team realized that the catalyst for the two-part primer was not added prior to application and failed to harden. The team members took measures to carefully remove the unhardened Duratec™ through sanding processes then reapplied more coats of the primer, ensuring the catalyst was added. This incident caused a week of delay in form preparation. Following hardening of the primer, team members lightly sanded the Duratec™ with 1500 grit sand paper to ensure the surface was as smooth as possible before adding mold release wax to aid in form removal.

After completion of primer and wax application, a series of grade screws were diligently mapped in accordance to tendon placement along the canoe, which were also used as depth indicators along the boat. These grade screws, along with additional depth indicators during concrete casting would ensure the desired shape and uniform thickness of *Prometheus*.

Before application of the pre-stress system, preemptive measures were taken to ensure the table did not move or bend under the load of the tendons as it has in previous years. Team members applied and tightened ratchet straps around the bottom of the table and added roughly 300 pounds of weight to help counteract the loads created on the table by the Kevlar® tendons. When beginning the assembly of the pre-stress system, the team came across problems with the newer Kevlar® that was purchased and found that the full tensile load could not be applied. The application of the primary reinforcement was subsequently delayed by a week to receive adequate materials. Meanwhile, other members of the construction division prepared the carbon-fiber mesh by means of tying two layers of the grids together with fishing line (figure 5). After completion of primary reinforcement application, the entre construction division cautiously tied the carbon fiber reinforcement to the tendons under the supervision of division managers and project managers, ensuring appropriate spacing between the form and sheets.

Figure 5: Team members securing layers of carbon fiber reinforcement

Preceding casting day, the aesthetics team drew *Prometheus*' intricate design onto the form and labeled it to mitigate design errors during casting day. The entire team came together on casting day to hand-pack the concrete onto the form. Beginning at the bow, the team packed across the form, paying close attention to the well-defined branch lines. With a total of 26 team members taking predetermined shifts throughout the day, packing took 19 hours to complete.

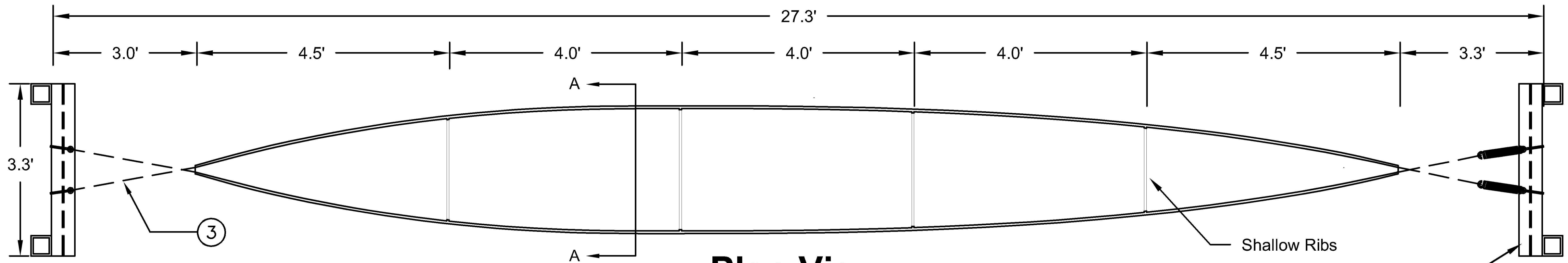
The wet-cure process occurred over 28 days, during which time finishing was carried out. For the first seven days, team members watered the canoe manually every four hours to ensure proper humidity during strengthening. After the first week or curing, an automatic watering and capture system was implemented to release water every six hours. At the time of this report, the team has begun wet sanding and will continue to sand throughout the curing process. Similar to the process during *Zephyr*, members will likely have to take extra precautions when sanding to ensure none of the colors in the design bleed.

After completion of curing, the team will continue to sand until all depth indicating screws are located. Once all grade screws are found and removed, the team will remove the form from the canoe by attaching wooden planks to the threaded rods and removing the pieces of the form. The voids and holes left by the grade screws will be filled with green and brown patch mix where necessary. The team will continue to sand the inside and outside of the boat in the weeks leading up to competition. The team will use up to 1500 grit sand paper to reduce frictional drag in the water while only sanding up to 400 grit on the inside to enhance paddler traction during races. After completion of sanding, the construction and aesthetics divisions will work together to apply the University and canoe names and finish sealing.

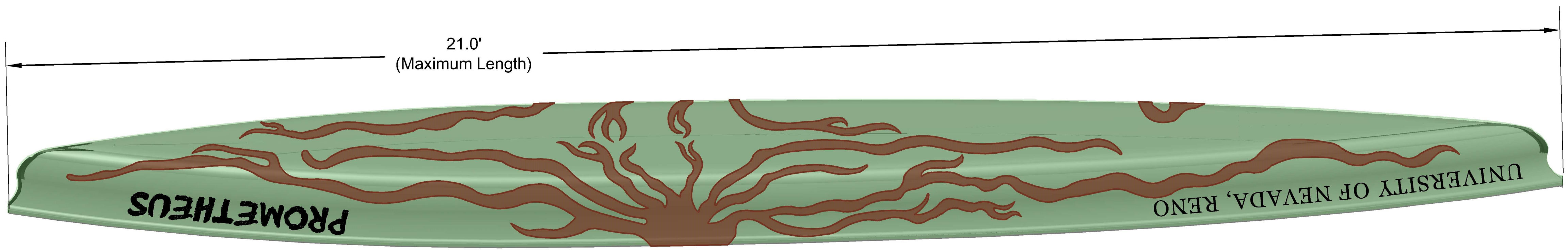
ID	Task Name	Duration	Start	Finish	Baseline Start	Baseline Finish
1	Project Start	0 days	9/8/17	9/8/17	9/8/17	9/8/17
2	Rules Release	0 days	9/8/17	9/8/17	9/8/17	9/8/17
3	Recruitment	14 days	9/8/17	9/22/17	9/8/17	9/22/17
4	Fundraising	205 days	9/8/17	4/1/18	9/8/17	3/9/18
5	**Hull Design**	**21 days**	**9/7/17**	**9/28/17**	**9/8/17**	**10/21/17**
6	Research	21 days	9/7/17	9/28/17	9/8/17	10/21/17
7	Hull Design Complete	0 days	9/28/17	9/28/17	10/21/17	10/21/17
8	**Structural Analysis**	**26 days**	**9/28/17**	**10/24/17**	**10/28/17**	**1/3/18**
9	Computer Software Learning	14 days	9/28/17	10/12/17	10/28/17	11/2/17
10	Composite Analysis & Design	8 days	10/12/17	10/20/17	11/4/17	11/13/17
11	Longintudinal Tendon Design	4 days	10/20/17	10/24/17	12/21/17	1/3/18
12	Analysis Complete	0 days	10/24/17	10/24/17	1/3/18	1/3/18
13	**Concrete Mix Design**	**148 days**	**9/8/17**	**2/3/18**	**9/8/17**	**2/9/18**
14	Material Procurement	54 days	9/8/17	11/1/17	9/8/17	10/10/17
15	Research	40 days	9/8/17	10/18/17	9/8/17	11/18/17
16	Preliminary Design & Testing	67 days	10/31/17	1/6/18	10/31/17	1/9/18
17	Final Material Testing	12 days	1/6/18	1/18/18	1/9/18	1/23/18
18	Aestetics Testing	8 days	1/7/18	1/15/18	1/23/18	1/26/18
19	Final Mix Selection	0 days	1/18/18	1/18/18	1/26/18	1/26/18
20	Pre-Weigh Materials	15 days	1/18/18	2/2/18	1/26/18	2/9/18
21	**Construction**	**220 days**	**9/8/17**	**4/16/18**	**9/22/17**	**4/17/18**
22	Laboratory Organization	14 days	9/22/17	10/6/17	9/22/17	10/13/17
23	Form Table Construction	1 day	10/6/17	10/7/17	10/14/17	10/15/17
24	Curing System Construction	2 days	10/7/17	10/9/17	12/27/17	12/29/17
25	Build Form	1 day	10/20/17	10/21/17	11/17/17	11/18/17
26	Form CNC	1 day	10/21/17	10/22/17	11/18/17	11/19/17
27	**Form Preparation**	**11 days**	**10/22/17**	**11/2/17**	**11/25/17**	**1/4/18**
28	Sanding	4 days	10/22/17	10/26/17	11/25/17	12/3/17
29	Bondo	3 days	10/26/17	10/29/17	12/4/17	12/15/17
30	Duratec	2 days	10/29/17	10/31/17	12/16/17	1/2/18
31	Wax	2 days	10/31/17	11/2/17	1/3/18	1/4/18
32	Grade Screw Installation	6 days	11/2/17	11/8/17	1/6/18	1/19/18
33	Tendon Installation	7 days	11/8/17	11/15/17	1/22/18	2/5/18
34	Tie Reinforcement	7 days	11/15/17	11/22/17	2/6/18	2/9/18
35	Canoe Casting	1 day	2/2/18	2/3/18	2/10/18	2/11/18
36	Canoe Casting Complete	0 days	2/3/18	2/3/18	2/11/18	2/11/18
37	Concrete Preliminary Curing	7 days	2/3/18	2/10/18	2/11/18	2/18/18
38	Concrete Final Curing	21 days	2/11/18	3/4/18	2/18/18	3/11/18
39	Wet Sanding	21 days	2/10/18	3/3/18	2/18/18	3/11/18
40	Prestress Tendon Release	1 day	3/4/18	3/5/18	3/11/18	3/12/18
41	Grade Screw Removal	1 day	3/3/18	3/4/18	3/30/18	3/31/18
42	**Finishing**	**220 days**	**9/8/17**	**4/16/18**	**1/5/18**	**4/17/18**
43	Sealer Research and Testing	45 days	9/8/17	10/23/17	1/5/18	2/15/18
44	Patching/Sanding Exterior	20 days	3/4/18	3/24/18	3/31/18	4/7/18
45	Patching/Sanding Interior	20 days	3/24/18	4/13/18	4/7/18	4/15/18
46	Sealing	2 days	4/13/18	4/15/18	4/16/18	4/17/18
47	Canoe Complete	0 days	4/15/18	4/15/18	4/17/18	4/17/18
48	Cross Section	36 days	10/22/17	11/27/17	12/16/17	3/25/17
49	Display Table	36 days	2/4/18	3/12/18	3/2/18	4/13/18
50	**Design Report**	**39 days**	**2/4/18**	**3/15/18**	**2/5/18**	**3/16/18**
51	Rough Draft	10 days	2/4/18	2/14/18	2/5/18	2/19/18
52	Peer/Professional Edit	20 days	2/14/18	3/6/18	2/19/18	3/10/18
53	Final Revision/Review	5 days	3/6/18	3/11/18	3/10/18	3/13/18
54	Printing	4 days	3/11/18	3/15/18	3/13/18	3/16/18
55	Paper Complete	0 days	3/15/18	3/15/18	3/16/18	3/16/18
56	**Oral Presentation**	**28 days**	**3/15/18**	**4/12/18**	**3/18/18**	**4/18/18**
57	Compose Verbal Presentation	7 days	3/15/18	3/22/18	3/18/18	3/24/18
58	Compose Visual Presentation	7 days	3/22/18	3/29/18	3/24/18	3/29/18
59	Practice and Critique	14 days	3/29/18	4/12/18	3/29/18	4/18/18
60	**Paddling**	**175 days**	**9/22/17**	**3/16/18**	**10/7/17**	**4/15/18**
61	Tryouts	8 days	9/22/17	9/30/17	10/7/17	10/15/17
62	Team Selection	7 days	9/30/17	10/7/17	10/15/17	10/21/17
63	Paddling Practice/Conditioning	160 days	10/7/17	3/16/18	10/21/17	4/15/18
64	Mid-Pacific Conference Prep	4 days	4/15/18	4/19/18	4/18/18	4/19/18
65	Mid-Pacific Conference	0 days	4/19/18	4/19/18	4/19/18	4/19/18

Prometheus
Project Schedule
Date: 3/09/2018

Ta sk | Milest one | Sum mary | Criti cal | Base line | ine Milest | ne Sum



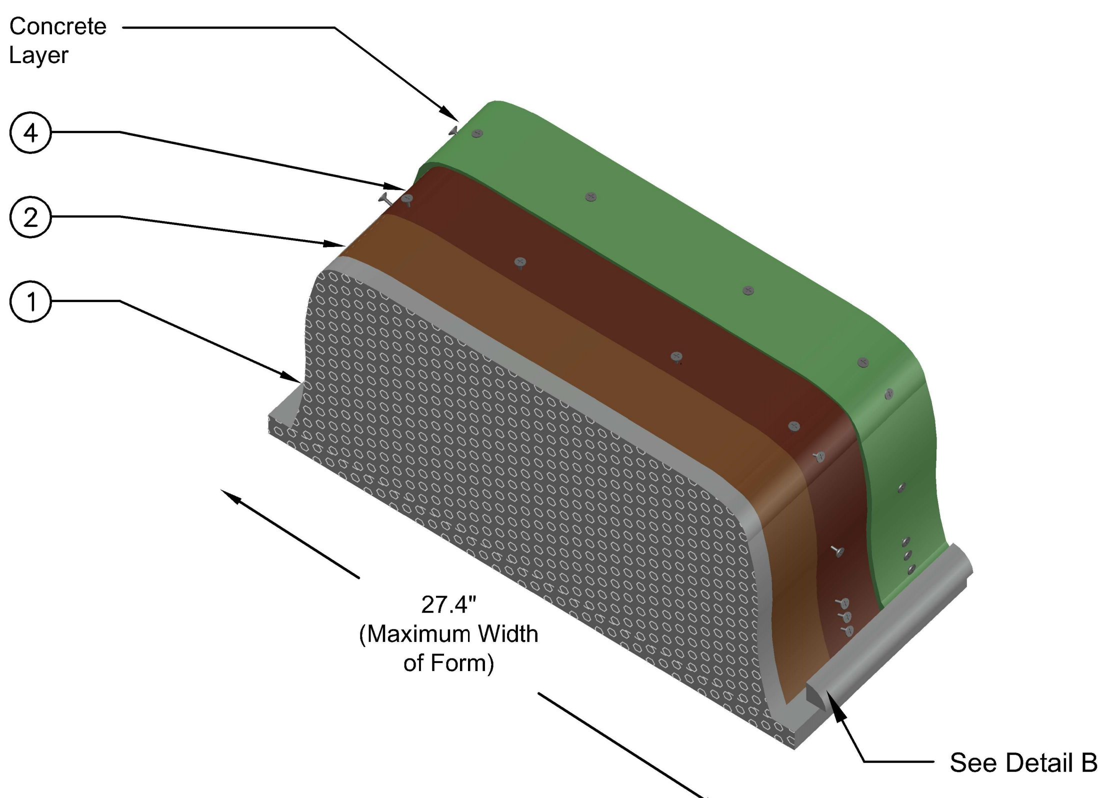
Plan View



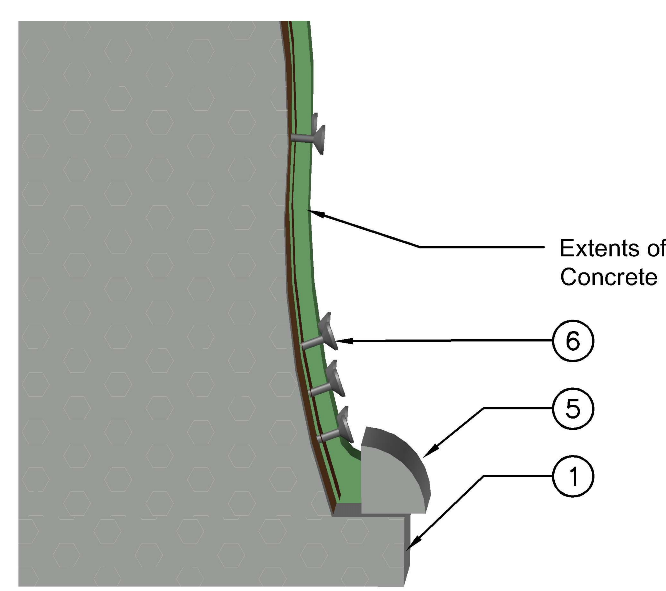
Elevation View

General Notes:

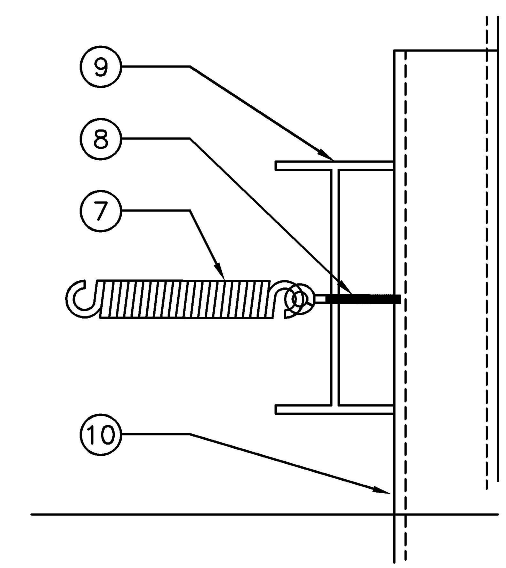
1. Drawings not to scale
2. Only two longitudinal prestress anchorages are shown for clarity
3. Total longitudinal prestressing force: P_{jack}=4.4 kips



Section A - A
Widest Section



Detail B
Gunwale



Detail C
Longitudinal Prestress Anchorage

University of Nevada, Reno
Concrete Canoe

Bill of Materials

	Qty	Description
	50.6 lbs.	Type 1 White Portland Cement
	92.7 lbs.	VCAS-140™
	16.9 lbs.	NewCem® Slag Cement
	69.2 lbs.	Haydite #8
	32.8 lbs.	Haydite #16
	20.3 lbs.	Poraver® Siscorspheres (.25-0.5 mm)
	33.4 lbs.	Poraver® Siscorspheres (.5-1 mm)
	19.0 lbs.	Poraver® Siscorspheres (2-4 mm)
	4.1 lbs.	Q-Cel® 6019S
	1.6 lbs.	Elemix™
	9.4 lbs.	Hydrated Lime Type S
	15.2 fl. oz.	Concrete Acrylic Fortifier
	82.1 fl. oz.	ADVA® Cast 575 (HRWR)
	32.1 fl. oz.	Hycrete® X1002
	24.6 fl. oz.	Daravair® AT30 (AEA)
	61.9 fl. oz.	V-Mar® F100 (VMA)
	2.5 lbs.	Nycon® PVA Fibers (8 mm)
	2.5 lbs.	Nycon® PVA Fibers (12 mm)
	1.4 lbs.	Powder Pigments
	4 units	Transverse Threaded Steel Rod
	138.0 sq. ft.	CT 272 Carbon Fiber Grid
	36 units	Ferrule and Stopper
	4 sq. ft.	Steel Mesh
	90 fl. oz.	Sealer
	1 unit	Vinyl Lettering
1	32 cu. ft.	Expanded Polyurethane Foam
2	3.5 gal.	Duratec® (Surface Treatment)
3	400 ft.	Kevlar® Cable
4	2 gal.	Bondo®
5	42 ft.	Quarter Round Molding (3/4" x 3/4")
6	356 ct.	Grade Screws
7	16 ct.	Steel Spring (L: 6" W: 1.5" k=0.2 k/in)
8	32 ct.	Eye Bolts/Nuts (L: 6" Dia: 1/2")
9	2 ct.	W 12 x 22
10	4 ct.	HSS 3-1/2" x 3-1/2" x 3/8"

PROMETHEUS

Design Drawing

Date: 3/09/2018

Engineers: M. Brock, Z. Stock

Drawn By: J. GUANTONE, A. HANSEN

Appendix A: References

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Appendix B: Mixture Proportions

Mixture Designation: Structural Mix

Cementitious Materials				
Component	*Specific Gravity*	*Volume (ft³)*	*Amount of CM (mass/volume) (lb/yd³)*	
Portland Cement, Type I, (White)	3.15	0.965	189.6	*Total Amount of cementitious materials* **600.4** *lb/yd³* *c/cm ratio* **0.32**
VCAS-140™	2.6	2.143	347.6	
NewCem® Slag Cement	2.87	0.353	63.2	

Fibers				
Component	*Specific Gravity*	*Volume (ft³)*	*Amount of Fibers (mass/volume) (lb/yd³)*	
Nycon PVA Fibers (8 mm)	1.3	0.117	9.52	*Total Amount of Fibers* 19.04 *lb/yd³*
Nycon PVA Fibers (12 mm)	1.3	0.117	9.52	

Aggregates							
Aggregates	*ASTM C330**	*Abs (%)*	*SG$_{OD}$*	*SG$_{SSD}$*	*Base Quantity (lb/yd³)*		*Volume (ft³)*
					OD	*SSD*	
Q-Cel® 6019S		2	0.19	0.194	*15.8*	16.2	1.337
Poraver® Siscorspheres 0.25-0.5 mm		15	0.75	0.86	*78.2*	89.9	1.671
Poraver® Siscorspheres 0.5-1.0 mm		9	0.56	0.61	*128.4*	140.0	3.676
Elemix™		5.5	0.04	0.042	*6.3*	6.6	2.505
Poraver® Siscorspheres 2-4 mm		7	0.35	0.37	*73.0*	78.1	3.342
Haydite #16	Y	20.9	1.51	1.83	*126.0*	152.3	1.337
Haydite #8	Y	19.5	1.50	1.79	*265.9*	317.7	2.840

Admixtures					
Admixture	*lb/gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd³)*	
QUIKRETE® Concrete Acrylic Fortifier	8.5	120	30	33.50	*Total Water from Admixtures,* $\sum w_{admx}$ **65.93** *lb/yd³*
ADVA® CAST 575 (HRWR)	8.9	45	40	11.27	
Daravair® AT30 (AEA)	8.3	14	5	5.18	
V-MAR® F100 (VMA)	8.4	35	35	8.96	
Hycrete X1002 (PRAH)	8.8	20	15	7.02	

Solids (Latex, Dyes, and Powdered Admixtures)				
Component	*Specific Gravity*	*Volume (ft³)*	*Amount (mass/volume) (lb/yd³)*	
QUIKRETE® Concrete Acrylic Fortifier	1.02	0.226	14.36	*Total Solids from Admixtures* **52.70** *lb/yd³*
*Powdered Pigment**	1.35	0.080	6.74	
Hydrated Lime Cement Type S	2.6	0.195	31.60	

Water			
	Amount (mass/volume) (lb/yd³)		*Volume (ft³)*
Water, lb/yd³		w: 240.19	3.849
Total Free Water from All Aggregates, lb/yd³		$\sum w_{free}$: -107.22	
Total Water from All Admixtures, lb/yd³		$\sum w_{admx}$: 65.93	
Batch Water, lb/yd³		w_{batch}: 281.49	

Densities, Air Content, Ratios and Slump						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	600.48	19.04	693.53	52.70	240.19	$\sum M$: 1605.94
Absolute Volume of Concrete, V, (ft³)	3.460	0.235	16.707	0.500	3.849	$\sum V$: 24.752
Theoretical Density, T, *(=∑M / ∑V)*	64.88 lb/ft³		***Air Content*** *[= (T – D)/T x 100%]*			8.3%
Measured Density, D	59.48 lb/ft³		***Slump, Slump flow***			1 in.
water/cement ratio, w/c:	1.267		***water/cementitious material ratio, w/cm:***			0.4

**Powder pigment colors vary*

Appendix B: Mixture Proportions

Mixture Designation: Patch Mix

Cementitious Materials				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Portland Cement, Type I, (White)	3.15	0.965	189.62	*Total Amount of cementitious materials* **600.4** lb/yd^3 *c/cm ratio* **0.32**
VCAS-140™	2.6	2.143	347.65	
NewCem® Slag Cement	2.87	0.353	63.21	

Aggregates							
Aggregates	*ASTM C330**	*Abs (%)*	SG_{OD}	SG_{SSD}	*Base Quantity (lb/yd^3)* OD	*Base Quantity (lb/yd^3)* SSD	*Volume (ft^3)*
Q-Cel® 6019S		2	0.19	0.194	9.8	10.0	0.827
Poraver® Siscorspheres 0.1-0.3 mm		22	0.90	1.0	46.6	56.6	0.827
Poraver® Siscorspheres 0.25-0.5 mm		15	0.75	0.86	77.4	89.0	1.653
Poraver® Siscorspheres 0.5-1.0 mm		9	0.56	0.61	231.1	251.9	6.614
Poraver® Siscorspheres 1-2 mm		7	0.44	0.47	68.1	72.9	2.480
Haydite #30	Y	19.5	1.57	1.88	275.4	329.1	2.811
Haydite #16	Y	20.9	1.51	1.83	124.6	1501.7	1.323

Admixtures					
Admixture	*lb/gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
QUIKRETE® Concrete Acrylic Fortifier	8.5	120	30	33.50	*Total Water from Admixtures,* $\sum w_{admx}$ **65.93** lb/yd^3
ADVA® CAST 575 (HRWR)	8.9	45	40	11.27	
Daravair® AT30 (AEA)	8.3	14	5	5.18	
V-MAR® F100 (VMA)	8.4	35	4	8.96	
Hycrete X1002 (PRAH)	8.8	20	15	7.02	

Solids (Latex, Dyes, and Powdered Admixtures)				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
QUIKRETE® Concrete Acrylic Fortifier	1.02	0.169	14.36	*Total Solids from Admixtures* **52.70** lb/yd^3
*Powdered Pigment**	1.35	0.080	6.74	
Hydrated Lime Cement Type S	2.6	0.195	31.60	

Water			
	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		*w*: 270.22	4.330
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -127.33	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: 65.93	
Batch Water, lb/yd^3		w_{batch}: 331.61	

Densities, Air Content, Ratios and Slump						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	600.48	0.00	832.80	52.70	270.22	$\sum M$: 1756.19
Absolute Volume of Concrete, V, (ft^3)	3.460	0.000	16.534	0.500	4.330	$\sum V$: 24.825
Theoretical Density, T, *($=\sum M / \sum V$)*	70.74 lb/ft³		***Air Content*** *[= (T – D)/T x 100%]*			8.1%
Measured Density, D	65.04 lb/ft³		***Slump, Slump flow***			3 in.
water/cement ratio, w/c:	1.425		***water/cementitious material ratio, w/cm:***			0.45

**Powder pigment colors vary*

Appendix B: Mixture Proportions

Mixture Designation: Interior Patch Mix

Cementitious Materials

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Portland Cement, Type I, (White)	3.15	0.952	187.1	*Total Amount of cementitious materials* **530.10** *lb/yd^3* *c/cm ratio* **0.35**
VCAS-140™	2.6	1.538	249.46	
NewCem® Slag Cement	2.87	0.522	93.54	

Aggregates

Aggregates	*ASTM C330**	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*Volume (ft^3)*
					OD	*SSD*	
Q-Cel® 6019S		2	0.19	0.194	6.0	6.2	0.509
Poraver® Siscorspheres 0.25-0.5 mm		15	0.75	0.86	39.8	45.7	0.850
Poraver® Siscorspheres 0.5-1.0 mm		9	0.56	0.61	160.3	174.7	4.587
Poraver® Siscorspheres 1-2 mm		7	0.44	0.47	70.0	74.9	2.548
Elemix™		5.5	0.04	0.042	10.6	11.2	4.247
Haydite #16	Y	20.9	1.51	1.83	400.2	483.8	4.247

Admixtures

Admixture	*lb/gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
QUIKRETE® Concrete Acrylic Fortifier	8.5	120	30	29.57	*Total Water from Admixtures, $\sum w_{admx}$* **58.20** *lb/yd^3*
ADVA® CAST 575 (HRWR)	8.9	45	40	9.95	
Daravair® AT30 (AEA)	8.3	14	5	4.57	
V-MAR® F100 (VMA)	8.4	35	4	7.91	
Hycrete X1002 (PRAH)	8.8	20	15	6.20	

Solids (Latex, Dyes, and Powdered Admixtures)

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
QUIKRETE® Concrete Acrylic Fortifier	1.02	0.169	12.67	*Total Solids from Admixtures* **112.96** *lb/yd^3*
*Powdered Pigment**	1.35	0.080	6.74	
Hydrated Lime Cement Type S	2.6	0.58	93.54	

Water

	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		*w*: 212.04	3.398
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -109.63	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: *58.20*	
Batch Water, lb/yd^3		w_{batch}: 263.47	

Densities, Air Content, Ratios and Slump

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	530.10	0.00	686.86	112.95	212.04	$\sum M$: 1541.95
Absolute Volume of Concrete, V, (ft^3)	3.012	0.000	16.989	0.865	3.398	$\sum V$: 24.254
Theoretical Density, T, *($=\sum M / \sum V$)*	63.57 lb/ft^3		***Air Content*** *[= (T – D)/T x 100%]*			10.2%
Measured Density, D	57.11 lb/ft^3		***Slump, Slump flow***			1 in.
water/cement ratio, w/c:	1.133		***water/cementitious material ratio, w/cm:***			0.4

**Powder pigment colors vary*

Appendix B: Mixture Proportions

Structural Mix Calculations

Step 1 Cementitious Materials

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

Portland Cement, Type 1, (white)

$$V = \frac{189.6\ lb}{3.15 * 62.4 \frac{lb}{ft^3}} = 0.965\ ft^3$$

VCAS-140™

$$V = \frac{347.6\ lb}{2.6 * 62.4 \frac{lb}{ft^3}} = 2.143\ ft^3$$

NewCem® Slag Cement

$$V = \frac{63.2\ lb}{2.87 * 62.4 \frac{lb}{ft^3}} = 0.353\ ft^3$$

$$\Sigma V_{cement} = 0.965\ ft^3 + 2.143\ ft^3 + 0.353\ ft^3 = 3.460\ ft^3$$

$$\Sigma M_{cement} = 189.6\ lb + 347.6\ lb + 63.2\ lb = 600.4\ lb$$

$$\frac{c}{cm} = \frac{189.6\ lb}{600.4\ lb} = 0.32$$

Step 2 Fibers

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

Nycon PVA Fibers (8 mm)

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

Nycon PVA Fibers (12 mm)

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

$$\Sigma V_{fibers} = 0.117\ ft^3 + 0.117\ ft^3 = 0.235\ ft^3$$

$$\Sigma M_{fibers} = 9.52\ lb + 9.52\ lb = 19.04\ lb$$

Step 3 Aggregates

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

Q-Cel® 6019S

$$V = \frac{15.8\ lb}{0.190 * 62.4 \frac{lb}{ft^3}} = \frac{16.2\ lb}{0.194 * 62.4 \frac{lb}{ft^3}} = 1.337\ ft^3$$

Poraver® Siscorspheres 0.25-0.5 mm

$$V = \frac{78.2\ lb}{0.75 * 62.4 \frac{lb}{ft^3}} = \frac{89.9\ lb}{0.86 * 62.4 \frac{lb}{ft^3}} = 1.671\ ft^3$$

Poraver® Siscorspheres 0.5-0.1 mm

$$V = \frac{128.4\ lb}{0.56 * 62.4 \frac{lb}{ft^3}} = \frac{140\ lb}{0.61 * 62.4 \frac{lb}{ft^3}} = 3.676\ ft^3$$

Elemix™

$$V = \frac{6.3\ lb}{0.04 * 62.4 \frac{lb}{ft^3}} = \frac{6.6\ lb}{0.042 * 62.4 \frac{lb}{ft^3}} = 2.505\ ft^3$$

Poraver® Siscorspheres 2-4 mm

$$V = \frac{73\ lb}{0.35 * 62.4 \frac{lb}{ft^3}} = \frac{78.1\ lb}{0.37 * 62.4 \frac{lb}{ft^3}} = 3.342\ ft^3$$

Haydite #16

$$V = \frac{126\ lb}{1.51 * 62.4 \frac{lb}{ft^3}} = \frac{152.3\ lb}{1.83 * 62.4 \frac{lb}{ft^3}} = 1.337\ ft^3$$

Haydite #8

$$V = \frac{265.9\ lb}{1.5 * 62.4 \frac{lb}{ft^3}} = \frac{317.7\ lb}{1.79 * 62.4 \frac{lb}{ft^3}} = 2.840\ ft^3$$

$$\Sigma V_{aggregates} = 1.337\ ft^3 + 1.671\ ft^3 + 3.676\ ft^3 + 2.505\ ft^3 + 3.342\ ft^3 + 1.337\ ft^3 + 2.840\ ft^3 = 16.707\ ft^3$$

$$\Sigma M_{aggregates} = 16.2\ lb + 89.9\ lb + 140\ lb + 6.6\ lb + 78.1\ lb + 152.3\ lb + 317.7\ lb = 693.53\ lb$$

$$V_{ASTM\ C330} = \frac{1.337\ ft^3 + 2.840\ ft^3}{693.53\ ft^3} * 100 = 25\%$$

Step 4 Solids

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

Appendix C: Example Structural Calculation

Step 1 Total Applied Forces and Assumptions

Table 1: Values of applied forces from routine calculations

L(x)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
W	0.0	5.3	5.8	6.4	7.1	8.1	8.8	9.3	9.5	9.7	9.8	9.9	10.0	10.0	10.0	10.0	9.9	9.4	8.4	7.4	6.0	5.44
P	0.0	0.0	0.0	0.0	210.0	0.0	0.0	160.0	0.0	0.0	0.0	0.0	0.0	0.0	160.0	0.0	0.0	210.0	0.0	0.0	0.0	0.0
F	0.0	9.3	17.0	26.9	36.8	48.6	57.3	62.4	64.0	65.1	65.2	64.7	63.5	62.3	60.2	58.1	53.9	46.8	33.0	19.4	4.3	0.0
R	0.0	-4.1	-11.2	-20.4	180.4	-40.5	-48.6	106.9	-54.5	-55.4	-55.4	-54.8	-53.5	-52.3	109.9	-48.	-44.1	172.7	-24.57	-12.05	1.64	5.44

Assumptions and Comments:

- 2-dimensional, simply supported beam
- Co-Ed sprint race loading case
- Canoe self-weight is not uniformly distributed
- Buoyant force is determined using the submerged section volume and unit weight of water and the mix which is calculated by the 2008 NCCT's Structural Analysis Spreadsheet.
- Variable R, used to calculate shear forces, is not represented in Figure 1

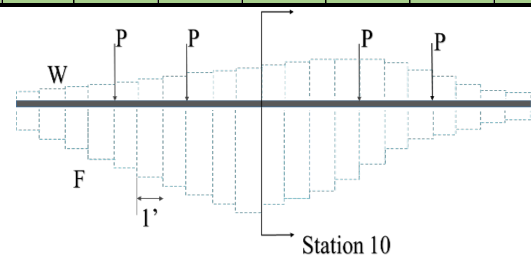

Figure 1: Free Body Diagram

Table Key:

L(x) =	Distance from Bow	[ft.]
P =	Support Reaction	[lb.]
W =	Self-Weight of Canoe	[lb.]
F =	Buoyant Forces	[lb.]

Step 2 Shear Forces

Table 2: Values of shear forces $V(x) = V_{(x-1)} - R_x$ [lb.]

L(x)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
V(x)	0.0	1.7	12.9	33.3	-147.1	-106.6	-58.0	-165.0	-110.5	-55.1	0.3	55.1	108.6	160.9	51.0	99.0	143.1	-29.5	-5.0	7.1	5.4	0.0

Step 3 Moment Forces

Table 3: Values of moment forces $M(x) = \int_{x-1}^{x} V(x)dx$ [lb.−ft.]

L(x)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
M(x)	0.0	-1.8	-0.1	12.8	46.1	-101.0	-207.6	-265.6	-430.6	-541.0	-596.1	-565.8	-540.7	-432.0	-271.2	-220.1	-121.1	22.0	-7.5	-012.5	-5.4	0.0

Comments:

- Shear forces in Figure 2 and bending moments in Figure 3 were calculated at each one foot interval.

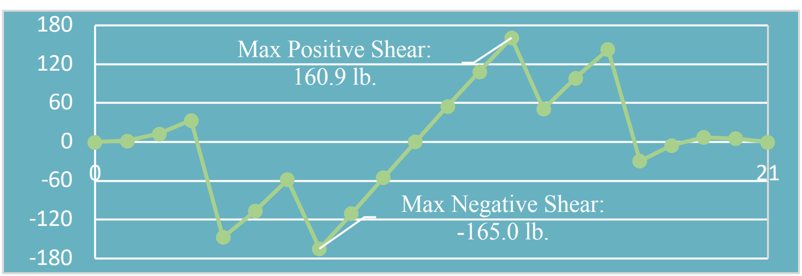

Figure 2: Shear Diagram

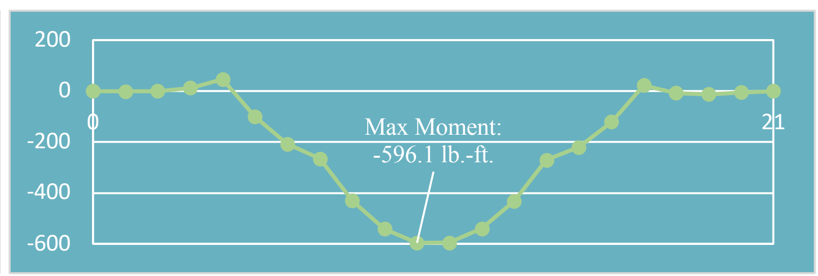

Figure 3: Moment Diagram

Appendix C: Example Structural Calculation Continued

Step 4 Shear and Moment Variables

Comments:

- A load factor of 1.25was added to the max moment to account for dynamic effects (Paradis and Gendron, 2006).
- Max moment occurs at station 10

$$M_{max} = M_{10}$$

$$M_{10} = -596.1\ lb.-ft.$$

$$M_{10} * 1.25 = -745.13\ lb.-ft.$$

$$V_{10} = 0.3\ lb.$$

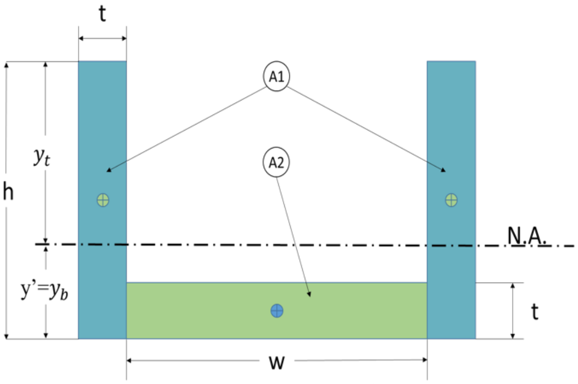

Figure 4: Area at Station 10

Step 5 Define Variables

$t = 0.5\ in.$ $h = 12.47\ in.$ $w = 27.12\ in.$

Step 6 Area Calculations

$$A_1 = t * h \qquad A_1 = 6.24\ in.^2$$

$$A_2 = w * t \qquad A_2 = 13.56 in.^2$$

$$A_{tot} = 2A_1 + A_2 \qquad A_{tot} = 26.04\ in.^2$$

Step 7 Determine Neutral Axis

$$y' = \frac{[2\left(A_1\left(\frac{h}{2}\right)\right)+A_2\left(\frac{t}{2}\right)]}{[2*A_1+A_2]} \qquad y' = 3.12\ in.$$

$$d_1 = \left(\frac{h}{2}\right) - y' \qquad d_1 = 3.12\ in.$$

$$d_2 = y' - t \qquad d_2 = 2.62\ in.$$

$$y_t = h - y' \qquad y_t = 9.35\ in.$$

$$y_b = -y' \qquad y_b = -3.12\ in.$$

Step 8 Moment of Inertia

$$I_1 = \frac{t*h^3}{12} \qquad I_1 = 80.80\ in.^4$$

$$I_2 = \frac{w*t^3}{12} \qquad I_2 = 0.28\ in.^4$$

$$I = 2(I_1 + A_1 * d_1{}^2) + (I_2 + A_2 * d_2{}^2)$$

$$I = 376.45\ in^4$$

Step 9 Determine Internal Stresses Without Pre-stress

$$\sigma_t = \frac{-M*y_t}{I} \qquad \sigma_t = 222.08\ \text{psi Tension}$$

$$\sigma_b = \frac{-M*y_b}{I} \qquad \sigma_b = 74.11\ \text{psi Compression}$$

$$Q = 2(A_1 * d_1) + (A_2 * d_2)$$

$$Q = 74.46\ in^3$$

$$\tau = \frac{V_{10}*Q}{I*(2t)} \qquad \tau = 0.06\ psi$$

Step 10 Tendon Loads

Comments:

- A 1.25 safety factor accounts for pre-stressing losses (AASHTO 2016).
- e = eccentricities from Kevlar® cables (spreadsheet)

$$P = -\frac{4400}{1.25}\ lb.$$

$$P = -3520\ lb.$$

$$e = 2.02\ in.$$

Step 11 Internal Stresses with Pre-stress

$$\sigma_t = \frac{P}{A_{tot}} + \frac{Pey_t}{I} + \frac{-M * y_t}{I}$$

$$\sigma_t = -135.18 - 176.60 + 222.08\ psi$$

$$\sigma_t = -89.70\ psi$$

$$\sigma_b = \frac{P}{A_{tot}} + \frac{Pey_b}{I} + \frac{-M * y_b}{I}$$

$$\sigma_b = -135.18 + 58.93 + 74.11\ psi$$

$$\sigma_b = -2.14\ psi$$

Appendix C: Example Structural Calculation Continued

Table 4: Shows the summary of results of all four calculated loading cases

Load Case	Max Moment [lb.-ft.]	Max Positive Shear [lb.]	Max Negative Shear [lb.]
Display	420.1	75.9	-89.2
Transportation	556.5	88.6	-89.8
Men's Sprint	-1011.0	214.0	-26.8
Co-ed	-596.1	160.9	-165.0

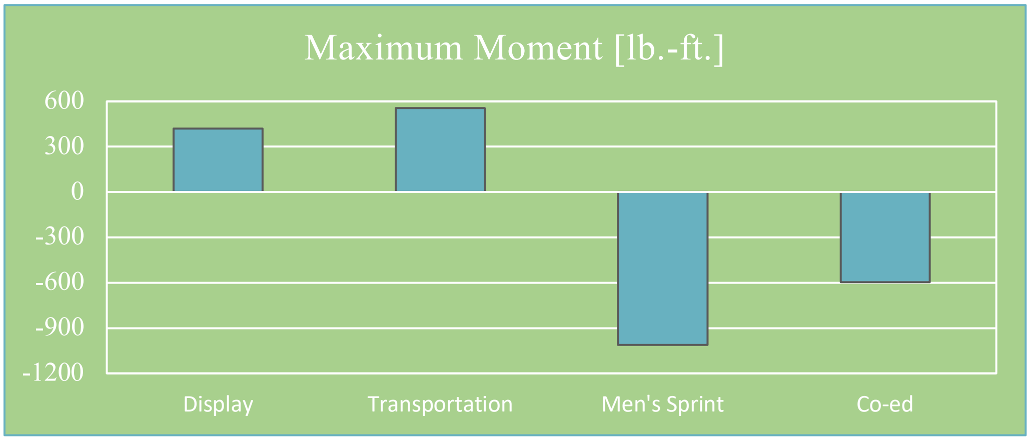

Figure 5: Graphical representation of maximum moments for expected loading cases

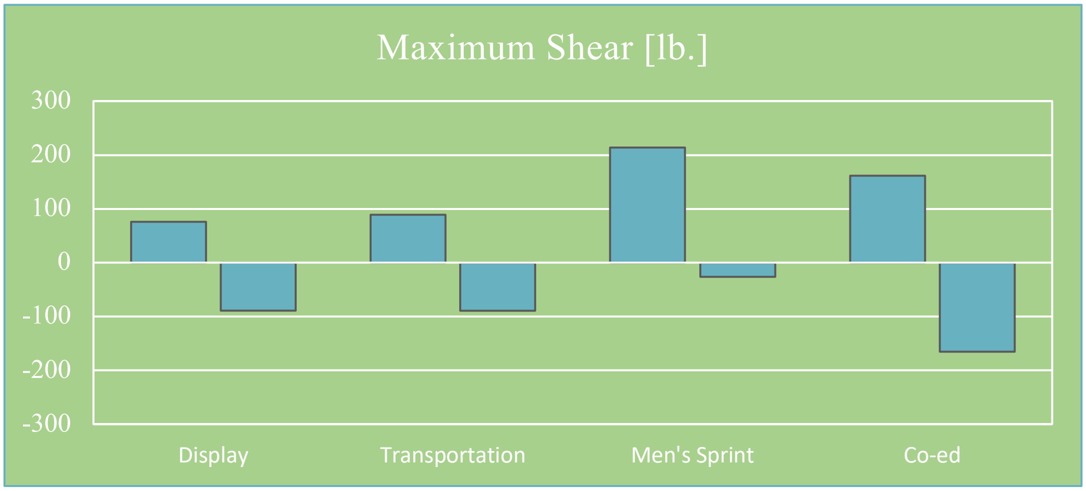

Figure 6: Graphical representation of shear forces for expected loading cases

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

Reinforcement Component	Component Thickness (in.)
Carbon Fiber	0.035
Kevlar® Tendon	0.125
Ferrule	0.125
Threaded Rod	0.25
Steel Mesh	0.069

Figure 1: Summary of Reinforcement Thickness

Section A Standard Canoe Wall, Typical

Minimum Concrete Wall Thickness: 0.5 in.

$$\frac{t_{reinforcement}}{t_{concrete}} = \frac{t_{tendon} + 2 * t_{carbon\ fiber}}{t_{concrete}} = \frac{0.125 + 2 * 0.035}{0.5} * 100 = 39\% \leq 50\%$$

Section B Rib Location

Minimum Concrete Wall Thickness: 1.0 in.

$$\frac{t_{reinforcement}}{t_{concrete}} = \frac{t_{tendon} + 2 * t_{carbon\ fiber} + t_{threaded\ rod}}{t_{concrete}} = \frac{0.125 + 2 * 0.035 + 0.25}{1.0} * 100 = 44.5\% \leq 50\%$$

Section C Gunwale

Minimum Concrete Wall Thickness: 1.0in.

$$\frac{t_{reinforcement}}{t_{concrete}} = \frac{0}{t_{concrete}} = 0\% \leq 50\%$$

Section D Bulkhead

Minimum Concrete Wall Thickness: 1.5 in.

$$\frac{t_{reinforcement}}{t_{concrete}} = \frac{2 * (t_{tendon} + t_{steel\ mesh})}{t_{concrete}} = \frac{2 * (0.125 + 0.069)}{0.5} * 100 = 25.9\% \leq 50\%$$

Section E Anchorage Zone

Minimum Concrete Wall Thickness: 1.5 in.

$$\frac{t_{reinforcement}}{t_{concrete}} = \frac{2 * (t_{tendon} + t_{steel\ mesh}) + t_{ferrule}}{t_{concrete}} = \frac{2 * (0.125 + 0.069) + 0.125}{0.5} * 100 = 34.2\% \leq 50\%$$

Note – Reinforcement thicknesses are determined based upon guidelines given in section 4.3.1 of the 2018 ASCE National Concrete Canoe Competition Rules and Regulations.

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

Percent Open Area Calculations: Carbon Fiber Reinforcing Grid

Variable Definitions:

- N_1=number of apertures along sample length
- N_2=number of apertures along sample length
- aperture_1=spacing of reinforcement (center-to center) along sample length
- aperture_2=spacing of reinforcement (center-to center) along sample width
- T_1=thickness of reinforcement along sample length
- T_2=thickness of reinforcement along sample width

Input Parameters

- $N_1 = 6$
- $N_2 = 7$
- $\text{aperture}_1 = 1.5$ in.
- $\text{aperture}_2 = 1.5$ in.
- $T_1 = 0.15$ in.
- $T_2 = 0.15$ in.

Solution:

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

$$d_2 = \text{aperture}_2 + 2 * \left(\frac{t_1}{2}\right) = 1.5 + 2 * \left(\frac{0.15}{2}\right) = 1.65 \text{ in.}$$

$$\text{Length} = n_1 * d_1 = 6 * 1.65 = 9.9 \text{ in.}$$

$$\text{Width} = n_2 * d_2 = 7 * 1.65 = 11.55 \text{ in.}$$

$$\sum \text{Area}_{\text{open}} = n_1 * n_2 * \text{aperture}_1 * \text{aperture}_2 = 6 * 7 * 1.5 \text{ in.} * 1.5 \text{ in.} = 94.5 \text{ in.}^2$$

$$\sum \text{Area}_{\text{total}} = \text{Length} * \text{Width} = 9.9 \text{ in.} * 11.55 \text{ in.} = 114.345 \text{ in.}^2$$

$$\text{POA} = \frac{\sum \text{Area}_{\text{open}}}{\sum \text{Area}_{\text{total}}} = \frac{94.5 \text{ in.}^2}{114.345 \text{ in.}^2} * 100 = 82.6\% \;(> 40\% \text{ minimum}) \qquad \text{O.K.}$$

Percent Open Area Calculations: Galvanized Steel Hardware Cloth

Solution:

$$d_1 = \text{aperture}_1 + 2 * \left(\frac{t_1}{2}\right) = 0.45 + 2 * \left(\frac{0.05}{2}\right) = 0.5 \text{ in.}$$

$$d_2 = \text{aperture}_2 + 2 * \left(\frac{t_1}{2}\right) = 0.45 + 2 * \left(\frac{0.05}{2}\right) = 0.5 \text{ in.}$$

$$\text{Length} = n_1 * d_1 = 7 * 0.5 = 3.5 \text{ in.}$$

$$\text{Width} = n_2 * d_2 = 7 * 0.5 = 3.5 \text{ in.}$$

$$\sum \text{Area}_{\text{open}} = n_1 * n_2 * \text{aperture}_1 * \text{aperture}_2 = 7 * 7 * 0.45 \text{ in.} * 0.45 \text{ in.} = 9.92 \text{ in.}^2$$

$$\sum \text{Area}_{\text{total}} = \text{Length} * \text{Width} = 3.5 \text{ in.} * 3.5 \text{ in.} = 12.25 \text{ in.}^2$$

Input Parameters

- $N_1 = 7$
- $N_2 = 7$
- $\text{aperture}_1 = 0.45$ in.
- $\text{aperture}_2 = 0.45$ in.
- $T_1 = 0.05$ in.
- $T_2 = 0.05$ in.

$$\text{POA} = \frac{\sum \text{Area}_{\text{open}}}{\sum \text{Area}_{\text{total}}} = \frac{9.92 \text{ in.}^2}{12.25 \text{ in.}^2} * 100 = 81.0\% \;(> 40\% \text{ minimum}) \qquad \text{O.K.}$$