# INCENDIUM

The University of Nevada, Reno

2017 Concrete Canoe Design Report

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## *Executive Summary*

On any normal night the Black Rock Desert is covered with nothing but darkness and dust; on this night the land is lit ablaze by a 105 ft. inferno resembling a man signifies that Burning Man has come to a close. Burning Man is an annual festival held in an uninhabitable region of Northern Nevada where people showcase artistic masterpieces, unite with others who share similar interest, and relish in the freedom among the dust and sand. For one week each year, Black Rock City appears with the infrastructure needed to support 70,000 people and then disappears with no trace left behind (Burning Man, 2016). The location of this engineering marvel is 200 miles from the University of Nevada, Reno campus. Much like the attitude and atmosphere expressed through Burning Man, the Nevada Concrete Canoe Team (NCCT) is a culmination of the passion and drive of ambitious civil engineering students hoping to make the world more vibrant using engineering solutions. The concrete canoe is a chance for these young men and women to express creative passion through an otherwise unique medium, the result of which is the 2017 Concrete Canoe, *Incendium.*

The University of Nevada, Reno is home to over 22,000 students, 2,462 of which comprise the diverse College of Engineering (UNR 2017). The NCCT encompasses 30 members with a range of experience in a variety of different engineering fields. The team has participated in the Mid-Pacific Conference over the past 12 years, competing against universities from Northern California and China. The NCCT has been invited to the National Concrete Canoe Competition (NCCC) since 2006, most recently competing with *Zephyr* (3rd, 2016), *Aquatone* (6th, 2015), and *Alluvium* (1st, 2014).

This year's team experienced an accelerated construction schedule of 3 weeks due to Computer Numerical Control (CNC) issues with the form. *Incendium's* hull was designed to be faster on turns without compromising straight line speed. To do so, the maximum length was decreased. *Incendium* also has an increased maximum beam length of 13.5 in. giving more stability to each paddler during races. All changes were made based off *Aquatone*'s original dimensions. Final dimensions of *Incendium* can be seen in Table 1.

**Table 1**: Dimensions and reinforcement

| Dimensions | |
|---|---|
| Colors | Red, Yellow, Orange, Brown, Dark Grey |
| Weight* | 180 lb |
| Length (max) | 20.5 ft |
| Width (max) | 27 in. |
| Depth (max) | 13.6 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**

The structural mix chosen for *Incendium* incorporates the new rule set by the Committee on National Concrete Canoe Competitions (CNCCC) by using at least 25 percent by volume ASTM C330 (ASTM C330/C330-14) compliant aggregate. Project managers chose a sustainable aggregate sourced from a local mine and a byproduct of coarse grained ASTM C330 aggregate. The team had problems creating a mix with a unit weight less than water, but achieved this goal using a high design air content and a coarse gradation properties can be found in Table 2. The fade of colors creates a fire-like presence to not only represent Burning Man, but also signifies the fiery passion the team has for the competing at competition.

**Table 2**: Concrete properties used for *Incendium*

| 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 | 54.3/52 | 1200 | 1240 | 470 | 16.5 |
| Patch | 66.5/62 | 2980 | N/A | 640 | 18.6 |

*** ASTM C496/C496M-11**

## *Project Management*

Devoted project managers began the year by recruiting new members. Many team members from the 2016 year graduated, a challenge familiar to many university competition teams. The lack of returning members created a potential production deficit for the project managers during the start of the 2016-2017 academic year. Prioritizing recruitment, project managers began an aggressive campaign to increase membership through campus club fairs and making presentations in classes throughout the College of Engineering. The campaign proved successful; the membership grew by 300 percent from the beginning of the year, ensuring enough people would be available to work on and complete the project.

The project managers redefined their management scheme to optimize social, financial, and environmental sustainability. They sought to increase social sustainability through the retainment of members and by evenly distributing production. To accomplish this, the management scheme was expanded to include junior managers in the construction and design sections shown in the Organization Chart on Page 3. Project managers appointed junior managers to sections identified as being critical to the project schedule. These junior managers helped division managers organize tasks and acquire materials such that risk associated with the postponement of tasks would be minimized. This management scheme proved successful during critical construction and mix periods; with the construction schedule pushed back 61 days, the team accelerated the construction schedule by 481 percent to leave an adequate amount of time for canoe finishing. Junior managers were successful in the development and testing division as well. Compared to the previous year's budget, project managers were able to save a total of $895 in concrete development and concrete casting, resulting in the costs shown in Table 3. This was due to the lower unit cost of mixes and the decreased number of test mixes.

**Table 3**: Saved mix design expenses

| Mix Design | 2016 | 2017 | Savings |
|---|---|---|---|
| Concrete Development | $1,050.00 | $225.00 | $825.00 |
| Concrete Casting | $420.00 | $350.00 | $70.00 |
| Total | $1,470.00 | $575.00 | $895.00 |

This year's project schedule was created around major project milestones. The milestones chosen by the managers include hull design, tendon and composite analysis, final mix selection, casting day, canoe finish, and the Mid-Pacific Regional Conference shown in the Project Schedule on Page 11. After assigning days for the milestones, the project managers worked backwards to determine how long it would take to complete each task and set a critical path. Project managers referenced previous year's schedules to help with determining durations for each task. Tasks were achieved by scheduling enough time to ensure optimal completion. The float in the initial schedule allowed for quality work to be done on the form and also allowed for more time to be devoted to development and testing of the mix design.

While more time was allocated to critical path items like hull design, structural analysis, and mix design development, project managers hoped to dedicate the same amount of hours towards the canoe as the previous years. With 150 hours allocated towards form construction and over 300 hours for development and testing, project managers spent more time ensuring each task was achieved in the proper time frame. This distribution was created due to the rule change including an ASTM C330 aggregate in the concrete.

When creating a budget, project managers had to decide where to allocate funds to achieve project goals. Starting with a list of expenditures and dividing up monetary funds for each division was the initial plan to achieve financial sustainability. This provides a preliminary estimate for how much funding was needed from donations. With the donation of the ASTM C330 aggregate, project managers were able to redirect funds to replenishing construction supplies, such as tools for future years, gathering materials for the design, and building a quality display. Also, with the increased number of members on the team, project managers hoped to put aside enough money to send every member to the regional competition. Overall, project managers achieved their goals of recruiting new members and allocating enough time to prepare for competition.

## *Quality Assurance / Quality Control*

The project managers of *Incendium* upheld CNCCC rule compliance and safety measures throughout all aspects of design and construction. Quality control performed by project manages included conducting training days, checking material qualification and design calculations, increasing material procurement time, and standard concrete inspection on casting day. Quality assurance set by the project managers included testing members on construction methods learned, re-inspecting tasks completed by team members, reviewing allowed materials, inspecting calculations, setting tolerance levels, and getting managers American Concrete Institute (ACI) certified.

Quality control was intended to ensure that all completed tasks met the appropriate standards and were completed in accordance with *Incendium's* design. Project managers spent 20 hours training team members to increase the quality of tasks performed by the team. The time spent on training became essential for a quality product. Project managers explained the method for each task performed, potential mistakes that can compromise overall quality, safety hazards, and the expected end result of each task. After every training session, project managers administered verbal quizzes to team members while inspecting the performance, allowing team members to understand the task assigned.

Issues with communication and modeling programs led to the accelerated construction schedule discussed in the Project Management on Page 1. Lack of quality control over scheduling, and communication between construction managers and the Computer Numerical Control (CNC) operator contributed to the construction schedule being pushed back by 14 days. Problems with the original modeling software and the CNC operator pushed back construction another 42 days. The CNC operator had little experience with AutoCAD, the original modeling software for *Incendium*, which created the biggest setback to the construction schedule. Project managers handled this situation by increasing time for research and development, acquiring construction materials, and learning a new modeling program. Increased time for research and development allowed the design team to create a more effective mix. The construction team took advantage of this time by checking inventory and preparing for an accelerated construction schedule. To address this problem, project managers learned how to model the canoe in SolidWorks®. This provided a better model for the CNC operator to work with, resulting in mold that was more accurately cut and reduced the amount of form prep work required.

*Zephyr's* team encountered problems of a polymer latex modifier that did not meet current CNCCC rules, which led to deductions on *Zephyr's* final product. To ensure that this issue would not happen again, project managers allocated to the safety manager the task of verifying that *Incendium's* construction materials complied with CNCCC rules. The safety manager continuously checked compliance of materials throughout the design and construction phases, concluding that all materials planned to be used for *Incendium* met CNCCC rule compliance.

Structural and mix calculations were initially performed on programmed Microsoft Excel files to reduce potential design and computational errors. Project managers also compared results from the teams mix design Excel file to the required mix design sheet in Appendix B to confirm that the team's final mix choices complied with CNCCC rules. Project managers had the required mix design sheet reviewed by past members, and the review confirmed that all calculations were performed accurately. An average relative error of 2.5 percent was found between the two design sheets. Project managers took this into account when designing mixes for development and testing, confirming that mix designs met the 25 percent by volume ASTM C330 rule.

Project managers decided to increase the time for weighing material to two weeks in order to decrease the chance of error. Design managers used the calculated volume of *Incendium* and the tested relative yield of the structural mix to determine that 70 mixes would need to be weighed out for casting day. Project managers set a tolerance of one percent for the weighing of materials. Stating this range on concrete sheets made it easy for team members to stay in compliance with this tolerance. One of the design managers received ACI, Concrete Field Testing Technician- Grade I certification to provide quality assurance of all tests performed by the team.

*Organization Chart*

Ryen Blair (Sr.) and William Cumming (Sr.)
Project Managers

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

Antoni Bran (Fr.)
Safety Mgr.

Updated SDS binder and implemented safety techniques.

**Paddlers**

- Meghan Brock (So.)
- Jillian Tobin (Fr.)
- Kayla Tam (So.)
- Maggie Wilbanks (Sr.)
- Ryen Blair (Sr.)
- Ian Meyer (Fr.)
- Gunner Scott (Jr.)
- Jared Stimac (Jr.)
- Zach Wolfe (Jr.)

Alex Spears (Fr.)
Construction Mgr.

Directed all construction including form preparation, casting and finishing.

Riley Durose (Fr.)
Junior Construction Mgr.

**Assistants**

- Meghan Brock (So.)
- Evan Jordan (Sr.)
- Peter Montejo (Jr.)
- Kayla Tam (So.)
- Gunner Scott (Jr.)
- Jared Stimac (Jr.)
- Maggie Wilbanks (Sr.)

Katie Kramer (Jr.)
Academics Mgr.

Directed academic tasks including presentation information, design paper, and engineer's notebook.

**Assistants**

- Evan Jordan (Sr.)
- Dani Palffy (Sr.)

Zach Wolfe (Jr.)
Mix Design Mgr.

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

Zack Stock (So.)
Junior Mix Design Mgr.

**Material Procurement**

- Brendan Chang (Jr.)
- Justin Fairbrook (Jr.)

**Assistants**

- Antoni Bran (Fr.)
- Jillian Tobin (Fr.)
- Kevin Vigallon (So.)

Jillian Tobin (Fr.)
Aesthetics Mgr.

Provided artwork for project including canoe graphics, display, and canoe stand.

**Assistants**

- Elizabeth Bence (So.)
- Tanya Flint (Sr.)
- Sydney Kaplan (So.)

## *Hull Design and Structural Analysis*

The project managers for *Incendium* designed a hull that can compete in all competition races without favoring one race over the other. The previous two hull designs of *Zephyr* (UNRCC 2016) and *Aquatone* (UNRCC 2015), were analyzed to achieve this goal. *Aquatone's* hull was optimized for faster straight line speed, but experienced adverse effects with regards to the overall turning speed of the canoe. *Zephyr* was built with maneuverability in mind, but this led to reduced tracking and poor paddler stability. *Incendium's* hull is the incorporation of historically successful design with anticipated qualities that will result in success throughout all competitions.

Managers began by altering the length of the canoe to optimize maneuverability while negotiating canoe tracking. To achieve the desired improvement in maneuverability the length of *Aquatone* was reduced from 21.8 ft. to 20.5 ft. The benefit of this comes from decreasing the distance from the center of turning to the resultant lateral force acting against the canoe, decreasing the resistance turning moment and increasing turning speed. Increasing *Incendium's* maximum beam by 0.5 in. to 13.5 in. brought the maximum width of the canoe to 27 in. The keel, bow, and midsection were all increased by 0.5 in. each to compensate for the overall beam width and keep the general shape of *Aquatone's* hull design. This change increased *Incendium's* freeboard and decreased the wetted surface area, effectively decreasing the turning moment. In addition, the increase of freeboard and max beam width all contributed to paddler stability in the canoe, reducing *Incendium's* probability of capsizing, and a prominent issue with *Zephyr*.

All of *Incendium's* design choices were made with knowledge acquired by project managers' use of an Excel spreadsheet developed by a previous Nevada team made by the NCCT (UNRCC 2008). The Excel sheet calculates performance properties of the canoe such as freeboard and turning speed, and these calculations in previous years have proven to be an excellent resource for estimating times. All calculations and measurements have been within a correlation of +/-10 percent.

With *Incendium's* beam being one in. larger and the length one ft shorter than *Aquatone*, *Incendium* calculated to be on average 10.29 percent faster on turns and sits 4.78 percent higher in the water than *Aquatone*. Managers obtained this without sacrificing skin drag, which provides a good indication of acceleration. Overall, the managers believe they will achieve the goals set of making a canoe with faster turning, more stability than previous years, and keeping straight line speed. Results can be seen in Table 4.

With the design complete, the design managers conducted a structural analysis of the canoe. To begin, managers input *Incendium's* dimensions, paddler load locations, and concrete properties into the team's structural analysis spreadsheet. The spreadsheet calculates structural parameters at one-foot intervals along the longitudinal length of the canoe. Moment of inertia, centroid, and cross-sectional areas at each interval were also included. Project managers calculated the location discrepancy between the resultants of the non-uniformly distributed forces, self-weight, and the concentrated paddler loads.

**Table 4**: Comparison of the past three canoes

| Canoe Name | Lowest Free Board (in.) | Total Drag (lb.) | 180 Turn Time (s.) |
|---|---|---|---|
| *Zephyr* | 5.54 | 24.1 | 6.06 |
| *Aquatone* | 7.95 | 24.7 | 6.80 |
| *Incendium* | 8.03 | 25.4 | 6.10 |

The team analyzed four loading situations: male sprint, co-ed, display with the canoe upside down, and transportation with the canoe right side up, seen in Figure 1. The structural analysis for both transportation and display were modeled after a simply-supported beam using non-uniform distributed self-weight of the canoe as the only applied load. The transportation scenario has the maximum positive moment of 1379 lb.-ft, while the display load calculated did not govern the design. The analysis of paddler loading cases were set as non-uniform distributed hydrostatic reactions, basing calculations on waterline elevation and waterline angle relative to the canoe. For the male sprint scenario male paddlers with two point loads of 230 lb. at 36 in. and 228 in. from the bow. Co-ed was modeled having 230 lb. at 36 in. and 84 in. from the bow and 160 lb. 228 lb. at 180 in. and 228 in., respectively. The male scenario had a maximum negative moment of 632 lb.-ft.

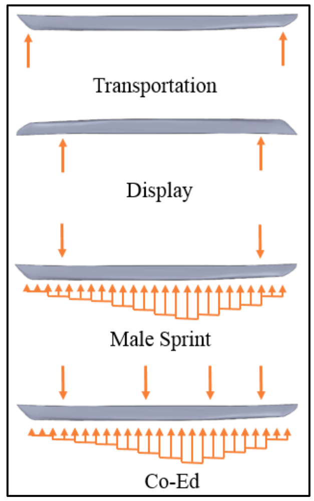



**Figure 1:** Loading cases

Managers designed a prestress system to offset flexural stresses from the moment of the loading cases into acceptable numbers. The prestress system used 14 Kevlar® tendons, each with a tensile load of 325 lb. and a total jacking force of 4550 lbs. Adding another tendon group to *Zephyr's* prestress system mitigated longitudinal cracking, which was an issue experienced by *Zephyr*. A greater quantity of tendons at a smaller tensile load distributed more evenly through the cross-section of the canoe and reduced concentrated compressional stresses in the concrete. The prestress design accounts for 25 percent losses in accordance with AASHTO LRFD Bridge Design Specification (AASHTO 2016). Three tendons were placed along the gunwale of the canoe with a fourth tendon closer to the centroid in order to reduce the negative moment experienced during paddler loads. The other three tendons were placed on the bottom and chine to counteract the increase in tensile stress at both locations due to the tendons near the gunwale. This resulted in minimum required concrete compressive strength of 1040 psi and minimum modulus of rupture of 280 psi.

Figure 2 shows the comparison of moment envelopes of *Zephyr* and *Incendium*. *Zephyr* had a higher jacking force over fewer tendons giving more concentrated loads. This jacking force was more than needed, which contributed to it having a longitudinal cracking problem. To mitigate this, the tensile load in *Incendium* was decreased by 19 percent in each tendon. Two more tendons were added to help offset the moment without having to increase the load on each tendon. The Excel spreadsheet that was used to find the required placement and jacking forces was also used to find the correct tendon path. The analysis shows the determined tendon path is more than sufficient in offsetting tensile stresses created by the loading cases, helping to prevent cracking of the concrete in *Incendium.*

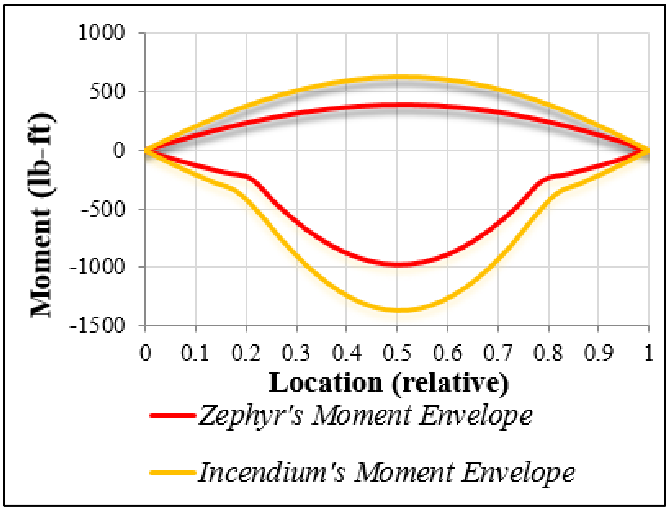



**Figure 2:** Comparison of *Zephyr* and *Incendium* moment envelope

With *Incendium's* pretensioning system requiring total jacking force of 4550 lb. over 14 tendon (each tendon having a force of 325 lbs.) the required concrete 1040 psi and 280 psi for compressive strength and modulus of rupture, respectively.

## *Development and Testing*

The goals for *Incendium* included a mix design that had ASTM C330 structural light weight aggregate to meet the requirements of the new rules set by the CNCCC. Design managers set a target weight for the structural mix less than 60 pcf. The design team chose 60 pcf because it was achievable with the use of new material and provided a small safety factor for a buoyant concrete. Increased sustainability of the aggregate used in the canoe was another goal set for *Incendium*. Design managers decided that, to achieve the set goals, time must allocated specifically for testing various aggregate gradations to observe the resulting unit weight and strength effects on the concrete mixture. Following several ASTM test procedures to ensure accuracy, managers evaluated the performance of concrete properties, resulting in the construction of a competitive final product.

*Zephyr's* structural mix served as the baseline mix due to its high flexural strength, low unit weight, and creditable test results to compare new mixes. Cementitious materials consisted of ground-granulated blast furnace slag (GGBFS), Type 1 white portland cement, vitreous calcium aluminosillicate (VCAS™), and Hydrated Lime Type S. The aggregate gradation consisted of recycled glass Poraver® Siscorspheres ranging in size from 0.1 to 4 mm in diameter, and Q-Cel® 6019S. The Q-Cel® microspheres helped reduce unit weight while increasing compressive strength. Polyvinyl alcohol (PVA) fibers at 0.87 percent by volume aided in increasing flexural strength of the mix. Admixtures included ADVA® Cast 575, a high range water reducer that improves the workability of the concrete, V-MAR® F100, a viscosity modifier that stabilizes the mix constituents, and Rhoplex® MC-1834P, a polymer modifying admixture that improves adhesion of the concrete to the male mold. An air entraining admixture, Daravair® AT30, helped achieve an air content of seven percent. Following the initial trail batch, the design team tested compressive strength tests on two in. by four in. cylindrical samples at 7, 14, and 28-day intervals and found a 28-day compressive strength of 1,940 psi (ASTM C39/C39M-16b) and a dry unit weight of 49.4 pcf (ASTM C138).

The newly implemented restriction by CNCCC of using at least 25 percent by volume of ASTM C330 aggregate forced design managers to consider the effects new aggregates would have on the mix. The design team adjusted the baseline mix by replacing portions of the non-ASTM C330 aggregate with the required amount of 25 percent by volume full gradation ASTM C330 aggregate. The resulting concrete mixture, with a unit weight over 70 pcf and compressive strength of 3000 psi, was not sufficient to the team's initial goals. Design managers concluded that the answer to this issue was to introduce the use of engineered polymeric spheres Syntheon Elemix™, and sieving (ASTM C136/136-M) the ASTM C330 aggregate. Elemix™, the lightest aggregate available to the design team, was added to the structural mix to help reduce the density. Analysis of *Aquatone's* structural mix determined that an increase in Elemix™ proportions reduced both the concrete's density and the compressive strength (UNRCC 2015). Additional testing was still necessary due to the compressive strength requirement of 1004 psi and a modulus of rupture of 280 psi. Design managers concluded that, to optimize aggregate proportioning, sieving of ASTM C330 aggregate would be necessary and beneficial to construct a structural mix that met the team's goals.

Design managers then started investigating if a structural mix with a density less than water could be achieved with the chosen ASTM C330 aggregate. This ASTM C330 aggregate was preferred due to its sustainable aspects since it was a byproduct from the production of larger gradations that the mine could not utilize. Sieving of the ASTM C330 aggregate was conducted because it was hypothesized that individual aggregate size ranges would have different specific gravities than the combined gradation. Design managers allocated sieving ASTM C330 aggregate to the material procurement team. The material procurement team then sieved the aggregate into #4, #8, #16, #30, #50, #100, and #200 sieve sizes (ASTM C136/136-M). The separated

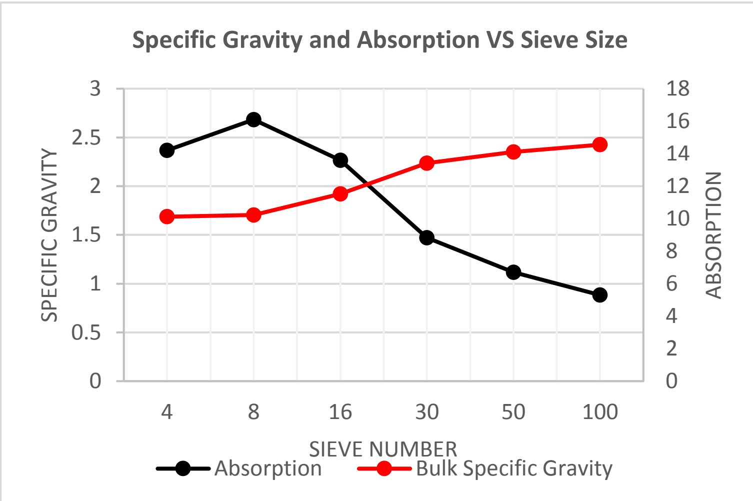



**Figure 3**: Absorption and specific gravity of each ASTM C330 aggregate size

material was then sent to a local testing firm to perform specific gravity and absorption (ASTM C127). These results can be seen in Figure 3. Testing concluded that the larger aggregate contained the lowest specific gravity by 36 percent relative to the other aggregate sizes. Therefore, the design team moved forward with compressive strength and unit weight (ASTM C138/C138M-16A) testing with the inclusion of #4 and #8 sieved aggregates, due to low specific gravities.

The design team constructed a gap graded mix consisting of four aggregates: ASTM C330 #4 and #8, Elemix® at 50 percent by volume, and Q-Cel® at 25 percent by volume were tested. This produced a unit weight of 53 pcf and a 28-day compressive strength of only 500 psi. Due to the low strength values, the team started looking into the effects of gap graded mixes with Poraver® Siscorspheres to increase strength. The addition of Poraver® Siscorspheres in gap graded mixes created a structural mix with a four percent lower unit weight, but 25 percent reduction in compressive strength compared to the full ASTM C330 gradation mix. The design team then tested a coarse well graded mix, which produced a close to optimal mix with 11 percent reduction in unit weight and 53 percent reduction in strength.

The coarse graded mix produced a compressive strength of 1500 psi and a density of 65 pcf, design managers decided that a coarse graded mix could meet the required strength and provides a low enough unit weight to meet the team's goals. Design managers knew that increasing the design air content decreased the unit weight and compressive strength of the material. To quantify this effect, three different mixes with the same gradation, but with different design air contents, were tested. Final results from these tests can be found in Figure 4. After analyzing the results, design mangers determined that a 15 percent air content would provide an optimal combination of compressive strength and unit weight.

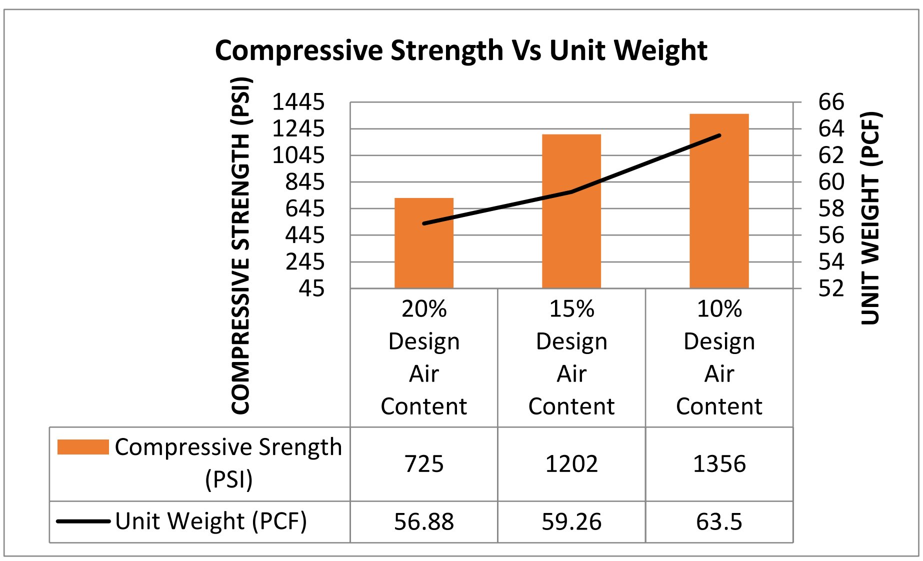



**Figure 4**: Compressive strength verses unit weight for each design air content

Additional admixture dosages were then adjusted by the design team to optimize the concrete characteristics during the development process. The latex polymer modifier, Rhoplex® MC-1834P, did not comply with ASTM standards of the 2017 NCCC rules (ASCE NCCC 2016). Testing the effects on the concrete with the removal of the polymer modifier showed no change in compressive strength or unit weight, leading to the removal Rhoplex® MC-1834P from the structural mix. The design team decided to add in Hycrete® X1001, a permeability-reducer to replace the Rhoplex®, which decreases moisture absorption, to help repel race-day water from saturating the concrete. This will also help reduce longitudinal cracks forming along *Incendium*.

Daravair® was used above the recommended manufacturer dosage due to previous Nevada teams concluding that the increased dosage can achieve lighter concrete without any adverse effects (UNRCC 2016). The final amount added was found to reduce the unit weight to a desirable amount while maintaining a minimum strength requirement. The final concrete admixtures and their respective dosage rates be found in Table 5.

**Table 5:** Admixture dosages

| Admixture | Type | Recommended Dosage (fl oz./cwt) | Actual Dosage (fl. oz./cwt) |
|---|---|---|---|
| Adva® Cast 575 | HRWR | 2 to 10 | 45 |
| Daravair® AT30 | AEA | 0.25 to 3 | 14 |
| V-MAR® F100 | VMA | 3 to 12 | 35 |
| Hycrete X1002 | PRAH | 40.9 | 41 |
| Hydrated Lime Type S | | N/A | |

Primary reinforcement of carbon fiber mesh was selected for *Incendium*. Carbon fiber mesh was chosen because of its high modulus of elasticity and its low unit weight. The 1.5 in. x 1.5 in. spacing in the carbon fiber mesh resulted in an 82.6 percent open area, allowing ease of constructability during casting day. Analysis of last year's layering scheme led design managers to conclude that workability around the mesh could be improved. Project managers decided that layering two sheets of carbon fiber mesh on top of the tendons, after tensioning, would address the workability issue from last year. Incorporating the carbon fiber reinforcement increased the composite flexural strength of the concrete. Structural analysis of *Incendium* provided a required modulus of rupture of 280 psi. The final structural mix chosen achieved a modulus of rupture just above this requirement with a tested value of 310 psi (ASTM C78/C78-16b). This modulus of rupture combined with the carbon fiber reinforcement gave a flexural strength of 1200 psi. The structural analysis requirements and actual structural mix results can be found in Table 6. These results provided information that assured project managers that *Incendium* can withstand the stress induced from competition.

**Table 6:** Final concrete properties

| Property | Analysis Requirements | Actual Results |
|---|---|---|
| Compressive Strength (psi) | 1040 | 1200 |
| Modulus of Rupture (psi) | 280 | 310 |
| Flexural Strength (psi) | N/A | N/A |

Secondary reinforcement of pretensioned Kevlar® synthetic fiber rope was also added to the canoe. This reinforcement helped improve structural strength by putting the canoe in a state of compression. Test results from last year showed that the use of Kevlar® rope is light weight and can withstand high tensile loads (UNRCC 2016). Tests from *Zephyr* also showed that Kevlar® had enough adhesion to the concrete with stand tensile loads applied. Kevlar® rope provided a lighter, stronger canoe, with safer construction practices while maintaining the benefits of a pretension reinforcement.

The structural mix for *Incendium* was heavier than previous years; therefore, the design managers accounted for this problem by using leftover foam in the bulkheads rather than pure concrete. The design team established that the foam bulk heads would save the most weight and meet the required strength if the bulk heads were layered with alternating foam and concrete sections. Concrete surrounding the foam and placed in between the foam layers would help the bulk heads resist any loading experienced at the bow and stern during handling or unforeseen impacts, while helping to reduce overall weight.

The design team developed a patch mix to fill surface imperfections while maintaining pigment consistency. The water-to-cementitious ratio was increased from 0.4 to 0.45 to create a more fluid mix. Aggregate sizes incorporated in this mix were reduced; the largest aggregate size was material retained on sieve #16 (1.19 mm) of the ASTM C330 aggregate. This sieve size was chosen because of its low specific gravity of 1.96 and small enough size to fill the possible surface imperfections and voids. All other aggregate used in the patch mix were less than 1 mm in diameter. This led to the development of a lightweight concrete, which meets design requirements, and incorporates sustainable aspects upholding the national reputation the Nevada team has earned.

## *Construction*

*Incendium's* team set out to have a streamlined construction schedule that favored quality work over quantity of work. Due to schedule modification from problems with the form's acquisition, construction time saw a reduction of 481 percent. Despite the clear obstacle presented before them, the construction team used the additional time as an opportunity to focus on the sustainability of the team by increasing training as shown in Quality Control/ Quality Assurance on Page 3. The team did this with the intention that the construction of the form could be reasonably managed without costing more time to the schedule. With streamlined work days and a tight schedule, the team was focused on completing the required task while ensuring quality was maintained.

The schedule was drastically changed when the team acquired the 12 pcf CNC foam three months later than originally projected. The team went from a 77 day process with a very early casting day relative to previous years to a 16 day schedule with a casting day pushed back one month.

Once the form was acquired the bulkheads and rib locations were measured and cut from the form. The team removed the bulkheads to provide a space for the secondary reinforcement anchoring 15 in. from the bow, and 12 in. from the stern. Rib placement was every 4.1 ft., seen in Figure 5. In each of the four ribs 0.25 in. diameter threaded rod was used as reinforcement to provide support against transverse bending. Sixteen, 0.25 in. threaded rod where then anchored into the underside of the form for use during the form removal process. Bondo© body filler was used to fill chips, gouges or cuts in the form. After setting for one day the filler was sanded until smooth. The cut bulkheads of the form were sanded using low grit sand paper to acquire a rounded edge to reduce cracks when the bulkheads were constructed. This was done during the first week of form preparation.

**Figure 5:** Team cutting out ribs designated

Five coats of industrial primer Duratec® was applied to seal the form, filling any additional voids and giving a smooth surface finish that prevented physical bonding between concrete and the foam. The primer was then sanded with 1500-grit sand paper after a day of setting. Twelve layers of mold release wax was then applied for eventual ease of removal.

Grade screws were drilled into the form in accordance to the tendon path dictated by the analysis spreadsheet. These screws served both to guide the prestress tendons' longitudinal path along the canoe and also as depth indicators while casting *Incendium*.

The construction managers used Kevlar® cables to pre-stress the canoe, seen in Figure 6. Kevlar® tendons were used as a stronger, safer and more workable alternative than steel cables. Springs were used to apply and measure the required 325 lbs. of tension to each tendon. The managers used Hooke's law to determine the measured physical displacement of each individual spring that would yield the desired jacking load. The team placed plastic spacers between the tendons and the form to allow for concrete packing beneath each tendon.

**Figure 6**: Pretension system


**Figure 7:** Tying duel layer mesh together

As one construction team applied the prestress system a second team was tasked with cutting out carbon fiber mesh and tying the two layers together, seen in Figure 7. This was done to speed up the process of tying the mesh to the tendons and to ensure the absence of protrusions. Protrusions in the mesh that extended beyond the thickness of the hull would have to be cut out, thus the team practiced great care in this process. Additionally, the tightening of the mesh served to reduce longitudinal cracking in the concrete. The two layer system was placed to identically replicate the scheme used during concrete mix development and testing.

Before casting, *Incendium's* graphical design was mapped out onto the form with multiple color ink pens to make sure the proper design was obtained on casting day. Hand-packing took 12 hours to complete in a single day with a total of 23 team members. Each member was given a station along the canoe where they were to pack from the gunwale up, while being mindful that concrete was being placed evenly throughout the day. With this long schedule and the amount of participants, more attention to canoe thickness and graphics was needed to assure quality control of the final product.

On casting day, the design team performed unit weight measurements (ASTM C138/ C138M-16a), made concrete cylinders (ASTM C470/C470M-15) to be used for compressive strength tests after 28 days of curing (ASTM C39/C39M-16b). The ACI certified manager, mentioned in Quality Control/ Quality Assurance on Page 2, was present to provide assurance that all ASTM tests were performed properly. Design managers then shared this knowledge with the rest of the team. Results of the certification became apparent with increased accuracy in test results.

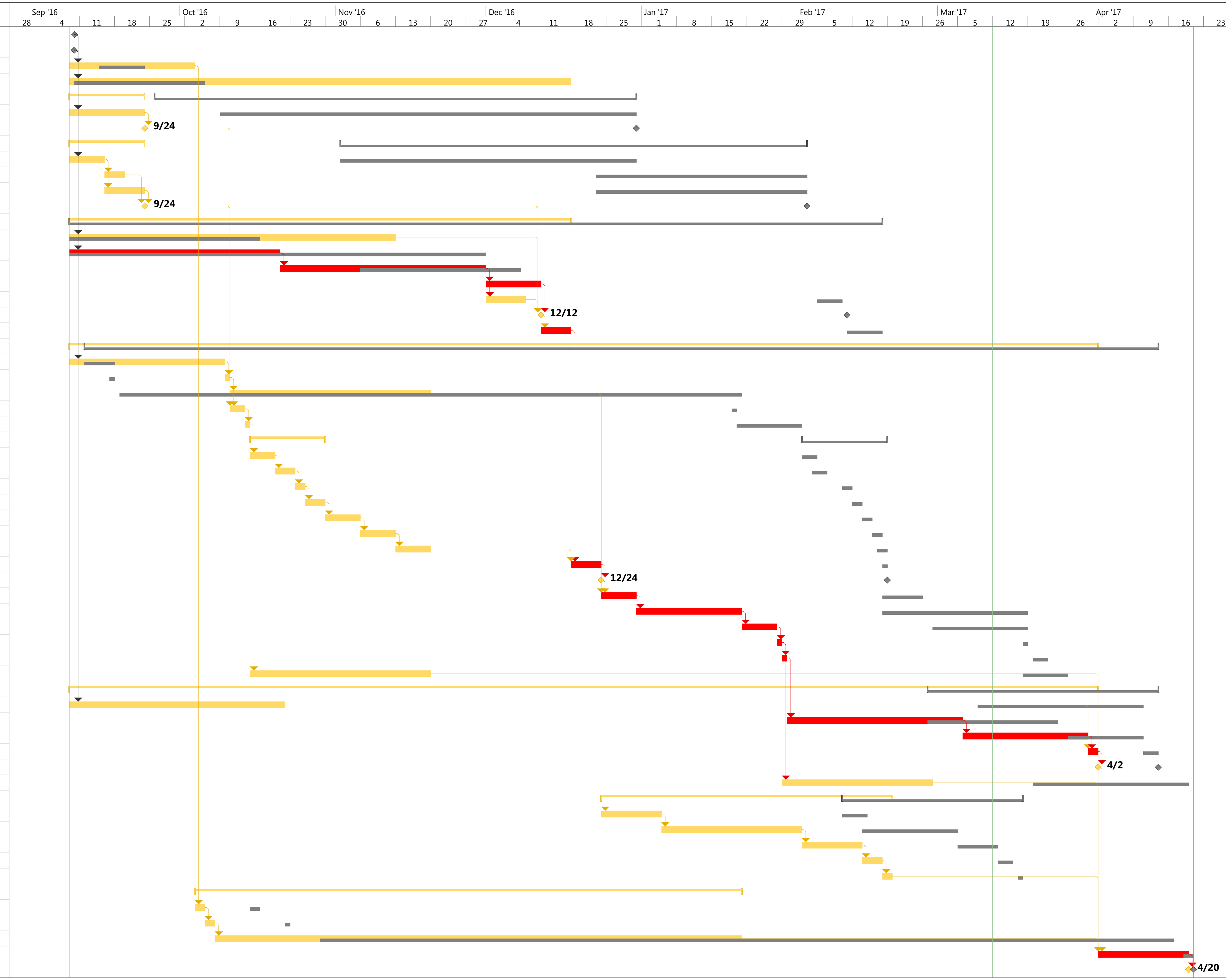
The 28-day cure of the concrete proceeded underneath tightly bound plastic to maintain a humid environment. For the first seven of the 28 days the team hand watered the canoe using spray bottles. The rest of the cure time was spent under a self-made automated watering system constructed from PVC and an irrigation system. The team began wet sanding after seven days to accelerate the finishing process, seen in Figure 8.

At the time of this report, the canoe was still curing and not all tasks were completed in the schedule. After sanding is complete on the outside, the grade screws will be removed and the canoe will be released from the form by attaching planks to the 0.25 in. threaded rods embedded in the foam mold. The team will remove the spacers and fill the subsequent voids with grey patch mix on the inside. With *Incendium* off the form the team will begin a repeated regimen of sanding one day and patching one day to acquire a smooth finish. The canoe will be finished with 400-grit sand paper on the inside to provide more stability for paddlers while 1500-grit sandpaper on the outside to ensure minimal surface-to-water friction. *Incendium* will then be sealed. Even with having an accelerated schedule, *Incendium's* team was able to come together, reevaluate the situation, and build a canoe worthy of competition that continues the exceptional legacy of the NCCT.

**Figure 8:** Team members wet sanding

# Project Schedule

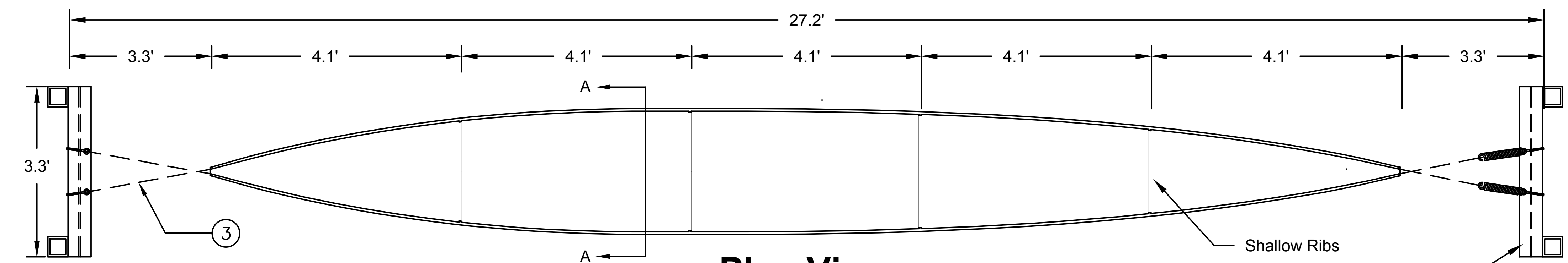
| ID | Task Name | Duration | Start | Finish | Actual Start | Actual Finish |
|---|---|---|---|---|---|---|
| 1 | **Project Start** | 0 days | 9/9/16 | 9/9/16 | 9/9/16 | 9/9/16 |
| 2 | **Competition Rules Release** | 0 days | 9/9/16 | 9/9/16 | 9/9/16 | 9/9/16 |
| 3 | **Recruitment** | 25 days | 9/9/16 | 10/4/16 | 9/15/16 | 9/23/16 |
| 4 | **Fundraising** | 100 days | 9/9/16 | 12/18/16 | 9/10/16 | 10/5/16 |
| 5 | **Hull Design** | **15 days** | **9/9/16** | **9/24/16** | **9/26/16** | **12/30/16** |
| 6 | Hull Design Research | 15 days | 9/9/16 | 9/24/16 | 10/9/16 | 12/30/16 |
| 7 | Hull Design Complete | 0 days | 9/24/16 | 9/24/16 | 12/30/16 | 12/30/16 |
| 8 | **Structural Analysis** | **15 days** | **9/9/16** | **9/24/16** | **11/2/16** | **2/2/17** |
| 9 | Computer Software Learning | 7 days | 9/9/16 | 9/16/16 | 11/2/16 | 12/30/16 |
| 10 | Longitudinal Tendon Analysis | 4 days | 9/16/16 | 9/20/16 | 12/23/16 | 2/2/17 |
| 11 | Composite Analysis and Design | 8 days | 9/16/16 | 9/24/16 | 12/23/16 | 2/2/17 |
| 12 | Analysis Complete | 0 days | 9/24/16 | 9/24/16 | 2/2/17 | 2/2/17 |
| 13 | **Concrete Mix Design** | **100 days** | **9/9/16** | **12/18/16** | **9/9/16** | **2/17/17** |
| 14 | Material Procurement | 65 days | 9/9/16 | 11/13/16 | 9/9/16 | 10/16/16 |
| 15 | Research | 42 days | 9/9/16 | 10/21/16 | 9/9/16 | 11/30/16 |
| 16 | Preliminary Design and Testing | 41 days | 10/21/16 | 12/1/16 | 11/6/16 | 12/7/16 |
| 17 | Final Material Testing | 11 days | 12/1/16 | 12/12/16 | 12/8/16 | 2/5/16 |
| 18 | Aesthetics Testing | 8 days | 12/1/16 | 12/9/16 | 2/5/17 | 2/9/17 |
| 19 | Final Mix Selection | 0 days | 12/12/16 | 12/12/16 | 2/10/17 | 2/10/17 |
| 20 | Pre-Weigh Materials | 6 days | 12/12/16 | 12/18/16 | 2/11/17 | 2/17/17 |
| 21 | **Construction** | **205 days** | **9/9/16** | **4/2/17** | **9/12/16** | **4/13/17** |
| 22 | Laboratory Organization | 31 days | 9/9/16 | 10/10/16 | 9/12/16 | 9/17/16 |
| 23 | Form Table Construction | 1 day | 10/10/16 | 10/11/16 | 9/17/16 | 9/17/16 |
| 24 | Curing System Construction | 40 days | 10/11/16 | 11/20/16 | 9/19/16 | 1/20/17 |
| 25 | Build Form | 3 days | 10/11/16 | 10/14/16 | 1/19/17 | 1/19/17 |
| 26 | Form CNC | 1 day | 10/14/16 | 10/15/16 | 1/20/17 | 2/1/17 |
| 27 | **Form Preperation** | **15 days** | **10/15/16** | **10/30/16** | **2/2/17** | **2/18/17** |
| 28 | Sanding | 5 days | 10/15/16 | 10/20/16 | 2/2/17 | 2/4/17 |
| 29 | Bondo | 4 days | 10/20/16 | 10/24/16 | 2/4/17 | 2/6/17 |
| 30 | Duratec | 2 days | 10/24/16 | 10/26/16 | 2/10/17 | 2/11/17 |
| 31 | Wax | 4 days | 10/26/16 | 10/30/16 | 2/12/17 | 2/13/17 |
| 32 | Grade Screw Installation | 7 days | 10/30/16 | 11/6/16 | 2/14/17 | 2/15/17 |
| 33 | Tendon Application | 7 days | 11/6/16 | 11/13/16 | 2/16/17 | 2/17/17 |
| 34 | Tie Reinforcement | 7 days | 11/13/16 | 11/20/16 | 2/17/17 | 2/18/17 |
| 35 | Canoe Casting | 6 days | 12/18/16 | 12/24/16 | 2/18/17 | 2/18/17 |
| 36 | Canoe Casting Complete | 0 days | 12/24/16 | 12/24/16 | 2/18/17 | 2/18/17 |
| 37 | Concrete Premliminary Curing | 7 days | 12/24/16 | 12/31/16 | 2/18/17 | 2/25/17 |
| 38 | Concrete Final Curing | 21 days | 12/31/16 | 1/21/17 | 2/18/17 | 3/18/17 |
| 39 | Wet Sanding | 7 days | 1/21/17 | 1/28/17 | 2/28/17 | 3/18/17 |
| 40 | Prestress Tendon Release | 1 day | 1/28/17 | 1/29/17 | 3/18/17 | 3/18/17 |
| 41 | Grade Screw Removal | 1 day | 1/29/17 | 1/30/17 | 3/20/17 | 3/22/17 |
| 42 | Cross-Section Construction | 36 days | 10/15/16 | 11/20/16 | 3/18/17 | 3/26/17 |
| 43 | Finishing | 205 days | 9/9/16 | 4/2/17 | 2/27/17 | 4/13/17 |
| 44 | Sealer Research and Testing | 43 days | 9/9/16 | 10/22/16 | 3/9/17 | 4/10/17 |
| 45 | Patching/Sanding Exterior | 35 days | 1/30/17 | 3/6/17 | 2/27/17 | 3/24/17 |
| 46 | Patching/Sanding Interior | 25 days | 3/6/17 | 3/31/17 | 3/27/17 | 4/10/17 |
| 47 | Sealing | 2 days | 3/31/17 | 4/2/17 | 4/11/17 | 4/13/17 |
| 48 | Canoe Finish | 0 days | 4/2/17 | 4/2/17 | 4/13/17 | 4/13/17 |
| 49 | **Display Table** | **30 days** | **1/29/17** | **2/28/17** | **3/20/17** | **4/19/17** |
| 50 | **Design Report** | **58 days** | **12/24/16** | **2/20/17** | **2/10/17** | **3/17/17** |
| 51 | Compose Rough Draft | 12 days | 12/24/16 | 1/5/17 | 2/10/17 | 2/14/17 |
| 52 | Peer/Professional Editing | 28 days | 1/5/17 | 2/2/17 | 2/14/17 | 3/4/17 |
| 53 | Final Revisions and Review | 12 days | 2/2/17 | 2/14/17 | 3/5/17 | 3/12/17 |
| 54 | Print Design Report | 4 days | 2/14/17 | 2/18/17 | 3/13/17 | 3/15/17 |
| 55 | Paper Complete | 2 days | 2/18/17 | 2/20/17 | 3/17/17 | 3/17/17 |
| 56 | **Paddling** | **109 days** | **10/4/16** | **1/21/17** | **10/15/16** | **4/16/16** |
| 57 | Tryouts | 2 days | 10/4/16 | 10/6/16 | 10/15/16 | 10/16/16 |
| 58 | Team Selection | 2 days | 10/6/16 | 10/8/16 | 10/22/16 | 10/22/16 |
| 59 | Paddling Practice and Conditioning | 105 days | 10/8/16 | 1/21/17 | 10/29/16 | 4/16/17 |
| 60 | **Mid-Pac Prep/Proect Float** | **18 days** | **4/2/17** | **4/20/17** | **4/19/17** | **4/20/17** |
| 61 | **Mid-Pacific Conference** | **0 days** | **4/20/17** | **4/20/17** | **4/20/17** | **4/20/17** |



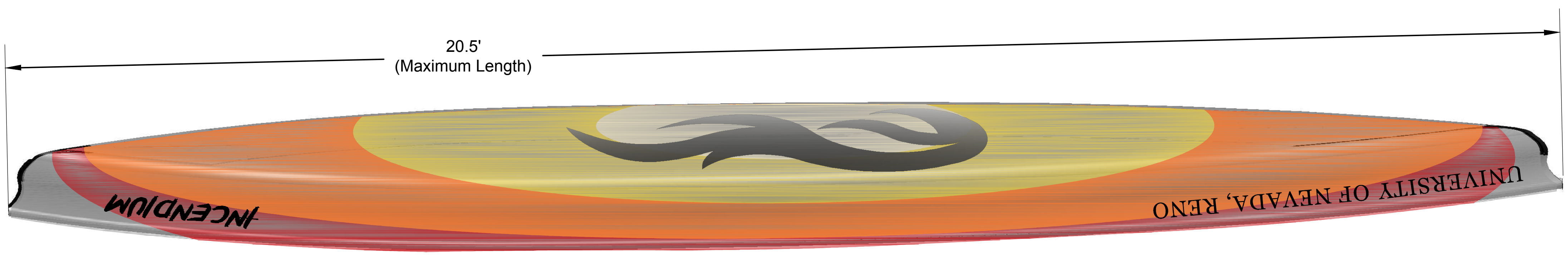

Project: Working Schedule Yay
Date: 3/12/17

Task | Milestone | Summary | Critical | Baseline | Baseline Milestone | Baseline Summary

Page 1



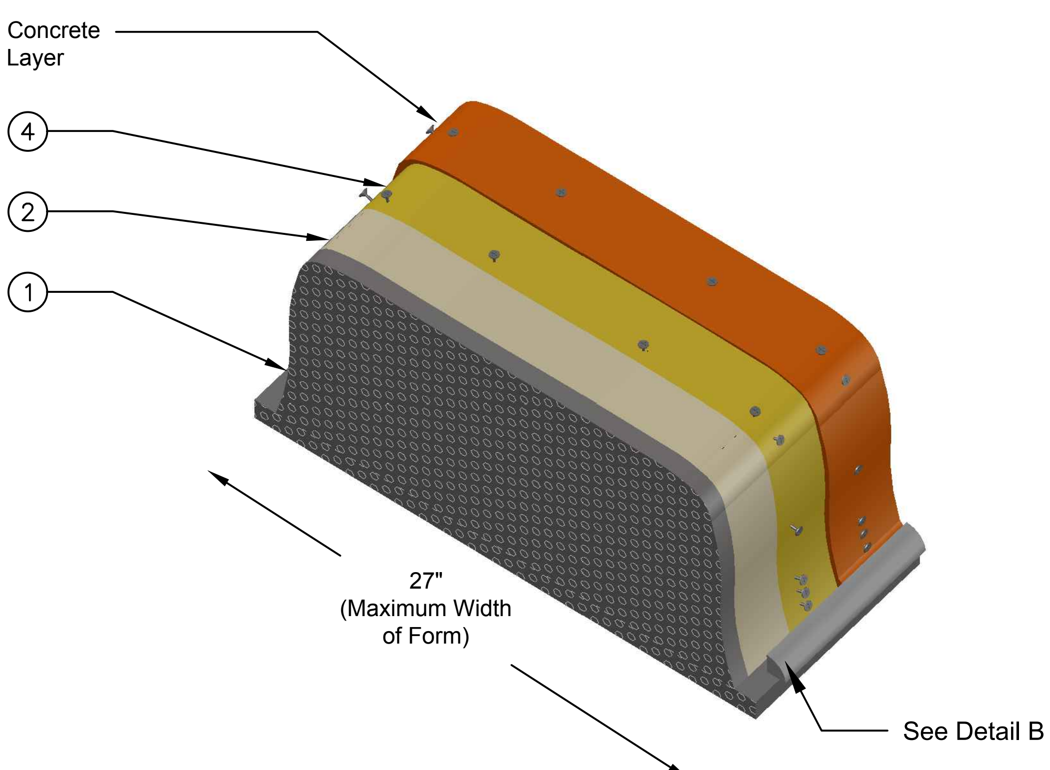

## Plan View




## Elevation View

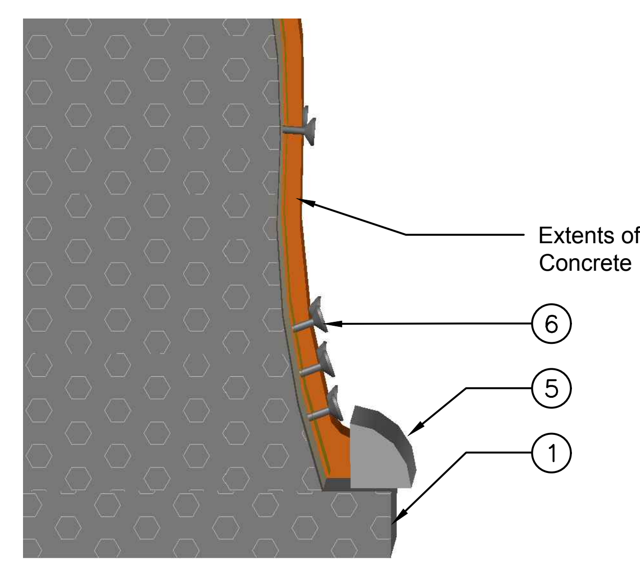
## General Notes:

1. Drawings not to scale
2. Only two longitudinal prestress anchorages are shown for clarity
3. Total longitudinal prestressing force: $P_{jack}$=4.6 kips



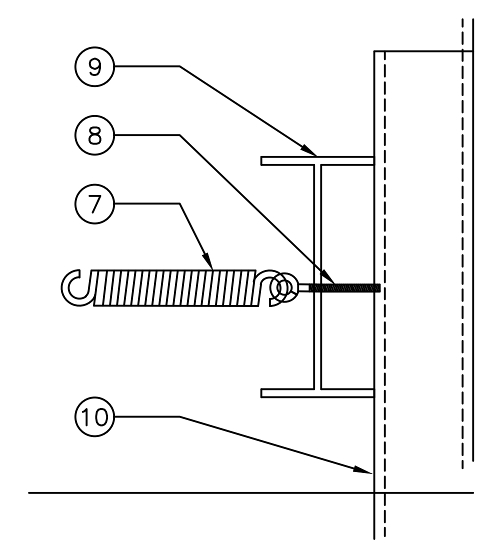

**Section A - A**

**Widest Section**




**Detail B**

**Gunwale**




**Detail C**

**Longitudinal Prestress Anchorage**

University of Nevada, Reno

Concrete Canoe

**Bill of Materials**

| | Qty | Description |
|---|---|---|
| | 49.1 lbs. | Type 1 White Portland Cement |
| | 81.8 lbs. | VCAS-140™ |
| | 16.4 lbs. | NewCem® Slag Cement |
| | 48.7 lbs. | ASTM C330 #4 |
| | 81.1 lbs. | ASTM C330 #8 |
| | 9.0 lbs. | Poraver® Siscorspheres (.25-0.5 mm) |
| | 33.7 lbs. | Poraver® Siscorspheres (.5-1 mm) |
| | 18.1 lbs. | Poraver® Siscorspheres (2-4 mm) |
| | 2.5 lbs. | Q-Cel® 6019S |
| | 1.4 lbs. | Elemix™ |
| | 16.4 lbs. | Hydrated Lime Type S |
| | 73.6 fl. oz. | ADVA® Cast 575 (HRWR) |
| | 64.1 fl. oz. | Hycrete® X1002 |
| | 23.0 fl. oz. | Daravair® AT30 (AEA) |
| | 57.2 fl. oz. | V-Mar® F100 (VMA) |
| | 2.5 lbs. | Nycon® PVA Fibers (6 mm) |
| | 2.5 lbs. | Nycon® PVA Fibers (12 mm) |
| | 1.4 lbs. | Powder Pigments |
| | 4 units | Transverse Threaded Steel Rod |
| | 36.6 sq. ft. | CT 272 Carbon Fiber Grid |
| | 24 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 gal. | Duratec® (Surface Treatment) |
| 3 | 228 ft. | Kevlar® Cable |
| 4 | 2 gal. | Bondo® |
| 5 | 41 ft. | Quarter Round Molding (3/4" x 3/4") |
| 6 | 356 ct. | Grade Screws |
| 7 | 12 ct. | Steel Spring (L: 6" W: 1.5" k=0.2 k/in) |
| 8 | 28 ct. | Eye Bolts/Nuts (L: 3" Dia: 3/8") |
| 9 | 2 ct. | W 12 x 22 |
| 10 | 4 ct. | HSS 3-1/2" x 3-1/2" x 3/8" |

INCENDIUM

**Design Drawing**

Date: 3/08/2017

Engineers: R. BLAIR

Drawn By: J. GUANTONE, A. HANSEN

## *Appendix A: References*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The following an email from the Burning Man committee giving us permission to use the burning man symbol in the paper.

**Josh Lease** <josh.lease@burningman.org> 11/9/16

to me

Hi Katie & William,

Thank you for taking the time to answer our questions. If you would like to use the an image or likeness of the BELIEVE sculpture or any other art seen at Burning Man you would need to get that permission from the artist. In the BELIEVE case the Laura Kimpton is the Artist. She has a contact form on her website, here: [http://laurakimpton.com/contact/](http://laurakimpton.com/contact/)

Otherwise in terms of the Burning Man logo for the uses you have described:

> The University of Nevada, Reno, 2016-2017 Concrete Canoe Team may use the Burning Man name and logo trademarks on your canoe and team shirts and in your paper and related academic materials, provided that you do not sell the canoe or shirts or make any other commercial use of Burning Man's intellectual property.
>
> In your paper and in any other printed or online materials that describe or display photographs of the boat's design, we ask that you please include the following disclaimer:
>
> > **The Burning Man name and logo are registered trademarks of Decommodification LLC, which is not affiliated with the Concrete Canoe Team, and are used with permission.**

Should you have additional questions or concerns, please don't hesitate to let us know.

Best,
Josh

# *Appendix B: Mixture Proportions*

Mixture Designation: Structural 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 | *189.6* | *Total Amount of cementitious materials 568.8 $lb/yd^3$ c/cm ratio 0.33* |
| *VCAS-140* | 2.6 | 1.948 | *316.0* | |
| *Slag Cement* | *2.6* | 0.390 | 63.2 | |

**Fibers**

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

**Aggregates**

| Aggregates | ASTM C330* | Abs (%) | $MC_{stk}$ (%) | $SG_{SSD}$ | Base Quantity ($lb/yd^3$) | | Volume $_{SSD}$, ($ft^3$) | Batch Quantity (at $MC_{stk}$) ($lb/yd^3$) |
|---|---|---|---|---|---|---|---|---|
| | | | | | OD | SSD | | |
| *Q-Cel® 6019S* | | 2 | 0 | 0.14 | *6.4* | 6.5 | *0.745* | 6.4 |
| *Poraver® Siscorspheres 0.25-0.5 mm* | | 4 | 0 | 0.75 | *33.5* | 34.9 | *0.745* | 33.5 |
| *Poraver® Siscorspheres 0.5-1.0 mm* | | 4 | 0 | 0.56 | *125.2* | 130.2 | *3.726* | 125.2 |
| *Elemix™* | | 6 | 0 | 0.04 | *5.3* | 5.6 | *2.236* | 5.3 |
| *Poraver® Siscorspheres 2-4 mm* | | 4 | 0 | 0.3 | *67.1* | 69.8 | *3.726* | 67.1 |
| *ASTM C 330 Sand #8* | Y | 16 | 0 | 1.71 | *233.2* | 270.5 | *2.535* | 233.2 |
| *ASTM C 330 Sand #4* | Y | 14 | 0 | 1.69 | *110.2* | 125.9 | *1.193* | 110.2 |

**Admixtures**

| Admixture | lb/gal | Dosage (fl.oz/cwt) | % Solids | Amount of Water in Admixture ($lb/yd^3$) | |
|---|---|---|---|---|---|
| *ADVA® CAST 575 (HRWR)* | *8.9* | *45* | *40* | *10.71* | *Total Water from Admixtures, $\sum w_{admx}$ **41.76** $lb/yd^3$* |
| *Daravair® AT30 (AEA)* | *8.3* | *14* | *5* | *4.93* | |
| *V-MAR® F100 (VMA)* | *8.4* | *35* | *4* | *12.65* | |
| *Hycrete X1002 (PRAH)* | *8.8* | *41* | *15* | *13.47* | |

**Solids (latex, dyes and powdered admixtures)**

| Component | Specific Gravity | Volume ($ft^3$) | Amount (mass/volume) ($lb/yd^3$) | |
|---|---|---|---|---|
| *Color Pigment*** | 1.270 | 0.066 | 5.23 | *Total Solids from Admixtures 68.44 $lb/yd^3$* |
| *Hydrated Lime Type S* | 2.600 | 0.390 | 63.21 | |

**Water**

| | Amount (mass/volume) ($lb/yd^3$) | | | Volume ($ft^3$) |
|---|---|---|---|---|
| *Water, $lb/yd^3$* | | *w:* | *227.55* | *3.647* |
| *Total Free Water from All Aggregates, $lb/yd^3$* | | *$\sum w_{free}$:* | *-62.41* | |
| *Total Water from All Admixtures, $lb/yd^3$* | | *$\sum w_{admx}$:* | *41.76* | |
| *Batch Water, $lb/yd^3$* | | *$w_{batch}$:* | *248.20* | |

**Densities, Air Content, Ratios and Slump**

| | cm | fibers | aggregates | solids | water | Total |
|---|---|---|---|---|---|---|
| Mass of Concrete, M, (lb ) | *568.80* | 19.04 | 580.9 | 68.44 | 227.55 | *$\sum M$: 1464.78* |
| Absolute Volume of Concrete, V, ($ft^3$) | 3.302 | *0.235* | *14.907* | *0.456* | *3.647* | *$\sum V$: 22.547* |
| Theoretical Density, T, *(=$\sum M$ / $\sum V$)* | 64.97 | *$lb/ft^3$* | Air Content [= (T - D)/T x 100%) | | | *16.5%* |
| Measured Density, D | 54.25 | *$lb/ft^3$* | Slump, Slump flow | | | 1 *in.* |
| water/cement ratio, w/c: | 1.20 | | water/cementitious material ratio, w/cm: | | | 0.4 |

*** 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 | 189.6 | Total Amount of cementitious materials |
| VCAS-140™ | 2.6 | 1.948 | 316.0 | 568.8 $lb/yd^3$ |
| NewCem® Slag Cement | 2.6 | 0.390 | 63.2 | c/cm ratio 0.33 |

## Aggregates

| Aggregates | ASTM C330* | Abs (%) | $MC_{stk}$ (%) | $SG_{SSD}$ | Base Quantity ($lb/yd^3$) OD | Base Quantity ($lb/yd^3$) SSD | $Volume_{SSD}$, ($ft^3$) | Batch Quantity (at $MC_{stk}$) ($lb/yd^3$) |
|---|---|---|---|---|---|---|---|---|
| Q-Cel® 6019S | | 2 | 0 | 0.56 | 48.4 | 49.3 | 1.412 | 48.38 |
| Poraver® Siscorspheres 0.1-0.3 mm | | 4 | 0 | 0.3 | 63.6 | 66.1 | 3.532 | 63.57 |
| Poraver® Siscorspheres 0.25-0.5 mm | | 4 | 0 | 0.75 | 127.2 | 132.3 | 2.827 | 127.21 |
| Poraver® Siscorspheres 0.5-1.0 mm | | 4 | 0 | 1.71 | 290.0 | 301.6 | 2.827 | 290.04 |
| ASTM C 330 Sand #16 | Y | 14 | 0 | 1.92 | 372.7 | 423.4 | 3.534 | 372.74 |

## Admixtures

| Admixture | lb/gal | Dosage (fl.oz/cwt) | % Solids | Amount of Water in Admixture ($lb/yd^3$) | |
|---|---|---|---|---|---|
| ADVA® CAST 575 (HRWR) | 8.9 | 50 | 40 | 11.90 | Total Water from Admixtures, $\sum w_{admx}$ **44.75** $lb/yd^3$ |
| Daravair® AT30 (AEA) | 8.3 | 14 | 5 | 4.93 | |
| V-MAR® F100 (VMA) | 8.4 | 40 | 4 | 14.45 | |
| Hycrete® X1002 (PRAH) | 8.8 | 41 | 15 | 13.47 | |

## Solids (latex, dyes and powdered admixtures)

| Component | Specific Gravity | Volume ($ft^3$) | Amount (mass/volume) ($lb/yd^3$) | |
|---|---|---|---|---|
| Color Pigment** | 1.270 | 0.066 | 5.23 | Total Solids from Admixtures 68.44 $lb/yd^3$ |
| Hydrated Lime Type S | 2.600 | 0.390 | 63.21 | |

## Water

| | Amount (mass/volume) ($lb/yd^3$) | | | Volume ($ft^3$) |
|---|---|---|---|---|
| Water, $lb/yd^3$ | | w: | 255.99 | 4.102 |
| Total Free Water from All Aggregates, $lb/yd^3$ | | $\sum w_{free}$: | -70.89 | |
| Total Water from All Admixtures, $lb/yd^3$ | | $\sum w_{admx}$: | 44.75 | |
| Batch Water, $lb/yd^3$ | | $w_{batch}$: | 282.13 | |

## Densities, Air Content, Ratios and Slump

| | cm | fibers | aggregates | solids | water | Total |
|---|---|---|---|---|---|---|
| Mass of Concrete, M, (lb ) | 568.80 | 0.00 | 901.94 | 68.44 | 255.99 | $\sum M$: 1795.24 |
| Absolute Volume of Concrete, V, ($ft^3$) | 3.302 | 0.000 | 14.132 | 0.456 | 4.102 | $\sum V$: 21.994 |
| Theoretical Density, T, $(=\sum M / \sum V)$ | 81.65 | $lb/ft^3$ | Air Content [= (T - D)/T x 100%) | | | 18.6% |
| Measured Density, D | 66.49 | $lb/ft^3$ | Slump, Slump flow | | | 3 in. |
| water/cement ratio, w/c: | 1.35 | | water/cementitious material ratio, w/cm: | | | 0.45 |

** Pigment colors vary

# *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 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W | 0.0 | -4.8 | 0.0 | -5.4 | -6.0 | -6.5 | -7.1 | -7.6 | -8.0 | -8.4 | -8.8 | -9.1 | -9.2 | -9.3 | -9.3 | -9.3 | -9.1 | -8.9 | -8.1 | -7.5 | -6.8 | -5.6 | 0.0 | -5.1 |
| P | 0.0 | 0.0 | 77.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 82.0 | 0.0 |
| F | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| R | 0.0 | -4.8 | 77.6 | -5.4 | -6.0 | -6.5 | -7.1 | -7.6 | -8.0 | -8.4 | -8.8 | -9.1 | -9.2 | -9.3 | -9.3 | -9.3 | -9.1 | -8.9 | -8.1 | -7.5 | -6.8 | -5.6 | 82.0 | -5.1 |

**Assumptions:**

- 2-Dimensional Beam
- Non - Uniformly Distributed Weight
- Display support, simply supported, reactions a foot from each side
- Variable R is not represented in Figure 1, but is used for calculation of shear forces.

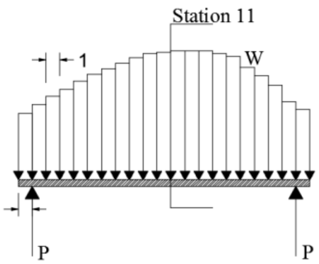


**Figure 1:** Free Body Diagram

**Table Key:**

| | | |
|---|---|---|
| L(x) = | Distance from Bow | [ ft.] |
| P = | Support Reaction | [ lb.] |
| W = | Self-Weight of Canoe | [ lb.] |
| F = | Force of Buoyancy Forces | [ lb.] |
| R = | Summation of Loads (w, P, F) | [ lb.] |

## Step 2 SHEAR FORCES

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

| L(x) | 0 | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| V | 0.0 | -4.8 | 72.8 | 67.4 | 61.4 | 54.9 | 47.9 | 40.3 | 32.3 | 23.9 | 15.1 | 6.0 | -3.2 | -12.5 | -21.9 | -31.2 | -40.3 | -49.2 | -57.2 | -64.7 | -71.5 | -77.1 | 4.9 | 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 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M | 0.0 | -2.4 | -2.4 | 65.0 | 129.4 | 187.6 | 239.0 | 283.1 | 319.4 | 347.5 | 367.0 | 377.5 | 378.9 | 371.0 | 353.8 | 327.3 | 291.6 | 246.9 | 193.7 | 132.7 | 64.6 | -9.7 | -9.7 | 0.0 |

**Comments:**

- Shear forces in Figure 2 and bending moments in Figure 3 were calculated at one foot intervals. Values were then interpolated to complete each

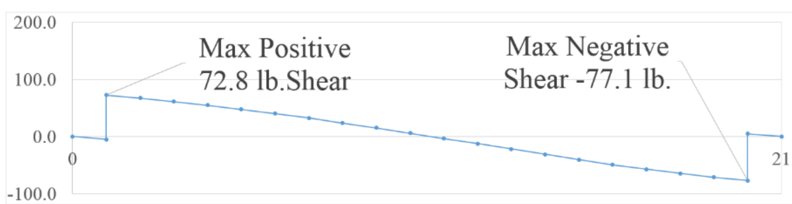


**Figure 2:** Shear Diagram

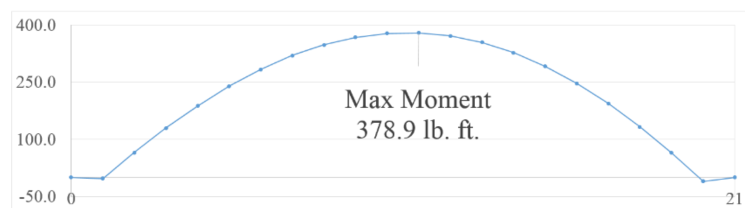


**Figure 3:** Moment Diagram

# *Appendix C: Example Structural Calculation Continued*

## Step 4 SHEAR AND MOMENT VARIABLES

**Comments:**

- A load factor of 1.25 was added to the max moment to account for dynamic effects.
- Max moment occurs at station 11

$M_{max} = M_{11}$

$M_{11} = 378.9\ lb * ft.$

$M_{11} * 1.25 = 473.75\ lb\text{–}ft.$

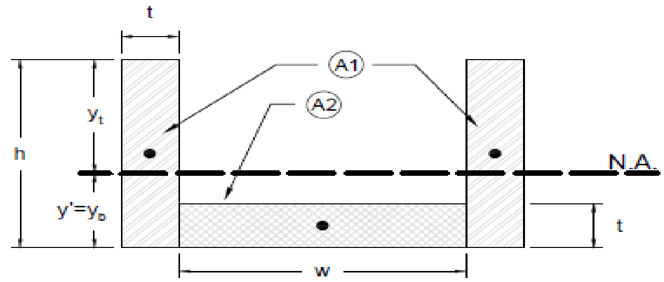


**Figure 4:** Area at Station 11

## Step 5 DEFINE VARIABLES

$t = 0.5\ in.$ $h = 12.5\ in.$ $w = 11.85\ in.$

## Step 6 AREA CALCUATIONS

$A_1 = t * h$ $A_1 = 5.93\ in^2$

$A_2 = w * t$ $A_2 = 12.5\ in^2$

$A_{tot} = 2A_1 + A_2$ $A_{tot} = 18.43\ in^2$

## Step 7 DETERMINE NEUTRAL AXIS

$$y' = \frac{\left[2\left(A_1\left(\frac{h}{2}\right)\right) + A_2\left(\frac{t}{2}\right)\right]}{[2*A_1 + A_2]} \qquad y' = 4.32\ in.$$

$$d_1 = \left(\frac{h}{2}\right) - y' \qquad d_1 = 3.82\ in.$$

$$d_2 = y' - t \qquad d_2 = 1.93\ in.$$

$$y_t = h - y' \qquad y_t = 8.18\ in.$$

$$y_b = -y' \qquad y_b = -4.32\ in$$

## Step 8 MOMENT OF INTERTIA

$$I_1 = \frac{t*h^3}{12} \qquad I_1 = 0.12\ in^4$$

$$I_2 = \frac{w*t^3}{12} \qquad I_2 = 81.38\ in^4$$

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

$$I = 214.52\ in^4$$

## Step 9 DETERMINE INTERNAL STRESSES WITHOUT PRESTRESS

$$\sigma_t = \frac{-M*y_t}{I} \qquad \sigma_t = -216.76\ psi\ Compres.$$

$$\sigma_b = \frac{-M*y_b}{I} \qquad \sigma_b = 114.50\ psi\ Tension$$

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

$$Q = 70.87\ in^3$$

$$\tau = \frac{V_{11}*Q}{I*(2t)}$$

$$\tau = 0.00\ psi$$

## Step 10 TENDON LOADS

**Comments**:

- A 1.25 safety factor accounts for prestressing losses.
- e = eccentricities from Kevlar cables (spreadsheet).

$P = -\frac{4550}{1.25}\ lb.$

$e = 2.02\ in.$

## Step 11 INTERNAL STRESSES WITH PRESTRESS

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

$$\sigma_t = -197.56 - 280.42 - 18.06\ psi$$

$$\sigma_t = -496.04\ psi$$

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

$$\sigma_b = -197.56 + 148.12 + 9.54\ psi$$

$$\sigma_b = -39.89\ psi$$

# Appendix C: Example Structural Calculation Continued

**Table 4:** Shows the results of all four loading situations expected

| Loading Case | Max Moment [lb.*ft.] | Max Positive [lb.] | Max Negative [lb.] |
|---|---|---|---|
| Display | 378.9 | 72.8 | -77.1 |
| Transportation | 505.7 | 80.3 | -81.7 |
| Men's Sprint | -1103.5 | 229.8 | -221.4 |
| Co-ed | -939.8 | 189.5 | -217.7 |

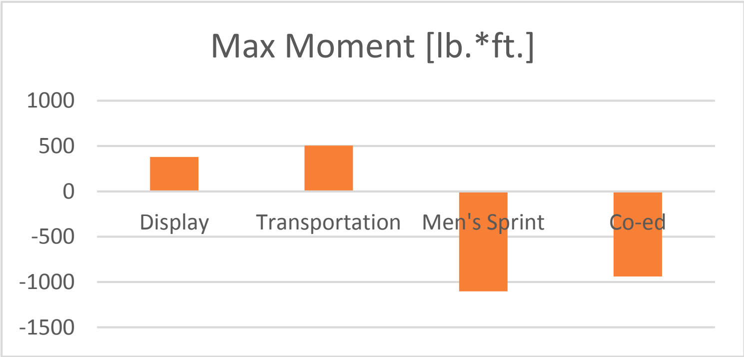


**Figure 5:** Graphical representation of moment at all four loading situations expected

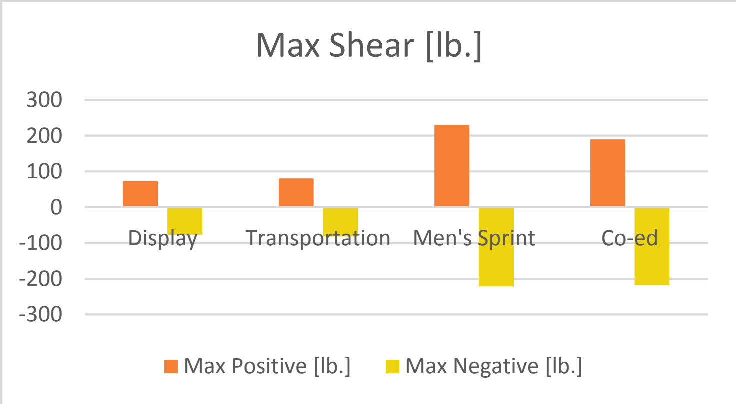


**Figure 6:** Graphical representation of shear at all four loading situations expected

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

Summary of Reinforcement Thickness:

$t_{carbon\ fiber}$: 0.035 in $t_{tendon}$: 0.125 in $t_{ferrule} = 0.125$ in $t_{threadedrod} = 0.25$ in $t_{steel\ mesh}$: = 0.069 in

## Section A: Standard Canoe Wall, Typical

Minimum Concrete Wall Thickness: 0.5 in

$$\frac{t_{Reinforcement}}{t_{Concrete}} = \frac{t_{tendon} + 2 * t_{carbonfiber}}{t_{Concrete}} = \frac{.125 + 2 * .035}{0.5} * 100 = 39\% \leq 50\%$$

## Section B: Rib Location

Minimum Concrete Wall Thickness: 1.0 in

$$\frac{t_{Reinforcement}}{t_{Concrete}} = \frac{t_{tendon} + 2 * t_{carbonfiber} + t_{threadedroad}}{t_{Concrete}} = \frac{0.125 + 2 * 0.035 + 0.25}{1.0} = 44.5\% \leq 50\%$$

## Section C: Gunwale

Minimum Wall Thickness: 1.0 in

$$\frac{t_{Reinforcement}}{t_{Concrete}} = \frac{0}{t_{Concrete}} = 0\% \leq 50\%$$

## Section D: Bulkhead

Minimum Wall Thickness: 1.5 in

$$\frac{t_{Reinforcement}}{t_{Concrete}} = \frac{2 * (t_{tendon} + t_{steelmesh})}{t_{Concrete}} = \frac{2 * (0.125 + 0.069)}{1.5} = 25.9\% \leq 50\%$$

## Section E: Anchorage Zone

Minimum Wall Thickness: 1.5 in

$$\frac{t_{Reinforcement}}{t_{Concrete}} = \frac{2 * (t_{tendon} + t_{steelmesh}) + t_{ferrule}}{t_{Concrete}} = \frac{2 * (0.125 + 0.069) + .125}{1.5} = 34.2\% \leq 50\%$$

General Note: Reinforcement thicknesses determined as per section 4.3.1 of the 2017 ASCE National Concrete Canoe Competition Rules and Regulations

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

**Input Parameters:**

$n_1$: 6 $n_2$: 7 $aperture_1$: 1.5 in $aperture_2$: 1.5 in

$t_1$: 0.15 in $t_2$: 0.15 in

**Solution**:

$$d_1 = aperture_1 + 2 * \left(\frac{t_1}{2}\right) = 1.5 + 2 * \left(\frac{0.15}{2}\right) = 1.65\ in$$

$$d_2 = aperture_2 + 2 * \left(\frac{t_2}{2}\right) = 1.5 + 2 * \left(\frac{0.15}{2}\right) = 1.65\ in$$

$$Length = n_1 * d_1 = 6 * 1.65 = 9.9 in \qquad Width = n_2 * d_2 = 7 * 1.65 = 11.55\ in$$

$$\sum Area_{open} = n_1 * n_2 * aperture_1 * aperture_2 = 6 * 7 * 1.5^2\ in^2 = 94.5\ in^2$$

$$\sum Area_{total} = Length * Width = 9.9 * 11.55 = 114.345\ in^2$$

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

## Percent Open Area Calculations: Galvanized Steel Hardware Cloth

**Input Parameters:**

$n_1$: 7 $n_2$: 7 $aperture_1$: 0.45 in $aperture_2$: 0.45 in

$t_1$: 0.05 in $t_2$: 0.05 in

**Solution**:

$$d_1 = aperture_1 + 2 * \left(\frac{t_1}{2}\right) = .45 + 2 * \left(\frac{0.05}{2}\right) = 0.5\ in$$

$$d_2 = aperture_2 + 2 * \left(\frac{t_2}{2}\right) = .45 + 2 * \left(\frac{0.05}{2}\right) = 0.5\ in$$

$$Length = n_1 * d_1 = 7 * 0.5 = 3.5\ in \qquad Width = n_2 * d_2 = 7 * 0.5 = 3.5\ in$$

$$\sum Area_{open} = n_1 * n_2 * aperture_1 * aperture_2 = 7^2 * 0.45^2\ in^2 = 9.923\ in^2$$

$$\sum Area_{total} = Length * Width = 3.5^2 = 12.25\ in^2$$

$$POA = \frac{\sum Area_{open}}{\sum Area_{total}} = \frac{9.923\ in^2}{12.25\ in^2} = 81.0\% \ (> 40\% \text{minimum}) \quad O.K.$$