BEARNEATH THE SEA

UNIVERSITY OF CALIFORNIA, BERKELEY

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Despite all the technological advances of the last century, a staggering 90 percent of the world's oceans remain unmapped, and an even greater percentage remains unexplored. As such, the deep sea may be considered the last, and seemingly never-ending, frontier on Earth that parallels two of the fundamental principles of engineering: curiosity and endless opportunity for innovation. Motivated by these values, the 2019 UC Berkeley Concrete Canoe Team aimed to explore the vast opportunities in project management, lean construction practices, and concrete mix design.

Located across the bay from the Golden Gate Bridge, the University of California, Berkeley was founded in 1868 as the flagship institution of the UC system. Consistently ranked as one of the top undergraduate civil engineering programs in the world, UC Berkeley continues to maintain its reputation of excellence in research, social responsibility, and sustainable innovation. In the 31 years of participating in the ASCE National Concrete Canoe competition, UC Berkeley has qualified for Nationals 21 times, with 5 championships and 15 Top-5 finishes. For the past 3 Mid-Pacific Conference competitions, UC Berkeley placed 4th with *RadiCal* in 2016, and 2nd with *Bear Necessities* and *OptiCal Illusion* in 2017 and 2018, respectively.

Table 1: *Bearneath the Sea* **Specifications**	
Name	*Bearneath the Sea*
Length	135 in.
Maximum Width	24.75 in
Maximum Depth	16 in
Average Thickness	0.6 in
Weight	260 lbs
Primary Colors	Blue, green, white
Primary Reinforcement	Basalt Mesh and ARG Scrim
Secondary Reinforcement	13 mm PVA

Just as humankind continues to explore the extents of the ocean, *Bearneath the Sea*'s patch and finishing mixes are the culmination of the UC Berkeley Concrete Canoe team's exploration of different materials for lightweight concrete. With the addition of Rule 3.3.3b, which changed the classification of material that passes through the No. 200 sieve from aggregate to mineral filler, extensive research was performed to identify a new, compliant aggregate light enough to replace a portion of our K1 Glass Bubbles. After testing several structural lightweight aggregates, the team selected Hess Pumice, an amorphous aluminum silicate, which has a loose bulk density less than the density of water. By conducting more experiments on chemical admixtures, the Materials division decided to reduce the amount of water and increase the amount of chemical admixtures to improve the consistency and strength of the concrete.

Table 2: Material Properties

Mix	**Structural**	**Patch**	**Finishing**
Plastic Unit Weight (pcf)	66.6	111.4	102.9
Oven-Dried Unit Weight (pcf)	61	109	101
28-Day Compressive Strength (psi)	1470	6960	4860
28-day Tensile Strength (psi)	210	900	n/a
Composite Flexural Strength (psi)	810	3830	n/a
Air Content (%)	-11.6%	-3.8%	-1.4%

With the Construction division's implementation of a female mold, the team exceeded the scheduled predictions and achieved sustainability goals by minimizing the amount of concrete, adhesives, nails, and wax consumed. The novel female mold is compatible with full-height, bent plywood panels, prefabrication of an interlocking formwork, and three-dimensional printing of more intricate formwork pieces, all of which facilitated an earlier casting date.

The Project Management of *Bearneath the Sea* revamped the overall organization of the project timeline and adjoined a new weekly work plan and look-ahead schedule to the existing master plan and labor productivity program. SmartSheet™, a live scheduling software, was implemented by all officers to focus and clarify the current tasks and critical activities for all divisions. This improved transparency between divisions and helped coordinate events that required multiple divisions.

In concurrence with the vibrant graphics and ever-increasing curiosity of the team, these innovations have resulted in a sustainable, high-quality final product, *Bearneath the Sea*, that will continue the outstanding legacy of UC Berkeley Concrete Canoe.

Bearneath the Sea's hull design was modeled off of *OptiCal Illusion*'s design to build off of last year's paddling successes. To make hull modifications, the Hull Design division took an innovative, paddler input-based approach that focused on increased maneuverability for the slalom races. Yet another novel experiment was comparing this year's and last year's canoes in the physical flume test. Implementing these targeted changes and performing experiments make this year's hull design one of UC Berkeley's most innovative yet.

Table 3: Hull Characteristics		
	Bearneath the Sea (2019)	*OptiCal Illusion* (2018)
Max Depth (in.)	16.0	15.2
Length to Beam Ratio	9.40	9.36
Bow and Stern Angles (from the vertical)	35° and 30°	20° and 30°
Bow and Stern Rockers (in.)	2 and 4	1 and 1.4
Min. Hull Thickness (in.)	0.50	0.50
Avg. Hull Thickness (in.)	0.6	0.55
Weight (lbs)	260	235

The switch from 2018's single gender endurance race to this year's slalom race catalyzed the majority of the hull design changes. For example, the Hull Design division altered the wall height, chine curvature, and rocker size to improve maneuverability. During last year's slalom section, paddlers noticed that while turning, the canoe occasionally tipped almost to a point where water flooded in. To avoid any potential overturning this year, the maximum depth of the walls was raised by 0.8 in. Combined with a more curved bottom compared to the flat bottom of *OptiCal Illusion*, this change allows paddlers to lean more into turns, thus lowering the turning radius and improving slalom times.

To further optimize maneuverability, the team added significant bow and stern rockers. The presence of the rockers creates a sloping hull reducing the wetted surface area of the bottom of the canoe. With this decreased area of the canoe in the water, the paddlers can more easily rotate the canoe during the turns. These three major changes improving maneuverability will set the paddlers up for efficient turns during the slalom-heavy races.

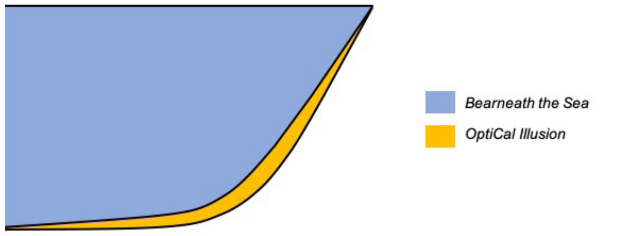


Figure 1. Comparison of bow shape between *Bearneath the Sea* and OptiCal Illusion.

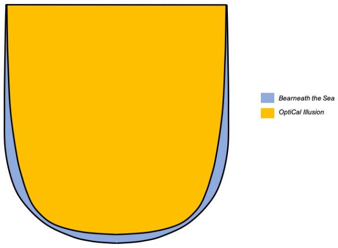


Figure 2. Rounder chines on *Bearneath the Sea*

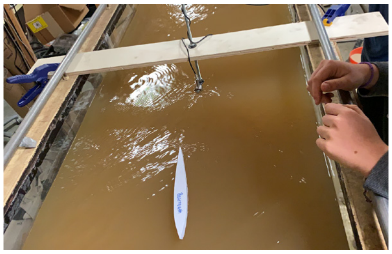


Figure 3. A 3D printed model of *Bearneath the Sea* is flume tested.

Once changes were made to improve maneuverability, the Hull Design division elected to increase straight line speed by implementing two changes: narrowing the width of the bow and increasing the angle between the bow and the vertical. In comparison to *OptiCal Illusion*, *Bearneath the Sea*'s bow tapers off sharply both in width and in angle to cut through the water more smoothly. Figure 1 demonstrates the increase in angle between the bow and a vertical line from the tip of the bow; this angle was increased from 20 to 35 degrees. Both of these changes further add to the effect of decreasing the weight and wetted surface area of the bow.

Bearneath the Sea was modeled in SolidWorks®, where cross-sectional splines were altered to create the desired curves of the hull. To qualitatively corroborate design changes, the Hull Design division performed flume testing with a 1:25 scale 3D printed models of the canoes, comparing *Bearneath the Sea* to *OptiCal Illusion*. Using a load cell, the drag force was measured against a flow that simulated straightline speed.

Centering *Bearneath the Sea*'s hull design changes based on paddler feedback and new course changes highlights the focus on this year's theme of innovative design. Furthermore, by implementing flume testing, the Hull Design division hopes to leave experimental framework and data in place for future generations of UC Berkeley Concrete Canoe.

Once the final hull design was completed, the Structural Analysis division started performing calculations for the new hull. The main objective was to maintain the structural integrity of the canoe during all five loading cases for *Bearneath the Sea*, which has slightly higher walls than *OptiCal Illusion*.

Shear and moment structural calculations were first computed by hand and later checked thoroughly with RISA 2-D and MATLAB. Five different loading cases were considered: display, transportation, and male, female, and coed races. The canoe was idealized as a statically determinate, simply supported beam, with its self weight and buoyant forces distributed uniformly along the span of the beam. Paddlers were simplified as point loads. Using the Materials division's initial estimate of 60 pcf base mix and assuming that the canoe has an half-inch thickness, the canoe's self-weight was estimated to be 240 lbs. Male and female paddlers weights were assumed to be 167 and 125 lbs, respectively.

To ensure the structural integrity of the canoe, the Structural Analysis division used Load and Resistance Factor Design (LRFD). All paddlers' weights were multiplied by a factor 1.6 and the canoe self-weight was multiplied by a factor of 1.2 to account for any variability in mix design and concrete strength. Thus, the factored weights for the male and female paddlers became 267 and 200 lbs respectively and 312 lbs for the canoe self-weight. After LRFD analysis, the uniformly distributed buoyant force in the racing load cases was calculated so that the canoe remained in static equilibrium.

For the other two loading cases, force distributions and support locations were set up to best match the actual forces the canoe would experience. For display, it was assumed that the two stands were 3 feet away from the canoe ends, completely supporting the canoe's weight. For the transportation scenario, twenty people—simplified as point loads—were carrying the canoe, with two people carrying the ends and nine people distributed evenly on each side of the canoe. For the coed race, the male paddlers were placed at 20% and 80% and the female paddlers at 35% and 65% of the canoe's length. For the two-person races, paddlers were modeled as point loads four feet from each end.

After completing all calculations, it was determined that the maximum positive moment occurred at 3.9 ft and 15.6 ft from the bow during the coed race. However, the maximum positive moment occurred during the two-person male race at the center of the canoe, 9.75 ft from the bow. Next, flexural calculations were performed to find the maximum compressive and tensile strengths of the canoe. The normal stresses due to flexure were in the elastic region because transverse sections of a structural member remain plane (Beer et al. 2012). Since the stresses are elastic and below the effective yield strength, they have a linear distribution along the cross-section. Linear-elastic analysis produced a maximum compressive strength of 95.8 psi at the gunwale and a maximum tensile strength of 30.8 psi at the hull.

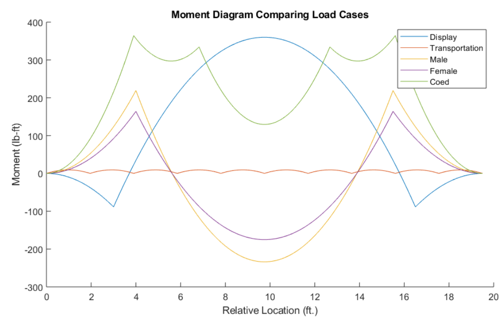


Figure 4. Moment Envelope Diagram

With these maximum design strengths, a safety factor was decided based on last year's competition experience. *OptiCal Illusion* did not sustain any noticeable cracks after the display, transportation, or races at the MidPac conference. As such, this year the same factor of safety of 4 was applied to the maximum calculated stresses. Thus, a minimum compressive strength of 383.4 psi and tensile strength of 123.3 psi were requirements for the concrete mix design from the Materials division.

To estimate the shear stress in the chine, the canoe wall was modeled as a cantilever beam with water pushing on it from one side. Using the maximum shear formula for a rectangular section, adjusting for dynamic waves, and taking the unit weight of water as 63 pcf, the shear stress in the chine was calculated to be 14.05 psi. For the gunwale deflection calculation, the canoe wall was again assumed to be a cantilever beam. Using the differential equations for deflection and assuming the canoe wall has a rectangular cross-section, the deflection at the gunwale was calculated to be approximately 0.1461 in. Punching stress calculations determined that the material strength requirement to avoid fracture caused by an imbalanced paddler is 16.67 psi.

Since last year's canoe sustained little visible damage, the Structural division chose to continue using two layers of basalt reinforcement along the length of the canoe, with one layer of alkali-resistant glass (ARG) reinforcement at the ends. This process was even more compatible with the new female mold as it took the shape of the formwork. With a conservative structural mix, the structural integrity of *Bearneath the Sea* is ensured.

At last year's MidPac competition, *Optical Illusion* far exceeded the team's expectations for the dunk test, rising to the surface nearly instantaneously once released, and it performed well structurally throughout the competition. Due to this success, the Materials division decided to use *OptiCal Illusion*'s mix as a baseline while keeping in mind some modifications. The goals of this year's Materials division included building off of the structural and lightweight success of *Optical Illusion,* developing mixes that complied with rule changes and creating a structural mix with a workability that would complement the team's transition from a male mold to a female mold.

Table 4: Constituents Used

Material Name	Intended Use	Applicable ASTM Standard
Lehigh ASTM Type I-II (AASHTO Type I) Portland Cement	Cement	ASTM C150
Lehigh Allcem Blast Furnace Slag	Cementitious Material	ASTM C989 Grade 120
BASF MasterLife Silica Fume 100	Cementitious Material	ASTM C1240
Vitro Minerals VCAS White Pozzolans	Cementitious Material	ASTM C618, ASTM C1157
NYCON-PVA RECS100	Fibers	ASTM C1116
Utelite Structural Fine Lightweight Aggregate	Aggregate	ASTM C330
EnStyro Recycled Shredded EPS (Expanded Polystyrene) Foam <3/32"	Aggregate	None
Trinity Frazier Park Structural Fine Lightweight Aggregate	Aggregate	ASTM C330
Hess Pumice Grade 2	Aggregate	ASTM C330
3M Glass Bubbles K1	Aggregate/Mineral Filler	None
Direct Colors Concrete Pigment	Pigment	ASTM C979
Euclid Chemical SBR Latex	Polymer Modifier	ASTM C1059
GCP Applied Technologies ADVA Cast 530	Superplasticizer	ASTM C494
Grace V-MAR 3	Rheology-modifying admixture	ASTM C494
Eclipse Floor 200	Shrinkage reducing admixture	ASTM C494 Type S

The division determined the performance of various concrete mixes with regard to their strength, cohesiveness, and workability using several standard ASTM tests. Slump (ASTM C143) and spread (ASTM C1611) tests allowed an assessment of the mixes' cohesiveness and workability. Compressive strength tests (ASTM C39) were conducted on each mix at 7, 14, and 28 days of curing. The combination of these tests helped to determine if a mix was an improvement from the last mix, as the goal was to improve workability without a corresponding reduction in strength. Conducting other tests, namely split tensioning tests (ASTM C496) to determine the tensile strength, and a modified center-point loading flexural strength test (ASTM C293), further helped decide if a mix was better than previous mixes.

Figure 5. Packing cylinders for testing

Materials division members chose to use the same cements that were used last year in *Optical Illusion*. Portland Cement (ASTM C150) was the primary cement while slag (ASTM C989) and silica fume (ASTM C1240) were used as a partial cement replacement. The exact brand and material name can be found in Table 4. Since slag is a waste product of the coal industry, continuing to use it not only helps create a mix with good cohe siveness but also helps to meet the sustainability goal set by the team. Silica fume helps reduce the density of a mix with its low specific gravity and increases the strength by filling in voids left by larger particles, so it was decided to slightly increase its replacement ratio.


Figure 6. Testing new mix for workability and adding materials to improve quality

The same aggregates for the base mix were also used. Utelite™ is an expanded shale that has a specific gravity (sg) of 1.73 and an absorption capacity of 31.4%. It offers one of the lowest densities of all ASTM C330 compliant aggregates. In addition to Utelite™, the division incorporated recycled shredded expanded polystyrene (EPS) foam from Enstyro Inc., which has an absorption capacity of 0%. The Materials division continued to use the same gradation, a grade size less than 3/32 in. (sg = 0.032). Following results from last year's testing, it was decided to use the same fibers, 13mm Polyvinyl Alcohol (PVA) fibers (ASTM C1116), which have a high elastic modulus and prevent small cracks in concrete from propagating. 13% of Utelite's weight falls below the No. 200 sieve, so in the first batch, the amount of Utelite was increased and the amount of EPS decreased. Thus, the volume of aggregate meeting ASTM C330 to the total volume ratio could meet the required 25% even while counting the lower 13% of the total Utelite weight as mineral filler instead of aggregate. The mixture proportions of the test mixes are reported in Table 5. This first mix design resulted in a very dry and unworkable mix. In the following mix, members addressed this issue by adding water. This new mixture had an adequate slump, but it was not sticky enough and was very difficult to place. Additionally, this resulted in a high water-to-cementitious material ratio, which lowered the strength to a value that did not meet that minimum requirements provided by the Structural division.

Table 5: Development Process of Structural Mix

Material	Baseline	Mix 1	Mix 2	Final Mix
Cement (%)	8.4	8.4	9	9.1
Slag (%)	4.1	4.1	4	4
Silica Fume (%)	0.63	0.63	1	1
EPS (%)	51	48	48	48.6
Utelite (%)	17.5	20.5	16	16.7
Admixture Dosage of ADVA-VMAR-Eclipse (fl oz/cwt)	29-42-15	29-42-15	29-42-15	108.2-176.3-47.3
w/cm ratio	0.46	0.46	0.69	0.42
Compressive Strength (psi)	1280	N/A	N/A	1470

In order to address the issue of dry mixes, a larger amount of the total water count was incorporated as admixture water instead of batch water. For the next mix, the team performed moisture content analyses of admixtures to replace about 17% of batch water with an increase in admixtures. This allowed the mix to fully utilize the beneficial qualities of admixtures. ADVA Cast 530 (ASTM C494) is a superplasticizer, used primarily for its water-reducing capabilities. It also reduces segregation and improves the consistency of the mix. In order to prevent the mix from becoming too fluid, the Materials division also increased the amount of V-MAR 3 (ASTM C494), an admixture that "increase[es] the viscosity of the concrete while still allowing the concrete to flow without segregation" (TDS). The Technical Data Sheet for V-MAR 3 also states that it is recommended for use with ADVA series superplasticizers. The low water-to-cement ratio that resulted from the changes to the mix increased the risk of drying shrinkage, so the team also increased the amount of the shrinkage reducing admixture, Eclipse Floor 200 (ASTM C494 Type S).

These changes resulted in an optimal structural mix that yielded a compressive strength of 1470 psi, a slump of 0.5 inches, water to cementitious material of 0.42, a wet unit weight of 66.6 pcf and an air content of

-11.6%. This wet unit weight suggests that the concrete has a greater specific gravity than water. When testing this mix, concrete in cylinders were heavily compacted to gauge the specific gravity in the worst case scenario. The high compressive capabilities of EPS are responsible for the high density seen in the plastic unit weight as well as the theoretically impossible negative air content. The concrete in the canoe was not compacted as much, so it has a lower density. Additionally, the oven dried unit weight was found to be 60.52 pcf for these heavily compacted samples, so the concrete in the canoe must have a smaller specific gravity than water. This mix also resulted in a higher strength than the baseline mix, pointing to the success of the final mixture. Finally, the workability of the mix was different this year because the concrete stuck to itself better than it stuck to other surfaces, including the mold. This was not a problem with the female mold because there was no danger of it sliding off the sides of the mold. Instead, it easily stuck to concrete that was placed at a lower elevation, and there was very little concrete waste adding to the sustainability of the resulting mix design.

Figure 7. Demolded canoe exterior in need of patch mix

Last year's canoe was extremely buoyant, and sat well above the water. In fact, paddlers expressed that this led to the canoe having an issue with rocking, and there was a danger of tipping when the canoe was being turned. Because of this, the team were less concerned with having very lightweight mixtures for the patch and finishing mixes. The purpose of the patch mix is to fill in concavities on the surface of the canoe and to provide a uniform surface for the application of the finishing mix. The finishing mix is used to apply graphics, and it is produced in various colors using powdered pigments. Previously, the mix relied on a high volume of K1 to ensure these mixes had a smaller specific gravity than water. This year, only 10% of the total K1 volume was large enough to be counted as aggregate as per Section 3.3.3a of the competition rules. Therefore, the team had to use less of this very lightweight aggregate and instead increased the use of the heavier and larger ASTM C330 compliant aggregates. It was decided that having heavier mixes this year would not be an issue given the feedback from the previous year, and the fact that the base mix is still very light and comprises the bulk of the canoe.

The cements used for the patch mix were portland cement, slag, and VCAS. The team chose to use Trinity #1 Sand (ASTM C330) and Hess Pumice (ASTM C330) for the patch mix. Trinity has a specific gravity of 1.79 and an absorption capacity of 21.1%. Hess Pumice has a specific gravity of 1.71 and an absorption capacity of 14.8%. The goals for the patch mix were to have a mix that easily stuck to the existing layers of structural concrete and could be spread evenly and thinly to fill low areas. This was easily achieved by using the high-admixture approach developed during the testing for the base mix. The division used the same admixtures that were used in the base mix, and ended up with a mix with a high strength of 6960 psi. To minimize the use of this mix due to its high specific gravity, members mixed in small batches and placed it on the canoe in thin layers. The high fluidity of the mix made it easy to place the concrete in such a way.

The finishing mix was created alongside the design work being done by the graphics division. The team wanted a similar consistency as the patch mix so that it could also be applied in thin layers which are ideal for the graphics mix. The graphics mix must be even finer so that it can be applied in an even thinner layer, so the Trinity was switched out for 3M K1 Glass Bubbles. The division used similar amounts of admixtures, with the addition of SBR Latex to reduce the risk of surface microcracking caused by drying shrinkage. The graphics division assisted with the selection and testing of pigments to reach the desired colors taking into account the brightening effect curing has on concrete. These changes resulted in a smooth, aesthetically pleasing mix that was easy to apply.

Figure 8: Members applying finishing graphics concrete mix over vinyl stencils

This year, the Materials division started with the baseline mix used in *Optical Illusion* and then succesfully developed new mixes that satisfied the aggregate proportioning rules while also increasing strength and workability to better suit the team's needs.

Bearneath the Sea embodies the discovery of new things and the huge potential for exploration, as well as an awareness of how innovation affects the environment and, subsequently, the balance of life under the sea. This year's team aimed to capture this spirit in the construction process of the canoe.

Historically, Berkeley has chosen to build wooden molds instead of expanded polystyrene foam molds, which require fewer man-hours but release pollutants and carcinogens during production (USEPA, 1994; USEPA, n.d.). Wooden molds, however, can easily be composted using on-campus facilities. Oriented strand board (OSB) was selected for the skeleton of the mold because of its multi-directional strength and resistance to splitting from nails driven into its side faces. In addition, its manufacturing process incorporates 75% of the log, using wood that would otherwise go to waste (Kaestner 55). Plywood was selected to form the surface of the mold because of its versatility and strength. A custom low-formaldehyde interior grade plywood made for use with laser cutting machines was chosen.

Figure 9: Full-scale mockup of the end section of the canoe

This year, rather than constructing a scaled-down mock-up of the whole canoe as in previous years, the team optimized its use of time by creating small, full-scale sections. With the time saved, two sections focusing on critical segments of the canoe could be constructed while still staying ahead of schedule. By building models in full-scale, the team could test how materials and construction processes would work on the final mold. Additionally, new members were trained on safety practices, construction techniques, and concrete casting while making mock-ups. First, a model of a female mold was constructed to identify possible problems that the team might face (Figure 9). It was determined that although the bow and stern would be a challenge to construct, the female mold would yield a smoother exterior surface, a more accurately constructed keel, and a reduction in concrete waste. A second model was constructed to test innovative ideas, such as interlocking parts, prefabricated panels, and a solution to the challenge of constructing the ends, 3D-printed parts.

Figure 10: Interlocking skeleton with spacers being used during panel installation

Using the SolidWorks® model created by the Hull Design division, interlocking pieces were designed to create the skeleton of the mold (Figure 10). The spine was split into three detachable pieces to facilitate the demolding process. Cross-sectional views were taken at 10-inch intervals to guide the curvature of the surface of the mold. Pieces were cut out of 7/16-inch OSB with a CNC router located on campus. Creating an interlocking framework reduced error to produce a mold which was much more accurate to the design. The fitted spine piece held the cross-sectional pieces at a consistent distance and restricted rotation in two axes, so team members only had to secure one axis of rotation, improving the quality of the framework and greatly accelerating its construction. As an additional measure to regulate spacing and rotation between cross-sectional pieces, plywood spacers were placed to temporarily hold edges of the pieces at the desired distance as the mold was built (Figure 10). These spacers were designed to be easily removable for future reuse.

Figure 11: Panels with living hinges extending from the chine to the bottom of the canoe

Prefabricated panels were created by flattening sections of the SolidWorks® model and laser cutting the outlines out of ⅛-inch thick plywood. Panels were first soaked in water for an hour to increase flexibility, then installed by brad nailing them onto the OSB framework (Figure 11). This created a drastically smoother surface for the mold compared to techniques used in previous years, almost eliminating the need for wood glue, and greatly reducing the amount of time spent constructing the curved sections of the mold. Living hinges were added to parts of the canoe with a smaller radius of curvature, allowing the plywood to bend more (Figure 11). Overall, the panels preserved resolution in the transfer from the design model to the physical model.

Formwork for the bow and stern was 3D printed based on the SolidWorks® model, which produced a degree of accuracy never before achieved by our team on the ends of our canoe. The pieces were fitted onto the mold and held in place by duct tape for easy removal during the demolding process.

½-inch wide strips were cut out of plywood to line the top of the mold and provide a level edge for the casting of the gunwales. Members used a water-based, non-toxic, and biodegradable wood glue to secure layers of the strips to the mold and build the edge (Figure 12). After sanding the mold and filling in gaps with a paste mixture of sawdust and glue, the mold was coated with a layer of wax as a demolding agent. Wax was chosen because it is biodegradable, easy to apply, and does not require sanding, unlike the plaster used in previous years. Lastly, the exterior of the mold was coated with a waterproofing sealer to protect the wood during the curing process.

Figure 12: Finished mold coated with wax and with strips lining gunwale edges

To expedite the casting process and reduce the risk of the formation of cold joints, the team pre-cut both layers of the basalt mesh reinforcement to the shape of the canoe prior to casting. Small steel wires were affixed to the first layer of reinforcement. After casting concrete over it, the wires were tied to the second layer of reinforcement to hold it in place. At the bow and stern, an additional layer of alkali- resistant glass fiber reinforcement was added for protection in the event of a collision.

During casting, concrete batch sizes were optimized to provide just enough material for the team to place before it starts setting. Officers also monitored the timing between the mixing of each batch to optimize the output rate of the concrete and decrease the waiting time for fresh concrete. Concrete was distributed to ensure each member had a supply of fresh concrete, which was hand-placed onto the mold in three layers with reinforcement in between. Depth gauges were handed out to each team member to constantly check the depth of each layer of concrete. By casting even layers, sanding time was reduced and reinforcement was ensured to be at the proper depth within the canoe.

Figure 13: Assembled curing chamber

After casting, a curing chamber was erected from a reusable framework of polyvinyl chloride piping supporting a layer of tarps to enclose the canoe with four air humidifiers (Figure 13). The humidifiers were placed at even distances along the canoe to facilitate even curing of the concrete, and humidity monitors were used to ensure that the chamber was kept at a humidity of over 90%. The sloping design allowed condensation to collect on one side and drip into buckets, where water was collected and used to refill the humidifiers. *Bearneath the Sea* cured for 49 days during the university's final examination week and winter break. With the extended curing period, the canoe gained strength to meet the standards set by the team.

Upon returning to school, team members dismantled the curing chamber and reused the tarps to erect a larger sanding tent, enclosing the area around the canoe to prevent dust from contaminating air in the shared lab space. Members were briefed on the hazards of inhaling concrete dust and given respirators and personal protective equipment to use while sanding, which only took place under officer supervision. Coarse grit sandpaper and a concrete patch mix were used to level the surface of the canoe. Using point- cloud laser scans taken before and after casting, officers determined which areas needed sanding or patching and directed members accordingly.

The canoe was demolded and flipped to allow members to work on the exterior of the canoe. First, the spine pieces were detached to demold the ends. Then the canoe was lifted out as the middle section of the mold was peeled away. Braces, screws, and nails were removed so the wood could be composted. All braces and screws were saved to be reused in future years. In comparison to the male mold used in previous years, the female mold was much easier to demold.

Due to the smooth surface created by prefabricated panels, the exterior of the canoe required much less sanding. The finishing graphics concrete mix was applied directly after sanding with coarse grit sandpaper to provide a rougher surface for the mix to adhere to. Then members sanded with incrementally finer grits of sandpaper to achieve the desired smoothness. Lastly, a waterproofing sealant was applied to preserve the vivid design of *Bearneath the Sea*.

The implementation of a precise and thorough project management scheme was crucial to surpassing *Bearneath the Sea*'s goals of quality, innovation, and sustainability. This year's key strategies involved look-ahead scheduling and weekly work plans, two key of lean construction.

The scheduling process began by determining major milestones from the previous years' schedules and the rules and regulations. From there, the project managers started from the 2019 MidPac Conference and worked backwards in the schedule until reaching the very beginning of the project. With careful attention to critical activities, delayed activities in previous years, and activities with inherent uncertainty, free float was added to duration of the activity to counteract any unforeseen delays.

Table 5: ***Bearneath the Sea*** **Milestones**

Milestone	Variance Between Baseline and Reality (days)	Reason for Variance
Hull Design Completion	0	-
Research of Construction Methods Completion	0	-
Canoe Formwork Completion	-8	Prefabrication of formwork pieces
Casting Canoe	-55	Early casting at end of Fall semester
Sanding Completion	+7	Stricter quality control on sanding
Design Paper Completion	+8	More time spent on presentation completion
Presentation Slides Completion	-14	Adjustment to meet deadline set by host school
Graphics Completion	-7	Shifted members into Materials division to hasten mix design process

The successful prefabrication of many portions of *Bearneath the Sea*'s formwork accelerated the mold construction process, which typically delays the casting date until after the new year. As a result, *Bearneath the Sea* was casted before students left for winter break and cured for the next 7 weeks. The extra curing time allowed for the slow reactions of pozzolanic materials to take place, increasing the strength of the concrete prior to sanding and demolding.

The project managers implemented the Critical Path Method in Microsoft® Project by developing predecessor-successor relationships between activities to define the order in which they needed to be completed. *Bearneath the Sea*'s critical path in both the baseline schedule and the final schedule included sanding, patching, and applying the finishing mix and sealer. Although the expedited construction process allowed for a much earlier casting date and created additional free float for subsequent activities, a stricter quality management plan for sanding and patching was implemented. Thus, the duration of patching and sanding was originally underestimated in the baseline schedule.

To maximize efficiency throughout the year, most members were trained in materials and construction methods while working on the two mock-up cross-sections so that during the year, members could be shifted between divisions. This allowed for uninterrupted progress, minimized idle workers, and expedited the casting process. Because some members of the Hull Design, Structural Analysis, Graphics, and Paddling divisions were already trained at the beginning of the year, mobilization for casting day, where we need a continuous flow of concrete mixing and placement, was much easier. We had a total of 36 members come out to casting day this year.

The project managers and division leaders met every week to create a weekly work plan and keep the division leaders aware of each other's activities. Division leaders would provide updates on their number of members, productivity, and deliverables needed from other divisions. With careful planning of every event on a weekly basis, the team reduced the total person-hours from 3,300 man-hours to 3,000 man hours, a 10% reduction (see Figure 14). After the weekly officer meetings, the entire team with officers and members alike, met for an hour in our DeCal (Democratic Education at Cal, a program that allows students to receive units for student-led courses) to have teamwide discussions and educate new members on the activities of other divisions. In the beginning of the year, all mem- -bers and officers were required to take an online health and safety course, a lab walkthrough with the lab manager, and specific training on tools or materials they would be using throughout the year before being allowed to do any work.

Because of the extra research on different lightweight aggregates and a novel formwork construction process, the operational budget for *Bearneath the Sea* was estimated to be $5,900 with $2,600 dedicated to the final product's production costs. Although the team's total allocation was decreased by approximately 10% from last year, the team was able to reduce costs by reusing construction and concrete materials from previous years to supplement material donations and reducing concrete waste with a female mold.

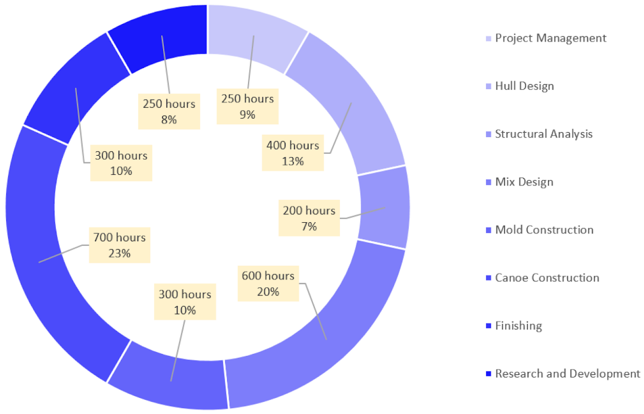


Figure 14: Division of Man-Hours

In order to accommodate *Bearneath the Sea*'s accelerated schedule for casting, the Quality Assurance and Quality Control (QA/QC) division's largest focus this year was the improvement of the team's procurement and document tracking procedures. With these modifications, the QA/QC division also pressed for more team-wide involvement in quality control efforts, promoting a culture where every member plays an important role in the overall quality of the project.

After experiencing major coordination setbacks when deliveries delayed the schedule for *OptiCal Illusion*, this year's management team adopted a new software, SmartSheet, in order to track a more detailed procurement schedule. SmartSheet is an online, cloud-based platform that allowed the officers to schedule and link procurement durations to their relevant, succeeding activities (Figure 15). Each officer created a phase schedule specific to their division, which allowed the team to more accurately assess necessary procurement durations that were not captured with the high-level master schedule created in Microsoft Project. Due to the collaborative nature of the software, tasks could be assigned to team members, who could then update their statuses (complete, in progress, etc.) for all other members to see. As a result, when the plywood mold activities were trending to complete ahead of schedule, the procurement activities were automatically pulled in, and members

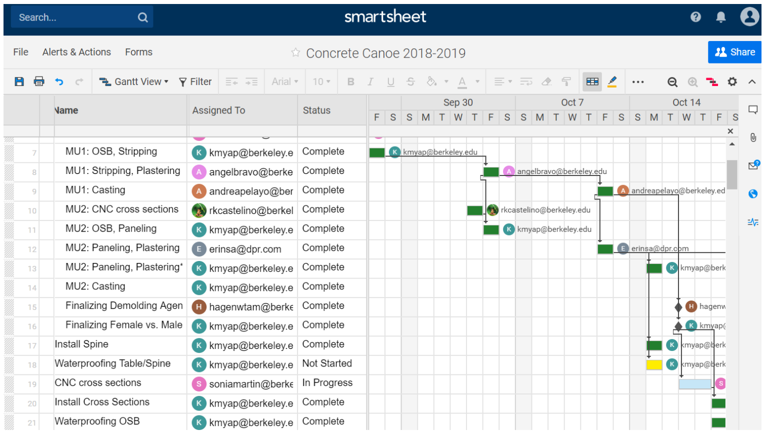


Figure 15: Sample of schedule as tracked through Smartsheet

were notified, so that adjustments could be accommodated without a loss of time.

With regards to tracking RFI responses, SmartSheet also enabled members to link pertinent documents directly to the impacted activities, ensuring information and changes were being properly circulated. Additionally, SDS and MTDS sheets were attached to the procurement, casting, patching, and graphics activities, confirming the compliance of every material. Likewise, structural calculation documents were attached to the Structural Analysis division's schedule, where other members could check for clarity and accuracy. By utilizing this tool, officers only needed to look at one source of information for document tracking, which streamlined the QA/QC program as a whole and ensured *Bearneath the Sea* met and exceeded all requirements.

Hagen Tam (Jr)

Project Manager/ Team Captain
Responsible for budgeting, scheduling, logistics and overall coordination of functional groups

Angel Bravo (Jr)

Jr. Project Manager/ Team Captain
Assisted project manager and worked with division officers to ensure deadlines were consistently met

Erin Saiki (Sr)

QA/QC
Oversaw project progression to guarantee quality, improve efficiency and minimize delays

Arisa Nguyen (Sr)

Social
Recruited new members and planned social events to boost moral during year

Andrea Pelayo (Jr)

Materials
Developed and tested sustainable, compliant concrete mixes

Uma Krishnaswamy (Fr)
Geraldine Fabro (So)
John Bryant Cadiz (So)
Matthew Michalek (Fr)
Karen Lee (Fr)
Ellis Spickerman (Fr)
Brandon Wong (Fr)
Alexis Bryl (Sr)

Cindy Ke (So)

Structural Analysis
Analyzed critical loading cases and resulting material requirements

Bryant La (Fr)
Jiu (Kris) Chang (Fr)
Kevin Ting (Jr)
Jose ALatorre (So)

Sonia Martin (Jr)

Hull Design
Analyzed past designs and developed new, optimized hull design

Jennifer Lee (Jr)
Brandon Wong (Fr)
Jonathon Li (Jr)
Jeffrey Cheng (Fr)

Rohan Castelino (So)

Graphics
Designed graphical elements of canoe, stands, product display and paper

Jason Park (Fr)
Zachary Wu (Fr)
Matthew Tran (Fr)
Jessica Yu (Fr)

Katrina Yap (Jr)

Construction
Directed construction of canoe mold, casting and cross-section

Amber Chau (Sr)
Arisa Nguyen (Sr)
Maggie Chen (Jr)
Marcus D'Avignon (Fr)
Jason Fan (Fr)
Polytimi Kontothanasi (Fr)
Anne Koo (Fr)
Sara Kopunova (Fr)
Wayne Monical (Fr)
Jake Nuesca (Fr)
Austin Vuong (Sr)

Kevin Ting (Jr)

Jose Alatorre (So)

Paddling
Oversaw paddler training sessions and instructed new paddlers

Alexis Bryl (Sr)
Austin Vuong (Sr)
Sam Liu (Sr)
Arisa Nguyen (Sr)
Katrina Yap (Jr)
Matthew Takara (So)
Austin Chen (Fr)
Jake Nuesca (Fr)
Jason Fan (Fr)
Matthew Lalunio (Fr)
Omar Hassan (Fr)
Tracy Tanusi (Fr)

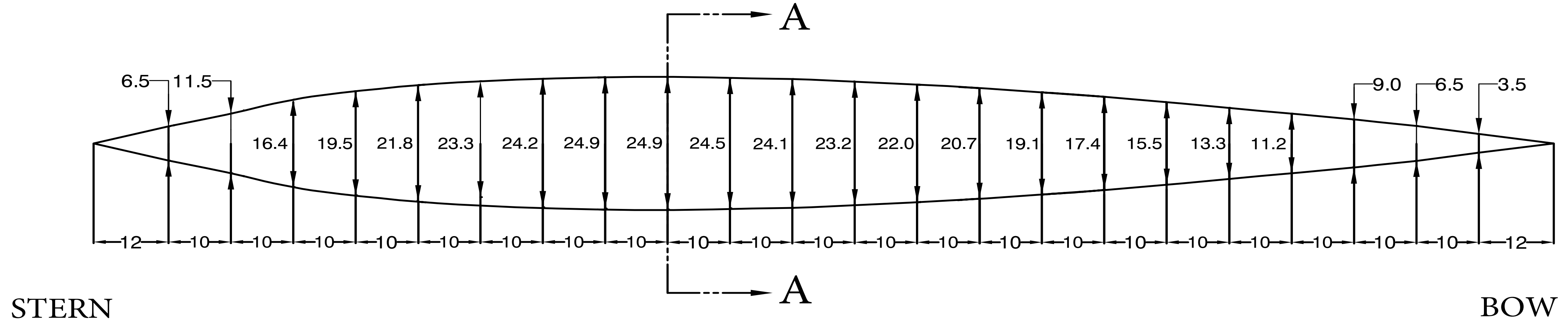
Project Schedule

ID	Task Name	Duration	Start	Finish
1	**Project Milestones**	**177 days**	**Wed 8/22/18**	**Sat 4/20/19**
2	Project Start	0 days	Wed 8/22/18	Wed 8/22/18
3	Hull Design Completion	0 days	Thu 10/18/18	Thu 10/18/18
4	Research of Construction Methods Completion	0 days	Fri 10/26/18	Fri 10/26/18
5	Canoe Formwork Completion	0 days	Thu 11/22/18	Thu 11/22/18
6	Casting Canoe	0 days	Sun 12/2/18	Sun 12/2/18
7	Sanding Completion	0 days	Mon 3/18/19	Mon 3/18/19
8	Design Paper Completion	0 days	Fri 3/22/19	Fri 3/22/19
9	Presentation Slides Completion	0 days	Fri 3/22/19	Fri 3/22/19
10	Graphics Completion	0 days	Mon 4/8/19	Mon 4/8/19
11	MidPac Start	0 days	Thu 4/18/19	Thu 4/18/19
12	MidPac End	0 days	Sat 4/20/19	Sat 4/20/19
13	**Functional Activities**	**175 days**	**Wed 8/22/18**	**Wed 4/17/19**
14	**Hull Design**	**156 days**	**Wed 8/22/18**	**Fri 3/22/19**
15	Research of Preliminary Hull Design	23 days	Wed 8/22/18	Fri 9/21/18
16	Prolines Modeling	3 days	Mon 9/24/18	Wed 9/26/18
17	Flume Test	5 days	Mon 9/24/18	Fri 9/28/18
18	Hull Design Revisions	14 days	Mon 10/1/18	Thu 10/18/18
19	SolidWorks Modeling	7 days	Fri 10/19/18	Mon 10/29/18
20	Panel Drawing Extrapolation	14 days	Tue 10/30/18	Fri 11/16/18
21	Construction Drawing	10 days	Mon 3/11/19	Fri 3/22/19
22	**Structural Analysis**	**44 days**	**Wed 8/22/18**	**Mon 10/22/18**
23	Analysis Classes and Research	30 days	Wed 8/22/18	Tue 10/2/18
24	Loading Case Analysis	1 day	Fri 10/19/18	Fri 10/19/18
25	Sample Calculations	1 day	Mon 10/22/18	Mon 10/22/18
26	**Materials & Mix Design**	**154 days**	**Wed 8/22/18**	**Wed 3/20/19**
27	Material Procurement	43 days	Wed 8/22/18	Fri 10/19/18
28	Research of Preliminary Mix Design	43 days	Wed 8/22/18	Fri 10/19/18
29	Trial Batching and Testing Base Mix	28 days	Mon 10/22/18	Wed 11/28/18
30	Trial Batching and Testing Patch Mix	28 days	Tue 1/22/19	Wed 2/27/19
31	Trial Batching and Testing Finishing Mixes	28 days	Tue 2/12/19	Wed 3/20/19
32	**Construction**	**175 days**	**Wed 8/22/18**	**Wed 4/17/19**
33	Material Procurement	43 days	Wed 8/22/18	Fri 10/19/18
34	Research of Construction Methods	48 days	Wed 8/22/18	Fri 10/26/18
35	Machine Equipment Training	22 days	Wed 8/22/18	Thu 9/20/18
36	**Mock Ups**	**37 days**	**Fri 9/21/18**	**Mon 11/12/18**
37	CNC Cross Sections	10 days	Fri 9/21/18	Thu 10/4/18
38	Install Cross Sections	5 days	Fri 9/28/18	Thu 10/4/18
39	Stripping and Paneling	16 days	Fri 9/28/18	Fri 10/19/18
40	Casting Mock Up 1	1 day	Fri 10/12/18	Fri 10/12/18
41	Casting Mock Up 2	1 day	Mon 10/22/18	Mon 10/22/18
42	Demold Mock Up 1	1 day	Fri 11/2/18	Fri 11/2/18
43	Demold Mock Up 2	1 day	Mon 11/12/18	Mon 11/12/18
44	***Bearneath the Sea***	**123 days**	**Fri 11/2/18**	**Wed 4/17/19**
45	Waterproofing Table and Spine	1 day	Fri 11/2/18	Fri 11/2/18
46	CNC Cross Sections	1 day	Mon 11/5/18	Mon 11/5/18
47	Install Cross Sections	1 day	Tue 11/6/18	Tue 11/6/18
48	Waterproofing Cross Sections	1 day	Tue 11/6/18	Tue 11/6/18
49	Paneling	12 days	Wed 11/7/18	Thu 11/22/18
50	Casting	1 day	Sun 12/2/18	Mon 12/3/18
51	Curing	37 days	Mon 12/3/18	Tue 1/22/19
52	Sanding and Patching	42 days	Wed 1/23/19	Tue 3/19/19
53	Demolding	1 day	Mon 2/25/19	Mon 2/25/19
54	Sealing	4 days	Fri 4/12/19	Wed 4/17/19
55	**Final Product Deliverables**	**21 days**	**Wed 3/13/19**	**Tue 4/9/19**
56	Cutaway Cross Section	15 days	Wed 3/13/19	Tue 4/2/19
57	Canoe Stand Construction	1 day	Wed 4/3/19	Wed 4/3/19
58	Display Table Construction	5 days	Thu 4/4/19	Tue 4/9/19
59	**Graphics**	**168 days**	**Wed 8/22/18**	**Mon 4/8/19**
60	Theme Research and Development	50 days	Wed 8/22/18	Tue 10/30/18
61	Canoe Graphics Application Research	30 days	Wed 10/31/18	Mon 12/10/18
62	Canoe Graphics Design	50 days	Sun 12/16/18	Thu 2/21/19
63	Canoe Paper Design	30 days	Wed 10/31/18	Mon 12/10/18
64	Display Design	30 days	Wed 10/31/18	Mon 12/10/18
65	Stand Design	30 days	Wed 10/31/18	Mon 12/10/18
66	Canoe Graphics Application	15 days	Wed 3/20/19	Mon 4/8/19
67	Presentation Design	26 days	Mon 2/18/19	Fri 3/22/19
68	**Paddling**	**174 days**	**Wed 8/22/18**	**Tue 4/16/19**
69	Padding Recruitment	20 days	Wed 8/22/18	Tue 9/18/18
70	Paddling Training	154 days	Wed 9/19/18	Tue 4/16/19
71	Time Trials	1 day	Sat 3/9/19	Sat 3/9/19
72	**Technical Paper**	**91 days**	**Wed 11/28/18**	**Sun 3/31/19**
73	Draft Paper	40 days	Wed 11/28/18	Mon 1/21/19
74	Paper Editing	46 days	Tue 1/22/19	Fri 3/22/19
75	Paper Submission	1 day	Fri 3/29/19	Sun 3/31/19
76	**Presentation**	**60 days**	**Tue 1/22/19**	**Wed 4/10/19**
77	Script Writing	20 days	Tue 1/22/19	Fri 2/15/19
78	Presentation Rehearsal	40 days	Mon 2/18/19	Wed 4/10/19
79	**MidPac Competition**	**3 days**	**Thu 4/18/19**	**Sat 4/20/19**

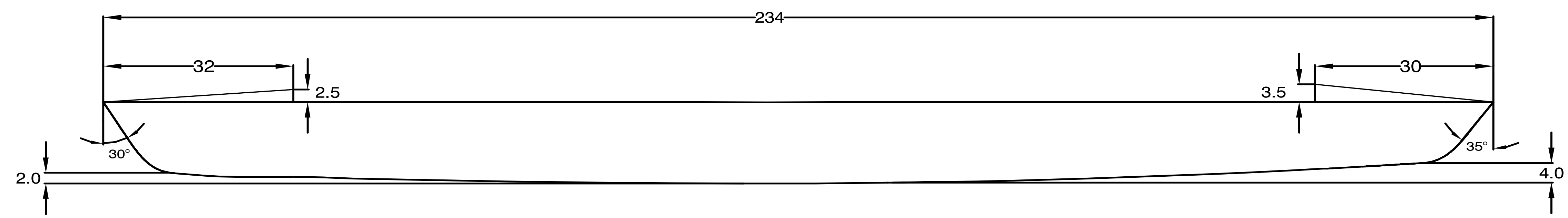
Project: Concrete Canoe Sched
Date: Sun 3/31/19

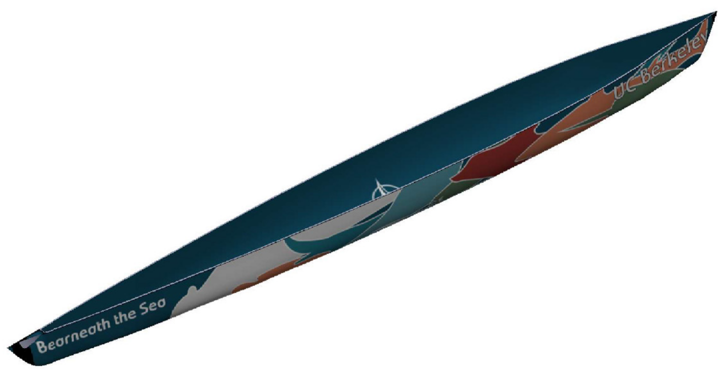
Task | Milestone | Summary | Critical | Baseline | Baseline Milestone | Baseline Summary

PLAN VIEW

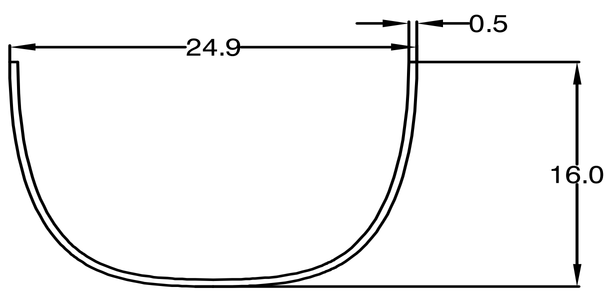


ELEVATION VIEW

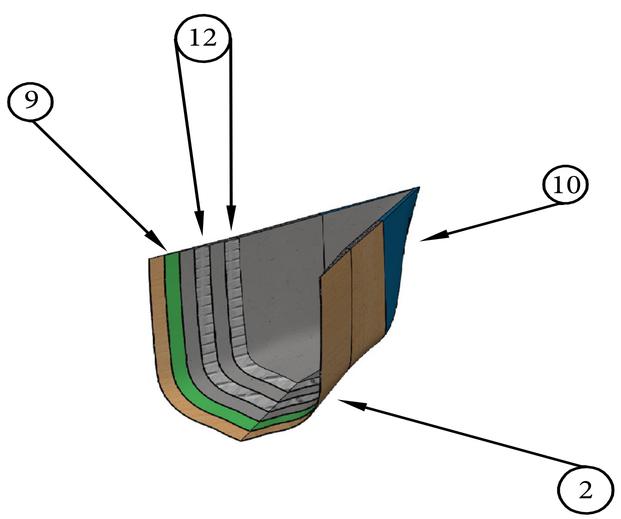




ISOMETRIC VIEW



SECTION AA



CUTAWAY SECTION

CALIFORNIA CONCRETE CANOE

Bill of Materials

NO.	DESCRIPTION	QTY
1	Plywood	1 - 4'x4'x3/16"
2	Plywood	16 - 2'x4'x1/8"
3	Oriented Strand Board (OSB)	4 - 4'x8'x1/2"
4	Metal Screws	~170 - 1/2"
5	Corner Braces	80 - 2"x2"
6	Galvanized Steel Strap	4 - 6"x0.13"
7	Brad Nails	~750 - 1/2"
8	Brad Nails	~500 - 5/8"
9	Wax	0.88 lbs.
10	Polylactic Acid (PLA)	4.79 lbs.
11	Duct Tape	4 ft.
12	Basalt Reinforcement	128 sq. ft.
13	Alkali-Resistant Glass (ARG) Scrim	4 sq. ft.
14	Recycled Styrofoam Flotation	~2 cu. ft.
15	Steel Ties	45 - 3" ties
16	Sealer	1 gallon
17	White Cement Type 1, ASTM C150	111.33 lbs.
18	Slag Cement	49.60 lbs.
19	Silica Fume	6.04 lbs.
20	VCAS 160	10.59 lbs.
21	13 mm PVA Fibers	0.50 lbs.
22	Shredded EPS Foam	4.62 lbs.
23	Utelite Crushed Lightweight Aggregate	90.48 lbs.
24	Hess Pumice Grade 2	28.61 lbs.
25	Trinity #1 Sand	5.76 lbs.
26	3M K1 Glass Bubbles	0.74 lbs.
27	ADVA	143.64 fl. oz.
28	VMAR	231.17 fl. oz.
29	Eclipse	67.57 fl. oz.
30	SBR Latex	8.17 fl. oz.
31	Blue Pigment	0.25 lbs.
32	White Pigment	0.1 lbs.
33	Green Pigment	0.1 lbs.
34	Red Pigment	0.1 lbs.
35	Orange Pigment	0.1 lbs.
36	Black Pigment	0.5 lbs.

Bearneath the Sea

DESIGN DRAWING

Note: All dimensions are in inches.

DRAWN BY: Sonia Martin	DATE: 03/23/2019
CHECKED BY: Hagen Tam	PAGE 12

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MIXTURE DESIGNATION: BASE MIX

CEMENTITIOUS MATERIALS				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
White Cement Type 1	3.15	2.33	*457.3*	*Total Amount of cementitious materials* ***679.9*** *lb/yd^3* *c/cm ratio* ***0.673***
Slag Cement	2.90	1.03	*187.1*	
Silica Fume	2.20	0.26	*35.5*	

FIBERS				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of Fibers (mass/volume) (lb/yd^3)*	
13mm PVA Fibers	1.3	0.036	*2.935*	*Total Amount of Fibers* ***2.935*** *lb/yd^3*

AGGREGATES							
Aggregates	*ASTM C330**	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*Volume (ft^3)*
					OD	*SSD*	
Shredded EPS Foam	No	0	0.035	0.035	*27.16*	27.16	12.43
Utelite Crushed Lightweight Structural Aggregate	Yes	31.4	1.32	1.73	*351.8*	462.2	4.28

ADMIXTURES					
Admixture	*lb/gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
ADVA 530	*8.9*	*108.2*	*30.6*	*35.5*	*Total Water from Admixtures, $\sum w_{admx}$* ***132.5*** *lb/yd^3*
V-MAR 3	*8.5*	*176.3*	*2.3*	*77.8*	
Eclipse 200	*7.7*	*47.3*	*0.7*	*19.2*	

SOLIDS (LATEX, DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Mineral Filler (Passing No. 200 sieve) *Utelite Passing No.200 sieve*	**1.73**	**0.64**	**69.1**	*Total Solids from Admixtures* ***69.1*** *lb/yd^3*

WATER			
	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		*w*: 284.8	4.56
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -75.46	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: *132.5*	
Batch Water, lb/yd^3		w_{batch}: 227.8	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	679.9	2.935	489.4	69.1	284.8	*$\sum M$:1526.1*
Absolute Volume of Concrete, V, (ft^3)	3.62	0.036	16.71	0.64	4.56	*$\sum V$:25.57*
Theoretical Density, T, *($=\sum M / \sum V$)*	*59.68 lb/ft^3*		***Air Content*** *[= (T – D)/T x 100%]*			*-11.61%*
Measured Density, D	*66.61 lb/ft^3*		***Slump, Slump flow***			*0.5 in.*
water/cement ratio, w/c:	0.623		***water/cementitious material ratio, w/cm:***			0.419

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

Cementitious Materials
Volume of White Portland Cement: $Volume_{WhitePortlandCement}$ = Amount $_{WhitePortlandCement}$/((SG $_{White\ Portland\ Cement}$)(62.43)) = 457.3/((3.15)(62.43)) = 2.325 ft^3
Volume of Ground Granulated Blasted Furnace Slag: Volume $_{Slag}$ = Amount $_{Slag}$/((SG $_{Slag}$)(62.43)) = 187.1/((2.90)(62.43)) = 1.033 ft^3
Volume of Silica Fume: Volume $_{SilicaFume}$ = Amount $_{SilicaFume}$/((SG $_{SilicaFume}$)(62.43)) = 35.5/((2.20)(62.43)) = 0.258 ft^3

Fibers
Volume of 13mm PVA Fibers: Volume$_{Fibers}$ = Amount $_{Fibers}$/((SG $_{Silica\ Fume}$)(62.43)) = 2.935/((1.3)(62.43)) = 0.036 ft^3

Aggregates	
Shredded EPS Foam	Utelite Crushed Lightweight Structural Aggregate (Not Passing No. 200 Sieve)
$Abs = \frac{W_{SSD}-W_{OD}}{W_{OD}} \times 100\% = \frac{27.16-27.16}{27.16} \times 100\% = 0.0\%$ $MC_{total} = \frac{W_{STK}-W_{OD}}{W_{OD}} \times 100\% = \frac{27.16-27.16}{27.16} \times 100\% = 0.0\%$ $MC_{free} = MC_{total} - Abs = 0.0\% - 0.0\% = 0.0\%$ $w_{free} = W_{OD} \times \left(\frac{MC_{free}}{100\%}\right) = 27.16 \times \frac{0}{100\%} = 0\ lbs$ $Volume = \frac{W_{SSD}}{(SG_{SSD})(62.43)} = \frac{27.16}{(0.035)(62.43)} = 12.43\ ft^3$	$Abs = \frac{W_{SSD} - W_{OD}}{W_{OD}} \times 100\% = \frac{462.2 - 351.8}{351.8} \times 100\% = 31.38\%$ $MC_{total} = \frac{W_{STK} - W_{OD}}{W_{OD}} \times 100\% = \frac{386.4 - 351.8}{351.8} \times 100\% = 9.84\%$ $MC_{free} = MC_{total} - Abs = 9.84\% - 31.4\% = -21.45\%$ $w_{free} = W_{OD} \times \left(\frac{MC_{free}}{100\%}\right) = 351.8 \times \frac{-21.45\%}{100\%} = -75.46\ lbs$ $Volume = \frac{W_{SSD}}{(SG_{SSD})(62.43)} = \frac{462.2}{(1.73)(62.43)} = 4.28\ ft^3$

Aggregate-Concrete Ratio Requirement
$Aggregate\ Ratio\ (\%) = Volume_{Aggregate}/27 \times 100\% = \frac{4.28 + 12.43}{27} \times 100\% = 61.9\%$ $61.9\% > 25\%\quad OKAY!$

Densities, Air Content, Slumps, and Ratios
Mass of Concrete (M): $$M = Amount_{CM} + Amount_{Fibers} + Amount_{Aggregates} + Amount_{Solids} + Amount_{Water}$$ $$M = 679.9\ lbs + 2.935\ lbs + 489.4\ lbs + 69.1\ lbs + 284.8\ lbs = 1526.1\ lbs$$
Absolute Volume of Concrete (V): $$V = Volume_{CM} + Volume_{Fibers} + Volume_{Aggregates} + Volume_{Solids} + Volume_{Water}$$ $$V = 3.62\ ft^3 + 0.036\ ft^3 + 16.71\ ft^3 + 0.64\ ft^3 + 4.56\ ft^3 = 25.57\ ft^3$$
Theoretical Density (T): $$T = \frac{M}{V} = \frac{1526.1\ lbs}{25.57\ ft} = 59.68\ lbs/ft^3$$
Measured Density (Wet Unit Weight) (D): $$Mass_{Container}: 16.13\ lbs$$ $$Volume_{Container}: 0.2\ ft^3$$ $$Mass_{Container\ and\ Concrete}: 29.975\ lbs$$ $$D = \frac{Mass_{Concrete}}{Volume_{Container}} = \frac{29.452\ lbs - 16.13\ lbs}{0.2\ ft^3} = 66.61\ ft^3$$
Air Content: $$Air\ Content = \frac{T - D}{D} \times 100\% = \frac{(59.68\ lbs/ft^3) - (66.61\ lbs/ft^3)}{(59.68\ lbs/ft^3)} = -11.61\%$$
Water Cement Ratio: $$\frac{284.8\ lbs\ water}{457.3\ lbs\ cement} = 0.623$$
Water-Cementitious Material Ratio: $$\frac{284.8\ lbs\ water}{679.9\ lbs\ cement} = 0.419$$
Measured Slump: $$Slump = 0.5\ in$$

MIXTURE DESIGNATION: PATCH MIX

CEMENTITIOUS MATERIALS				
Component	***Specific Gravity***	***Volume (ft³)***	***Amount of CM (mass/volume) (lb/yd³)***	
White Cement Type I	3.15	2.90	*570.8*	*Total Amount of cementitious materials* ***1,142*** *lb/yd³* *c/cm ratio* ***0.500***
Slag Cement	2.9	1.89	*342.8*	
VCAS	*2.6*	*1.41*	*228.7*	

FIBERS				
Component	***Specific Gravity***	***Volume (ft³)***	***Amount of Fibers (mass/volume) (lb/yd³)***	
N/A				*Total Amount of Fibers* _______ *lb/yd³*

AGGREGATES							
Aggregates	***ASTM C330****	***Abs (%)***	***SG_{OD}***	***SG_{SSD}***	***Base Quantity (lb/yd³)***		***Volume (ft³)***
					OD	***SSD***	
Hess Pumice Sand	Yes	14.8%	1.49	1.71	*684.4*	785.7	7.36
Trinity Sand #1 (Sieve 12)	Yes	21.1%	1.74	1.79	*412.7*	473.8	4.24

ADMIXTURES					
Admixture	***lb/gal***	***Dosage (fl. oz / cwt)***	***% Solids***	***Amount of Water in Admixture (lb/yd³)***	
ADVA 530	*8.9*	*71.6*	*30.6*	*39.4*	*Total Water from Admixtures,* $\sum w_{admx}$ ***155.7*** *lb/yd³*
V-MAR 3	*8.5*	*117.4*	*2.3*	*86.8*	
Eclipse 200	*7.7*	*46.3*	*0.7*	*29.5*	

SOLIDS (LATEX, DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)				
Component	***Specific Gravity***	***Volume (ft³)***	***Amount (mass/volume) (lb/yd³)***	
Hess Pumice Sand (Passing No. 200 sieve)	**1.71**	**0.07**	**7.5**	*Total Solids from Admixtures* ***48.8*** *lb/yd³*
Trinity Sand #1 (Passing No. 200 sieve)	**1.79**	**0.37**	**41.3**	

WATER			
	Amount (mass/volume) (lb/yd³)		***Volume (ft³)***
Water, lb/yd³		*w*: 439.6	*7.04*
Total Free Water from All Aggregates, lb/yd³		$\sum w_{free}$: -91.1	
Total Water from All Admixtures, lb/yd³		$\sum w_{admx}$: 155.7	
Batch Water, lb/yd³		w_{batch}: 429.0	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP						
	cm	***fibers***	***aggregates***	***solids***	***water***	***Total***
Mass of Concrete, M, (lb)	1,142	0	1259.5	48.8	439.6	*∑M: 2,889.9*
Absolute Volume of Concrete, V, (ft³)	6.2	0	11.6	0.44	7.04	*∑V:25.28*
Theoretical Density, T, *(=∑M / ∑V)*	*114.3 lb/ft³*		***Air Content*** *[= (T – D)/T x 100%]*			*2.2%*
Measured Density, D	*111.8 lb/ft³*		***Spread***			*23 in.*
water/cement ratio, w/c:	0.770		***water/cementitious material ratio, w/cm:***			0.385

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

MIXTURE DESIGNATION: FINISHING MIX

CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
White Cement Type I	3.15	4.22	*830.0*	*Total Amount of cementitious materials* **1479.4** lb/yd^3 *c/cm ratio* **0.561**
Slag Cement	2.9	2.27	*411.6*	
VCAS	*2.6*	*1.47*	*237.8*	

FIBERS

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

AGGREGATES

Aggregates	*ASTM C330**	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*Volume (ft^3)*
					OD	*SSD*	
Hess Pumice Sand	Yes	14.8%	1.49	1.71	*613.0*	703.5	6.59
3M K1 Glass Bubbles (Not Passing No. 200 sieve)	No	0%	0.125	0.125	*2.2*	2.2	0.28

ADMIXTURES

Admixture	*lb/gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
SBR Latex	*8.4*	*16.36*	*48.0*	*8.3*	*Total Water from Admixtures, $\sum w_{admx}$* **49.5** lb/yd^3
ADVA 530	*8.9*	*18.45*	*30.6*	*13.2*	
V-MAR 3	*8.5*	*17.25*	*2.3*	*16.6*	
Eclipse 200	*7.7*	*13.82*	*0.7*	*11.4*	

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

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
SBR Latex	**1.01**	**0.12**	**7.6**	*Total Solids from Admixtures* **78.0** lb/yd^3
Pigment	**1.99**	**0.35**	**43.5**	
Hess Pumice Sand (Passing No. 200 sieve)	**1.71**	**0.067**	**7.1**	
3M K1 Glass Bubbles (Passing No. 200 sieve)	**0.125**	**2.54**	**19.8**	

WATER

	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		w: 503.2	*8.06*
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -57.6	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: 49.5	
Batch Water, lb/yd^3		w_{batch}: 511.3	

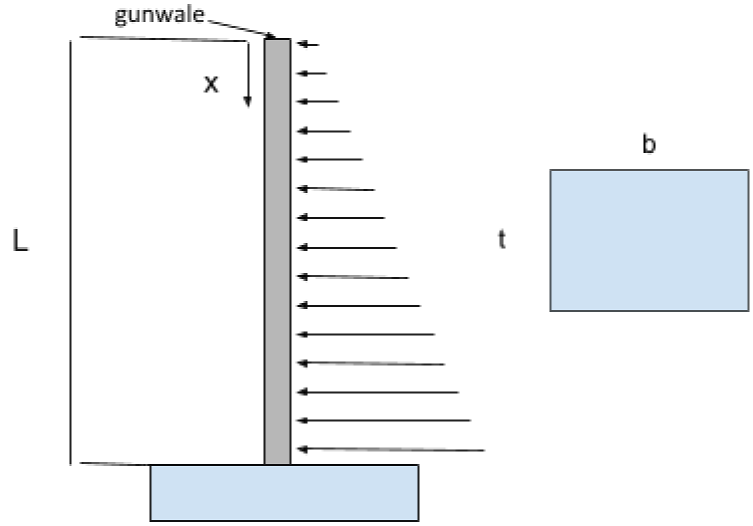
DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	1479.4	0	705.7	78.0	503.2	*$\sum M$: 2766.3*
Absolute Volume of Concrete, V, (ft^3)	7.96	0	6.87	3.08	8.06	*$\sum V$: 25.97*
***Theoretical Density, T,** (=$\sum M / \sum V$)*	*106.5 lb/ft^3*		***Air Content** [= (T – D)/T x 100%]*			*3.3 %*
Measured Density, D	*102.9 lb/ft^3*		***Spread***			*25.5 in.*
water/cement ratio, w/c:	0.606		***water/cementitious material ratio, w/cm:***			0.34

I. Shear Stress in Chines and Deflection in Gunwales

Assumptions:

- Structural elements that decrease deflection values are not considered.
- Canoe side wall is vertical.
- Canoe is submerged to the point that the waterline is at the gunwale but not pouring over into the canoe.
- Can model side walls as cantilever beam.
- Brackish water has a unit weight of 63 pcf.
- Neglect the use of reinforcement and the ratio of concrete-to-reinforcement moduli.



Stress calculations:

Chine Depth: $L = 16\ in. - 0.6\ in. = 15.4\ in.$

Water pressure, P, amplified by a factor of 1.3 to account for dynamic waves: P = 1.3ρgx

$$P_{max} = 1.3\rho gL = (1.3)(63\ pcf)(15.4\ in.) = (1.3)(.036563\ lbs/in^3)(15.4\ in.) = 0.730\ psi$$

Assume a horizontal depth, b, into the paper of 1 in.

$$V_{max} = \frac{PbL}{2} = \frac{(0.730\ psi)(1\ in.)(15.4\ in.)}{2} = 5.62\ lbs$$

Shear stress, $\tau_{max} = \frac{3V}{2A}$

$$\tau_{max} = \frac{3V}{2A} = \frac{(3)(5.62\ lbs.)}{(2)(1\ in.)(0.6\ in.)} = \mathbf{14.05\ psi}$$

Deflection calculations:

$$E = w_c^{1.5} 33\lambda\sqrt{(f'c)} = (67^{1.5})(33)(0.75)\sqrt{(1470)} = 520{,}410\ psi$$

$$I = (1/12)bt^3 = (1/12)(1\ in.)(0.6\ in.)^3 = .018\ in^3$$

$$\delta_{max} = \frac{wd^4}{30EI} = \frac{(0.730\ psi * 1 in.)(15.4\ in.)^4}{(30)(520{,}410\ psi)(0.018\ in^3)} = \mathbf{0.1461\ in.}$$

II. Estimate for Punching Stress, Vn, per ACI 318 for a Two-Way Slab

Punching stress Calculation:

Caused by load: $\sigma_u = \frac{P_u}{b_0 d}$

$$P_u = (0.75)(200\ lbs) = 150\ lbs.$$

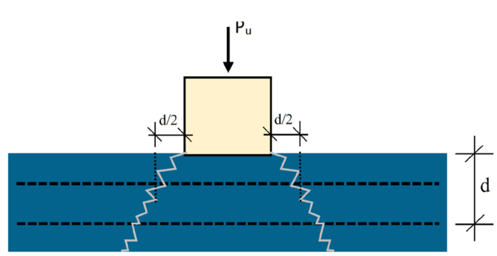
$$d = 0.5\ in.$$

$$c_1 + d = 4\ in. + 0.5\ in. = 4.5\ in.$$

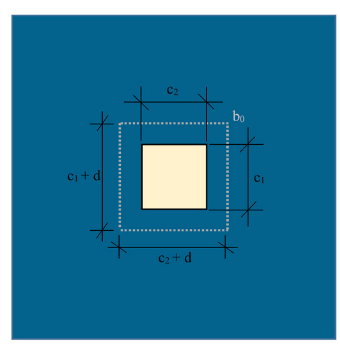
$$c_2 + d = 4\ in. + 0.5\ in. = 4.5\ in.$$

$$b_0 = 4\ sides * 4.5\ in. = 18\ in.$$

$$\sigma_u = \frac{V_c}{b_0 d} = \frac{150\ lbs.}{(18\ in.)(0.5\ in.)} = \mathbf{16.67\ psi}$$



Elevation



Plan

III. Load Cases and Cross Sectional Calculations

Assumptions:

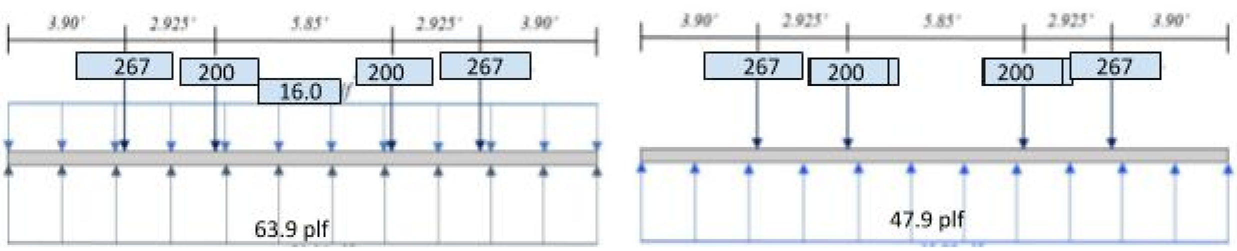
- Coed Maximum Moment at 3.9 ft from bow
- Canoe walls and bottom simplified to three rectangles placed at right angles to each other.
- Cross section is non-transformed (includes no reinforcement).

Variables:

Max moment = 364 lb ft
Thickness of hull: t_{hull} = 0.7 in
Thickness of gunwale: t_{gun} = 0.5 in
Cross-section width, b = 12.25 in
Cross-section depth, H = 14.00 in

Sample Free Body Diagrams:

	Estimated Weight (lbs.)	Factored Weight (lbs.)
Canoe	260	312
Male Paddler	167	267.2
Female Paddler	125	200



Coed Load Case Calculation:
Length of canoe = 19.5 ft
Distributed load (w) = 1.2(260)/19.5 = 16.0 plf
Distributed buoyant reaction = w_{total} / L = (312+2*267.2+2*200)/19.5 = 63.9 plf
Net distributed force = 62.69 - 14.78 = 47.9 plf

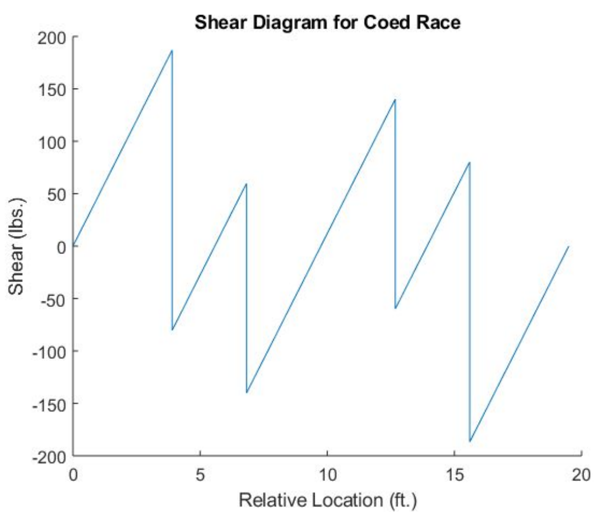
Cross Section Sample Calculation:
Area of Bottom: A1 = bt_h = 8.75 in^2
Area of Wall: A2 = $(H-t_{hull})t_g$ = 6.65 in^2
Centroid of Wall : $y_1 = t_h/2$ = 0.375 in
Centroid of Bottom: $y_2 = t_h + (H-t_h)/2$ = 7.35 in
Neutral Axis: $y_c = \Sigma Ay / \Sigma A$ = 3.41 in
Moment of Inertia of Cross-Section: $I = \Sigma(I + Ad^2)$ = 483 in^4
Max compressive stress $\sigma^- = My_{top}/I$ = -95.8 psi
Max tensile stress $\sigma^+ = My_{bottom}/I$ = 30.8 psi

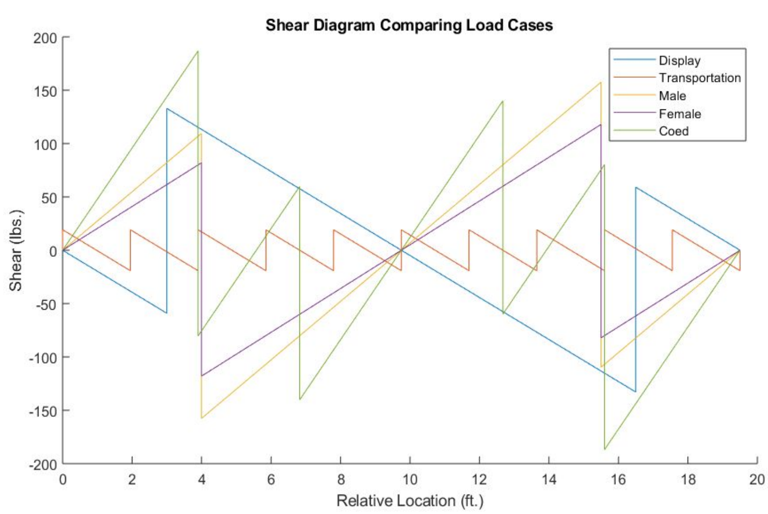
Results:

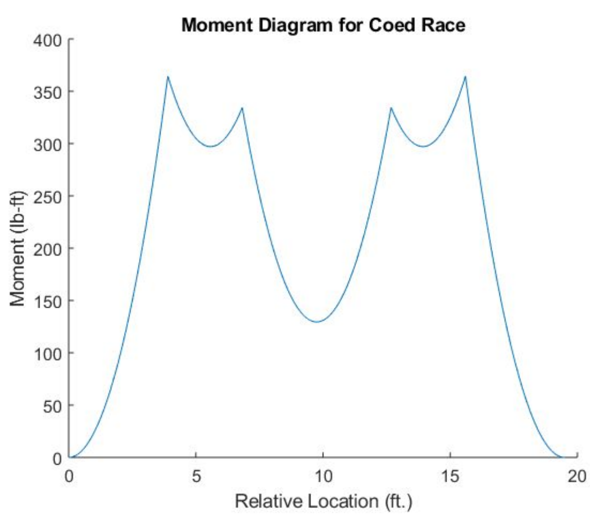
Loading Case	**Max M (lb ft)**	**Moment of Inertia (in^4)**	**Max Compressive (psi)**	**Max Tensile (psi)**
Coed	364	483	**-95.8**	**30.8**
Display	270	702	-62.0	13.0
Transportation	7.02	222	-3.2	2.0
Male	219	483	-58.5	18.7
Female	164	483	-43.8	14.0

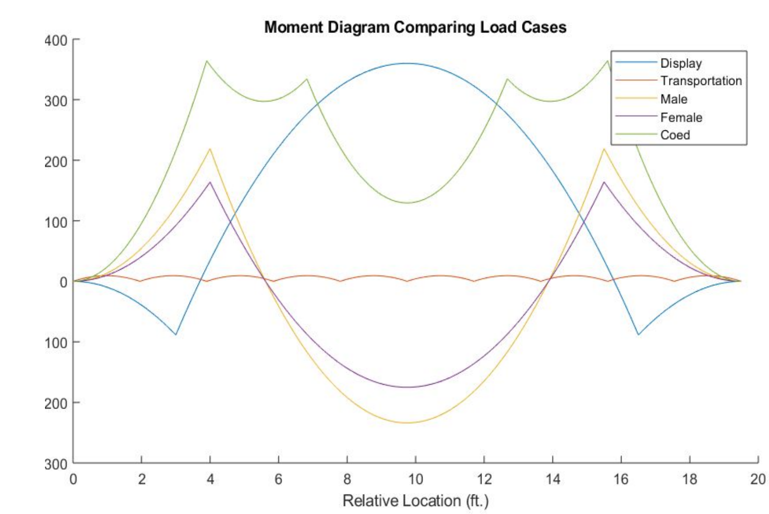
Minimum requirement for compression (x4 of maximum compressive stress)= **-383.4 psi**
Minimum requirement for tension (x4 of maximum tensile stress) = **123.3 psi**

Shear and Bending Moment Diagrams:

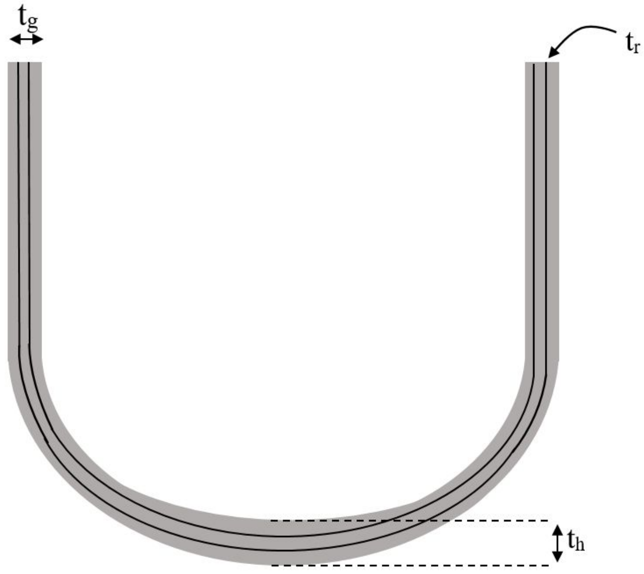








Hull Thickness Calculations: Canoe hull and gunwales are the only locations of reinforcement. Two layers of mesh run from one gunwale to the other along the canoe.



Variables:

t_g : thickness of canoe gunwale = 0.5 *in*

t_h : thickness of canoe hull = 0.7 *in*

t_r : thickness of reinforcement mesh (Basalt and ARG) = 0.05 *in*.

Gunwales:

Percent thickness of reinforcement = $\frac{2t_r}{t_g}$ (100%) = $\frac{2(0.05\ in)}{0.5\ in}$(100%) = 20.0% (< 50% *maximum*) **Compliant**

Hull:

Percent thickness of reinforcement = $\frac{2t_r}{t_h}$ (100%) = $\frac{2(0.05\ in)}{0.7\ in}$(100%) = 14.3% (< 50% *maximum*) **Compliant**

Percent Open Area (POA) Calculations:

Variables:

d_1 : spacing of reinforcement (center-to-center) along sample length

d_2 : spacing of reinforcement (center-to-center) along sample width

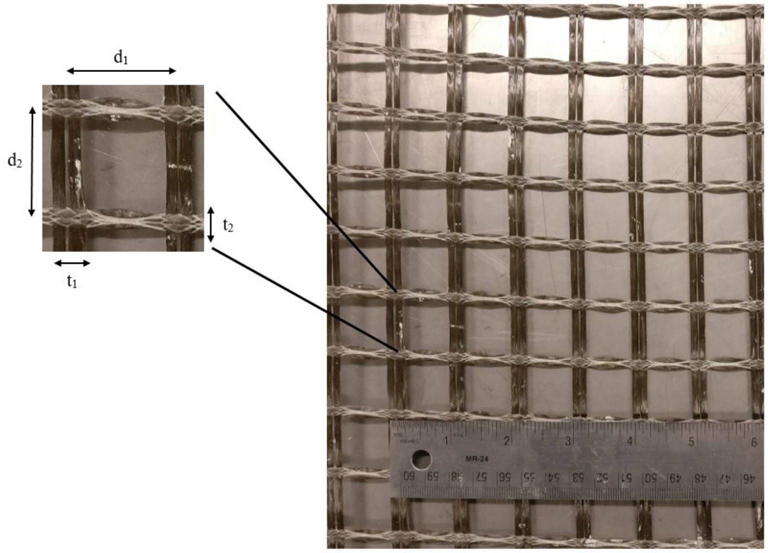
t_1 : thickness of reinforcement along sample length

t_2 : thickness of reinforcement along sample width

n_1 : number of apertures along sample length

n_2 : number of apertures along sample width

Basalt Fiber Mesh: Two layers placed along the main span



$d_1 = 1.0\ in$
$d_2 = 1.0\ in$
$t_1 = 0.25\ in$
$t_2 = 0.156\ in$
$n_1 = 7$
$n_2 = 9$

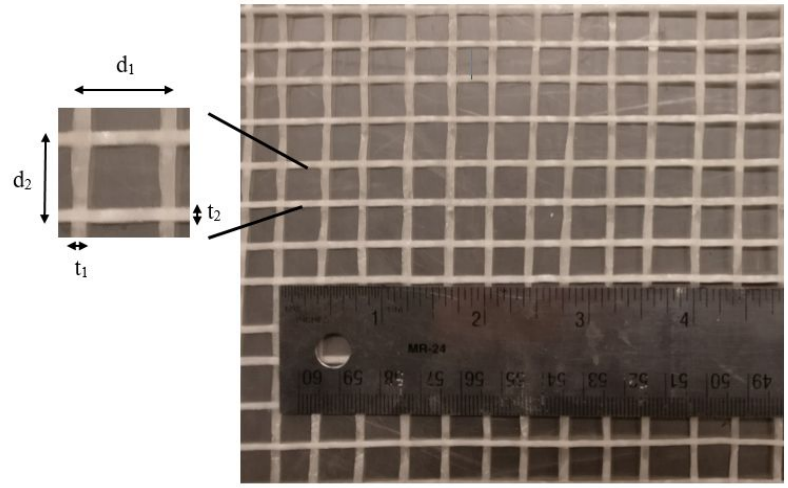
Sample Length: L = $d_1 n_1 = (1.0\ in)(7) = 7.0\ in$
Sample Width: W = $d_2 n_2 = (1.0\ in)(9) = 9.0\ in$
Open Area per aperture:
$A_{open} = (d_1 - t_1)(d_2 - t_2) = (1.0\ in\ - 0.25\ in)(1.0\ in - 0.156\ in) = 0.633\ in^2$

Total Open Area: $\sum Area_{open} = n_1 n_2 A_{open} = (7)(9)(0.633\ in^2) = 39.88\ in^2$

Total Area: $Area_{total} = LW = (7.0\ in)(9.0\ in)\ = \ 63\ in^2$

POA = $\frac{\sum Area_{open}}{Area_{total}}(100\%) = \frac{39.88\ in^2}{63\ in^2}(100\%) = 63.3\%$ (>40% minimum) **Compliant**

Alkali Resistant Glass (ARG) Mesh: placed at canoe ends



$d_1 = 0.375\ in$
$d_2 = 0.375\ in$
$t_1 = 0.0625n$
$t_2 = 0.0625\ in$
$n_1 = 13$
$n_2 = 12$

Sample Length:
$L = d_1 n_1 = (0.375\ in)(13) = 4.875\ in$
Sample Width:
W = $d_2 n_2 = (0.375\ in)(12) = 4.5\ in$
Open Area per aperture:
$A_{open} = (d_1 - t_1)(d_2 - t_2) = (0.375\ in\ - 0.0625\ in)^2 = 0.0977\ in^2$

Total Open Area: $\sum Area_{open} = n_1 n_2 A_{open} = (12)(13)(0.0977\ in^2) = 15.23\ in^2$

Total Area: $Area_{total} = LW = (4.875\ in)(4.5\ in)\ = \ 21.94\ in^2$

POA = $\frac{\sum Area_{open}}{Area_{total}}(100\%) = \frac{15.23\ in^2}{21.94\ in^2}(100\%) = 69.4\%$ (>40% minimum) **Compliant**