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EXECUTIVE SUMMARY

Encompassing the nation’s largest subtropical wetland, Everglades National Park provides sanctuary for thirty-six protected animal species across nearly 1.5 million grassy acres in south Florida. The natural, pulsing surface water flow of the larger Everglades basin has been increasingly disrupted due to land development since the late 1800s. While it was human intervention that originally altered the flow balance, today, a more holistic engineering mentality is employed to remedy past oversights. The Comprehensive Everglades Restoration Plan (CERP) leads the effort to protect and preserve the water resources of the Everglades. Located several hundred miles to the north in Gainesville, the University of Florida (UF) has created research and extension programs to address these pressing issues. These programs aim to enhance the quality of the ecosystem and improve the abundance and diversity of native species, while also accommodating urban and agricultural water demands.

As one of the most comprehensive and academically diverse public universities in the nation, UF serves more than 50,000 students annually with 16 colleges and more than 150 research centers and institutes (University of Florida (a) 2014). The UF Concrete Canoe Team, competing in one of the largest ASCE conferences, has placed 1st in the Southeast Region the last three years and finished 12th (AcceleGator, 2014), 3rd (ConquistaGator, 2013), and 5th (VindiGator, 2012) at the national level.

The UF Team began its season by moving production from a satellite facility to an on-campus research laboratory. The space proved to be effective for recruitment purposes, drawing in a larger, younger team than in previous years. With youth came inexperience, prompting captains, with the help of team veterans, to formally draft best management practices to guide future teams. Proximity to numerous active research projects allowed the team to better utilize university resources. With the move, many construction and mix design techniques were improved in order to meet space constraints and ensure safety of the team members.

Outside of the lab, the paddling team was committed to kneeling in all five races in an effort to maximize its competitive advantage. Accordingly, the hull design was developed to enhance paddler stability without impeding maneuverability. The concrete mix design focused on improving tensile strengths while incorporating new materials to create a low density mix. In an effort to improve upon previous teams’ final product scores, a schedule was created which dedicated more time to construction planning and visual display fabrication. Emphasis was placed on uniform gunwale thickness when designing the canoe form. To enhance aesthetic quality, the team integrated a three-dimensional cast concrete alligator, both an Everglades native and the UF mascot, into the canoe’s interior surface.

To pay tribute to this marvel of nature and bring awareness to the effort to preserve the diverse ecosystem of the Everglades, UF proudly captures the beauty of this “river of grass” with its 2015 canoe: ForeverGlades.

<table>
<thead>
<tr>
<th>Maximum Length</th>
<th>22.0 ft.</th>
<th>Maximum Height</th>
<th>13.5 in.</th>
<th>Average Thickness</th>
<th>0.375 in.</th>
<th>Weight</th>
<th>178 lb</th>
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<tr>
<td>Reinforcement</td>
<td>Wet Unit Weight</td>
<td>50.5 pcf</td>
<td>Oven Dried Unit Weight</td>
<td>40.6 pcf</td>
<td>Compressive Strength</td>
<td>1,512 psi</td>
<td>Tensile Strength</td>
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<td></td>
<td>Oven Dried Unit Weight</td>
<td>50.3 pcf</td>
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<td>282 psi</td>
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<td></td>
<td>Compressive Strength</td>
<td>2,148 psi</td>
<td>Tensile Strength</td>
<td>282 psi</td>
<td>Wet Unit Weight</td>
<td>49.5 pcf</td>
<td>Oven Dried Unit Weight</td>
</tr>
<tr>
<td></td>
<td>Tensile Strength</td>
<td>129 psi</td>
<td>Composite Flexural Strength</td>
<td>1,272 psi</td>
<td>Wet Unit Weight</td>
<td>55.2 pcf</td>
<td>Oven Dried Unit Weight</td>
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<td>Wet Unit Weight</td>
<td>120.0 pcf</td>
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<td>105.8 pcf</td>
<td>Compressive Strength</td>
<td>N/A</td>
<td>Tensile Strength</td>
</tr>
</tbody>
</table>

Table 1: ForeverGlades Concrete Properties
A single head captain, acting as the project manager, took on the tasks of recruitment, budgeting, scheduling, and delegating for the *ForeverGlades* team. To complete the team, five captains were selected as project engineers to lead concrete mix design, hull design/structural analysis, visual design, construction, and paddling.

Similar to that used by CERP, an adaptive management approach allowed the team to monitor progress and make the appropriate changes required to meet prescribed goals. Risk management was ensured by pairing veterans with inexperienced team members for construction processes, and quality control was supplemented by using external resources to help critique the design paper. Quality assurance was provided throughout the project by requiring the captains to submit progress reports and schedules at the beginning of each week to ensure that tasks followed the master schedule created by the project manager.

Using this master schedule, captains adhered to a critical path rooted in team historical data and planned improvements. This critical path included hull design selection, mold completion, practice canoe completion, and competition canoe completion. Major milestones not included on the critical path consisted of mix design finalization, selection of the paddling team, and completion of the design paper. These milestones were determined based on past experience and accomplished through clear and constant communication as well as timeline awareness among all captains.

The *ForeverGlades* team understood the benefits that fabricating both a practice and a competition canoe would provide for quality assurance and educating a young team. In order to ensure there was sufficient time to design, place, and cure two concrete canoes, the schedule for structural analysis, hull design, mold construction, and mix design was rigorous and closely followed. With the donation of nearly all concrete materials and admixtures, creating a second canoe added a minimal cost of $600 to the *ForeverGlades* budget. The practice canoe allowed 18 newly-recruited members to become familiar with the precision required during the placement process. Additionally, the team had the opportunity to test new construction and mix design techniques to mitigate errors before the competition canoe placement one month later.

Efficiency in time management and the donation of a second shotcrete gun allowed for a reduction of 75 person-hours from the placement of the practice canoe to the competition canoe. Overall, the team put in over 2,800 person-hours designing, testing, and constructing *ForeverGlades* (Figure 1).

![Figure 1: ForeverGlades Person-Hours](image_url)

Before using the lab, each team member was required to attend an informative, concrete canoe-specific safety training session, as well as complete 12 hours of online safety courses through the University. After the initial session, the team was instructed on each tool used in the lab to ensure competence and safety at all times. Those working with concrete materials were required to read material safety data sheets for the materials and personal protective equipment was required and supplied in all areas of the lab. The team worked hand-in-hand with the laboratory staff to guarantee appropriate handling of tools and materials.

The operational budget for all necessary material procurement and construction processes of the canoe was set at $4,800. Since no financial assistance is received from the University itself, the team sought to fundraise through engineering firms and UF Concrete Canoe alumni directly. Since the team was fortunate enough to receive several material donations for the concrete mix design as well as colored sealer, construction and visual display components were left to bear the brunt of the canoe completion cost. Over $9000 was raised during the year to cover project expenses, travel costs, and registration fees which allowed for a substantial sum to be allocated to the future team.

Finally, a strict paddling regimen was overseen, incorporating two gym sessions and two mandatory lake practices per week beginning in the fall. The team benefitted immensely from the opportunity to practice in the chosen hull design (the practice canoe) in the months leading up to the competition.
ORGANIZATION CHART

TYLER MOKRIS
CONSTRUCTION & PADDLING
- Construct mold of canoe shape
- Oversee quality control during pour day
- Construct stands and cutaway section
- Schedule team practices
- Teach proper paddling techniques

ZACK Prytula
HULL DESIGN & STRUCTURAL ANALYSIS
- Design hull shape of canoe
- Create and test scale models of potential hull designs
- Perform structural analysis for loading conditions

DANIELLE KENNEDY
PROJECT MANAGEMENT
- Supervise all captain positions
- Enforce safety precautions within every task
- Ensure completion of projects under time constraints
- Manage finances and fundraising events

KEVIN CARABEO
VISUAL DESIGN
- Design overall aesthetics of canoe for visual display
- Implement theme with every design
- Experiment with a variety of finishing techniques

TERESA LEWIS
MIX DESIGN
- Research sustainable additives for mix design
- Test and experiment concrete mixes
- Finalize mix for application on canoe

MICHAEL FERGUSON
MIX DESIGN

ASSISTANTS
- CONSTRUCTION: David Betchell (Fr., 1)
  William Broxton (Jr., 1)
  Dallas Dunbar (Jr., 1)
  Philippe Holas (So., 1)
  Shawn Miller (Jr., 1)
- VISUAL DESIGN: Allison Dykes (So., 1)
  Anna Kiriazes (Jr., 1)
  Becca Kiriazes (Fr., 1)
  Emily Starkey (Jr., 1)
  Ethan Stoop (Jr., 1)
  Mary Sullivan (Fr., 1)
  Justin Tagle (Jr., 1)
- MIX DESIGN: Christopher Allison (Fr., 1)
  Ryan Caburn (Fr., 1)
  Jordan Dawley (So., 1)
  Griselda Ruan (Jr., 1)
  Krystal Somerville (Jr., 1)
- PADDLING: Kevin Carabeo (Jr., 1)
  Alcide Goire (Sr., 3)
  Philippe Holas (So., 1)
  Danielle Kennedy (Sr., 3)
  Teresa Lewis (Jr., 2)
  Rachel Meiser (Sr., 3)
  Tyler Mokris (Sr., 3)
  Mary Sullivan (Fr., 1)

ADVISORS
- Dr. Christopher Ferraro
- Dr. Robert J. Thieke
- Michael Perry
- Benjamin Watts
The *ForeverGlades* hull design team drew upon well documented and successful hull forms from past years to maintain a tradition of excellence in design. Obtaining feedback from last year’s paddlers and using *AcceleGator* as a baseline, the team focused on refining the hull for improved race performance. Design goals were geared toward balancing straight-line speed and maneuverability, while improving stability in order to accommodate the kneeling paddling style.

The design team sought to increase straight line speed by reducing the hull’s wave-making resistance. This can be achieved by maximizing waterline length; however, with the canoe length constrained at 22 ft. (ASCE/NCCC 2015), other parameters had to be altered. The bow rocker was decreased from 5.5 in. to 4 in. This decrease in curvature reduced maneuverability which, in turn, increased tracking. To compensate, the rocker curvature was maintained along the hull bottom, providing less lateral resistance and promoting boundary layer cohesion. This combination maintained sufficient maneuverability while minimizing wave-making resistance (Winters 2006).

The continued use of a transom stern this year also helped to maximize waterline length. This truncation allows flow to continue as if the canoe actually extended out to a point as shown in Figure 2. The increased effective waterline length results in a decrease in form resistance. Proper separation was achieved through correct sizing of the truncation by maintaining the Froude numbers of at least 2.0 (Maki et al. 2005).

The *ForeverGlades* hull profile was flattened slightly, which enhanced the initial stability of the canoe (Gullion 1994). The need for improved stability was expressed by paddlers in order to more comfortably and effectively deliver power while kneeling. Wave-making resistance tends to increase with a larger surface area; however, with a flatter bottom, the sanding process can be carried out more accurately, giving the hull a smoother finish and reducing friction drag when compared with *AcceleGator* (University of Florida (b) 2014). A 15 degree raked bow, added for aesthetic purposes, decreased the amount of deadwood in the bow, further reducing wetted surface area and friction drag. From previous years’ scale model test data, this bow angle was determined to be the most efficient (University of Florida 2007).

Hulls were designed using FREE!ship (Timoshenko 2013) and compared using the fluid dynamics program, Mitchlet (Lazauskas 2013). This was done to accurately determine the designs with the least wave resistance. Resistance was analyzed for hull speeds ranging from 1 to 6 knots (1.69 to 10.12 ft./s), the estimated maximum speed during the co-ed sprint race. From these results, 4 final designs were tested for straight-line speed and maneuverability. Scale models at 1:6 size were milled using a computer numerical controlled (CNC) machine at an on-campus fabrication center. This scale was chosen to best maintain model similitude, matching Froude numbers while remaining in an acceptable range of Reynolds number.

Based on design criteria and scale model test performance which balanced speed and turning, a final hull was selected with a shallow arch bottom, 22-ft. length, 26-in. beam, and 2-in. transom stern. *ForeverGlades* improves upon last year’s straight-line speed while maintaining comparable turning ability and meeting all design goals.

Structural analysis was performed with the purpose of determining the critical tensile and compressive strengths required for the hull to undergo various predetermined loading cases. The loading conditions considered included the two-male loading, four person loading, and the demolding, transportation, and display of the canoe. Analysis was performed longitudinally along the length of the canoe and laterally along the beam of the hull to obtain critical values. For each orientation of analysis, the canoe was assumed to be a two-dimensional beam.
For longitudinal analysis, the hull was divided into 3-in. sections to evaluate the location of the maximum moment. Assuming rectangular sections for ease of calculation, the moment of inertia for each was determined. A program in Excel (Microsoft 2010) was developed to find the shear forces and bending moments along the beam using the principles of Euler-Bernoulli beam theory. Figure 3 shows the free body diagram used to analyze the canoe in the longitudinal direction.

![Free Body Diagram for Men's Sprint](image)

Figure 3: Free Body Diagram for Men’s Sprint

For racing conditions, the canoe was modeled to be continuously supported by the buoyant force, which acts equal and opposite to that of the weight of water displaced. Using displacements for specific loading cases, the draft was determined from the program FREE!ship (Timoshenko 2013). From the draft, the submerged volume of each section was calculated and multiplied by specific weight of water to obtain the buoyant force. The weight of the canoe, assumed from last year’s canoe as 160 lb, was uniformly distributed over its length. Point loads of 160 lb and 140 lb represented the male and female paddlers, respectively. These values were then increased by 25% to 200 lb and 170 lb. This increase accounted for dynamic load amplification during the races (Paradis and Gendron 2006). The loads were placed 4 ft. and 18 ft. from the bow, simulating paddler placement for the men’s races. Two female loads were added at 8 ft. and 14 ft. for the co-ed sprint. Analysis of the display scenario resulted in the determination of the optimal placement of two stands at 4 ft. and 17 ft. from the bow.

The two-male loading scenario was found to produce the critical loading case, with a maximum negative bending moment of 9,464 in.-lb located 11 ft. from the bow. Using the location of the section’s neutral axis and the principle of flexure, the tensile and compressive stresses in the section were calculated to be approximately 84 psi and 258 psi, respectively. Based on the concrete properties from the previous year, the minimal acceptable tensile and compressive strengths were determined to be 100 psi and 1,300 psi. These strengths provide a longitudinal factor of safety of 1.2, sufficient capacity for tolerating the stresses induced from the considered loading cases.

During bow-initiated turns, a paddler’s hips often push against the top of the gunwales. A lateral analysis of the hull was required to determine these resulting stresses (Figure 4). The co-ed sprint race was the critical loading case for lateral analysis due to larger forces against the gunwales and the larger buoyant force due to the weight of the four paddlers. A force of 200 lb was assumed to act on the gunwales from a shift in the paddlers’ weights, causing a moment of 2,362 in.-lb located at the chine. The canoe was assumed to be 0.375 in. thick with a layer of carbon fiber mesh between each of the three layers of concrete. The carbon fiber mesh reinforcement provides a tensile strength of 512 ksi and elastic modulus of 33.4 Msi (TorayCA 2014). Using the transformed area method, the moment allowed by the reinforced concrete is 294 in.-lb, significantly lower than the required strength.

![Free Body Diagram for Lateral Analysis](image)

Figure 4: Free Body Diagram for Lateral Analysis

To increase the maximum allowable moment, three 1 in. deep structural ribs were added – one behind the bow paddle, one amidship, and one toward the stern – providing enough room for the aftmost paddler. The added ribs raised the maximum allowable moment to 6,440 in.-lb, which increased the overall lateral factor of safety to 2.73 and assuaged concerns over paddler hip impacts.
As the 2014-2015 campaign began, the mix design team resolved to further build upon the success achieved in the previous year. To this end, the ForeverGlades team looked to improve the compressive, tensile, and flexural strengths of the canoe, while simultaneously recapturing the low unit weights and smooth outer finishes of years past. In doing so, the team was able to create mixes which surpassed calculated structural requirements by a large degree.

The mix design used in the inner layer of the previous year’s canoe, AcceleGator, was recreated as a baseline for the mix design process as it achieved high strength and aesthetic appeal. With 14-day compressive and composite flexural strengths of 1,638 and 1,194 psi, respectively, the control mix performed satisfactorily with a wet unit weight of 47.7 pcf and a water-to-cementitious materials ratio (w/cm) of 0.40 (University of Florida (b) 2014). Nonetheless, ForeverGlades’ mix design team set out to make substantial improvements, designing, testing, and analyzing over four dozen mixes through the process shown in Figure 5. After initially curing at room temperature for three days, the specimens were placed in a 105ºF limewater bath for an additional 11 days. This 14-day period was chosen to maintain the timeframe desired for the number of tests to be completed during the development stage.

After curing, 2 in. by 4 in. cylindrical specimens were tested in compression in general accordance with ASTM C39. Tensile briquette specimens were created and tested in accordance with ASTM C307, and composite panels were tested in third-point flexure using a modified version of ASTM C78 (Figure 6). This modified technique was employed since the panels were too thin to conform to the exact requirement of the standard.

In order to maintain workability while improving upon AcceleGator’s strength-to-weight ratio, the ForeverGlades team focused primarily upon cementitious materials and proportions. Given the lack of limitations on the proportion of portland cement in this year’s competition, complete replacement of this material was considered. Portland cement content was lowered in steady increments until it constituted zero percent of the cementitious material. However, once the proportion of portland cement fell below 25% of the mix’s total cementitious material, relative strength and bond properties were drastically reduced. Decreasing the amount of portland cement required the mix to utilize ground blast furnace slag. Ground blast furnace slag’s propensity for strength gains under elevated curing temperatures contributed to strength increases observed during testing (Ferraro 2009).

The team introduced two new cementitious materials, VCAST™ 160 and white portland cement to the mix design regimen for consideration. Often considered very similar to gray portland cement, white portland cement was a novel addition for ForeverGlades’ mix team due to its light color and its high potential for reactivity with pozzolans, which stems from its low ferrite content (Lubeck et al. 2011). VCAST™ 160, a recycled glass powder, was tested for its ability to lower water demand which allows for the pozzolanic material to be used in concrete with low w/cm (Hossain et al. 2008). Ultimately, VCAST™ 160 was selected over two alternatives, Class F fly ash and metakaolin. The three alternatives were extensively tested in several variations and the highest compressive strength resulted from a complete replacement of metakaolin and fly ash with VCAST™ 160. Furthermore, its white color made it an attractive candidate for the ForeverGlades team, as neither the off-white metakaolin nor the gray fly ash could foster lighter-
tinted mixes; which was part of the team’s aesthetic strategy of creating a lighter-colored canoe for sealing purposes.

Of significant concern noticed by the AcceleGator team was the continued propagation of cracks on the hull, an issue which arose late in the 2014 season. In order to increase tensile strength, the ForeverGlades team employed basalt fibers. Basalt fibers are lightweight fibers made from molten rock with a tenacity higher than that of steel. They improve flexural strength, do not absorb water, and have the same coefficient of thermal expansion as concrete (Cheng Concrete 2014). Although basalt fibers have a lower clumping risk when mixed, they still leave the shotcrete gun vulnerable to clogging. To offset this risk and remain in accordance with ASTM C1116, the well-staffed ForeverGlades team dedicated hundreds of hours to the separation of fibers from one another. Several methods, including the use of compressed air, were tested to increase the efficiency of separating fibers, but hand separation proved most effective. As a result of separation, the individual fibers assimilated themselves more fluidly into the mix, and issues with clumping and workability were largely overcome. Furthermore, the fibers lent significant tensile strength to the specimens tested, providing increases of up to 137% over control mixes.

SikaLatex® R was used in previous years as a polymer modifier. Styrene-butadiene rubber (SBR) latex, a newly-donated material, was tested as a potential replacement for SikaLatex® R due to its popularity with other successful teams. A direct replacement of SBR latex for SikaLatex® R in a control mix led to higher workability and a lower water demand, both of which were desirable properties. However, SikaLatex® R was still used for the middle layer of ForeverGlades for its air-entraining ability; further air entrainment was achieved through the use of Darex® AEA. This middle layer mix provided desirable strengths and unit weights for this year’s team. Unfortunately, SikaLatex® R introduced voids and an undesirable finish. For this reason, it was replaced with SBR latex in the visible layers and structural ribs.

To achieve the level of workability necessary for shotcreting, ADVA® Cast 600, a superplasticizer, was used in conjunction with WRDA® 60, a mid-range water reducer. Varying levels of these plasticizers were employed in each layer, accounting for differences in placement method, aggregate gradation, and fiber content. Efforts to prevent drying of mixes prior to placement were aided by the use of V-MAR® 3, a rheology-modifying admixture.

AcceleGator’s aggregate blend, developed from rigorous testing, was adopted by the ForeverGlades team in order to focus its efforts on changes in cementitious materials, fibers, and admixtures. The five aggregates, – three sizes of Poraver®, S38 and K15 glass microspheres – allowed for superior gradation and strength-to-weight ratios. For the two surface layers, increased quantities of S38 and K15 were utilized in lieu of the largest-sized Poraver®, creating a smooth, lightweight mix.

Aiming to control quality and consistency of test results, the mix team decided to forgo the traditional compaction method of hand tamping specimens, employing a vibrating table during casting. Control mixes, which were produced by both manual and mechanical compaction, showed a stark contrast between the methods. Specimens created using the vibrating table, including both cylinders and briquettes, saw significant decreases in void quantity and size, leading to increased tensile and compressive strengths. Most importantly, the use of the vibration table also standardized the samples made by eliminating human error introduced by tamping previously observed. This produced better comparisons between mixes and a more accurate representation of the final concrete product used in the canoe.

After setting, demolding, and curing for 14 days, the bearing surfaces of the cylindrical specimens were lightly sanded using a belt sander to remove large deformations. New for this year, unbonded neoprene caps per the specifications of ASTM 1232 were used during the compressive strength testing (Figure 7). These caps allowed for consistent comparisons between specimens by creating a smooth, parallel bearing surface perpendicular to the applied axial load during compressive strength testing (NRMCA 2014).
A new procedure for mixing fresh concrete was undertaken this year to increase slump and prevent mixes from drying out too quickly on long placement days. As suggested by UF faculty, all wet materials were added to the mixing bowl after dry mixing for 45 seconds, as opposed to adding water reducers after an initial wet mixing period. Fresh mixes were noticeably more workable, showing an increase in slump. Actual unit weights also proved more consistent with predicted unit weights, suggesting that Darex® AEA was most efficacious when added alongside the other wet materials.

The ForeverGlades team was determined to incorporate sustainability into every aspect of the project. In the past, cleaning of mixing equipment was done with a hose in a constantly draining basin using at least 5,000 gallons of water per placement day. As part of this year’s effort, shop towels were replaced with cloth towels, and water usage was closely monitored and limited on both placement days. A basin containing 45 gallons of water was used for cleaning large equipment while a five-gallon bucket was used to clean syringes, small buckets, and other small batching tools. It was determined that merely 140 gallons of water were used for cleaning on each placement day.

The glass particles constituting all sizes of Poraver® aggregate are recycled, providing a level of environmental sustainability mirrored by the recycled glass powder of VCAS™ 160. Ground blast furnace slag represents another sustainable material, as its use in concrete precludes its environmentally-harmful disposal as an industrial by-product. Substantial donations were secured for many of the materials, including white portland cement, slag, S38, K15, and all admixtures, save SikaLatex® R. Economic sustainability was thereby maximized for the mix design phase of the project.

Like many of its predecessors, ForeverGlades includes three layers of concrete. In previous years, the larger-sized aggregates would become dislodged during troweling, producing a rough surface. This year, a mix excluding larger-sized aggregates was used for both the inner and outer layers, rather than just the outermost layer of the canoe, as was the case in AcceleGator. This omission allowed for an increase in surface area and decrease in void quantity, ultimately creating a more aesthetically-pleasing canoe with decreased drag. The mix design including all sizes of Poraver® proved to be strongest in tension and compression; it was therefore used in the middle layer and structural ribs to provide flexural support throughout the canoe. Finally, the inner two layers and the ribs contain basalt fibers to aid in tension and flexure. Kevlar®-impregnated carbon fiber mesh was used as structural reinforcement and was embedded between each layer of the canoe. Strips of the mesh were also placed in between two lifts of concrete when hand-placing the structural ribs. The final mixes employed in ForeverGlades (shown in Table 2) developed strengths that exceeded the requirements set by the structural analysis while meeting goals set for hue and unit weight.

<table>
<thead>
<tr>
<th>Concrete Properties</th>
<th>Inner Layer</th>
<th>Middle Layer</th>
<th>Outer Layer</th>
<th>Structural Ribs</th>
<th>Aesthetic Paste</th>
<th>AcceleGator Inner Layers</th>
<th>AcceleGator Outer Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Unit Weight</td>
<td>50.5 pcf</td>
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<td>49.5 pcf</td>
<td>55.2 pcf</td>
<td>120.0 pcf</td>
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<td>49.3 pcf</td>
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<td>w/cm</td>
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<td>0.34</td>
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<td>1,512 psi</td>
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<td>282 psi</td>
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<td>Basalt Chopped Fibers</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Latex</td>
<td>SBR</td>
<td>SikaLatex®R</td>
<td>SBR</td>
<td>SBR</td>
<td>No</td>
<td>SikaLatex®R</td>
<td>SikaLatex®R</td>
</tr>
<tr>
<td>Flexural Strength*</td>
<td>1,272 psi</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>1,194 psi</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: ForeverGlades Concrete Properties Compared to AcceleGator
With the move to an on-campus facility, the *ForeverGlades* team had to make several adjustments in order to better operate in the new space. The major change involved making the canoe form mobile in order to reduce spatial and logistical problems within the lab. This meant eliminating the table on which the form had been built in the past and constructing the form directly on a steel beam. Heavy-duty casters were attached to the beam, allowing it to be easily maneuvered. Eliminating the table surface also cut this year’s plywood use in half.

The form’s mobility allowed sanding to be done outside of the lab, reducing respiratory concerns within the team’s confined area. Additionally, this enabled the team to accommodate the ever-changing research projects within the shared lab space.

Based on the team’s experience level and the ability to better regulate layer thickness while shotcreting, a male form was chosen for *ForeverGlades*. Rather than having it CNC milled, the form was crafted by hand. This method allowed the team to stay within its budget and familiarize newer team members with the level of precision that would later be required during placement. Instead of foam, the team chose to use wood as the primary material for constructing the form. This choice was motivated by the sustainable harvesting of the available lumber and the ability to reuse pieces of the previous year’s form.

Cross sections at 1 ft. increments were obtained from the design software, then printed and cut from ¾ in. plywood. The cross sections were cut with an added rectangular piece at their bases, allowing them to fit directly into the beam and included a lip at the gunwales. This lip was designed at the desired thickness of the canoe to ensure uniformity when troweling on placement day. The steel beam contains holes every 4 in. on-center, enabling better accuracy in placing the sections at 1 ft. increments. The rigidity of the beam also aided in keeping the cross sections aligned. Plywood spacers and wooden triangles braced each side of the sections and were bolted to the beam (Figure 8). Once every section was in place, a transit level was used to align each one along the hull’s centerline.

The construction team nailed ½ in. wide plywood strips to the edges of the cross sections, connecting them and forming the canoe’s curved shape. A 5/16 in. thickness was chosen for these strips because it provided enough flexibility to follow the hull’s contours but enough rigidity to resist deflection during sanding. Once completed, the team used a belt sander to make an initial pass over the entire form before applying Bondo® to fill in gaps and depressions. Repeated sanding and Bondo® applications resulted in a smooth, even form surface. The entire form was then coated in a laminating resin to waterproof the wood. When the resin was completely cured, precut adhesive foam designs were applied to the form in order to create an inlaid effect on the concrete.

Insulation foam was used instead of wood to create the finer details of the hull’s shape. The bow and stern sections of the hull were sculpted from layered foam using a variable speed orbital sander to achieve the shape prescribed by the FREE!ship (Timoshenko 2013) file. The three structural rib sections were carefully hand-sanded to achieve roughly the desired profile. A meticulous application of Bondo® provided the freedom to create the preferred trapezoidal shape (Figure 9). The chamfered design was implemented to ease demolding and mitigate stress concentrations by reducing sharp inside corners.

The *ForeverGlades* team made it a priority to optimize the lengthy placement day process where possible. The practice placement day was scrutinized by team captains, and changes were implemented for competition placement day. Competition placement day proved to be more efficient as a second shotcrete gun was donated and twice as many trowelers were trained to smooth the
fresh concrete. This allowed the team to work on larger sections of the canoe more efficiently and finish troweling before the concrete became unworkable.

The team began placement day by thoroughly applying vegetable oil to the form as a natural release agent. Next, two layers of concrete were hand-placed in each rib, with a strip of carbon fiber mesh reinforcement embedded between them. Immediately thereafter, the first layer was shotcreted and troweled to a ruled thickness of 1/8 in.; marked pins were used by trowelers to ensure a consistent thickness throughout each layer. Once complete, carbon fiber mesh was placed over the entire canoe and embedded into the first layer by hand. The next layer was also applied at 1/8 in., after which a second sheet of carbon fiber was embedded into the canoe. Layer thickness was carefully monitored at the gunwale lip.

A thicker, final layer was applied at 3/16 in. to allow the team to more effectively sand away exterior imperfections while maintaining the final thickness of 3/8 in. On this layer, the gunwale lip allowed team members to trowel straight up from its edge, ensuring regularity along the length of the canoe. Extra care was taken in finishing the outer layer to minimize the amount of time needed later for sanding. The canoe was then covered in plastic for the next three days to retain moisture as the concrete set.

A new, modular curing tank was constructed to maximize the efficiency of the team’s limited lab space. Since the tank could be easily disassembled, the side panel was removed and the entire form was rolled into the tank, while still attached to the beam. A water heater and soaker hose were used over the entire canoe to recirculate water infused with calcium hydroxide to aid in the curing process (Figure 10). A double layer of burlap ensured that the canoe’s surface remained moist. With the tank acting as a catch basin, there was minimal water loss during this phase of curing. At the end of the initial 14-day curing, the form was removed from the tank, and the canoe was demolded. This time frame simulates the strength and age at which specimens were tested during the design phase. Compressed air was employed for the first time this year to separate the concrete from the form, several team members were able to lift the canoe off of the wooden form. The foam sections used to shape the bow and stern were left in the canoe as flotation. The curing tank was then reassembled, filled with limewater, and the canoe was submerged for an additional two weeks at 135 °F to complete curing. This system was able to achieve a higher temperature than first anticipated, allowing greater opportunity for strength gain than test specimens (NRMCA 2006).

At the conclusion of the curing process, the canoe was removed from the tank, and concrete was hand-placed to cover the flotation at the bow and stern. Minor air voids in the hull’s interior were also filled in at this time. The interior and exterior of the canoe were carefully hand sanded to remove imperfections and create the optimum surface for applying sealer. Long, wooden sanding blocks were used to mitigate “waviness” along the outside walls of the canoe. Incrementally moving from 100 to 300 grit sandpaper helped the team achieve the finest finish for sealer.

To better integrate this year’s theme into the construction of ForeverGlades, the team decided to incorporate a three-dimensional alligator on the interior of the hull (Figure 11). The three portions of the alligator’s body were sculpted from clay, and a corn starch and silicone mixture was used to create flexible molds. To maintain continuity with the canoe, the fine, inner layer mix was used to cast the alligator. A special mix was created to bond it to the hull. The alligator was then strategically placed in the canoe based upon aesthetics and paddler safety. ForeverGlades was then thoroughly cleaned before carefully applying colored sealer.


ASTM (2010). “Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).” C78/C78M-10e1, West Conshohocken, PA.


## Mixture ID: Inner Layer

| Design Batch Size (ft³): | 0.125 |

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<thead>
<tr>
<th>Cementitious Materials</th>
<th>Design Proportions (Non SSD)</th>
<th>Actual Batched Proportions</th>
<th>Yielded Proportions</th>
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<tbody>
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<td>CM1 White Cement, Type I</td>
<td>Amount (lb/yd³)</td>
<td>Volume (ft³)</td>
<td>Amount (lb)</td>
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<tr>
<td>CM2 Blast-Furnace Slag</td>
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<td>0.763</td>
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<td>CM3 VCAS™ 160</td>
<td>2.90</td>
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<td>1.824</td>
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<td>A3 S38 Glass Microspheres</td>
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<td>W1a. Water from Admixtures</td>
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<td>W1b. Additional Water</td>
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<td>Ad2 ADVA® CAST 600 Superplasticizer</td>
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<td>14.40</td>
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<td>Yield, ft³ = (M / D)</td>
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<td>Relative Yield = (Y / Y₀)</td>
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### Mixture ID: Middle Layer

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<td>Design Batch Size (ft³)</td>
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#### Cementitious Materials

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<tr>
<th>Material</th>
<th>SG</th>
<th>Amount (lb/yd³)</th>
<th>Volume (ft³)</th>
<th>Amount (lb)</th>
<th>Volume (ft³)</th>
<th>Amount (lb/yd³)</th>
<th>Volume (ft³)</th>
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<tr>
<td>CM1 White Cement, Type I</td>
<td>3.15</td>
<td>143.75</td>
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<td>CM2 Blast-Furnace Slag</td>
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<td>CM3 VCAS™ 160</td>
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<td>115.00</td>
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**Total Cementitious Materials:**

- Amount (lb/yd³): 575.00
- Volume (ft³): 3.19
- Amount (lb): 2.66
- Volume (ft³): 0.01

#### Aggregates

<table>
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<tr>
<th>Material</th>
<th>Abs:</th>
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<td>Poraver® (1.0-2.0mm)</td>
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<td>122.02</td>
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**Total Aggregates:**

- Amount (lb/yd³): 452.77
- Volume (ft³): 17.04
- Amount (lb): 2.10
- Volume (ft³): 0.08

#### Water

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<th>Amount (lb)</th>
<th>Volume (ft³)</th>
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<td>Water for CM Hydration (W1a + W1b)</td>
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<td>Additional Water (W1b)</td>
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<td>91.50</td>
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**Total Water:**

- Amount (lb/yd³): 294.51
- Volume (ft³): 3.13
- Amount (lb): 1.36
- Volume (ft³): 0.01

#### Solids Content of Latex Admixtures and Dyes

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<td>SikaLatex® R</td>
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**Total Solids of Admixtures:**

- Amount (lb/yd³): 74.59
- Volume (ft³): 1.15
- Amount (lb): 0.35
- Volume (ft³): 0.05

#### Admixtures (including Pigments in Liquid Form)

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<td>WRDA® 60 Superplasticizer</td>
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**Water from Admixtures (W1a):**

- Amount (lb/yd³): 104.00
- Volume (ft³): 0.48
- Amount (lb): 126.41

#### Cement-Cementitious Materials Ratio

- 0.25

#### Water-Cementitious Materials Ratio

- 0.34

#### Slump, Slump Flow, in.

- 11.00

#### Mass of Concrete, lbs

- 1400

#### Absolute Volume of Concrete, ft³

- 24.532

#### Theoretical Density, lb/ft³ = (M / V)

- 57.06

#### Design Density, lb/ft³ = (M / D)

- 51.85

#### Measured Density, lb/ft³

- 54.18

#### Air Content, % = [(T - D) / T x 100%] + 100%

- 9.14

#### Yield, ft³ = (M / D)

- 27

#### Relative Yield = (Y / Y₀)

- 0.957
### Mixture ID: Outer Layer

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#### Cementitious Materials

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<th>Volume (ft³)</th>
<th>Amount (lb)</th>
<th>Volume (ft³)</th>
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#### Fibers

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#### Aggregates

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#### Water

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#### Solids Content of Latex Admixtures and Dyes

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#### Admixtures (Including Pigments in Liquid Form)

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</thead>
<tbody>
<tr>
<td>Ad1</td>
<td>WRDA® 60 Water Reducer</td>
<td>9.6 lb/gal</td>
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<td>Ad2</td>
<td>ADVA® CAST 600 Superplasticizer</td>
<td>9.2 lb/gal</td>
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<td>0.011</td>
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<td>3.87</td>
<td>1.51</td>
<td>0.11</td>
<td>0.007</td>
</tr>
<tr>
<td>Ad4</td>
<td>Darex® AEA Air Entainer</td>
<td>8.5 lb/gal</td>
<td>5.00</td>
<td>0.74</td>
<td>0.28</td>
<td>0.02</td>
<td>0.001</td>
</tr>
<tr>
<td>Ad5</td>
<td>Styrene-butadiene Rubber Latex</td>
<td>8.4 lb/gal</td>
<td>48.00</td>
<td>158.67</td>
<td>32.49</td>
<td>4.41</td>
<td>0.150</td>
</tr>
</tbody>
</table>

#### Water from Admixtures (W1a):

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>

#### Design Proportions (Non SSD)

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>

#### Actual Batched Proportions

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>

#### Yielded Proportions

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>

### Additional Calculations

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>

| Cement-Cementitious Materials Ratio | 0.25 | 0.25 | 0.25 |
| Water-Cementitious Materials Ratio | 0.66 | 0.66 | 0.66 |
| Slump, Slump Flow, in. | 11.00 | 11.00 | 11.00 |
| M Mass of Concrete, lbs | 1420 | 6.58 | 1337 |
| V Absolute Volume of Concrete, ft³ | 24.305 | 0.113 | 22.877 |
| T Theoretical Density, lb/ft³ = (M / V) | 58.44 | 58.44 | 58.44 |
| D Design Density, lb/ft³ = (M / 27) | 52.60 |     |     |
| D Measured Density, lb/ft³ | 49.51 | 49.51 |     |
| A Air Content, % = (T - D) / T x 100% | 9.98 | 15.28 | 15.28 |
| Y Yield, ft³ = (M / D) | 27 | 0.133 | 27 |
| Ry Relative Yield = (Y / Y_D) | 1.062 |     |     |
## Mixture ID: Structural Ribs

### Design Proportions (Non SSD)

<table>
<thead>
<tr>
<th>Cementitious Materials</th>
<th>Amount (lb/yd³)</th>
<th>Volume (ft³)</th>
<th>Amount (lb)</th>
<th>Volume (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM1 Blast Furnace Slag</td>
<td>143.75</td>
<td>0.731</td>
<td>0.67</td>
<td>0.003</td>
</tr>
<tr>
<td>CM2 White Cement, Type I</td>
<td>316.25</td>
<td>1.748</td>
<td>1.46</td>
<td>0.008</td>
</tr>
<tr>
<td>CM6 Blast Furnace Slag</td>
<td>115.00</td>
<td>0.709</td>
<td>0.53</td>
<td>0.003</td>
</tr>
</tbody>
</table>

### Total Cementitious Materials: 3.19 0.01

<table>
<thead>
<tr>
<th>Amount (lb/yd³)</th>
<th>Volume (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.731</td>
<td>0.003</td>
</tr>
<tr>
<td>1.748</td>
<td>0.008</td>
</tr>
<tr>
<td>0.709</td>
<td>0.003</td>
</tr>
<tr>
<td>625.69</td>
<td>3.47</td>
</tr>
</tbody>
</table>

### Fibers

| F1 Basalt Chopped Fibers KV13 | 3.00 | 0.018 | 0.01 | 0.001 | 3.26 | 0.020 |

### Total Fibers: 3.00 0.02

### Aggregates

<table>
<thead>
<tr>
<th>A1 Poraver® (1.0-2.0mm)</th>
<th>Abs: 25</th>
<th>0.38</th>
<th>124.10</th>
<th>5.234</th>
<th>0.57</th>
<th>0.024</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2 Poraver® (0.5-1.0mm)</td>
<td>Abs: 25</td>
<td>0.46</td>
<td>150.23</td>
<td>5.234</td>
<td>0.70</td>
<td>0.024</td>
</tr>
<tr>
<td>A3 Poraver® (0.25-0.50mm)</td>
<td>Abs: 25</td>
<td>0.59</td>
<td>128.45</td>
<td>3.489</td>
<td>0.59</td>
<td>0.016</td>
</tr>
</tbody>
</table>

### Total Aggregates: 460.47 17.45 2.13 0.08 501.07 18.98

### Water

<table>
<thead>
<tr>
<th>W1 Water for CM Hydration (W1a + W1b)</th>
<th>172.50</th>
<th>2.764</th>
<th>0.80</th>
<th>0.013</th>
<th>187.71</th>
<th>3.008</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1a Water from Admixtures</td>
<td>69.09</td>
<td>0.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W1b Additional Water</td>
<td>103.41</td>
<td>0.48</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Total Water (W1 + W2): 273.19 2.76 1.26 0.01 297.28 3.01

### Solids Content of Latex Admixtures and Dyes

| S1 Styrene-butadiene Rubber Latex | 57.50 | 0.912 | 0.27 | 0.004 | 62.57 | 0.993 |

### Total Solids of Admixtures: 57.50 0.91 0.27 0.004 62.57 0.99

### Admixtures (Including Pigments in Liquid Form)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ad1 WRDA® 60 Water Reducer</td>
<td>9.6</td>
<td>34.00</td>
<td>11.59</td>
<td>3.30</td>
<td>0.31</td>
<td>0.015</td>
<td>12.62</td>
</tr>
<tr>
<td>Ad2 ADVAR® CAST 600 Superplasticizer</td>
<td>9.2</td>
<td>40.00</td>
<td>9.79</td>
<td>2.42</td>
<td>0.26</td>
<td>0.011</td>
<td>85.26</td>
</tr>
<tr>
<td>Ad3 V-MAR® 3 Viscosity Modifying Agent</td>
<td>8.5</td>
<td>2.00</td>
<td>2.16</td>
<td>0.81</td>
<td>0.06</td>
<td>0.004</td>
<td>2.35</td>
</tr>
<tr>
<td>Ad4 Darex® AEA Air Entrainer</td>
<td>8.5</td>
<td>5.00</td>
<td>0.74</td>
<td>0.27</td>
<td>0.02</td>
<td>0.001</td>
<td>0.80</td>
</tr>
<tr>
<td>Ad4 Styrene-butadiene Rubber Latex</td>
<td>8.4</td>
<td>48.00</td>
<td>317.51</td>
<td>62.30</td>
<td>8.45</td>
<td>0.288</td>
<td>345.50</td>
</tr>
</tbody>
</table>

### Water from Admixtures (W1a):

| 69.09 | 0.32 | 93.65 |

### Cement-Cementitious Materials Ratio

| 0.25 | 0.25 | 0.25 |

### Water-Cementitious Materials Ratio

| 0.30 | 0.30 | 0.30 |

### Slump, Slump Flow, in.

| 9.00 | 9.00 | 9.00 |

### M Mass of Concrete, lbs

| 1369 | 6.34 | 1490 |

### V Absolute Volume of Concrete, ft³

| 24.328 | 0.113 | 26.473 |

### T Theoretical Density, lb/ft³ = (M / V)

| 56.28 | 56.28 | 56.28 |

### D Design Density, lb/ft³ = (M / 27)

| 50.71 | 50.71 | 50.71 |

### D Measured Density, lb/ft³

| 55.18 | 55.18 | 55.18 |

### A Air Content, % = [(T - D) / T x 100%]

| 9.90 | 1.95 | 1.95 |

### Y Yield, ft³ = (M / D)

| 27 | 0.115 | 27 |

### Ry Relative Yield = (Y / Y₀)

| 0.919 | 0.919 | 0.919 |
## Mixture ID: Aesthetic Paste

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Design Batch Size (ft³)</th>
<th>Yielded Proportions</th>
<th>Actual Batched Proportions</th>
<th>Design Proportions (Non SSD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM1</td>
<td>3.15</td>
<td>1312.29</td>
<td>6.676</td>
<td>1500.00</td>
</tr>
<tr>
<td>A1</td>
<td>2.65</td>
<td>1562.57</td>
<td>9.450</td>
<td>1786.08</td>
</tr>
<tr>
<td>W1</td>
<td>1.00</td>
<td>364.33</td>
<td>4.84</td>
<td>416.44</td>
</tr>
<tr>
<td>W1a</td>
<td>1.00</td>
<td>73.80</td>
<td>4.83</td>
<td>84.35</td>
</tr>
<tr>
<td>W1b</td>
<td>1.00</td>
<td>228.03</td>
<td>4.83</td>
<td>260.65</td>
</tr>
<tr>
<td>W2</td>
<td>1.00</td>
<td>62.50</td>
<td>4.83</td>
<td>71.44</td>
</tr>
<tr>
<td>S1</td>
<td>N/A</td>
<td>243.51</td>
<td>12.18</td>
<td>357.00</td>
</tr>
<tr>
<td>S2</td>
<td>N/A</td>
<td>84.35</td>
<td>0.28</td>
<td>115.00</td>
</tr>
<tr>
<td>S3</td>
<td>N/A</td>
<td>228.03</td>
<td>0.28</td>
<td>357.00</td>
</tr>
<tr>
<td>P1</td>
<td>N/A</td>
<td>260.65</td>
<td>0.28</td>
<td>357.00</td>
</tr>
</tbody>
</table>

### Solids Content of Latex Admixtures and Dyes

<table>
<thead>
<tr>
<th>Admixture</th>
<th>Solids</th>
<th>Dosage</th>
<th>Water in Admixture</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ad1</td>
<td>9.2</td>
<td>67.80</td>
<td>243.51</td>
<td>213.04</td>
</tr>
</tbody>
</table>

### Water from Admixtures (W1a):

<table>
<thead>
<tr>
<th></th>
<th>Amount (lb/yd³)</th>
<th>Volume (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1a Water from Admixtures</td>
<td>84.35</td>
<td>0.28</td>
</tr>
<tr>
<td>W2 Water for Aggregates, SSD</td>
<td>71.44</td>
<td>0.24</td>
</tr>
</tbody>
</table>

### Water Content

- **Total Water (W1 + W2):** 364.33 lb/yd³
- **Total Water (W1):** 84.35 lb/yd³
- **Total Water (W2):** 228.03 lb/yd³

### Design Proportions

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount (lb/yd³)</th>
<th>Volume (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM1</td>
<td>1500.00</td>
<td>7.63</td>
</tr>
<tr>
<td>A1</td>
<td>1562.57</td>
<td>9.45</td>
</tr>
<tr>
<td>W1</td>
<td>364.33</td>
<td>4.84</td>
</tr>
<tr>
<td>W1a</td>
<td>73.80</td>
<td>4.83</td>
</tr>
<tr>
<td>W1b</td>
<td>228.03</td>
<td>4.83</td>
</tr>
<tr>
<td>W2</td>
<td>62.50</td>
<td>4.83</td>
</tr>
<tr>
<td>S1</td>
<td>243.51</td>
<td>12.18</td>
</tr>
<tr>
<td>S2</td>
<td>84.35</td>
<td>0.28</td>
</tr>
<tr>
<td>S3</td>
<td>228.03</td>
<td>0.28</td>
</tr>
<tr>
<td>P1</td>
<td>260.65</td>
<td>0.28</td>
</tr>
</tbody>
</table>

### Additional Water

- **Total Water (W1a + W1b):** 416.44 lb/yd³
- **Water for Aggregates, SSD:** 62.50 lb/yd³
- **Water for CM Hydration:** 84.35 lb/yd³

### Total Solids of Admixtures

- **Total Solids of Admixtures:** 67.80 lb/yd³

### Cement-Cementitious Materials Ratio

- **Cement-Cementitious Materials Ratio:** 1.00

### Water-Cementitious Materials Ratio

- **Water-Cementitious Materials Ratio:** 0.23

### Design Proportions

- **Design Proportions:** (Non SSD)

### Actual Batched Proportions

- **Actual Batched Proportions**

### Yielded Proportions

- **Yielded Proportions**

### Performance Properties

- **Slump, Slump Flow:** 11.00 in.
- **Mass of Concrete:** 3703 lbs
- **Absolute Volume of Concrete:** 23.961 ft³
- **Theoretical Density:** 154.52 lb/ft³
- **Design Density:** 137.13 lb/ft³
- **Measured Density:** 119.97 lb/ft³
- **Air Content:** 11.25%
- **Relative Yield:** 1.143
<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Cement, Type I</td>
<td>25.74 lb</td>
<td>$0.76/lb</td>
<td>$19.57</td>
</tr>
<tr>
<td>Slag (Grade 100)</td>
<td>56.64 lb</td>
<td>$0.02/lb</td>
<td>$1.13</td>
</tr>
<tr>
<td>VCAST™ 160</td>
<td>20.60 lb</td>
<td>$0.76/lb</td>
<td>$15.65</td>
</tr>
<tr>
<td>Quikrete® All-Purpose Sand</td>
<td>5.92 lb</td>
<td>$0.10/lb</td>
<td>$0.59</td>
</tr>
<tr>
<td>Poraver® 0.25 - 0.5 mm</td>
<td>22.47 lb</td>
<td>$0.70/lb</td>
<td>$15.73</td>
</tr>
<tr>
<td>Poraver® 0.5 - 1.0 mm</td>
<td>9.35 lb</td>
<td>$0.70/lb</td>
<td>$6.54</td>
</tr>
<tr>
<td>Poraver® 1.0 - 2.0 mm</td>
<td>7.72 lb</td>
<td>$0.70/lb</td>
<td>$5.40</td>
</tr>
<tr>
<td>S38® Glass Bubbles</td>
<td>24.75 lb</td>
<td>$11.98/lb</td>
<td>$296.46</td>
</tr>
<tr>
<td>K15® Glass Bubbles</td>
<td>1.67 lb</td>
<td>$12.50/lb</td>
<td>$20.88</td>
</tr>
<tr>
<td>High-Range Water-Reducer</td>
<td>10.98 fl. oz.</td>
<td>$0.12/fl. oz.</td>
<td>$1.32</td>
</tr>
<tr>
<td>Water Reducer (WRDA® 60)</td>
<td>10.98 fl. oz.</td>
<td>$0.04/fl. oz.</td>
<td>$0.44</td>
</tr>
<tr>
<td>Rheology-Modifying Admixture (V-MAR® 3)</td>
<td>2.94 fl. oz.</td>
<td>$0.15/fl. oz.</td>
<td>$0.44</td>
</tr>
<tr>
<td>Air-Entraining Admixture (DAREX® AEA)</td>
<td>0.67 fl. oz.</td>
<td>$0.04/fl. oz.</td>
<td>$0.03</td>
</tr>
<tr>
<td>Bonding Agent (Daraweld® C)</td>
<td>12.18 fl. oz.</td>
<td>$0.06/fl. oz.</td>
<td>$0.73</td>
</tr>
<tr>
<td>Latex (SikaLatex® R)</td>
<td>0.90 gal.</td>
<td>$11.87/gal.</td>
<td>$10.69</td>
</tr>
<tr>
<td>Latex (Styrene-Butadiene Rubber)</td>
<td>0.82 gal.</td>
<td>$25.60/gal.</td>
<td>$20.96</td>
</tr>
<tr>
<td>Carbon Fiber Reinforcement (TORAYCA® T300)</td>
<td>180 sq. ft.</td>
<td>$2.40/sq. ft.</td>
<td>$432.00</td>
</tr>
<tr>
<td>Fibers (Basalt KV13 Chopped)</td>
<td>0.34 lb.</td>
<td>$7.82/lb.</td>
<td>$2.68</td>
</tr>
<tr>
<td>Adhesive Foam Inlays</td>
<td>3 sq. ft.</td>
<td>$8.00/sq. ft.</td>
<td>$24.00</td>
</tr>
<tr>
<td>Foam Flotation</td>
<td>1 sheet</td>
<td>$12.98/sheet</td>
<td>$12.98</td>
</tr>
<tr>
<td>Sealer/Stain</td>
<td>1 gal.</td>
<td>$45.00/gal.</td>
<td>$45.00</td>
</tr>
<tr>
<td>Canoe Mold</td>
<td>Lump Sum</td>
<td></td>
<td>$293.09</td>
</tr>
</tbody>
</table>

**Total Production Cost** $1,226.31
Buoyant Forces

Assumptions:

Rectangular Section
Uniform distribution of force along each section
3-in. sections, D
Wetted Width, W = 25.20 in.
Wetted Height, H = draft = 5.7 in.
Unit Weight of Water, \( \gamma_w = 62.4 \text{ lb/ft.}^3 \)

Submerged Volume, \( V \)
\[
V = D \times H \times W = 3.0 \text{ in.} \times 5.7 \text{ in.} \times 25.20 \text{ in.} \\
= 430.97 \text{ in.}^3
\]

Submerged Area, \( A \)
\[
A = \frac{V}{D} = \frac{430.97 \text{ in.}^3}{3.0 \text{ in.}} = 143.657 \text{ in.}^2 = 0.997 \text{ ft.}^2
\]

Distributed Buoyant Force (\( F_B \)) at One 3in. Section
\[
F_B = \gamma_w \times A \\
= 62.4 \text{ lb./ft.}^3 \times 0.997 \text{ ft.}^2 = 62.25 \text{ lb./ft.}
\]
Resultant Buoyant Force Magnitude, $F_{RB}$

$$F_{RB} = \sum_{0/ft}^{11/ft} F_B = 290.2 \text{ lb}$$

Resultant Buoyant Force Location, $X_{RB}$

$$X_{RB} = \frac{\sum_{0/ft}^{11/ft} F_B x}{\sum_{0/ft}^{11/ft} F_B} = 7.38 \text{ ft}.$$  

Canoe Weight, $W_c$

Assumptions:

Uniform distribution of weight along entire canoe length.

Weight of canoe, $W_c = 160 \text{ lb}$

One 200 lb male paddler located at $x = 4 \text{ ft}$.

Resultant Magnitude of Canoe Weight, $F_{RW}$

$$F_{RW} = \frac{W_c}{2} = \frac{160 \text{ lb}}{2} = 80 \text{ lb}$$

Resultant Location of Canoe Weight, $X_{RW}$

$$X_{RW} = \frac{L}{2} = \frac{11 \text{ ft}}{2} = 5.5 \text{ ft}.$$  

Maximum Moment, $M$ Located at $x = 11 \text{ ft}$.

$$M_{11/ft} = \sum M = -80 \text{ lb} (11.00 \text{ ft} - 5.5 \text{ ft}) + -200 \text{ lb} (11.00 \text{ ft} - 4 \text{ ft}) + 290.2 \text{ lb} (11.00 \text{ ft} - 7.38 \text{ ft}) = -788 \text{ ft} \cdot \text{lb} = -9464 \text{ in} \cdot \text{lb}$$

Moment of Inertia, $I_{xx}$

Assumptions:

C-channel beam

Height of gunwale, $b = 13.31 \text{ in}$.

Thickness of bottom, $t = 0.375 \text{ in}$.

Thickness of gunwale, $s = 0.375 \text{ in}$.

Width of bottom (outside), $d = 25.33 \text{ in}$.

Width of bottom (inside), $h = (25.33 \text{ in} - 2 \times 0.375 \text{ in}) = 24.45 \text{ in}$.

$$y = \text{ location of neutral axis (from top of section)}$$

$$I_{xx} = \frac{2sb^3 + ht^3}{3} - A(b - y)^2 = 367.6 \text{ in}^4$$

where

$$A = bd - h(b - t) = 20.82 \text{ in}^2$$

and

$$y = b - \frac{2b^2s + ht^2}{2bd - 2h(b - t)} = 10.04 \text{ in}.$$  

Stresses on Section

$$\sigma = \frac{M \cdot c}{I}$$

c = distance from neutral axis to edge of section

Compressive Stress, $\sigma$

$$\sigma = \frac{(-9464 \text{ in} \cdot \text{lb}) \cdot (10.04 \text{ in})}{367.6 \text{ in}^4} = -258.3 \text{ psi}$$

Tensile Stress, $\sigma$

$$\sigma = \frac{(-9464 \text{ in} \cdot \text{lb}) \cdot (-13.31 \text{ in})}{367.6 \text{ in}^4} = 84.2 \text{ psi}$$