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Amusement parks rides are some of the most heavily engineered structures devised solely for fun. Thrill seekers flock to these parks to live on the edge and feel the adrenaline rush of a lifetime. Since 1875, amusement parks have been improving upon old rides and inventing new ones to continue to feed the adrenaline junkies’ risk while providing the utmost safety to the rider and its surroundings. Drexel University has embraced the ideas and traits of these awe inspiring theme parks to compete in the 2014 ASCE National Concrete Canoe Competition™ with the drive and energy of those thrill seekers.

Founded in 1891, Drexel consists of nine colleges and four schools with an enrollment of 25,500 undergraduate and graduate students, including 750 in the Civil, Architectural and Environmental Engineering department. Located in the heart of Philadelphia and operating one of the oldest and largest mandatory cooperative education programs in the country, Drexel serves students and society through comprehensive academic offerings in an urban setting, with global outreach embracing research, scholarly activities, and community initiatives.

Drexel unveils Drage, a second-generation canoe built using shotcrete. Seeking to improve upon our recent placements in the Mid-Atlantic Conference (3rd in 2011, 2nd in 2012 and 2013) and advance to the national level for the first time since 2008, our team produced a competitive product by incorporating enhancements in construction and shotcrete design while reducing cost, labor and waste. Furthermore, an increase in productivity and efficiency was accomplished through the delegation of managerial roles allowing effective supervision and mentoring of an influx of new members training them for sustained success.

Nordic for “dragon” (our school mascot), Drage is also the term for the Viking long ships which our selected color scheme and vibrant designs reflect. Based on a Wenonah® Minnesota 3™ canoe modified to enhance racing performance, it is the same design used in 2013 (Table 2). A male mold milled last year was refurbished and reused this year with a new lower strongback that provided a more ergonomic shooting height. The hull is a lightweight, moderate strength, fiber reinforced composite of Type I portland cement, Class F fly ash, silica fume and metakaolin with a blend of microspheres, expanded shale and cork (Table 3). Lightweight and sustainable, the use of cork allowed our team to meet a goal of incorporating at least one new material not previously used in Drexel canoes. The composite includes three layers of glass fiber mesh with recycled nylon carpet fibers dispersed within the concrete matrix.

Highlights of various features and practices implemented during the course of the project are summarized below (Table 4) and elaborated on in further detail in the report. Although this project is like a roller coaster, the 2014 Drexel Concrete Canoe Team is only at the peak of the first hill with Drage.

---

**Table 1: Drexel by the Numbers**

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Length (L)</td>
<td>19 ft. 9 ¾ in.</td>
</tr>
<tr>
<td>Maximum Beam (B)</td>
<td>29 ½ in.</td>
</tr>
<tr>
<td>Center Depth</td>
<td>12 ½ in.</td>
</tr>
<tr>
<td>Bow &amp; Stern Rocker</td>
<td>1 ½ in.</td>
</tr>
<tr>
<td>Hull Thickness</td>
<td>5/8 in.</td>
</tr>
<tr>
<td>Weight</td>
<td>342 lbs.</td>
</tr>
<tr>
<td>Color Scheme:</td>
<td>Brown, Black, Red, Blue and Yellow</td>
</tr>
</tbody>
</table>

---

**Table 2: Drage Specifications**

- **Shotcrete Mixture**
  - Unit Weight (plastic)¹: 73.2 pcf
  - Unit Weight (oven-dried)¹: 57.8 pcf
  - Unit Weight (plastic)²: 68.9 pcf
  - Unit Weight (oven-dried)²: 49.9 pcf
- **Compressive Strength, f'**,³: 2200 psi
- **Modulus of Rupture, M**³: 350 psi

---

**Table 3: Select Material Properties**

- **Dryvit® Standard Plus Mesh**
  - Percent Open Area: 69%
  - Mass/Area: 4.3 oz/ft²
  - Tensile Strength: 225 lb/in

- **Nycon®G Reclaimed Nylon Fibers**
  - Length: 0.75 in.
  - Specific Gravity: 1.1
  - Tensile Strength: 8 – 13 ksi

- **Reinforced Concrete Composite**
  - Flexural Strength³: 790 psi

---

**Table 4: Innovative Features, Fiscal Measures and Sustained Practices**

- **Industrial By-Products as Pozolans**
- **Reclaimed Nylon Fibers**
- **100% Sustainable Aggregates**
- **Low VOC Coatings, Stains & Sealers**
- **Use of Refurbished 2013 Mold**
- **Materials Procured at Reduced Cost**
- **18% Reduction in Budget (vs. 2013)**
- **Endowment for Future Teams**
- **Use of Cork Aggregate**
- **Probabilistic Structural Analysis**
- **Use of Accelerating Admixture**
- **Nearly Paperless Practice**
**PROJECT MANAGEMENT**

A proven organizational structure (Page 2) was used to distribute workload, maintain lines of communication and develop quality products within the given time and budget constraints. This structure also allows new members to be supervised and mentored by team veterans, laying down a foundation for sustained success. The team is led by a Project Manager (PM) and Assistant Project Manager (APM) responsible for overseeing daily operations, resource allocation and fiscal management. The PM and APM work directly with the leaders of four main divisions (Engineering, Construction, Mix Design, and Theme) to plan tasks, schedule work sessions, handle procurement and track labor hours. Quality Assurance/Quality Control (QA/QC) and Health & Safety (H&S) officers work in conjunction with the division leaders focusing their efforts on monitoring, training personnel and compiling documentation.

Weekly coordination meetings are held while progress updates, punch lists and two-week “look ahead” schedules are sent via e-mail. Project files are stored on Google Drive allowing ease in file management and document retrieval while serving as a collaboration platform for work products. Coordination began in July 2013 with the development of the preliminary budget and major milestones (Figure 1) based on past records, experience and logic. The schedule (Page 9) was refined following receipt of Conference deadlines. The critical path starts with the issuance of the Rules then follows hull design, mold construction, canoe casting and ends with the completion of Drage. The nine weeks incorporated into the schedule between canoe casting and completion, intended to provide recovery time, was needed due to a two week delay in mold construction. A total of 2,885 hours (Figure 2) were spent on the project – 2,410 for completion prior to the Mid-Atlantic Conference with an additional 475 in preparation for the National Competition. Compared to the same point last year (Conference), a nearly 200 hour decrease in time was realized due primarily to the reuse of hull design and experienced gun operators.

Project expenditures totaling $10,300 capture the costs of the concrete composite design and construction related to the mold, canoe, display and wood frame/plastic shotcreting room (Figure 3). A detailed breakdown of the canoe production cost is presented in Appendix C. The reuse of the EPS mold, salvaging of construction materials and donation of concrete making products result in the project being $1,500 under the original estimate. Conference and National Competition related costs such as registration, lodging and transportation are on the order of $9,200.

The overall goal of the quality program is to improve production and avoid issues which could lead to possible defects and non-conformance. The main facets of our QA process are a submittal register for all proposed materials and products and a three-tier compliance review. Extensive laboratory testing, implementation of project controls and “on the job” (OTJ) training sessions are key components of the QC program that has been continually refined over the years. The use of external quality measures to supplement our own include team mentoring by a practicing engineer (and Drexel canoe alum) experienced in construction QA/QC, onsite technical assistance by a shotcrete specialist and third-party reviews of calculations, test results and design report drafts.

The management team adopted an informal process of identifying and assessing risks, including a tailored “Go/No Go” evaluation, and used techniques such as transfere, avoidance, and reduction to minimize consequences. Prime examples include the outsourcing of the milling of a mold, the use of external QA/QC measures and incorporating recovery time into the schedule. Strict adherence to the university’s laboratory policies, familiarity with the products and their hazards through access to Material Safety Data Sheets (MSDS), proper training on equipment prior to their use, providing appropriate personal protective equipment (PPE) and maintaining a clean working environment are vital components of our Health & Safety program. Proper material handling/storage and equipment operating procedures were demonstrated and safety concerns were communicated during weekly “toolbox meetings” by the construction foreman and H&S officer. As a result of these efforts, there have been no lost time injuries or accidents on this project.
**Asst Project Manager**

Douglas Boyer

Assisted Project Manager in execution of his duties; Conducted compliance review of various project deliverables to ensure adherence to competition rules.

**Assistants**

Alex Gagliardi
Colleen Hyde
Nathan Barry

**Theme Manager**

Nathan Barry

Managed layout and aesthetics of the final product display; Oversaw graphic design of presentation and paper.

**Theme Assistants**

Santiago Uribe
Colleen Hyde
Maria Raggousis
Steve Kreeley

**Mix Manager**

Alex Gagliardi

Developed concrete mix design; Performed laboratory testing; Conducted concrete research and development.

**Mix Assistants**

Freddy Watcher
Steve Kreeley
Dylan Eckels
Lissa Daugherty
Kathie Cheng
Leonard Lui

**Construction Manager**

Douglas Boyer

Oversaw layout and construction efforts from prep work to final touches; Maintained laboratory and shotcrete equipment.

**Construction Assistants**

Colleen Hyde
Freddy Watcher
Nathan Barry
Alex Gagliardi

**Health and Safety Officer**

Mike Setaro

Obtained MSDS for materials used; Ensured proper material handling and storage; Oversaw team’s use of PPE.

**QH/QC Officer**

Santiago Uribe

Internal reviews of data, calculations and project deliverables; Compliance checks with Rules and Regulations.

**Paddling Coordinator**

Ashley Rodriguez

Scheduled weekly paddling practices; Coordinated sessions with team’s paddling coach.

**Paddlers**

Nathan Barry
Santiago Uribe
Freddy Watcher
Kathie Cheng
Yosep Bak

**Advisors & Consultants**

ASCE Faculty Advisor
Joseph Martin, PhD, PE
Structural Analysis
Franklin Moon, PhD, PE
Ivan Bartoli, PhD
Mix Design
Marc Schroader, PE
Paddling Coach
Dave Cliffel
Technical Consultant
Edwin Williams

**Engineering Manager**

Christopher Magruder

Analyzed structural design; Reviewed glass fiber reinforced concrete design; Performed structural analysis.

**Engineering Assistants**

Alex Gagliardi
Colleen Hyde
Santiago Uribe
Nathan Barry

**Project Manager**

Christopher Magruder

Managed day-to-day operations; Ensured on time completion of project within budget; Supervised testing efforts to ensure compliance with industry standards.

**Project Assistants**

Santiago Uribe
Colleen Hyde
Maria Raggousis
Steve Kreeley

**Paddling Coach**

Dave Cliffel

Technical Consultant
Edwin Williams
Hull Design and Structural Analysis

Relying on a knowledge of hull design developed over the years through literature review, consultation with naval architects and performance assessment of our canoes and those of our competitors, our designers based last year’s Urban Legend on a Wenonah® Minnesota 3™ canoe (Wenonah 2013). Modifications were made to a laser-scanned copy of a Minnesota 3 to increase acceleration, straight-line speed, tracking and maneuverability (Drexel 2013). General HydroStatics™ software (Creative Systems Inc. 2013) was used to quantify the design and predict performance through naval parameters, including but not limited to, wetted surface area, prismatic coefficient (Cp), length-to-beam (L/B) and displacement/length (D/L) ratios. Drage uses the 2013 Urban Legend design with the only modification this year being a 2 in. reduction in depth to remove excessive freeboard and promote more efficient paddling.

Drage, at 19 ft., 9 3/4 in., is shorter that the Minnesota 3’s 20 ft. length. The maximum beam width was reduced by 17% to 29 1/2 in., decreasing the wetted area and frictional drag. The resulting L/B ratio, a parameter inversely proportional to wave resistance, of 8.0 is within the practical range to maximize speed for the race configurations (Keyser 2006) and comparable to other national-caliber hulls (Cal Poly SLO 2011, UNR 2013, Florida 2013). Along with narrow beams, excellent D/L ratios are required to achieve high speeds (Winters 2001a). For marathon racers, the classification of racing canoes that many concrete canoes resemble, ratios are between 25 and 30 (Figure 4). Although Drage’s shape and geometry are consistent with these streamlined canoes, its D/L ratios are skewed due to its 342 lbs. self-weight as compared to 30–50 lbs. ultra-light graphite or Kevlar® canoes. Accounting for this weight difference, Drage is still expected to exhibit a good balance of racing characteristics. While most sophisticated hulls are both long and asymmetrical (Jensen 1993), Drage is longitudinally symmetrical with a sharp bow and low entry angle (12°). These changes result in a high capacity design that allows paddlers to accelerate to, and maintain, top speed with less effort and tracks straighter reducing the need for course corrections.

To produce a fast hull, the team considered theoretical hull speed and prismatic coefficient, Cp. For displacement vessels, maximum speed (V) occurs when wave length equals the vessel’s waterline length (L), and is expressed as:

\[
V = \frac{(32.2 \text{ ft/sec}^2 \times \text{Waterline Length, ft})^{0.5}}{2 \pi} \tag{2}
\]

For a 20 ft. long canoe, the hull speed is 10.3 ft/sec and occurs at the speed/length (S/L) ratio of 1.34. As shown in Figure 5, Cp is a measurement of the relative shape of the bow and stern, and directly correlates to hull speed and wave-making resistance (Winters 2001b). Typical values range from 0.40 to 0.78 for racing boats. For the S/L of 1.34, the optimum value of Cp is considered to be 0.63 (Sailboat-Cruising.com 2013). The coefficient for Drage varies between 0.56 (women’s tandem) and 0.59 (four person) and are indicative of a competitive hull for the racing scenarios.

Drage’s shallow arch combines the maneuverability and stability of a flat-bottom section with the speed and tracking of a circular one (Jensen 1993). This shape allows the canoe to sit higher in the water resulting in low submerged volume and wetted surface area (~32 sf) which reduces water resistance in turns and skin friction (Gillmer and Johnson 1982).

Last year, the Minnesota 3’s tumblehome was transformed into straight sidewalls, while its 20 1/2 in. bow and 17 in. stern heights were lowered to a uniform 14.5 in. gunwale. This year, the depth is reduced to 12.5 in. so that 6 in. of freeboard remains under the assumed four-person load. A moderate 1 1/2 in. rocker provides the maneuverability essential for negotiating the slalom/turning buoys and 180° hairpin turns. Together, the rocker and beam increase stability by lifting the ends out the water, leaving more of the wider, more stable sections in the water. Lastly, a total of 3.6 cf of concrete-encased EPS foam with a buoyant force/unit volume of ~60 pcf is placed in the bow and stern sections to overcome the 57 lbs. of negative buoyancy when completely submerged.
Drage’s structural reliability is based on a probabilistic approach where the demands of known, controlled loading conditions are compared to its structural capacity. The resulting safety (or reliability) index, $\beta$, is defined as the number of standard deviations ($\sigma$) that the average safety margin ($m$) is from failure (Figure 6) and is expressed as

$$\beta = m / \sigma \quad (4)$$

Internal stresses were determined using pure bending principles in a statically-determinant design. For conservatism, the hull is modeled as a simple beam with non-transformed U-channel sections, $\frac{5}{8}$ in. thick, with cross-sectional areas, moments of inertia and neutral axes determined at 1 ft. intervals. The weight of the canoe is uniformly distributed while 200 lbs. male (m) and 160 lbs. female (f) paddlers are modeled as point loads positioned to maximize bending moments. Resulting buoyant forces are distributed as a function of volumetric water displacement along the hull and hydrostatic pressures on the sidewalls are based on the drafts estimated by General HydroStatics. The original analysis was for a 250 lbs. hull (Drexel 2014) and updated to reflect Drage’s actual 342 lbs. weight.

From a longitudinally standpoint, maximum bending moments on the water occur in the 4-person scenario (Figure 7). When the two bow and two stern paddlers are situated closer together [at 3.5 ft. (m), 5.5 ft. (f), 14.5 ft. (f) and 16.5 ft. (m) from the bow], a negative 220 ft-lb moment is induced. As female paddlers are repositioned to 8 ft. and 12 ft., making the loading more evenly distributed, a positive 252 ft-lb moment is generated. The largest bending moment (855 ft-lb) occurs on land while in the simply-supported condition (on display), resulting in a compressive stress of 189 psi in the gunwale and a 61 psi tensile stress in the bilge. Inverting the canoe results in the tensile stress of 189 psi now in the gunwale (Table 5).

The extreme static condition of the canoe displaced to the point that the waterline matches the top of gunwale was used to evaluate stresses in the chines. In this case, the sidewall and chine are modeled as a cantilevered beam with hydrostatic pressure acting as a linearly distributed load. The resulting -10.4 ft-lb moment induces stresses of 160 psi in the chines. A shear stress of 33 psi occurs at the transition of sidewall to the chine in this maximum displacement scenario but is lower than the shear stresses found in other load scenarios (Table 5). Comparatively, a compressive strength of 117 psi is needed for a $\frac{5}{8}$ in. thick plate to resist the puncture shear stress (ACI 318) caused by a male paddler shifting his weight onto the effective area of one knee which is taken as $4 \frac{5}{8}$ in. x $4 \frac{5}{8}$ in. square.

Dynamic load amplification (DLA) factors are routinely applied to account for paddler momentum during races with the most commonly accepted value of 1.25 (Paradis and Morency 2006). Noting that higher factors (up to 2.2) were recommended in the same canoe used in that study (Paradis and Gendron 2006), our team applied a DLA of 2.5 to further account for variability of natural frequencies resulting from different hull thickness, shape and geometry.

Stresses during transit are minimal since the canoe is continuously supported in a container. However, damage sustained by previous canoes in transit has led to the elimination of our practice of strapping them down and constraining it which result in stress concentrations along the sidewalls. Lastly, designers evaluated the lifting of the canoe with a portable hoist to determine the appropriate number and location of straps to provide support in the demolding process.

The properties of the concrete and reinforced composite are compared to the structural demands to determine the safety index (Table 10, Page 6). The $\beta$ of 3.5 (1-in-10,000 chance of failure due to either excessive load or understrength) serves as the benchmark for comparison (MacGregor et al. 2004). As discussed in Development and Testing, the compressive, flexural and shear capacities far exceed the stresses found in this conservative design approach. Coupled with the structural integrity of similar designs, Drage is designed to withstand the rigors of competition.
Development and Testing

The development of a lightweight shotcrete mixture was accomplished through an iterative process of varying the amounts and proportions of cementitious materials (cm), aggregates, fibers and admixture dosages and evaluating strength, density and aesthetics. A total of 17 mixtures formulated per the Absolute Volume Method (ACI 211.1) were tested per industry standards (Table 6) and their “shootability” evaluated through small-scale tests. Our 2013 mixture (68 pcf; 1,700 psi) of Type I portland cement, Class F fly ash, metakaolin and silica fume with a blend of two microspheres, expanded shale and polymeric spheres (Drexel 2013) was used as the baseline. Refinements were made with the goals of maintaining moderate strength and low unit weight, evaluating new aggregate sources, addressing microsphere absorption issues and reducing “set up” time.

The minimum c/cm ratio of 0.30 (ASCE 2013) offers flexibility in using supplementary cementitious materials (SCM) such as industrial by-products to lower density, enhance engineering properties and increase sustainability. Such use in Drexel canoes can be traced back four decades when local incinerator residue was used in a project focusing on waste utilization (Berkovitz et al. 1973). In trial batches, the total cm content ranged from 750 to 1100 pcy to provide enough medium for spread, stability and viscosity. Type I portland cement (ASTM C150) was held between 40% to 50% (by mass), while Class F fly ash (ASTM C618), a by-product of coal-fired furnaces at power generation facilities, was incorporated between 25% and 40%. Mixtures also included metakaolin (ASTM C618), silica fume (ASTM C1240) or a combination of the two. Produced from heating kaolin clay, metakaolin increases concrete strength when used as a replacement for cement content up to 15% (Sabir et al. 2001). Silica fume, known for its improvements stemming from the addition of an extremely fine powder to the binder paste (Detwiler and Mehta 1989), was added between 5% and 10% to limit water demand and the potential for brittle concrete (Carette and Malhotra 1983).

Two new sustainable aggregate sources, Rotocell® and cork, were evaluated as potential substitutes in this year’s mixture. An expanded pumice, Rotocell® was considered for its rough texture and light weight, but was highly absorptive (100%+) and clogged the shotcrete gun. As a result, it was eliminated early on in the design process. Polymeric spheres (Elemix®) are extremely lightweight (SG = 0.04), however, they were difficult to work with in the shotcrete last year. A suitable alternative was found in cork which is well known for its resilient nature, elasticity, impermeability and environmental friendliness. The particular granules used are 1 to 2 mm in diameter, include a portion of recycled wine corks and were locally available (Maryland). Cork has properties similar to those of the polymeric spheres, such as very low specific gravity and no absorption (Table 7), and replaces the Elemix® spheres one for one.

Known for low specific gravities, high crush strengths, spherical shape and fineness, various microspheres are extensively used in concrete canoes. Our experience with Sicsorspheres™ conditioned to the manufacturer’s absorption values (Poraver 2011) resulted in dry mixtures with little to no workability, leading to the conclusion that it soaks up mix water. There are discrepancies in the values reported by others and our own testing indicated values 3 times that of the manufacturer (Table 8). These higher values may be attributed to the fact that our testing was done per the ASTM C128 standard of 20 ± 4 hours while Poraver tested samples submerged for only 5 minutes. Absorptions for another commonly used aggregate, cenospheres, vary as well. Our testing indicated an absorption of 38%, while the supplier (CenoStar 2014) reports it in terms of oil absorptivity (16 to 18 g oil/100 cc). These values appear to be indicative of their porous and absorptive nature as described by others (Shukla et al. 2001).

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Expanded shale, common in structural lightweight concrete, is also used. Another sustainable material (reduction in volume of raw material extracted through the bloating process), it is known for allowing the internal curing of concrete as water for hydration is readily released from its pores. The nearly spherical shape of the aggregates selected allow the constituents to flow over and around one another minimizing internal stresses and increasing workability. The composite aggregate accounts for nearly 44% of the shotcrete volume but only 14% of its weight. The fineness of the composite gradation (0.25 to 2 mm) results in a uniform, easy to sand finish exhibiting low surface voids (bugholes).

The dosages of admixtures were determined on a trial-and-error basis using the manufacturer’s recommended dosages as a guide (Table 9). Type S hydrated lime (ASTM C207) was added for its controlled plasticity, workability and ability to improve strength and durability by converting inert binders into calcium silicate hydrate. The final cement-to-lime ratio is below the typical range due to the SCMs making up a substantial amount of the paste. Fluidity is achieved using a high range water reducing (HRWR) admixture to produce a thick consistency at w/cm ratios of 0.5 or less. To achieve a desirable finish, a viscosity modifying admixture (VMA) provided a stable viscosity and improved material suspension. High initial air content promotes flow out of the gun and was attained using an air entraining admixture (AEA). Last year, a set retarder (Pozzolith® XR-100) was used to extend workability but resulted in several work stoppages to allow the shotcrete to firm up enough to apply the next layer. This year, an accelerating admixture was incorporated and resulted in a nearly 50% reduction in construction time even with a dosage well below the manufacturer’s recommendations.

Trial batches had plastic densities of 63 to 72 pcf when prepared per ASTM C138 with 28-day compressive strengths (f’c) of 1,500 to 1,700 psi. Drilled cores and sawed beams obtained from test panels (Figure 8) using the same mixtures yielded higher densities (67 to 79 pcf) and higher compressive strengths (~20 to 30%). This is most likely attributed to a higher compactive effort of shotcreting compared to rodding layers in test cylinders. Oven-dried cylinders of rodded and shotcreted mixtures exhibited a 10 to 20 pcf decrease in density, most likely resulting from the release of relatively large amount of water retained within the microspheres. Fresh unit weights and w/cm ratios matched well with predictions using aggregates conditioned to the higher SSD absorption values and without the need to spike admixture dosages. The selected mixture is a lightweight, moderate strength shotcrete [73.2 pcf (plastic), 57.8 pcf (oven-dried); f’c (28 day) = 2,200 psi]. Proportions presented in Appendix B are from specimens prepared per ASTM C138 which yielded a 68.9 pcf plastic density.

Based on the robustness of the last year’s composite, a similar design is used for Drage. Three layers of Dryvit® Standard Plus glass fiber mesh (4.3 oz/yd², 225 lb/in tensile strength, 69% open area) reinforce the 1/4 in. thick composite. Known for its impact and cracking resistance, light weight, this mesh has been successfully used in numerous canoes (e.g., Drexel 1999, 2013). Short, discontinuous fibers were also added to the concrete for increased ductility and crack resistance. Several synthetic fibers were considered with Nycon®G recycled nylon fibers (0.75 in. long) selected based on its ease of flow out of the gun, increase in tensile/flexural strength and reduction of shrinkage cracks. Fiber contents ranged from 0.2 to 1% (by volume) in trial batches with the final mixture containing 0.45%. Flexural strength tests on unreinforced and reinforced beams yielded average modulus of rupture (Mr) values of 320 psi and 790 psi, respectively.

Given the low structural demands compared to the relatively high capacities of the concrete and reinforced composite, the probabilities of failure (Pf) in compression, flexure (tension) and shear are much lower than 1-in-10,000 as shown by β values greater than 3.5 as illustrated in Table 10. These results are indicative of a strong, resilient design, and its performance at the Mid-Atlantic Conference demonstrates that Drage can easily handle the anticipated loading conditions.
CONSTRUCTION

Between 2006 and 2012, Drexel used a dual-mold system for the placement of a self-consolidating concrete (SCC), continually refining the system to improve alignment, reinforcement placement, thickness control and speed of construction. The displacement method used with the system captured the Tony A. Crest Innovation Award at the 2008 National Competition in Montreal, CN. As our Mid-Atlantic competitors continue to use proven hand-placement methods, questions fielded at the conference level several years ago about “new innovations in construction techniques” led to the assumption that judges were looking for Drexel to consider other methods even though few teams (Cal Poly Pomona 2012) have successfully used highly flowable concrete, such as SCC, in this competition.

Last year, our designers evaluated the risks and benefits of several concrete canoe construction techniques – hand-placement, “sheetcrete” (Cal Berkeley 2003), shotcrete (wet mix), gunite (dry mix) and our own SCC displacement method – considering the costs, schedule, materials and learning curves associated with each. Eventually, shotcreting was selected given its flexibility in design, ease in the placement of reinforcement and the fact that it is a proven construction method for concrete canoes (Florida 2008, Laval 2012). Based on the quality of last year’s final product, this method was again selected for building Drage.

Drexel chose to refurbish and reuse the 2012-13 mold for Drage. Upon selection of the Minnesota 3™ as the basis of the hull design in 2012, a 3-D model was generated by laser scanning it with a Leica ScanStation (Figure 9) and importing into an AutoCAD file so that the modifications highlighted in Hull Design could be made. A male mold was selected due to its compatibility with shotcrete application and reinforcement installation. A 3-section mold was fabricated from 1.5 pcf expanded polystyrene (EPS) foam with a five-axis computer numerically controlled (CNC) milled by the Global Foam Company (Figure 11). Refurbishing of the mold required it to be reassembled then having surface voids and areas of minor damage repaired using a low VOC water-based compound which were sanded smooth with 400-grit sandpaper. Some rotted wood was also replaced. Once sanded, the mold was resealed with three coats of low VOC epoxy hard-coating to achieve the desired hardness (Figure 10). An alignment system (Figure 12) consists of two 1 in. wide by 3/8 in. deep dadoes routed into a 1 in. thick plywood inlay integrated into the foam mold. Two square aluminum railings attached to a strongback run along the dadoes and support the mold.

A large wood frame and plastic room was constructed in the workspace to contain particulate matter and concrete fallout and later to serve as the curing room. Large fans and centrifugal ventilators were utilized to direct airborne particles out of the workspaces in an efficient manner. In addition, all members were required to wear the proper PPE including P100 respirators, gloves, safety glasses and face shields. Nozzlemen and gun operators also wore Tyvek suits during shotcreting operations.

Prior to casting, a generous coating of release agent was applied to facilitate mold removal; aggregates were pre-conditioned to their saturated surface-dry (SSD) state and reinforcing mesh was cut to size. On casting day, the shotcrete was initially prepared by mixing the cementitious materials, aggregates, water and admixtures in large bucket mixers. The nylon fibers where then incorporated using small paddler mixers to minimize clumping.
After testing (Figure 13) indicated that density and spread specifications were met, the first layer of shotcrete was sprayed onto the mold until approximately 3/16 in. of cover was achieved. This layer was followed by a continuous layer of Dryvit® mesh (Figure 15) which was cut and overlapped as needed to remove wrinkles and conform to the hull contours. A second layer of shotcrete, ¼ in. thick, was applied (Figure 14) followed by another layer of reinforcement. A 1/8 in. layer of shotcrete was applied followed by a custom cut layer of mesh placed on the underside of the canoe. The final shotcrete layer, 3/16 in. thick, was placed and hand-troweled to achieve a smooth finish. The construction layup of alternating layers of concrete and reinforcing mesh is depicted in Figure 17.

The overall thickness was approximately 3/4 in. to allow for surface irregularities to be sanded down to the desired final thickness of 5/8 in. Toothpicks with line indicators were used as depth gauges to obtain a consistent thickness. The casting was completed in 4 hours aided by the use of the accelerating admixture that provided a more consistent flow out of the gun creating a more uniform thickness. Last year’s casting took nearly 8 hours.

After casting, plastic sheeting was applied to internally cure the concrete. Within 48 hours, a timer-controlled misting system was set up. Sanding began on the exterior after one week while it was still supported by the mold. The concrete was wet sanded to eliminate wetting/drying cycles while curing, reduce dust and provide a smooth finish. After 14 days, the mold was removed from the canoe by using a portable hoist to lift and flip the canoe to allow the mold sections to be removed, and then placed under the misting system to continue curing and wet sanding. Once the exterior was completed, the canoe was flipped over and work began on the interior. Drage was sanded using progressively finer sandpaper to obtain a smooth surface finish for the application of KEIM silicate material stains and Epo–Shield Gloss sealer. After the removal of concrete extending above the design shear line and installation of concrete-encased EPS foam flotation tanks (Figure 16), final sanding was performed using diamond grit sanding pads reclaimed from a granite fabrication shop.

Throughout the entire project, the team has been committed to safety, sustainability and innovation (Table 11). Through research, testing and sound engineering judgment, coupled with the use of a proven construction method, Drage has exceeded our expectations. After a 5 year absence at the national level, Drexel now screams toward the “double barrel loop” (National Competition) in Johnstown, PA, as a formidable competitor on and off the water.

<table>
<thead>
<tr>
<th>Safety</th>
<th>Sustainability</th>
<th>Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreman with 30 hr OSHA Safety Training</td>
<td>Reuse of 2013 mold</td>
<td>Simplistic design for minimal labor force and low waste generation</td>
</tr>
<tr>
<td>OSHA Respirator Fit Testing</td>
<td>Low VOC coatings</td>
<td>Accelerator led to a 50% reduction in casting time</td>
</tr>
<tr>
<td>Overhead hoist reducing manpower requirements</td>
<td>Vegetable oil-based release agent</td>
<td>Hopper gun improvements</td>
</tr>
<tr>
<td>On the Job Training</td>
<td>Low water usage</td>
<td>Vibrant Stains</td>
</tr>
<tr>
<td>Zero Lost Time Due to Injury</td>
<td>Only FSC certified lumber</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12% fallout reduction</td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 13: QUALITY CONTROL TESTING**
Fresh concrete was sampled for unit weight, slump flow and visual stability (above), and cylinders and beams were cast for confirmatory strength testing.

**FIGURE 14: “SHOOTING” THE DRAGE**
A hopper-style, high-volume, low-pressure (HVLP) spraying system, constructed of commercially available parts, was used to apply the shotcrete.

**FIGURE 15: DRYVIT® REINFORCEMENT**
Pliable and easy to cut, the mesh has adequate opening size to allow the concrete to strikethrough and bond resulting in a durable concrete composite.

**FIGURE 16: FINISHING TOUCHES**
Surfaces were wet sanded smooth, foam flotation tanks encased in concrete installed (above), and the shear line cut to final design height.

**FIGURE 17: CONSTRUCTION LAYUP SCHEME**

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Start 2013-2014 Project</td>
<td>0 days</td>
<td>Mon 7/1/13</td>
<td>Mon 7/1/13</td>
</tr>
<tr>
<td>2</td>
<td>Summer Materials Research &amp; Procurement</td>
<td>48 days</td>
<td>Mon 7/15/13</td>
<td>Wed 9/18/13</td>
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<tr>
<td>3</td>
<td>Shotcrete Research and Development</td>
<td>60 days</td>
<td>Wed 9/8/13</td>
<td>Tue 12/10/13</td>
</tr>
<tr>
<td>4</td>
<td>Rules Released</td>
<td>0 days</td>
<td>Fri 9/13/13</td>
<td>Fri 9/13/13</td>
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<tr>
<td>5</td>
<td>Hull Design Selection</td>
<td>5 days</td>
<td>Fri 9/13/13</td>
<td>Thu 9/19/13</td>
</tr>
<tr>
<td>6</td>
<td>Fall Concrete Mixes</td>
<td>80 days</td>
<td>Sat 9/21/13</td>
<td>Fri 1/10/14</td>
</tr>
<tr>
<td>7</td>
<td>Structural Analysis</td>
<td>43 days</td>
<td>Mon 11/11/13</td>
<td>Fri 1/10/14</td>
</tr>
<tr>
<td>8</td>
<td>Test Shotcrete Corings</td>
<td>28 days</td>
<td>Wed 11/20/13</td>
<td>Fri 12/7/13</td>
</tr>
<tr>
<td>9</td>
<td>Composite Mix Design</td>
<td>10 days</td>
<td>Sat 12/28/13</td>
<td>Fri 1/10/14</td>
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<td>10</td>
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<td>34 days</td>
<td>Sat 12/14/13</td>
<td>Sat 2/1/14</td>
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<td>11</td>
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<td>17 days</td>
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<td>Wed 1/29/14</td>
</tr>
<tr>
<td>12</td>
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<td>0 days</td>
<td>Sat 2/1/14</td>
<td>Sat 2/1/14</td>
</tr>
<tr>
<td>13</td>
<td>Reinforcement Construction</td>
<td>2 days</td>
<td>Sat 2/8/14</td>
<td>Tue 2/11/14</td>
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<td>14</td>
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<td>10 days</td>
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<td>Thu 2/13/14</td>
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<tr>
<td>15</td>
<td>Shotcrete Canoe</td>
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<td>Sun 2/16/14</td>
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<td>16</td>
<td>Canoe Curing</td>
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<td>Mon 2/17/14</td>
<td>Wed 3/26/14</td>
</tr>
<tr>
<td>17</td>
<td>Theme Selection</td>
<td>0 days</td>
<td>Sun 3/15/14</td>
<td>Sun 3/15/14</td>
</tr>
<tr>
<td>18</td>
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<td>Fri 3/17/14</td>
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<td>Tue 1/14/14</td>
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<td>Wed 1/15/14</td>
<td>Mon 2/10/14</td>
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<td>21</td>
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<td>Wed 2/11/14</td>
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<tr>
<td>22</td>
<td>Design Paper Submission</td>
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<td>Wed 3/29/14</td>
<td>Wed 3/19/14</td>
</tr>
<tr>
<td>23</td>
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<td>14 days</td>
<td>Sat 3/1/14</td>
<td>Thu 3/20/14</td>
</tr>
<tr>
<td>24</td>
<td>Canoe Hull Outfit and Finishing</td>
<td>12 days</td>
<td>Tue 3/18/14</td>
<td>Tue 4/8/14</td>
</tr>
<tr>
<td>25</td>
<td>Transportation to Regionals</td>
<td>2 days</td>
<td>Thu 4/10/14</td>
<td>Fri 4/11/14</td>
</tr>
<tr>
<td>26</td>
<td>Regional Conference</td>
<td>2 days</td>
<td>Sat 4/12/14</td>
<td>Sun 4/13/14</td>
</tr>
<tr>
<td>27</td>
<td>Nationals Fundraising</td>
<td>30 days</td>
<td>Mon 4/14/14</td>
<td>Fri 5/23/14</td>
</tr>
<tr>
<td>28</td>
<td>Design Paper Revisions</td>
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<td>Mon 4/14/14</td>
<td>Mon 5/12/14</td>
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<tr>
<td>29</td>
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<td>Wed 5/14/14</td>
<td>Wed 5/14/14</td>
</tr>
<tr>
<td>30</td>
<td>Cross-section Modifications</td>
<td>28 days</td>
<td>Wed 4/10/14</td>
<td>Fri 6/6/14</td>
</tr>
<tr>
<td>31</td>
<td>Display Table Alterations</td>
<td>30 days</td>
<td>Wed 4/10/14</td>
<td>Tue 6/10/14</td>
</tr>
<tr>
<td>32</td>
<td>Transportation to Nationals</td>
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<td>Wed 6/18/14</td>
<td>Thu 6/19/14</td>
</tr>
<tr>
<td>33</td>
<td>ASCE National Competition</td>
<td>3 days</td>
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<td>Sat 6/21/14</td>
</tr>
</tbody>
</table>

**Drexel University: Drage**

**Date:** 5/13/2014
APPENDIX A - REFERENCES

American Concrete Institute (ACI) Committee 211 (2009). “Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91) (Reapproved 2009), American Concrete Institute, Farmington Hills, MI.

ACI Committee 318 (2011). “Building Code Requirements for Structural Concrete and Commentary,” (ACI 318-11), American Concrete Institute, Farmington Hills, MI.


## Appendix B - Mixture Proportions

### Mixture ID: Shotcrete

<table>
<thead>
<tr>
<th>Y₀</th>
<th>Design Batch Size (ft³):</th>
<th>1.00</th>
</tr>
</thead>
</table>

#### Cementitious Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Design Proportions (Non SSD)</th>
<th>Actual Batched Proportions</th>
<th>Yielded Proportions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM1</td>
<td>Portland Cement, Type I (ASTM C150)</td>
<td>3.15</td>
<td>17.78</td>
</tr>
<tr>
<td>CM2</td>
<td>Silica Fume (ASTM C1240)</td>
<td>2.20</td>
<td>1.76</td>
</tr>
<tr>
<td>CM3</td>
<td>Metakaolin (ASTM C618)</td>
<td>2.50</td>
<td>5.30</td>
</tr>
<tr>
<td>CM4</td>
<td>Fly Ash, Class F (ASTM C618)</td>
<td>2.38</td>
<td>10.44</td>
</tr>
</tbody>
</table>

**Total Cementitious Materials:** 952.50 | 5.604 | 35.28 | 0.21 | 976.52 | 5.74

#### Fibers

<table>
<thead>
<tr>
<th>Material</th>
<th>Design Proportions (Non SSD)</th>
<th>Actual Batched Proportions</th>
<th>Yielded Proportions</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Nycon G® Recycled Nylon Fibers (0.75 in.)</td>
<td>1.10</td>
<td>0.31</td>
</tr>
</tbody>
</table>

**Total Fibers:** 8.34 | 0.122 | 0.31 | 0.005 | 8.55 | 0.125

#### Aggregates

<table>
<thead>
<tr>
<th>Material</th>
<th>Design Proportions (Non SSD)</th>
<th>Actual Batched Proportions</th>
<th>Yielded Proportions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Cenospheres (0.3 – 0.6 mm)</td>
<td>0.25</td>
<td>3.24</td>
</tr>
<tr>
<td>A2</td>
<td>Sicsorospheres (1 - 2 mm)</td>
<td>0.40</td>
<td>1.44</td>
</tr>
<tr>
<td>A3</td>
<td>Sicsorospheres (0.5 - 1 mm)</td>
<td>0.47</td>
<td>0.79</td>
</tr>
<tr>
<td>A4</td>
<td>Sicsorospheres (0.25 - 0.5 mm)</td>
<td>0.59</td>
<td>0.25</td>
</tr>
<tr>
<td>A5</td>
<td>Utelite® Expanded Shale</td>
<td>1.82</td>
<td>0.10</td>
</tr>
<tr>
<td>A6</td>
<td>Cork</td>
<td>0.06</td>
<td>0.19</td>
</tr>
</tbody>
</table>

**Total Aggregates:** 250.50 | 11.504 | 9.26 | 0.426 | 256.30 | 11.795

#### Water

<table>
<thead>
<tr>
<th>Material</th>
<th>Design Proportions (Non SSD)</th>
<th>Actual Batched Proportions</th>
<th>Yielded Proportions</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>Water for cm Hydration (= W1a + W 1b)</td>
<td>1.00</td>
<td>15.88</td>
</tr>
<tr>
<td>W1a. Water from Admixtures</td>
<td>11.85</td>
<td>0.44</td>
<td>12.15</td>
</tr>
<tr>
<td>W1b. Additional Water</td>
<td>416.78</td>
<td>15.44</td>
<td>427.29</td>
</tr>
<tr>
<td>W2</td>
<td>Water for Aggregates (SSD)</td>
<td>1.00</td>
<td>4.73</td>
</tr>
</tbody>
</table>

**Total Water:** 556.20 | 6.869 | 20.60 | 0.254 | 570.23 | 7.042

#### Solids Content of Latex, Dyes and Admixtures in Powder Form

<table>
<thead>
<tr>
<th>Material</th>
<th>Design Proportions (Non SSD)</th>
<th>Actual Batched Proportions</th>
<th>Yielded Proportions</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Type S Hydrated Lime (ASTM C207)</td>
<td>2.20</td>
<td>0.01</td>
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</table>

**Total Solids of Admixtures:** 47.50 | 0.35 | 0.16 | 0.01 | 48.70 | 0.35

#### Admixtures (in liquid form)

<table>
<thead>
<tr>
<th>Material</th>
<th>Design Proportions (Non SSD)</th>
<th>Actual Batched Proportions</th>
<th>Yielded Proportions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ad1</td>
<td>Sika Siguniti® L72 AF</td>
<td>11.80</td>
<td>8.00</td>
</tr>
<tr>
<td>Ad2</td>
<td>Sika Viscocrete® 2100 - HRWR</td>
<td>9.00</td>
<td>3.80</td>
</tr>
<tr>
<td>Ad3</td>
<td>Sika Stabilizer VMA</td>
<td>8.40</td>
<td>7.00</td>
</tr>
<tr>
<td>Ad4</td>
<td>Sika Air 260</td>
<td>8.43</td>
<td>5.00</td>
</tr>
</tbody>
</table>

**Water from Admixtures (1a):**

<table>
<thead>
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<th>Design Proportions (Non SSD)</th>
<th>Actual Batched Proportions</th>
<th>Yielded Proportions</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.85</td>
<td>0.44</td>
<td>12.15</td>
</tr>
</tbody>
</table>

#### Notes:

1. Proportions listed are based on cylinders prepared per ASTM C138.
2. Density of cores (ASTM C1604) from shotcrete test panels prepared per ASTM C1140 were found to be 73.2 pcf.
# APPENDIX C - BILL OF MATERIALS

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Units</th>
<th>Unit Price</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cementitious Materials</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type I Portland Cement (ASTM C150)</td>
<td>112.0</td>
<td>lbs.</td>
<td>$1.05</td>
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<tr>
<td>Silica Fume (ASTM C1240)</td>
<td>11.1</td>
<td>lbs.</td>
<td>$2.00</td>
<td>$22.17</td>
</tr>
<tr>
<td>Metakaolin (ASTM C618)</td>
<td>33.4</td>
<td>lbs.</td>
<td>$0.81</td>
<td>$27.04</td>
</tr>
<tr>
<td>Class F Fly Ash (ASTM C618)</td>
<td>65.8</td>
<td>lbs.</td>
<td>$0.43</td>
<td>$28.29</td>
</tr>
<tr>
<td><strong>Aggregate Sources</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CenoStar® Cenospheres (0.3 – 0.6 mm)</td>
<td>43.2</td>
<td>lbs.</td>
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<td>$172.71</td>
</tr>
<tr>
<td>Poraver® Sicsorspheres™ (1.0 – 2.0 mm)</td>
<td>19.1</td>
<td>lbs.</td>
<td>$0.70</td>
<td>$13.38</td>
</tr>
<tr>
<td>Poraver® Sicsorspheres™ (0.5 – 1.0 mm)</td>
<td>30.8</td>
<td>lbs.</td>
<td>$0.70</td>
<td>$21.58</td>
</tr>
<tr>
<td>Poraver® Sicsorspheres™ (0.25 – 0.5 mm)</td>
<td>12.3</td>
<td>lbs.</td>
<td>$0.70</td>
<td>$8.63</td>
</tr>
<tr>
<td>Utelite™ Expanded Shale #10 Mesh</td>
<td>15.4</td>
<td>lbs.</td>
<td>$0.89</td>
<td>$13.72</td>
</tr>
<tr>
<td>Cork Granules</td>
<td>2.5</td>
<td>lbs.</td>
<td>$3.09</td>
<td>$7.62</td>
</tr>
<tr>
<td><strong>Admixtures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sika® Sigunit L72 AF (Accelerator)</td>
<td>18.7</td>
<td>fl. oz.</td>
<td>$0.10</td>
<td>$1.87</td>
</tr>
<tr>
<td>Sika® Viscocrete 2100 (HRWR)</td>
<td>12.3</td>
<td>fl. oz.</td>
<td>$0.12</td>
<td>$1.47</td>
</tr>
<tr>
<td>Sika® Stabilizer (VMA)</td>
<td>16.3</td>
<td>fl. oz.</td>
<td>$0.10</td>
<td>$1.63</td>
</tr>
<tr>
<td>Sika® Air 260 (AE)</td>
<td>9.3</td>
<td>fl. oz.</td>
<td>$0.05</td>
<td>$0.47</td>
</tr>
<tr>
<td>Super Limoid Type S Lime (ASTM C207)</td>
<td>11.1</td>
<td>lbs.</td>
<td>$0.40</td>
<td>$4.43</td>
</tr>
<tr>
<td><strong>Reinforcing Materials</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Dryvit® Glass Fiber Reinforcing Mesh</td>
<td>240</td>
<td>Sq. ft.</td>
<td>$0.25</td>
<td>$60.00</td>
</tr>
<tr>
<td>Nycon®G Recycled Fibers</td>
<td>2.6</td>
<td>lbs.</td>
<td>$0.65</td>
<td>$1.71</td>
</tr>
<tr>
<td><strong>Flotation Materials</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>16”x18”x 0.5” Foam Sheets</td>
<td>50</td>
<td>ea.</td>
<td>$0.76</td>
<td>$38.00</td>
</tr>
<tr>
<td><strong>Male Mold System and Related Items</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>EPS Mold Assembly</td>
<td>1</td>
<td>LS</td>
<td>$1,239.00</td>
<td>$1,239.00</td>
</tr>
<tr>
<td>Mold Alignment Assembly</td>
<td>1</td>
<td>LS</td>
<td>$387.00</td>
<td>$387.00</td>
</tr>
<tr>
<td>Crete-Lease 880 VOC Release Agent</td>
<td>1</td>
<td>Gal</td>
<td>$40.15</td>
<td>$40.15</td>
</tr>
<tr>
<td><strong>Concrete Stain and Sealer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KEIM Silicate Mineral Stain</td>
<td>5</td>
<td>Liter</td>
<td>$48.00</td>
<td>$240.00</td>
</tr>
<tr>
<td>Epo-Shield Concrete Sealer</td>
<td>2</td>
<td>Gal</td>
<td>$41.73</td>
<td>$83.46</td>
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<tr>
<td><strong>TOTAL COST</strong></td>
<td></td>
<td></td>
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<td>$2,532.03</td>
</tr>
</tbody>
</table>

Notes: 1. Cost of EPS Mold Assembly (from 2013) is carried over to reflect actual total production cost.
2. Unit prices based on values provided by suppliers or based on cost of purchased product.