

Argentum



University of Nevada, Reno
2008 Concrete Canoe Design Report

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Executive Summary

The University of Nevada, Reno is located 25 miles northwest of the one of the most famous mining boomtowns of the “Old West”—Virginia City. It was here in 1859 that the first and largest U.S. deposit of silver, the Comstock Lode, was discovered. That discovery fueled economic growth in the Nevada Territory, ultimately leading to statehood in 1864.

Less than thirty years later, in 1887, the Nevada Legislature created a land-grant university in Reno to serve the state by providing education in mining, agriculture, and the liberal arts. Since then, the University of Nevada, Reno has expanded to include 14 colleges of diverse disciplines and over 16,000 students. Today, the Department of Civil and Environmental Engineering operates one of the premier earthquake simulation facilities in the nation; the 320 students in the department are proud to be associated with some of the finest members of the engineering community.

The University of Nevada, Reno competes alongside ten Northern California universities in the Mid-Pacific Conference (Mid-Pac), historically one of the most competitive conferences in the nation. Starting in 2005, the concrete canoe team made three consecutive appearances at Mid-Pac, creating a new tradition. Despite the lack of experience, the team won second place with **euphoria** at Mid-Pac in 2006, qualifying for the National Concrete Canoe Competition (NCCC) where they placed sixth overall. Then, in 2007, the team placed first at the conference level and third at the NCCC with **Cerulean**.

In 2008, the team sought to continue their success by recruiting new members and passing on knowledge acquired over the past three years. The project management system was modified to allow younger and less experienced students to step into leadership positions. The team refined last year’s innovative construction techniques and constructed a prestressed, monolithically cast canoe, the specifications of which are listed in Table 1. A detailed analysis was performed to design a prestressing system that eliminated longitudinal tensile stresses in the canoe. Building upon **Cerulean**’s remarkable performance in the races, the hull design was altered to improve turning and top speed while maintaining acceleration. Advances in mix design included testing for optimal constituent blending and developing methods for better fiber dispersion and air entrainment. The engineering properties of the

Table 1: Canoe Details.

| <i>Argentum</i> Details | | | |
|-------------------------------------|---|------------|---------------------|
| Weight: | 175 lbs | Depth: | 12.25" |
| Length: | 19.98' | Thickness: | 1/2" |
| Width: | 28.38" | Color: | White Concrete/Blue |
| Reinforcement and Composite Details | | | |
| Main Reinforcement | 1" Carbon Fiber Scrim 1/4" dia. Steel All-Thread (ribs) 1/2" Steel Mesh (bow/stern) | | |
| Prestress | 1/16" dia. Steel Cable | | |
| Composite Flexural Strength | 1220 psi | | |

concrete are listed in Table 2. To reflect the state colors

Table 2: Concrete Properties.

| Properties | Structural Mix | Patch Mix |
|----------------------|----------------|-----------|
| Unit Weight | 57.10 pcf | 56.26 pcf |
| Compressive Strength | 1640 psi | 2010 psi |
| Modulus of Rupture | 420 psi | 560 psi |

of Nevada and its mining heritage, the canoe was named the Latin word for silver. The canoe was made from white concrete complimented by blue and gray acid stain. It is with great satisfaction that the University of Nevada presents... *Argentum*.

Hull Design

Argentum was designed to maximize maneuverability, top speed, and acceleration. Significant improvements from **Cerulean** include wider bow sections, a narrower waterline (WL) beam, and changes in rocker. Features similar to **Cerulean** are styling, highly asymmetrical rocker, hard chines, flat bottom, and a sharp entrance angle.

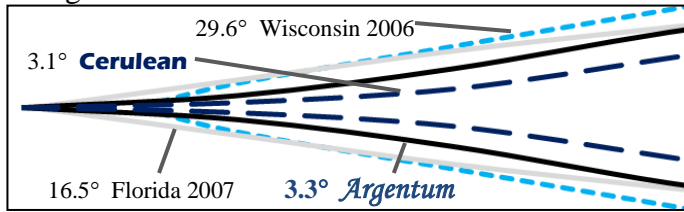


Figure 1: Men's Sprint Bow Waterlines & Entrance Angles.

Maintaining **Cerulean's** best-in-nation acceleration was a priority. Hull designs of past national concrete canoes were entered in a spreadsheet named *Aquaholic*, which the team developed to calculate key canoe performance indicators. One significant difference in *Argentum* versus other canoes is a sharp bow entrance angle created by concave waterlines (Figure 1). The team theorizes that sharp entrance angles improve acceleration from low speeds or a stop. Wider bow sections allow *Argentum* to displace more water per unit of surface area. As a result, it has the same wetted surface area as **Cerulean** despite a narrower WL beam (Table 4). Together, wetted surface area and surface roughness create the greatest component of drag during acceleration; consequently, the low wetted surface area has a large impact on acceleration, as well as top speed. The predictive methods for acceleration proved accurate based on *Argentum's* observed acceleration during the 2008 Mid-Pac races.

The biggest weakness in the design of **Cerulean** was maneuverability.

Over the past three years Nevada (2006, 2007) developed a method to predict turning; this research culminated in 2008 in direct prediction of the time required to make a 180° turn in a sprint race. It is estimated by the equation: $t = [\sum A \cdot d \cdot (1 + 2 \sin \theta)]^{1/2}$, where t is estimated time in seconds, A is lateral area of a unit length of the canoe in square feet, d is its distance to the center of turning in feet, and θ is the keel angle in degrees, summed over the length of the canoe. Table 3 shows predicted turning times for *Argentum* compared to other canoes, as calculated in *Aquaholic*. The predicted turning times agree

Table 3: Theoretical Coed Sprint Turning Times from *Aquaholic*.

| Canoe | 180° Turn Time |
|------------------------|----------------|
| Mich. Tech 2005 | 9.0 s |
| Nevada 2007 | 8.8 s |
| <i>Argentum</i> | 8.3 s |
| Clemson 2004 | 8.2 s |
| Wisconsin 2006 | 7.3 s |
| Florida 2007 | 7.0 s |

Table 4: Hull Specifications.

Values averaged for all load cases

| Property | Cerulean | <i>Argentum</i> |
|----------------|----------------------|----------------------|
| Length | 19.98' | 19.98' |
| Width | 28.12" | 28.12" |
| Depth | 12.25" | 12.12" |
| WL Length | 19.56' | 19.97' |
| WL Beam | 25.21" | 24.91" |
| Freeboard | 6.13" | 6.32" |
| Length/Beam | 9.32 | 9.62 |
| C _p | 0.53 | 0.56 |
| Wetted Area | 35.6 ft ² | 35.9 ft ² |
| Total Area | 58.5 ft ² | 58.9 ft ² |

within ten percent and follow the trend of measurements made during the 2007 NCCC races. The greatest aids to turning are shallow draft, rocker, and a flat keel. *Argentum* uses **Cerulean's** control philosophy, allowing both tracking and turning by use of heavy bow rocker and minimal stern rocker. At race speeds, the canoe enters a state of semi-planing and the sharp stern keel submerges to act as a rudder. When the canoe slows for turns, the stern rises for easier turning. Hard chines create additional maneuverability, allowing the canoe to be turned by leaning.

The top speed of a canoe is primarily limited by wave drag, which is the dominant form of drag at race speeds. Wave drag can be reduced either by additional length, or by changes in shape that increase the efficiency of movement. The prismatic coefficient (C_p) and length-to-beam ratio are simple and effective indicators of the efficiency of a shape at various speeds. *Argentum* has a widened bow, changes in rocker, and a narrower waterline beam, which created a C_p value better than **Cerulean's** for top straight-line speed, yet lower than Winter's (2006) recommended values. The target C_p value for *Argentum* was estimated from experience to provide a better balance between speed and turning than Winter's values. An altered sheer profile and extra freeboard further improve top speed by preventing weight added by water entering the canoe. Through improvements to speed, turning, and acceleration, *Argentum* is expected to be the fastest concrete canoe Nevada has ever paddled.

Analysis

The structural analysis of *Argentum* advanced the analysis techniques developed for *Cerulean*, with an emphasis on composite design to ensure load sharing between the concrete and internal reinforcement (Biszick, 1999). SAP2000 v.11[®] (Computers and Structures, 2007) was selected as the primary tool for analysis of *Argentum* for its ability to model multi-layer shell elements. By discretely modeling internal reinforcement, a more accurate prediction of concrete stresses was achieved, leading to a structurally efficient and intrinsically stronger canoe. The team developed a spreadsheet to design a more efficient prestressing system using basic principles of prestressed concrete design.

The analysis of *Argentum* considered six load cases: simply supported (right-side up and up-side down), prestress-only, two-man sprint, three-man sprint, and coed sprint. The assumed material properties, confirmed by the mix design team, included concrete with a Poisson's ratio of 0.2, a density of 57.10 pcf, an elastic modulus of 835 ksi, and reinforcement with an elastic modulus of 29,000 ksi. Experience guided the analysis team in setting allowable stress limits of 60 percent of the modulus of rupture and 70 percent of the compressive strength of the concrete; an additional load factor of 1.25 was used to account for dynamic load effects (Paradis, 2005).

To design the prestressing for *Argentum*, the analysis expanded upon methods developed for Nevada's 2006 canoe, *euphoria*. An idealized "stick" model was developed in Microsoft Excel[®] to generate a design moment-envelope, composed of the maximum of the moments from five load cases (Figure 2). The analysis team used the moment-envelope and conventional methods of prestressed concrete design (Nawy, 2006) to determine values for eccentricity, center of gravity, and jacking forces of the prestress system. The AASHTO (2007) provisions for lump-sum prestress losses were used to calculate losses of 26 percent due to creep, shrinkage, elastic shortening, and steel relaxation. Using the calculated losses, individual tendon jacking forces were varied iteratively in the spreadsheet until tensile stresses due to longitudinal bending were eliminated for all considered load cases. This corresponded to 16 tendons with total jacking force of 3440 lbs (300 lbs at the gunwales, 200 lbs around the chines, and 160 lbs near the keel). The jacking forces and tendon profiles were entered into the Finite Element Analysis (FEA) model.

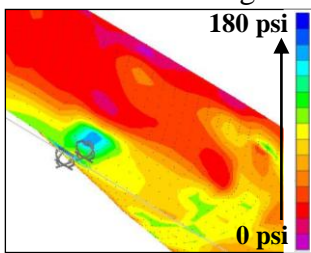


Figure 3: FEA Model.

A three-dimensional model of the canoe was imported from the hull design to perform the FEA (Figure 3). Buoyant forces from the hull design were modeled for each paddling load case as a surface pressure on the exterior of the canoe that varied linearly with depth. Paddler loads were modeled by restraining the vertical degree of freedom at each paddler "knee". Using this method, artificial self-equilibrating reactions due to water pressure and self-weight were automatically imposed at each restraint; the stern of the canoe was restrained from translation in the two lateral planes to create model stability. This innovative technique replaced previous methods used for model stability that generated inaccurate bending in the model. The FEA also considered the stiffening effects of four transverse ribs, each with a cross sectional area of 0.5 in², and enlarged gunwales with an area of 0.34 in². The locations and shapes of these were determined based on ergonomics and aesthetics by the paddling and construction teams upon approval by the analysis team. The FEA showed a maximum factored dynamic principle tensile stress of 228 psi, generated by the two-man sprint load case.

The results of the analysis revealed that the concrete required a minimum compressive strength of 400 psi, a modulus of rupture of 380 psi, an elastic modular ratio of 34 (reinforcement to concrete), and a minimum composite flexural strength of 460 psi. The analysis team is confident in the validity of the composite design and that the structural design of *Argentum* will result in a strong, durable canoe.

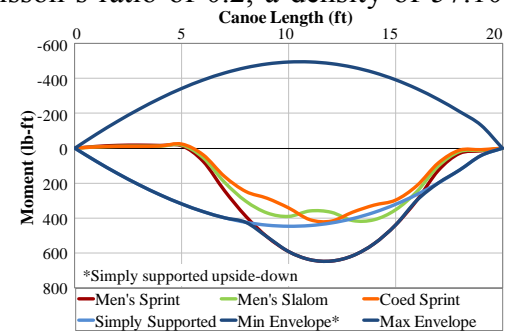


Figure 2: Moment Envelopes for Prestress.

Development and Testing

The mix design team for *Argentum* was challenged with the creation of a concrete mix that was strong enough to withstand the rigors of the competition, yet inherently buoyant. Other primary objectives were aesthetics and workability for proper placement. Based on these goals and the results of the structural analysis, the team developed the following design parameters: a unit weight less than 60 pcf, a 28-day compressive strength greater than 400 psi, a minimum composite strength of 460 psi, a modulus of rupture greater than 380 psi, an elastic modular ratio of at least 34, and a malleable white concrete capable of accommodating acid stain.

Many materials were used in the development of the composite structure of *Argentum*. An epoxy-coated carbon fiber scrim was employed based on its excellent performance in *Cerulean*. Sisorc[®] glass spheres ranging in diameter from 0.25 mm to 2 mm were used as the primary aggregate to produce a durable, lightweight concrete. The 3M[®] K20 microspheres (specific gravity 0.2) used in *Cerulean* were replaced with 3M[®] K1 microspheres (specific gravity of 0.125) to minimize unit weight. Polyvinyl alcohol (PVA) fibers were used to increase the flexural strength of the concrete. Metakaolin was used to lower the permeability of the concrete and for improved long-term strength.

A baseline concrete mixture was developed using the absolute volume mix design method. The baseline mixture had a water/cementitious materials ratio (w/cm) of 0.4, a cementitious materials content of 674 lbs/yd³ (65 percent Type I white portland cement, 30 percent Class F fly ash, and 5 percent metakaolin), 1.5 percent PVA fibers by volume, and a blended composite aggregate that contained less than 5 percent passing the No. 100 sieve by mass. For quality control, the team cast 2" x 4" cylinders from the mix, which were tested at 7, 14, and 28 days using the methods prescribed by ASTM C39. The baseline mixture had a 28-day compressive strength of 1620 psi and a unit weight of 59.59 pcf (ASTM C138).

After the baseline mix, the team batched 21 additional mixes, adjusting cement, air, and fiber contents to achieve strength, density, and workability goals. Maintaining workability proved difficult due to high demand on the cement paste, caused by a low w/cm ratio and the large surface area of the aggregates and PVA fibers. To lessen the demand on the cement paste, the void ratios and optimal packing densities of 15 composite gradations were investigated based on the method of Wong and Kwan (2005). Lower volumes of voids between aggregates reduced the amount of cement paste required to fill these voids. The void ratio was determined by measuring individual and composite aggregate volumes and quantified in terms of volume reduction. The blend with the largest volume reduction had the lowest void ratio and was selected as the design blend.

New mixing procedures were tested for effectiveness in fiber dispersion and air entrainment. Previously, all dry ingredients were blended before adding the water and liquid admixtures; PVA fibers were added last. This procedure was ineffective in entraining air and led to fiber clumping. In the procedure developed for 2008, the water and liquid admixtures were added to the cementitious materials first and then blended at high speeds for several minutes. This provided enough agitation for proper air entrainment and sufficient time for the admixtures to react with the cementitious materials. Next, PVA fibers and a proprietary fiber dispersing admixture (GST 1200GX) were added to the mix and blended with a high speed mixer until dispersion was achieved. The dispersing admixture was added at the manufacturer's recommended dosage of 0.2 percent of the total dry mix weight. Finally, the aggregates were added to complete the concrete mix. Tests revealed that the fiber content could be reduced by 50 percent from the baseline mix, while still exceeding the target flexural strength by 40 psi as a result of the new procedure (Figure 4).

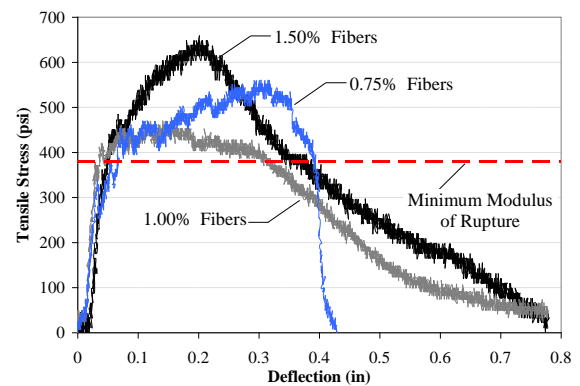


Figure 4: Effect of Various Fiber Contents.

The development phase of the mix design included testing admixtures to achieve proper concrete consistency and adequate air content. High-range water reducing admixtures (HRWRA), viscosity modifying admixtures (VMA), and air entraining admixtures (AEA) were all tested. At the recommendation of the admixture manufacturer, polycarboxylate-based HRWRA's were used for their high efficiency. Adva[®] 170

was used as the main workability-improving agent, while Adva[®] Cast 575 and V-Mar[®] 3 promoted cohesion and prevented segregation. Various dosages of Daravair[®] AT60 AEA were tested until a gravimetric air content of 8.07 percent was achieved (ASTM C138). Recommended dosage rates of all admixtures and the amounts used are shown in Table 5. Testing showed that exceptionally high amounts of HRWRA's were necessary to achieve acceptable cohesion and malleability for proper consolidation. The manufacturer was consulted to determine the adverse effects of such high admixture dosages. High dosages of V-Mar[®] 3 may decrease overall concrete strength, but excessive amounts of all other admixtures should not be detrimental. Because the concrete mix exceeded the strength requirements of the analysis, the high dosage of V-Mar[®] 3 was deemed acceptable.

Table 5: Admixture Dosage Rates.

| Admixture | Type | Manufacturer's Recommended Dosage | Actual Dosage Used in Mix |
|----------------------------|-------|-----------------------------------|---------------------------|
| Daravair [®] AT60 | AEA | 0.25-3 fl oz/cwt | 61.4 fl oz/cwt |
| Adva [®] Cast 575 | HRWRA | 2-10 fl oz/cwt | 30.7 fl oz/cwt |
| Adva [®] 170 | HRWRA | 3-9 fl oz/cwt | 57.5 fl oz/cwt |
| V-Mar [®] 3 | VMA | 10-40 fl oz/yd ³ | 207 fl oz/yd ³ |

The final structural concrete mix design had a cementitious materials content of 674 lbs/yd³, a w/cm ratio of 0.4, a fiber content of 0.75 percent by volume, and a unit weight of 57.10 pcf. Fly ash was removed from the baseline mix and metakaolin was increased to improve aesthetics and reduce permeability. The structural concrete exhibited strengths that met or exceeded the requirements of the analysis. The structural mix design is shown in Appendix B.

A second concrete mix was used for patching. The patch mix design, shown in Appendix B, was needed to fill air voids and create a smooth outer surface. In an effort to improve concrete consistency, the cementitious materials content was increased to 708 lbs/yd³ and the PVA fibers were removed. The large aggregates were removed for a more finely graded composite that improved finishing characteristics and allowed easier sanding.

Several reinforcing meshes were tested in composite concrete beams during the development of **Cerulean** (Nevada, 2007). Based on those results, a 1" x 1" epoxy-coated carbon fiber scrim with 76 percent open area (POA) was selected as the primary reinforcement for *Argentum*. Carbon fiber has several advantages over steel or fiberglass: workability, low weight, high modulus of elasticity (29,000 ksi), and superior bonding to and between layers of concrete. The carbon fiber mesh was tested in structural composite



Figure 5: Composite Beam.

beams (Figure 5) using third-point loading tests (ASTM C78) to determine composite flexural strength. Secondary reinforcement included a 1/2" x 1/2" (78 percent POA) steel mesh in the bow and stern and 1/16" diameter galvanized steel prestressing cables. Test results from Nevada (2007) were used to

Table 6: Summary of Structural Concrete Properties.

| Property | Analysis Requirements | Actual Properties |
|-----------------------------|-----------------------|-------------------|
| Unit Weight | 60.00 pcf (max) | 57.10 pcf |
| Compressive Strength | 400 psi (min) | 1650 psi |
| Modulus of Rupture | 380 psi (min) | 420 psi |
| Composite Flexural Strength | 460 psi (min) | 1220 psi |
| Elastic Modular Ratio | 34 (min) | 35 |

determine the elastic modulus, yield strength, and ultimate strength of the prestressing cables.

Repeated testing of concrete batches and carbon fiber composite beams resulted in a structurally sound canoe with mechanical properties as shown in Table 6. All engineering properties met the requirements of the analysis. The light color of the

concrete and the smooth finish of the patch mix allowed superior aesthetics and better application of acid stain, allowing *Argentum* to be an exceptional final product.

Project Management and Construction

The goal of the project management was to meet the technical demands of the project through scheduling, budgeting, safety, and quality by providing planning, organization, and control (Jacobs and Chase, 2008). Project management was organized as a committee rather than hierarchically. There were four management divisions: construction, academics, paddling, and project management. Each division had two co-chairs, providing an arrangement that alleviated the workload and responsibility that overwhelmed past project managers. The organizational structure of the team is shown on Page 7.

Cost planning for *Argentum* was based on an examination of the 2006-2007 project, resulting in a \$4,700 operating budget, excluding travel. In the first three years, the Nevada Concrete Canoe Team had high capital costs because of the recent foundation of the team. Over time, some items such as paddles and power tools did not need to be re-purchased, resulting in reduced expenses; this was considered in the development of the budget. To lower costs further, the team asked companies for material donations of items locally available and reused materials from previous years whenever possible. Fundraising was planned to coincide with expenditures to provide a relatively constant cash flow.

Major milestones and the critical path were also planned based on those of the 2007 project. Factors such as time saved from new construction techniques and extra time required for additional emphasis on mix design were considered when planning the durations of activities in the 2008 schedule. Twenty days were placed between the final milestone and the Mid-Pac competition date to offset potential prolongations of some activities caused by inexperience. The 20-day buffer was made possible by elimination of the full-scale prototype canoe from the old schedule; it was not necessary because of increased familiarity with the construction process.

The critical path and major milestones included the completion of the hull design, form, canoe pour, and canoe finishing. The project schedule, detailed on Page 8, gives the planned and actual execution dates of milestones and indicates the critical path. Eight major milestone variances were experienced, which are summarized in Table 7. Delays were primarily caused by inexperience in construction and analysis, and were compensated by the 20-day buffer and acceleration of subsequent steps on the critical path. In all, 16 key team members contributed 3,340 total

Table 7: Milestone Variances.

| Milestone | Variance | Cause |
|---------------------|----------|------------------|
| Composite Analysis | 28 days | Inexperience |
| Final Mix Selection | 28 days | Late Analysis |
| Design Report | 16 days | Later Due Date |
| Table Construction | 19 days | Slow Fabrication |
| Form Construction | 10 days | Table Late |
| Canoe Pour | 37 days | Form Late |
| Form Removal | 36 days | Late Pour Day |
| Canoe Completed | 8 days | Later Mid-Pac |

hours to the design, testing, construction, and paddling of *Argentum* (Table 8).

Table 8: Project Hours.

| Phase | Hours |
|--------------|-------|
| Design | 660 |
| Testing | 340 |
| Construction | 1580 |
| Paddling | 760 |
| Total | 3340 |

Keeping a three week “look-ahead” allowed division co-chairs to anticipate each phase of the project to organize personnel, scheduling, and material procurement. Frequent review of the schedule allowed procurement of long-lead items, such as reinforcement and aggregates, far in advance. Consequently, there were fewer delays caused by materials not being on site than in past projects. Weekly meetings allowed the team to monitor progress, safety, and future deadlines. Safety was discussed at each meeting, and again prior to each activity, such as a cold paddling practice or working with fiberglass. The safety manager mandated that team members review applicable Material Safety Data Sheets and use personal protective equipment when appropriate, such as safety goggles, body suits, respirators, gloves, and proper clothing. The project managers and the ASCE Student Chapter Treasurer held bi-monthly meetings to ensure cost control and to account for all purchases.

Experienced team members were present during critical phases of the project as a risk management strategy and to provide quality assurance. Parts of the project that were especially risky were given their own risk management procedures. Examples include a small practice pour for testing of acid stains and sealers and starting a hand-formed mold while investigating a mold created by a computerized numerical

control (CNC) machine. The latter procedure showed its value when CNC was not a viable option due to the lack of local sources. To provide quality control, task-specific procedures were exercised during all phases of construction. For example, a laser was used to create a straight keel line, and temporary grade screws were placed in the mold and cast in the concrete to provide depth gages during sanding.

Construction began with the cutting, welding, and assembly of a reusable steel table to support a highly prestressed canoe. To accurately form the male mold the hull design was plotted with AutoCAD® 2006 onto 80 paper cross-sections. These were secured to smooth slabs of high density polystyrene (selected for availability) and cut with a hotwire system created from a car battery charger and Nichrome wire.



The thicknesses of the polystyrene pieces varied between two, four, and six inches to control offsets between sections created by the hull's curvature. The sections were glued together and their corners were sanded off to create the shape of the canoe. A second hotwire was shaped from a stiff wire into an aesthetic shape with an area of 0.5 in² to cut four ribs in the form. The mold was fiberglassed to reinforce it for prestressing and to allow reuse if a second pour became necessary. To protect the polystyrene from the fiberglass resin, four layers of Kilz® primer were applied before fiberglassing. A gel coat was applied and sanded to a smooth finish. Finally, the form was cut into five sections, with a key in the center that allowed the sides to fold in for easy extraction after curing (Figure 6).

Figure 6: Form Key. Reinforcement began with eight 1/16" diameter galvanized steel cables set at a height of 3/16" off the form. Grade screws were drilled into the form to a height of 1/2" at intervals along each tendon (Figure 7); the tendons were tied to the screws with stainless steel wire to control height. A layer of epoxy-coated carbon fiber scrim was tied tightly to the tendons for spacing consistency. A second layer of eight tendons was then placed 3/8" off the form, and carbon fiber scrim was tied to these tendons to create a spaced, double layered reinforcement profile. The cables in each layer were pre-tensioned to 300 lbs at the gunwale, 200 lbs at the chines, and 160 lbs near the keel. Each tendon was monitored with steel springs (Figure 8); the length of each spring was precisely measured with calipers, and the prestress force was calculated from the spring constant. The carbon fiber scrim was heated to provide greater flexibility when wrapped around sharp curves in the form such as the chines. A flexible 1/2" galvanized steel mesh was used as reinforcement in the bow and stern instead of carbon fiber scrim due to the sharp keel at these locations.



Figure 7: Grade Screws.

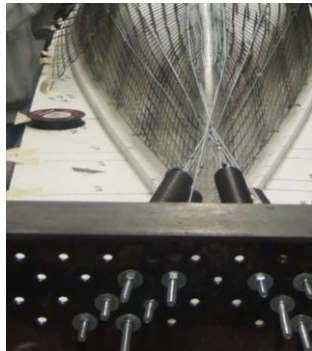
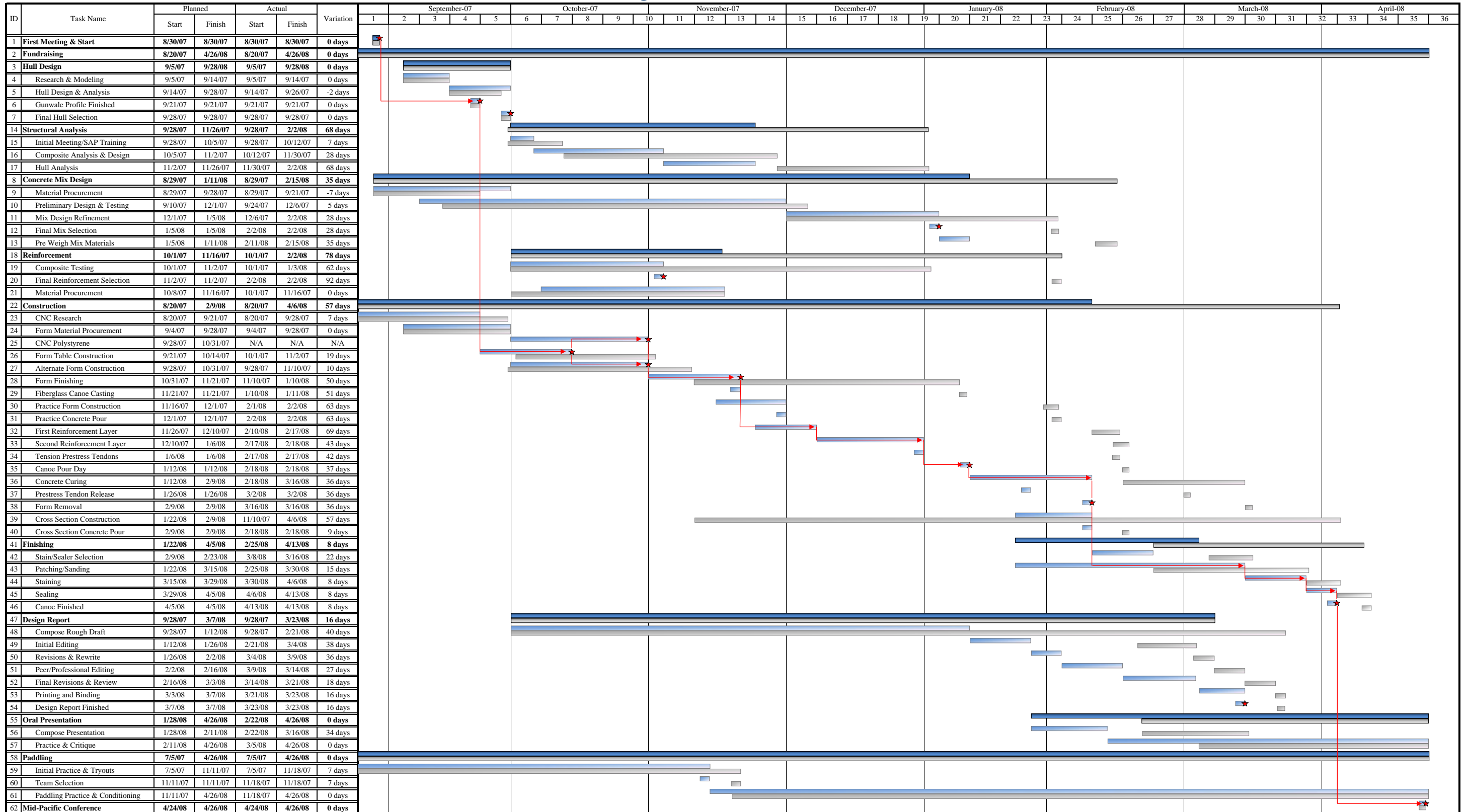


Figure 8: Prestress System.

The mix team pre-weighed dry mix materials prior to pour day to ensure consistency and speed during concrete placement. Concrete was pushed through the reinforcement, hand packed, and continually checked for compaction and depth (Figure 7). Placement started at the gunwale of the bow and proceeded upward and toward the stern for uniformity. The concrete was finished with vibrating trowels, an innovation of the 2006 team, and the grade screws were temporarily left in the form to give precise 1/2" depth during troweling and sanding. After the pour, the canoe was placed under sheets and a Visquine® tarp and wetted four times per day to provide hydration during curing. Wet sanding on the canoe's exterior began after seven days. After a 13-day cure period the grade screws were removed, the prestressing tendons were released, and concrete was placed over the exposed ends of the tendons. After 14 additional days of curing the fiberglass form was removed, and patching and sanding continued on both the interior and exterior of the canoe until it was free of surface irregularities and sanded with up to a 400-grit paper. Enamel paint lettering was sprayed on and two coats each of acid stain and sealer were applied following manufacturer's instructions. Finally, the sealer was finished with automotive color sanding techniques to provide a high-gloss surface as the final touch to *Argentum*.

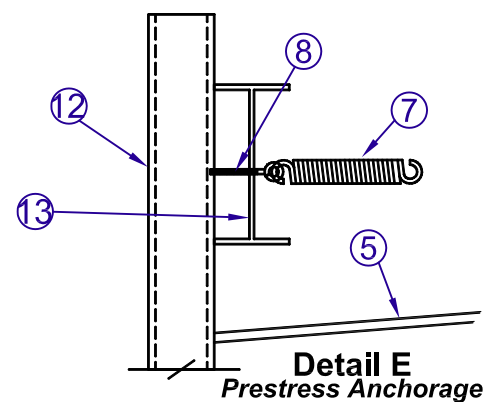
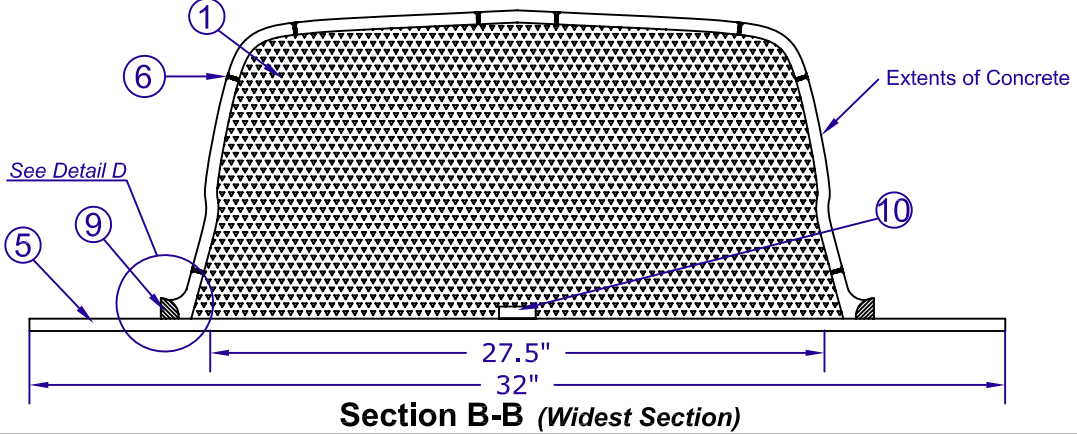
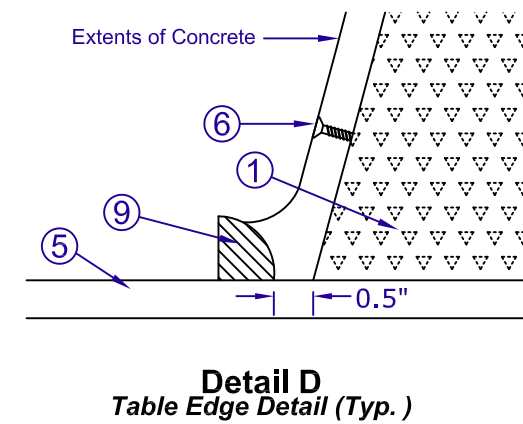
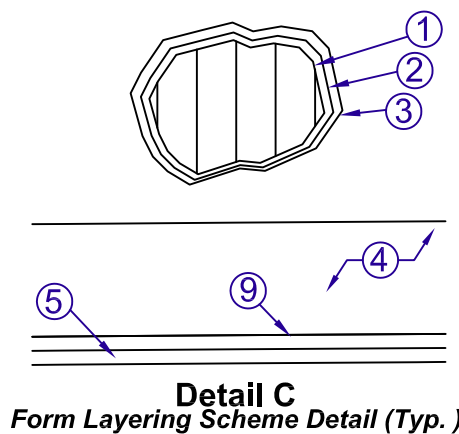
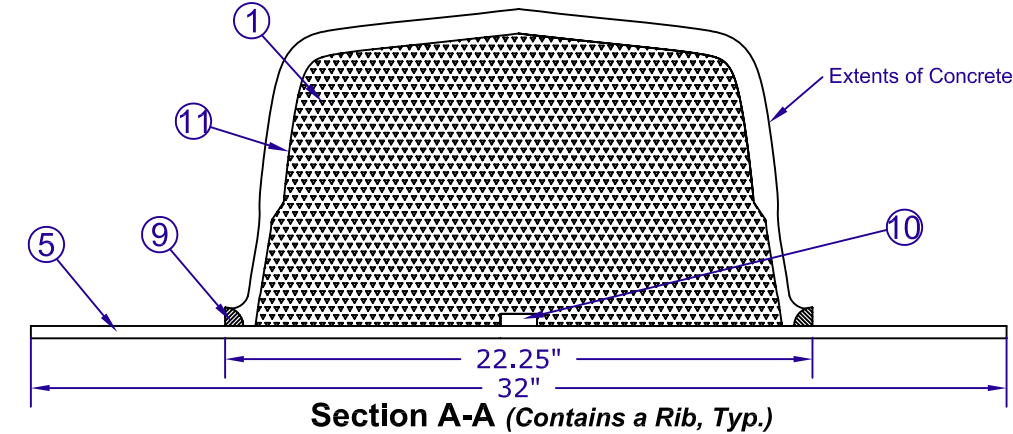
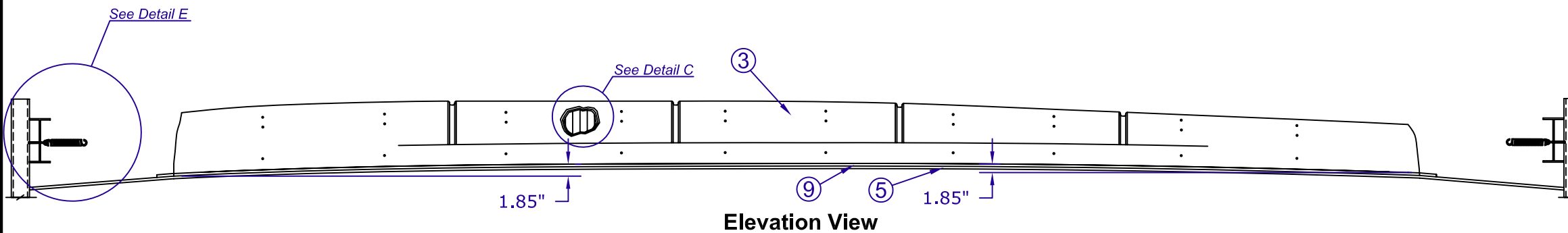
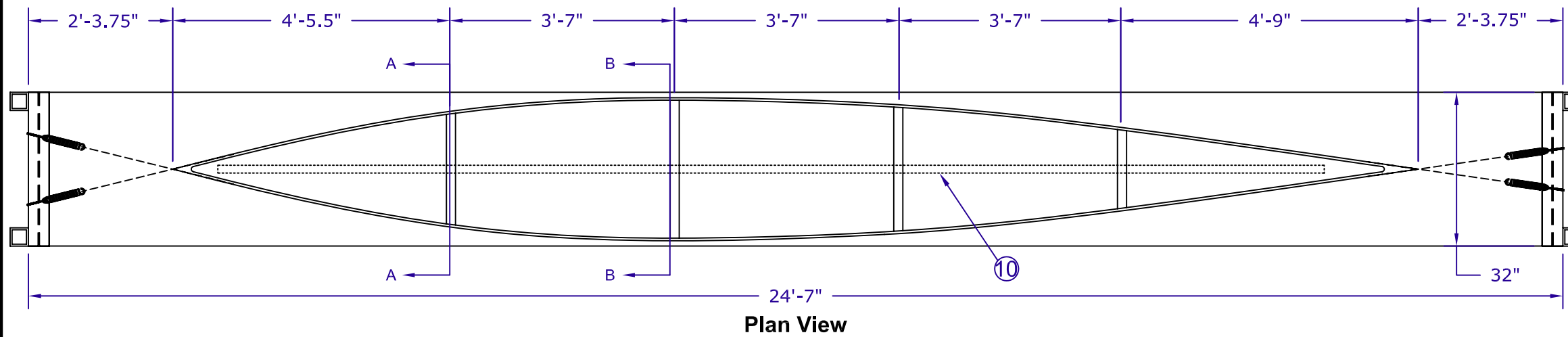
2008 *Argentum* Project Schedule





Summary (Planned) █ Task (Planned) █ Major Milestone ★

Summary (Actual) █ Task (Actual) █ Critical Path →



Bill of Materials

| Part | Qty | Description |
|------|--------|--|
| ① | 80 ct | Expanded Polystyrene (2", 4", and 6" thick sections) |
| ② | 59 sf | Kilz® Primer (Surface Treatment) |
| ③ | 59 sf | Fiberglass Shell (Surface Treatment) |
| ④ | 59 sf | Bondo (Surface Treatment) |
| ⑤ | 76 sf | Plywood (½" thick, 7-ply) |
| ⑥ | 157 ct | Grade Screws (½" protruding into concrete) |
| ⑦ | 16 ct | Steel Spring (7-⁄8", 1-⁄8" dia., k=300 lbf/in) |
| ⑧ | 32 ct | Eye Bolts/Nuts (3" long, ¼" dia.) |
| ⑨ | 40 lf | Plastic Trim (¾" radius) |
| ⑩ | 18 lf | Wood Chamfer Strip (1-½" x ½") |
| ⑪ | 3 sf | Dry Wall Mud (Surface Treatment, ribs only) |
| ⑫ | 20 lf | HSS 3½ x 3½ x ³⁄₈ (Prestress Anchorage) |
| ⑬ | 4 lf | W12 x 22 (Prestress Anchorage) |

Argentum Form Design Drawing

General Notes:
 1. Drawings not to scale
 2. Only two prestress anchorages are shown for clarity

Date: 3/3/2008

Engineer: MCFARLANE/CUKROV/DURHAM

Drawn By: STRICKLER



University of Nevada, Reno
Concrete Canoe

Bill of Materials

| Part | Qty | Description |
|------|----------|---|
| ① | 2.74 cf | Structural Concrete (1640 psi, 57.1 pcf, 6.8% air) |
| ② | 87 sf | Carbon Fiber Mesh (1"x1" grid, 76% open area) |
| ③ | 320 lf | Prestress Tendon (1/16" Woven Steel Cable) |
| ④ | 11.33 lf | Threaded Rod (1/4" Steel, each rib) |
| ⑤ | 116 sf | Finishing Concrete† (56.26 pcf, 11.8% air) |

Argentum Hull Design Drawing

- General Notes:
1. Drawings not to scale
 2. Width measurements do not include gunwale, except where noted
 3. Total Prestressing Force: $P_{jacked} = 3.44$ kips, Losses = 0.894 kips (26%)
 4. Minimum Concrete Compressive Strength at Release: 1000 psi

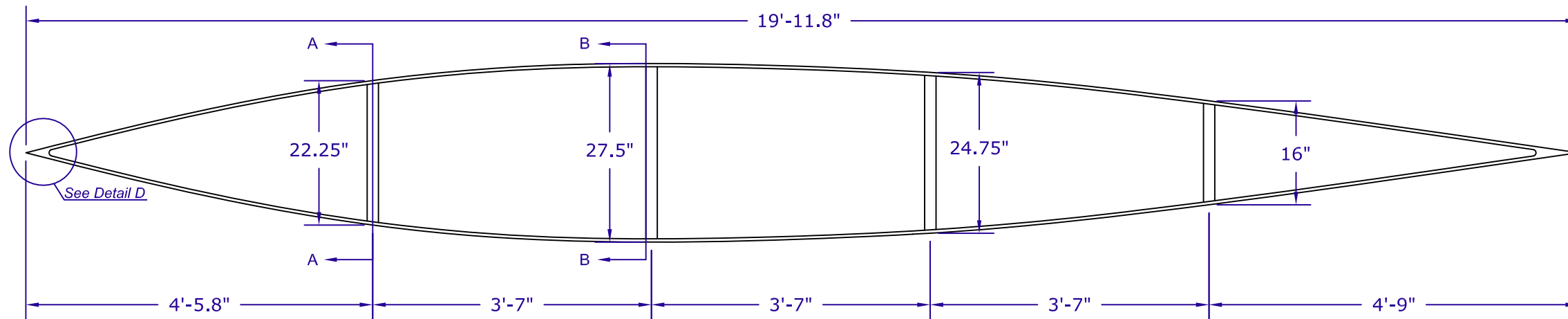
† Applied to surface of canoe after form removal

Date: 3/3/2008

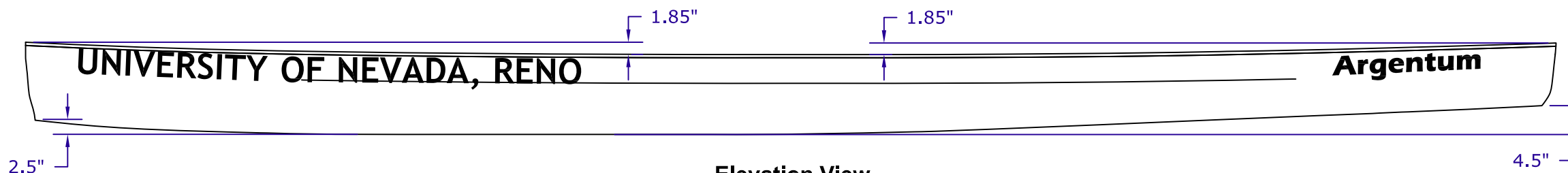
Engineer: MCFARLANE/TAYLOR

Drawn By: STRICKLER

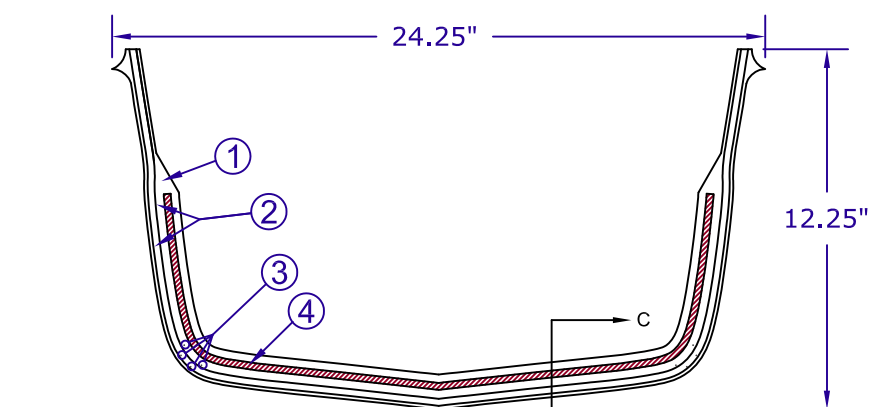
| | |
|-------|----|
| SHEET | OF |
| 10 | 10 |



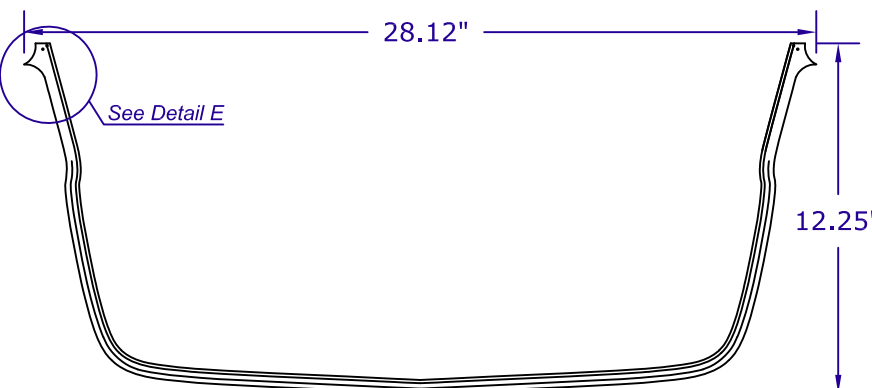
Plan View



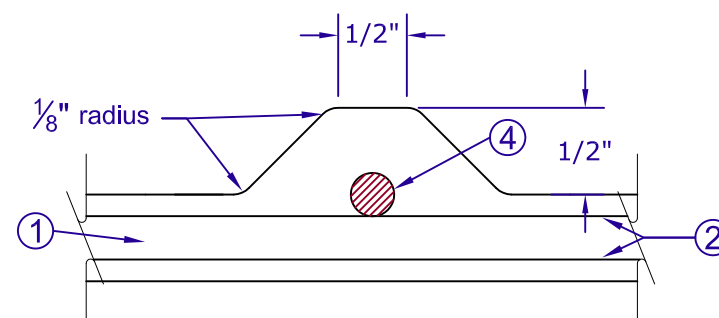
Elevation View



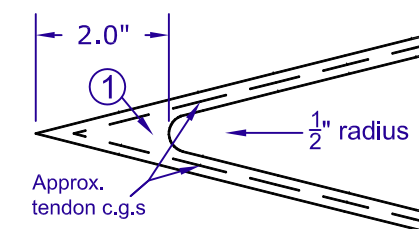
Section A-A (Contains a Rib, Typ.)



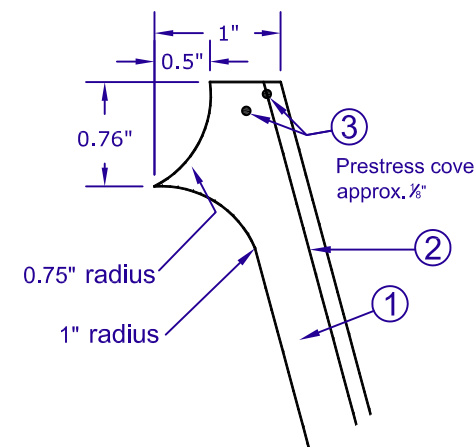
Section B-B (Widest Section)



Section C-C (Rib Detail, Typ.)



Detail D
Bulkhead Detail (Typ. Bow & Stern)



Detail E
Gunwale Detail

Appendix A: References

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Appendix B: Mixture Proportions

2008 Concrete Canoe Mix Design

Structural Concrete Mix

| Cementitious Materials | | Specific Gravity* | Non-SSD Proportions as Designed | | Actual Batched Proportions | | Yielded Proportions | | |
|---|--|-------------------|---------------------------------|--|----------------------------|---------------------------------------|------------------------------|--|--|
| | | | Amount (lb/yd ³) | Volume (ft ³) | Amount (lb) | Volume (ft ³) | Amount (lb/yd ³) | Volume (ft ³) | |
| Batch Size (ft ³): | | 0.250 | | | | | | | |
| 1. Portland Cement, Type I, (White) | | 3.15 | 539.14 | 2.743 | 4.99 | 0.025 | 553.68 | 2.817 | |
| 2. Metakaolin | | 2.68 | 134.78 | 0.806 | 1.25 | 0.007 | 138.42 | 0.828 | |
| Total of All Cementitious Materials | | | 673.92 | 3.549 | 6.24 | 0.033 | 692.10 | 3.645 | |
| Fibers | | | | | | | | | |
| 1. Nycon PVA Fibers | | 1.30 | 16.43 | 0.203 | 0.15 | 0.002 | 16.87 | 0.2080 | |
| Aggregates | | | | | | | | | |
| 1. Siscor 1-2 mm Absorption: 4.0% | | 0.44 | 129.62 | 4.721 | 1.20 | 0.044 | 133.11 | 4.848 | |
| 2. Siscor 0.5-1.0 mm Absorption: 4.0% | | 0.56 | 70.70 | 2.023 | 0.65 | 0.019 | 72.61 | 2.078 | |
| 3. Siscor 0.25-0.5 mm Absorption: 4.0% | | 0.75 | 315.63 | 6.744 | 2.92 | 0.062 | 324.14 | 6.926 | |
| 4. 3M K1 (Glass Bubbles) Absorption: 0.0% | | 0.13 | 22.89 | 2.822 | 0.21 | 0.026 | 23.51 | 2.898 | |
| Total of All Aggregates | | | 538.83 | 16.310 | 4.99 | 0.151 | 553.37 | 16.750 | |
| Water | | | | | | | | | |
| Batched Water [^] | | 1.0 | 234.18 | 3.753 | 2.17 | 0.035 | 237.23 | 3.802 | |
| Total Water Added for Aggregate Absorption | | 1.0 | 20.64 | 0.331 | 0.19 | 0.003 | 20.91 | 0.335 | |
| Total Water from All Admixtures [§] | | 1.0 | 35.39 | 0.567 | 0.33 | 0.005 | 35.85 | 0.575 | |
| Total Water | | | 290.21 | 4.651 | 2.69 | 0.043 | 293.99 | 4.711 | |
| Admixtures | | % Solids | Amount (fl oz/cwt) | Water [‡] in Admixtures (lb/yd ³) | Amount (fl oz) | Water [‡] in Admixtures (lb) | Amount (fl oz/cwt) | Water [‡] in Admixtures (lb/yd ³) | |
| 1. AEA Density, 8.8 lb/gal | | 50.0% | 61.4 | | 3.8 | | 63.0 | | |
| 2. HRWRA (Adva 170) Density, 10.0 lb/gal | | 65.0% | 57.5 | 10.596 | 3.6 | 0.098 | 59.1 | 10.901 | |
| 3. HRWRA (AdvaCast) Density, 8.8 lb/gal | | 20.0% | 30.7 | 11.379 | 1.9 | 0.106 | 31.5 | 11.738 | |
| 4. VMA Density, 8.3 lb/gal | | 0.0% | 30.7 | 13.416 | 1.9 | 0.125 | 31.5 | 13.842 | |
| 5. Fiber Disperser[†] Density, 2.8 lb/gal | | 100.0% | 5.8 | 0.000 | 0.4 | 0.000 | 6.0 | 0.000 | |
| Cement-Cementitious Materials Ratio | | | 0.80 | | 0.80 | | 0.80 | | |
| Water-Cementitious Materials Ratio [∞] | | | 0.40 | | 0.40 | | 0.40 | | |
| Flow (flow table), Slump, Slump Flow, in. | | | 0.0 | | 0.0 | | 0.0 | | |
| Air Content, % | | | 9.25 | | 8.07 | | 8.07 | | |
| Density (Unit Weight), lb/ft ³ ‡ | | | 56.36 ‡ | | 57.10 ‡ | | 57.10 ‡ | | |
| Gravimetric Air Content, % | | | | | 8.07 | | | | |
| Yield, ft ³ ‡ | | | 27.0 ‡ | | 0.2 ‡ | | 27.0 ‡ | | |

* For aggregates provide ASTM C 127 oven-dry bulk specific gravity.

[^] Excluding water added for aggregate absorption

[‡] Water content of admixture

[§] If impact on water-cementitious materials ratio is less than 0.01, enter zero.

[†] Denotes solid admixture; units shown are oz/cwt or oz, where appropriate

[∞] Calculated as quantity of "Batched Water" plus "Total Water from All Admixtures" divided by "Total of All Cementitious Materials"

‡ Includes volume of dry fiber dispersing admixture (SG = 0.33)

2008 Concrete Canoe Mix Design

Patch Concrete Mix

Batch Size (ft³): 0.085

| Cementitious Materials | | Specific Gravity* | Non-SSD Proportions as Designed | | Actual Batched Proportions | | Yielded Proportions | |
|---|----------------------|-------------------|---------------------------------|--|----------------------------|---------------------------------------|------------------------------|--|
| | | | Amount (lb/yd ³) | Volume (ft ³) | Amount (lb) | Volume (ft ³) | Amount (lb/yd ³) | Volume (ft ³) |
| 1. Portland Cement, Type I, (White) | | 3.15 | 566.09 | 2.880 | 1.78 | 0.009 | 523.55 | 2.664 |
| 2. Metakaolin | | 2.68 | 141.52 | 0.846 | 0.45 | 0.003 | 130.89 | 0.783 |
| Total of All Cementitious Materials | | | 707.62 | 3.726 | 2.23 | 0.012 | 654.43 | 3.446 |
| Fibers | | | | | | | | |
| 1. None | | | | | | | | |
| Aggregates | | | | | | | | |
| 1. Siscor 0.5-1.0 mm | | 0.56 | 179.45 | 5.135 | 0.56 | 0.016 | 165.96 | 4.749 |
| Absorption: 4.0% | | | | | | | | |
| 2. Siscor 0.25-0.5 mm | | 0.75 | 424.59 | 9.072 | 1.34 | 0.029 | 392.68 | 8.391 |
| Absorption: 4.0% | | | | | | | | |
| 3. 3M K1 (Glass Bubbles) | | 0.13 | 23.61 | 2.910 | 0.07 | 0.009 | 21.83 | 2.691 |
| Absorption: 0.0% | | | | | | | | |
| Total of All Aggregates | | | 627.64 | 17.118 | 1.98 | 0.054 | 580.47 | 15.831 |
| Water | | | | | | | | |
| Batched Water [^] | | 1.0 | 257.92 | 4.133 | 0.81 | 0.013 | 238.54 | 3.823 |
| Total Water Added for Aggregate Absorption | | 1.0 | 24.16 | 0.387 | 0.08 | 0.001 | 22.35 | 0.358 |
| Total Water from All Admixtures [§] | | 1.0 | 25.12 | 0.403 | 0.08 | 0.001 | 23.24 | 0.372 |
| Total Water | | | 307.21 | 4.923 | 0.97 | 0.015 | 284.12 | 4.553 |
| Admixtures | | % Solids | Amount (fl oz/cwt) | Water [‡] in Admixtures (lb/yd ³) | Amount (fl oz) | Water [‡] in Admixtures (lb) | Amount (fl oz/cwt) | Water [‡] in Admixtures (lb/yd ³) |
| 1. AEA | Density, 8.8 lb/gal | 50.0% | 6.1 | | 0.1 | | 5.7 | |
| 2. HRWRA | Density, 10.0 lb/gal | 65.0% | 11.0 | 2.128 | 0.2 | 0.007 | 10.1 | 1.968 |
| 3. HRWRA | Density, 8.8 lb/gal | 20.0% | 19.0 | 7.395 | 0.4 | 0.023 | 17.6 | 6.839 |
| 4. VMA | Density, 8.3 lb/gal | 0.0% | 34.0 | 15.601 | 0.8 | 0.049 | 31.4 | 14.428 |
| Cement-Cementitious Materials Ratio | | | 0.80 | | 0.80 | | 0.80 | |
| Water-Cementitious Materials Ratio [∞] | | | 0.40 | | 0.40 | | 0.40 | |
| Flow (flow table), Slump, Slump Flow, in. | | | 0.0 | | 0.0 | | 0.0 | |
| Air Content, % | | | 6.00 | | 13.06 | | 13.06 | |
| Density (Unit Weight), lb/ft ³ | | | 60.83 | | 56.26 | | 56.26 | |
| Gravimetric Air Content, % | | | | | 13.06 | | | |
| Yield, ft ³ | | | 27.0 | | 0.1 | | 27.0 | |

* For aggregates provide ASTM C 127 oven-dry bulk specific gravity.

[^] Excluding water added for aggregate absorption and water from admixtures

[‡] Water content of admixture

[§] If impact on water-cementitious materials ratio is less than 0.01, enter zero.

[∞] Calculated as quantity of "Batched Water" plus "Total Water from All Admixtures" divided by "Total of All Cementitious Materials"

Appendix C: Gradation Curves and Tables

| | |
|----------------------------|----------------------|
| Concrete Aggregate: | Siscor 1-2 mm |
| Sample Weight (g): | 265.0 |
| Specific Gravity: | 0.44 |
| Fineness Modulus: | 2.29 |

| Sieve Size | Diameter (mm) | Weight Retained (g) | Cumulative Weight Retained (g) | Percent Finer (%) |
|------------|---------------|---------------------|--------------------------------|-------------------|
| 3/8 inch | 9.50 | 0.0 | 0.0 | 100.0% |
| No. 4 | 4.75 | 0.0 | 0.0 | 100.0% |
| No. 8 | 2.36 | 0.0 | 0.0 | 100.0% |
| No. 16 | 1.18 | 191.5 | 191.5 | 27.7% |
| No. 30 | 0.60 | 72.3 | 263.8 | 0.5% |
| No. 50 | 0.30 | 0.0 | 263.8 | 0.5% |
| No. 100 | 0.15 | 0.0 | 263.8 | 0.5% |

| | |
|----------------------------|--------------------------|
| Concrete Aggregate: | Siscor 0.5-1.0 mm |
| Sample Weight (g): | 91.7 |
| Specific Gravity: | 0.56 |
| Fineness Modulus: | 3.48 |

| Sieve Size | Diameter (mm) | Weight Retained (g) | Cumulative Weight Retained (g) | Percent Finer (%) |
|------------|---------------|---------------------|--------------------------------|-------------------|
| 3/8 inch | 9.50 | 0.0 | 0.0 | 100.0% |
| No. 4 | 4.75 | 0.0 | 0.0 | 100.0% |
| No. 8 | 2.36 | 0.0 | 0.0 | 100.0% |
| No. 16 | 1.18 | 0.0 | 0.0 | 100.0% |
| No. 30 | 0.60 | 53.3 | 53.3 | 41.9% |
| No. 50 | 0.30 | 35.3 | 88.6 | 3.4% |
| No. 100 | 0.15 | 1.0 | 89.6 | 2.3% |

| | |
|----------------------------|---------------------------|
| Concrete Aggregate: | Siscor 0.25-0.5 mm |
| Sample Weight (g): | 398.5 |
| Specific Gravity: | 0.75 |
| Fineness Modulus: | 4.09 |

| Sieve Size | Diameter (mm) | Weight Retained (g) | Cumulative Weight Retained (g) | Percent Finer (%) |
|------------|---------------|---------------------|--------------------------------|-------------------|
| 3/8 inch | 9.50 | 0.0 | 0.0 | 100.0% |
| No. 4 | 4.75 | 0.0 | 0.0 | 100.0% |
| No. 8 | 2.36 | 0.0 | 0.0 | 100.0% |
| No. 16 | 1.18 | 0.0 | 0.0 | 100.0% |
| No. 30 | 0.60 | 0.5 | 0.5 | 99.9% |
| No. 50 | 0.30 | 363.5 | 364.0 | 8.7% |
| No. 100 | 0.15 | 32.1 | 396.1 | 0.6% |

| | |
|----------------------------|--------------|
| Concrete Aggregate: | 3MK1 |
| Sample Weight (g): | 55.0 |
| Specific Gravity: | 0.125 |
| Fineness Modulus: | 5.94 |

| Sieve Size | Diameter (mm) | Weight Retained (g) | Cumulative Weight Retained (g) | Percent Finer (%) |
|------------|---------------|---------------------|--------------------------------|-------------------|
| 3/8 inch | 9.50 | 0.0 | 0.0 | 100.0% |
| No. 4 | 4.75 | 0.0 | 0.0 | 100.0% |
| No. 8 | 2.36 | 0.0 | 0.0 | 100.0% |
| No. 16 | 1.18 | 0.0 | 0.0 | 100.0% |
| No. 30 | 0.60 | 0.0 | 0.0 | 100.0% |
| No. 50 | 0.30 | 0.0 | 0.0 | 100.0% |
| No. 100 | 0.15 | 3.1 | 3.1 | 94.4% |

Concrete Aggregate: Structural Concrete Composite Aggregate
Fineness Modulus: 3.65

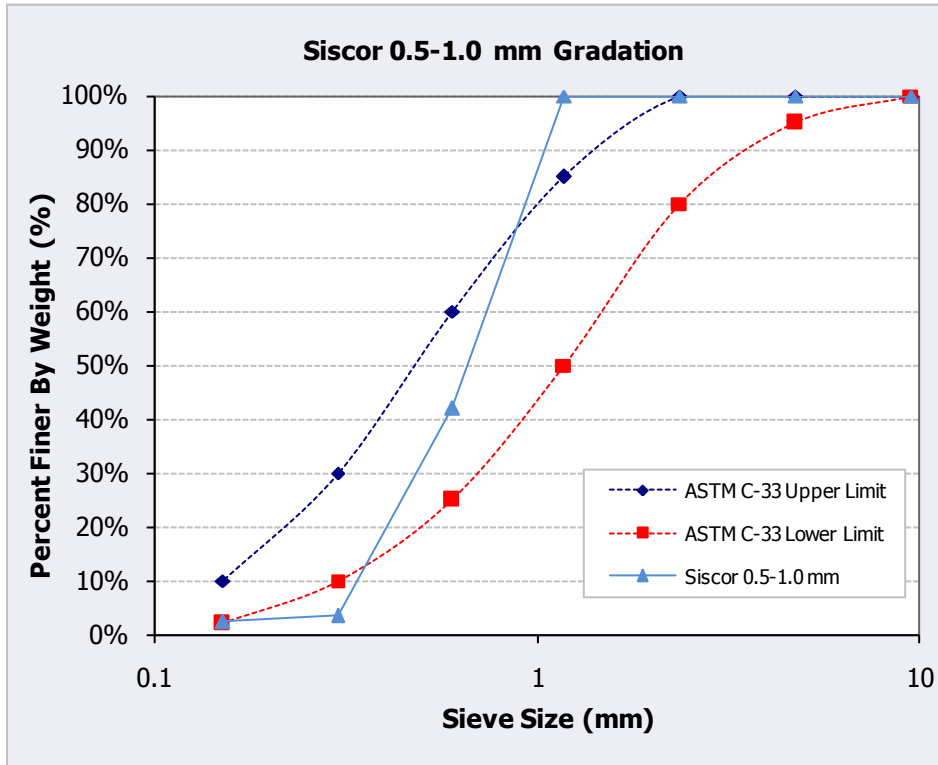
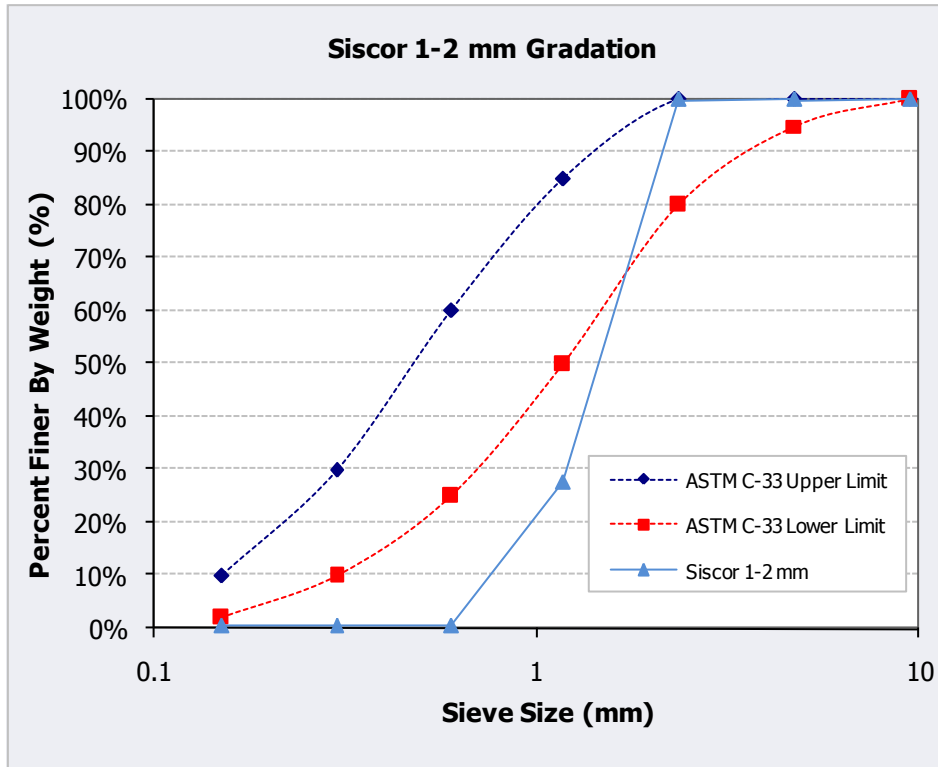
| Sieve Size | Siscor 1-2 mm | Siscor 0.5-1.0 mm | Siscor 0.25-0.5 mm | 3M K1 | Composite [†] |
|------------|------------------|----------------------|-----------------------|--------|------------------------|
| 3/8 inch | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| No. 4 | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| No. 8 | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| No. 16 | 27.7% | 100.0% | 100.0% | 100.0% | 82.6% |
| No. 30 | 0.5% | 41.9% | 99.9% | 100.0% | 68.3% |
| No. 50 | 0.5% | 3.4% | 8.7% | 100.0% | 9.8% |
| No. 100 | 0.5% | 2.3% | 0.6% | 94.4% | 4.7% |

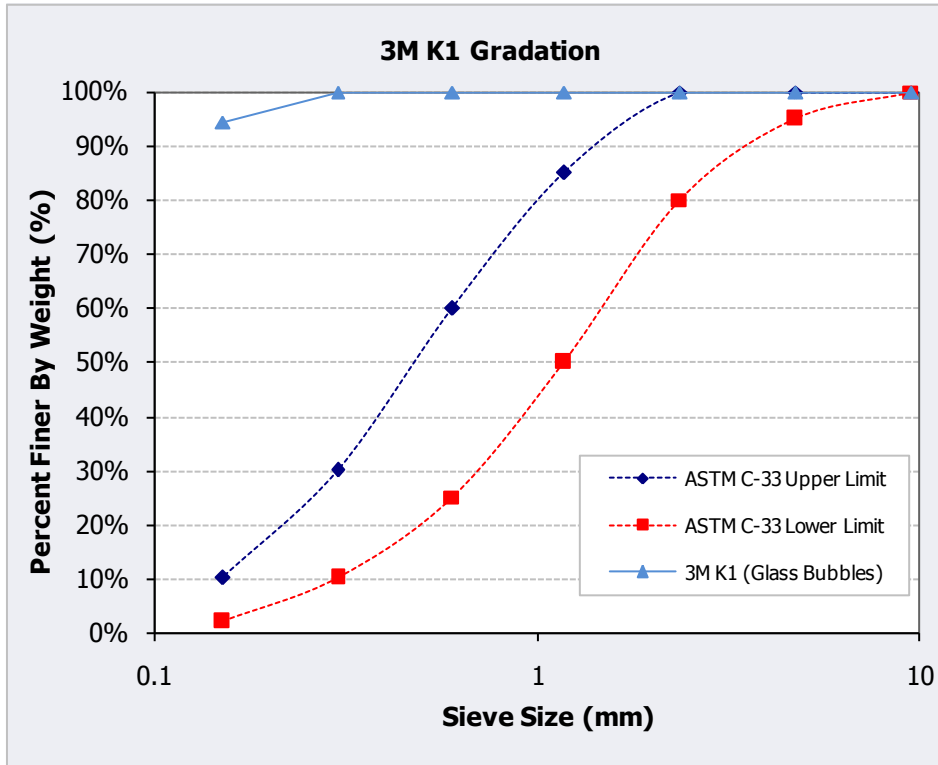
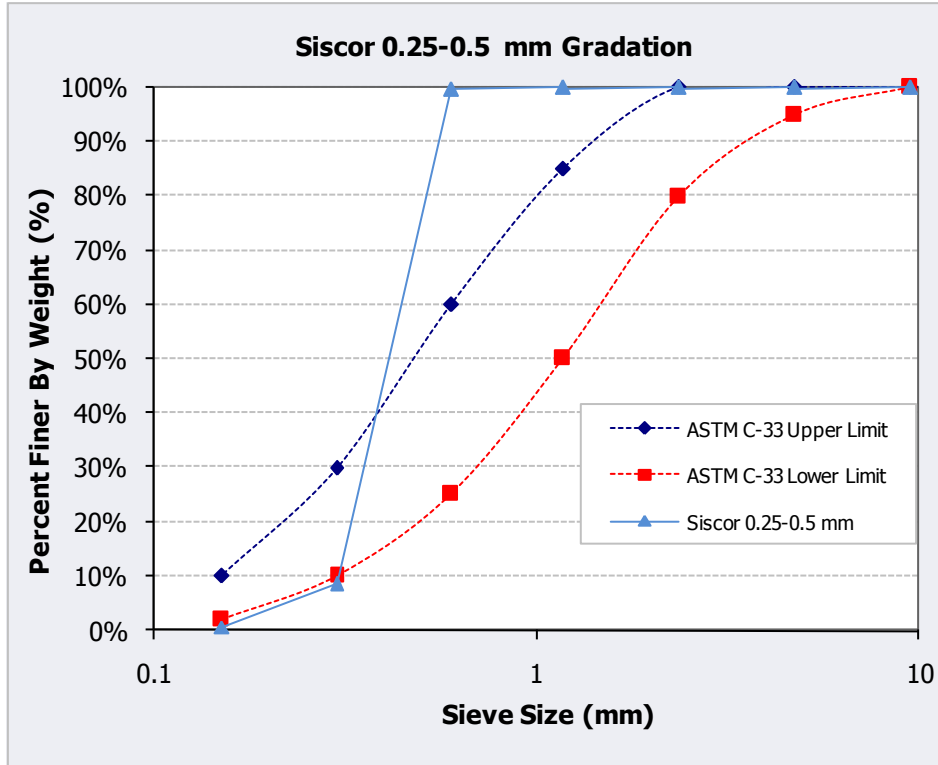
† Blend Ratio is 24.1% Siscor 1-2 mm, 13.1% Siscor 0.5-1.1 mm, 58.6% Siscor 0.25-0.5 mm, and 4.2% 3M K1

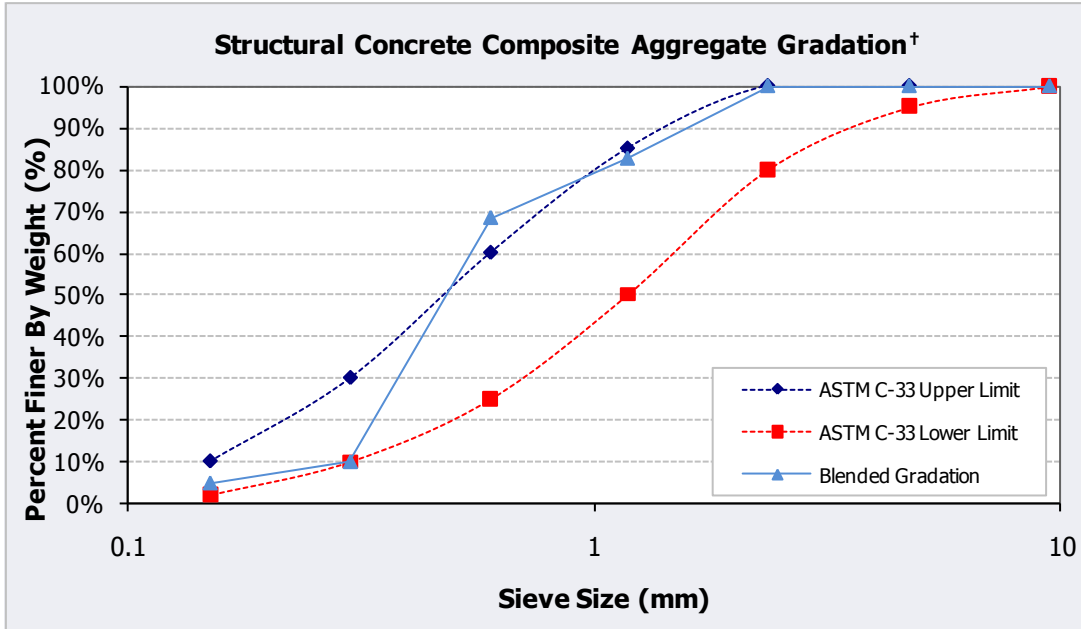
Concrete Aggregate: Patch Concrete Composite Aggregate
Fineness Modulus: 3.99

| Sieve Size | Siscor 0.5-1.0 mm | Siscor 0.25-0.5 mm | 3M K1 | Composite [†] |
|------------|----------------------|-----------------------|--------|------------------------|
| 3/8 inch | 100.0% | 100.0% | 100.0% | 100.0% |
| No. 4 | 100.0% | 100.0% | 100.0% | 100.0% |
| No. 8 | 100.0% | 100.0% | 100.0% | 100.0% |
| No. 16 | 100.0% | 100.0% | 100.0% | 100.0% |
| No. 30 | 41.9% | 99.9% | 100.0% | 83.3% |
| No. 50 | 3.4% | 8.7% | 100.0% | 10.6% |
| No. 100 | 2.3% | 0.6% | 94.4% | 4.6% |

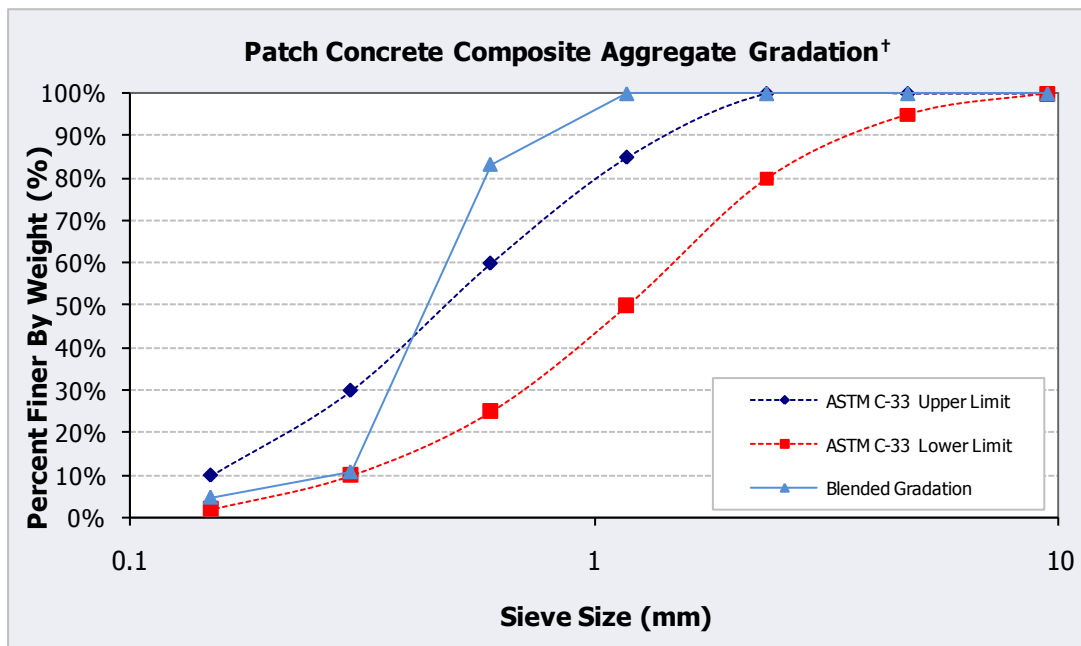
† Blend Ratio is 28.6% Siscor 0.5-1.1 mm, 67.6% Siscor 0.25-0.5 mm, and 3.8% 3M K1







[†]Blend Ratio is 24.1% Siscor 1-2 mm, 13.1% Siscor 0.5-1.1 mm, 58.6% Siscor 0.25-0.5 mm, and 4.2% 3M K1



[†]Blend Ratio is 28.6% Siscor 0.5-1.1 mm, 67.6% Siscor 0.25-0.5 mm, and 3.8% 3M K1