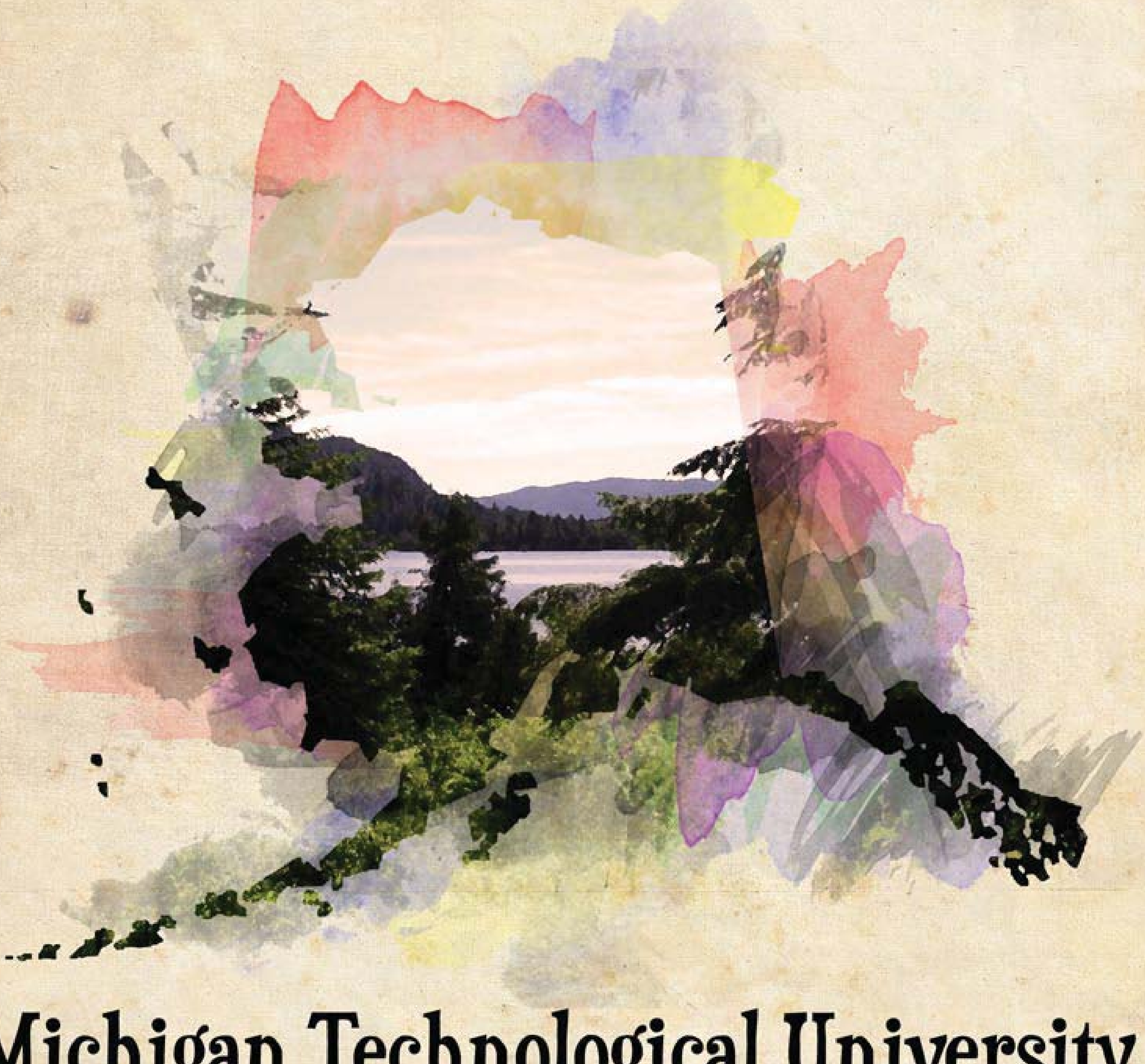
FRONTIER



Michigan Technological University
Concrete Canoe
2010-2011 Design Paper

Table of Contents

Executive Summary

Michigan Technological University (Michigan Tech) is located in the northern region of Michigan's Upper Peninsula. The combination of the University's location and the team's forward-thinking attitude coincide with the state of Alaska's official slogan, "North to the Future." Michigan Tech's Concrete Canoe team took this motto, which resembles the University's slogan, "Create the Future," as a battle cry of its own. Furthermore, as tribute to the team's advisor – who spent 33 years in Alaska – the team chose an Alaskan theme for this year's concrete canoe.

The team learned that Michigan Tech has much in common with the state of Alaska including a fierce winter climate and low population density. Thus there are many shared interests, particularly in the team's favorite outdoor activities such as ice fishing, snowmobiling, and skiing, among many others. The team was fascinated by the native Tlingit art which is featured prominently on the exterior of this year's canoe. The vast forests inspired a cabin-like display area with many hours devoted to chopping and debarking timber before construction could begin. The team also learned from a local craftsman how to craft a totem pole and found a competitively-used dogsled to use as a display prop. The awe-inspiring natural beauty of Alaska was incorporated into every aspect of the team's design.

The Michigan Tech Concrete Canoe team has been participating in the North Central Conference since 1978 and has represented the conference at the national level eleven times, achieving fourth place in last year's competition. This year's most significant innovations were within the areas of empirical stress analysis and reinforcement design. Strain gages were used during dynamic testing to find stresses along the entire length of the competition's standardized hull. This involved a large commitment of time and energy, however the results of the analysis allowed for a truly engineered reinforcement scheme which completely justified the investment. With an Alaskan theme and many new innovations, the team is proud to present its 2010-2011 canoe, **FRONTIER** (see Tables 1 and 2 for canoe details).

Table 1: Canoe Characteristics

Name	FRONTIER
Weight	164 lbs
Length	20 feet
Width	31 3/16 inches
Depth	16 inches
Nominal Thickness	3/8 inch
Main Color	White
Complimentary Colors	Red, Light Blue, Light Green

Table 2: Canoe Engineering Properties

Unit Weight	60.2 pcf
28-day Compressive Strength	1,026 psi
28-day Tensile Strength	389 psi
Site-Specific Reinforcement	Chromarat C-Grid® CT275 Carbon Fiber Grid
Fiber Reinforcement	Nycon Kuralon™ RF4000 and RECS15 Polyvinyl Alcohol Fibers

Analysis

Michigan Tech returned home from the 2010 National Concrete Canoe Competition™ (NCCC) debating the accuracy of the team's Finite Element Analysis (FEA) and what the critical loading scenario actually was. Before the 2011 NCCC rules were released the team had cast a prototype canoe and created a detailed plan to empirically answer these questions.

Michigan Tech's prototype canoe, *Ursula*, was designed to test the possibility of using minimal reinforcement. The team theorized that the tensile strength of the concrete alone would be able to withstand the stress calculated in the FEA. To maintain a tensile factor of safety of two, a four-inch strip of mesh reinforcement was placed along the upper edge of each gunwale in accordance with last year's FEA output. Minimal reinforcement eased placement, allowing trowelers to achieve a nominal hull thickness of 3/8 inches. With the reduced amount of concrete placed in *Ursula*, the canoe weighed just 116 pounds.

While testing *Ursula*, a crack formed beneath a paddler, flooding the canoe. The team's extensive review of the failure discovered two flaws in the prototype: poor quality control procedures and an error in the punching shear analysis. Cutting *Ursula* into six-inch wide cross sections revealed that certain areas had been cast too thin. The second flaw was within the team's FEA, since it overlooked the concerns of punching shear stress. The loading area of the paddlers' weight was too large skewing the punching shear results.

After *Ursula* broke, the team shifted its focus to determine the canoe's punching shear stress during race conditions. An exact modulus of elasticity (Young's modulus) of the team's reinforced concrete was needed to determine the stress on the canoe. Testing was performed using an adaptation of ASTM C469 for this year's concrete mix, Kodiak, as well as the 2008-2009 concrete mix, Accretion, which was used in both *Ursula* and **POLARIS**, the team's 2009 canoe. Kodiak produced an average Young's modulus of 453 ksi, while Accretion had a value of 506 ksi. Knowing the Young's modulus of the team's reinforcement material, Chromarat C-Grid® CT275 Carbon Fiber Grid (C-Grid®), allowed the team to find the strength of the composite material using the rule of mixtures. Applying this rule, the Young's modulus of **POLARIS**'s three-fifths of an inch reinforced concrete was found to be 896 ksi whereas a 3/8-inch thick, 2x2-foot plate, made from Kodiak, was 1,088 ksi.

To test punching shear stress, the team applied strain gages to the 2x2-foot plate with two layers of reinforcement. Maximum stresses of 330 psi and 310 psi were found under normal loading conditions for a paddler kneeling and sitting, respectively. This test was performed with a typical male paddler, weighing 200 lbs, holding an additional 40 lbs of weight to accommodate for a paddler's dynamic loading factor of 1.2. The team determined the dynamic loading factor after empirical tests showed that a paddler creates an additional downward force equivalent to 20% of their body weight while paddling. Two layers of reinforcement were deemed necessary after a plate with only one layer of reinforcement failed under the same loading conditions.

Last year's FEA results found the male sprint to be the critical loading case. To confirm this, 73 strain gages were placed at key locations on **POLARIS**. After many hours of testing, it was confirmed that the greatest tensile stress (85 psi) occurred on the outside gunwale 10 feet, 2 inches from the bow during the men's sprint buoy turn as seen in Figure 1 on page 2.

Through testing, the team found that all canoes have a proportional stress that is dependent on their thickness. Understanding this, the team used the bending moment equation to find the stress in a 3/8-inch thick canoe. The moment was found to be very close to the same for all of the team's canoes. Thus, the team assumed that the second moment of inertia and the strain gages distance from the neutral axis are the basis of the factor needed to convert stress from **POLARIS** to any other canoe of a similar hull shape. The team was then able to calculate a maximum gunwale tensile strength requirement of 135 psi in **FRONTIER**.

Figure 1: Time-correlated video and testing data helped depict that posting created the highest gunwale stress.

Strain gage testing proved that the FEA was giving higher stress values in different locations than what was actually occurring. The team was confident in its strain gage data and broke away from its tradition of putting two layers of continuous reinforcement throughout the canoe. Thus, the team designed its first-ever site-specific reinforcement scheme (see Figure 2).

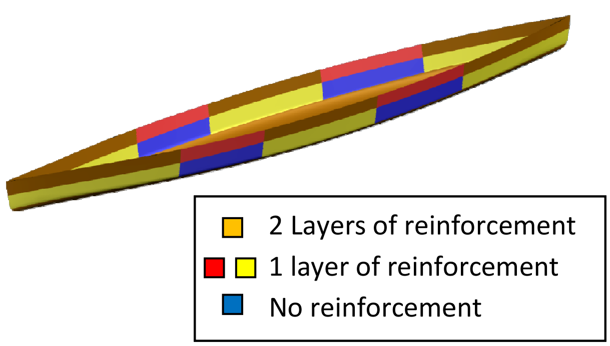


Figure 2: **FRONTIER**'s reinforcement scheme as viewed from above. The bow of the canoe is to the left.

Post Analysis

At the 2011 North Central Conference, a crack formed on **FRONTIER**'s port side 13 feet, 8 inches from the bow during the men's sprint preliminary races (see Figure 3). During the first strokes of the men's sprint race, the paddlers heard a cracking sound. However, the paddlers finished the race. Upon returning to shore, the team reviewed the extent of the damage and concluded that the concrete had failed structurally. The team believed that the four-and-a-half inch strip of reinforcement along the gunwale cap would be sufficient to hold the canoe together and continued racing. For the rest of the races, the team placed the stern paddler directly in line with the crack to avoid creating a larger moment about the fracture.

After competition an extensive visual inspection was done on **FRONTIER**. The team discovered that fine cracks formed on the starboard side of the canoe in both locations where there is no reinforcement. From the visual inspection the team concluded that the cause of the structural crack may be due to poor quality control that amplified a stress concentration created by the reinforcement scheme. In addition the team realized that when comparing the stresses of two canoes, both the bending moment equation and the torsion equation must be used. These equations depend on holding moment and torque values the same in both canoes. Using this combined-loading approach the team calculated a new maximum gunwale stress of 147 psi 10 feet, 2 inches from the bow. This stress was determined assuming that the paddlers could create a torque of 214 ft-lbs on the canoe during a buoy turn. The fine cracks were determined to have formed after the initial failure; when the stress normally held on the port side of the canoe was redistributed to go through the port side's reinforcement as well as the starboard side's reinforced concrete.

Figure 3: The structural crack on **FRONTIER**'s port side.

To ensure that FRONTIER withstands the national competition, the team tested reinforcement samples and ran additional empirical tests on POLARIS. The first test on POLARIS was used to determine whether the team overlooked a much larger stress in the areas where no reinforcement was placed during initial testing. These new tests proved however, that the team had previously determined the correct max stresses.

The team then tested POLARIS to see if moving the stern paddlers to the crack location would decrease the stresses the canoe would experience in that area. The move yielded an average stress reduction of 35%, resulting in a maximum tensile stress of 75 psi. After the move the team determined that the reinforcement produced a factor of safety of 3.28 through the structural crack. From the post-analysis testing the team is confident in FRONTIER's ability to survive the NCCC.

Development and Testing

Due to matching hull designs, similar aesthetic demands, low unit weight, and ample strength, the team used the 2009-2010 mix, Kippis, as a baseline for this year's mix. Upon receiving this year's rules, the team began material research and testing. During testing, one aspect of each batch was changed while all other variables were held constant. The team used a five-tier system to adjust binders, aggregates, fibers, water to cementitious materials (w/c) ratio, and admixtures. These tiers are referred to as I, II, III, IV, and V, respectively.

The team tested binders while researching new sustainable aggregates. Tier I testing began using various ratios of Type I White Portland Cement, vitreous calcium aluminosilicate (VCAS™) 8 and 160 white pozzolans, and grade 120 ground granulated blast-furnace slag (GGBFS). Binders were that were dark in color were eliminated before testing began; the final binder ratio was based on strength and workability.

Since the 2010-2011 rules require a minimum of two different sustainable aggregates, tier II began with the team searching for a recycled aggregate to complement Poraver® glass spheres (a post-consumer recycled product). The team looked into recycled rubber, glass, concrete, foam, slag, and cork. Due to concerns regarding specific gravity, glass and concrete were eliminated. Foam, rubber, and cork were dismissed based on low strength characteristics. Despite being dark in color and heavy, Lafarge True Lite Lightweight Aggregate™ was chosen as a second recycled aggregate because of its strength. Ultimately, the aggregates used in Kodiak were Poraver® glass spheres, Lafarge True Lite Lightweight Aggregate™, and 3M™ K-1 microspheres.

While tiers I and II were being tested, fiber testing was also conducted. Loose-strand fiber reinforcement was deemed necessary for additional tensile strength. Prior knowledge indicated that workability would be compromised if fibers were too long or used in excess. Nycon Kuralon™ RF4000 (30mm) and RECS15 (8mm) polyvinyl alcohol (PVA) fibers were selected for the final mix in a 2:1 ratio, respectively, as the optimal workable blend.

In tier IV, the team experimented with the amount of water in each mix to optimize unit weight, strength, and workability. After testing 0.35, 0.40, and 0.45 w/c ratios, 0.35 was determined to yield the best combination of these characteristics.

The top two mixes from tiers I and II were mixed with the fiber blend found in tier III and the w/c ratio from tier IV. Finally, admixtures were adjusted to further complement the final mix. The selection process relied on the compatibility of the admixtures with the proportions of the other concrete components. Xypex Xycrylic-Admix was used for its waterproofing quality, ability to reduce shrinkage, and to allow for an ambient cure; no dosage was specified by the manufacturer. A high-range water-reducer

(HRWR), BASF Glenium® 3030 NS, was chosen to boost mix workability while retaining the w/c ratio and consequently, the strength of the mix. To achieve the necessary workability, the HRWR manufacturer's recommended 3-8 fl oz/cwt dosage was exceeded.

Six 2x4-inch cylinders were made for each batch tested. Compressive and split-tensile tests were completed in accordance with ASTM standards. After numerous weeks of mixing and testing, the team found this year's mix, Kodiak, to have ideal strength and unit weight properties, producing 1,026 psi in compression, 389 psi in tensile, and a unit weight of 60.2 pcf. Final structural mix components are shown in Appendix B.

In addition to Kodiak, a concrete finishing mix and an inlay/outlay mix were developed. The finishing mix was designed to optimize the canoe's surface for staining while the inlay/outlay mix was designed for vibrant color and ease of placement. During aesthetic mix testing, binders were held constant from the structural mix to maintain color. The team decided that Poraver® 1.0-2.0mm glass spheres were detrimental to aesthetic demands and excluded them from the mixes. Instead, the team used Poraver® 0.25-0.5mm and 0.5-1.0mm glass spheres in the inlay/outlay mix and Poraver® 0.25-0.5mm glass spheres in the finishing mix. Sieved Lafarge True Lite Lightweight Aggregate™ was used in both mixes to meet the required number of sustainable aggregates. Fibers were excluded from both mixes as they decreased workability and detracted from a uniform finish. The manufacturer recommended dosage of HRWR was exceeded to increase the workability of the mixes. After the binders, aggregates, and admixtures were chosen, Direct Colors pigments were tested in various amounts and combinations with the inlay/outlay mix.

Once final mixes were determined, the team chose Chromarat C-Grid® CT275 Carbon Fiber Grid as its primary reinforcement based on prior knowledge. This material has a percent open area of 84.75%, Young's modulus of 34,500 ksi, and a yield stress of 325 ksi. The reinforcement was cast into 2x2-foot plates and strain gages were applied to accurately determine the punching shear that the reinforced concrete could withstand.

As a paddler exerts pressure on the bottom of the canoe it will bow outward, increasing the potential for the concrete to crack. If this were to happen, water would seep into the canoe, jeopardizing the paddlers' safety and the canoe's survivability. Understanding this, the team set the baseline for the factor of safety to be the concrete's tensile strength.

The team's strain gage analysis of the stresses in **POLARIS** revealed that previous years' FEAs had been overestimating the normal in-plane stress while the punching shear stress was vastly underestimated. A factor of safety of 1.18 ensures that the concrete, under normal loading conditions, possesses adequate strength.

When designing Kodiak, it was determined that the critical factor of safety was dependent on the punching shear created by a kneeling paddler. In previous years the concrete's limiting factors of safety were the in-plane compressive and tensile stresses. However, analysis this year concluded that both stresses were less than 150 psi. Comparing these values to the strength of Kodiak proved to the team that these were not the concrete's limiting factors of safety.

Project Management and Construction

As in years past, the team was led by both a senior and junior co-captain. Throughout all portions of the project, the team was overseen by both a safety and compliance chair. The team was then split into three major categories: construction, engineering, and competition. The most important facets were led by experienced members of the team with an emphasis on interaction between newer and older members. This ensured knowledge could be passed down and increase potential for success in future years. More information can be found in the organization chart on page 7.

At the beginning of the academic year, the team participated in a general safety course lead by Michigan Tech's Civil and Environmental Engineering Department safety coordinator. This familiarized all team members with safety equipment, material safety data sheets, fire extinguishers, exit routes, and proper emergency contact information. The team's safety chair also explained proper power equipment use and care. An emphasis was made on using personal protective equipment when working testing and construction tasks. In addition, the team's facility and construction methods were inspected by the University Health and Safety Department as a proactive safety measure.

The team was fortunate to have a majority of supplies and materials donated from affiliated sponsors. While this significantly reduced the costs for canoe design and construction, a strong emphasis remained on team fundraising to account for travel costs for the 30 member team. Donated materials were estimated to be $12,000, while the team has had to spend $3,000 on remaining necessary materials. The Bill of Materials for FRONTIER can be found in Appendix C.

To meet analysis and design demands, material decisions and procurement had to be completed early in the academic year. Material acquisition took place as soon as the competition rules were released, using residual funds from the previous year. Mix testing commenced using residual and newly purchased materials.

Milestones were activities that completed a major segment of the project. These were determined using the 2009-2010 project schedule and are shown in Table 3. The milestones are indicated with a star on the project schedule, seen on page 8. These were met through hard work, commitment, and the guidance of project managers.

Table 3: Milestone Activities

Final Theme Decision – 10/13/10
Structural Mix Design Selection – 11/30/10
Final Analysis Results – 12/16/10
Reinforcement Selection – 12/16/10
Concrete Placement – 1/9/11
Determination of Paddlers – 2/10/11
Design Paper Submittal – 2/28/11
Display Components Complete – 3/30/11
Finishes Complete – 3/27/11
North Central Conference Competition – 4/3/11
Design Paper Submittal – 5/7/11
National Concrete Canoe Competition – On Track

The critical path was based on any activity that, if not completed by its scheduled date, would postpone completion of the entire project. These activities are shown in Table 4 and can also be seen on the project schedule in red. To complete all of these tasks, the team worked 3,200 man-hours on development and testing, 118 man-hours casting FRONTIER, and is projected to spend 475 man-hours applying finishes.

Table 4: Critical Path Activities

Analysis
Analysis Results
Reinforcement Selection
Procurement of Reinforcement
Pre-Cutting Reinforcement
Concrete Placement
Initial Cure with Mold
Sanding
Inlays, Outlays, and Staining
Sealing
Finishes Complete

The team ordered a CNC-milled, female-style mold made from 10% pre-consumer recycled high-density polystyrene foam. The mold was received in two sections, cut in half along the keel. Two layers of epoxy were applied to each section to provide a stiff surface for concrete placement as well as create a barrier to prevent water loss through the foam.

After the epoxy set, the sections were put together and fastened by lining up the edges and attaching the mold to a rigid frame. This can be seen in the design drawing located on page 9. Holes were drilled at increments of eight inches along the keel, chines, and gunwales to enable the reinforcement to be anchored on casting day. Before casting, Huron Technologies Release Coating 7572 was applied. Manufacturer specifications state that the release agent is designed for use between concrete and epoxy surfaces for an aesthetically-appealing result.

Prior to and during casting day, the facility and materials were cooled and maintained at temperatures between 40°-50°F in order to retard the initial set of Kodiak. On casting day, three 1/8-inch layers of concrete were placed with two layers of C-Grid® CT275 site-specific reinforcement. Slump, unit weight, temperature, and air content were all measured during concrete placement in accordance with ASTM standards. Hull thickness was vigilantly monitored using custom depth gages at one-eighth, one-fourth, and three-eighths of an inch to correlate between the three layers of concrete.

Following completion of casting, the team began sanding the interior of the canoe after seven days of ambient curing. The canoe was de-molded after 14 days and outlays were placed soon after. A finishing mix was applied to both the interior and exterior of FRONTIER. Water-based stains were then used to enhance the overall aesthetic appeal. The canoe and school names were added using an inlay/outlay technique. A high-gloss sealer was applied completing the construction process.

Innovation and Sustainability

This year, the team strived towards innovative and sustainable features, including additional testing procedures and new recycled materials. Through empirical testing the team found actual stresses and determined the critical loading scenario of a canoe. These design uncertainties have perplexed competitors in the past.

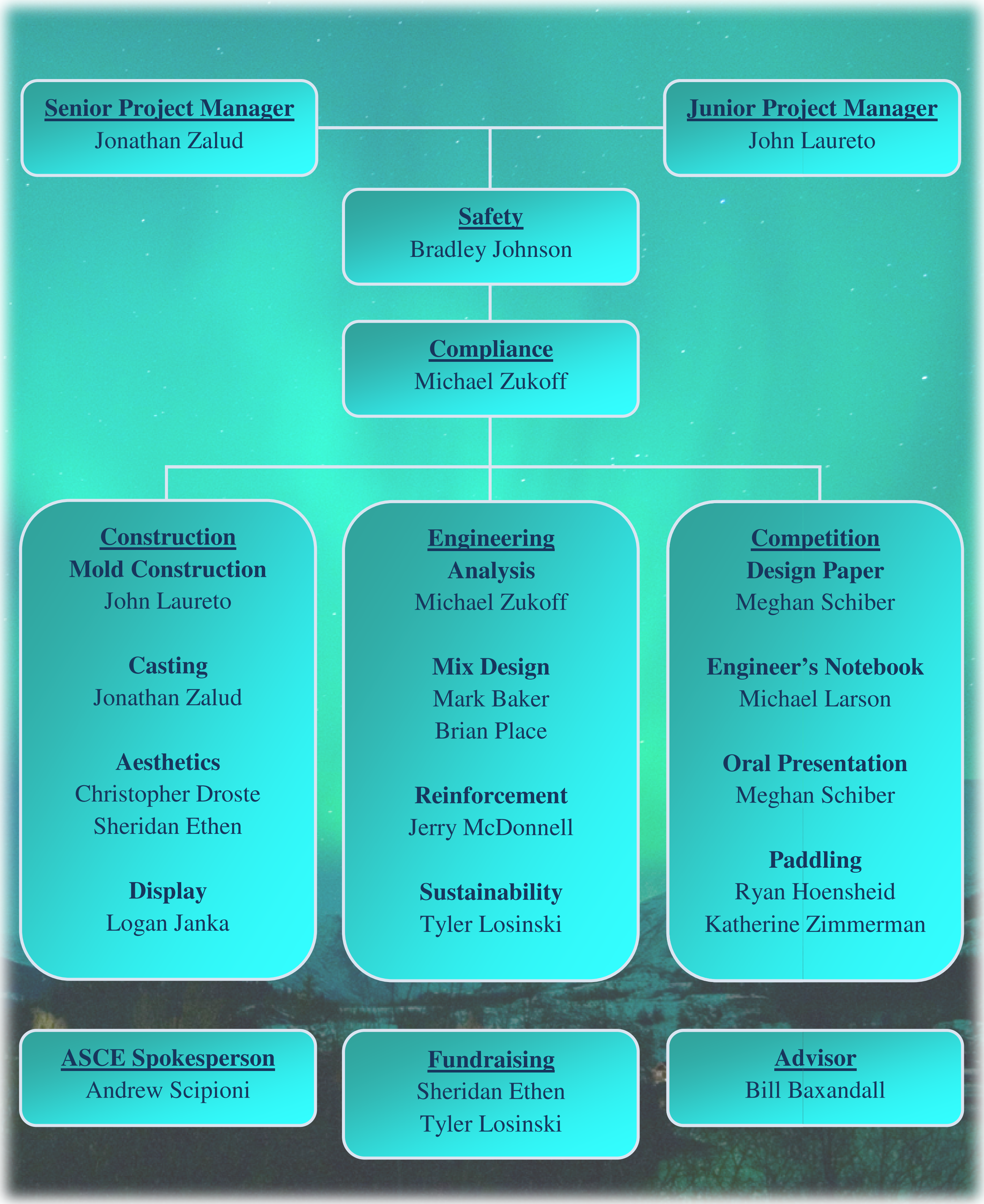
The team used 73 strain gages placed at key locations along POLARIS to disprove the coinciding FEA scheme and determine the most critical loading scenario. To capture data from full scale races, the strain gages were connected to Narada transmitters. These transmitters, created by a professor at Michigan Tech, could capture and store six minutes of data before relaying the data to a computer on shore. As a result of these tests, the team created a site-specific reinforcement scheme after many years of using continuous reinforcement.

In terms of sustainability, FRONTIER is composed of 47% by mass and nearly 32% by volume recycled materials. Several of the binders and two of the three aggregate sources are sustainable materials. The team's innovative reinforcement scheme allowed for the quantity of both mesh reinforcement and concrete to be reduced. All materials were used conservatively and reused or recycled whenever possible.

Another sustainable practice was the use of a release aid that was designed to separate concrete from an epoxy surface. This not only allowed for an easy de-molding of the canoe, but also caused no major damage to the mold, enabling the team to reuse the mold in the future.

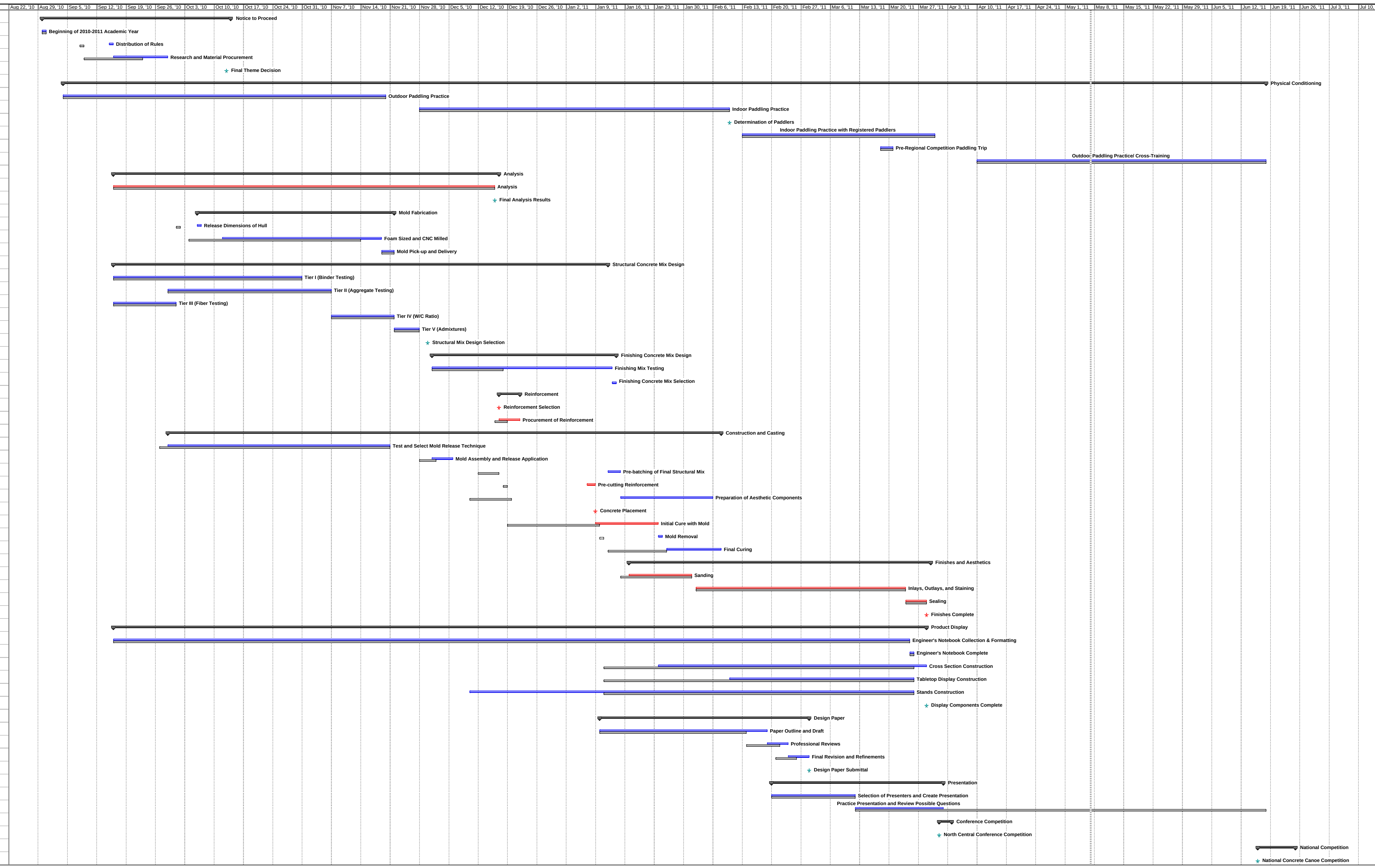
The team's effort and attention to detail led to many innovative and sustainable procedures. Less consumed raw material, a more in-depth analysis, a site-specific reinforcement scheme, and aesthetically-appealing yet structurally-sound mix all combined to make FRONTIER the most engineered canoe ever produced by Michigan Tech.

Organization Chart

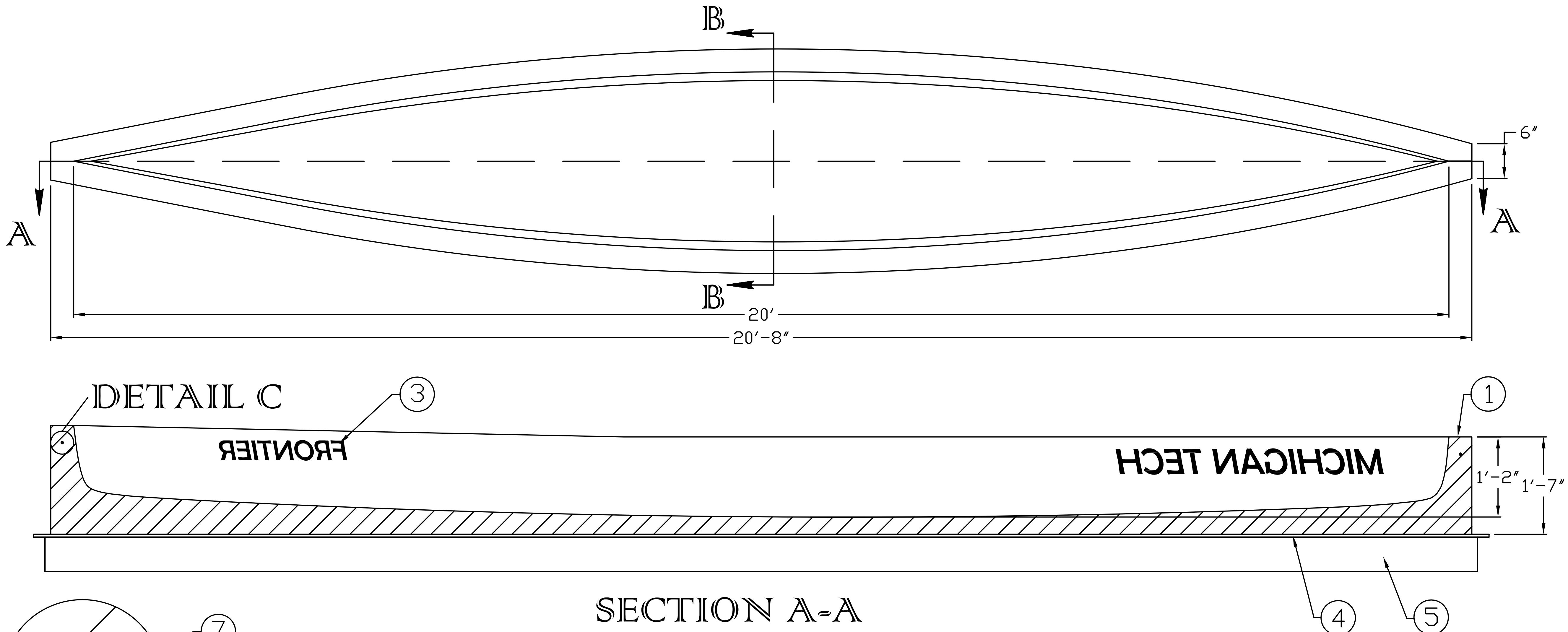


PROJECT SCHEDULE

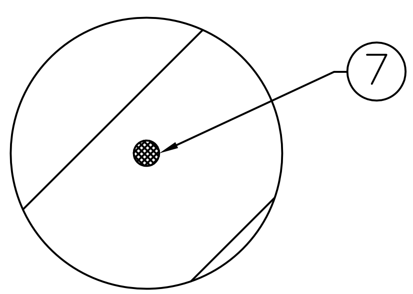
ID	Task Name	Baseline Start	Baseline Finish	~Actual Start~	~Actual Finish~
1	**Notice to Proceed**	**Mon 8/30/10**	**Wed 10/13/10**	**8/30/10**	**10/13/10**
2	Beginning of 2010-2011 Academic Year	Mon 8/30/10	Mon 8/30/10	8/30/10	8/30/10
3	Distribution of Rules	Wed 9/8/10	Wed 9/8/10	9/15/10	9/15/10
4	Research and Material Procurement	Thu 9/9/10	Wed 9/22/10	9/16/10	9/28/10
5	Final Theme Decision	Wed 10/13/10	Wed 10/13/10	10/13/10	10/13/10
6	**Physical Conditioning**	**Sat 9/4/10**	**Wed 3/30/11**	**9/4/10**	**On Track**
7	Outdoor Paddling Practice	Sat 9/4/10	Fri 11/19/10	9/4/10	11/19/10
8	Indoor Paddling Practice	Sun 11/28/10	Wed 2/9/11	11/28/10	2/9/11
9	Determination of Paddlers	Thu 2/10/11	Thu 2/10/11	2/10/11	2/10/11
10	Indoor Paddling Practice with Registered Paddlers	Sun 2/13/11	Wed 3/30/11	2/13/11	4/9/11
11	Pre-Regional Competition Paddling Trip	Fri 3/18/11	Sun 3/20/11	3/18/11	3/20/11
12	Outdoor Paddling Practice/ Cross-Training	Sun 4/10/11	Fri 6/17/11	4/10/11	On Track
13	**Analysis**	**Thu 9/16/10**	**Thu 12/16/10**	**9/16/10**	**12/16/10**
14	Analysis	Thu 9/16/10	Wed 12/15/10	9/16/10	12/15/10
15	Final Analysis Results	Thu 12/16/10	Thu 12/16/10	12/16/10	12/16/10
16	**Mold Fabrication**	**Fri 10/1/10**	**Sun 11/21/10**	**10/6/10**	**11/21/10**
17	Release Dimensions of Hull	Fri 10/1/10	Fri 10/1/10	10/6/10	10/6/10
18	Foam Sized and CNC Milled	Mon 10/4/10	Sat 11/13/10	10/12/10	11/18/10
19	Mold Pick-up and Delivery	Fri 11/19/10	Sun 11/21/10	11/19/10	11/21/10
20	**Structural Concrete Mix Design**	**Thu 9/16/10**	**Tue 11/30/10**	**9/16/10**	**11/30/10**
21	Tier I (Binder Testing)	Thu 9/16/10	Sat 10/30/10	9/16/10	10/30/10
22	Tier II (Aggregate Testing)	Wed 9/29/10	Sat 11/6/10	9/29/10	11/6/10
23	Tier III (Fiber Testing)	Thu 9/16/10	Thu 9/30/10	9/16/10	9/30/10
24	Tier IV (W/C Ratio)	Sun 11/7/10	Sun 11/21/10	11/7/10	11/21/10
25	Tier V (Admixtures)	Mon 11/22/10	Sat 11/27/10	11/22/10	11/27/10
26	Structural Mix Design Selection	Tue 11/30/10	Tue 11/30/10	11/30/10	11/30/10
27	**Finishing Concrete Mix Design**	**Wed 12/1/10**	**Thu 1/13/11**	**12/1/10**	**1/13/11**
28	Finishing Mix Testing	Wed 12/1/10	Fri 12/17/10	12/1/10	1/12/11
29	Finishing Concrete Mix Selection	Thu 1/13/11	Thu 1/13/11	1/13/11	1/13/11
30	**Reinforcement**	**Thu 12/16/10**	**Sat 12/18/10**	**12/16/10**	**12/21/10**
31	Reinforcement Selection	Thu 12/16/10	Thu 12/16/10	12/16/10	12/16/10
32	Procurement of Reinforcement	Thu 12/16/10	Sat 12/18/10	12/17/10	12/21/10
33	**Construction and Casting**	**Mon 9/27/10**	**Tue 1/25/11**	**9/29/10**	**2/7/11**
34	Test and Select Mold Release Technique	Mon 9/27/10	Sat 11/20/10	9/29/10	11/20/10
35	Mold Assembly and Release Application	Sun 11/28/10	Wed 12/1/10	12/1/10	12/5/10
36	Pre-batching of Final Structural Mix	Sun 12/12/10	Thu 12/16/10	12/16/10	12/18/10
37	Pre-cutting Reinforcement	Sat 12/18/10	Sat 12/18/10	1/7/11	1/8/11
38	Preparation of Aesthetic Components	Fri 12/10/10	Sun 12/19/10	12/19/10	1/9/11
39	Concrete Placement	Sun 12/19/10	Sun 12/19/10	1/9/11	1/9/11
40	Initial Cure with Mold	Sun 12/19/10	Sun 1/9/11	1/9/11	1/23/11
41	Mold Removal	Mon 1/10/11	Mon 1/10/11	1/24/11	1/24/11
42	Final Curing	Wed 1/12/11	Tue 1/25/11	1/25/11	2/7/11
43	**Finishes and Aesthetics**	**Sat 1/15/11**	**Tue 3/29/11**	**1/17/11**	**3/27/11**
44	Sanding	Sat 1/15/11	Mon 1/31/11	1/17/11	1/31/11
45	Inlays, Outlays, and Staining	Wed 2/2/11	Wed 3/23/11	2/2/11	3/21/11
46	Sealing	Thu 3/24/11	Mon 3/28/11	3/23/11	3/26/11
47	Finishes Complete	Tue 3/29/11	Tue 3/29/11	3/27/11	3/27/11
48	**Product Display**	**Thu 9/16/10**	**Sun 3/27/11**	**9/16/10**	**3/30/11**
49	Engineer's Notebook Collection & Formatting	Thu 9/16/10	Thu 3/24/11	9/16/10	3/29/11
50	Engineer's Notebook Complete	Fri 3/25/11	Fri 3/25/11	3/30/11	3/30/11
51	Cross Section Construction	Tue 1/11/11	Fri 3/25/11	1/21/11	3/25/11
52	Tabletop Display Construction	Tue 1/11/11	Fri 3/25/11	2/10/11	3/25/11
53	Stands Construction	Tue 1/11/11	Fri 3/25/11	12/10/10	3/17/11
54	Display Components Complete	Sun 3/27/11	Sun 3/27/11	On Track	3/30/11
55	**Design Paper**	**Mon 1/10/11**	**Fri 2/25/11**	**1/10/11**	**2/28/11**
56	Paper Outline and Draft	Mon 1/10/11	Sun 2/13/11	1/10/11	2/18/11
57	Professional Reviews	Mon 2/14/11	Mon 2/21/11	2/19/11	2/23/11
58	Final Revision and Refinements	Mon 2/21/11	Fri 2/25/11	2/24/11	2/28/11
59	Design Paper Submittal	Fri 2/25/11	Fri 2/25/11	2/28/11	2/28/11
60	**Presentation**	**Sun 2/20/11**	**Sat 4/2/11**	**2/20/11**	**On Track**
61	Selection of Presenters and Create Presentation	Sun 2/20/11	Fri 3/11/11	2/20/11	3/14/11
62	Practice Presentation and Review Possible Questions	Sat 3/12/11	Fri 6/17/11	3/15/11	On Track
63	**Conference Competition**	**Fri 4/1/11**	**Sun 4/3/11**	**4/1/11**	**4/3/11**
64	North Central Conference Competition	Fri 4/1/11	Sun 4/3/11	4/1/11	4/3/11
65	**National Competition**	**Thu 6/16/11**	**Sun 6/19/11**	**On Track**	**On Track**
66	National Concrete Canoe Competition	Thu 6/16/11	Sun 6/19/11	On Track	On Track



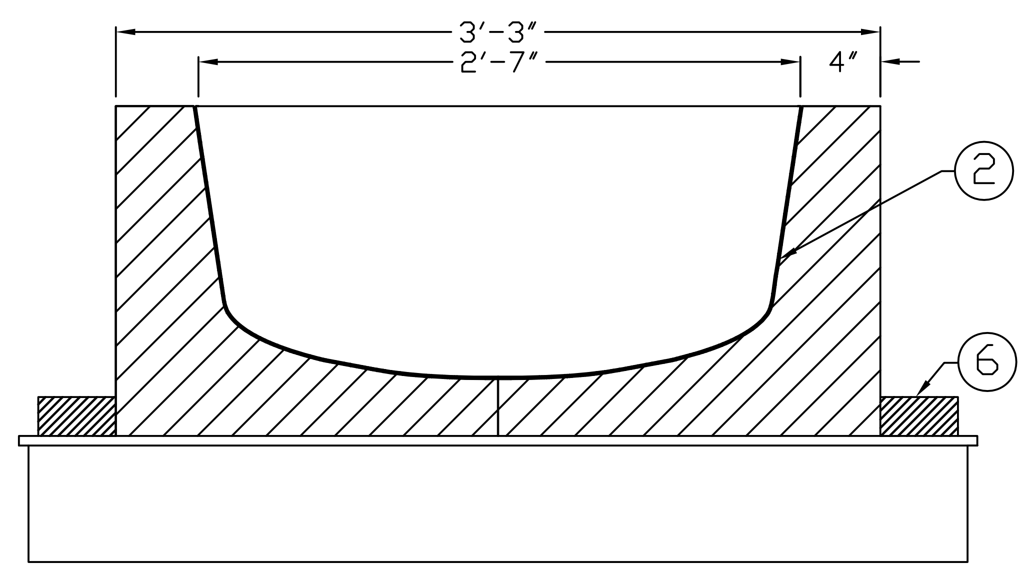
Critical — Task — Baseline — Milestone — Summary



SECTION A-A



DETAIL C
SCALE 4:1



SECTION B-B
SCALE 2:1

BILL OF MATERIALS

NO.	DESCRIPTION	QTY.	UNIT COST	SUBTOTAL
1	POLYSTYRENE FOAM MOLD	2 PIECES	$800/PIECE	$1,600
2	EPOXY	1 GAL	$42.20/GAL	$42.20
3	VINYL INLAY	83 SQ IN	$0.12/SQ IN	$9.96
4	1/2" OSB	48 SQ FT	$0.42/SQ FT	$20.16
5	2"X6" LUMBER	56 LN FT	$0.48/LN FT	$26.88
6	2"X4" LUMBER	4 LN FT	$0.35/LN FT	$1.40
7	3/8" X 8" BOLT ASSEMBLY	2 EA.	$0.75 EA.	$1.50
			TOTAL	$1,702.10

MichiganTech

MICHIGAN TECHNOLOGICAL
UNIVERSITY
CONCRETE CANOE
1400 TOWNSEND DRIVE
HOUGHTON, MI 49931

DRAWING NAME: MOLD DESIGN	DATE: 2/24/2011
BOAT NAME: FRONTIER	
DRAWN BY: ANDREW SCIPIONI	SCALE: 1:20
CHECKED BY: JON ZALUD	SHEET: 9

Appendix A – References

ASTM. (2007). “Standard Test Method for Bulk Density (“Unit Weight”) and Voids in Aggregate.” *C29/C29M-07,* West Conshohocken, Pennsylvania.

ASTM. (2009). “Standard Practice for Making and Curing Concrete Test Specimens in the Field.”*C31/C31M-09A,* West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.”*C39/C39M-05,*West Conshohocken, Pennsylvania.

ASTM. (2007). “Standard Terminology Relating to Concrete and Concrete Aggregates.” *C125-07,*West Conshohocken, Pennsylvania.

ASTM. (2007). “Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate.” *C127-07,* West Conshohocken, Pennsylvania.

ASTM. (2007). “Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate.” *C128-07,* West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Test Method for Sieve Analysis of Fine and Course Aggregates.” *C136-06,* West Conshohocken, Pennsylvania.

ASTM. (2009). “Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete.” *C138 / C138M - 09,* West Conshohocken, Pennsylvania.

ASTM. (2009). “Standard Test Method for Slump of Hydraulic-Cement Concrete.” *C143 / C143M - 09,* West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Specification for Portland Cement.” *C150-05,* West Conshohocken, Pennsylvania.

ASTM. (2008). “Standard Practice for Sampling Freshly Mixed Concrete.” *C172-08,* West Conshohocken, Pennsylvania.

ASTM. (2009). “Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method.” *C173 / C173M - 09,* West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method.” *C231 / C231M -09b,* West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Specifications for Air-Entraining Admixtures for Concrete.” *C260-01,* West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression.” *C469-02,* West Conshohocken, Pennsylvania.

ASTM. (2008). “Standard Specification for Chemical Admixtures for Concrete.” *C494/C494M-08a,* West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.” *C496/C496M-04,* West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Test Method for Determining Density of Structural Lightweight Concrete.”*C567-05a,* West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Specification for Pigments for Integrally Colored Concrete.” *C979-05,* West Conshohocken, Pennsylvania.

ASTM. (2009). “Standard Specification for Ground Granulated Blast-Furnace Slag for use in Concrete and Mortars.” *C989-09,* Conshohocken, Pennsylvania.

ASTM. (2009). “Standard Specification for Fiber-Reinforced Concrete and Shotcrete.” *C1116-09,*West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Specification for Latex and Powder Polymer Modifiers for Hydraulic Cement Concrete and Mortar.” *C1438-99e1,* West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Test Method for Poisson’s Ratio at Room Temperature.” *E132-04,* West Conshohocken, Pennsylvania.

Callister, William D. (2008). “Fundamentals of Materials Science and Engineering: An Integrated Approach.” John Wiley & Sons, Inc.

Michigan Tech Concrete Canoe. (2009). “Polaris.” NCCC Design Paper, Michigan Technological University, Houghton, Michigan.

Michigan Tech Concrete Canoe. (2010). “Yooper.” NCCC Design Paper, Michigan Technological University, Houghton, Michigan.

NCCC Rules. (2011). “2011 American Society of Civil Engineers National Concrete Canoe Competition Rules and Regulations,” online at: http://content.asce.org/files/pdf/2011NCCCRules-Final091710.pdf

Appendix B – Mixture Proportions

	Mixture: Kodiak Structural		Design Proportions (Non SSD)		Actual Batch Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3): 0.057							
Cementitious Materials		SG*	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Federal White Type I White Portland Cement	3.15	326.04	1.659	0.68	0.003	332.40	1.691
CM2	Lafarge NewCem® GGBFS	2	157.80	1.264	0.33	0.003	160.88	1.289
CM3	VCAS™ 8	2.60	157.80	0.973	0.33	0.002	160.88	0.992
CM4	VCAS™ 160	2.60	157.80	0.973	0.33	0.002	160.88	0.992
	Total Cementitious Materials:		**799.45**	**4.868**	**1.67**	**0.010**	**815.04**	**4.963**
Fibers								
F1	Nycon Kuralon™ RF4000 30mm	1.30	10.53	0.130	0.02	0.000	10.74	0.132
F2	Nycon Kuralon™ RECS15 8mm	1.30	5.27	0.065	0.01	0.000	5.37	0.066
	Total Fibers:		**15.80**	**0.195**	**0.03**	**0.000**	**16.11**	**0.199**
Aggregates								
A1	Poraver® 1.0-2.0mm Abs: 2.0	0.53	78.48	2.373	0.16	0.005	80.01	2.419
A2	Poraver® 0.5-1.0mm Abs: 2.0	0.71	78.48	1.771	0.16	0.004	80.01	1.806
A3	Poraver® 0.25-0.5mm Abs: 2.0	0.88	82.59	1.504	0.17	0.003	84.20	1.533
A4	3M™ K-1 Abs: 0.0	0.14	85.64	9.804	0.18	0.020	87.31	9.995
A5	Lafarge True Lite Aggregate™ Abs: 2.0	3.00	108.82	0.581	0.23	0.001	110.94	0.593
	Total Aggregates:		**434.01**	**16.033**	**0.91**	**0.033**	**442.48**	**16.346**
Water								
W1	Water for CM Hydration (W1a+W1b)	1.00	239.83	3.844	0.50	0.008	244.51	3.918
	W1a. Water from Admixtures^		94.93		0.002		96.78	
	W2b. Additional Water		144.91		0.50		147.73	
W2	Water for Aggregates, SSD	1.00	6.97		0.01		7.10	
	Total Water *(W1 +W2)*:		**246.80**	**3.844**	**0.52**	**0.008**	**251.62**	**3.918**
Solids Content of Latex Admixtures and Dyes								
S1	Xypex Xycrilic-Admix	1.05	112.19	1.712	0.23	0.004	114.38	1.746
	Total Solids of Admixtures:		**112.19**	**1.712**	**0.23**	**0.004**	**114.38**	**1.746**
Admixtures (including Pigments in Liquid Form)		% Solids	Dosage (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)	Amount (fl oz)	Water‡ in Admixture (lb)	Dosage (fl oz/cwt)	Water‡ in Admixture (lb)
Ad1	Xypex Xycrilic-Admix 8.76 *lb/gal*	28.02	215.24	84.77	3.43	0.002	219.44	86.42
Ad2	BASF Glenium 3030® NS HRWR 9.18 *lb/gal*	20.27	22.23	10.16	0.01	0.000	22.67	10.36
	Water from Admixtures (W1a) :			**94.93**		**0.002**		**96.78**
	Cement-Cementitious Materials Ratio		0.41		0.41		0.41	
	Water-Cementitious Materials Ratio		0.3		0.3		0.3	
	Slump, Slump Flow, *in.*		1.00 +/ 0.50		0.50		0.50	
M	Mass of Concrete, *lbs*		1608.26		3.37		1639.62	
V	Absolute Volume of Concrete, *ft*^{3}		26.652		0.055		27.172	
T	Theoretical Density, *lb/ft*^{3} = (M/V)		60.34		61.17		60.34	
D	Design Density, *lb/ft*^{3} = (M/27)		59.57					
D	Measured Density, *lb/ft*^{3}				60.20		60.20	
A	Air Content, % = [(T-D)/T x 100%]		1.29		1.58		0.24	
Y	Yield, ft^3 = (M/D)		27		0.056		27	
R_y	Relative Yield = (Y/YD)				0.981			

Some numbers shown may be off (second and third decimal place) due to the use of Excel spreadsheet (rounding) *Abs. = Absorption (in %)*

** For aggregates, provide ASTM C 128 oven-dry bulk specific gravity* *‡ Water content of admixture*

^ If impact on w/cm is less than 0.01, enter zero

	Mixture: Kodiak End Cap			Design Proportions (Non SSD)		Actual Batch Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3):	0.057							
Cementitious Materials			SG*	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Federal White Type I White Portland Cement		3.15	318.09	1.618	0.68	0.003	327.43	1.666
CM2	Lafarge NewCem® GGBFS		2	153.96	1.234	0.33	0.003	158.48	1.270
CM3	VCAS™ 8		2.60	153.96	0.949	0.33	0.002	158.48	0.977
CM4	VCAS™ 160		2.60	153.96	0.949	0.33	0.002	158.48	0.977
	Total Cementitious Materials:			**779.95**	**4.750**	**1.67**	**0.010**	**802.86**	**4.889**
Aggregates									
A1	Poraver® 1.0-2.0mm	Abs: 2.0	0.53	68.34	2.067	0.15	0.004	70.35	2.127
A2	Poraver® 0.5-1.0mm	Abs: 2.0	0.71	68.34	1.543	0.15	0.003	70.35	1.588
A3	Poraver® 0.25-0.5mm	Abs: 2.0	0.88	71.63	1.305	0.15	0.003	73.74	1.343
A4	3M™ K-1	Abs: 0.0	0.12	77.39	10.002	0.17	0.021	79.66	10.295
A5	Lafarge True Lite Aggregate™	Abs: 2.0	3.00	96.20	0.514	0.21	0.001	99.02	0.529
	Total Aggregates:			**381.91**	**15.429**	**0.82**	**0.033**	**393.13**	**15.882**
Water									
W1	Water for CM Hydration (W1a+W1b)		1.00	233.99	3.750	0.50	0.008	240.86	3.860
	W1a. Water from Admixtures^			92.61		0.00		95.33	
	W2b. Additional Water			141.37		0.50		145.52	
W2	Water for Aggregates, SSD		1.00	6.09		0.01		6.27	
	Total Water *(W1 +W2)* **:**			**240.08**	**3.750**	**0.51**	**0.008**	**247.13**	**3.860**
Solids Content of Latex Admixtures and Dyes									
S1	Xypex Xycrilic-Admix		1.05	109.45	1.671	0.23	0.004	112.67	1.720
	Total Solids of Admixtures:			**109.45**	**1.671**	**0.23**	**0.004**	**112.67**	**1.720**
Admixtures (including Pigments in Liquid Form)			% Solids	Dosage (fl oz/cw t)	Water‡ in Admixture (lb/yd^3)	Amount (fl oz)	Water‡ in Admixture (lb)	Dosage (fl oz/cw t)	Water‡ in Admixture (lb)
Ad1	Xypex Xycrilic-Admix	8.76 *lb/gal*	28.02	215.24	82.70	3.43	0.002	221.57	85.13
Ad2	BASF Glenium 3030® NS HRWR	9.18 *lb/gal*	20.27	22.23	9.91	0.01	0.000	22.88	10.21
	Water from Admixtures (W1a) **:**				**92.61**		**0.002**		**95.33**
	Cement-Cementitious Materials Ratio			0.41		0.41		0.41	
	Water-Cementitious Materials Ratio			0.3		0.3		0.3	
	Slump, Slump Flow, *in.*			2.00 +/ 0.50		1.50		1.50	
M	Mass of Concrete, *lbs*			1511.39		3.24		1555.79	
V	Absolute Volume of Concrete, ft^3			25.599		0.055		26.351	
T	Theoretical Density, lb/ft^3	= (M/V)		59.04		59.04		59.04	
D	Design Density, lb/ft^3	= (M/27)		55.98					
D	Measured Density, lb/ft^3					58.55		58.55	
A	Air Content, %	= [(T-D)/T x 100%]		5.19		0.83		0.83	
Y	Yield, ft^3	= (M/D)		27		0.055		27	
R_y	Relative Yield	= (Y/YD)				0.971			

Some numbers shown may be off (second and third decimal place) due to the use of Excel spreadsheet (rounding) *Abs. = Absorption (in %)*

** For aggregates, provide ASTM C 128 oven-dry bulk specific gravity* *‡ Water content of admixture*

^ If impact on w/cm is less than 0.01, enter zero

	Mixture: Kodiak Finishing		Design Proportions (Non SSD)		Actual Batch Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3): 0.057							
Cementitious Materials		SG*	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Federal White Type I White Portland Cement	3.15	298.34	1.518	0.64	0.003	290.67	1.479
CM2	Lafarge NewCem® GGBFS	2	150.71	1.208	0.32	0.003	146.84	1.177
CM3	VCAS™ 8	2.60	152.76	0.942	0.33	0.002	148.83	0.917
CM4	VCAS™ 160	2.60	100.47	0.619	0.22	0.001	97.89	0.603
	Total Cementitious Materials:		**702.29**	**4.286**	**1.51**	**0.009**	**684.23**	**4.176**
Aggregates								
A1	Poraver® 0.25-0.5mm Abs: 2.0	0.88	252.21	4.593	0.54	0.010	245.72	4.475
A2	3M™ K-1 Abs: 0.0	0.14	98.42	11.266	0.21	0.024	95.89	10.977
A3	Lafarge True Lite Aggregate™ Abs: 2.0	3.00	133.28	0.712	0.29	0.002	129.85	0.694
	Total Aggregates:		**483.91**	**16.571**	**1.04**	**0.036**	**471.47**	**16.145**
Water								
W1	Water for CM Hydration (W1a+W1b)	1.00	210.69	3.376	0.45	0.007	205.27	3.290
	W1a. Water from Admixtures^		144.42		0.00		140.71	
	W2b. Additional Water		66.27		0.45		64.56	
W2	Water for Aggregates, SSD	1.00	7.71		0.02		7.51	
	Total Water *(W1 +W2)* **:**		**218.40**	**3.376**	**0.47**	**0.007**	**212.78**	**3.290**
Solids Content of Latex Admixtures and Dyes								
S1	Xypex Xycrilic-Admix	1.05	164.96	2.518	0.35	0.005	160.72	2.453
	Total Solids of Admixtures:		**164.96**	**2.518**	**0.35**	**0.005**	**160.72**	**2.453**
Admixtures (including Pigments in Liquid Form)		% Solids	Dosage (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)	Amount (fl oz)	Water‡ in Admixture (lb)	Dosage (fl oz/cwt)	Water‡ in Admixture (lb)
Ad1	Xypex Xycrilic-Admix 8.76 *lb/gal*	28.02	360.27	124.64	5.18	0.003	351.01	121.43
Ad2	BASF Glenium 3030® NS HRWR 9.18 *lb/gal*	20.27	49.26	19.78	0.02	0.000	47.99	19.27
	Water from Admixtures (W1a) **:**			**144.42**		**0.004**		**140.71**
Cement-Cementitious Materials Ratio			0.42		0.42		0.42	
Water-Cementitious Materials Ratio			0.3		0.3		0.3	
Slump, Slump Flow, *in.*			4.50 +/ 0.50		5.00		5.00	
M	Mass of Concrete, *lbs*		1569.56		3.38		1529.21	
V	Absolute Volume of Concrete, *ft^3*		26.752		0.058		26.064	
T	Theoretical Density, *lb/ft^3* = (M/V)		58.67		58.67		58.67	
D	Design Density, *lb/ft^3* = (M/27)		58.13					
D	Measured Density, *lb/ft^3*				57.69		57.69	
A	Air Content, % = [(T-D)/T x 100%]		0.92		1.67		1.67	
Y	Yield, ft^3 = (M/D)		27		0.059		27	
R_y	Relative Yield = (Y/YD)				1.026			

Some numbers shown may be off (second and third decimal place) due to the use of Excel spreadsheet (rounding) *Abs. = Absorption (in %)*

** For aggregates, provide ASTM C 128 oven-dry bulk specific gravity* *‡ Water content of admixture*

^ If impact on w/cm is less than 0.01, enter zero

	Mixture: Kodiak Red Finishing			Design Proportions (Non SSD)		Actual Batch Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft³):	0.057							
Cementitious Materials			SG*	Amount (lb/yd³)	Volume (ft³)	Amount (lb)	Volume (ft³)	Amount (lb/yd³)	Volume (ft³)
CM1	Federal White Type I White Portland Cement		3.15	300.48	1.529	0.64	0.003	303.36	1.543
CM2	Lafarge NewCem® GGBFS		2.99	187.74	1.006	0.40	0.002	189.53	1.016
CM3	VCAS™ 8		2.60	112.64	0.694	0.24	0.001	113.72	0.701
CM4	VCAS™ 160		2.60	150.19	0.926	0.32	0.002	151.63	0.935
	Total Cementitious Materials:			**751.05**	**4.155**	**1.60**	**0.009**	**758.23**	**4.195**
Aggregates									
A1	Poraver® 0.5-1.0mm	Abs: 8.0	0.71	140.96	3.182	0.30	0.007	142.31	3.212
A2	Poraver® 0.25-0.5mm	Abs: 6.3	0.88	253.71	4.620	0.54	0.010	256.13	4.664
A3	3M™ K-1	Abs: 22.0	0.12	28.21	3.646	0.06	0.008	28.48	3.681
A4	Lafarge True Lite Aggregate™	Abs: 12.1	2.16	140.96	1.046	0.30	0.002	142.31	1.056
	Total Aggregates:			**563.84**	**12.494**	**1.20**	**0.027**	**569.22**	**12.613**
Water									
W1	Water for CM Hydration (W1a+W1b)		1.00	262.87	4.213	0.56	0.009	265.38	4.253
	W1a. Water from Admixtures^			94.81		0.00		95.71	
	W2b. Additional Water			168.06		0.56		169.67	
W2	Water for Aggregates, SSD		1.00	50.52		0.11		51.01	
	Total Water *(W1 +W2)* **:**			**313.39**	**4.213**	**0.67**	**0.009**	**316.39**	**4.253**
Solids Content of Latex Admixtures and Dyes									
S1	Xypex Xycrilic-Admix		1.05	100.20	1.529	0.21	0.003	101.15	1.544
S2	Red Pigment		8.05	11.41	0.023	0.02	0.000	11.52	0.023
	Total Solids of Admixtures:			**100.20**	**1.529**	**0.21**	**0.003**	**101.15**	**1.544**
Admixtures (including Pigments in Liquid Form)			% Solids	Dosage (fl oz/cwt)	Water‡ in Admixture (lb/yd³)	Amount (fl oz)	Water‡ in Admixture (lb)	Dosage (fl oz/cwt)	Water‡ in Admixture (lb)
Ad1	Xypex Xycrilic-Admix	8.76 *lb/gal*	28.02	204.62	75.70	2.97	0.002	206.57	76.43
Ad2	BASF Glenium 3030® NS HRWR	9.18 *lb/gal*	20.27	44.48	19.10	0.68	0.000	44.91	19.29
	Water from Admixtures (W1a) **:**				**94.81**		**0.002**		**95.71**
	Cement-Cementitious Materials Ratio			0.40		0.40		0.40	
	Water-Cementitious Materials Ratio			0.35		0.35		0.35	
	Slump, Slump Flow, *in.*			4.00 +/ 0.50		4.50		4.50	
M	Mass of Concrete, *lbs*			1728.48		3.67		1745.00	
V	Absolute Volume of Concrete, *ft³*			22.391		0.048		22.605	
T	Theoretical Density, *lb/ft³*	= (M/V)		77.20		77.20		77.20	
D	Design Density, *lb/ft³*	= (M/27)		64.02					
D	Measured Density, *lb/ft³*					65.07		65.07	
A	Air Content, %	= [(T-D)/T x 100%]		17.07		15.71		15.71	
Y	Yield, ft³	= (M/D)		27		0.056		27	
R_y	Relative Yield	= (Y/YD)				0.991			

Some numbers shown may be off (second and third decimal place) due to the use of Excel spreadsheet (rounding) *Abs. = Absorption (in %)*

** For aggregates, provide ASTM C 128 oven-dry bulk specific gravity* *‡ Water content of admixture*

^ If impact on w/cm is less than 0.01, enter zero

				Design Proportions (Non SSD)		Actual Batch Proportions		Yielded Proportions	
Mixture: Kodiak Blue Finishing									
Y_D	Design Batch Size (ft^3):	0.057							
Cementitious Materials			SG*	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Federal White Type I White Portland Cement		3.15	300.48	1.529	0.64	0.003	304.15	1.547
CM2	Lafarge NewCem® GGBFS		2.99	187.74	1.006	0.40	0.002	190.03	1.018
CM3	VCAS™ 8		2.60	112.64	0.694	0.24	0.001	114.02	0.703
CM4	VCAS™ 160		2.60	150.19	0.926	0.32	0.002	152.02	0.937
	Total Cementitious Materials:			**751.05**	**4.155**	**1.60**	**0.009**	**760.21**	**4.206**
Aggregates									
A1	Poraver® 0.5-1.0mm	Abs: 8.0	0.71	140.96	3.182	0.30	0.007	142.68	3.220
A2	Poraver® 0.25-0.5mm	Abs: 6.3	0.88	253.71	4.620	0.54	0.010	256.80	4.677
A3	3M™ K-1	Abs: 22.0	0.12	28.21	3.646	0.06	0.008	28.56	3.691
A4	Lafarge True Lite Aggregate™	Abs: 12.1	2.16	140.96	1.046	0.30	0.002	142.68	1.059
	Total Aggregates:			**563.84**	**12.494**	**1.20**	**0.027**	**570.71**	**12.646**
Water									
W1	Water for CM Hydration (W1a+W1b)			262.87	4.213	0.56	0.009	266.07	4.264
	W1a. Water from Admixtures^		1.00	94.81		0.00		95.96	
	W2b. Additional Water			168.06		0.56		170.11	
W2	Water for Aggregates, SSD		1.00	50.52		0.11		51.14	
	Total Water *(W1 +W2)* **:**			**313.39**	**4.213**	**0.67**	**0.009**	**317.21**	**4.264**
Solids Content of Latex Admixtures and Dyes									
S1	Xypex Xycrilic-Admix		1.05	100.20	1.529	0.21	0.003	101.42	1.548
S2	Blue Pigment		2.69	0.31	0.002	0.00	0.000	0.31	0.002
	Total Solids of Admixtures:			**100.20**	**1.529**	**0.21**	**0.003**	**101.42**	**1.548**
Admixtures (including Pigments in Liquid Form)			% Solids	Dosage (fl oz/cw t)	Water‡ in Admixture (lb/yd^3)	Amount (fl oz)	Water‡ in Admixture (lb)	Dosage (fl oz/cw t)	Water‡ in Admixture (lb)
Ad1	Xypex Xycrilic-Admix	8.76 *lb/gal*	28.02	204.62	75.70	2.97	0.002	207.11	76.63
Ad2	BASF Glenium 3030® NS HRWR	9.18 *lb/gal*	20.27	44.48	19.10	0.68	0.000	45.02	19.34
	Water from Admixtures (W1a) **:**				**94.81**		**0.002**		**95.96**
Cement-Cementitious Materials Ratio				0.40		0.40		0.40	
Water-Cementitious Materials Ratio				0.35		0.35		0.35	
Slump, Slump Flow, *in.*				4.00 +/ 0.50		4.50		4.50	
M	Mass of Concrete, *lbs*			1728.48		3.67		1749.56	
V	Absolute Volume of Concrete, ft^3			22.391		0.048		22.664	
T	Theoretical Density, lb/ft^3	= (M/V)		77.20		77.20		77.20	
D	Design Density, lb/ft^3	= (M/27)		64.02					
D	Measured Density, lb/ft^3					65.24		65.24	
A	Air Content, %	= [(T-D)/T x 100%]		17.07		15.49		15.49	
Y	Yield, ft^3	= (M/D)		27		0.056		27	
R_y	Relative Yield	= (Y/YD)				0.988			

Some numbers shown may be off (second and third decimal place) due to the use of Excel spreadsheet (rounding) *Abs. = Absorption (in %)*

* *For aggregates, provide ASTM C 128 oven-dry bulk specific gravity* ‡ *Water content of admixture*

^ *If impact on w/cm is less than 0.01, enter zero*

Mixture: Kodiak Green Finishing				Design Proportions (Non SSD)		Actual Batch Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft³):	0.057							
Cementitious Materials			SG*	Amount (lb/yd³)	Volume (ft³)	Amount (lb)	Volume (ft³)	Amount (lb/yd³)	Volume (ft³)
CM1	Federal White Type I White Portland Cement		3.15	300.48	1.529	0.64	0.003	302.56	1.539
CM2	Lafarge NewCem® GGBFS		2.99	187.74	1.006	0.40	0.002	189.04	1.013
CM3	VCAS™ 8		2.60	112.64	0.694	0.24	0.001	113.42	0.699
CM4	VCAS™ 160		2.60	150.19	0.926	0.32	0.002	151.23	0.932
	Total Cementitious Materials:			**751.05**	**4.155**	**1.60**	**0.009**	**756.25**	**4.184**
Aggregates									
A1	Poraver® 0.5-1.0mm	Abs: 8.0	0.71	140.96	3.182	0.30	0.007	141.93	3.204
A2	Poraver® 0.25-0.5mm	Abs: 6.3	0.88	253.71	4.620	0.54	0.010	255.46	4.652
A3	3M™ K-1	Abs: 22.0	0.12	28.21	3.646	0.06	0.008	28.41	3.671
A4	Lafarge True-Lite Lightweight Aggregate™	Abs: 12.1	2.16	140.96	1.046	0.30	0.002	141.93	1.053
	Total Aggregates:			**563.84**	**12.494**	**1.20**	**0.027**	**567.74**	**12.580**
Water									
W1	Water for CM Hydration (W1a+W1b)		1.00	262.87	4.213	0.56	0.009	264.69	4.242
	W1a. Water from Admixtures^			94.81		0.00		95.46	
	W2b. Additional Water			168.06		0.56		169.22	
W2	Water for Aggregates, SSD		1.00	50.52		0.11		50.87	
	Total Water *(W1 +W2)* **:**			**313.39**	**4.213**	**0.67**	**0.009**	**315.56**	**4.242**
Solids Content of Latex Admixtures and Dyes									
S1	Xypex Xycrilic-Admix		1.05	100.20	1.529	0.21	0.003	100.89	1.540
S2	Green Pigment		6.63	2.07	0.005	0.00	0.000	2.09	0.005
	Total Solids of Admixtures:			**100.20**	**1.529**	**0.21**	**0.003**	**100.89**	**1.540**
Admixtures (including Pigments in Liquid Form)			% Solids	Dosage (fl oz/cw t)	Water‡ in Admixture (lb/yd³)	Amount (fl oz)	Water‡ in Admixture (lb)	Dosage (fl oz/cw t)	Water‡ in Admixture (lb)
Ad1	Xypex Xycrilic-Admix	8.76 *lb/gal*	28.02	204.62	75.70	2.97	0.002	206.03	76.23
Ad2	BASF Glenium 3030® NS HRWR	9.18 *lb/gal*	20.27	44.48	19.10	0.68	0.000	44.79	19.24
	Water from Admixtures (W1a) **:**				**94.81**		**0.002**		**95.46**
	Cement-Cementitious Materials Ratio			0.40		0.40		0.40	
	Water-Cementitious Materials Ratio			0.35		0.35		0.35	
	Slump, Slump Flow, *in.*			4.00 +/ 0.50		4.50		4.50	
M	Mass of Concrete, *lbs*			1728.48		3.67		1740.44	
V	Absolute Volume of Concrete, *ft³*			22.391		0.048		22.546	
T	Theoretical Density, *lb/ft³*	= (M/V)		77.20		77.20		77.20	
D	Design Density, *lb/ft³*	= (M/27)		64.02					
D	Measured Density, *lb/ft³*					64.90		64.90	
A	Air Content, %	= [(T-D)/T x 100%]		17.07		15.93		15.93	
Y	Yield, ft³	= (M/D)		27		0.057		27	
R_y	Relative Yield	= (Y/YD)				0.993			

Some numbers shown may be off (second and third decimal place) due to the use of Excel spreadsheet (rounding) *Abs. = Absorption (in %)*

* *For aggregates, provide ASTM C 128 oven-dry bulk specific gravity* ‡ *Water content of admixture*

^ *If impact on w/cm is less than 0.01, enter zero*

Appendix C – Bill of Materials

Lafarge NewCem® GGBFS	lb	28.5	$ 0.0054	$ 0.15
VCAS™ 8	lb	28.5	$ 0.35	$ 9.98
VCAS™ 160	lb	28.5	$ 0.35	$ 9.98
Poraver® 1.0-2.0mm	lb	11.8	$ 0.85	$ 10.03
Poraver® 0.5-1.0mm	lb	8.83	$ 0.85	$ 7.51
Poraver® 0.25-0.5mm	lb	11.8	$ 0.85	$ 10.03
Lafarge True Lite Lightweight Aggregate™	lb	14.7	$ 0.003	$ 0.04
3M™ K-1	lb	11.8	$ 11.03	$ 130.15
Nycon Kuralon™ RECS15 (8mm) PVA	lb	0.99	$ 6.60	$ 6.53
Nycon Kuralon™ RF4000 (30mm) PVA	lb	1.98	$ 6.90	$ 13.66
Xypex Xycrylic-Admix	lb	14.1	$ 5.10	$ 71.95
BASF Glenium® 3030 NS	gal	0.16	$ 15.00	$ 2.40
Chromarat C-Grid® CT275	sq ft	105	$ 1.91	$ 200.67
Direct Colors Red Pigment	oz	1.17	$ 0.74	$ 0.87
Direct Colors Light Green Pigment	oz	0.07	$ 0.74	$ 0.05
Direct Colors Light Blue Pigment	oz	0.04	$ 0.74	$ 0.03
Ameripolish Water-Based Concrete Dye Black	gal	0.20	$ 68.95	$ 13.79
Ameripolish Water-Based Concrete Dye Blue	gal	0.10	$ 68.95	$ 6.90
Ameripolish Water-Based Concrete Dye Green	gal	0.05	$ 68.95	$ 3.45
Ameripolish Water-Based Concrete Dye Red	gal	0.10	$ 68.95	$ 6.90
Ameripolish Water-Based Concrete Dye Yellow	gal	0.05	$ 68.95	$ 3.45
ChemMasters Crystal Clear-A	gal	1.00	$ 22.00	$ 22.00
Huron Technologies Release Coating 7572	gal	0.25	$ 22.50	$ 5.63
Mold	LS	1	$ 1,702.10	$ 1,702.10
			Total Production Cost	**$ 2,253.64**