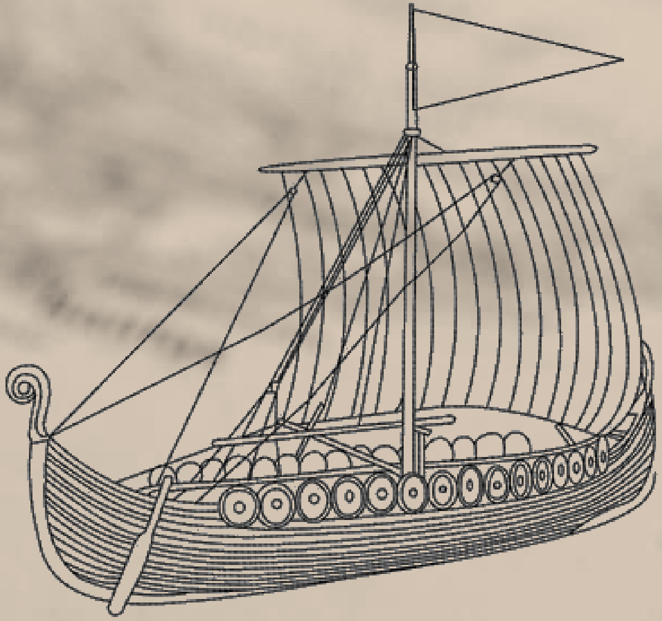
DREKAR

University of Michigan



2013 Design Paper

Concrete Canoe
UNIVERSITY OF MICHIGAN

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Executive Summary

The University of Michigan, one of the first research institutions in the world, was founded in 1817, about 20 years before Michigan became a state. Throughout its history, it has been a leader in academic excellence, and highly respected for its renowned research and education systems. We trace our excellence back to the age of the Vikings, whose blood still runs in our veins. These Norse explorers, warriors, and merchants explored and settled wide areas of Europe, Asia, and the North Atlantic Islands. Similarly, Michigan Engineering promotes the expansion of fundamental engineering knowledge both in the field and classroom. Undergraduate research and student project teams allow students to obtain hands-on engineering experience, helping to establish MCCT as a major competitor in the North Central Regional Competition. To honor the Viking spirit, we have created *DREKAR* to once again reclaim Viking glory.

Michigan is perhaps most well-known for its College of Engineering, founded in 1854, along with its Medical School and athletic programs. Descending from the Viking triumphs and superiority, we have built *DREKAR* to continue this legacy and to “Hail to the Victors”. A Drekar is a Viking raiding ship, which is ornately decorated with dragons to ward off the legendary sea monsters. In 2011, Ann Arbor hosted the North Central ASCE Student Conference and served as a home to friendly competition. Throughout the years, the Michigan Concrete Canoe team has expanded on campus. Students of more diverse backgrounds and areas of study, outside of civil engineering, have joined the team, improving our performance each year. *IT’S A TRAP*, the 2011 canoe, placed second in Technical Presentation, third in the Technical Report, and fifth overall. Last year, *CRONUS* had our strongest finish to date, placing fourth in Technical Report and in Final Product, for an overall finish of fourth place.

With a new captain for our Viking ship, this year’s crew has once again expanded in size. However, we retained many experienced members, as few members parted ways since last year. This additional experience proved useful throughout this year and allowed for a more streamlined design, build, and test processes. We were able to create new designs and concrete mixes and then test them as a team to determine which would work best for us. Once again, we completed safety training to work in the Wilson Student Team Project Center, the site of *DREKAR’s* construction.

Innovations for the creation of DREKAR included an optimized hull design for the best racing capability and the addition of new admixtures to our concrete mix design. With a large, diverse, and more experienced team, we are confident that our canoe will live up to its promising capabilities, and that *DREKAR* will not let down its Viking predecessors.

DREKAR	
Weight	173 lbs.
Length	19 Feet 10 Inches
Width	30 Inches
Depth	14 Inches
Hull Thickness	½ Inch
Concrete Colors	Grey
Concrete Unit Weight	66.41(wet)/65.22(dry) lb/ft^3
Compressive Strength	1241 psi
Split Tensile Strength	196.4 psi
Flexural Strength	214.1 psi
Reinforcement	Fiberglass Mesh

Project Management

The project began this year on August 31, 2012, with the first of three recruitment activities for the year. Upon release of the NCCC rules, research on mix design and hull design began. This year, MCCT wanted to focus on quality control and assurance, and a checklist system based on NCCC rules and ASTM standards was devised for each aspect of the project, and managed by a dedicated team member. This year's schedule was modeled after the 2012 project schedule. Major activities were either classified as Milestone activities or Critical Path events. Milestone activities marked the beginning of each project phase. The following Milestone activities were identified:

- Recruit New Members
- Research Aggregate Materials
- Mix & Test Sample Batches
- Cut & Assemble Mold
- Place Canoe
- De-mold & Sand Canoe
- Stain & Seal Canoe
- Create Display & Stand

Critical Path events were steps that needed to be completed in order to move on to the next phase of the project. The Critical Path events are as follows:

- Hold Mass Recruitment Meeting
- Finalize Mix Design
- Cut Foam Mold
- Place Canoe
- De-mold Canoe
- Attend Competition

The "Place Canoe" event was the most important critical path event, as any delay in canoe construction would delay the overall project completion significantly. Pour day was January 26, 2013 and happened on schedule.

Senior team members led each division and instructed newer members on concrete development, placement, and quality control, with an emphasis on following ASTM standards and safety procedures. This year, the Department of Occupational Safety and Environmental Health at the University of Michigan reassessed MCCT's current practices to ensure that team members were wearing proper protective equipment, such as gloves and respirators during all stages of design and construction. An increase in test mixes this year allowed for more training in mix development for newer members.

This year's project was divided into four categories. Resource acquisition remained important throughout the duration of the project. The total number of man-hours for the project can be split into the four major project categories:

- Research and Development (includes concrete material research, testing, preparing test cylinders, and documenting research findings): 90 man-hours
- Hull Design (includes creating 3-D model of canoe, preparing cut-paths, and analyzing structural features): 175 man-hours
- Construction (includes cutting foam sheets, assembling and finishing the mold, pouring, testing, and finishing the canoe): 480 man-hours
- Resource Acquisition (includes recruiting new members, soliciting potential sponsors, purchasing materials, and scheduling space/machines): 125 man-hours

This year, MCCT had a budget of $4,000. The budget was primarily allocated towards concrete materials, mold and construction materials, competition, transportation, and recruiting, with discretionary spending on miscellaneous items. New avenues for funding and partnership at the University of Michigan were explored including the Naval Architecture and Marine Engineering department and the Central Student Government. The current projected cost for the project is $3200, $800 under budget. This number could potentially change, as some additional costs may be incurred prior to competition.

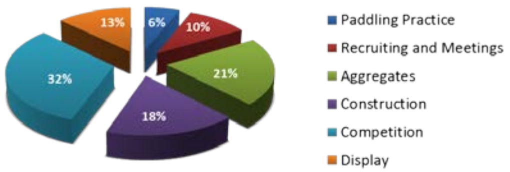
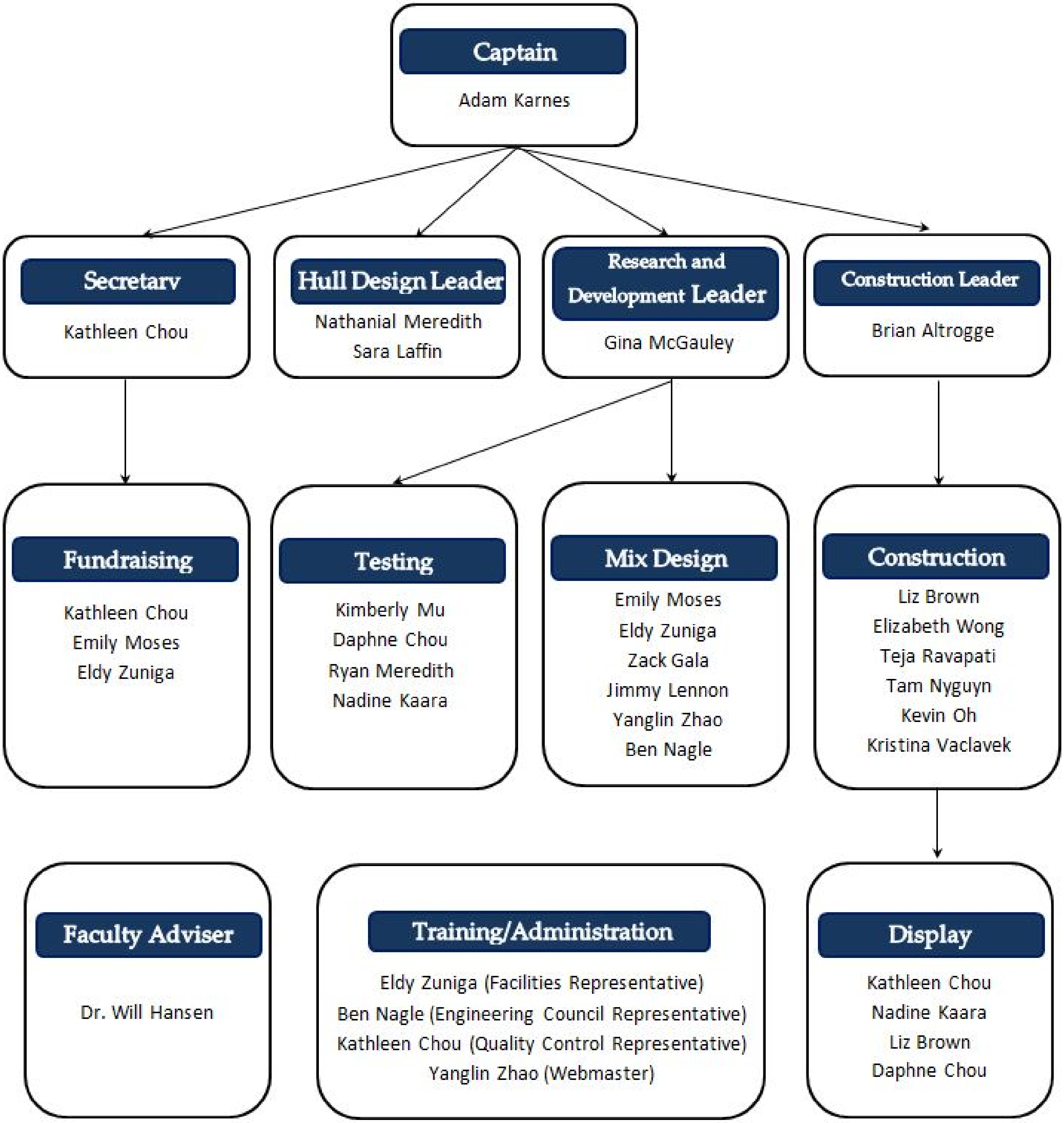


Figure 1: Budget allocation for *DREKAR*.

Organization Chart



Hull Design and Structural Analysis

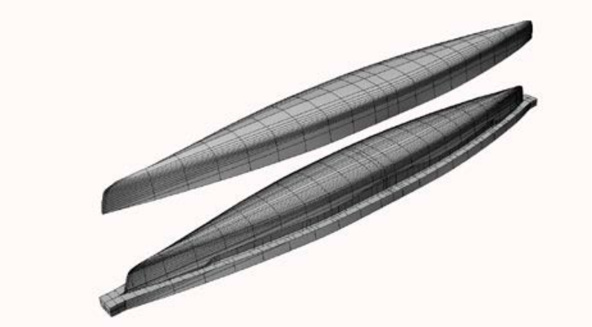


Figure 2. The final copy of the canoe that includes the outer hull form. The hull above the mold shows how the final hull form will relate to the canoe mold.

In designing *DREKAR*, we started with the 2009-2011 Standard Concrete Hull Design provided by NCCC and modified it according to our primary design focuses. One of our focuses was the comfort of the paddlers and canoe transporters. Based on previous canoe designs, we understood that paddlers stroke more efficiently and become less fatigued when they do not have to reach over the side of a wide canoe. Another disadvantage to a wide canoe is that it is more difficult to properly support its underside during transportation. Our last focus was to reduce the weight of the canoe to make transport and momentum gain easier.

We started the process by importing the provided table of offsets into Maxsurf Modeler to get a basic canoe form. We then used the features of this program to define the desired boundary dimensions, which can be found in the table below.

Table 1: Boundary conditions for hull design of DREKAR.

Boundary Dimensions	
Length	19 Feet 10 Inches
Beam	30 Inches
Depth	14 Inches

After importing the outer dimensions, we started to adjust the point offsets to shape the canoe to the desired form. From there, we exported the model to Rhinoceros 4.0 where we did the final model details such as adding thickness and a gunwale to the canoe. To accommodate paddlers, we shortened the beam by 5.5 inches to make it easier for the paddler to reach over the canoe. This change will allow the paddler to apply more force to moving the canoe forward. To shorten the beam while minimizing change to the underwater profile, we created straight walls along the midsection of the canoe above the waterline.

Another design goal was to make the canoe lighter than it has been in previous years. Several changes were made to accommodate this. First, we shortened the depth by making a straight planar cut through the model, decreasing it by 2 inches. This would also distribute stress on the canoe more evenly in the load case where the gunwales are flat on the ground. The decrease in depth also resulted in an increase in the stress in the gunwales, which we counteracted by redesigning the gunwale. This stress was important to counteract because the male sprints causes high stress in the gunwales. To adjust the stress in the gunwales without adding unnecessary weight, we transferred the equivalent rib weight to the upper edge of the gunwale. The largest weight reduction change made from last year's hull was reducing the hull thickness from 0.75 inches to a minimum thickness of 0.5 inches, which reduced the weight by 33%. The final design decision for the new gunwale was based on the fundamental equation for stress based on applied moments.

$$\sigma = \frac{M * D}{I}$$

Multiple cross section configurations were analyzed with the help of AutoCAD to calculate the moment of inertia, I, and distance to the neutral axis, D. Global bending moment, M, was calculated using Maxsurf Stability. We modified the gunwale to decrease the bending arm as much as possible while also increasing the moment of inertia. This shifted the neutral axis upward and decreased the amount of stress in the gunwale. Total area was also considered regarding weight gain vs. weight loss compared to last year's model. To account for the stress increase without adding significant weight, we added a gradient to the gunwale so that the gunwale was thickest where the most stress would occur. The gunwale is a gradient from 0.5 inches along the keel and lower chine to a maximum of 1.25 inches at the upper edge of the gunwale. The gunwale is also varied longitudinally, fading out 3.5 feet from either end of the canoe. A comparison between this years and last year's design is in the figure found below.

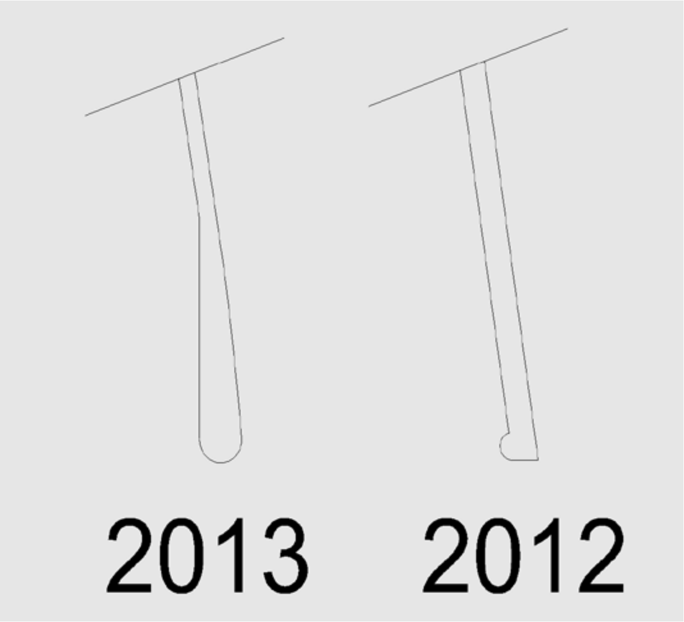


Figure 3: Comparison of 2012 and 2013 cross sectional canoe hull design.

The largest moment will occur during the male endurance sprint, due to both males sitting the maximum distance from the longitudinal center of buoyancy. The maximum bending stress allowed is 575 ft-lbs. Given the cross section of the canoe, this required the concrete to have a minimum tensile strength of 166 psi with a safety factor of 2. This year, we have chosen a two-support stand design, compared to the three from last year. This will cause an increase from last year's keel stress but is still within the allowable tensile strength of the concrete. Along with the male endurance sprint, this is the most stress the canoe will face during the competition.

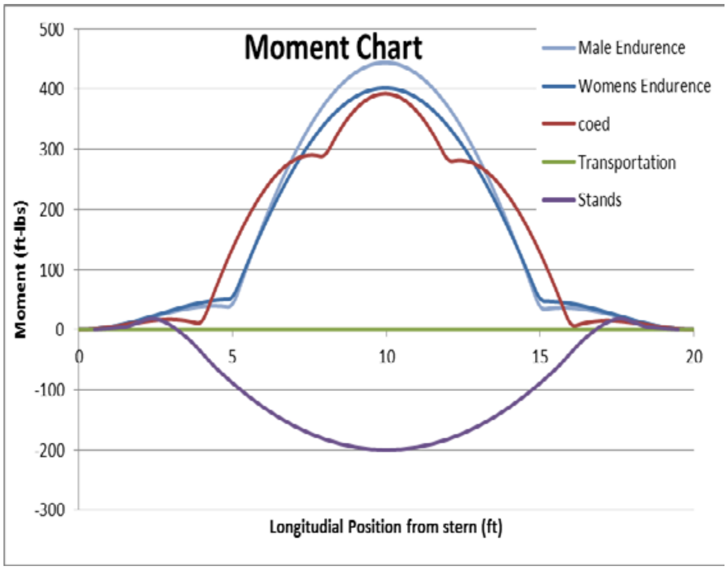


Figure 4: Loading case bending moments.

When analyzing resistance, we used Maxsurf Resistance to calculate the coefficients. Because not all resistance components can be accounted for in the same coefficients, they must first be broken down to accommodate their different formulations. Total resistance is normally broken down into a Froude number dependent component – wave resistance (residuary resistance) and a Reynolds number dependent component – viscous resistance (friction resistance). Using this, total resistance is then wave + viscous or residual + friction. All calculations were done using a speed of 2 knots, which gave us the values in Table 2.

Table 2: Resistance values for hull design of DREKAR.

Resistance	1.86 lbf
Froude Number	0.134

Development and Testing

MCCT's primary goals this year were to improve upon the lightweight concrete design from previous years and to further increase the concrete's workability and strength. We also wanted to identify the ideal ratio of admixtures while using aggregates which we already had on hand. To accomplish this, we strategically altered material quantities and replaced old admixtures. The mix used to construct *CRONUS* was used as a baseline because of its successful performance in the 2012 competition. We believe that the high strength was enough to justify using this mix, even with its theoretical density of 62.4 pcf, which is essentially neutrally buoyant. We also tested mixes based on the 2011 mix design, but the test mixes were too weak and the decreases in density not significant enough to convince us to use them. The baseline mix had a 21-day strength of 1481 psi.

Figure 5: Concrete cylinders being formed for testing.

We used an aggregate composition identical to the one from *CRONUS* because of the successful high strength which we achieved that year. Using the same aggregates not only helped the team to focus on the admixtures for the canoe, but also allowed MCCT to economically use materials that were already on hand. The aggregates for the mix included K1 glass microspheres, two different sizes of Poraver, finely graded Haydite, Bionic Bubbles, SG300 and SG900. Similarly to last year, we were very pleased with the workability of the concrete during placing. Because of the mix's ideal slump, we were able to spread and smooth over the concrete effectively during construction.

The cementitious materials in our baseline mix design included Type 1 White Portland Cement, Rice Husk Ash (RHA), and Ground Granulated Blast Furnace Slag (GGBFS). We chose again this year to use GGBFS, a locally available by-product of steel production, as a recycled cementitious material. RHA is also a locally available, inexpensive, recycled material which we used in our mix. This year, MCCT tested and decided to use Komponent, a shrinkage reducer and cementitious material, in *DREKAR*. As suggested by the supplier, we replaced 15% of our cementitious material with Komponent. We also kept the other three cementitious materials at the same ratios relative to each other to maintain their interaction. MCCT focused this year on improving the use of admixtures in our mix, and Komponent was chosen as an alternative to a shrinkage-reducing admixture because of its additional benefits as a cementitious material with a lower specific gravity than Portland Cement. Komponent was also chosen because its strengthening effect on concrete mixes.

Figure 6: Mixing aggregate and cementitious material with admixtures.

The most significant change in *DREKAR*'s mix from the baseline mix was the replacement of the admixtures. These changes were made by consulting with material suppliers, graduate students, and professors. The admixtures used in *CRONUS* were Glenium 7500 and AE90, a superplasticizer and air entrainer, respectively. All the admixtures used by MCCT this year were newly acquired. This eliminated both concerns of chemical deterioration from age and of cross-contamination between the old admixtures from usage of the same measurement device. We purchased the superplasticizer (ADVA 555) and the air entrainer (Darex II) from the same supplier to ensure that the the two admixtures would be chemically compatible. We found that getting new admixtures and better controlling for their quantities improved the consistency across mixes.

Sixteen test batches of concrete were mixed to test the effects of varying dosages of the admixtures. We first tested a mix very similar to our 2011 baseline, substituting appropriate aggregates for those that we no longer had access to, and with approximately half the amount of fiber. The amount of fiber was reduced due to concerns that the fibers might adversely affect both strength and workability of the mix. In following mixes, we then replaced 15% of the cementitious material with Komponent to test the effect of adding the shrinkage-reducer. We found that it reduced shrinkage cracking in our concrete after 14 days of curing.

Figure 7: Separating fibers to use in varying proportions in test mixes.

The rest of the test mixes maintained those changes and differed only by varying the dosage of a single admixture. The suggested dosage of the admixtures was given by the supplier as a range; therefore, we chose to test each admixture at a low, mid and high end of the range. MCCT determined that the optimal dosages of the admixtures were mid-range for the air-entrainer (3 fl oz./cwt) and low range for the superplasticizer (8 fl oz./cwt).

After deciding that the strengths of those test mixes were undesirable, we tested the 2012 mix using the new admixtures, then adding Komponent. With our final mix we adjusted the admixture dosages to what we had previously determined was ideal. We were able to gain a strength of 1242 psi, slightly lower than the 2012 mix. Cylinders were made from each test batch, and tested for 28-day strength according to ASTM C 109. The final mix for *DREKAR* was chosen because it had the strength necessary for our canoe design, but was also highly workable, allowing us to better control for thickness and uniformity on pour day.

Figure 8: Cylinders of test mixes after compression testing.

MCCT chose to use the same fiberglass mesh reinforcement used in previous years for several reasons. First, the mesh has a very high strength-to-weight ratio and had been successful in preventing any significant cracking in previous canoes. Additionally, the mesh had an open area of 50%, allowing for adequate bonding between the two layers of concrete. Finally, the team was able to cut costs and reduce construction waste by using excess fiberglass mesh available from previous years.

Construction

This year’s construction method for *DREKAR* followed that of the previous year; the team again chose to use a male mold. A male mold decreased the amount of foam needed and improved concrete adhesion during construction to mitigate the effects of slump on canoe thickness. A 3-D model of the canoe mold was created using Rhinoceros 4.0 and then sliced into 124 two-inch thick sections along its length. The resulting sections were then organized to fit on 4’ by 8’ foam sheets and cut using a CNC router. Key holes were cut into each section so 2”x4”s could be used for alignment during mold assembly. To ensure the absolute accuracy of the mold, all sections were cut three-dimensionally using a spherically tipped drill bit to within 1/32 of an inch.

Figure 9: Cutting the foam mold using a 3-axis CNC router.

Several innovations were added to this year’s construction of *DREKAR*. Three sight holes were cut in the mold, each placed the maximum distance away from each other to counter any axial rotation during mold assembly. Because the canoe was designed with a gradient in thickness, MCCT required a method to regulate the thickness along the gunwale. The mold was designed with the outer edge of the hull placed on the bottom of the foam block, so that it could be traced by two specially designed tools. The tools utilized two offset tangent lines that would be used to follow the track along the bottom of the mold. One tool was designed to regulate half hull thickness for mesh placement, while the other tool was designed to follow the outer edge of the hull. A high number of passes on a three axis CNC router ensured that the mold was as a smooth as possible so that the tools would not have an issue tracing the edge of the mold.

As with previous years, mold sections were aligned along a 2”x4” ‘spine’ on four tables placed end-to-end. These tables were leveled prior to the mold assembly to reduce torque on the mold. The 2” mold sections were aligned using the previously mentioned site holes and glued together using Gorilla Glue. The mold was lightly sanded and drywall compound was used to fill in any imperfections and gaps between sections. The exterior surface of the mold receiving concrete was then covered with a single layer of double-wide duct tape. The larger width of these strips allowed a reduction in the number of tape seams by half, ensuring a smoother interior surface and reduced finishing work.

Figure 10: Final concrete mix material amounts for pour day.

On pour day, 12 0.2 ft^3 batches of concrete were measured, mixed, and systematically placed in 1/4” layers from stern to bow. The first layer was staggered one batch ahead of the second so that a sufficient base could be laid down to accept the fiberglass mesh. Once in place, the second 1/4” layer was placed on top of the mesh reinforcement.

An accurate hull thickness was a chief concern in the design phase and was achieved during construction by assigning four team members to the task of quality control. Specialized concrete measurement devices were developed to ensure a consistent thickness of concrete for each layer. These devices were marked at ¼ inches to verify concrete thickness throughout the pouring process. The first layer of concrete was placed on the mold by hand with little compaction to ensure sufficient concrete bonding through the mesh. This also increased sustainability by ensuring that concrete was not wasted during the placing of each layer. Three foot sections of fiberglass mesh reinforcement with a one-inch overlap between sections were placed between the two layers of concrete. The second layer of concrete, placed on top of this mesh, was compacted and smoothed with trowels.

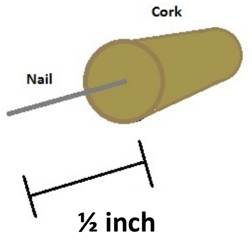


Figure 11: Sustainable quality control devices were used to maintain ½ inch concrete layers.

After placement, the canoe was wet-cured in a temperature controlled environment for fourteen days. Once cured, the canoe exterior was thoroughly sanded. In the upcoming weeks, the canoe will be demolded, and the interior will be sanded. The canoe will be stained with a design in accordance to our Viking theme, and then sealed to protect the aesthetic design. The canoe will be swamp tested to determine whether or not additional floatation will be necessary.

Figure 12: Hand placing of the first concrete layer on top of foam mold.

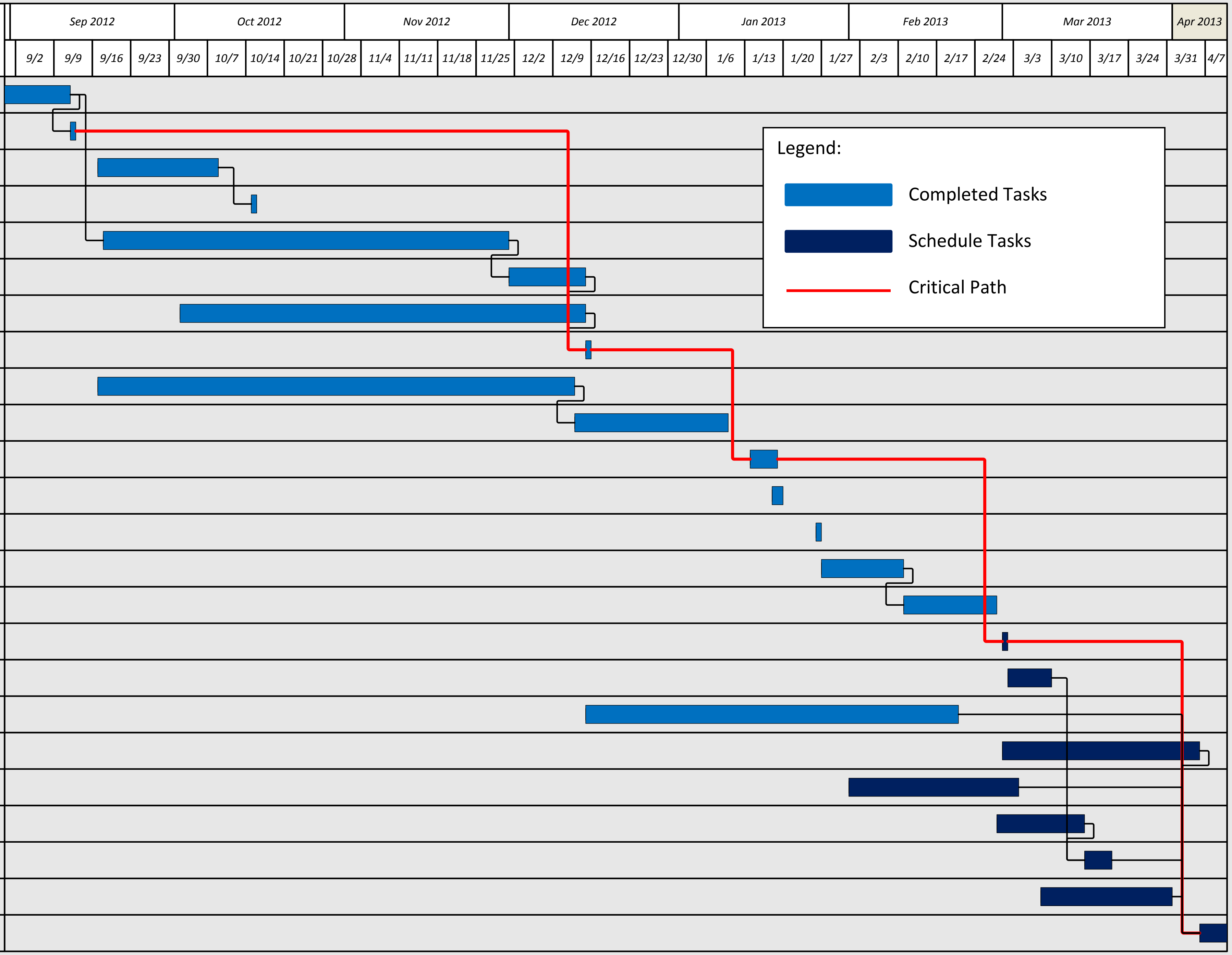
One primary focus for the construction of *DREKAR* was to incorporate sustainability in all areas of the construction process. Leftover raw materials used in previous canoes were used, minimizing environmental and economic impacts of shipping new materials to Ann Arbor. Sustainable cementitious materials Rice Husk Ash (RHA) and Ground Granulated Blast Furnace Slag (GGBFS) were incorporated into *DREKAR*'s final mix. GGBFS is a cementitious material that is a by-product of steel manufacturing. RHA is an ash created from burning rice husks for fuel in the processing of a rice paddy. RHA, normally a pollutant when dumped in surrounding environments, can be incorporated as a cementitious material into concrete, acting as concrete strengthener and minimizing environmental impact.

Many sustainable aggregates were also used. Haydite is expanded shale and is considered sustainable as it reduces the volume of material that is mined and amount of energy used in transportation. Poraver, SG-300, SG-900, and Bionic Bubbles are different varieties of recycled glass and ceramic spheres that were all used in the mix. These materials allowed MCCT to create a mix with 93% sustainable aggregates and 49% sustainable cementitious materials.

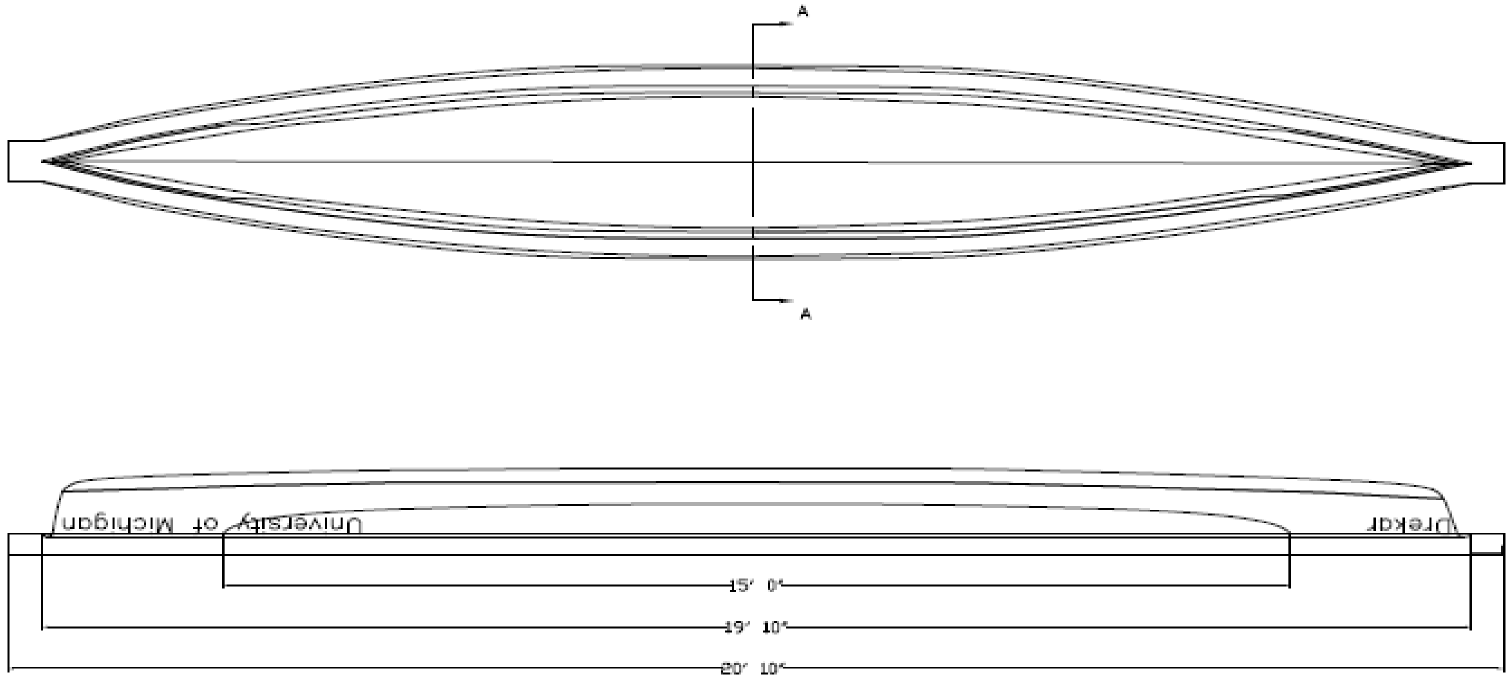
MCCT considered safety to be of utmost importance in the construction and finishing of *DREKAR*. All team members were required to attend safety training classes prior to working in laboratory facilities, and were required to use personal protective equipment, including safety glasses, respirators and gloves during mixing, placing and sanding. The Department of Occupational Safety and Environmental Health (OSEH) at the University of Michigan was contacted prior to sanding to ensure the safest working conditions. As with every project, MCCT's goal was to produce quality through improvements to previous years' techniques, while creating an environment in which newer members could learn from more experienced ones. This resulted in a more unified team, which worked collaboratively to solve problems more effectively than in previous years.

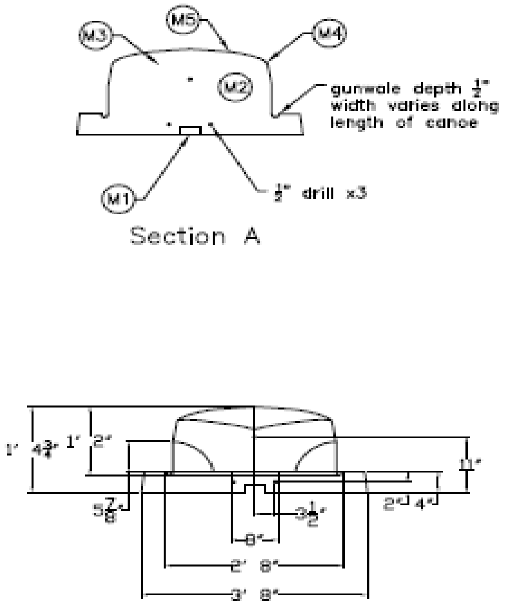
Project Schedule

ID	Task Name	Start	Finish	Duration
1	New Member Recruitment	8/31/2012	9/11/2012	1w 5d
2	Mass Meeting	9/12/2012	9/12/2012	1d
3	Draft Sponsorship Letters	9/17/2012	10/8/2012	3w 1d
4	Mail Sponsorship Letters	10/15/2012	10/15/2012	1d
5	Materials Research	9/18/2012	11/30/2012	10w 4d
6	Test Mixing	12/1/2012	12/14/2012	2w
7	Cylinder Testing	10/2/2012	12/14/2012	10w 4d
8	Final Mix Selection	12/15/2012	12/15/2012	1d
9	Hull Modeling	9/17/2012	12/12/2012	12w 3d
10	Arrange Cut Paths	12/13/2012	1/9/2013	4w
11	Mold Cutting	1/14/2013	1/18/2013	5d
12	Mold Assembly and Preparation	1/18/2013	1/19/2013	2d
13	Place Canoe	1/26/2013	1/26/2013	1d
14	Canoe Curing	1/27/2013	2/10/2013	2w 1d
15	Exterior Sanding	2/11/2013	2/27/2013	2w 3d
16	De-mold Canoe	3/1/2013	3/1/2013	1d
17	Interior Sanding	3/2/2013	3/9/2013	1w 1d
18	Technical Paper Writing	12/15/2012	2/20/2013	9w 5d
19	Technical Presentation Practice	3/1/2013	4/5/2013	5w 1d
20	Design and Construct Display	2/1/2013	3/3/2013	4w 3d
21	Staining Canoe	2/28/2013	3/15/2013	2w 2d
22	Sealing Canoe	3/16/2013	3/20/2013	5d
23	Paddling Practice	3/8/2013	3/31/2013	3w 3d
24	Competition	4/6/2013	4/10/2013	5d



Design Drawing





MCCT BILL OF MATERIALS

ITEM	QTY.	DESCRIPTION
M1	3	LUMBER 2"x4"x8'
M2	16	FOAMBOARD 4'x8'x2"
M3	1	WOOD GLUE
M4	1	DRYWALL COMPOUND
M5	1	DUCT TAPE COATING

NOTES:
3 DIMENSIONAL CROSS SECTIONS OF 2 INCH THICKNESSES ARE OBTAINED ALONG THE LENGTH OF THE CANOE USING RHINOCEROS 4.0, TO BE CUT OUT USING A CNC ROUTER.

ONCE ALIGNED USING 2x4's AND GLUED TOGETHER, THE FOAM CROSS SECTIONS ARE TO BE SANDED SMOOTH AND COATED WITH DRYWALL COMPOUND. THE MOLD IS TO BE COATED IN DUCT TAPE TO FACILITATE DEMOLDING.

Naval Architecture
&
Marine Engineering

MCCT Canoe - "Drekar"

VESSEL DESIGNED FOR:
ASCE NCCC

DESIGNED AND DRAWN BY:
Michigan Concrete Canoe Team

DATE:2/20/2013
SCALE: 3/8":1'
SHEET 1 OF 1

Appendix A: References

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Appendix B: Mixture Proportions

Mixture ID: Grey Structural Mix				Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
YD	Design Batch Size (ft3):		1						
Cementitious Materials			SG	Amount (lb/yd3)	Volume (ft3)	Amount (lb)	Volume (ft3)	Amount (lb/yd3)	Volume (ft3)
CM1	Portland Cement Type I		3.15	340.00	1.730	12.59	0.064	430.05	2.19
CM2	RHA		2.50	85.00	0.545	3.15	0.020	107.51	0.69
CM3	GGBFS		2.90	246.50	1.362	9.13	0.050	311.78	1.72
CM4	Komponent		3.10	118.50	0.613	4.39	0.023	149.88	0.77
	Total Cementitious Materials:			**790.00**	**4.25**	**29.26**	**0.16**	**999.23**	**5.37**
Fibers									
F1	PVA Fiber		1.30	5.00	0.062	0.19	0.002	6.32	0.08
	Total Fibers:			5.00	0.062	0.19	0.002	6.324	0.078
Aggregates									
A1	K1	Abs: 0.1	0.13	30.00	3.846	1.11	0.142	37.95	4.86
A2	Haydite	Abs: 10	1.15	80.00	1.115	2.96	0.041	101.19	1.41
A3	SG300	Abs: 3	0.80	20.00	0.401	0.74	0.015	25.30	0.51
A4	SG 900	Abs: 3	0.80	30.00	0.601	1.11	0.022	37.95	0.76
A5	Bionic Bubbles	Abs: 3	0.60	70.00	1.870	2.59	0.069	88.54	2.36
A6	Poraver 0.5-1mm	Abs: 3	0.47	110.00	3.751	4.07	0.139	139.13	4.74
A7	Poraver 0.25-0.5mm	Abs: 3	0.55	80.00	2.331	2.96	0.086	101.19	2.95
	Total Aggregates:			**420.00**	**13.914**	**15.56**	**0.515**	**531.23**	**17.60**
Water									
W1	Water for CM Hydration (W1a + W1b)		1.00	394.21	6.317	3.04	0.234	498.61	7.99
	W1a. Water from Admixtures			63.28		2.34		80.03	
	W1b. Additional Water			330.93		0.70		418.58	
W2	Water for Aggregates, SSD		1.00	14.63		0.54		18.50	
	Total Water (W1 + W2):			**408.84**	**6.32**	**3.59**	**0.234**	**517.12**	**7.99**
Solids Content of Latex Admixtures and Dyes									
S1	Dow Liquid Latex Modifier		1.05	57.57	0.88	2.13	0.033	72.82	1.11
	Total Solids of Admixtures:			**57.57**	**0.88**	**2.13**	**0.033**	**72.819**	**1.111**
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/yd3)
Ad1	Water Reducer	*8.9 lb/gal*	5	8.00	4.17	2.34	0.155	10.12	5.28
Ad2	Air Entrainer	*8.7 lb/gal*	5	3.00	1.53	0.88	0.057	3.79	1.94
Ad3	Liquid Latex Modifier	*8.8 lb/gal*	47	200	57.57	58.52	2.132	252.97	72.82
	Water from Admixtures (W1a):				**63.28**		**2.34**		**80.03**
Cement-Cementitious Materials Ratio				0.430		0.430		0.430	
Water-Cementitious Materials Ratio				0.499		0.499		0.499	
Slump, Slump Flow, in.				4±1		3.000		4±1	
M	Mass of Concrete. lbs			1681.41		50.72		2126.72	
V	Absolute Volume of Concrete, ft3			25.42		0.94		32.15	
T	Theorectical Density, lb/ft3 = (M / V)			66.14		66.14		66.14	
D	Design Density, lb/ft3 = (M / 27)			62.27					
D	Measured Density, lb/ft3					64.15		64.15	
A	Air Content, % = [(T - D) / T x 100%]			5.85		3.01		3.01	
Y	Yield, ft3			27		0.791		27	
Ry	Relative Yield = (Y / YD)					0.791			

Appendix C: Bill of Materials

Material	Quantity (lbs)	Unit Cost	Total Price
Portland Cement Type I	45.33	0.037	$1.68
GGBFS	32.89	0.025	$0.82
RHA	11.33	0.16	$1.81
Komponent	15.45	0.24	$3.71
PVA Fiber	0.67	2.27	$1.52
K1	4	7.77	$31.08
Haydite	10.67	0.05	$0.53
Bionic Bubbles	9.33	12.81	$119.52
SG-300	2.67	3.11	$8.30
SG-900	4	1.16	$4.64
Poraver 0.5-1 mm	14.67	0.7	$10.27
Poraver 0.25-0.5	10.67	0.7	$7.47
Dow Liquid Latex Modifier	14.5	8.41	$121.95
ADVA Cast 555	0.59	12.38	$7.30
Darex II	0.22	9.37	$2.06
Fiberglass Mesh (sq ft)	51.4	0.14	$7.20
Acid Wash (gal)	2	9	$18.00
Stain (gal)	2	82	$164.00
Sealer (gal)	2	26	$52.00
Paint for Lettering (oz)	4	2.5	$10.00
Foam Mold, Complete	1 mold	638	$638.00
Sand Paper	3 packs	$30/pack	$90.00
Total Production Cost			$1,301.86