



## TABLE OF CONTENTS

Report:	
Executive Summary	i
Analysis	1
Development and Testing	2
Project Management and Construction	5
Innovation and Sustainability	7
Organizational Chart	8
Project Schedule	9
Design Drawings	10
Appendices:	
References	A
Mixture Proportions	B
Gradation Table and Curve	C

HYDROTHUNDER SPECIFICATIONS	
Weight	240 lbs
Length	240 in
Maximum Width	31.2 in
Maximum Depth	14 in
Average Thickness	3/4 in
Color	Black and Yellow
Mesh Thickness	1/8 in
PVA Fiber Length	3/8 in

## EXECUTIVE SUMMARY

When the University of Michigan's progressive education paths expanded into the versatile field of engineering, Civil Engineering was the first department to be created in 1854. Since then, the department has taught students to be at the forefront of engineering technology and advancements; the participation of the Michigan Concrete Canoe Team (MCCT) in the A.S.C.E. North Central Regional Conference is a chance to demonstrate the quality of this education. Each year, leading individuals combine forces to form a small yet tremendously strong and dedicated team. Inspired by the strength of its members, MCCT 2009 strived to achieve a strong, durable concrete composite through investigative and innovative means.

Throughout the year MCCT focused on optimizing design and construction of the 2009 canoe to ensure its outstanding performance in the competition. Introduced were more calculations and simulations to optimize the analysis, formwork construction and mix design. Built from the experience of veteran members and the inventive ideas of new members, MCCT is proud to present the 2009 canoe **HydroThunder**. The canoe is comprised of two 3/8in layers of PVA fiber reinforced concrete enclosing a single layer of polyethylene mesh. The resulting 62.5 pounds per cubic foot (pcf) mix has a 28-day compressive strength of 1300 pounds per square inch (psi) and has an average residual compressive strength of 730 psi through a strain of three percent. The flexural strength of the canoe is 520 psi at first cracking.

The name **HydroThunder** was chosen as an illustration of nature's raw power, and a reminder that Mother Nature is a force to be reckoned with. Keeping as close to nature as possible, MCCT's mix design and aggregate selection have been advanced to reflect how the University of Michigan embraces the "Live Green, Go Blue" initiative.

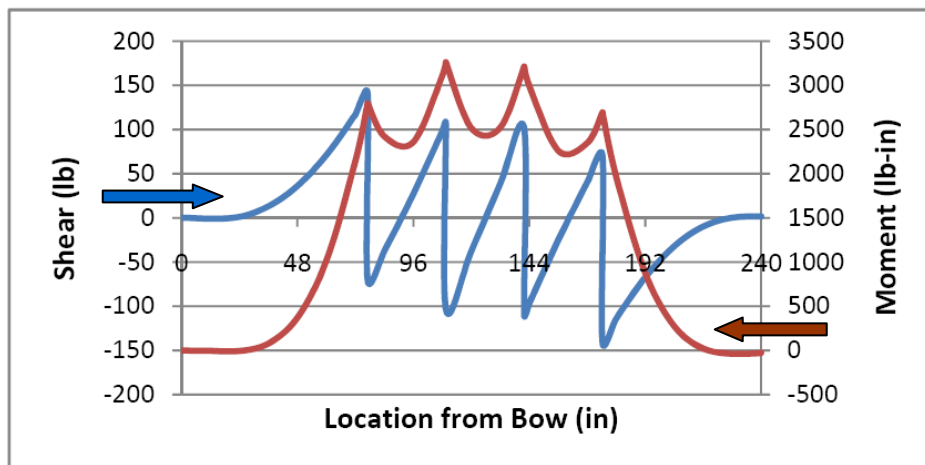
## ANALYSIS

MCCT 2009 began the analysis process by outlining calculations to be performed using hydrostatic canoe modeling and finite element modeling to determine the minimum strength requirements for the canoe. After the canoe was modeled in 3D in Rhinoceros and imported to AutoCAD, the canoe was examined at each of the five waterlines at twenty stations along the length. (See Design Drawing for visual of waterlines and stations.) The canoe volume for each station was determined along with the volumes submerged for each waterline. With this information, the distributed weight along the length was established for an assumed concrete density of 62.4 lb/cf. The submerged volume of canoe was used to determine the buoyant forces acting on the canoe.

The loading due to the co-ed medley was examined for a passenger load case that submerged the canoe to waterline three. This loading case was selected to examine the worst case loading due to the races. By examining the canoe at waterline three, the weight of each passenger was set at about 210 lb each, allowing for conservative results. Discretizing the canoe at each station, the shear forces were determined by subtracting the canoe weight from the buoyancy force. Then using Riemann sums, the moments for the co-ed loading were calculated from the shear forces (Figure 1). The canoe was also examined as upright, simply supported when out of the water.

Based on the results for the co-ed sprint and simply supported cases, the canoe will require a minimum compressive strength of 260 psi and minimum tensile strength of 120 psi. These requirements include a safety factor of two, selected based on experience from previous analyses. Team is also confident that the canoe will not suffer from local failures, such as punching shear below paddlers' knees, from the previous year's calculations.

The MCCT began the finite element analysis (FEA) process by importing the three-dimensional model from Rhinoceros into the FEA program ABAQUS. None of the team members had previous experience with FEA modeling, so the assistance of graduate level students was required. Unfortunately, the model would not mesh appropriately to yield accurate results. The team also tried modeling the canoe in ANSYS, but realistic pressure loads could not be applied. Although the team was not able to create a viable FE model, the team did put forth much effort in attempting this new task. The team is confident in the results determined from the hydrostatic analysis, and therefore, continued to proceed with development and testing.



**Figure 1: Co-Ed Sprint Loading Results**



## DEVELOPMENT AND TESTING

The baseline mix for **HydroThunder** included the following components used for MCCT's 2008 canoe, *Maizin' Race*:

### **Cementitious Materials:**

- Portland Cement Type I: high-early strength not required
- Fly Ash (FA) Type C: useful for filling voids; decreases permeability while increasing long-term strength
- FA Type F: similar to Type C; potential long-term detrimental reactions with PVA fibers
- Norchem Silica Fume: stiffens mix for placement on female mold; less dense than FA

### **Reinforcement:**

- PVA Fibers 3/8in: provides residual strength by bridging micro cracks
- Fiberglass Mesh: provides residual strength for extensive cracking

### **Aggregates:**

- K15 Glass Bubbles: low specific gravity material for finest aggregate
- Poraver 0.5-2mm: recycled glass sphere with low specific gravity
- Haydite A Expanded Slate: high crush strength; natural aggregate

### **Admixtures:**

- Superplasticizer: reduce water; disperse fibers; improve workability
- Air Entrainer: regulate void size
- Latex Modifier: reduce water and increase fiber-mesh-concrete bond

The 2009 MCCT team decided on several mix goals varying significantly from previous years' experiences, requiring extensive new investigation. The baseline mix was modified to accommodate the following goals for the 2009 mix:

- Incorporate more recycled materials

The recycled aggregates used in the mix are the Poraver spheres, which are recycled fine glass shard waste of the glass industry. To support the green initiatives, an additional size of Poraver (0.25-0.5mm) was added to the baseline mix. The overall weight factor for all Poraver sizes was increased, thus, decreasing the specific gravity and smoothing the aggregate gradation.

- Investigate the use of new mesh with larger size openings between strands

Since the same fiberglass mesh had been used for the MCCT canoes for the past two years, MCCT 2009 wanted a more innovative canoe with a new mesh. The mesh was selected based primarily on geometry and then tested to ensure sufficient tensile strength.

- Use pigmented concrete in the mix instead of staining the canoe after construction

The use of pigmented concrete was intended to provide a more aesthetically pleasing finish than the staining used in previous years and to reduce the amount of time needed for finishing.

- Procure new natural aggregate to avoid excessive selective sieving of Haydite

A different expanded slate, Solite, was selected to replace Haydite. The Solite was selected because of its lower specific gravity, its comparably high crush strength, and its gradation better fit this year's needs. The Solite only required selective sieving to remove the particles finer than the 100 sieve. MCCT was able to use the Solite with a maximum particle diameter of approximately 2.36mm because a mesh with larger openings was chosen this year.

- Construct canoe using a female mold rather than a male mold

A female mold was chosen rather than a male mold for a consistent exterior surface and ease of formwork removal.

**Testing**

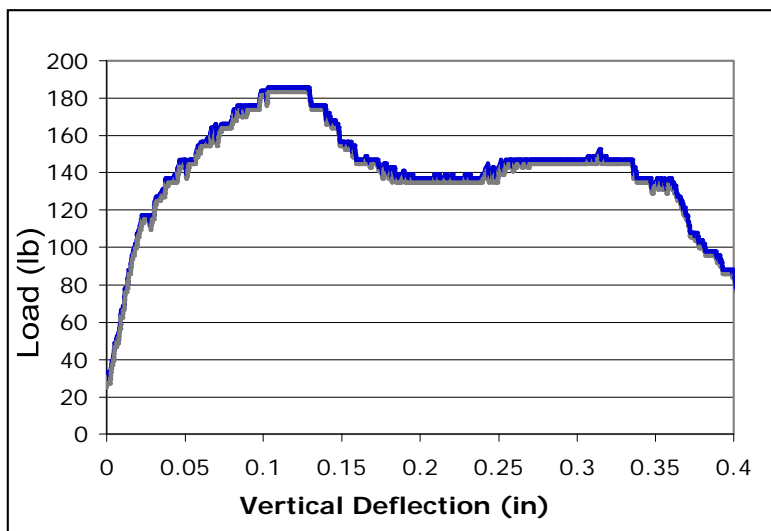
Several batches were considered consistent with the 2009 mix goals. After considering the potential options, two batches were selected and tested for compressive strength (ASTM C39). The batches had different distributions of Poraver. Batch 2 redistributed five percent by weight of Poraver 0.5-1.0mm to Poraver 1.0-2.0 mm. The intent was to decrease the density of the mix, since larger particles have a lower bulk density than smaller particles, and to smooth the gradation curve. Batch 1 had a maximum 28-day compressive strength of 1300 psi and a specific gravity of 61 lb/cf (Figure 4). Batch 2 had a 28-day compressive strength of 2500 psi and a specific gravity of 60 lb/cf. The difference in compressive strength is exaggerated by the fact that the two mixes were tested in cylinders of different sizes (4in diameter Batch 1; 3in diameter Batch 2).

In addition to compression testing, plate samples were tested with third-point and center-point bending tests according to ASTM C78 and ASTM C293, respectively. The team was interested in finding a new mesh with larger open areas since MCCT 2008 had difficulty ensuring concrete bonding through the small holes in the fiberglass mesh. The main purposes of the flexural tests were to determine the flexural properties of the PVA fibers and compare the previous year’s fiberglass mesh with the new polyethylene mesh. The percent open area (POA) of the polyethylene mesh is 72 percent with hole sizes about four times larger than the fiberglass mesh. The results and setup of a third-point test are shown in Figure 2 and 3, respectively. The results of the tests indicate that the PVA fibers provide significant residual strength after initial concrete cracking. The plate test results conclude that the canoe with PVA fibers and polyethylene mesh will have sufficient tensile strength to withstand the bending stresses determined in analysis.

**Admixtures**

The final admixture selection changed very little from the baseline mix. However, there were slight increases in the admixture volumes as the overall cementitious material density decreased. Less dense CM implies a greater number of cementitious particles per pound, requiring more admixture to produce the desired results. The dosage of air entertainer was increased to ensure

the desired air content. The latex was also lightly applied directly to the concrete between layers to promote bonding with the mesh. The admixtures were all used per the manufacture’s specified dosages.



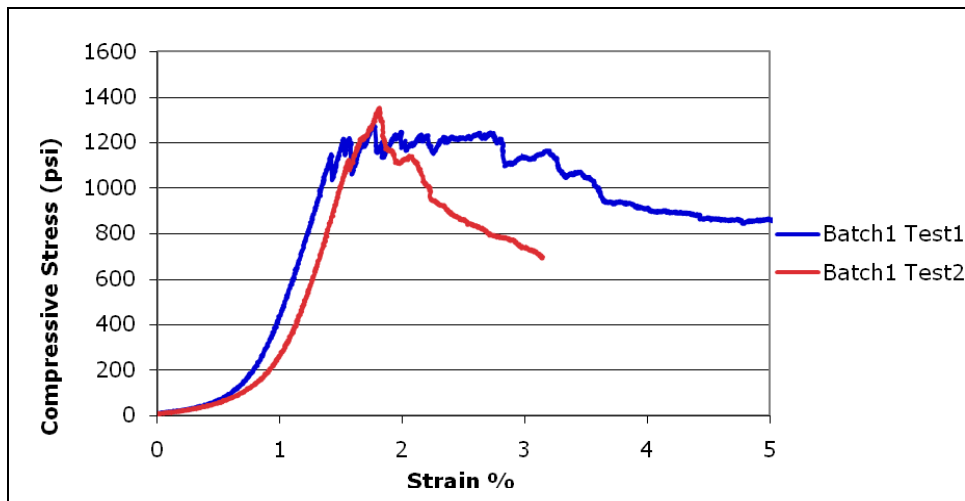
**Figure 2 and 3: Third-point Load-Deflection Results and Setup for Plate with Fiberglass mesh**



Last year for coloring, the team used a yellow acid-based stain on the grey concrete. The result was arguably a dark gold color that looked dirty and unappealing, so finding an alternative method to color the canoe was a priority. Pigmented concrete was researched and selected for several reasons: it was less time-consuming than using stain, did not affect the concrete strength in small doses, and resulted in a more uniform and evenly-distributed color. Different pigment colors were tested and dosages were varied within the manufacturer's specifications to obtain the desired colors. Black pigment in combination with the standard grey concrete was selected while white concrete was used with the yellow pigment for a truer final color. The pigmented concrete achieved the goals for coloring: the black is crisp, and the lightening bolts are bright and intimidating.

### **Final results**

The cementitious material proportions in the final mix were varied slightly from the baseline to ensure a large percentage of recycled cementitious materials were used. Also, the advanced lightweight FA Type F (Tecfil) used last year was eliminated from the mix since it proved too costly to obtain. Ultimately, Batch 1 was selected as the Final Mix because the compressive strength was large enough to satisfy the compressive demands and provided a smoother finished surface. The pigment added to the mix increased the canoe unit weight to 62.5 lb/cf. Since the batched density is so close to the density of water, the canoe may require additional floatation to pass the swamp test. The final mix for the 2009 canoe has a compressive strength of 1300 psi and a flexural strength of 520 psi for the uncracked section.



**Figure 4: Batch 1 Compressive Strength Results**



## PROJECT MANAGEMENT

The team held its first mass meeting on September 18, 2008. Outlined during this meeting were the goals of the team as well as how team members would benefit from participation. Once the team composition was established, the co-captains explained the various facets of the competition and the team was divided into subgroups (See Organizational Chart). An approximate time-line for the entire project was also determined as described below.

The team organized weekly meetings and each team member was given specific tasks. Tasks were divided into short term and long term. Short-term tasks were solo efforts, while longer term tasks were subgroup efforts, consisting of several members. The two captains oversaw mix design and construction, respectively, giving the team direction right from the first meeting. The team also focused their thoughts on “green” engineering every step of the way as such an approach would help the team achieve its yearly goals. Great emphasis was placed on learning from previous years and how the team could strive to eliminate all past flaws. Most team members were also given the task of finding sponsors for the following year as well improving upon the construction methods employed during the current year. Thus the team was looking ahead while focusing on the present.

One of the initial administrative items addressed during the year was submitting funding letter requests to corporate sponsors. During the initial planning phase, the budget for the team was outlined and the amounts were allocated as follows: Mix materials-\$600, Construction-\$800, Traveling, food and miscellaneous-\$1000. These values were primarily based on previous years’ spending habits. Additional funds were allocated to mix development since new mesh and pigments were to be purchased. In addition to corporate sponsors, financial support also came directly from the UM’s College of Engineering and the Civil and Environmental Department.

### **Critical Path Activities**

The milestones were scheduled such that adequate time would be allowed for delays due to unavoidable circumstances. The milestones identified by the team were the following:

- 1) First Meeting held: Start 9/18/2008, Number of Days-1.
- 2) Mix Design and Testing: Start 11/6/2008, Number of Days-100.
- 3) Finalize Cutpaths: Start 11/6/2008, Number of Days-85.
- 4) Formwork routing: Start 1/30/2009, Number of Days-1.
- 5) Pour Day: Start 2/15/2009, Number of Days-1.
- 6) Sanding, Lettering and Clear Coat: Start 3/5/2009, Number of Days-14.
- 7) Rowing practice: Start 3/19/2009, Number of Days-3.

The completion dates of critical path items were primarily determined around the zero float date for pour day. The pour date was selected so the canoe would be placed prior to spring vacation, allowing for adequate curing time prior to demolding and finishing. The formwork routing date was determined based on availability of the CNC router while also considering the minimum formwork construction duration was two weeks. The routing date was originally scheduled for mid-January to allow for one month of formwork construction but was ultimately delayed due to CNC scheduling conflicts and to the fact that previous members did not properly train current members last year regarding cutpath creation processes.

The breakdown of the number of man-hours the team spent were as follows: mix design development 100 hours, hull modeling 30 hours, construction and cutpaths 30 hours, formwork cutting 30 hours, canoe pouring 70 hours, finishing 50 hours, and rowing practice 15 hours.

Building on past design concepts and construction processes, the formwork construction began by creating a detailed three-dimensional hull design model in Rhinoceros from this year's standard required hull design. The model was then converted into two-dimensional contours in AutoCAD taken every 2 inches on center since the formwork was to be constructed with 2-inch insulation board. To simplify formwork construction and routing requirements, rather than using 3D routing at the bow and stern, the entire formwork was constructed from 2D contours.

The 2D contours were then oriented to fit 8' by 4' sheets while minimizing insulation waste. The width of the formwork was also varied along the length to minimize waste and formwork costs. Keys were also routed in the sections so structural 2x4s could be used for alignment during assembly. Five-foot long sections were then assembled with wood glue. Once dry, the separate sections were assembled to create the whole formwork and then sanded. Drywall compound was used to fill in imperfections and create a consistently smooth interior surface. The drywall compound was sanded and oiled prior to concrete placement.

The concrete was placed in two 3/8 inch layers and finished by hand and by rolling existing cylinders along the surface for compaction. Between the concrete layers, three foot sheets of polyethylene mesh was placed with minimum six-inch overlap between sheets. The length of mesh sheets was selected to allow for a balance between placement of layers to avoid cold joints between layers. After pouring the canoe was covered in wet sheets, which were rewet frequently, and cured for 18 days. After demolding and swamp testing, the canoe will be coated with a slurry mix as required. The whole canoe will be thoroughly sanded and sealed.

Safety is always the most important issue during construction. All MCCT members were required to take the safety training before working in laboratory facilities. Each member of the team was responsible for attending safety training by the beginning of October, so that he/she could proceed with individually assigned tasks. Furthermore, protective equipment, such as gloves, masks, and safety glasses, were used during the application of drywall mud, the sanding of the concrete, and during concrete mixing.



**Figure 5: Sanding Formwork Sections prior to Completing Assembly**



**Figure 6: Canoe Placement, Note Placement of Mesh between Layers**

## INNOVATION AND SUSTAINABILITY

The creation of the Environmental Protection Agency in 1970 resulted in increases in environmental protection policy standards designed to reduce the emissions of contaminants. Thankfully for society, civil engineers prevent millions of pounds of manufacturing process waste from entering landfills by supplementing conventional components of concrete with recycled waste materials. This section will describe MCCT’s approach to using sustainable materials in the design and construction of this year’s “green” canoe **HydroThunder**. Green engineering principles were employed during each stage of canoe preparation. By planning, the team ritually applied a list of green principles before starting a component of the project.

Constructing new custom formwork each year results in significant product waste each year. Originally, the MCCT considered using an outsourced high precision double-sided fiberglass formwork. Investigation of the process revealed that the method conflicted with this year’s green theme because it required all single use consumable materials. Thus, the team proceeded with the traditionally constructed formwork, but donated nearly all waste created during formwork routing to art students. This act prevented the foam from going to a landfill, while

To supplement the materials available a unique idea generated was to recycle previous canoes in the newly designed mix. This common practice in various engineering firms was pursued with disappointing results. The only available company to satisfy our request could not have provided the recycled aggregate is sizes small enough to be used. Thus, the team decided to investigate other alternatives with commercially available recycled aggregates. Instead of allowing the previous canoes to go unused, the team will investigate donating the canoe to a high school for a new home as a means of “up-cycling”.

This year the team also employed a high weight percentage of three sizes of Poraver glass sphere aggregates the mix design. Poraver uses 100% consumer recycled glass in the production of the product, which was a key selling point for our team. To minimize atmosphere effects of transporting the material to our school, the team decided to purchase all supplies from the closest distributor.

The team used multiple byproduct materials, in the mix design this year, produced from processes unrelated to concrete. One of the materials used, fly ash, is produced in mass quantities as a byproduct at coal combustion power plants. Fly ash helps to reduce the overall cost of concrete and prevents useful material from going to a landfill. The purpose of using coal ash as opposed to wood ash is that the coal fly ash contains silicone, iron, and aluminum dioxides, which react with lime enhancing the strength of the concrete. Additionally, silica fume is recovered from the production of high purity silicone products. Due to its high surface area to weight ratio small additions of silica fume allows concrete mixes to quickly develop strength as the fume readily reacts with the combination of salts in the mix.

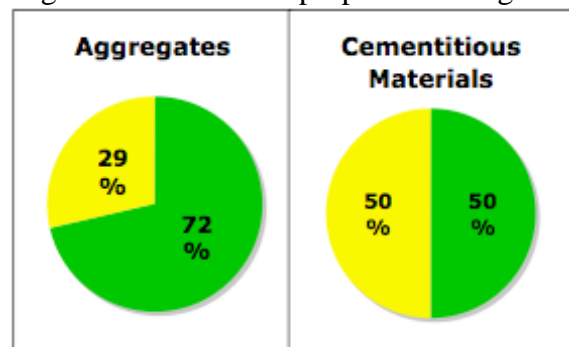
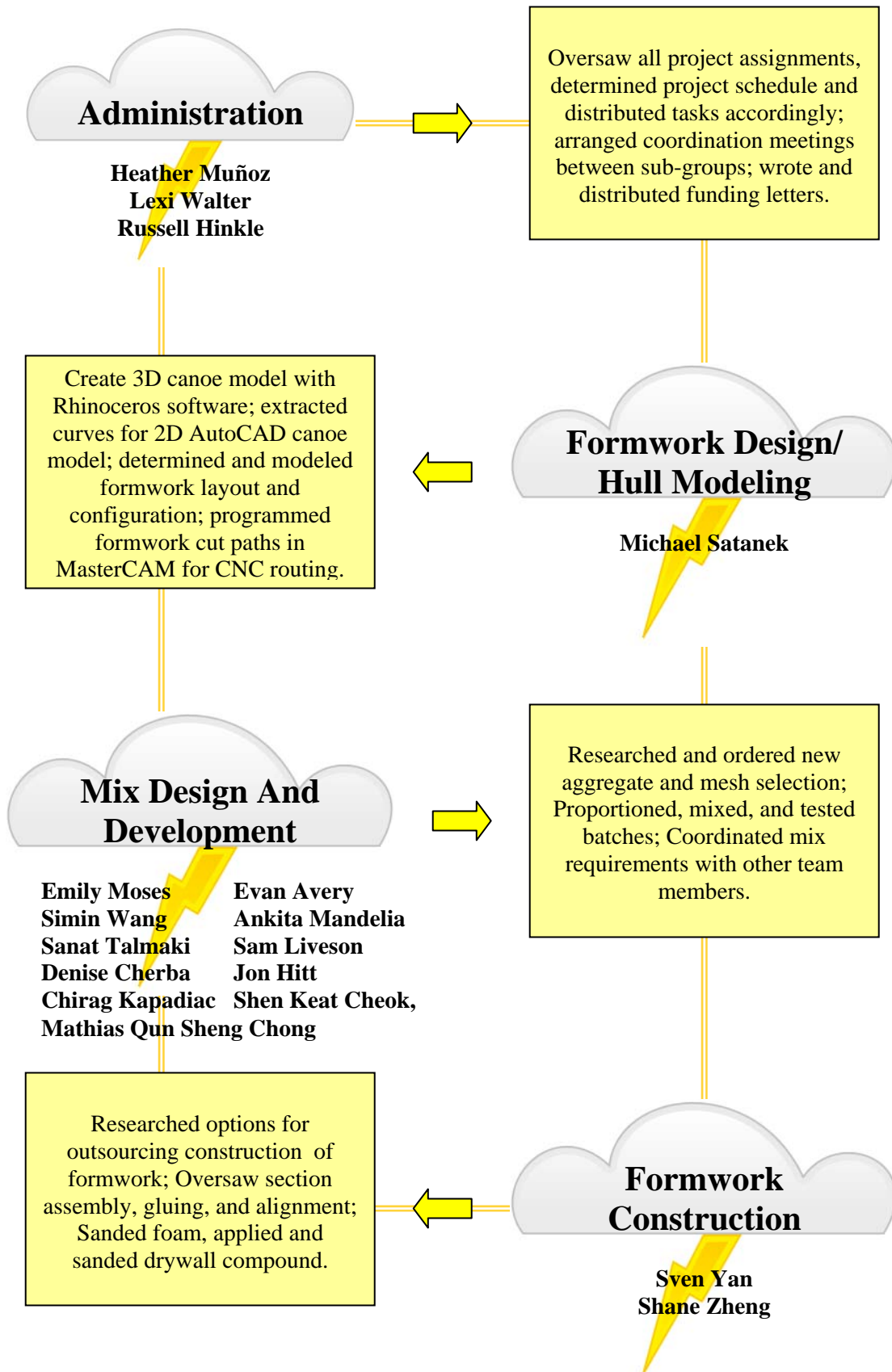


Figure 7: Percent by Weight of Recycled Material  
Green = Recycled, Yellow = Non Recycled



ORGANIZATIONAL CHART



## APPENDIX A: REFERENCES

ACI 318-08, "Building Code Requirements for Structural Concrete," American Concrete Institute. (copyright 2008).

ASTM C 31/C 31M, "Standard Practice for Making and Curing Concrete Test Specimens in the Field," ASTM International Book of Standards vol.04.02. (copyright 2005)

ASTM C33-03, "Standard Specification for Concrete Aggregates," ASTM International Book of Standards vol.04.02. (copyright 2005).

ASTM C109/C109M-02, "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars," ASTM International Book of Standards vol.04.01. (copyright 2005).

ASTM C150-04ae1, "Standard Specification for Portland Cement," ASTM International Book of Standards vol.04.01. (copyright 2005).

ASTM C947-03, "Standard Test Method for Flexural Properties of Thin-Section Glass-Fiber-Reinforced Concrete," ASTM International Book of Standards vol.04.05. (copyright 2005).

"Concrete Answers." Alabama Pigment Company Summer Newsletter. (copyright 2006).

"Effect of Specimen Size and Shape on the Compressive Strength of High Strength Concrete." Alaa S. Malaikah (accessed February 2009)

"Ferrocement and Laminated Cementitious Composites," Antoine E. Naaman. (copyright 2000).

"Lightning Storm Photos from August 7<sup>th</sup>, 2005." Mike Theiss. (Cover page photo) [http://www.mthurricane.com/Lightning/Florida\\_Lightning\\_02.jpg](http://www.mthurricane.com/Lightning/Florida_Lightning_02.jpg)

"Poraver Product Specifications" (copyright Poraver North America, 2006) < [http://www.poraver.com/02rohstoff/pdf/product\\_specifications.pdf](http://www.poraver.com/02rohstoff/pdf/product_specifications.pdf) > (accessed October 2009)

"Rhinceros, NURBS Modeling for Windows." (copyright Robert McNeel & Assoc. 2003). <<http://www.rhino3d.com>> (accessed October 2009).

"Shell Element Internal Forces/Stresses Output Convention" (copyright Computers & Structures, Inc., 2006) <c:\program files\SAP2000\help\20105.html> (accessed November 2009)

"3M Scotchlite Glass Bubbles: K and S series Product Information." (copyright 3M 2006). <[http://www.3m.com/microspheres/s\\_k\\_1.html](http://www.3m.com/microspheres/s_k_1.html)> (accessed October 2009).

## APPENDIX B: MIXTURE PROPORTIONS

TABLE 3.1 - SUMMARY OF MIXTURE PROPORTIONS		Proportions as Designed		Batched Proportions		Yielded Proportions	
Batch Volume: 0.35 cubic ft	Specific Gravity	Amount (lb/yd <sup>3</sup> )	Volume (ft <sup>3</sup> )	Amount (lb)	Volume (ft <sup>3</sup> )	Amount (lb/yd <sup>3</sup> )	Volume (ft <sup>3</sup> )
<b>Cementitious Materials</b>							
Portland Cement Type I	3.15	400	2.04	4.89	0.02	402	2.05
Fly Ash Type C	2.40	320	2.14	3.91	0.03	322	2.15
Norchem Silica Fume	2.30	80	0.56	0.98	0.01	80	0.56
C.M. Totals:		800	4.73	9.79	0.06	804	4.75
<b>Fibers</b>							
PVA Fiber	1.30	13	0.16	0.2	0.00	13	0.16
<b>Aggregates</b>							
K15	0.15	26	2.82	0.3	0.03	27	2.84
Absorption < 0.1%							
Batched Moisture < 0.1%							
Solite	1.14	110	1.55	1.4	0.02	111	1.56
Absorption 5%							
Batched Moisture < 0.1%							
Poraver 1-2mm	0.39	127	5.23	1.6	0.06	128	5.25
Absorption 3%							
Batched Moisture < 0.1%							
Poraver 0.5-1mm	0.47	120	4.09	1.5	0.05	121	4.11
Absorption 3%							
Batched Moisture < 0.1%							
Poraver 0.25-0.5mm	0.55	96	2.80	1.2	0.03	97	2.81
Absorption 3%							
Batched Moisture < 0.1%							
Aggregate Totals:		480	16.49	6	0.20	483	16.58
<b>Water</b>							
Batched Water	1.00	293	4.70	3.6	0.06	295	4.72
Total Free Water - Aggregates	1.00	0	0.00	0.0	0.00	0	0.00
Total Water - Admixtures	1.00	27	0.43	0.3	0.01	27	0.43
Total Water:		320	5.13	3.9	0.06	322	5.16
<b>Admixtures</b>							
	% Solids	Amount (fl oz/cwt)	Water in Admixture (lb/yd <sup>3</sup> )	Amount (fl oz)	Water in Admixture (lb)	Amount (fl oz/cwt)	Water in Admixture (lb/yd <sup>3</sup> )
Master Builders Glenium 3030	5%	23.0	11.4	2.3	0.14	23	11.40
Master Builders AE90	5%	3.0	1.5	0.3	0.02	3	1.49
Dow Liquid Latex Modifier	50%	54.0	14.0	5.3	0.17	54	14.09
Black Pigment* - SG=4.9	100%	100.0	0.00	5.6	0.00	54	0.00
Cement-CM Ratio		0.50			0.50		0.50
Water-CM Ratio		0.40			0.40		0.40
Slump, in.		0.2			0.2		0.2
Design Air Content, %		6%					
Density (Unit Weight)**, lb/ft <sup>3</sup>		62.7			58.9		58.8
Gravimetric Air Content, %					6%		6%
Yield**, ft <sup>3</sup>		28.6			0.35		28.6

\*Solid Admixture: Units are oz/cwt or oz as appropriate

\*\*Includes volume of dry pigment

**TABLE 3.1 - SUMMARY OF MIXTURE PROPORTIONS**

Batch Volume: 0.35 cubic ft	Specific Gravity	Proportions as Designed		Batched Proportions		Yielded Proportions	
		Amount (lb/yd <sup>3</sup> )	Volume (ft <sup>3</sup> )	Amount (lb)	Volume (ft <sup>3</sup> )	Amount (lb/yd <sup>3</sup> )	Volume (ft <sup>3</sup> )
<b>Cementitious Materials</b>							
White Portland Cement Type I	3.15	400	2.04	4.88	0.02	403	2.05
Fly Ash Type C	2.40	320	2.14	3.91	0.03	322	2.15
Norchem Silica Fume	2.30	80	0.56	0.98	0.01	81	0.56
C.M. Totals:		<b>800</b>	<b>4.73</b>	<b>9.77</b>	<b>0.06</b>	<b>806</b>	<b>4.76</b>
<b>Fibers</b>							
PVA Fiber	1.30	13	0.16	0.2	0.00	13	0.16
<b>Aggregates</b>							
K15	0.15	26	2.82	0.3	0.03	27	2.84
Absorption < 0.1%							
Batched Moisture < 0.1%							
Solite	1.14	110	1.55	1.3	0.02	111	1.56
Absorption 5%							
Batched Moisture < 0.1%							
Poraver 1-2mm	0.39	127	5.23	1.6	0.06	128	5.27
Absorption 3%							
Batched Moisture < 0.1%							
Poraver 0.5-1mm	0.47	120	4.09	1.5	0.05	121	4.12
Absorption 3%							
Batched Moisture < 0.1%							
Poraver 0.25-0.5mm	0.55	96	2.80	1.2	0.03	97	2.82
Absorption 3%							
Batched Moisture < 0.1%							
Aggregate Totals:		<b>480</b>	<b>16.49</b>	<b>6</b>	<b>0.20</b>	<b>484</b>	<b>16.61</b>
<b>Water</b>							
Batched Water	1.00	293	4.70	3.6	0.06	295	4.73
Total Free Water - Aggregates	1.00	0	0.00	0.0	0.00	0	0.00
Total Water - Admixtures	1.00	27	0.43	0.3	0.01	27	0.43
Total Water:		<b>320</b>	<b>5.13</b>	<b>3.9</b>	<b>0.06</b>	<b>322</b>	<b>5.17</b>
<b>Admixtures</b>							
	% Solids	Amount (fl oz/cwt)	Water in Admixture (lb/yd <sup>3</sup> )	Amount (fl oz)	Water in Admixture (lb)	Amount (fl oz/cwt)	Water in Admixture (lb/yd <sup>3</sup> )
Master Builders Glenium 3030	5%	23.0	11.4	2.2	0.14	23	11.43
Master Builders AE90	5%	3.0	1.5	0.3	0.02	3	1.49
Dow Liquid Latex Modifier	50%	54.0	14.0	5.3	0.17	54	14.12
Yellow Pigment* - SG=4.2	100%	100.0	0.00	5.6	0.00	54	0.00
Cement-CM Ratio		0.50			0.50		0.50
Water-CM Ratio		0.40			0.40		0.40
Slump, in.		0.2			0.2		0.2
Design Air Content, %		6%					
Density (Unit Weight)**, lb/ft <sup>3</sup>		62.5			58.9		58.8
Gravimetric Air Content, %					6%		6%
Yield**, ft <sup>3</sup>		28.7			0.35		28.7

\*Solid Admixture: Units are oz/cwt or oz as appropriate

\*\*Includes volume of dry pigment

## APPENDIX C: GRADATION TABLE AND CURVE

		Factored									
Composite		K15		Solite		P.25-.5		P0.5-1		P1-2	
<b>100.0</b>		5.5		23.0		20.0		25.0		26.5	
<b>100.0</b>		5.5		23.0		20.0		25.0		26.5	
<b>95.4</b>		5.5		18.4		20.0		25.0		26.5	
<b>67.9</b>		5.5		12.6		20.0		25.0		4.8	
<b>38.9</b>		5.5		8.8		20.0		4.6		0.0	
<b>16.1</b>		5.5		6.6		3.6		0.4		0.0	
<b>5.0</b>		5.0		0.0		0.0		0.0		0.0	
Weight Factor:		5.5%		23.0%		20.0%		25.0%		26.5%	
cm <sup>3</sup> per Kilo:		367		202		364		532		680	
Grams per Kilo:		55		230		200		250		265	
SG:		0.15		1.14		0.55		0.47		0.39	
		Percent Finer									
No.	K15	Ret.	Solite	Ret.	P.25-.5	Ret.	P0.5-1	Ret.	P1-2	Ret.	
3/8"	100	0	100	0	100	0	100	0	100	0	
4	100	0	100	0	100	0	100	0	100	0	
8	100	0	79.9	20.1	100	0	100	0	100	0	
16	100	0	54.8	45.2	100	0	100	0	18	82	
30	100	0	38.4	61.6	100	0	18	82	0	100	
50	100	0	28.7	71.3	18	82	2	98	0	100	
100	90	10	0	100	0	100	0	100	0	100	
SG:	0.15		1.14		0.55		0.47		0.39		

