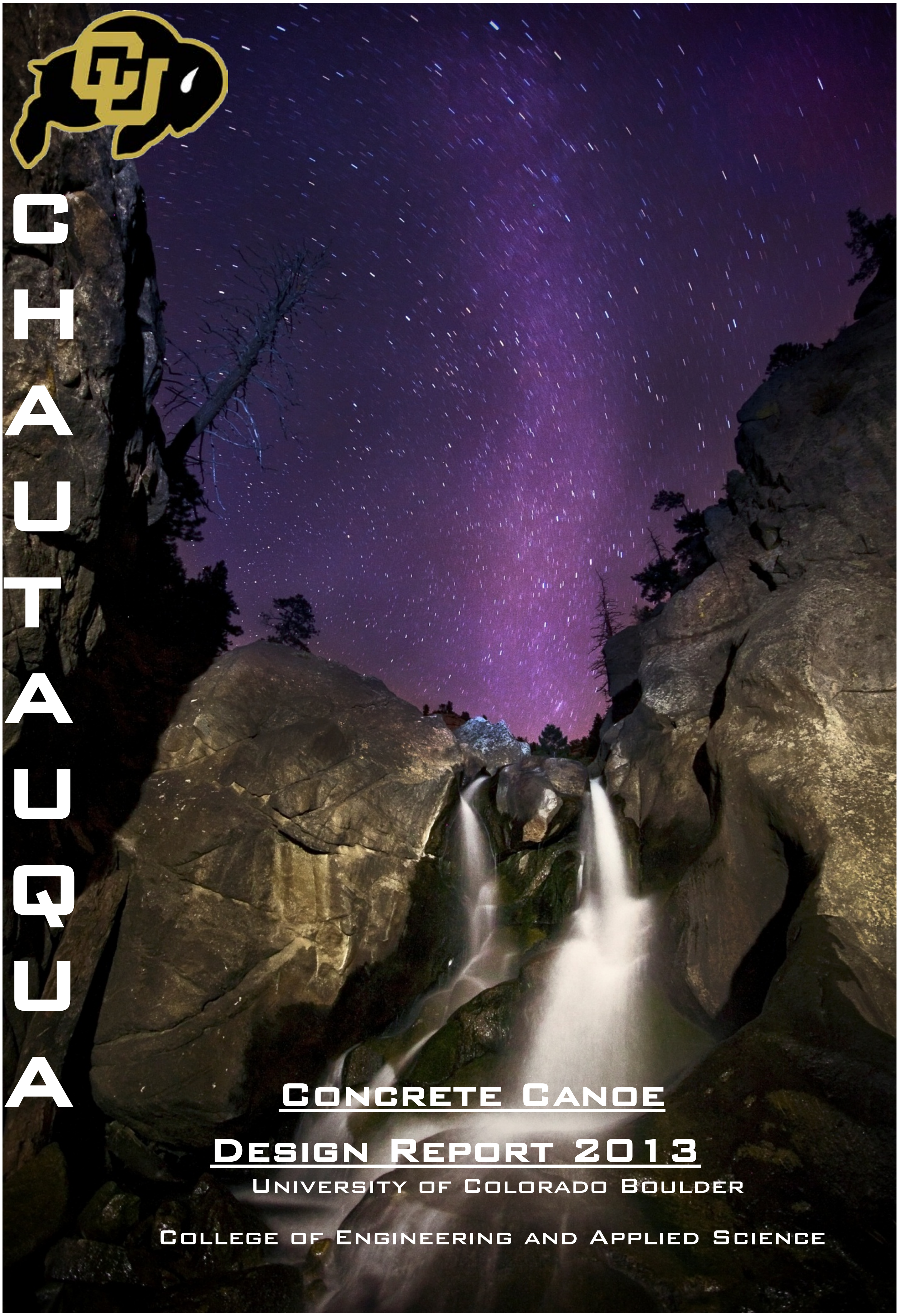


CHAUTAUQUA

Concrete Canoe Design Report 2013

University of Colorado Boulder

College of Engineering and Applied Science

Contents

Executive Summary

Last September, ten brave souls ventured forth on a mission to reinvent the University of Colorado at Boulder's concrete canoe program. This year, The University of Colorado will be entering the first canoe into the Concrete Canoe competition in at least four years. The largest challenge to overcome this year was our lack of experience and nonexistent knowledge base about the project and competition. Perseverance and determination has fueled this year's creation of the ***CHAUTAUQUA***. We feel that we have a canoe designed and ready for competition, and we could not be more proud with our success in reinventing the program this year.

Home to the Rocky Mountains, Colorado is known for its focus on the great outdoors. The University of Colorado attracts students from all over the world for its academic excellence and pure beauty. With one of the most beautiful campuses in the country, students have numerous outdoor activities right at their fingertips. Our campus in Boulder sits at the foothills of the Rocky Mountains and right at the base of the Flatirons in Chautauqua Park.

In the early 1900's, America experienced its first mass educational and cultural movement known as The Chautauqua Movement. Many rural towns lacking opportunities in secondary education established "Chautauqua" as a way to spread the movement's ideals of lifelong learning and love of nature. The Colorado Chautauqua, located in Boulder, Colorado and now known just as Chautauqua Park, is one of the few remaining Chautauqua's in the United States today. Deemed an "exceptional representation of the Chautauqua Movement,"(Chautauqua) The Colorado Chautauqua was named a National Historic Landmark, and its grounds are open and free to the public, allowing the general population to live and breathe the Movement's principles of education, learning, and uplifting entertainment. We exemplify this idealism with our spirit and our applied academia. We have proven our 34" wide, 20'8" long, and 15" tall canoe design to meet the load and density requirements using ASTM concrete testing techniques and lightweight materials. Our structural analysis proves that our canoe may need to withstand forces greater than three kips during competition, and seven day testing results put our concrete strength just above this criteria as shown in Table 1. Galvanized wire mesh is incorporated into an innovative pre-tensioning system and is accompanied by a layer of fiberglass cloth reinforcement. We developed effective construction methods such as a curved table and a smooth, nonstick form design. Beyond the technicalities of the science behind the ***CHAUTAUQUA***, we have managed to dress her up with some colored, inlayed concrete consisting of green, yellow, red, and black hues. Despite having no actual performance data to base our assumptions on, we feel confident, nonetheless, that we will succeed at this year's Concrete Canoe competition.

Table 1: Concrete Properties		
Dry Sample Weight	1.11	Lb
Wet Sample Weight	2.00	Lb
Sample Size	0.0245	Ft^3
Sample Density	45.2	Lb/ft^3
Youngs Modulus	21.1	Ksi
7 Day Yield Stress	11	Ksi

Table 2: Estimated Final Product Properties		
Volume of Canoe	4.31	Ft^3
Concrete Weight	194	Lb
Reinforcement Weight	15	Lb
Excess Moisture Weight	10	Lb
Total Canoe Weight	219	Lb

Project Management

CHAUTAUQUA's team was assembled in late September when our captain was selected. Members came and went throughout the first semester, but our fearless team slowly emerged into ten motivated members. During the project we had to be as efficient as possible to overcome the challenges we faced which is why project management played a particularly essential role in the project. To quantify the time spent on this endeavor we created five different project categories as follows: fundraising, construction, academics, mix design, and management. The hours spent on the canoe totaled to about 480 man-hours, split among the tasks as shown in Figure 1.

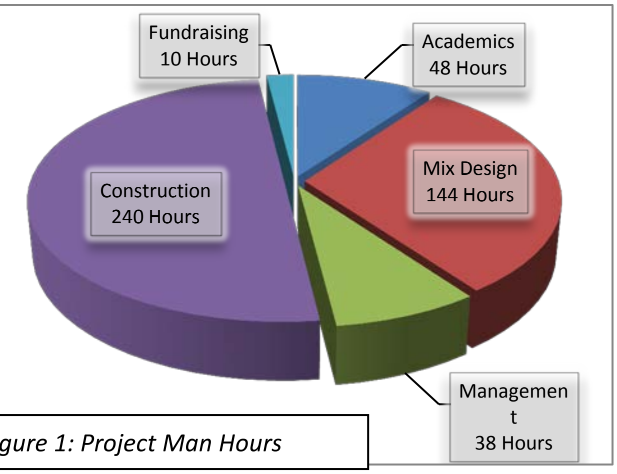


Figure 1: Project Man Hours

No matter the motivation, the budget always presents one initial roadblock. Given that our team had no prior experience with the canoe competition, we came up with our budget estimate entirely from scratch. We first did some research and brainstorming about what exactly would be needed to construct this canoe. Our next step was to consider what other costs we might come across such as transportation out to competition.

To raise the necessary funds, we spread our cause to the widest range of people. The first thing we needed was some immediate start-up support since we began with no leftover money. For these initial funds, we turned to close supporters through Kick Start. While the team was then underway, we applied for additional funds through grants and sought out industry sponsors.

Another task was to determine our timeline for the project. We created the schedule based off some general ideas we gathered from our research on how long it would realistically take to develop our mix and build ***CHAUTAUQUA*** in time for competition. The critical path was determined by identifying jobs that needed to be done by a specified date. We strived to stick to our original schedule, but because of unforeseen obstacles a few of our major milestones had variances which are summarized in Table 3.

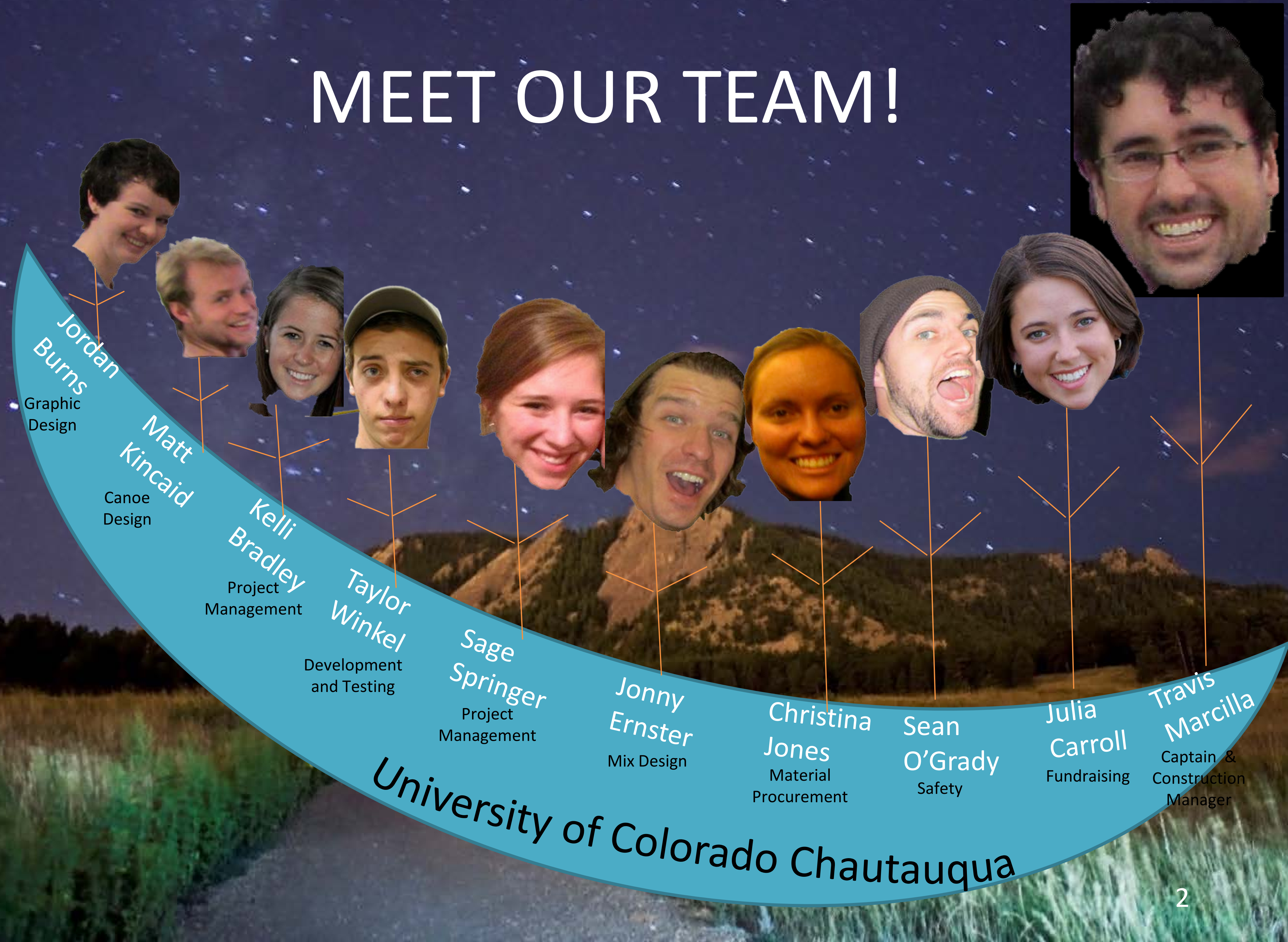
In any project of this scope and size it is very important to make sure everyone on-board has the proper safety training and is always aware of their surroundings. To make sure all team members were as safe as possible; members who would be working with machinery were given proper training for the tasks at hand. Before any major task was initiated, our safety manager observed the scene and provided necessary safety equipment.

Table 3: Major Milestone Variances

Milestone	Variance	Reason
Canoe Design	Weeks	Inexperience and Work Load
Final Mix Selection	Months	Design Learning curve and Material Collection
Pour Day	Months	Depended on Design and Construction
Design Report	Months	The whole project was more involved than expected

The combination of the team's motivation, management practices, and priority on safety allowed for us to complete the tasks effectively, efficiently, and safely as we strived to minimize our spending and stick to the project schedule.

MEET OUR TEAM!



Hull Design and Structural Analysis

This year, ***CHAUTAUQUA***'s hull took on the hull design provided by the Concrete Canoe competition. This was done in order to simplify the design process and allow this year's inexperienced team to focus on the multiple other tasks needed to be completed for ***CHAUTAUQUA***'s success. As our Concrete Canoe program continues and grows in knowledge and confidence, unique design of the canoe's hull will be taken into consideration.

To determine whether the designed canoe would meet stress requirements, a 2-dimensional beam approximation was used to determine the bending stress in the canoe hull. ***CHAUTAUQUA*** was modeled as both a simply supported beam as well as a beam with a cantilever at mid-span. The distributed load imposed by the buoyant force on the hull was neglected as a worst-case scenario design. The upward force of the water below the canoe would significantly reduce the bending moment on all loading combinations, so unlikely extreme support scenarios were used to see if ***CHAUTAUQUA*** could exceed the stresses likely to be encountered. Failure of a canoe is almost certain to occur due to bending, rather than shear, so shear stresses were not considered in this analysis. Additionally, torsional stresses due to water turbulence and waves were not considered. The three loading conditions considered are described in Table 4. The most extreme scenario was found when ***CHAUTAUQUA*** was carrying four paddlers, 175 pounds each, applying a bending stress of 2,185 pounds per square inch. This is also portrayed graphically in Figure 2.

Table 4: Loading Conditions Considered

Condition	Loading	Bending Stress (psi)
1	Simply Supported beam, 3 paddlers at 60-inch intervals.	1638
2	Simply Supported beam, 4 paddlers at 48-inch intervals	2185
3	Single Support at mid-ship. 1 person 60" from bow, one 60" from stern	203

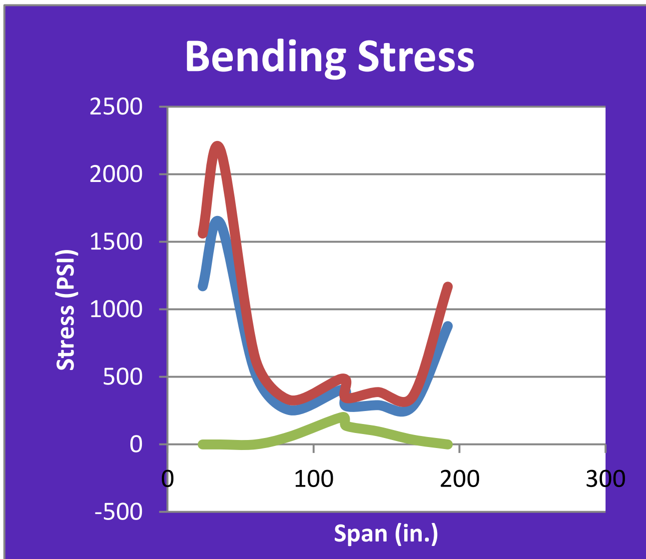


Figure 2: Bending Stress

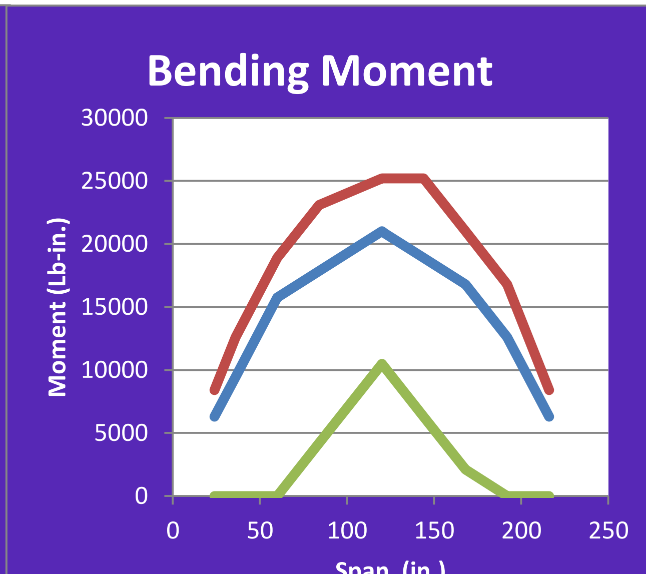


Figure 3: Bending Moment

Condition1 Condition 2 Condition 3

The stress analysis of ***CHAUTAUQUA*** as a beam was done using the standard equation for bending stress, $\boldsymbol{\sigma = \frac{Mz}{I_y}}$**.** The moment of inertia was approximated by determining a 5th order regression equation for the geometry of several stations using the data points given in the standard hull design. The 5th order regression analysis equations appeared to be hypersensitive to rounding errors at the near the bow and stern of the boat where moment of inertia was low. As a result, the moment of inertia calculations near the bow and stern of the boat were erroneously low and thus, stress calculations at those stations were neglected.

This analysis indicated that the boat hull must be designed to endure a bending stress of 2,185 pounds per square inch. Compression testing of the concrete used in the hull indicated a compressive strength of approximately 10,800 pounds per square inch and a modulus of elasticity of 21,111 pounds per square inch, indicating that ***CHAUTAUQUA*** should not fail in compressive bending.

As the concrete canoe program at our university develops in the next few years the team hopes to consider more stress conditions. The simple beam analysis is a good start to understanding the types of forces that act on the canoe. There are many situations that are unaccounted for such as making the turns and travel to the competition. To address these unknown forces the team has designed the concrete to meet the flotation requirement with maximum strength. Once we see how our prototype canoe holds up to the conditions, it will be easier to design for speed and lightest possible weight.

Development and Testing

CHAUTAUQUA's development and testing stage took more time than originally expected. With the initial delay in gathering start-up funds, we began material procurement late in the first semester, two months after we originally planned. Next year we will be testing in September using left over materials from this year. We envy the advantage of our competitors who have years of experience as to what materials to even consider using in their mix designs. *CHAUTAUQUA*'s team had to reinvent the wheel at every step of the way. However, even without prior knowledge and know-how, our motivated team took advantage of our own inexperience and developed our own, unique methods for developing our concrete mix.

Initially, we began development with research, taking a look at what has been successful and popular in past competitions. We also looked around our local area at what was most readily available, convenient for procurement, and friendly to our budget. From there, we decided which materials we wished to test as our principle aggregates. Our most expensive ingredients, Poraver and 3M, kindly donated samples of their products so we could do some initial testing. Our other lightweight aggregate was discovered locally when we walked into the concrete supply store, explaining to them we were out to make lightweight concrete. The man behind the counter, seeming elderly and wise, gave us his advice, "Well, I've been making lightweight concrete for thirty years, and we use Persolite." Questioning what Persolite was, he responded, "Well it is that white material in potting soil. But make sure not to use more than 25% for your aggregate or it will weaken your concrete." Taking his advice, we bought a bag to test.

Not knowing much about these materials, our team began testing. In order to observe how each material behaved, we tested each of the three aggregate potentials separately before we began combining them in various proportions. We discovered that the quantity of each material was where the magic happened. We had to develop the right ratio of materials in order to achieve maximum strength and low density.

In order to begin tackling the specifics of the concrete design spreadsheet, we first did some initial tests of various material ratios as to compare our design spreadsheet with real samples. All our strength tests of our concrete cylinders were performed using a loading machine the team was granted access to in our Civil Engineering lab.


Figure 4: Making Strength Test Samples

After observing the behavior of each potential aggregate separately, we created our first sample to test using 3M hollow glass microspheres and Persolite. This sample had a density of 48.35 pounds per cubic foot and strength of about 2400 psi. This base mix gave us a starting point and outlined where we had to go from there. We continued testing by playing with the quantities of our ingredients to see how it would affect the strength and density. Our spreadsheet, once up, operational, and proved accurate, allowed us to assess the effects theoretically of adding different amounts of each material.

Ultimately, we loved the low density the 3M microspheres provided our mix. As our testing continued we realized that if we decided to choose 3M as one of our principle aggregates, we would have to make a sizeable investment towards more products, setting back our budget dramatically and potentially delaying the pour day which was becoming critical. A decision had to be made. In order to stay on schedule and budget, the ***CHAUTAUQUA***'s team had to sacrifice our preferred mix, resulting in a heavier canoe. Our final official mix using Persolite, Poraver, White Portland, Fly Ash, Polypropylene Fibers, Latex, and water reducer has a wet density of 81.5 pounds per cubic foot, a final dry density of 45 pounds per cubic foot, and strength of 11 kips per square inch. Figure 5 shows the stress-strain diagram obtained from our strength tests on our final mix design.

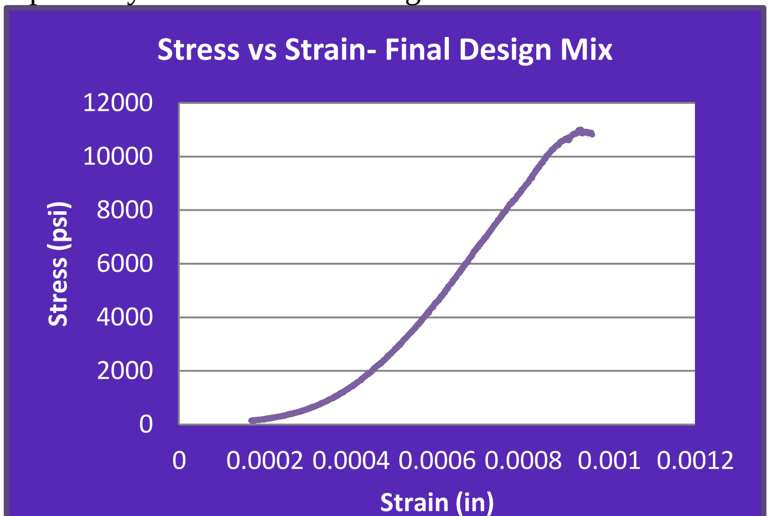


Figure 5: Stress Strain Diagram

Structural analysis showed that we needed merely three kips to withstand torsional forces, but we were too scared to ride that line this year, and we decided to play it a little safer.

In order to increase the strength within the ***CHAUTAUQUA*** we developed several building techniques. We knew we would need to increase the shear strength for the weight of its passengers, and when the canoe would be turning. To simulate the effects that a knee would have digging into the canoe we devised a series of 1' square boxes that were 5/8" deep. We were able to apply force to these that led to valuable design information. We made one sample with no mesh reinforcement, one with only galvanized wire and one with both galvanized wire and fiberglass mesh. The dual mesh system demonstrated the greatest resistance to force. But there were some concerns that needed to be assessed. It was apparent that the holes in the mesh were too small for the concrete to completely bond to itself around the material, but in order to achieve this desired added tensile strength, we decided to use the dual mesh system despite these concerns.

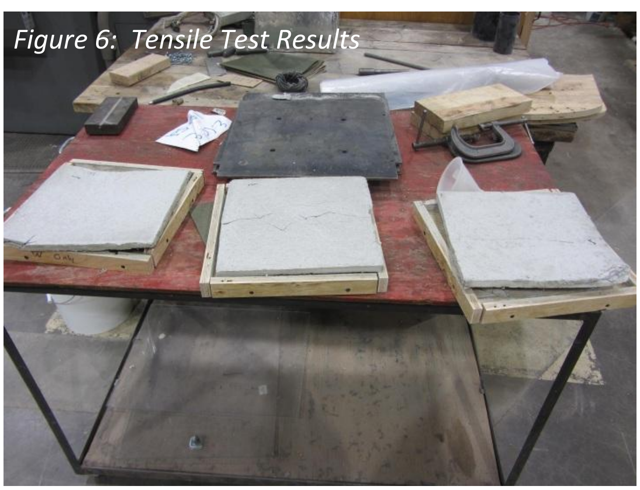


Figure 6: Tensile Test Results

Strength testing on the concrete samples is per ASTM standards using three inch diameter, six inches tall cylinders. Testing of the various samples showed the importance of adding fibers to the mix. The samples containing fibers not only showed a higher compressive strength, but they made the concrete more elastic and dramatically improved the tensile strength. Great care was taken to properly distribute the fiber addition to each batch to avoid clumping which would make weak points in the concrete. A well-prepared homogeneous sample proved to make a real difference in the strength testing results.

Construction

The construction process began with the building of a level table able to withstand the weight of the wet concrete. Using reclaimed lumber and plywood the construction team was able to incorporate the curve at the bow of the canoe directly into the table design. This was achieved by building two walls the length of the canoe with different stud heights allowing the top plate and plywood deck to follow the proper curve. Lumber members act as joists between the walls to provide support and backing for the hull construction above. Additional blocking is included in the ends of the table to provide extra support for the steel wire reinforcement system. The cross-section plywood members used in the construction of the ***CHAUTAUQUA****'s* hull form are fashioned using the standard hull design information provided by the competitions organization. The design team imported the dimensions provided into AutoCAD© and printed scale cross sectional areas which were used as templates. The plywood sections were then nailed into place using blocking. Additional blocking was inserted for the addition of ribs, but it was decided that rib construction would be something we try to achieve next year. The skeleton structure was then sanded down to eliminate any high spots.

Figure 7: Cross-Sectional Members for Canoe Hull Form

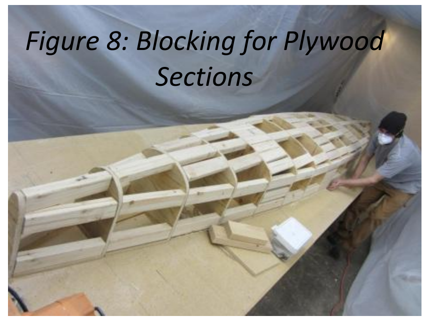


Figure 8: Blocking for Plywood Sections

The original plan was to use sheets of reclaimed Masonite to wrap around the curve, and give the concrete a nice smooth form. Reality proved to be somewhat different when the Masonite refused to make the sharp bend. The solution was to use Masonite where ever possible, and then use drywall mud to sculpt the desired shape. This turned out to be a great plan and after a few layers, the form came out looking very smooth and streamlined. Heat shrink plastic was then wrapped around the form to keep the concrete from sticking.

Figure 9: Shrink Plastic Application

Figure 10: Reinforcement System

Though it has been more than four years since CU has entered the competition, fear of the last team's fate still lurks in the team members' minds. Their canoe broke in half around the first turn, motivation for us to incorporate a pre-tensioning and double reinforcement system. As described previously in Development and Testing, this was achieved using a combination of galvanized wire mesh, fiberglass mesh screen, and steel wire. Next year the team hopes to use carbon fiber, but due to cost and availability of materials steel seemed to be a good choice for the ***CHAUTAUQUA***. A shell was built out of the wire mesh and the steel wire was stretched out over. The tensioning of the steel used a turnbuckle and spring scale system, and once the desired tension of 100lbs was achieved on each of the six tension wires, the wire was attached to the galvanized mesh. The idea was for the tension in the wire to be converted to the wire mesh after the concrete had dried and the tension wire was cut. The theoretical effect will be the whole system acting together thus never allowing the concrete to crack during the rigors of competition.

In early January, the ***CHAUTAUQUA*** truly began to take form. The mixing team stood ready with the key ingredients, measuring devices, a drill-powered mixer, and bucket at hand. The pour team waited eagerly for the first bucket-full of fresh concrete. A little more water than designed needed to be added to the mixture to allow the concrete to ooze through the galvanized mesh properly. To keep the height of the pour uniform, screws are inserted at key locations and set at exactly ¾" out from the form. The concrete was worked into the mesh and left at about ¼" below the screw heads. A layer of fiberglass mesh was added, to be followed by the rest of the concrete. After the concrete was allowed to set for a little while the screws were removed and a trowel was used to smooth the hull. Working in the spirit of true teammates, we were astonished to find ourselves completely done and cleaned up in only six hours.

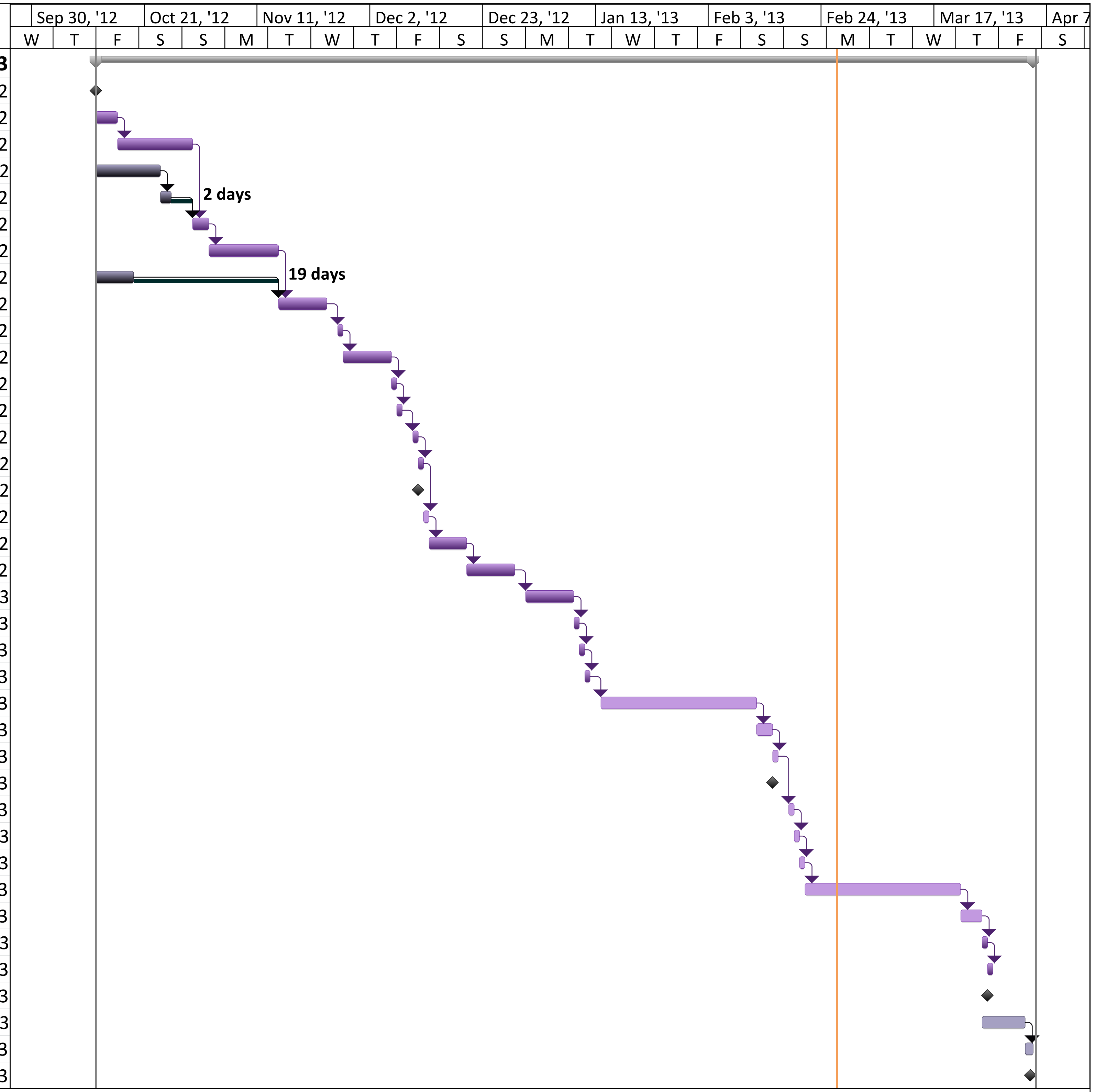
Figure 11: Pour Day

A sealed tent was prepared beforehand with humidifiers to achieve a controlled environment that would allow the concrete to cure slowly and help prevent cracking. Spray bottles and a plastic cover were also used to keep the moisture level high. This kept the concrete soft enough until the next day for art to be carved into the bottom of the canoe along with the lettering. Over the next couple weeks colored concrete filled those designs. And that brings us up to date. The finishing from here on out includes removing the canoe from the form, putting a thin coat of concrete on the inside, and carving interior artwork. With sanding we expect to be very close to our ¾" thickness goal. In testing our samples for flotation, we realized just how porous our concrete really is. Therefore, the finishing coat will be extremely important and this process is still under design.

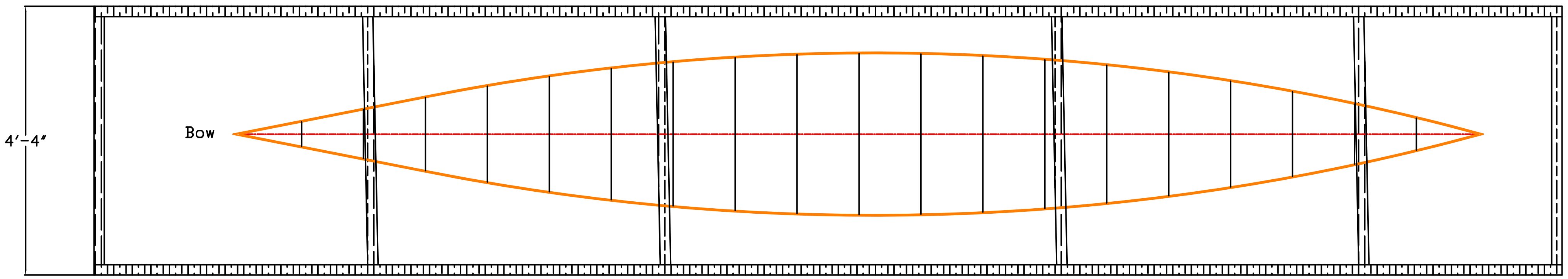
Figure 12: Carving the Lettering

The use of nearly all recycled materials for the construction of the table and the form allowed for lower costs and minimal environmental impact. Since our glass microspheres are made from recycled material and were donated as well, the only real construction cost was for the reinforcement, a belt sander, safety gear, and the remaining concrete ingredients. The plan is to return the materials used for the table to the place that they came from in hopes that someone else will be able to use the materials again. All of the concrete ingredients were checked for environmental impact and health risks, and only materials that we felt confident about were selected.

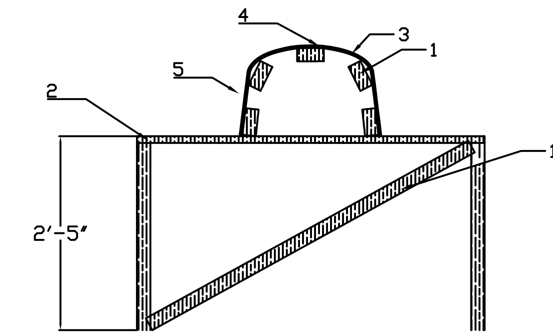
ID	Name	Leveling Delay	Duration	Start	Finish
0	**CU Concrete Canoe 12 Project Schedule**	**0 edays**	**124.5 days**	**Fri 10/12/12**	**Thu 4/4/13**
1	Project Starts	0 edays	0 days	Fri 10/12/12	Fri 10/12/12
2	Clear Work Area	0 edays	2 days	Fri 10/12/12	Mon 10/15/12
3	Manufacure all Wood Materials	0 edays	10 days	Tue 10/16/12	Mon 10/29/12
4	Build Work Table	0 edays	8 days	Fri 10/12/12	Tue 10/23/12
5	Measure Out/Survey Table	0 edays	2 days	Wed 10/24/12	Thu 10/25/12
6	Place Cross Sections	0 edays	3 days	Tue 10/30/12	Thu 11/1/12
7	Install Blocking between cross sections	0 edays	9 days	Fri 11/2/12	Wed 11/14/12
8	Rig tent over table	0 edays	5 days	Fri 10/12/12	Thu 10/18/12
9	Sand down blocking unil flush	0 edays	7 days	Thu 11/15/12	Fri 11/23/12
10	Place Plyboard sheathing over blocking and sections	0 edays	1 day	Mon 11/26/12	Mon 11/26/12
11	Place 1 st Drywall layer over sheathing	0 edays	7 days	Tue 11/27/12	Wed 12/5/12
12	Smooth and sand first layer	0 edays	1 day	Thu 12/6/12	Thu 12/6/12
13	2nd Layer of drywall	0 edays	1 day	Fri 12/7/12	Fri 12/7/12
14	smooth and sand second layer	0 edays	1 day	Mon 12/10/12	Mon 12/10/12
15	place shrink wrap plastic over drywall form exterior	0 edays	1 day	Tue 12/11/12	Tue 12/11/12
16	Form Construction Complete	0 edays	0 days	Tue 12/11/12	Tue 12/11/12
17	Place wire mesh matrix over form	0 edays	1 day	Wed 12/12/12	Wed 12/12/12
18	Realign wire mesh with screws	0 edays	5 days	Thu 12/13/12	Wed 12/19/12
19	Glue all wire mesh	0 edays	7 days	Thu 12/20/12	Fri 12/28/12
20	Construct Pretensioning system	0 edays	7 days	Mon 12/31/12	Tue 1/8/13
21	Glue tensioned wires to mesh	0 edays	1 day	Wed 1/9/13	Wed 1/9/13
22	Instal fiberglass mesh	0 edays	1 day	Thu 1/10/13	Thu 1/10/13
23	Pour Outside Hull	0 edays	1 day	Fri 1/11/13	Fri 1/11/13
24	Outside Hull Cures	0 edays	21 days	Mon 1/14/13	Mon 2/11/13
25	Color Outside Hull	0 edays	3 days	Tue 2/12/13	Thu 2/14/13
26	Sand down Hull	0 edays	1 day	Fri 2/15/13	Fri 2/15/13
27	Outside Concrete Layer Ready	0 edays	0 days	Fri 2/15/13	Fri 2/15/13
28	release wires and ready for pouring	0 edays	1 day	Mon 2/18/13	Mon 2/18/13
29	Construct Form Stands for Inside Hull	0 edays	1 day	Tue 2/19/13	Tue 2/19/13
30	Pour Inside Layer	0 edays	1 day	Wed 2/20/13	Wed 2/20/13
31	Inside Hull Cures	0 edays	21 days	Thu 2/21/13	Thu 3/21/13
32	Color Inside Layer	0 edays	2 days	Fri 3/22/13	Mon 3/25/13
33	Sand Down inside Layer	0 edays	1 day	Tue 3/26/13	Tue 3/26/13
34	Seal Concrete	0 edays	1 day	Wed 3/27/13	Wed 3/27/13
35	Finish Canoe Construction	0 edays	0 days	Wed 3/27/13	Wed 3/27/13
36	Construct Canoe Craddle	0 edays	6 days	Tue 3/26/13	Tue 4/2/13
37	Drive out to Competition	0 edays	1.5 days	Wed 4/3/13	Thu 4/4/13
38	Project Completion	0 edays	0 days	Thu 4/4/13	Thu 4/4/13



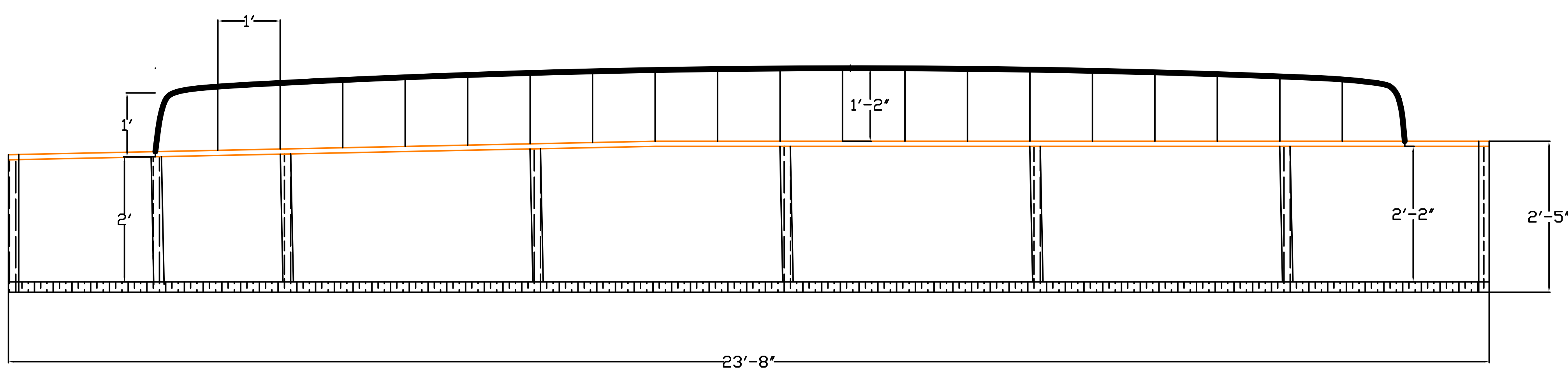
Critical	Slack	Rolled Up Critical Split	Inactive Summary	Start-only
Critical Split	Slippage	External Tasks	Manual Task	Finish-only
Task	Summary	External Milestone	Duration-only	Deadline
Split	Project Summary	Inactive Task	Manual Summary Rollup	Progress
Milestone	Rolled Up Critical	Inactive Milestone	Manual Summary	



Plan View



Typical Cross Section



Elevation View

Bill of Materials	
1	Reclaimed 2x4
2	Recycled particle board
3	Masonite
4	Drywall mud
5	5 mm Polyurethane
6	10 lb Box of Drywall Screws

See Appendix C for Prices and Quantities

ASCE Concrete Canoe Competition, 2013
Drawn By: Matt Kincaid
Date: February 24, 2013

"Chautauqua"
University of Colorado at Boulder
College of Engineering and Applied Sciences

Appendix A – References

"ASTM Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 25 Sept. 2012.

"ASTM Standard Specification for Air-Entraining Admixtures for Concrete." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 26 Sept. 2012.

"ASTM Standard Specification for Blended Hydraulic Cements." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 26 Sept. 2012.

"ASTM Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 26 Sept. 2012.

"ASTM Standard Specification for Fiber-Reinforced Concrete." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 10 Oct. 2012.

"ASTM Standard Specification for Latex and Powder Polymer Modifiers in Hydraulic Cement Concrete and Mortar." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 10 Oct. 2012.

"ASTM Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 10 Oct. 2012.

"ASTM Standard Specification for Silica Fume Used in Cementitious Mixtures." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 15 Oct. 2012.

"ASTM Standard Terminology Relating to Concrete and Concrete Aggregates." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 15 Oct. 2012.

"ASTM Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 15 Oct. 2012.

"ASTM Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 20 Oct. 2012.

"ASTM Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate." *ASTM International - Standards Worldwide*. N.p., n.d. Web. 21 Oct. 2012.

"Rules and Regulations." *American Society of Civil Engineers*. N.p., n.d. Web. 20 Sept. 2012.

Cal Poly Concrete Canoe (2012), Prospector, National Concrete Canoe Competition Technical Paper.

Chautauqua. "The Colorado Chautauqua National Historic Landmark." N.d. Web. 27 Feb 2013

"UW - Madison Concrete Canoe Team ."*NCCC Design Papers 2000-Present"*. N.p., n.d. Web. 21 Sept. 2012.

Appendix B – Mixture Proportions

Table 5: Structural Mix			Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft³):	0.05						
Cementitious Materials		SG	Amount (lb/yd³)	Volume (ft³)	Amount (lb)	Volume (ft³)	Amount (lb/yd³)	Volume (ft³)
CM1	Lehigh White Portland Type 1	3.15	480	2.44	0.873	0.004	510	2.60
CM3	Fly Ash Class C	2.55	320	2.01	0.582	0.004	340	2.14
			800	4.45	1.45	0.008	851	4.74
Fibers								
F1	Polypropylene Fiber	0.90	6.00	0.107	0.011	0.0002	6.38	0.114
	Total Fibers:		6.00	0.107	0.011	0.0002	6.38	0.114
Aggregates								
A1	Persolite Abs: 100%	2.30	173	1.21	0.314	0.002	184	1.28
A2	Poraver .04-.125 Abs: 32%	0.90	100	1.78	0.182	0.003	106	1.89
A3	Poraver .1-.3 Abs: 26%	0.60	170	4.56	0.309	0.008	181	4.85
A4	Poraver .25-.5 Abs: 21%	0.46	200	6.83	0.364	0.012	213	7.27
	Total Aggregates:		643	14.4	1.17	0.026	684	15.3
Water								
W1	Water for CM Hydration (W1a + W1b)	1.00	280	4.49	0.509	0.008	298	4.77
	W1a. Water from Admixtures		100		0.182		107	
	W1b. Additional Water		180		0.327		191	
W2	Water for Aggregates, SSD	1.00	291		0.528		309	
	Total Water *(W1 + W2)*:		571	4.49	1.04	0.01	607	4.77
Solids Content of Latex, Dyes and Admixtures in Powder Form								
S1	Latex	1.100	48.30	0.704	0.09	0.001	51.39	0.749
	Total Solids of Admixtures:		48.30	0.70	0.09	0.00	51.39	0.75
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	Plastol 5000 Type F *8.9 lb/gal*	40%	300.00	100.29	4.36	0.182	319.20	106.71
Ad2	Silka Latex R *9.2 lb/gal*	28%	300.00	124.20	4.36	0.226	319.20	132.15
	Water from Admixtures *(W1a)*:			100.29		0.41		238.86
Cement-Cementitious Materials Ratio			0.60		0.60		0.60	
Water-Cementitious Materials Ratio			0.35		0.71		0.71	
Slump, Slump Flow, *in*.			4+1in		4+1in		4+1in	
M	Mass of Concrete. *Lbs*		2067.82		3.76		2200.16	
V	Absolute Volume of Concrete, *ft³*		24.1		0.04		25.7	
T	Theorectical Density, *lb/ft³*		85.7		85.7		85.7	
D	Design Density, *lb/ft³*		76.6					
D	Measured Density, *lb/ft³*				81.5		81.5	
A	Air Content, *%*		10.7%		4.94%		4.94%	
Y	Yield, *ft³*		**27**		**0.0461**		**27**	
Ry	Relative Yield				0.940			

Table 6: Dyed Concrete Mix			Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3):	0.05						
Cementitious Materials		SG	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Lehigh White Portland Type 1	3.15	500	2.54	0.907	0.005	490	2.49
CM3	Fly Ash Class C	2.55	350	2.20	0.635	0.004	343	2.16
			850	4.74	1.54	0.009	833	4.65
Fibers								
F1	Polypropylene Fiber	0.90	6.00	0.107	0.011	0.0002	5.88	0.105
	Total Fibers:		6.00	0.107	0.011	0.0002	5.88	0.105
Aggregates								
A2	Poraver .1-.3 Abs: 32%	0.90	700	12.4	1.27	0.023	686	12.2
	Total Aggregates:		700	12.4	1.27	0.023	686	12.2
Water								
W1	Water for CM Hydration (W1a + W1b)	1.00	425	6.81	0.771	0.012	416	6.67
	W1a. Water from Admixtures		107		0.193		104	
	W1b. Additional Water		318		0.578		312	
W2	Water for Aggregates, SSD	1.000	221		0.401		217	
	Total Water *(W1 + W2)*:		646	6.81	1.17	0.012	633	6.67
Solids Content of Latex, Dyes and Admixtures in Powder Form								
S1	Latex	1.10	51.3	0.748	0.093	0.001	50.3	0.732
S2	Pigment	2.35	30.0	0.205	0.054	0.0004	29.4	0.200
	Total Solids of Admixtures:		81.3	0.952	0.148	0.002	79.7	0.933
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/yd^3)
Ad1	Plastol 5000 Type F *8.9 lb/gal*	40%	300	107	4.63	0.193	294	104
Ad2	Silka Latex R *9.2 lb/gal*	28%	300	132	4.63	0.239	294	129
	Water from Admixtures *(W1a)*:			107		0.433		234
Cement-Cementitious Materials Ratio			0.59		0.59		0.59	
Water-Cementitious Materials Ratio			0.50		0.76		0.76	
Slump, Slump Flow, *in*.			4+1in		4+1in		4+1in	
M	Mass of Concrete. *Lbs*		2283.52		4.14		2237.14	
V	Absolute Volume of Concrete, *ft^3*		25.05		0.05		24.54	
T	Theorectical Density, *lb/ft^3*		91.16		91.16		91.16	
D	Design Density, *lb/ft^3*		84.57					
D	Measured Density, *lb/ft^3*				82.9		82.9	
A	Air Content, *%*		7.22%		9.11%		9.11%	
Y	Yield, *ft^3*		**27**		**0.050**		**27**	
Ry	Relative Yield				1.021			

Appendix C – Bill of Materials

Item	Description	Purpose	Quantity	Unit cost	Total cost
2 X 3 8' Premium Stud		Form Table	9	$1.93	$17.37
4 mm Clear Poly Sheeting		Tent	1	$43.98	$43.98
1/4 '' X 200' All-Pupose Clothing		Tent	3	$18.21	$54.63
Medium Binder Clips	3 boxes	Tent	3	$2.99	$8.97
4 X 8 1/8" Hardboard Cull Sheet		Form Table	3	$5.00	$15.00
Nitrle Gloves		Safety	2	$12.99	$25.98
Respirator		Safety	2	$34.97	$69.94
Latex		Concrete	2	$11.87	$23.74
Coveralls	1 box	Safety	1	$22.97	$22.97
Galvanized Hardware Cloth		Reinforcement	1	$29.97	$29.97
All Purpose Joint Compound	5 gallons	Form	4	$9.25	$37.00
3" X 18", 36 grit Sanding Belt	2 belts/pack	Finishing	2	$5.97	$11.94
3" X 18", 50 grit Sanding Belt	2 belts/pack	Finishing	1	$5.97	$5.97
Glavanized finishing nails	box of nails	Form	1	$11.89	$11.89
3" X 18" Belt Sander		Finishing	1	$99.97	$99.97
14 guage Galvanized Wire		Reinforcement	1	$6.29	$6.29
5/16" Turn Buckle E & E		Reinforcement	6	$2.99	$17.94
Washers	in lbs	Reinforcement	1.25	$3.49	$4.36
7/32" Turnbuckle		Reinforcement	6	$1.99	$11.94
Super Glue		Form	28	$2.29	$64.12
3/8" Tile Spacers		Form	1	$2.59	$2.59
5/16" X 7" Carriage Bolt		Reinforcement	8	$0.88	$7.04
3/8" X 1 1/2" Fender Washer		Reinforcement	12	$0.32	$3.84
5/16" X 1 1/2" Fender Washer		Reinforcement	8	$0.30	$2.40
5/16" Finished Hex	5/16" - 18	Reinforcement	8	$0.07	$0.56
3/8" X 6" Eyebolt	2160 BC	Reinforcement	12	$2.00	$24.00
Hanging Scale	280 lb rating	Reinforcement	6	$49.99	$299.94
Heavy Duty Sponge	Pack	Finishing	1	$2.99	$2.99
12" X 3" Finishing Trowel		Finishing	1	$32.97	$32.97
Liquid Cement Color	100oz	Concrete	3	$4.27	$12.81
Concrete Color	various colors	Concrete	4	$9.85	$39.40
Polypropylene Fiber	1 Lb Bag	Concrete	2	$5.00	$10.00
Plastol Water Reducer	5000 QT	Concrete	7	$10.20	$71.40
Fly Ash	Class "C" 94lb	Concrete	1	$9.90	$9.90
Permalite Concrete Aggregate		Concrete	1	$9.75	$9.75
White Portland Cement		Concrete	1	$18.75	$18.75
06000/LAND/$5	Resource	Form Table	6	$5.00	$30.00
06000/LAND/$15	Resource	Form Table	4	$15.00	$60.00
04210/LUMB/2X4/F/PI	Resource	Form Table	42	$0.15	$6.30
04220/LUMB/2X6/PRIR	Resource	Form Table	18	$0.30	$5.40
Earplugs		Safety	1	$2.07	$2.07
Chemical Splash Goggles		Safety	4	$2.97	$11.88
Sanding Valved Respirator	5 pack	Safety	1	$13.97	$13.97
Hollow Glass Microspheres	donated	Concrete	3	$360.00	$1,080.00
2x6	donated	Table	30	$2.25	$67.50
Plywood	donated	Table	8	$23.45	$187.60
				Total	**$2,597.03**