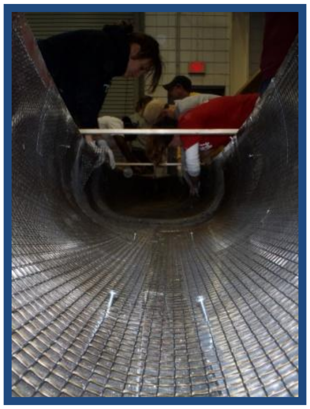
Lea

2012 Concrete Canoe

FAMU-FSU College of Engineering

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Executive Summary

The FAMU-FSU College of Engineering, located in the heart of Florida's state capital, Tallahassee, is a diverse engineering campus shared by the historically black university Florida Agricultural and Mechanical University (FAMU) and research involved university Florida State University (FSU). The joint venture campus, established in 1982, is within walking distance of the Center for Advanced Power Systems, the National High Magnetic Field Laboratory, FSU's High Performance Materials Institute, Florida's Department of Transportation Research Laboratory, and the Florida Center of Advanced Aero Propulsion, which houses Florida's largest wind tunnel.

Figure 1: Canoe pour in progress.

As a recipient of the Diversity Award, the FAMU-FSU College of Engineering is recognized as a unique program heavily engaged in research with a growing enrollment of over 2000 undergraduate and graduate students and diverse faculty members from over 20 countries. The American Society of Civil Engineers (ASCE) student chapter serves as an integral part of FAMU-FSU College of Engineering Civil and Environmental Department in involvement and professional growth.

The 2011 ASCE Southeast Student Conference was FAMU-FSU's first participation in the National Concrete Canoe Competition (NCCC) in four years. The team was comprised of determined students who accepted the challenge of re-establishing the concrete canoe presence at our college. With lack of previous experience in the competition, the 2011 team was able to present **Everglass**, an impressive and surprisingly competitive canoe to the regional conference. The 2012 Concrete Canoe team is motivated to carry on the ambitious nature instilled in our predecessors and to redefine FAMU-FSU on the NCCC Level.

The successful and innovative construction method developed in 2011 was used as a starting point in the creation of **Lea**. The mold system was refined to allow for easier form release and materials were reevaluated to maximize sustainability, without compromising strength and weight. It was clear from last year's race performance that our team could benefit from increased practice and preparation. As soon as we returned to Tallahassee, we wasted no time on improving our rowing techniques and hit the lake on our new practice concrete canoe, **Everglass**

Lea is FAMU-FSU's tribute to the Florida Beaches, our state's most popular and prized attractions. With the recent Deepwater Horizon disaster damaging the reputation of our beautiful beaches, our purpose is to portray the value of our alluring natural resources. In coincidence with thinking green, conservation, and sustainability, this year's canoe serves a reminder for reasons why we must take actions in preserving our delicate environment. The name **Lea** comes from the Hawaiian deity "Lea-ka-wahine", goddess of canoe builders. Considering this year's Southeastern Student Conference theme, "Breaking the Mold", **Lea** has been designed and constructed with innovation, creativity, and sustainability in mind. This year's canoe theme has taken us to new heights as we strive to return to high levels of concrete canoe competition using environmentally friendly, engineered materials.

Lea cost under $1000 and required less than 1700 hours to construct. In developing this year's mix and mold, the team decided to invest in expensive materials which proved to increase performance and ease construction time. Design software, past experience in canoe fabrication, and material testing enabled the team to plan, design, and construct this canoe. The FAMU-FSU ASCE Student Chapter is proud to present its 2012 competition canoe, **Lea**.

Lea's Specifications	
Length	20'-6"
Maximum Width	27''
Maximum Depth	13 ½ ''
Average Thickness	5/8"
Projected Weight	220 lbs
Canoe Colors	White, Yellow, Pink
Concrete Strength	950 psi
Main Reinforcement	Basalt Fiber Scrim & ¾" Chopped Basalt Fiber

In conjunction with the 2012 Southeastern Student Conference theme, "Breaking the Mold" and the relaxed NCCC Rules and Regulations hull shape criteria, the FAMU-FSU team decided on a revolutionary hull design unique to the competition.

Our team decided to take a new design approach, utilizing the flexible design parameters that outlined maximum measurements, but offered unrestricted minimum design specifications. **Lea**'s designed hull caters towards speed induction and low drag. The design team conceptualized a hull which would provide the appropriate balance between a sturdy shell and a racing chassis. We investigated several design aspects of a canoe hull which influence the vessel's performance in designing our canoe.

The design team researched various professional canoe racing designs with the intent to incorporate aspects into our concrete canoe. Several alternative designs were proposed, however were ultimately rejected by the construction team due to intricate mold structure and design.

The team conclusively opted for a modified tumblehome, round bottom design composed of certain characteristics commonly found in racing canoes ("Canoe Design"). Literature research demonstrated the tumblehome shape would provide enhanced maneuverability and increased speeds. The sleek and narrow hull is designed to reach fullness slowly; this allows for less resistance and thus induces speed all without compromising freeboard. It was also decided to flare the sides of the midsections which would allow the paddlers to heel the canoe over to carve turns. A rounded, smooth chine was designed with the intent to facilitate maneuverability and encourage high hull speeds. The entry line of the canoe was shaped with a rounded stem and sharp entry line with the intent of cutting through water as smoothly as possible. Although stability was reduced through the use of these hull parameters, we determined that through increased practice and preparation, balance could be mastered.

There were several alternatives investigated by the design team. A developed tee keel was originally proposed, but after further investigation it was determined that although a keel would increase the canoe's ability to track, an increase in drag would be much more significant. In addition, a keel would decrease the paddler's ability to make sharp turns. In order to provide for smoother turning however, a moderate rocker was included in the design.

Another goal this year that came into the hull design was the ability to produce a canoe which would not require the addition of foam for flotation. This was a unique feature which the FAMU-FSU team introduced in **Everglass** and a tradition we wanted to instill in our canoes.

The selected hull shape boasts a 20.5' length with the maximum width of 27". The maximum beam span is located slightly aft of mid-ship and toward the bow of the canoe, as **Lea**'s profile is marginally asymmetrical. A maximum depth of 13.5" allows the racers closer access to the water and reduces the length of the paddle stroke.

The canoe's hull was rendered on AutoCAD 2012 which was instrumental for both the Analysis team to investigate the structural properties, and for the construction team to develop the mold design.

Lea's unique features centered around optimizing speed make this canoe a forerunner in the 2012 NCCC.

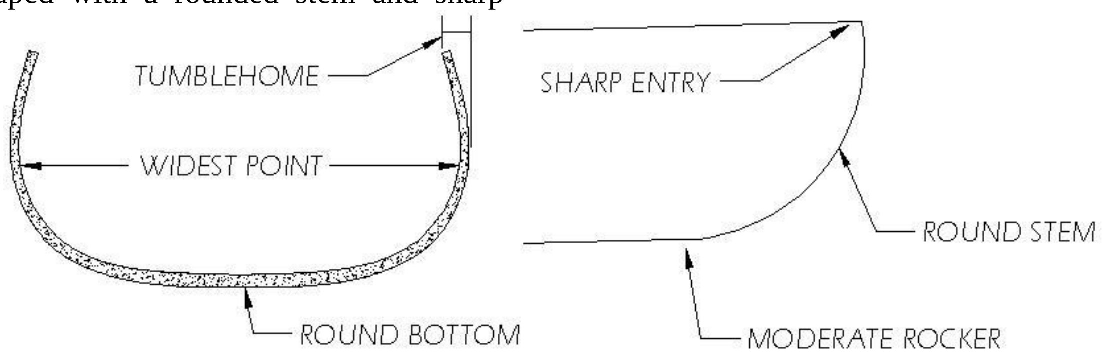


Figure 2: Hull properties.

The analysis team's primary goal was to model and better understand the forces **Lea** would operate under, which included multiple expected load cases. The team opted to use basic engineering principles in collaboration with generic, yet dependable, software to determine the canoe's hull stresses, draft, and expected capacity.

The team first imported the hull dimensions developed by the hull design team into Delft Ship, which calculated the hull shape's buoyancy properties. The worst load case assumed four 150 lb rowers, each spaced 4' apart, sitting in a 180 lb canoe having a ½" hull thickness and multiplying by a factor of safety of 1.5. The draft was computed to be 8". This was assuming a 60 pcf concrete mix, a value figured to be competitive based on previous experience.

Using this draft, the team calculated appropriate loads being applied on the hull by the displaced and moving water. This hull rendering allowed the team to take shape properties and the volume of displaced water of twenty selected cross-sections were calculated using a Microsoft Excel Spreadsheet, as assuming the canoe to be modeled as a squared off U-shaped beam.

The displaced volumes and shape properties were then imported into MDSolids, where the canoe was modeled as a simple, indeterminate plate of reinforced concrete. This assumed that the side-walls of the canoe did not contribute to the resistance of the buoyant forces acting underneath **Lea**'s hull.

The four locations where paddlers would be positioned inside the canoe were modeled as pin supports, and the reactionary buoyant force was modeled as a varying distributed load (VDL). This VDL was based upon the change of displaced volumes of the selected sections. These assumptions equated to a load case of all four rowers crouching on one knee, which was intuitively determined to cause the most stress at each point. The maximum bending moments are located beneath the four rowers at 1053, 1038, 1019, and 1007 lb-in (bow through stern paddler, respectively).

Without reinforcement, the induced stress would be 1810 psi in tension underneath the second rower. With one layer of basalt reinforcement scrim located 1/8" away from the exterior, the stresses reduced to 733 psi. This value was determined by translating the area of reinforcement into an equivalently stiff area of concrete, assuming the concrete had an ultimate strength of 1000 psi in compression with a ½ inch hull thickness. The analysis team thus determined that basalt reinforcement scrim with an elastic modulus of 12,900 ksi would be beneficial to adding flexural strength to the canoe.

Lea's walls undertake stresses induced by dynamic moving water as the rowers turn the canoe. In the team's calculations, moment-impulse and hydrostatic water pressures were applied to a foot long section of canoe wall. Using the turning rate of 28.1 degrees per second, the maximum water velocity hitting the hull would be nearly 5 ft/s at the bow of the canoe. If the entire sidewall of the hull were being loaded with this moving water in addition to the hydrostatic pressure, a maximum bending moment of 290 lb-in would have to be resisted by the canoe's walls. The flexural stress would thus be 200-psi with a basalt fiber scrim reinforcement layer, which is 27% of the maximum stress experienced by the bottom of the hull. The drag created as the canoe moves through the water would also induce a normal compression stress down the canoe's hull. Using the same hydraulic analysis as done with the side walls, the canoe hull would experience 397 lbs of normally acting compression, assuming the water was acting as if it were pushing against the widest part of the canoe at a speed of 10 ft/s. At the smallest cross-section in front of the first rower, this would entail a 46.5 psi compressive force, which is negligible considering load factorization.

Though most of the analysis was conservative, the team was content with the values. However, to account for any discrepancies performed in the calculations, an additional ¼' of concrete and basalt scrim was added on the bottom of the canoe's hull resulting in a reduced flexural strength requirement of 465.6 psi with the assumed compressive strength needs of 1000 psi. This also increases the anticipated canoe weight to 220 lbs.

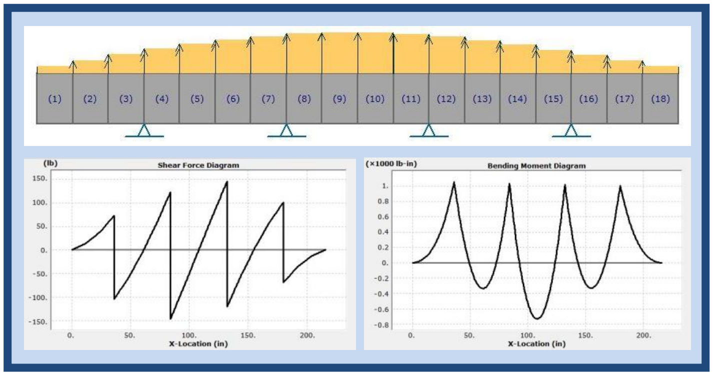


Figure 3: MDSolids model, shear and moment diagrams.

The mix design team set forth to meet the requirements laid out by the project goals, analysis team, and NCCC rules. The team was also tasked to find suitable aggregates that were not only lightweight, but robust, recycled, and compatible with cement. The team considered materials used in previous canoe's, as well as creative alternatives.

From previous experience, the team eliminated the choices of saw dust, broken glass, styrofoam, and recycled concrete. These materials are weak and cause significant shrinkage cracking during the curing process. The recycled concrete was rejected since it would contain latent cement content past the 30% by mass maximum limit.

The team discovered that toilets scrounged from refurbished homes were being recycled at local recycling centers. This, the team decided, was a suitable replacement due to porcelains high compressive strength. But, like the glass, the porcelain would have a specific gravity of around 2.5, making both as dense as sand. Since the glass and porcelain are often used as yard mulch and concrete aggregate, both were available pre-processed to certain sizes by vendors. Both the recycled glass and porcelain were ultimately chosen as suitable aggregates. Porcelain was used in the structural concrete mix, however it was not selected for the skim mix due to the relatively large particle size. Recycled glass was used to replace the porcelain in the skim coat for a smoother finish.

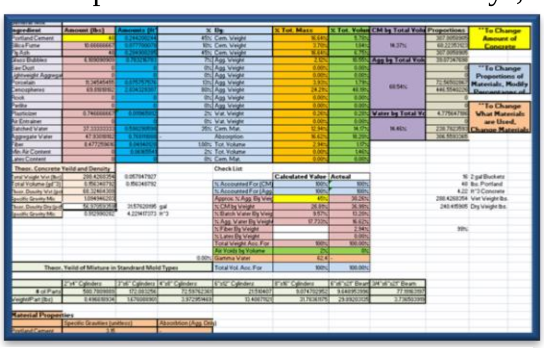


Figure 4: Mix design spreadsheet.

The team searched for other suitable aggregates to decrease the concrete's density. 3M Glass Bubbles K1 were found to be extremely light. However, they passed the No. 100 sieve and used up much of the water content the concrete needed for hydration. Thus the glass bubbles could only be used a maximum of 5% by mass of the aggregates. Upon consulting several concrete suppliers, expanded shale and expanded perlite were suggested to decrease the concrete's density significantly (Pickenpaugh 2010). However, recycled glass beads have been popular in several winning concrete canoe mixes, and are much lighter and stronger than the previously mentioned aggregates. Bags of ASTM C 150 Type I Portland cement, Class F fly ash, Grade 100 silica fume, expanded shale, air entertainers, and super plasticizers were donated to the team. The team purchased rolls of basalt scrim and chopped basalt fiber from Sudaglass, and Cenostar Corporation provided recycled glass beads (cenospheres).

All aggregates were sieved through the No.'s 8, 16, 30, 50, and 100 sieves, ensuring manufacturer specifications were met. Gradation curves were developed following ASTM C-136's methods, but size specifications do not strictly obey. The gradation, it was determined, would not play as much a part in concrete strength as the cementitious materials (c.m.) and strength of the aggregates would, since the limiting concrete strength would be in tension. The recycled porcelain, recycled glass, and recycled cenospheres bulk density and absorption were tested under ASTM C128 and recorded.

Due to the required high amount of cement replacement, the mix design team researched the effects of various cement replacers at elevated concentrations. Fly ash addition by 50% c.m. appeared to be weaker during early stages of curing than those with cement alone (WEI et al 2007). However, those mixes containing 5%-10% silica fume were shown to have equal and greater strengths at the same days, as well as enhanced 60 and 90 day strengths (Yazier 2006). Based upon literature review, the team concluded that a c.m. make-up of 45% Portland cement, 10% silica fume, and 45% Class F fly ash would produce concrete equivalent in strength to that with Portland cement alone. Slag was also considered, but it was determined to not contribute to concrete strength as drastically as fly ash and silica fume.

The team mixed batches of concrete in a systematic process. The process started by dry mixing the c.m. and aggregates in separate five containers. Batch water and aggregate water were then added to their respective buckets and mixed thoroughly. Saturated aggregates were then added to the c.m in intervals while continuously mixing. Appropriate levels of super-plasticizer were then added and mixed for 90 seconds to ensure enhanced air entrainment and concrete workability. ¾ in. long chopped basalt fiber was added last, since it decreased workability and inhibited mixing.

The team developed the concrete mix by utilizing and improving the mix design spreadsheet developed for **Everglass.** Material properties were added for our new aggregates based on manufacturer specifications and the spreadsheet was updated upon further material testing to reflect actual lab conditions.

A preliminary mix produced a 59.9 pcf, air content of 1.9% measured gravimetrically (ASTM C138) and 615.0 psi compressive strength at seven days (ASTM C39). Though it floated, and sufficed for compressive loading, the team desired to formulate a stronger, lighter mix. The team tested a total of seven different mixes before choosing a final mix design. Compressive strengths ranged between 305 and 810 pcf. The selected mix, which outperformed all others, has a dry density of 57.0 pcf, air content of 2.0%, and a 28 day compressive strength of 811.7 psi.

The team also performed modified ASTM C79 flexure tests on ¾" hull plates. These plates had a basalt scrim layer (percent open area greater than 40%) on the underside when they were poured so that the location of the rebar could be maximized. Constructing these beams also allowed the team to investigate how the concrete, basalt scrim, and aluminum flashing would interact. After removal from the forms, the team uncovered that some amount of scaling would occur. When mold release was applied to the aluminum however, the team found that the basalt scrim absorbed the release agent and retarded its adherence to the concrete. Ultimately the team decided not to use the mold release which meant a concrete surface (skim) coat application to the canoe after the main structural concrete and reinforcement placement. The ¾" design beams failed at 412.5 in-lb.

Both the cylinders and the beams experienced a significant amount of deformation before showing any signs of cracking due to the 1% fiber content. Furthermore, the beams failed when the scrim delaminated from the surface. Based upon previous canoe experience, the team realized this as a huge benefit, since cracks in the canoe does not necessarily mean canoe "failure". Canoes with cracks did not take on water, even when crack width was visibly saturated. This meant the canoe would be very durable during racing.

Though the compressive and flexural strengths fell below anticipated levels, the team extrapolated via research that an additional 34% increase in both values could be anticipated pushing the strengths to 1088 psi and 552 in-lb respectively. This value met the team's expectations and the mix was thus a well suited candidate for the construction of **Lea**.

The final mix design required that the c.m. compose of 26.8% by mass (of that, 45% cement, 45% fly ash, 10% silica fume). The aggregate filled 68.5% by volume, yet only 17.7% by mass (of that 80% cenospheres, 13% recycled porcelain, and 7% glass bubbles). ¾" chopped fibers composed 1% total volume and the remaining volume was filled with water. Water to c.m. ratio was 0.45 even though the initial plans called for a 0.4 water to c.m. ratio, the silica fume increased water demand for workability. Super-plasticizers were used in the mix according to manufacturer specifications, however the team felt that the use of air entrainers was not necessary since the dry density of the mixture was low enough to allow the concrete to float.

Figure 5: Flexural testing.

The skim coat mix developed by modifying the canoe's structural mix. The c.m. composition remained identical, however as previously stated, the recycled porcelain was swapped for recycled glass, and basalt fiber reinforcement was not included. The water to c.m. ratio was increased to 1.1 with the intent to increase workability and provide ease of application.

For aesthetics, several colors of stains are being applied in accordance with the guidelines set out by the rules. Once these stains cure, a concrete sealer will be applied that is in accordance with ASTM C 1315. It is assumed by the mix design team that the stain and sealer will not have any effect on the concrete's final material properties other than the finish color and texture.

The primary goal of the construction team was to determine, design, and build an effective female mold for this year's canoe. A female mold provides an accurate and finished outside shape to the canoe. The model created in AutoCAD 2012 for the analysis of the canoe was also used to compose 22 outside hull cross-sectional views along the length of the canoe. These cross-sectional views were taken at 12" center-to-center intervals over the 20.5' canoe length and were plotted full scale on 2'x4' paper. 4'x8' sheets of ½" plywood were then cut to 2'x4' pieces and the plotted rib sections were stapled onto them and cut out to represent the outside dimensions of the canoe at their respective cross-section locations.

The construction team identified that the tumblesome hull shape would not simply allow us to lift the canoe out of the mold and thus decided that the female ribs should be built in six independent sections. A latitudinal split in half and three separate longitudinal divisions make up the mold components. Therefore the ribs were constructed in ~6.5' lengths. In this fashion, upon form removal, the six pieces could be ejected from underneath the canoe.

While the female plywood ribs served as the majority of the canoe mold strength and shape, aluminum flashing was used to bridge the spacing between the ribs and to further increase the definition of the dimensions defined by the hull design team. The thin gauge aluminum flashing was chosen because of its ease of form fitting and more importantly its low reaction with the chosen concrete mix design. The use of this metal would allow the team to not only exercise the form removal idea, but would also provide a smooth, aesthetically pleasing appearance on the canoe exterior and reduce sanding and finishing efforts.

Based on the development and testing results from creating beams, the construction team determined that in order to maximize the reinforcement effects, the bottom layer of scrim would need to be placed as close to the exterior hull surface as possible. Because of the concrete's low slump and workability, the team decided to lay the fiber directly on the mold to ensure correct depth within the hull. Grade screws were used to control variability in the side walls and bottom hull of the canoe, as well as to serve as a gauge for the interior layer of reinforcement. The gauge screws further allowed the team to tightly place the scrim allowing for pre-tensioning of the reinforcement.

Lea was poured on January 2nd. The pour team was composed of eighteen students divided into three teams. Four students were designated concrete mixers, and two acted as runners delivering batches to

Figure 6: Mold construction process.

the rest of the pour team which placed concrete in the mold. The placement team was subdivided between initial placers and finishers who ensured a smooth finish and consistent depth. The most crucial aspect of the pour was preparation. Prior to mixing concrete, the mold pieces were secured with temporary screws and clamps. Additionally, the aluminum flashing was prepped by wiping and cleaning the metal to ensure a clean exterior concrete finish. The base basalt scrim layer was positioned prior to pouring and pre-tensioned with the use of the gauge screws.

The mixing team mixed premeasured aggregates in five gallon buckets for two gallon batches, which were mixed and provided to the placing team by the runners. The placing team began by placing the base layer of structural concrete at the bow of the canoe and worked their way towards the stern. The second placing team followed by placing an additional basalt scrim reinforcement layer and then installing the final layer of concrete while providing “vibrating“ and finishing techniques for the inside surface of the canoe.

Figure 7: 3D inlay.

The design team designed a 3D inlay of the FAMU-FSU College of Engineering seal. The inlay was constructed by stamping a rolled aluminum male stencil on the fresh concrete. The stencil was removed before the concrete set which left a clean and impressive impression of our college’s seal.

Upon four weeks of curing, the form was removed using the ejected mold technique. The six piece mold was removed without any problems and took less than 45 minutes for release. Although the reinforcement scrim was exposed in several areas, it bonded firmly with the structural concrete and required only a slight skim coat for aesthetics.

The skim coat was mixed and prepared in the same manner that the structural concrete was developed. Placement of the skim coat however, was a bit different than the original pouring technique. The canoe was first prepared by marking out where finishing concrete was needed; secondly a thin layer of the skim mix was placed on the predetermined spots. The freshly placed concrete was smoothed down with the use of a damp rag in order to reduce sanding time. This was done with the aid of a trowel. Once the skim coat dried, the patched spots were sanded down with a finely abrasive grit of sandpaper. This process was repeated several times until all abnormal depressions were smoothed out throughout the canoe. This process unfortunately took two weeks longer than originally planned and delayed the painting and sealing of the canoe. We believe however, that the extended amount of time spent patching and finishing will set **Lea** apart from other concrete canoes.

Project Management was driven by a team desire to place at the Regional Conference. After participating for the first time in six years in the 2010 Regional Conference, the team was driven to outperform the competition. The team's management consisted of the Project Manager and Jr. Project Manager, followed by divisional captains in the following departments: Analysis, Construction, Graphics, Mix Design, and Paddle Trainer.

One of the problems the FAMU-FSU team has faced in the past has been with continuance. An effort was made to recruit, retain, and train and rely on new younger members who would carry out the concrete canoe project in upcoming years. This year, the Jr. Project Manager position was established to ensure a smooth leadership transition for the 2013 and future Concrete Canoe teams. In addition, each division had at least one team member who had participated in the 2010 canoe competition. This provided the experience and expertise acquired in the previous competition.

A critical aspect to project management was accountability within each department. Team leaders were expected to organize and control their individual teams as well as communicate with the Project Managers concerning the overall progress of the development team. Weekly meetings held between all divisional captains and the Project Managers were instrumental in keeping the communication level where it needed to be for the project to be successful. Project schedule was evaluated during these meetings to ensure a solid work pace. Work distribution was relatively evenly distributed within each division, with materials testing, mold construction, and miscellaneous (materials collection, paddling practice, etc.) taking the majority of the project time.

A critical aspect to the success of the project revolved around fund raising. Milestones were established and a critical path was determined by defining tasks that had no float.

Figure 8: Private paddle lessons.

The project leaders had an original goal to complete mold construction and to place concrete prior to the winter recess in order to allow the canoe to cure during the holidays. It was realized, however that this goal would not be feasible due to a delay in mix testing.

Staying on schedule was primarily appropriated to allocating materials early enough in the design process. Divisional captains were tasked to develop resource need, which provided the project managers the ample opportunity to allocate materials. The project managers had to find unique alternatives to raising funds as this year's hosting predicament kept us from soliciting our typical donators who have so graciously assisted us in hosting the 2012 ASCE Southeastern Student Conference. In lieu of asking for monetary assistance, the canoe team looked for material donations. The Mix design team was able to acquire Portland cement, fly ash, silica fume, and slag from local North Florida concrete companies. The basalt reinforcement fibers and scrim were also acquired at a partial donation.

The Paddle training captain searched for innovative solutions to increase our paddle team's performance. New carbon fiber racing paddles were donated to the team by the FSU Student Government Association (FSU SGA), and the captain was able to set up a private meeting with members of the Florida Competition Rowers Association who donated their time in helping us develop paddle techniques. FSU SGA additionally donated low profile inflatable life jackets.

Each divisional captain followed and used appropriate safety precautions as required. As the primary concern, safety in all aspects of construction was implemented and enforced throughout all aspects of the project.

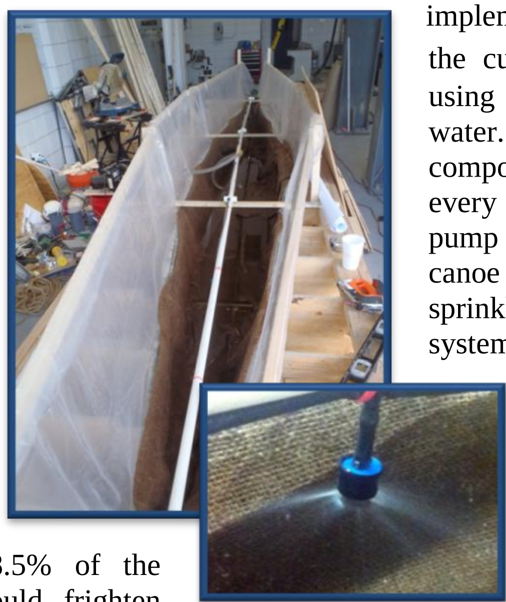
Activity	Work Hours
Structural Analysis	40
Mix Design & Testing	300
Mold Construction	450
Display, Stand, Cut-Away	600
Paddling Practice	500
Miscellaneous	300

Sustainability

Constructing a sustainable canoe was one of FAMU-FSU's main goals. The team focused on numerous innovations and sustainable materials to minimize the environmental impact of the production. The mix design team was tasked with finding suitable materials which would help us accomplish this goal. An astonishing 93% of the canoe aggregates by mass were recycled materials, as well as 55% of the c.m. In addition the team sought sustainability from the reinforcement mechanism. The basalt reinforcement fibers and scrim used in **Lea** are manufactured from extrusive igneous rock, a sustainable material expunged from volcanic magma.

In all, 93% of the canoe aggregates by mass were recycled materials, as well as 65% of the c.m. In all 50.7% of **Lea** was recycled. Ordinarily, having 98.5% of the aggregates being glass based would frighten engineers concerned about potential Alkili-silica reactions. However, the team saw that it could use these glass components without detrimental effect due to a preferential reaction between the cement and other c.m.'s. The team also moved away from using toxic resins and foams for fabricating the mold. This proved to be not only a huge cost savings, but also a time saver as the sheet metal was able to conform to the specified rib dimensions very well. Research performed by all design teams using school resources eliminated costs usually needed to perform scale modeling and large batch concrete testing, as well as savings on total project time.

Figure 9: Hydration system.



Another aspect where the team implemented sustainable fabrication was in the curing of our canoe. **Lea** was cured using a sprinkler system which recycled water. This innovative process was composed of a pump which set to turn on every three hours for five minutes. The pump drew water from the inside of the canoe and circulated it throughout the sprinklers. This was a low maintenance system which allowed the concrete to properly cure in a moist environment.

The team sought various other ways to keep sustainable. The canoe mold was salvaged as it will be modified into the transport unit for the canoe by reattaching the six segments and installing pneumatic casters. Additionally the team was able to reclaim the 2012 steel bridge and incorporate it into an attractive and innovative canoe display stand. The team found that sustainability greatly benefited the team financially. **Lea**'s uniqueness and sustainability sets it apart from other canoes.

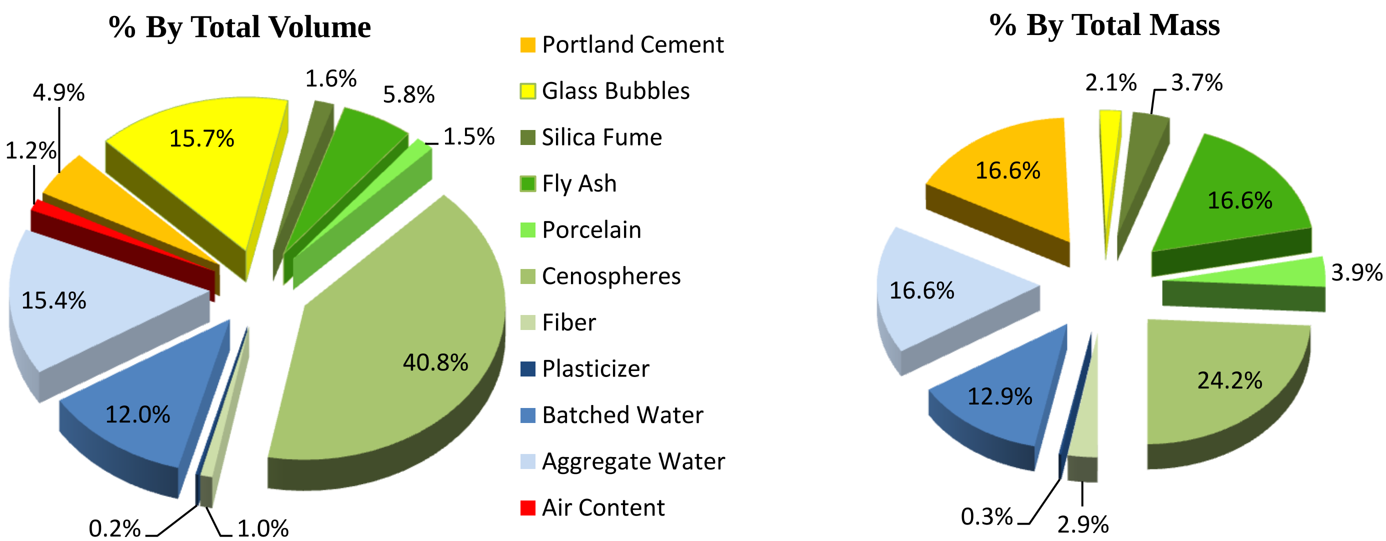


Figure 10: Concrete composition.

Organization Chart

Project Manager

Michael Perez

Jr. Project Manager

Laura Morris

Paddle Team

Kevin Brandewie
GG Gonzalez
Victoria Howard
Victoria Lopez
Dyan Talbott
Mike Tugwell

Analysis

GG Gonzalez

Provided analysis and administered the design paper and engineer's notebook.

Construction

Connor Howe

Managed mold construction, quality control during casting, and finishing of the canoe.

Graphics

Giuliana Mendez

Administered all aesthetic aspects of the project, including designs, presentation and display table.

Mix Design

Gustavo Toledo

Performed all research and testing for the concrete mixture and reinforcement schemes.

Trainer

Natasha Trimble

Organized workouts, training, practices, and selection of final teams.

Design Paper

Walter Augilar
Dana Hawes

Engineer's Notebook

Gustavo Toledo
Amanda Schram

Safety Engineer

Mike Tugwell

Assistant Engineers

GG Gonzalez
Victoria Lopez
Paul Webb

Assistant

Austin Coller
Kaitlyn Kliewer

Product Research

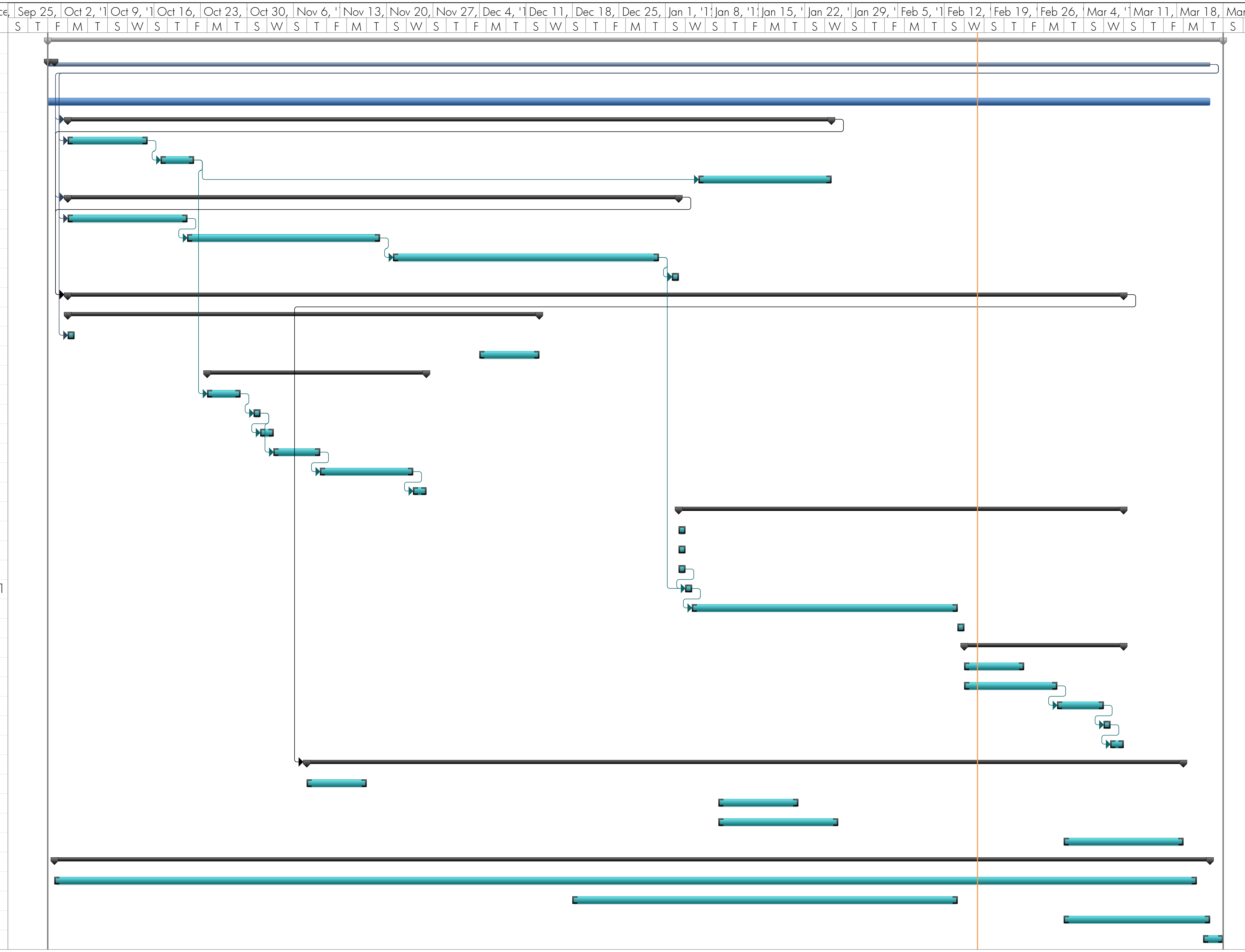
Victoria Howard
Giuliana Mendez
Kyle Lusk

Batching & Testing

Laura Morris
Frank Muir
Alex Fonteriz

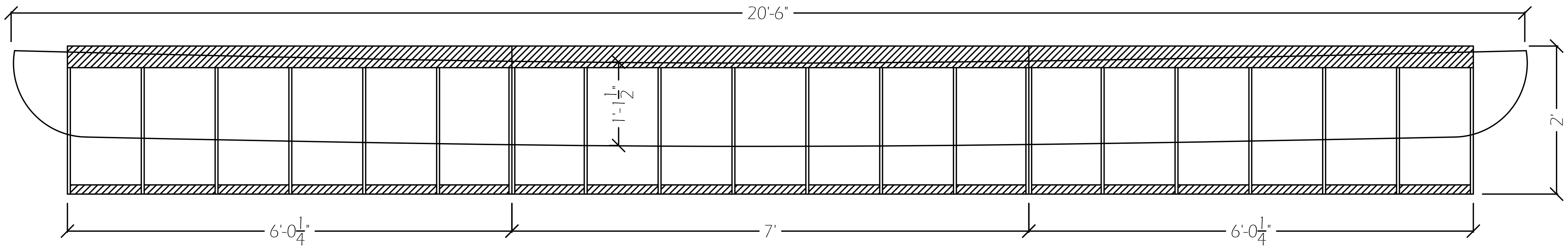
Project Schedule

ID	Task Name	Duration	Start	Finish	Predece
0	2012 Concrete Canoe	126 days?	Fri 9/30/11	Sat 3/24/12	
1	First Meeting & Start	1 day?	Fri 9/30/11	Fri 9/30/11	
2	Break up into teams				
3	Fundraising	125 days	Fri 9/30/11	Thu 3/22/12	
4	Hull Design	83 days	Mon 10/3/1	Wed 1/25/1	1
5	Hull Shape Research	10 days	Mon 10/3/1	Fri 10/14/11	1
6	Modeling	5 days	Mon 10/17/	Fri 10/21/11	5
7	Structural Analysis	14 days	Fri 1/6/12	Wed 1/25/1	6
8	Mix Design	66 days	Mon 10/3/1	Mon 1/2/12	1
9	Materials Research	14 days	Mon 10/3/1	Thu 10/20/1	1
10	Materials Aquisistion	21 days	Fri 10/21/11	Fri 11/18/11	9
11	Testing	30 days	Mon 11/21/	Fri 12/30/11	10
12	Final Mix Selection	1 day	Mon 1/2/12	Mon 1/2/12	11
13	Construction	115 days?	Mon 10/3/1	Fri 3/9/12	4,8
14	Theme	51 days?	Mon 10/3/1	Mon 12/12/	
15	Theme Selection	1 day?	Mon 10/3/1	Mon 10/3/1	1
16	Stencil Preparation	7 days	Sun 12/4/11	Mon 12/12/	
17	Mold Construction	25 days	Mon 10/24/	Fri 11/25/11	
18	CAD Rendering	5 days	Mon 10/24/	Fri 10/28/11	6
19	Plot Rib Sections	1 day	Mon 10/31/	Mon 10/31/	18
20	Cut Plywood Ribs	2 days	Tue 11/1/11	Wed 11/2/1	19
21	Frame Mold	5 days	Thu 11/3/11	Wed 11/9/1	19
22	Aluminum Attachment	10 days	Thu 11/10/1	Wed 11/23/	21
23	Final Mold Preparations	2 days	Thu 11/24/1	Fri 11/25/11	22
24	Canoe Construction	49 days	Tue 1/3/12	Fri 3/9/12	
25	Dry Batch Concrete	1 day	Tue 1/3/12	Tue 1/3/12	
26	Attach Depth Gauges	1 day	Tue 1/3/12	Tue 1/3/12	
27	Misc. Preparation	1 day	Tue 1/3/12	Tue 1/3/12	
28	Place Concrete	1 day	Wed 1/4/12	Wed 1/4/12	27,11
29	Cure Canoe	28 days	Thu 1/5/12	Mon 2/13/12	28
30	Mold Release	1 day	Tue 2/14/12	Tue 2/14/12	
31	Finish Work	18 days	Wed 2/15/1	Fri 3/9/12	
32	Sanding	7 days	Wed 2/15/1	Thu 2/23/12	
33	Place Finishing Mix	10 days	Wed 2/15/1	Tue 2/28/12	
34	Apply Stain	5 days	Wed 2/29/1	Tue 3/6/12	33
35	Apply Lettering	1 day	Wed 3/7/12	Wed 3/7/12	34
36	Apply Sealer	2 days	Thu 3/8/12	Fri 3/9/12	35
37	Product Display	94 days	Tue 11/8/11	Sun 3/18/12	13
38	Build Stands	7 days	Tue 11/8/11	Wed 11/16/	
39	Display Table	10 days	Mon 1/9/12	Fri 1/20/12	
40	Cross Section	14 days	Mon 1/9/12	Thu 1/26/12	
41	Engineers Notebook	13 days	Thu 3/1/12	Sun 3/18/12	
42	Conference Preparation	124 days	Sat 10/1/11	Thu 3/22/12	
43	Paddling Practice	123 days	Sat 10/1/11	Tue 3/20/12	
44	Design Paper	42 days	Sun 12/18/1	Mon 2/13/12	
45	Technical Presentation	16 days	Thu 3/1/12	Thu 3/22/12	
46	Attend SESC in Tallahassee, Fl	3 days	Thu 3/22/12	Sat 3/24/12	

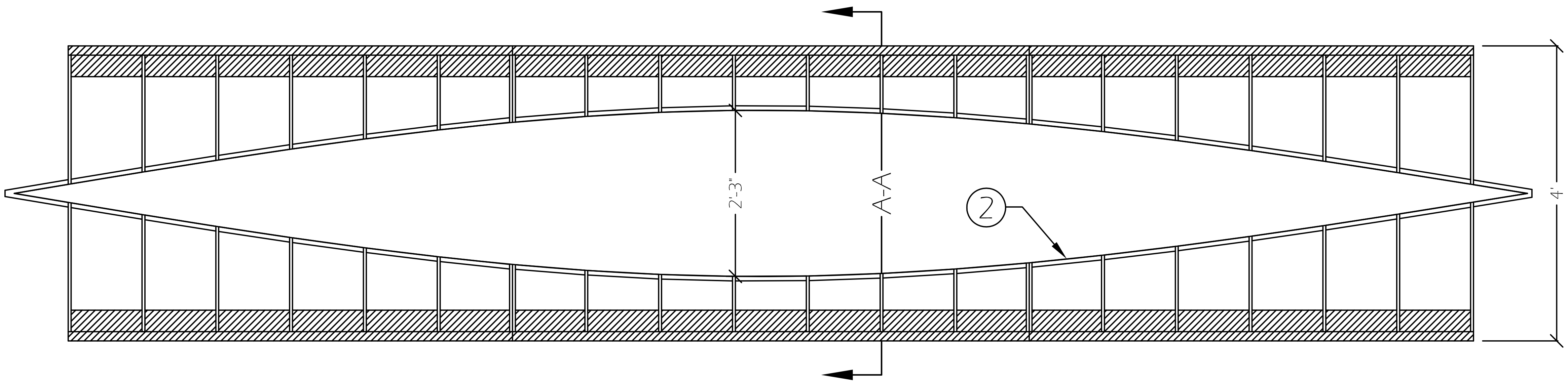


Project: 2012 Concrete Canoe
Date: Fri 2/17/12

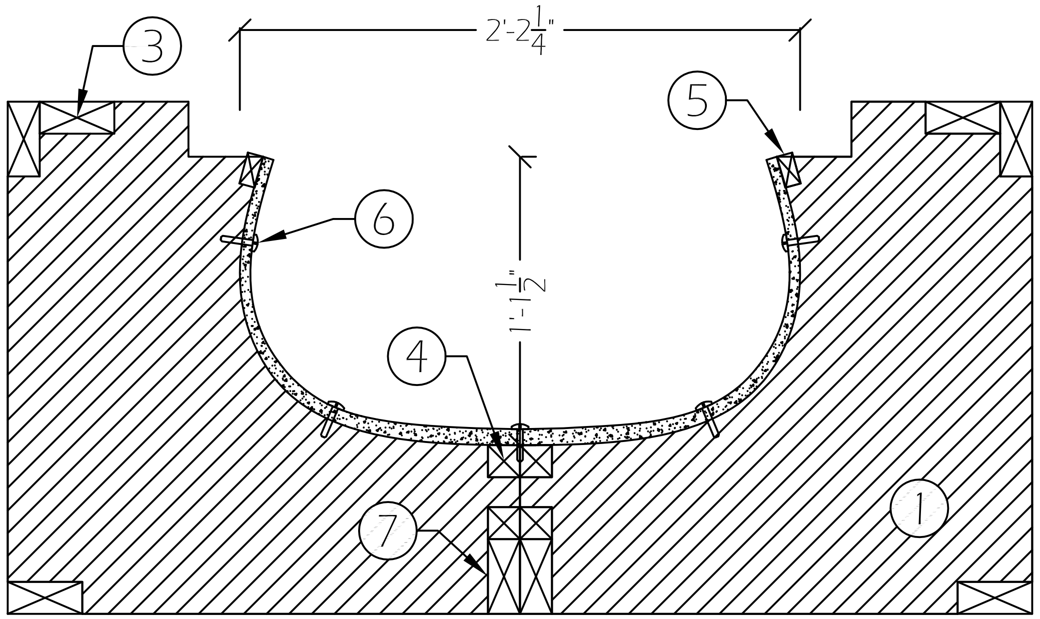
Task, Split, Milestone, Summary, Project Summary, External Tasks, External Milestone, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, Deadline, Progress



ELEVATION VIEW
SCALE: 1" = 1.75'



PLAN VIEW
SCALE: 1" = 1.75'



TYPICAL CROSS SECTION A-A
SCALE: 1" = 0.75'

RENDERED VIEW
NOT TO SCALE

Bill of Materials

ITEM	QTY.	DESCRIPTION
1	22	2'x4' $\frac{15}{32}$" PLYWOOD RIB
2	75'	CONTINUOUS 16" ALUMINUM FLASHING
3	76	2"x4"x12" BLOCKING
4	76	2"x2"x12" BLOCKING
5	38	1"x2"x12" BLOCKING
6	45	1" TEMPORARY GRADE SCREWS
7	325	2 ½" DECK SCREWS

LEA

FORM DESIGN DRAWING

GENERAL NOTES:

1. DRAWINGS NOT TO SCALE.
2. PLYWOOD RIB SPACING AT 12" CENTER TO CENTER.
3. ALUMINUM FLASHING FORMED ONTO PLYWOOD RIBS. ATTACHED WITH ½" STAPLES.
4. MOLD BUILT IN SIX INDEPENDENT PIECES FOR EASE OF FORM REMOVAL.

Date: February 17, 2012

Drawn By: Michael Perez

Approved By: Laura Morris

SHEET 11 OF 11

ASCE/NCCC. (2012). “2012 American Society of Civil Engineers® National Concrete Canoe Competition™: Rules and Regulations.” <http://concretecanoe.org/2012Trivia/2012NCCCRulesandRegulations.pdf> 6 February 2012

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

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

ASTM. (2009). “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens” C39/C39M-09, West Conshohocken, PA

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

"Canoe Design." The Ultimate Guide to Canoeing. Web. 17 Feb. 2012. <http://www.canoeing.com/canoes/choosing/design.htm>.

Horne, Jerry. Personal Interview. 12 December 2009

Holmes, Tommy. The Hawaiian Canoe. Editions Limited, 1993. Print.

Lamond, Klieger and. "Significance of Tests and Properties of Concrete and Concrete-Making Materials." American Society of Testing and Materials (1994): 534.

Pickenpaugh, Sam. Personal Interview. 6 January 2010

Yazici, Halit. "The Effect of Silica Fume and High-Volume Class C Fly Ash on the Mechanical Properties, Chloride Penetration, and Freeze-thaw Resistance of Self-compacting Concrete." Construction and Building Materials (2008): 456-452.

Mixture ID: Structural Mix			Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3):	0.2674						
Cementitious Materials		SG	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Type I Portland Cement	3.15	307.00	1.562	3.04	0.015	307.06	1.562
CM2	Elkem Microsilica®	2.20	68.22	0.497	0.68	0.005	68.23	0.495
CM3	Fly Ash Class F	2.70	307.00	1.822	3.04	0.018	307.06	1.818
	Total Cementitious Materials:		682.22	3.88	6.76	0.04	682.34	3.87
Fibers								
F1	3/4" Basalt 'chopped' Fiber	2.75	54.22	0.316	0.54	0.003	54.22	0.315
	Total Fibers:		54.22	0.32	0.54	0.00	54.22	0.32
Aggregates								
A1	K15 3M™ Glass Bubbles Abs: 40%	0.13	39.07	5.009	0.39	0.050	39.08	5.01
A2	GlassMODE Recycled Porelain Abs: 4%	2.40	72.57	0.485	0.72	0.005	72.57	0.48
A3	CW300 Recycled Cenospheres Abs: 65%	0.55	446.55	13.011	4.42	0.129	446.60	13.01
	Total Aggregates:		558.19	18.51	5.53	0.18	558.25	18.51
Water								
W1	Water for CM Hydration (W1a + W1b)	1.00	247.74	3.970	2.98	0.048	247.74	3.970
	W1a. Water from Admixtures		8.96		0.61		8.96	
	W1b. Additional Water		238.78		2.37		238.78	
W2	Water for Aggregates, SSD	1.00	306.56		3.04		306.56	
	Total Water *(W1 + W2)*:		554.30	3.97	6.01	0.05	554.30	3.97
Solids Content of Latex, Dyes and Admixtures in Powder Form								
S1	None	0.00	0.00	0.000	0.00	0.000	0.00	0.000
	Total Solids of Admixtures:		0.00	0.00	0.00	0.00	0.00	0.00
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	ADVA® 140 (M) HRWR *8.8 lb/gal*	17.10	10.74	8.96	0.73	0.606	10.7	8.960
	Water from Admixtures *(W1a)*:			8.96		0.61		8.96
Cement-Cementitious Materials Ratio			0.450		0.450		0.450	
Water-Cementitious Materials Ratio			0.81		0.89		0.81	
Slump, Slump Flow, *in.*			0.50		0.50		0.50	
M	Mass of Concrete. *lbs*		1848.93		18.84		1849.11	
V	Absolute Volume of Concrete, ft^3		26.67		0.27		26.67	
T	Theorectical Density, lb/ft^3 = *(M / V)*		69.32		69.13		69.34	
D	Design Density, lb/ft^3 = *(M / 27)*		68.48					
D	Measured Density, lb/ft^3				68.324		68.480	
A	Air Content, % = *[(T - D) / T x 100%]*		1.21		1.17		1.25	
Y	Yield, ft^3 = *(M / D)*		**27**		**0.276**		**27**	
Ry	Relative Yield = (Y / Y_D)				1.031			

Mixture ID: Skim Mix			Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft³):	0.2826						
Cementitious Materials		SG	Amount (lb/yd³)	Volume (ft³)	Amount (lb)	Volume (ft³)	Amount (lb/yd³)	Volume (ft³)
CM1	Type I Portland Cement	3.15	286.62	1.458	3.00	0.015	286.62	1.478
CM2	Elkem Microsilica®	2.20	63.69	0.464	0.67	0.005	64.01	0.468
CM3	Fly Ash Class F	2.70	286.62	1.701	3.00	0.018	286.62	1.720
	Total Cementitious Materials:		636.93	3.62	6.67	0.04	637.26	3.67
Fibers								
F1	None	0.00	0.00	0.000	0.00	0.000	0.00	0.000
	Total Fibers:		0.00	0.00	0.00	0.00	0.00	0.00
Aggregates								
A1	K15 3M™ Glass Bubbles Abs: 40%	0.13	36.48	4.677	0.38	0.050	36.31	4.777
A2	GlassFILL Recycled Glass Abs: 4%	2.54	67.75	0.427	0.71	0.004	67.83	0.382
A3	CW300 Recycled Cenospheres Abs: 65%	0.55	416.90	12.147	4.36	0.127	416.56	12.134
	Total Aggregates:		521.13	17.25	5.45	0.18	520.70	17.29
Water								
W1	Water for CM Hydration (W1a + W1b)	1.00	359.27	5.758	3.56	0.057	359.27	5.758
	W1a. Water from Admixtures		8.96		0.60		8.96	
	W1b. Additional Water		350.31		2.96		350.31	
W2	Water for Aggregates, SSD	1.00	286.20		3.00		286.20	
	Total Water *(W1 + W2)*:		645.47	5.76	6.56	0.06	645.47	5.76
Solids Content of Latex, Dyes and Admixtures in Powder Form								
S1	None	0.00	0.00	0.000	0.00	0.000	0.00	0.000
	Total Solids of Admixtures:		0.00	0.00	0.00	0.00	0.00	0.00
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	ADVA® 140 (M) HRWR *8.8 lb/gal*	17.10	16.87	8.96	1.13	0.598	16.9	8.960
	Water from Admixtures *(W1a)*:			8.96		0.60		8.96
	Cement-Cementitious Materials Ratio		0.450		0.450		0.450	
	Water-Cementitious Materials Ratio		1.01		0.98		1.01	
	Slump, Slump Flow, *in.*		0.75		0.75		0.75	
M	Mass of Concrete. *lbs*		1803.53		18.68		1803.43	
V	Absolute Volume of Concrete, *ft³*		26.63		0.28		26.72	
T	Theoretical Density, *lb/ft³* = *(M / V)*		67.72		67.58		67.50	
D	Design Density, *lb/ft³* = *(M / 27)*		66.80					
D	Measured Density, *lb/ft³*				66.724		66.800	
A	Air Content, % = *[(T - D) / T x 100%]*		1.36		1.26		1.04	
Y	Yield, *ft³* = *(M / D)*		**27**		**0.280**		**27**	
Ry	Relative Yield = *(Y / Y_D)*				0.991			

Appendix C: Bill of Materials and Production Cost Estimate				
Material	Quantity	Unit	Unit Cost	Total Cost
Cementitious Materials				
Type I Portland Cement	48	lbs	$0.11	$5.28
Fly Ash, Class F	48	lbs	$0.10	$4.80
Elkem Microsilica®	11	lbs	$0.15	$1.65
Aggregates				
CW300 Recycled Cenospheres	70	lbs	$4.29	$300.30
K15 3M™ Glass Bubbles	6.5	lbs	$6.94	$45.11
Recycled Porcelain	11.5	lbs	$2.00	$23.00
GlassFILL Recycled Glass	5.0	Lbs	$1.75	$8.75
Admixtures				
Super-Plasticizer	0.1	gal	$38.95	$3.90
Reinforcement				
Basalt Scrim	82	sq. yd	$1.01	$82.82
3/4" Chopped Basalt Fibers	8.5	lbs	$5.13	$43.61
Concrete Finishing				
Stains	3	gal	$27.33	$81.99
Sealer	2	gal	$29.99	$59.98
Canoe Form				
Completed Canoe Mold	1	lump sum	$325.00	$325.00
				$986.18