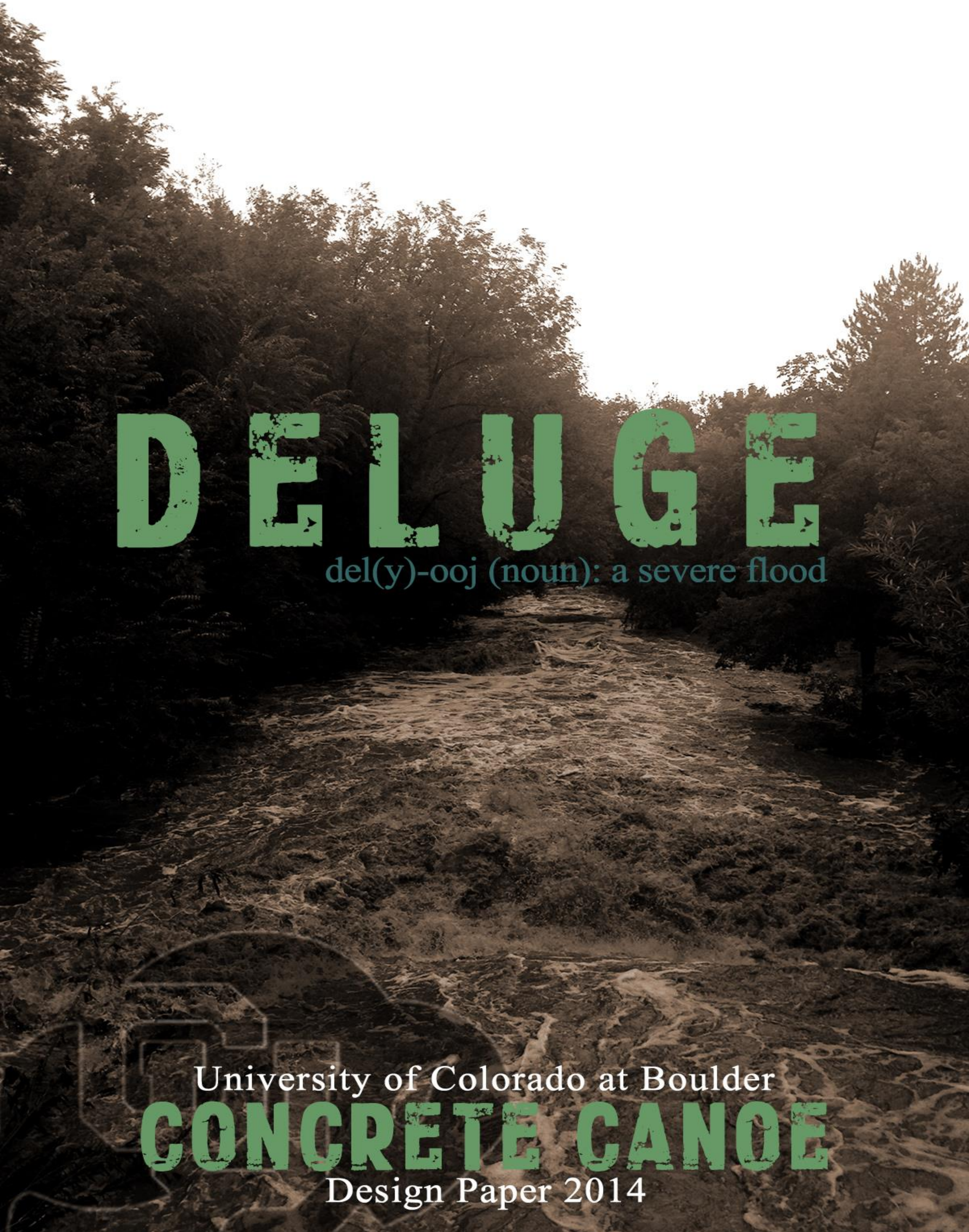


DELUGE

del(y)-ooj (noun): a severe flood

University of Colorado at Boulder

CONCRETE CANOE

Design Paper 2014

TABLE OF CONTENTS

List of Tables

List of Figures

EXECUTIVE SUMMARY

The formidable heights of the Rocky Mountains overshadow the foothills of Boulder, home of the University of Colorado, where the capricious fury of nature awaits all who approach. The unpredictable whims of mother Earth can and do, hit hard; the floodwaters of September 2013 struck the community with unrelenting force, inundating the city in debris. The ravaging flood waters galvanized the local community, inspiring an unprecedented unity to re-build the scarred landscape. The University of Colorado Concrete Canoe Team and ASCE student chapter rose up, initiating team effort and perseverance to help restore the community.

After an extended hiatus, the University of Colorado Concrete Canoe Team is now in its second year competing in the NCCC. Under the leadership of Travis Marcilla, last year's devoted captain, the team established a strong footing with the *Chautauqua*, taking sixth at the Rocky Mountain Regional Conference. Christina Jones is now building on that groundbreaking effort, and construction of *DOXY DELUGE* began with enthusiasm in the fall of 2013. Improvement can be witnessed in every aspect of the CU canoe program this year. The canoe itself is comprised of a new concrete mix, hull shape, and construction techniques. Faculty support has increased through a proposal which has solidified permanent construction space for ASCE to be used annually to build a canoe and a steel bridge. Strong development of a system of values, skills, traditions, and methods to pass along knowledge from year to year has been implemented. Ultimately, there is great aspiration for longevity of the program and for it to remain competitive.

DOXY DELUGE shows off a more slender figure, thinner gunwales, and is less than 2/3 the weight of last year's *Chautauqua*. Her concrete mix takes on a simple yet advantageous mix, purposefully utilizing five ingredients that best represent the team's goals, aspirations, and values for this year's project. Based on experience and acquired knowledge, the steel pre-tensioning system was improved. To help the community and simultaneously use sustainable practices, collected debris that had been swept downstream in the deluge provided an important aggregate in the concrete mix and display pieces. As opposed to harboring the perception of a canoe strong enough to withstand forces derived from beam analysis. Instead, localized failures are expected without complete failure, and this has changed the approach to the structural design with flexibility and ductility in mind. *DOXY DELUGE* incorporates all of these innovative ideas, and the team is anxious to compete and represent the University of Colorado.

Table 1: Specifications for DOXY DELUGE

Doxy Deluge Specifications	
Maximum Length: 18' 9"	28-day Tensile Strength: 120psi
Maximum Width: 28"	28-day Comp. Strength: 640psi
Maximum Depth: 16"	Concrete wet density: 56 lb/ft^3
Average Thickness: 1/2"	Concrete dry density: 50 lb/ft^3
Estimated Canoe Overall Weight: 170 lbs	Estimated Concrete Flexural Strength: 95psi
Various stain colors	Concrete Air content: 0.06%
* Conrete is currently a pearly white while stain is in tranist	

PROJECT MANAGEMENT

DOXY's team was quickly assembled from recruitment work in the spring semester after competition. Project management played an essential role to create subgroups to balance the many tasks associated with the project. The groups provided a focus for specific members and a chance to direct students to a specific task. To quantify the time spent on the project as a whole, five different project tasks were created as follows: fundraising, construction, academics, mix design, and management. The hours spent on the *DOXY DELUGE* totaled about 620 man-hours, split among the tasks as shown in Figure 1. During the fall semester, time was focused on team building, fundraising, design and initial construction. The spring semester was devoted to pouring and finishing.

Our team is still developing, as last year was our first year back to competition. Effort was put forth to gain professional sponsors to help our ASCE chapter grow. Our funds this year came from small grants from the University of Colorado Engineering Department and industry leaders. For preliminary mix design, some materials were donated by local providers while others were purchased after being donated to the academic cause last year.

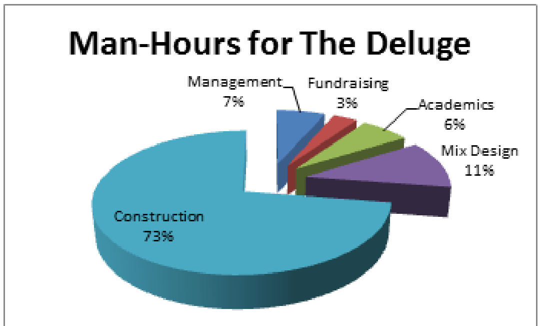


Figure 1: Hours Spent on different categories

Our schedule was built upon last year's timeline, with the goal to pour a month ahead of *Chautauqua* to allot extra time to finishing. Our critical path was determined by working backwards from a specific, goal date to do the big pour. Tasks on the critical path included initial material procurement, canoe design, form construction, final mix selection, pour, and final finishes. We strived to stay on schedule, and improvements from last year were made. Our major milestones included the canoe design and form construction, mix design selection, our pour day and this design paper. These tasks are the biggest tasks in the project and provide satisfaction and pride to team members when completed.

With a larger team than last year, many hands were available to work but that also meant many hands needed to be watched. For quality control, tasks were explained to members before anything began, and necessary communication was achieved to work as a team. Team leaders inspected work after meetings and on occasion required tasks to be redone as to provide quality control and manage the risks associated. In any project of this scope & size it is very important to make sure everyone has the proper safety training and is always aware of their surroundings. To make sure all team members were as safe as possible, members working with machinery were given proper training for the tasks at hand. This included the MTS machine for testing samples, and saws for cutting foam for the form. Before any major task was initiated, our safety manager observed the scene and provided necessary safety equipment such as gloves and masks for mixing samples. The combination of the team's motivation, management practices, and priority on safety allowed team *DOXY DELUGE* to complete tasks effectively, efficiently, and safely as we strived to minimize our spending and stick to the project schedule.

ORGANIZATIONAL CHART

Project Management
Oversaw all aspects. Responsible for project schedule. Task delegation, managing finances and quality control.

Christina Jones
Travis Marcilla

Design
In regards to hull, concrete mix, and overall aesthetics

Mix Design
Thomas Jamieson-Lucy
Benjamin Enssle
Becca Scheetz

Graphic Design
Nicole Kontour
Sage Springer
Kelli Bradley

Hull Design
Nathan Stambaugh
Torin McCue

Construction
Form and concrete preparation along with pouring and sanding

Form Construction
Nathan Stambaugh
Travis Marcilla

Pouring/Sanding
Benjamin Enssle
Torin McCue
Becca Scheetz
Travis Marcilla
Nathan Stambaugh
Miles Tripp
Thomas Jamieson-Lucy
Nicole Kontour
Matt Kincaid
Sage Springer
Kelli Bradley

Safety Engineer
Miles Tripp

Research
In regards to concrete mix, canoe structure, and reinforcement

Concrete Mix
Thomas Jamieson-Lucy
Christina Jones

Reinforcement
Travis Marcilla
Christina Jones
Miles Tripp

Structural Analysis
Miles Tripp
Travis Marcilla
Thomas Jamieson-Lucy

HULL DESIGN AND STRUCTURAL ANALYSIS

The hull design for *DOXY DELUGE* went through iterations to help improve turning speed and overall race performance. The hull is a drastic change for the team and is, in most every way, a primal change from last year's design, *Chautauqua*. As we enter our second year of competition, last year's experience showed the elevated importance of the canoe's racing characteristics. Rather than using the provided ASCE design, the hull design team started from scratch with new found focus to derive a design that will race well, have aesthetics, and possibly form the base for future year's designs.

Learning from our first year of competition, the design works to incorporate features that improve ability to take sharp turns as well as increase the ease of racing at top speed. To discover the effects that fundamental design elements, such as beam, geometry, stem shape, rocker angle and depth have on a canoe's performance, the design team took note of successful commercial canoeing products and their various strengths and applications. Through this investigative process the qualities that would manifest in the *DOXY DELUGE* were narrowed down and chosen. With last year's hull design acting as a standard for comparing changes, a decision matrix using multi-criteria decision analysis was created to decide the value and implementation of various qualities (Table 2).

Table 2: Multi criteria Decision Analysis for DOXY DELUGE

	Importance	6	10	8	8	6	
Option		Aesthetics	Complexity	Speed	Turning	Ease of use	**Total**
Beam	32in *	7	8	4	6	4	226
	30in	6	7	6	6	6	238
	28in	6	7	8	7	7	268
	26in	7	6	10	7	4	262
Shape	Flat *	8	8	7	5	10	284
	Rounded	9	7	9	7	7	294
	Vee	10	4	6	5	6	224
Stem	Square *	8	10	8	6	7	302
	Rounded	9	4	7	9	7	264
Profile	Flare	9	8	8	8	7	304
	Tumblehome	10	7	8	7	10	310
	Straight side *	8	8	9	7	8	304

* Characterists of Chautauqua

(shaded) Those Characteristics chosen for *DOXY DELUGE*

To fulfill the desire for increased race performance, the design team made three major changes for *DOXY DELUGE*. First, the principle geometry of the canoe was drastically changed to be that of a rounded elliptic cross-section down the whole of the canoe's length. This was chosen to improve the potential speed of the canoe and also allow for out-of-plane rowing and 'tipping' of the canoe to aid in sharp turning when compared to the *Chautauqua* (Table 1). Second, the beam was decreased by 4 inches to help improve the range of motion of the paddlers while keeping stability in thought. By not decreasing the beam beyond the maximum width of those paddling, the canoe will be less prone to roll over due to the shifting of the paddlers in the canoe. Finally, the length of the canoe was cut down by 10 inches to a total length of 18 feet and 9 inches to help reduce the volume of the design, decreasing the amount of material needed and ensuring the full canoe would fit on the team's pre-tensioning table of 24 feet with plenty of room for scales and tightening equipment on either side. These changes, though based in comparison with other designs and commercial products, were deemed to produce the racing results desired as well as add unique, intrinsic aesthetic appeal to *DOXY DELUGE*.

DOXY DELUGE is designed to be ductile. She is expected to crack and get banged around a little, yet survive. Essentially, the concrete is designed to be as light as possible and only strong enough to resist the pretension of the steel reinforcing system. The design team constantly kept in mind that the hull must have flexibility and elasticity so it will be able to see large displacements in the gunwales before failure. Failures are most likely to occur on the floor, so to strengthen this area *DOXY* utilizes thickened concrete of up to 1.5" deep (3 times that of the average hull) which doubles as three dimensional art.

The pretension system was brought back from last year and improved with 2 additional strands; 8 in total (figure 3). The same steel wire used for the pre-stress was used to add additional reinforcement orthogonal to the strands. Steel wire was chosen instead of carbon fiber after discussing that the extra weight was worth having less spacers to be patched afterward. The bow and the stern utilize aluminum mesh for additional strength and rigidity at the ends were consistent geometry matter the most.

Figure 3: Installation of Structural Reinforcement

Table 3: Predicted Tensile Loading and Max Load Cables Can Withstand

Tensile loading	Value	Units
Calculated	70	pounds
Safety Value	140	pounds
Rupture Force	160	pounds
* All data is considere to be applied to the pretensioned cables		
	Derived	
	Measured	

The largest compression force considered in design was the 100 pounds applied by the pre tension cables. Other failures are expected due to tension forces from live load (paddlers). Since our design thickness of the hull is ½ inch thick and there is 1 ½ inch distance from the upper most pretension wires to the gunwale, this section of the concrete is considered to have the greatest chance of failure in compression. This results in a compressive strength of 133 psi. By taking into account a factor of safety of 2 for the concrete design the final strength of at least 270 psi was determined.

It is expected that live load forces in the bottom of the canoe will be equally resisted by the water, thus only being a compressive force. This is less than the compressive force expected at the extreme fiber along the gunwale which determined the 270 psi design. The remaining threat of tensile failure is due to aggravated paddling. This scenario produces the greatest point loads that will be placed orthogonal to the pre-stress cables. The flexible design is expected to allow for nearly an inch of deflection on either side, which acts to dampen the forces from the paddlers and elastically dissipate the tensile stress. The reinforcing mesh provides strength greater than the expected punching force (Table 3). Transportation stresses are expected to be erratic, yet less than stresses occurring during form removal.

DEVELOPMENT & TESTING

Last year's mix proved to be strong but heavy. The goal for the concrete design team this year was to create the lightest and simplest possible mix, just strong enough to resist the forces the canoe will experience. After seeing how resilient the *Chautauqua* was, the design and mix teams had more experience with the strength required and the most strenuous scenarios a concrete canoe will experience. This year, knowing we wanted to make the lightest possible mix, two boxes of 3M K1 Glass Bubble were procured early in the fall semester. Testing experience from last year showed the desirable characteristics the K1 microspheres had to offer. With these and leftover materials, the testing and development program began.

Another priority this year was to create a unique mix. From thorough and necessary research done last year to get the newly revived team off the ground, it was noticed that many teams use similar aggregates and mixes. This lead to a desire to use something different, unique, and unconventional; the type of aggregates that, because of time, were simply not tested last year. Brainstorming unorthodox aggregates lead to testing charcoal, wood chips, and Trinity's expanded shale, a lightweight aggregate mined and processed outside of Boulder, Colorado.

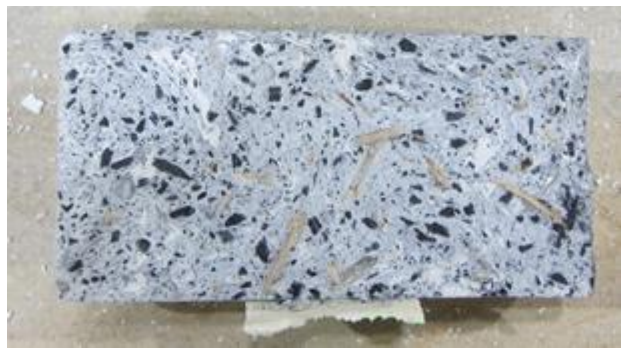


Figure 4: Testing of Unique Aggregates

For cementitious materials, the mix team began testing using Type I Portland cement along with fly ash. The baseline mix used these materials, as well as aggregates leftover from last year including Persolite and Poraver. With these materials for a baseline mix and a working design spreadsheet, the newly brainstormed aggregates could be tested and compared.

Figure 5: Sifting Woodchips

Independent tests of charcoal, wood, and Trinity shale using *Chautauqua's* baseline mix made an easy comparison with few variables. From these tests it was decided to not use charcoal because it provided no significant structural benefit and gave the concrete a dark color. Trinity expanded shale tested to be strong at the expense of weight. In tests with wood chips, the sustainable aggregate was found to enhance the tensile strength of the concrete while acting as a pragmatic source of community service.

During the fall flood in Boulder, many trees were swept down Boulder Creek and left on the banks when the waters receded. Trees left on the banks from the flood were cleaned up by the canoe team and were used to make wood shavings for our concrete mix. A chainsaw was used to produce the shavings that were then sifted to create two different sizes to be used in the final mix.

With an insight to these new aggregates, proportions of aggregates were mixed to try to find the perfect balance between strength and weight. Dozens of samples were tested with different proportions, but the final mix selected from this process was heavier than desired. Taking a step back, a series of tests began to achieve the desired density. The heavier Poraver was removed and replaced with more K1 glass bubbles. The shale was also removed due to its heavy nature and energy-intensive ceramic processing. Persolite, used in last year's mix, was light but also suspended in the air when handled so it was removed to improve the safety of the team during mixing the concrete in large batches.

This left a final mix in which every ingredient had a purpose. To be lightweight, K1 glass bubbles were utilized as a main aggregate. Larger aggregates, sustainability, and innovation were needed so flood wood was used. For a binding agent White Portland cement was selected which also provided a white palate ready for stain. Polypropylene fibers were used to add tensile strength, and Plastol 5000 type F water reducer helped with excessive water in the mix. With its simple, five-ingredient recipe, preparation for pour day was easier, saving time and money.

Concrete samples were tested on a MTS hydraulic testing machine and ASTM testing standards were closely followed in order to maintain a high level of accuracy and professionalism. This was done for compression as well as tensile testing. Other testing methods were implemented such as connectivity to the fiberglass mesh reinforcement that was used in the canoe. Results of this test showed that using smaller aggregates enabled *DOXY* to have a stronger connection through the same small apertures as last year. Beyond testing of concrete, the steel wire used for the pre-stressing needed to be tested as well. Scales with a tightening system were used to fail the steel wire. An average rupture force of 160 pounds was determined. These results combined with safety considerations, established the yielding force of 100 pounds necessary for the pre-stressing system.

The table below shows select samples tested with particle aggregates and a control baseline which shows tendencies of each aggregate independently. The effective development and testing program gets *DOXY DELUGE* closer to ride that line of failure, which will bring her success.

Table 4: Results of Iterative Sample Testing

Select Concrete Test Results					
Name	**Description**	**7 Day Comp. Strength**	**Dry Unit Weight**	**Pros**	**Cons**
Final	Final Mix	530 psi	50 pcf	Lightweight, strong	None
T1	Shale Mix	1200 psi	70 pcf	Strong	Heavy
C3	Charcoal	420 psi	45 pcf	Lightweight, interesting	Dark and Gloomy
Th5	Persolite	330 psi	40 pcf	Very lightweight	Weak, Airborne
Th8	Wood Mix	560 psi	45 pcf	Tensile strength	Difficult to Make

CONSTRUCTION

Last year's competition gave us an opportunity to learn about some of the means and methods other schools are utilizing to build their canoes. Something not an innovation for the canoe competition as a whole but a huge innovation for us, is to utilize foam for form construction as opposed to the wood form built last year. This allowed *DOXY* to take on a barreled hull-shape that last year, was not possible. This also allowed the incorporation of three-dimensional artwork, doubling as further strength reinforcement. This new methodology is extremely exciting because it saved a considerable amount of time and allowed redirection of focus towards more important aspects such as concrete design and reinforcement techniques.

One positive aspect of last year's design was the reinforcing system. This system provided strength beyond estimations on the *Chautauqua*, bringing realizing to its importance. Through improving this design, we were able to build a canoe that boasts half the thickness of last year. Last year, our goal was to have a vessel that would not break before or during the competition. This year, our goal was lighter, faster, more flexible, and to ride that failure line. *DOXY* has achieved this, and looking to the future, next year's canoe may even get closer.

The hull, similar to last year, utilized a male form. A generous foam donation was obtained. Overall, costs of the hull were much lower than last year. Using foam was also much safer. Hand saws and a rasp shaped the entire hull, unlike last year where power tools such as skill saws, sawzalls, jigsaws, compound miter saws, and nail guns were necessary. Scale drawings of cross-sectional areas were printed then drawn directly on eight-inch thick, cross-section chunks of foam. The shape was drawn on one side of each piece then each section was blended to the next using hand saws. Each section was then glued together and the whole form was glued to the table.

A series of electric wirecutters were designed to cut smoothly through the foam, but unfortunately, they proved hard to use and were not approved by the safety manager. Hand saws created a rougher exterior to the foam hull so the solution was to bring back the layer of drywall mud utilized last year. In this fashion, a smooth shape for the interior of the canoe was achieved and added more detail to the three-dimensional art. Once the shape was established, the pre-tensioning system was implemented. A favorite part of last year's design, it was a crucial element to install and improve upon. Innovations to last year's design were to add two more strands and use an appropriate yielding force to ensure all the strands correctly transferred tension stress to the concrete.

Figure 6: Foam Cross-sections for Form

Figure 7: Pre-stressed Tendons

Team members gained new engineering knowledge about pre-tensioned concrete, helping refine the perspective and application of the system. First, a wire cage was fastened for both ends of the canoe and positioned to the appropriate depth, 'd' distance within the concrete using spacers. The pre-tensioning wires were extended over these cages. Steel wires were wrapped tightly around turnbuckles at either end of the table, and then the turnbuckles were attached to a spring scale at one end. Wires attached to bolts underneath the table and held in position with a stack of lumber at each end, supported the turnbuckles at the appropriate height for the pre-stressed cable. Screws spaced every eight inches positioned each pre-stress member, held the pretension at the correct 'd' distance, and gaged concrete thickness for pouring. Vertical 'stirrups' were placed every inch and a half along the pre-tensioned strands, and fiberglass scrim was applied during the pour.

Another way the team learned and grew from last year was in preparation for pour day. Fibers were pre-separated, and flood woodchips were pre-sifted then organized by size. Containers were pre-marked for the correct volume of each material needed for a batch. This allowed faster mixing than placing which shaved three hours off of our pour time, an impressive six-hour work day. Once a rough layer was applied to the form at the appropriate thickness, the screws were removed and a trowel was used to make her smooth.

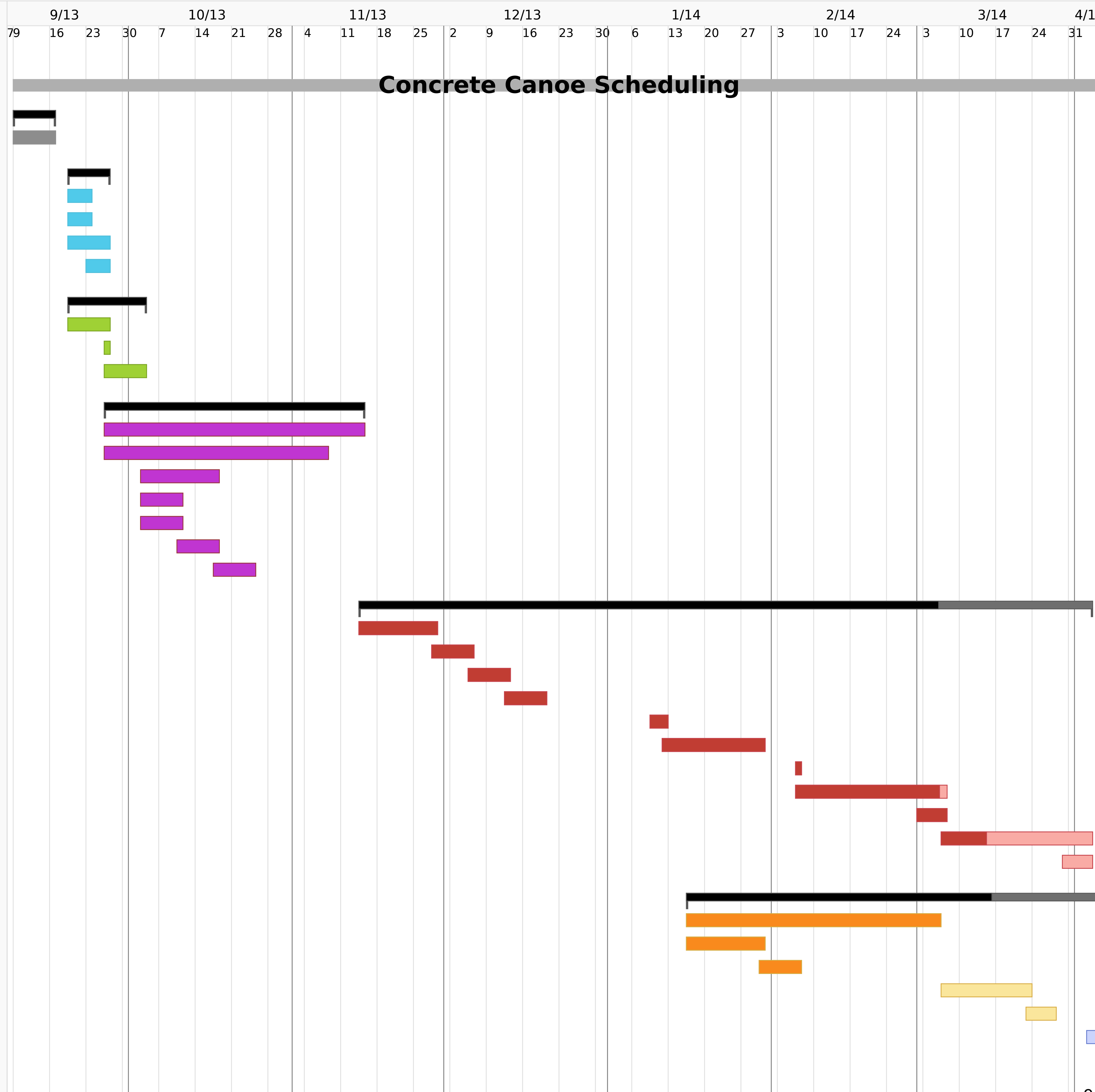
DOXY DELUGE was allowed a month to cure before flipping her over and removing the form. The foam made it possible to dig out the form even though the shape barreled out in the center. Another drastic improvement compared to last year's design was that only one pour was required. Last year another layer was poured on the inside for inlayed concrete. This year there is three-dimensional art and no cold joint. Spacers were pulled recently and patch work is the next task on the schedule. Detailed sanding, stain to add color, and concrete sealant are tasks to still be done before competition.

Figure 8: Finishing Touches on Pour Day

The most sustainable part of *DOXY DELUGE* is her use of recycled wood that was salvaged during community service work done for flood clean-up. To us and our community, she is a sign of rebuilding and moving forward. Other recycled aspects of *DOXY* include the reuse of last year's table, Portland cement recovered from older supplies, and the use of glass microspheres which are made of recycled materials. *DOXY DELUGE* was constructed with sustainability in mind, is built with more social awareness, and has less economic impact on our team and our community than last year's *Chautauqua*; a great success in our mind and an excellent representation of the University of Colorado Boulder.

Concrete Canoe Scheduling

Concrete Canoe Scheduling	start	end	87%
Theme	**09/09/13**	**09/16/13**	**100%**
FLOOD	09/09	09/16	100%
FUNDRAISING	**09/19/13**	**09/26/13**	**100%**
Make Fundraising Letter	09/19	09/23	100%
Gather Proposals for Inter-school Fund...	09/19	09/23	100%
Develop Budget	09/19	09/26	100%
Deliver Fundraising Letter	09/23	09/26	100%
HULL DESIGN	**09/19/13**	**10/03/13**	**100%**
Explore Alternative Designs	09/19	09/26	100%
Select Canoe Design	09/26	09/26	100%
Generate Computer Model Design	09/26	10/03	100%
CANOE ANALYSIS	**09/26/13**	**11/14/13**	**100%**
Test Mixtures	09/26	11/14	100%
Finalize Mixture	09/26	11/07	100%
Identify Failure Points	10/03	10/17	100%
Strength Requirements for Concrete	10/03	10/10	100%
Dynamics Analysis	10/03	10/10	100%
Beam Analysis	10/10	10/17	100%
Develop Solutions	10/17	10/24	100%
CONSTRUCTION	**11/14/13**	**04/03/14**	**79%**
Prepared Cross Sections	11/14	11/28	100%
Apply Sheetrock Mud	11/28	12/05	100%
Set Up Pre-Tensioning	12/05	12/12	100%
Apply Steel Mesh	12/12	12/19	100%
Install Screws to Gage Depth	01/09	01/11	100%
Test and Install Pretension Wires	01/11	01/30	100%
POUR DAY	02/06	02/06	100%
Concrete Curing	02/06	03/06	95%
Remove Canoe from Mold	03/01	03/06	100%
Patch and Sand Canoe	03/06	04/03	30%
Paint and Seal Canoe	03/29	04/03	0%
CONFERENCE	**01/16/14**	**04/05/14**	**73%**
Construct Engineers Notebook	01/16	03/05	100%
Design Display	01/16	01/30	100%
Gather Materials	01/30	02/06	100%
Construct Table Design	03/06	03/22	0%
Decorate and Finalize Canoe Stand	03/22	03/27	0%
Competition!!!!	04/03	04/05	0%



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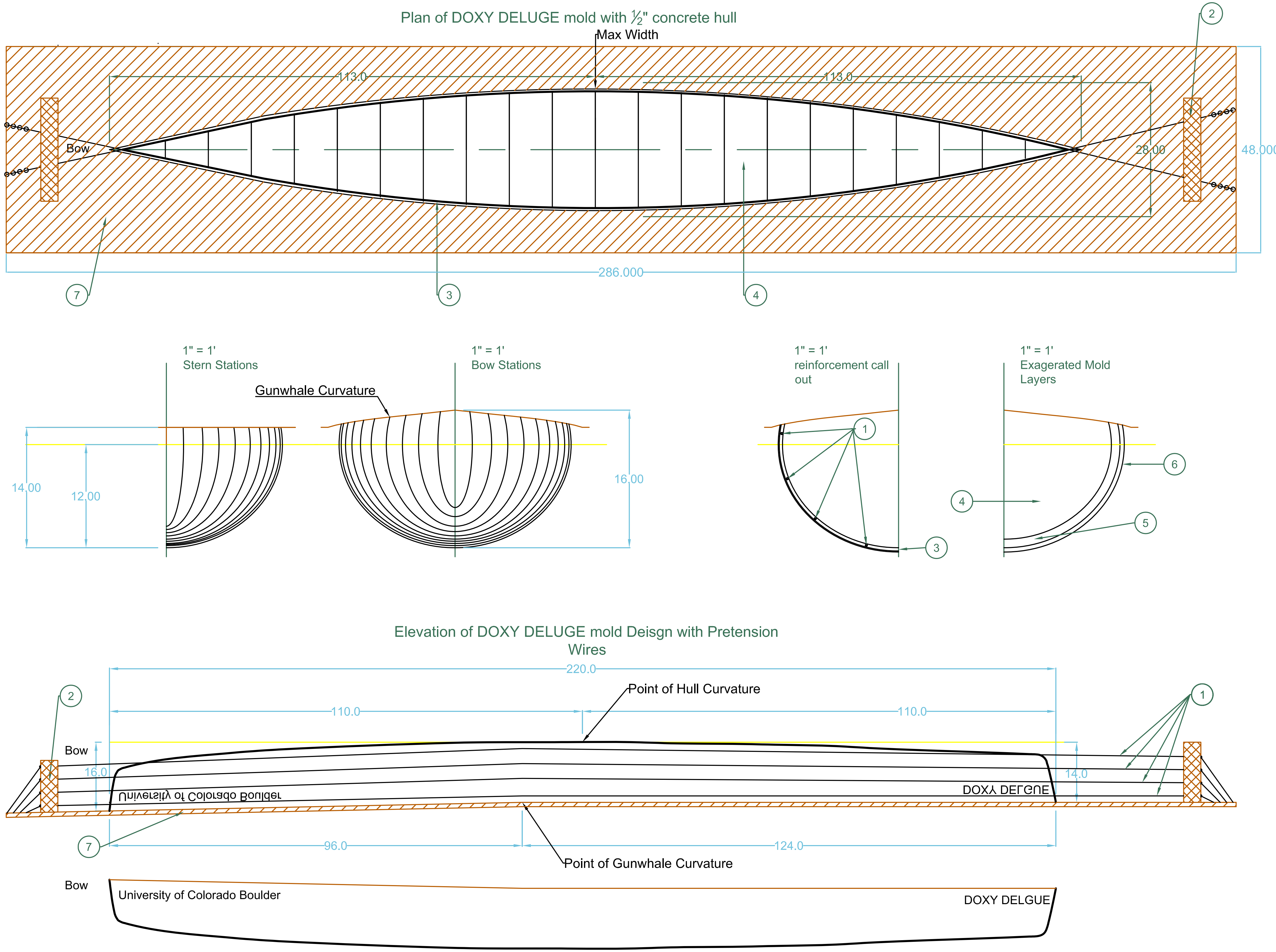
All units are inches



University of Colorado Boulder

DOXY DELUGE Design 2013 - 2014

Mat.		Qty.
1	Pretension 18 Gauge Steel Cable	151 ft
2	2 x 4; 2 ft long boards	12 boards
3	Concrete	3.5 cuft
4	Foam (in 22 10 in sections)	17 cuft
5	Dry Wall Mud	4.2 cuft
6	Heat Sealed Plastic Sheathing	67 sqft
7	1" thick Particle Board	96 sqft

Scale : ½" = 1' unless otherwise stated

Drawn By: Nathan Stambaugh | Date: 03/05/14

Checked By: Christina Jones | Date: 03/05/14

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APPENDIX A - REFERENCES

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APPENDIX B – MIX PROPORTIONS

			Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Mixture ID:								
Y_D	Design Batch Size (ft^3):	0.2						
Cementitious Materials		SG	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Portland Cement	3.15	710.00	3.612	5.26	0.027	578.02	2.941
	Total Cementitious Materials:		710.00	3.61	5.26	0.03	578.02	2.94
Fibers								
F1	Polypropylene Fiber	0.90	7.00	0.125	0.05	0.001	5.70	0.101
	Total Fibers:		7.00	0.12	0.05	0.00	5.70	0.10
Aggregates								
A4	Wood Abs: 100%	0.40	16.70	0.669	0.12	0.005	13.60	0.545
A6	Wood small Abs: 100%	0.40	33.30	1.334	0.25	0.010	27.11	1.086
A9	K1 Abs: 5%	0.13	125.00	16.026	0.93	0.119	101.76	13.047
	Total Aggregates:		175.00	18.03	1.30	0.13	142.47	14.68
Water								
W1	Water for CM Hydration (W1a + W1b)	1.00	319.50	5.120	5.26	0.084	578.02	9.263
	W1a. Water from Admixtures		59.24		0.44		48.23	
	W1b. Additional Water		260.26		4.82		529.79	
W2	Water for Aggregates, SSD	1.00	56.25		0.42		45.79	
	Total Water *(W1 + W2)*:		375.75	5.12	5.68	0.08	623.81	9.26
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*	40.00	200.00	59.24	10.52	0.44	162.8	48.23
	Water from Admixtures *(W1a)*:			59.24		0.44		48.23
	Cement-Cementitious Materials Ratio		1.000		1.000		1.000	
	Water-Cementitious Materials Ratio		0.45		1.000		1.000	
	Slump, Slump Flow, *in.*							
M	Mass of Concrete. *lbs*		1267.75		12.28		1350.00	
V	Absolute Volume of Concrete, ft^3		26.89		0.25		26.98	
T	Theorectical Density, lb/ft^3 = *(M / V)*		47.15		50.03		50.03	
D	Design Density, lb/ft^3 = *(M / 27)*		46.95					
D	Measured Density, lb/ft^3				50.000		50.000	
A	Air Content, % = *[(T - D) / T x 100%]*		0.42		0.06		0.06	
Y	Yield, ft^3 = *(M / D)*		**27**		0.246		**27**	
Ry	Relative Yield = *(Y / Y_D)*				1.228			

APPENDIX C – BILL OF MATERIALS

Item	Purpose	Quantity	Unit Cost ($)	Total Cost ($)
Medium Binder Clips	Tent	4	3.61	14.43
Bulldog Clip	Tent	1	8.42	8.42
Plastic	Tent	1	39.99	39.99
Mixing Paddles	Concrete	3	10.81	21.62
Respirators	Safety	3	41.85	125.55
White Portland Cement	Concrete	2	23.56	47.15
Deck Screws	Form	2 boxes	13.00	26.00
Scales	Reinforcement	3	46.78	140.34
Turnbuckles	Pre-Tensioning	1	18.42	18.42
Super Glue	Form	28	3.57	85.68
Screwbits	Form	3	1.84	5.52
3" X 18", 50 grit Sanding Belt	Finishing	1	5.97	5.97
K1 Hollow Glass Microspheres	Concrete	0.50	850	425
Battery	Form	1	10.54	10.54
Gloves	Safety	1	12.99	12.99
Water Reducer	Concrete	1	34.85	34.85
Joint Compound	Form	2	4.54	9.08
Handsaws	Form	3	11.33	33.99
3/8" Tile Spacers	Form	2	2.85	5.70
Brush	Finishing	1	3.2	3.20
Wire	Reinforcement	1	7.68	7.68
12" X 3" Finishing Trowel	Finishing	1	32.97	32.97
Spray Glue	Form	3	7.04	21.12
Screen	Reinforcement	2	17.28	34.56
Sealer	Concrete	1 can	48.00	48.00
Plastic	Form	3	13.83	41.49
Tie-Wire	Reinforcement	2	4.18	8.36
Concrete Stain	Finishing	4	25.00	100.00
Concrete Testing Cylinders	Testing	80	1.00	81.23
Foam	Form		130.00	130.00
Form Glue	Form	1 can	45.00	45.00
			Total	**1,624.85**