VOCAL

University of California, Berkeley

Concrete Canoe Technical Paper

MAY 2008

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Design Drawings:

VoCal's Specifications

Length	19 ft 11 in
Maximum Width	30.5 in
Maximum Depth	13.75 in
Hull Thickness	1/2 in
Weight	229 lb
Colors	Grey, Red, Black
Main Reinforcement	Carbon Fiber Scrim
Prestress Cables	1/8 in, Steel

Concrete Properties

Structural Mix	
Unit Weight	54.7 pcf
28-day Compressive Strength	1350 psi
White Finishing Mix	
Unit Weight	81.8 pcf
7-day Compressive Strength	2280 psi
Red Finishing Mix	
Unit Weight	82.6 pcf
7-day Compressive Strength	2230 psi
Black Finishing Mix	
Unit Weight	82.0 pcf
7-day Compressive Strength	1210 psi
Composite Shell	
Flexural Strength	1220 psi

EXECUTIVE SUMMARY

The University of California at Berkeley, located in the beautiful and diverse San Francisco Bay Area, has traditionally been recognized as a leader in both scholastic and cultural spheres. One of the most historically significant breakthroughs was the student-led Free Speech Movement of 1964. On Berkeley's Sproul Plaza, students organized massive protests against administrative restrictions on political and academic freedoms. Despite legal retributions, the students persevered and the university lifted its ban. Cal emerged as a stronghold of free expression and thought. This open environment has fostered an innovative spirit whose influence has led to the continued success of the Cal Concrete Canoe Team and the creation of *VoCal*.

In its years of participation at the MidPacific Regional Conference, the Cal team has qualified for the National Competition fifteen times and earned four National Titles. This year, a combination of experience and innovation has produced a canoe featuring an asymmetric hull that utilizes prestress cables in place of ribs. The team improved its design strategies by conducting more comprehensive research, including investigating a greater number of loading scenarios and performing thorough field testing. Given the extensive iterative process needed to determine the demands and capacities of the canoe, a Chief Technical Officer was added to the leadership team. Additionally, three finishing mixes were designed with the collaborative efforts of the Materials, Graphics, and Construction divisions to create a vivid, multi-layered mural capturing the historic scenes and inspirational heart of the Free Speech Movement.

In the past, the team offered canoe classes, each of which got students more involved, but focused only on the technical skills of one division – traditionally, either Materials or Hull Design. While each division within the team can operate independently, a goal for this year was to create a more cohesive team whose unified efforts would generate a high quality product. The classes were therefore restructured to encourage younger members to experience all aspects of the team. This included organizing field trips that allowed students to participate in construction and paddling exercises, providing a better understanding of the ways in which design theory translates into reality.

In recognition of the courageous voices of 1964, the 2008 Cal Concrete Canoe Team is proud to make a statement with *VoCal*.

HULL DESIGN

To design a canoe that featured the best compromise between straightline speed, maneuverability, and stability, the team reviewed past Cal canoes and selected the 2006 *Caliente* as a base template. Since during races, canoes typically spend less time maneuvering around buoys than moving through straight parts of the courses, the team primarily took advantage of *Caliente's* excellent tracking and straightline speed. However, engineers also agreed that improving *Caliente's* poor maneuverability would enhance ***VoCal's*** overall performance. Experience has revealed that hull design software accurately models straightline speed and stability, but has a limited ability to predict how design characteristics affect paddlers' focus on proper technique during races. To better understand canoe behavior, the team solicited feedback from veteran paddlers and integrated this into ***VoCal's*** design. Feature design elements of ***VoCal*** include a flat-bottom shape, nearly vertical walls, asymmetry, rocker adjustments, and a sharp stern keel line. Prolines® was the primary design software used to create and analyze this year's high-performing ***VoCal***.

The primary design modification was to change *Caliente's* V-shaped cross-sections to those that were flat-bottomed and nearly vertical-walled, which would significantly increase stability. Prolines® determines stability as a "righting arm," which is the distance between the canoe's center of gravity and the center of buoyant force (Papoulias 2002). Analysis showed that for a given loading condition, ***VoCal*** would have greater stability, since it exhibited a greater righting arm from small angle displacements (see Figure 1). This will allow paddlers to focus better and promote more aggressive paddling, resulting in increased speed. Engineers further determined that a maximum depth of 13.75 inches would provide a maximum heel angle of 26° during the coed race. Paddlers' feedback indicated that this would be sufficient to prevent water intrusion when the canoe was lowest in the water.

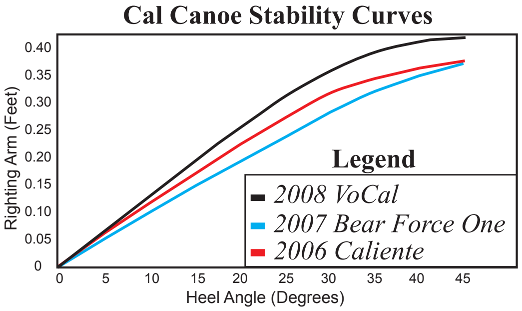


Figure 1: VoCal had a greater righting arm and hence greater stability.

A canoe with a symmetric hull has a tendency to climb the waves it generates, because the canoe will experience higher water pressure at the bow than at the stern (Jacobson 2005). Therefore, Caliente's base design was enhanced by giving ***VoCal*** a longer, narrower bow to better cut the water and a wider, flatter stern to provide improved buoyancy and stability. Greater acceleration will result, as more of paddlers' energy will be used to propel the canoe forward rather than upward.

A decent level of tracking will reduce corrective turning strokes, allowing for higher straightline speed. However, if the canoe tracks too well, paddlers will not be able to quickly negotiate turns. Based on past experience and the canoe's shape, engineers decided that a bow rocker of 4 inches and a stern rocker of 2 inches would offer the best compromise between maneuverability and tracking. While a canoe with a completely flat underside will track very poorly, a canoe with a keel line that spans from bow to stern will track extremely well. Past field research showed that canoes have a tendency to turn about a pivot point slightly aft of midship (Bear Force One 2007). Since a keel at the stern rather than the bow would therefore require less energy to turn, ***VoCal*** was designed with a strong stern keel line, giving paddlers a high level of control during races while enabling them to execute quick turns.

As wave drag is inversely proportional to the overall wetted length of the canoe, ***VoCal*** was designed to have the longest allowable hull of 239 inches to minimize wave drag (Rawson & Tupper 2001). Prolines® revealed that the integration of all the design adjustments will, on average, cause ***VoCal*** to experience approximately 19% less wave drag and 17% less total drag than *Caliente*, enabling greater acceleration.

A full-scale fiberglass prototype was created using ***VoCal's*** design. Paddlers confirmed that the new design outperformed recent canoes, because it was more stable and promoted high straightline speed, while achieving ample maneuverability.

ANALYSIS

Designing a composite shell that could withstand loads encountered during racing, transportation, and display conditions was a fundamental requirement for the structural analysis division. To achieve this goal, the team analyzed ***VoCal*** using SAP2000®, a finite element analysis (FEA) software. Engineers used the Allowable Stress Design method, as experience has shown that it is a reliable way to achieve an efficient and crack-free design.

The FEA model contained 4046 elements, each with maximum dimensions of two inches by two inches, a maximum aspect ratio of 2:1, and the properties of a reinforced concrete composite. Based on the results of preliminary mix designs, the team initially modeled the canoe with 1/2-inch thick composite elements composed of concrete and two layers of reinforcement scrim having an elastic modulus of 34,000 ksi and spaced 1/8 inch from each surface. While the analysis was being conducted, the materials division continuously updated the analysis division with the newest mix properties. Analysis engineers then verified that the use of the current model was appropriate for those properties.

Based on an early assessment of potential paddlers, the team modeled male paddlers as 160 pounds and females as 140 pounds each. Knees and seats were modeled as distributed loads and feet as point loads (see Figure 2). The support conditions were chosen to be a pin at the bow and a roller at the stern to eliminate any applied moment on the canoe as at a fixed support. To determine the water level and hydrostatic pressure outside the canoe for given loading scenarios, the model was equilibrated by minimizing the vertical reactions at the supports. This iterative process allowed the analysis team to accurately model the canoe in the water by balancing the canoe's self weight and downward loads against the upward hydrostatic forces.

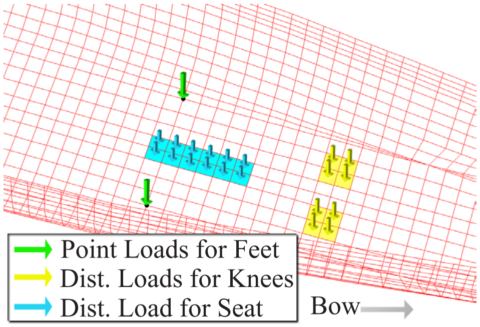


***Figure 2**: Depiction of the different loading models for knees, seats, and feet.*

The stresses in ***VoCal*** were calculated for thirteen different loading scenarios. For each of the five races, the team considered two paddler positions that represented the range of paddlers' movements during races. Engineers determined these to be kneeling upright and leaning forward while executing paddling strokes. In addition, engineers considered stresses due to lifting of the canoe with ten people, transportation in the trailer, and resting on the stands.

The FEA analysis revealed that the maximum stresses occurred during the four-person race when paddlers were leaning forward. In this scenario, stresses were highest at the knees and in the gunwale. To reduce these stresses, the team used a total of six prestress cables, modeled as tendons two and four inches from the gunwale and two inches from the bottom centerline of the canoe. Through an iterative process, the optimal loading force was found to be 200 pounds per cable, which provided a 10% and 35% reduction in maximum stresses at the knees and gunwale, respectively, eliminating the need for structural ribs. Stress relaxation due to elastic shortening, creep and shrinkage of concrete, and the slippage of the cables' ends was calculated using formulas in *Prestressed Concrete* (Raju 1994). Relaxation due to slippage of the cables' ends was eliminated by designing the tendons to have small embedded anchors at each end. Hand calculations revealed that the prestressed system with zero-slip anchorage had a stress relaxation of 27%. This loss was accounted for by tensioning each cable to 274 pounds during the actual construction process.

A factor of safety of 2 was chosen based on engineering judgment and past experience. With this factor of safety, the minimum design compressive stress was 337 psi and the required composite flexural strength was 367 psi.

A thorough analysis generated confidence that ***VoCal*** would remain structurally sound during all loading scenarios.

DEVELOPMENT AND TESTING

VoCal's materials division sought to create concrete mixes that were more workable than *Bear Force One's* and would provide ***VoCal*** with crisp and vivid graphics (see Figure 3). A mix was deemed workable if it was cohesive and could be placed on the form without slipping or cracking. Based on preliminary structural analysis, engineers set a maximum density of 55 pcf and minimum compressive strength of 1000 psi as the target properties of the structural mix. Dyed finishing mixes were developed to give the canoe a smoother surface and aesthetic appeal. A rigorous testing schedule allowed the team to optimize the proportions of ingredients and perfect its mixing procedure.

***Figure 3**: Picture of VoCal's vibrant interior mural created completely with dyed concrete finishing mixtures.*

Past Cal teams chose to improve upon baseline mixes from previous years by altering one ingredient at a time. ***VoCal's*** team decided that this method was inefficient and did not allow thorough research to be conducted in the limited time available. A new, more organized strategy was developed, in which engineers did not start from a baseline mix and instead first optimized proportions of cementitious materials, then aggregate gradation, then dosages of admixtures, and finally the mixing procedure.

The team began by developing a ratio of cementitious materials that would optimize the strength and density of the structural mix. The primary binder was Type I white Portland cement, selected for its ability to create light-colored concrete, which would provide an aesthetically pleasing base color for the canoe. Engineers added blast furnace slag, because it has a low specific gravity of 2.45 (compared to white Portland cement's specific gravity of 3.15), increases the mix's cohesion, and significantly contributes to the concrete's strength. The team also added metakaolin for its low specific gravity of 2.60 and pozzolanic ability to refine the concrete's microstructure and increase its strength (Mehta and Monteiro 2006). After four weeks of experimentation, the team selected a cementitious ratio of 60% white Portland cement, 30% slag, and 10% metakaolin, as mixes with this blend were strong but also lightweight.

To achieve a density no greater than 55 pcf, the team needed to minimize the cement paste used. Designing a mix with well-graded aggregates maximizes compaction and minimizes voids that need to be filled with cementitious materials (Mehta and Monteiro 2006). The lack of a gradation requirement allowed engineers to optimize compaction by using a wide range of aggregate sizes. After experimenting with preliminary trial batches, the team rejected perlite and cenospheres, as both greatly increased the water requirement of the mix. Selected aggregates included recycled glass aggregates with diameters ranging from 0.25mm to 4mm and K1 glass microspheres. Sieve analyses (ASTM C136) and absorption tests (ASTM C128) verified these materials' properties. Ten different gradations were then created, and each was incorporated into a mix and evaluated based on the resulting density, strength, and workability of the concrete.

Synthetic fibers were used as secondary reinforcement to minimize crack propagation and increase the toughness of the concrete (Hannant 1978). Last year, 18mm polyvinyl alcohol (PVA) fibers were found to protrude from the surface of the canoe and cause problems with finishing due to their high stiffness and large diameter of 0.2mm. Additionally, polypropylene fibers were difficult to distribute evenly throughout the concrete. Recognizing these issues, ***VoCal's*** team used shorter 8mm PVA fibers with a smaller diameter of 0.04mm. These distributed more uniformly and did not hinder efforts to create a smooth surface finish. A center-point bending test (ASTM C293) revealed that inclusion of these fibers resulted in a 65% increase in the flexural strength of the concrete composite.

Bear Force One's materials engineers found that latex admixtures reduce the density of concrete, increase the workability of the mix, and entrain the required amount of air without the use of air entraining admixtures. ***VoCal's*** engineers chose a styrene butadiene rubber latex, because it increases the flexural strength and reduces the elastic modulus of the concrete (Kuhlmann and Walters 1993). The manufacturer recommended using a minimum of 128 fl oz/cwt. After testing six different dosages, the team decided to use 700 fl oz/cwt, as this dosage yielded the most workable mix without entraining an excessive amount of air.

Since the latex did not contain a stabilizer or a defoamer, the amount of air entrained was sensitive to how long the concrete was mixed. Therefore, a precise mixing procedure was developed to ensure consistent properties between batches of concrete. After several test batches, it was determined that mixing the concrete for a total of four minutes would create the desired gravimetric air content of ten percent (ASTM C138). A two-step procedure was developed in which cementitious materials and fibers were first mixed for one minute to ensure a proper distribution of the fibers, followed by the mixing in of aggregates, latex, and water for an additional three minutes.

A high ratio of the reinforcement's elastic modulus to concrete's elastic modulus was desired. This would allow the reinforcement to absorb most of the elastic strain energy before the concrete started experiencing crack-inducing tensile strain (Barbero 1999). Carbon fiber scrim was selected as the primary reinforcement for its high elastic modulus of 34,000 ksi and tensile strength of 3.5 kip/lf. Compared to the alkali resistant glass scrim used last year, this material gave the final composite a higher flexural strength and reduced cracking. Additionally, the new scrim featured a high percent open area of 73%, which allowed it to bond well with the concrete and prevented delamination.

After curing for 28 days, cylinders of the final structural mix were tested for compressive strength (ASTM C39) and composite plates were tested for flexural strength (ASTM C293). The results revealed that the structural mix had a compressive strength of 1350 psi, and the composite had a flexural strength of 1220 psi, properties which well exceeded the analysis division's requirements.

Informed by the analysis division that prestress cables were most effective when anchored inside the concrete, the materials division designed small metal anchors to fit securely to the ends of each cable. A pullout test (ASTM C900) was performed to ensure that the anchors could hold the required load of 200 pounds per cable without causing structural damage to the concrete. The test revealed that 350 pounds of force were necessary to cause failure (see Figure 4), demonstrating that the anchors were designed with a satisfactory factor of safety.

***Figure 4**: Concrete pullout test specimens before failure (left) and after failure (right).*

Last year, *Bear Force One's* hull had punctured under the knees of a paddler, suggesting that it would be prudent to test the durability of this year's composite. As each paddler uniquely shifts his or her weight while racing, significant guesswork would have been required to perform testing in a laboratory setting. The team decided that instead, field testing would be appropriate. During a scheduled paddling practice, a 15-inch square composite plate was supported at its corners and placed under each of the two heaviest paddlers. After being subjected to loads during two hours of racing, none of the plates showed signs of damage or deformation. From these results, the team was confident in ***VoCal's*** durability during races.

Finishing mixes were designed to be three different colors - white, red, and black. A desired high slump was achieved by minimizing the amount of aggregates and using a large dosage of latex. Aggregates were limited to the small 0.25-0.5mm recycled glass and K1 glass microspheres, which enabled the team to fill in small surface pores and sand the concrete very easily. Liquid coloring admixtures were used to create both the vibrant black and red finishing mixes. To enhance the color of each dyed mix, the team exceeded the manufacturer's recommended dosage for coloring admixtures of 78 fl oz/cwt and confirmed that this excess did not cause improper setting of the concrete.

After months of experimentation, the materials division developed a set of rich concrete mixes to construct the beautifully crafted ***VoCal***.

CONSTRUCTION

The construction division set an ambitious goal to build a clean and smooth canoe with the most detailed and realistic graphics the Cal team had ever created.

After the completion of ***VoCal’s*** hull design and 3D CAD model, a three-piece male form was milled using a computer numerically controlled drill. The form was made from expanded polystyrene foam, selected for its fine pore structure and low cost. To prepare the form for Casting Day, the team applied two coats of polystyrene sealant to create a hard exterior. Remaining pores in the form were filled with drywall mud. Two thin layers of epoxy were then applied to prevent the drywall from bonding to cured concrete. A thorough sanding of the prepped form created a smooth surface for concrete placement. Finally, temporary grooved spacers were placed on the form to allow the six 1/8-inch steel prestress cables to follow the form’s curvature.

To specialize labor and improve productivity on Casting Day, students were divided into four groups, one for each of the following tasks: mixing concrete batches, placing concrete layers, placing reinforcement, and laying out the prestress elements. Casting began by placing a 1/8-inch layer of concrete on the form, followed by a layer of carbon-fiber scrim. The prestress cables were then fitted into the temporary spacers’ grooves, and their ends were attached to an anchored system of springs and turnbuckles. The team then tensioned the cables with the turnbuckles. Measuring the elongation in the springs allowed the team to load each cable correctly. A 1/4-inch layer of concrete then covered the prestress cables, followed by another layer of scrim and one final 1/8-inch layer of concrete. To ensure a uniform thickness of each layer, wires of the appropriate diameter were spaced along the form. Concrete was then placed in between the wires and spread with rolling pins so that the top of the layer was flush with the tops of the wires. The thickness of each layer was additionally confirmed using pre-marked depth gauges.

After ***VoCal*** had dry cured for seven days, the exterior was finished with the internal form intact. The prestressed cables were cut after 28 days of curing. The team then flipped the canoe over onto cushions and removed the form with a hot wire cutter. Voids created by the spacers were filled with concrete, followed by a finishing of the interior.

The finishing process involved first applying a thin layer of the white finishing mix to create a smoother surface. After an additional seven days of curing, the canoe was sanded using sandpaper ranging from 60 through 2000-grit. Workers then brushed the dyed concrete mixes on top of vinyl stick-on stencils to create vivid murals along the canoe. A thorough sanding of these graphics before the stencils were removed left ***VoCal*** with nicely embossed and crisp images. A glossy look was achieved by adding two coats of concrete sealer, following the manufacturer’s recommendation that one gallon be applied per 200 square foot-coat.

Quality control was vital throughout the entire project. Previous Cal teams had Casting Day workers simultaneously cast along the entire length of the form, making quality control problematic. Each of ***VoCal’s*** layers was placed in a more orderly fashion, starting from the middle of the form and progressing towards the bow and stern (see Figure 5). An abundance of labor had allowed a quick fabrication of *Bear Force One*, but had made quality control difficult. Therefore, mandatory training sessions were held, featuring hands-on demonstrations of proper techniques for casting. ***VoCal’s*** finishing required a great level of care, as well. Graphics were sanded one color at a time, and to prevent colored concrete dust from contaminating concrete of different colors, plastic tarp was placed over exposed areas. While removing the stencils, the team examined three inch square portions at a time to ensure every detail was accounted for. The team’s impressively high quality canoe was generated by the enthusiasm and attention to detail shown by all involved in the construction process.

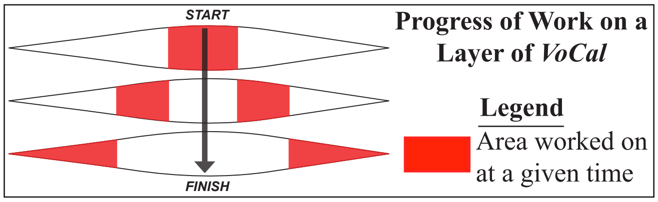


***Figure 5**: Casting on small sections of the form at a time allowed quality control officers to focus more effectively.*

PROJECT MANAGEMENT

VoCal's leadership team consisted of a project manager, a junior project manager, a chief technical officer, and a divisional officer for each of the following departments: hull design and analysis, materials, construction, paddling, and graphics. Making sure that the materials and analysis divisions had up-to-date information about each other's progress was critical to the design of a mix that had a sufficient factor of safety and a canoe that was structurally sound. The chief technical officer ensured that the materials division was developing ***VoCal's*** concrete with properties consistent with the analysis division's design.

VoCal's functional organization allowed team members to participate in divisions of their interest and facilitated an efficient sharing of technical expertise within each division. Solid horizontal communication between divisions was maintained by holding weekly officer meetings and consistently informing members about the developments within all divisions. In addition, the off-campus location of the team's construction site presented a unique challenge in keeping newer members involved. As a result, the team designed its canoe classes to include field trips to construction sessions and paddling practices. Exposing these members to multiple divisions allowed them to gain a diverse set of skills and a more holistic view of the team.

The project manager determined this year's budget and schedule by considering previous Cal teams' experiences as well as the weight of each task in the overall competition score. Collectively fundraising with other Cal engineering groups backed the team's allocation of $7,200 to concrete and construction materials, $16,000 to competition-related expenses, and $500 to an emergency fund to pay for unanticipated costs. Accounting for the potentially high cost of travel this year, the team made great efforts to reuse old supplies and acquire donated materials. To improve the tracking of finances and limit expenses, the project manager made all team purchases.

Table 1: *Milestone Activities*

Major Milestones	Deviations	Reason
Hull Design Complete	-6 days	Early Start
Final Concrete Mix	-3 days	Early Start
Form Prepped	None	Increased Work-Hours per Week
Casting Day	None	Effective Scheduling
Finishing	None	Effective Scheduling

Major schedule milestones (see Table 1) and the project's critical path were determined from previous experience. Milestones created an outline from which divisional officers developed their individual schedules. Activities on the critical path included hull design, completion of the form, casting of the canoe, and finishing of the canoe. To understand how critical activities were typically delayed, the team analyzed the baseline and actual schedules of previous Cal teams and surveyed past team project managers. It was discovered that most delays had occurred during the finishing phase due to occasional labor shortages. As a result, tasks had often been rushed, lowering the quality of the final product. To mitigate this risk and allow for this year's ambitious graphic designs, finishing of ***VoCal*** was scheduled to begin three weeks earlier than the average date set in the past.

Throughout the entire year, safety was critically important to the team. Labs and construction sites were properly ventilated, and participants were required to use protective gear, including gloves, masks, and goggles to protect against corrosive chemicals and airborne particulates. Furthermore, mandatory training was provided for those using hazardous materials and equipment.

VoCal's team members have contributed a total of 5400 person-hours to the project (see Table 2). Created by a Cal team backed by years of experience and students' dedication, ***VoCal*** is the product of innovative strategies and solid communication.

Table 2*: Person-Hours*

Activities	Person-Hours
Hull Design and Analysis	300
Mix Design and Testing	700
Construction	1300
Paddling	1900
Writing the Design Paper	500
Other (e.g., officer meetings)	700

ORGANIZATIONAL CHART

DAN GEE
Project Manager

Responsible for budgeting, scheduling, and overall team quality control.

DANIELLE DES CHAMPS
Junior PM

Will facilitate a smooth transition of leadership into the 2009 season.

ANDREW SUKKAR
Chief Technical Officer

Maintained solid communication between the Materials and Analysis divisions.

DANIEL CASTANEDA
Materials Officer

Developed concrete mixes and composites. Responsible for teaching the Fall canoe class.

Danielle Des Champs
Richard Huang
Nancy Huynh
Will Nguyen
Ruben Negrete
Erika Nevarez
Alyson Sato
Jamel Stewart

ASHLEY TAKATA
Construction Engineer

Oversaw the construction of the canoe, stands, and product display.

Jonathan Buckalew
Daniel Castaneda
Codie Davis
Danielle Des Champs
Dan Gee
David Leung
Danielle Love
Alyson Sato
Laura Talbot

DAVID LEUNG
Hull Design & Analysis Officer

Designed the canoe's hull and performed the structural analysis. Responsible for teaching the Spring canoe class.

Justin Barron
Justin Beutel
Winnie Chan
Forrest Cheney
Sandy Do
Michael Enciso
Nancy Huynh
Cyndi Lopez
Swe Shin Maung
Josh Mohayai
Will Nguyen

DANIELLA GUTIERREZ
Graphics Design Engineer

Designed the canoe's graphics, stands, and product display.

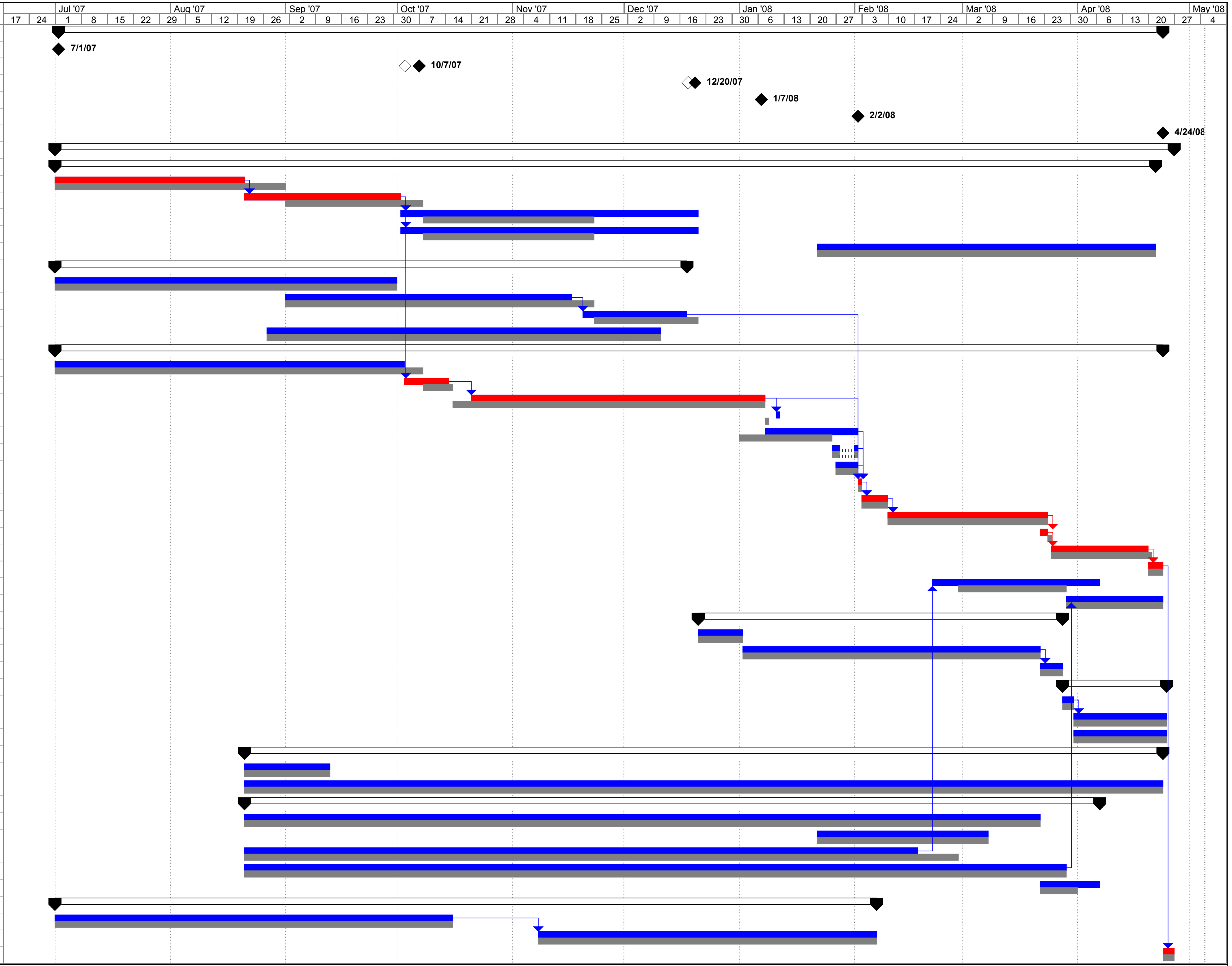
Elisha Ezersky
Nalat Yulong

DANIELLE DES CHAMPS
Paddling Coordinator

Oversaw paddling practices and instructed new paddlers.

Justin Beutel
Sandy Do
Dan Gee
Johnny Mendoza
Frank Menjivar
Nalat Yulong

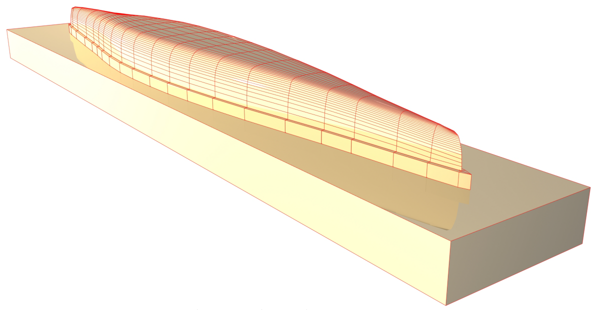
Task Name	Baseline Start	Baseline Finish	Actual Start	Actual Finish	Duration
Project Milestones	**7/1/07**	**4/24/08**	**7/1/07**	**4/24/08**	**297 days**
Project Start	7/1/07	7/1/07	7/1/07	7/1/07	
Hull Design Complete	10/7/07	10/7/07	10/1/07	10/1/07	
Final Mix Design	12/20/07	12/20/07	12/17/07	12/17/07	
Form Work Complete	1/7/08	1/7/08	1/7/08	1/7/08	
Casting Day	2/2/08	2/2/08	2/2/08	2/2/08	
MidPac Regional Competition	4/24/08	4/24/08	4/24/08	4/24/08	
Functional Activities	**7/1/07**	**4/24/08**	**7/1/07**	**4/26/08**	**301 days**
Hull Design and Analysis	**7/1/07**	**4/21/08**	**7/1/07**	**4/21/08**	**296 days**
Prolines Modeling	7/1/07	8/31/07	7/1/07	8/20/07	51 days
CAD Modeling	9/1/07	10/7/07	8/21/07	10/1/07	42 days
Prestressing Analysis	10/8/07	11/22/07	10/2/07	12/20/07	80 days
Loading Scenarios Analysis	10/8/07	11/22/07	10/2/07	12/20/07	80 days
Hull Design Class	1/22/08	4/21/08	1/22/08	4/21/08	91 days
Materials Development	**7/1/07**	**12/20/07**	**7/1/07**	**12/17/07**	**170 days**
Materials Research	7/1/07	9/30/07	7/1/07	9/30/07	92 days
Trial Batches and Modifications	9/1/07	11/22/07	9/1/07	11/16/07	77 days
Composite Test Plates	11/23/07	12/20/07	11/20/07	12/17/07	28 days
Materials Class	8/27/07	12/10/07	8/27/07	12/10/07	106 days
Construction	**7/1/07**	**4/23/08**	**7/1/07**	**4/23/08**	**298 days**
Materials Research	7/1/07	10/7/07	7/1/07	10/2/07	94 days
Form Milling	10/8/07	10/15/07	10/3/07	10/14/07	12 days
Form Preparation	10/16/07	1/7/08	10/21/07	1/7/08	79 days
Practice Canoe	1/8/08	1/8/08	1/11/08	1/11/08	1 day
Prestressing Rig Setup	1/1/08	1/25/08	1/8/08	2/1/08	25 days
Training for Casting Day	1/26/08	2/1/08	1/26/08	2/1/08	3 days
Final Pre-Casting Preparations	1/27/08	2/1/08	1/27/08	2/1/08	6 days
Casting Day	2/2/08	2/2/08	2/2/08	2/2/08	1 day
Curing	2/3/08	2/9/08	2/3/08	2/9/08	7 days
Exterior Finishing	2/10/08	3/23/08	2/10/08	3/23/08	43 days
Removal of Formwork	3/24/08	3/24/08	3/22/08	3/23/08	2 days
Interior Finishing	3/25/08	4/20/08	3/25/08	4/19/08	26 days
Punchlist Items	4/20/08	4/23/08	4/20/08	4/23/08	4 days
Stands	2/29/08	3/28/08	2/22/08	4/6/08	45 days
Displays and Cross Section	3/29/08	4/23/08	3/29/08	4/23/08	26 days
Design Paper	**12/21/07**	**3/27/08**	**12/21/07**	**3/27/08**	**98 days**
Rough Drafts	12/21/07	1/1/08	12/21/07	1/1/08	12 days
Editing	1/2/08	3/21/08	1/2/08	3/21/08	80 days
Printing and Submission	3/22/08	3/27/08	3/22/08	3/27/08	6 days
Presentation	**3/28/08**	**4/24/08**	**3/28/08**	**4/24/08**	**28 days**
Outline	3/28/08	3/30/08	3/28/08	3/30/08	3 days
Rehearsals	3/31/08	4/24/08	3/31/08	4/24/08	25 days
Visual Aids	3/31/08	4/24/08	3/31/08	4/24/08	25 days
Paddling	**8/21/07**	**4/23/08**	**8/21/07**	**4/23/08**	**247 days**
Recruitment	8/21/07	9/12/07	8/21/07	9/12/07	23 days
Training	8/21/07	4/23/08	8/21/07	4/23/08	247 days
Graphic Design	**8/21/07**	**3/31/08**	**8/21/07**	**4/6/08**	**230 days**
Canoe Aesthetics	8/21/07	3/21/08	8/21/07	3/21/08	214 days
Paper Design	1/22/08	3/7/08	1/22/08	3/7/08	46 days
Stands Design	8/21/07	2/28/08	8/21/07	2/17/08	181 days
Displays Design	8/21/07	3/28/08	8/21/07	3/28/08	221 days
T-shirt Design	3/22/08	3/31/08	3/22/08	4/6/08	16 days
Joint Fundraising	**7/1/07**	**2/6/08**	**7/1/07**	**2/6/08**	**221 days**
Budget and Donation Brochures	7/1/07	10/15/07	7/1/07	10/15/07	107 days
Company Calls	11/8/07	2/6/08	11/8/07	2/6/08	91 days
MidPacific Regional Competition	4/24/08	4/26/08	4/24/08	4/26/08	3 days



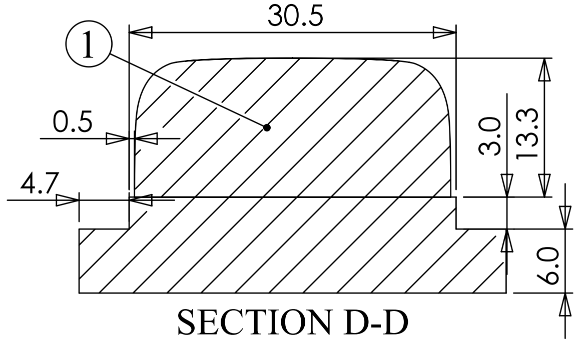
Project: ***VoCal***
Year: 2007-2008

Actual Task Progress ▬ Baseline ▬ Summary

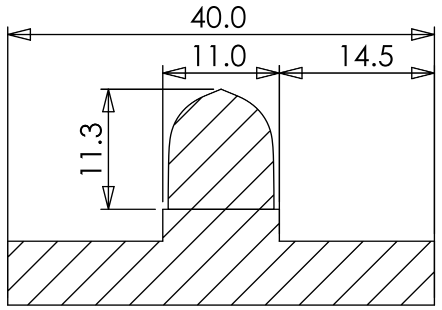
Actual Critical Progress ▬ Actual Milestone ◇ Baseline Milestone ◆



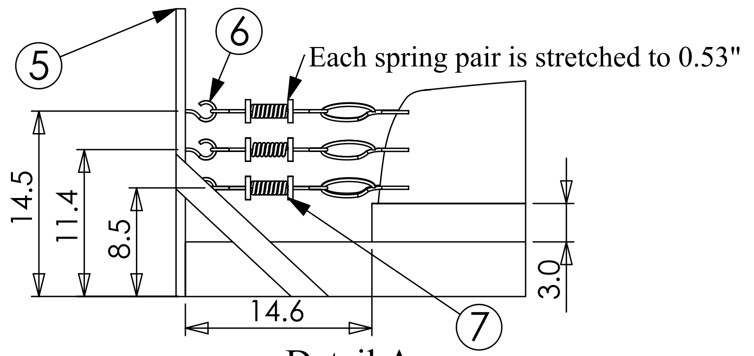
Rendered View



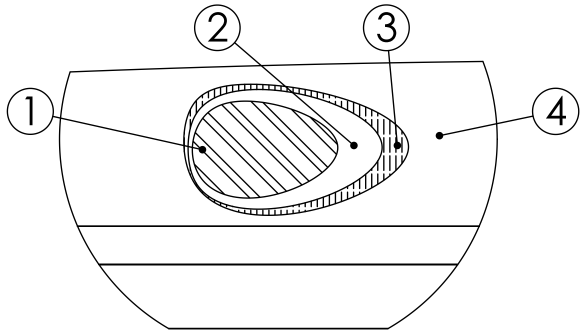
SECTION D-D
Widest Section



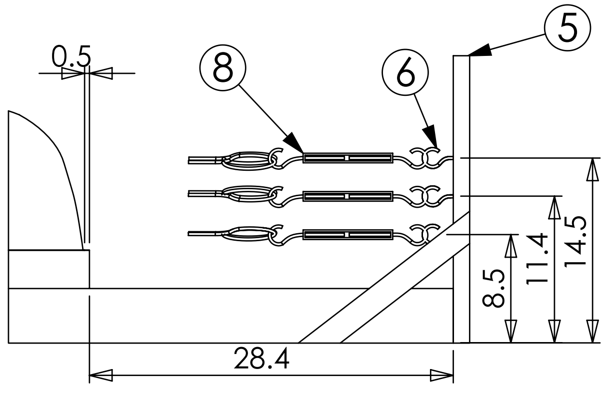
SECTION E-E
Stern



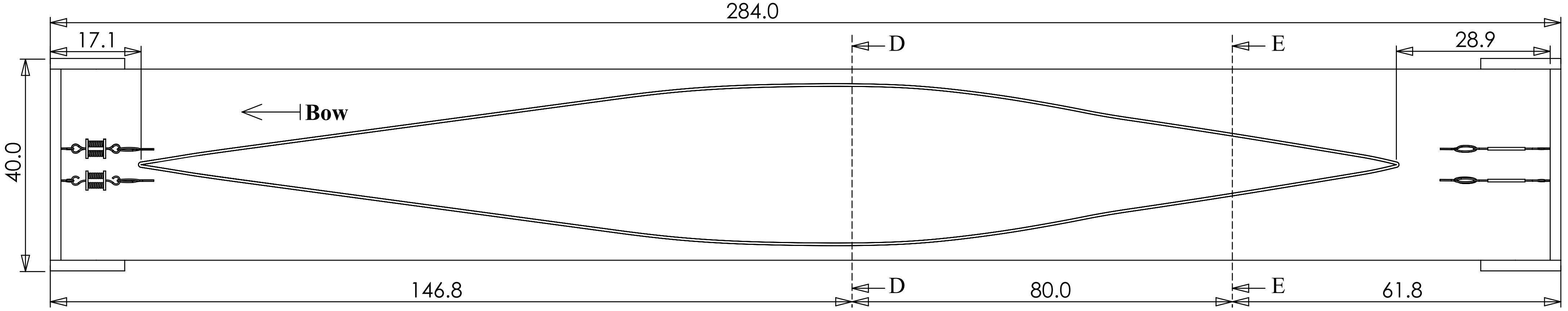
Detail A



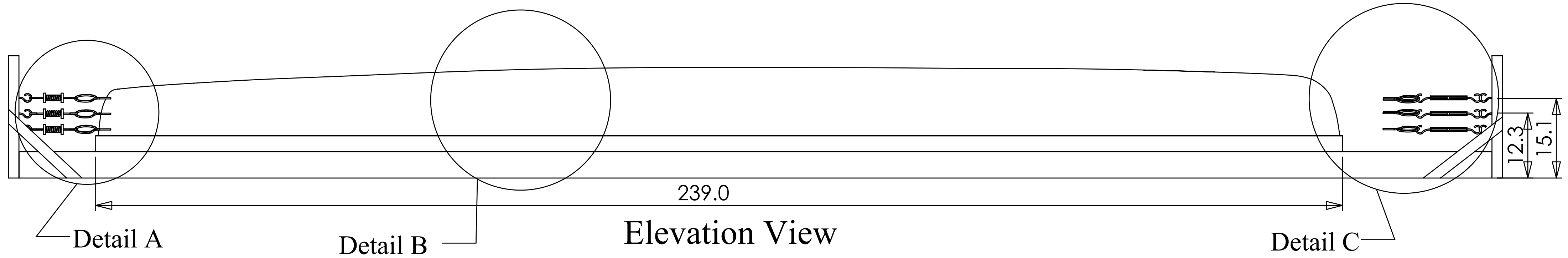
Detail B
Formwork Layers



Detail C



Plan View



Elevation View

University of California, Berkeley

Bill of Materials

Part	Description	Qty
1	2 lb. Expanded Polystrene Foam	355 cu. ft.
2	Styrospray Sealant	0.3 cu. ft.
3	Drywall Compound	0.3 cu. ft.
4	Epoxy	0.3 cu. ft.
5	2"x4" Wood Stud	48 ft.
6	225 lb. Metal Hook Screws	12 screws
7	187 lb/in Springs	12 springs
8	Turnbuckle	6

VoCal Formwork

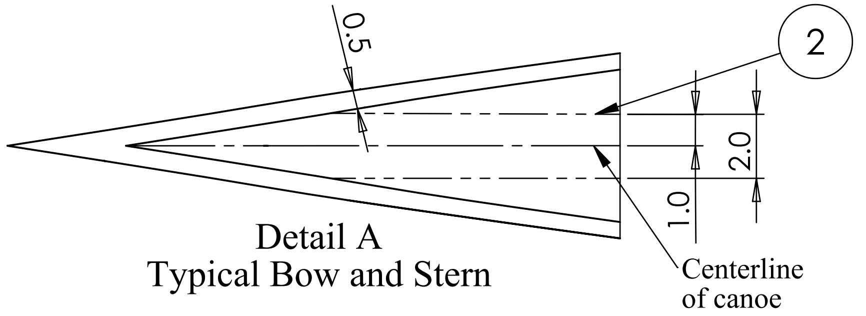
Notes:
1. Tolerance: +/- 1/8"
2. Units in Inches
3. Not Drawn to Scale
4. Cable anchorage alignment approximate

Drawn By:
David Leung
3/8/2008

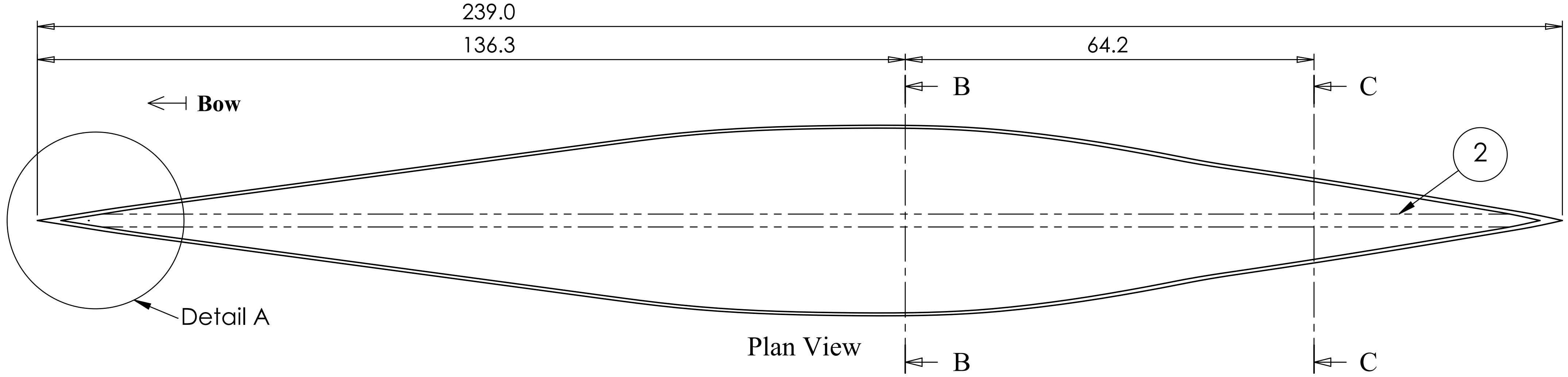
Checked By:
Dan Gee
3/12/2008

Sheet
1 of 2

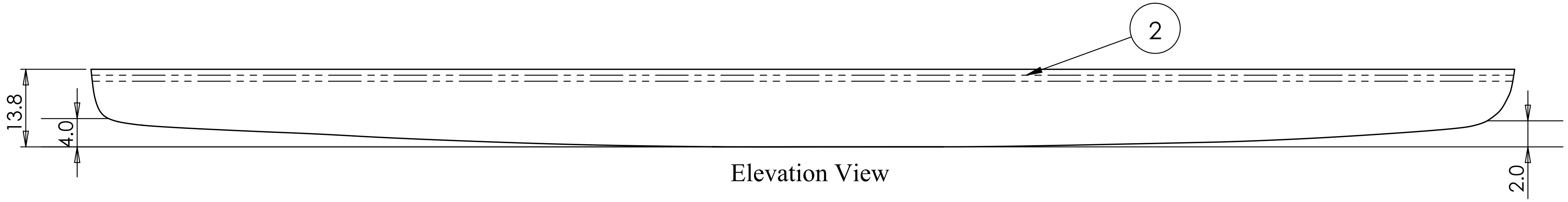
Rendered View



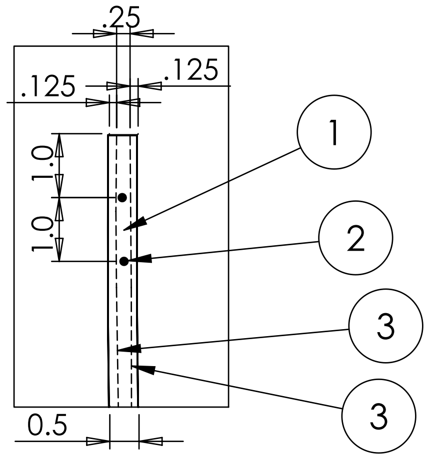
Detail A
Typical Bow and Stern



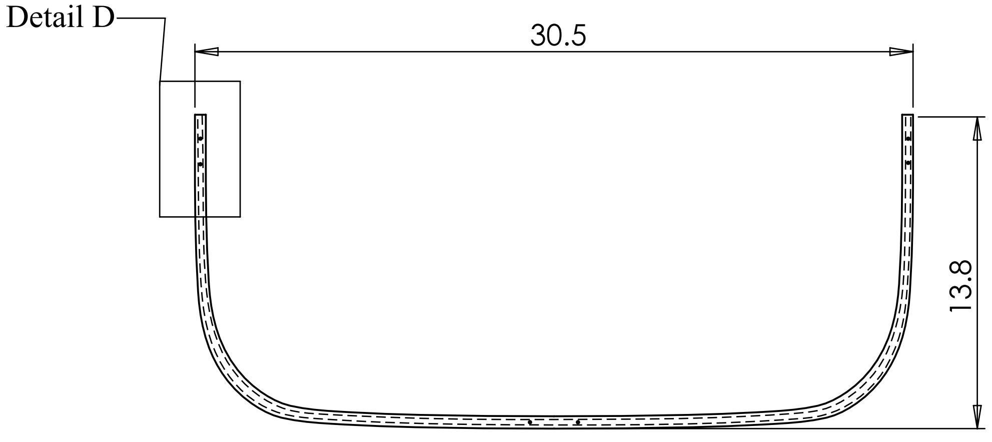
Plan View



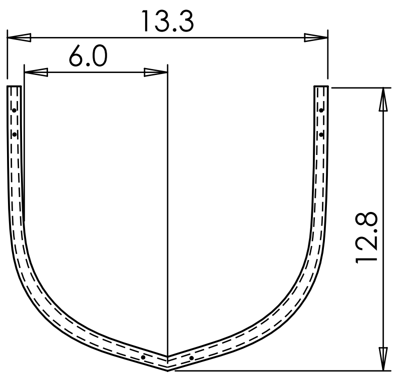
Elevation View



Detail D
Gunwale



SECTION B-B
Widest Beam



SECTION C-C
Stern

University of California, Berkeley

Bill of Materials

Part	Description	Qty
1	Structural Concrete	2.6 cu. ft.
2	1/8" Steel Prestress Cables	120 ft.
3	Carbon Fiber Scrim Reinforcement	124 sq. ft.
4	White Concrete Finishing Layer$^+$	0.46 cu. ft.
5	Black Concrete Finishing Layer$^+$	0.05 cu. ft.
6	Red Concrete Finishing Layer$^+$	0.01 cu. ft.

VoCal
Hull Design

Notes:
1. Tolerances: Hull Design: +/- 1/8"
   Shell Layer Thickness: +/- 1/16"
2. Units in Inches
3. Not Drawn to Scale

$^+$Applied during surface finish

Drawn By:
David Leung
3/8/2008

Checked By:
Dan Gee
3/12/2008

Sheet
2 of 2

APPENDIX A - References

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Mixture: Structural

Batch Size (ft^3): 0.3

		Non-SSD Proportions as Designed		**Actual Batched Proportions**		**Yielded Proportions**	
Cementitious Materials	Specific* Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
1. Type I White Portland Cement	3.15	376.69	1.916	4.19	0.021	375.47	1.910
2. Blast Furnace Slag, Grade 100	2.45	188.34	1.232	2.09	0.014	187.74	1.228
3. Metakaolin	2.60	62.78	0.387	0.70	0.004	62.58	0.386
Total of All Cementitious Materials		627.81	3.535	6.98	0.039	625.79	3.524
Fibers							
1. 8mm PVA	0.90	15.16	0.270	0.17	0.003	15.11	0.269
Aggregates							
1. K1 Glass Microspheres Absorption: 0%	0.12	14.77	1.973	0.16	0.022	14.72	1.966
2. 0.25-0.5 mm Recycled Glass Absorption: 25.0 %	0.62	51.70	1.336	0.57	0.015	51.54	1.332
3. 0.5-1 mm Recycled Glass Absorption: 25.0 %	0.47	77.55	2.644	0.86	0.029	77.30	2.636
4. 1-2 mm Recycled Glass Absorption: 25.0 %	0.39	132.95	5.463	1.48	0.061	132.52	5.445
5. 2-4 mm Recycled Glass Absorption: 25.0 %	0.38	92.33	3.894	1.03	0.043	92.03	3.881
Total of All Aggregates		369.30	15.310	4.10	0.170	368.11	15.261
Water							
Batched Water^	1.00	36.96	0.592	0.41	0.007	36.84	0.590
Total Water Added for Aggregate	1.00	88.63	1.420	0.98	0.016	88.35	1.416
Total Water from All Admixtures	1.00	182.15	2.919	2.02	0.032	181.56	2.910
Total Water		307.74	4.932	3.42	0.055	306.75	4.916
Admixtures	% Solids	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)	Amount (fl oz)	Water‡ in Admixture (lb)	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)
1. SBR Latex; Density: 10.01 lb/gal	47.00	700.00	182.15	48.83	2.02	700.00	181.56
Cement-Cementitious Materials Ratio		0.60		0.60		0.60	
Water-Cementitious Materials Ratio**		0.35		0.35		0.35	
Flow (flow table), Slump, Slump Flow, in.		1.00		1.00		1.00	
Air Content, %		10.00		10.3		10.3	
Density (Unit Weight), lb/ft^3		54.88		54.7		54.7	
Gravimetric Air Content, %				10.3			
Yield, ft^3***		27.0		0.3		27.0	

* *For aggregates provide ASTM C 127 oven-dry, bulk specific gravity.*

** *"Water" in the w/c ratio is the water used to hydrate the cementitious materials, equal to "Batched Water" plus the water from admixtures and thus excludes water absorbed by aggregate, as this does not contribute to the matrix strength.*

*** *"Yield" accounts for both the solids and water content of the admixtures.*

^ *Excluding water added for aggregate absorption. The appendix of the 2008 NCCC Rules states, "'Batched Water' is the total amount of water needed to hydrate the cementitious materials..." We interpreted this to mean that "Batched Water" only includes the actual amount of water measured and added to the mix minus the water absorbed by aggregates (and not the water from admixtures); else, "Total Water" would account for water from admixtures twice.*

‡ *Water content of admixture.*

Mixture: Black Finishing

Batch Size (ft^3): 0.02

		Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
Cementitious Materials	Specific* Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
1. Type I Portland Cement	3.15	1022.87	5.204	0.76	0.004	1012.73	5.152
Total of All Cementitious Materials		1022.87	5.204	0.76	0.004	1012.73	5.152
Aggregates							
1. K1 Glass Microspheres Absorption: 0%	0.12	10.33	1.380	0.01	0.001	10.23	1.366
2. 0.25-0.5 mm Recycled Glass Absorption: 25.0 %	0.62	334.07	8.635	0.25	0.006	330.76	8.549
Total of All Aggregates		344.40	10.015	0.26	0.007	340.99	9.915
Water							
Batched Water^	1.00	11.63	0.186	0.01	0.000#	11.52	0.185
Total Water Added for Aggregate	1.00	83.52	1.338	0.06	0.001	82.69	1.325
Total Water from All Admixtures	1.00	382.17	6.125	0.28	0.005	378.38	6.064
Total Water		477.32	7.649	0.35	0.006	472.59	7.574
Admixtures	% Solids	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)	Amount (fl oz)	Water‡ in Admixture (lb)	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)
1. Chromix Black; Density: 14.60 lb/gal	60.00	183.00	85.40	1.39	0.06	183.00	84.56
2. SBR Latex; Density: 10.01 lb/gal	47.00	700.00	296.77	5.30	0.22	700.00	293.83
Cement-Cementitious Materials Ratio		1.00		1.00		1.00	
Water-Cementitious Materials Ratio**		0.39		0.39		0.39	
Flow (flow table), Slump, Slump Flow, in.		7.00		7.00		7.00	
Air Content, %		8.00		8.9		8.9	
Density (Unit Weight), lb/ft^3		82.82		82.0		82.0	
Gravimetric Air Content, %				8.9			
Yield, ft^3***		27.0		0.02		27.0	

** For aggregates provide ASTM C 127 oven-dry bulk specific gravity.*

*** "Water" in the w/c ratio is the water used to hydrate the cementitious materials, equal to "Batched Water" plus the water from admixtures and thus excludes water absorbed by aggregate, as this does not contribute to the matrix strength.*

**** "Yield" accounts for both the solids and water content of the admixtures.*

^ Excluding water added for aggregate absorption. The appendix of the 2008 NCCC Rules states, "'Batched Water' is the total amount of water needed to hydrate the cementitious materials..." We interpreted this to mean that "Batched Water" only includes the actual amount of water measured and added to the mix minus the water absorbed by aggregates (and not the water from admixtures); else, "Total Water" would account for water from admixtures twice.

‡ Water content of admixture.

 # True volume is 0.0001 ft^3.

Mixture: Red Finishing

Batch Size (ft^3): 0.02

		Non-SSD Proportions as Designed		**Actual Batched Proportions**		**Yielded Proportions**	
Cementitious Materials	Specific* Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
1. Type I White Portland Cement	3.15	1060.18	5.394	0.79	0.004	1050.07	5.342
Total of All Cementitious Materials		1060.18	5.394	0.79	0.004	1050.07	5.342
Aggregates							
1. K1 Glass Microspheres Absorption: 0%	0.12	10.19	1.361	0.01	0.001	10.10	1.348
2. 0.25-0.5 mm Recycled Glass Absorption: 25.0 %	0.62	329.61	8.520	0.24	0.006	326.46	8.438
Total of All Aggregates		339.80	9.881	0.25	0.007	336.56	9.787
Water							
Batched Water^	1.00	28.64	0.459	0.02	0.000#	28.36	0.455
Total Water Added for Aggregate	1.00	82.40	1.321	0.06	0.001	81.62	1.308
Total Water from All Admixtures	1.00	371.05	5.946	0.27	0.004	367.51	5.890
Total Water		482.09	7.726	0.36	0.006	477.49	7.652
Admixtures	% Solids	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)	Amount (fl oz)	Water‡ in Admixture (lb)	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)
1. Chromix Medium Red; Density: 15.70 lb/gal	60.00	122.00	63.46	0.96	0.05	122.00	62.85
2. SBR Latex; Density: 10.01 lb/gal	47.00	700.00	307.59	5.50	0.23	700.00	304.66
Cement-Cementitious Materials Ratio		1.00		1.00		1.00	
Water-Cementitious Materials Ratio**		0.38		0.38		0.38	
Flow (flow table), Slump, Slump Flow, in.		7.00		7.00		7.00	
Air Content, %		8.00		8.9		8.9	
Density (Unit Weight), lb/ft^3		83.35		82.6		82.6	
Gravimetric Air Content, %				8.9			
Yield, ft^3***		27.0		0.02		27.0	

* *For aggregates provide ASTM C 127 oven-dry bulk specific gravity.*

** *"Water" in the w/c ratio is the water used to hydrate the cementitious materials, equal to "Batched Water" plus the water from admixtures and thus excludes water absorbed by aggregate, as this does not contribute to the matrix strength.*

*** *"Yield" accounts for both the solids and water content of the admixtures.*

^ *Excluding water added for aggregate absorption. The appendix of the 2008 NCCC Rules states, "'Batched Water' is the total amount of water needed to hydrate the cementitious materials..." We interpreted this to mean that "Batched Water" only includes the actual amount of water measured and added to the mix minus the water absorbed by aggregates (and not the water from admixtures); else, "Total Water" would account for water from admixtures twice.*

‡ *Water content of admixture.*

\# *True volume is 0.0003 ft^3.*

Mixture: White Finishing

Batch Size (ft^3): 0.02

		Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
Cementitious Materials	Specific* Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
1. Type I White Portland Cement	3.15	1127.95	5.738	0.84	0.004	1116.92	5.682
Total of All Cementitious Materials		1127.95	5.738	0.84	0.004	1116.92	5.682
Aggregates							
1. K1 Glass Microspheres Absorption: 0%	0.12	10.10	1.349	0.01	0.001	10.00	1.336
2. 0.25-0.5 mm Recycled Glass Absorption: 25.0 %	0.62	326.60	8.442	0.24	0.006	323.41	8.359
Total of All Aggregates		336.70	9.791	0.25	0.007	333.41	9.695
Water							
Batched Water^	1.00	66.40	1.064	0.05	0.001	65.75	1.054
Total Water Added for Aggregate	1.00	81.65	1.308	0.06	0.001	80.85	1.296
Total Water from All Admixtures§	1.00	327.25	5.244	0.24	0.004	324.06	5.193
Total Water		475.30	7.617	0.35	0.006	470.66	7.543
Admixtures	% Solids	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)	Amount (fl oz)	Water‡ in Admixture (lb)	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)
1. SBR Latex; Density, 10.01 lb/gal	47.00	700.00	327.25	5.85	0.24	700.00	324.06
Cement-Cementitious Materials Ratio		1.00		1.00		1.00	
Water-Cementitious Materials Ratio**		0.35		0.35		0.35	
Flow (flow table), Slump, Slump Flow, in.		7.00		7.00		7.00	
Air Content, %		8.00		8.9		8.9	
Density (Unit Weight), lb/ft^3		82.60		81.8		81.8	
Gravimetric Air Content, %				8.9			
Yield, ft^3***		27.0		0.02		27.0	

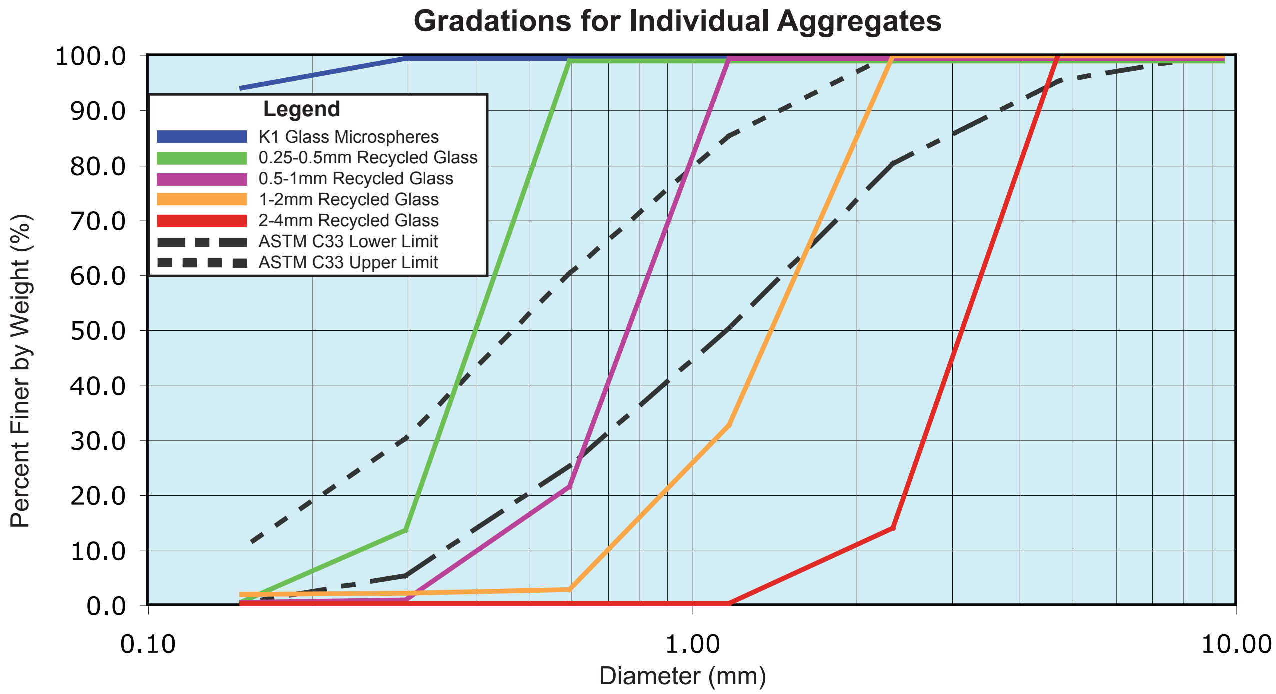
* *For aggregates provide ASTM C 127 oven-dry bulk specific gravity.*

** *"Water" in the w/c ratio is the water used to hydrate the cementitious materials, equal to "Batched Water" plus the water from admixtures and thus excludes water absorbed by aggregate, as this does not contribute to the matrix strength.*

*** *"Yield" accounts for both the solids and water content of the admixtures.*

^ *Excluding water added for aggregate absorption. The appendix of the 2008 NCCC Rules states, "'Batched Water' is the total amount of water needed to hydrate the cementitious materials..." We interpreted this to mean that "Batched Water" only includes the actual amount of water measured and added to the mix minus the water absorbed by aggregates (and not the water from admixtures); else, "Total Water" would account for water from admixtures twice.*

‡ *Water content of admixture.*



Concrete Aggregate: K1 Glass Microspheres
Sample Weight: 50.0g
Specific Gravity: 0.12
Fineness Modulus: 0.054

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.0	0.0	100.0
No. 4	4.75	0.0	0.0	100.0
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	0.0	0.0	100.0
No. 30	0.60	0.0	0.0	100.0
No. 50	0.30	0.0	0.0	100.0
No. 100	0.15	2.7	2.7	94.6
P 100	0.00	47.3	50.0	0.0

Concrete Aggregate: 0.25-0.5 mm Recycled Glass
Sample Weight: 183.4g
Specific Gravity: 0.62
Fineness Modulus: 1.84

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.0	0.0	100.0
No. 4	4.75	0.0	0.0	100.0
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	0.0	0.0	100.0
No. 30	0.60	0.0	0.0	100.0
No. 50	0.30	156.4	156.4	14.7
No. 100	0.15	24.0	180.4	1.6
P 100	0.00	3.0	183.4	0.0

Concrete Aggregate: 0.5-1 mm Recycled Glass
Sample Weight: 303.4g
Specific Gravity: 0.47
Fineness Modulus: 2.75

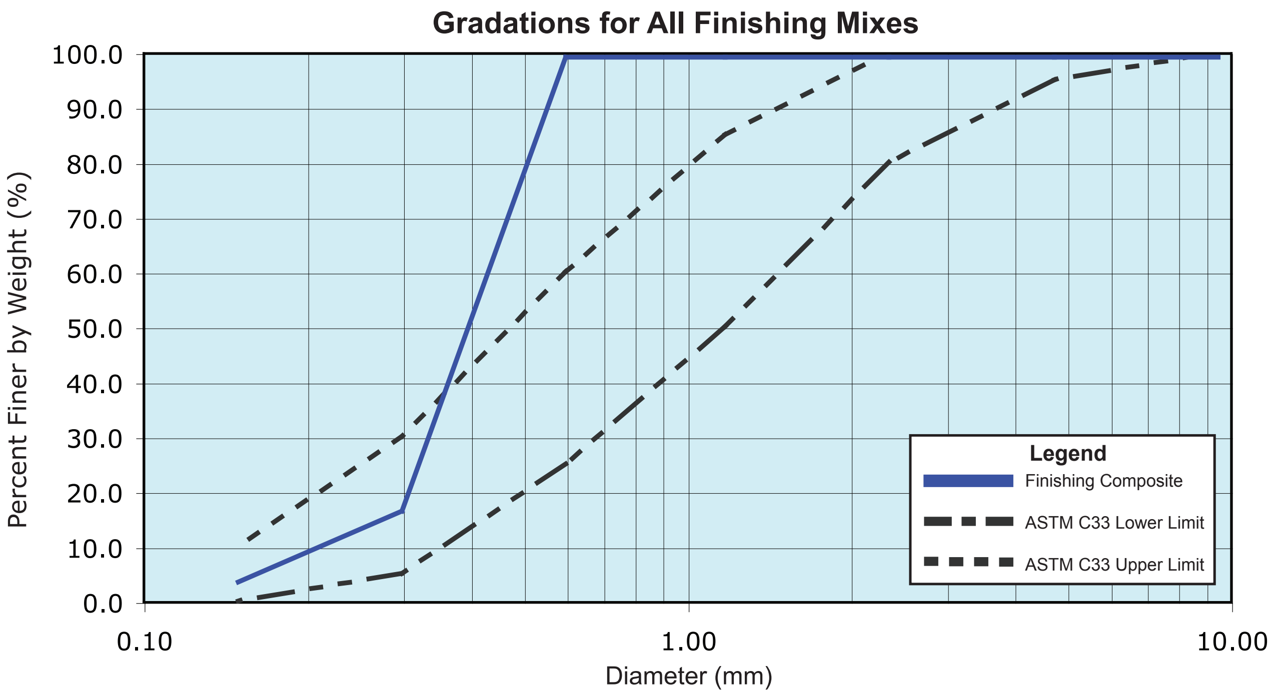
Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.0	0.0	100.0
No. 4	4.75	0.0	0.0	100.0
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	0.0	0.0	100.0
No. 30	0.60	236.2	236.2	22.1
No. 50	0.30	62.5	298.7	1.5
No. 100	0.15	1.3	300.0	1.1
P 100	0.00	3.4	303.4	0.0

Concrete Aggregate: 1-2 mm Recycled Glass
Sample Weight: 276.1g
Specific Gravity: 0.39
Fineness Modulus: 3.60

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.0	0.0	100.0
No. 4	4.75	0.0	0.0	100.0
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	185.5	185.5	32.8
No. 30	0.60	82.3	267.8	3.0
No. 50	0.30	2.0	269.8	2.3
No. 100	0.15	0.7	270.5	2.0
P 100	0.00	5.6	276.1	0.0

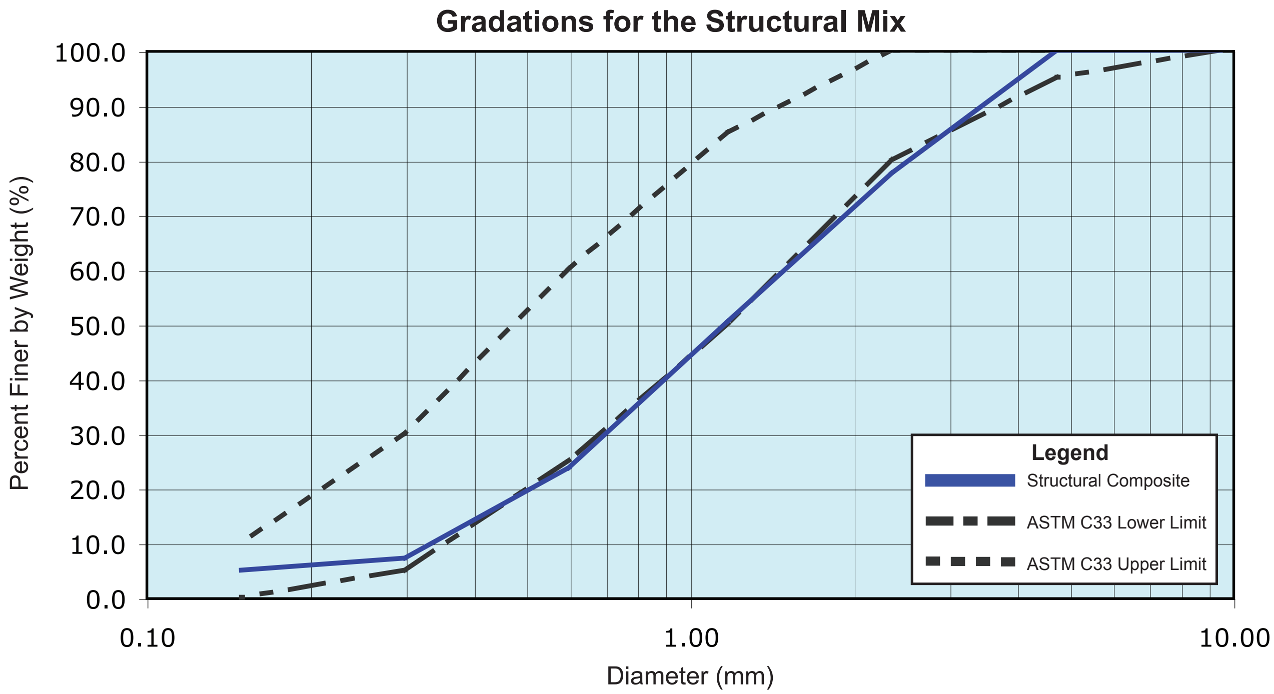
Concrete Aggregate: 2-4 mm Recycled Glass
Sample Weight: 162.5g
Specific Gravity: 0.38
Fineness Modulus: 4.86

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.0	0.0	100.0
No. 4	4.75	0.0	0.0	100.0
No. 8	2.36	140.2	140.2	13.7
No. 16	1.18	22.3	162.5	0.0
No. 30	0.60	0.0	162.5	0.0
No. 50	0.30	0.0	162.5	0.0
No. 100	0.15	0.0	162.5	0.0
P 100	0.00	0.0	162.5	0.0



Concrete Aggregate: Composite Blend of All Finishing Mixes
Sample Weight: 300.0g
Fineness Modulus: 1.78

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.0	0.0	100.0
No. 4	4.75	0.0	0.0	100.0
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	0.0	0.0	100.0
No. 30	0.60	0.0	0.0	100.0
No. 50	0.30	248.2	248.2	17.3
No. 100	0.15	38.6	286.8	4.4
P 100	0.00	13.2	300.0	0.0



Concrete Aggregate: Composite Blend of the Structural Mix
Sample Weight: 300.0g
Fineness Modulus: 3.36

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.0	0.0	100.0
No. 4	4.75	0.0	0.0	100.0
No. 8	2.36	67.3	67.3	77.6
No. 16	1.18	81.2	148.5	50.5
No. 30	0.60	80.4	228.9	23.7
No. 50	0.30	49.5	278.4	7.2
No. 100	0.15	6.6	285.0	5.0
P 100	0.00	15.0	300.0	0.0