

BLACK ♦ DIAMOND



EXPERTS
ONLY
♦

NEVADA



2011 Concrete Canoe Design Report
University of Nevada, Reno

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◆ EXECUTIVE SUMMARY ◆

Internationally known for their rugged terrain and breathtaking landscapes, the Sierra Nevada Mountains draw adventurers from all over the world each winter. The mountain range is home to Squaw Valley Ski Resort which hosted the 1960 Winter Olympic Games. At the games, a black diamond is the symbol that indicates the most difficult runs for skiers and snowboarders to overcome – making it an ideal theme for the 2011 Nevada concrete canoe.

Established in 1874, the University of Nevada, Reno continues to expand its student body and research opportunities. With approximately 18,000 students, 500 of whom study in the Civil and Environmental Engineering Department, the university is world-renowned for its earthquake research center. The Nevada Concrete Canoe Team competes alongside seven Northern California universities in the Mid-Pacific Conference (Mid-Pac), one of the most competitive regions in the nation. In 2005, the team revived its canoe program after a seven year hiatus with *All In* and finished in fifth place. The following year, Nevada qualified for the National Concrete Canoe Competition (NCCC) with *euphoria* where they finished sixth overall. With *Cerulean*'s third place finish at the NCCC in 2007, the team realized its potential for success, and in 2008, Nevada won its first national championship with *Argentum*. The team maintained a strong success at the NCCC in the following years with *FUSION* (5th, 2009) and *BATTLE BORN* (2nd, 2010).

The 2011 Nevada team, composed of half new members, made a strong appearance at Mid-Pac in hopes of participating again in the 2011 NCCC. Fresh enthusiasm combined with the experience of veteran members renewed the focus on research and increased pursuit for innovative and sustainable measures. An ambitious project manager oversaw five divisions: academics, mix design, construction, paddling, and graphics. A new universal structural analysis spreadsheet determined more accurate prestressing results and was designed to accommodate any canoe design, benefitting future Nevada teams. The team determined 14 longitudinal prestress tendons were necessary to minimize tensile stresses and included experimental transverse prestress tendons. The mix design division incorporated locally available used airsoft pellets to reduce the team's carbon footprint. The final concrete mixture is composed of 70 percent recycled materials; concrete properties are listed in Table 1, and canoe specifications are shown in Table 2. Improved aesthetic finishing on the canoe conveys rigorous winter activities and the beautiful scenery of the Sierra Nevada mountain range.

In the end, with utmost dedication and perseverance, the 2011 Nevada Concrete Canoe Team aspires to overcome the steep challenges of the concrete canoe competition with BLACK◆DIAMOND.

Table 1: Concrete Properties.

Properties	Structural Mix	Patch Mix
Unit Weight	58.8 pcf	55.2 pcf
Compressive Strength	1700 psi	1450 psi
Modulus of Rupture	300 psi	210 psi

Table 2: BLACK◆DIAMOND Specifications.

Weight: 146 lbs	Depth: 16.0"	Main Reinforcement	1.5" Carbon Fiber Scrim
Length: 20'-1"	Thickness: 0.50"		0.25" dia. Steel All-Thread (Ribs)
Width: 31.2"	Main Colors: Black, Blue, Brown		0.50" Steel Mesh (Bow/Stern)
Composite Flexural Strength: 1,200 psi		Prestress Tendon	0.06" dia. Steel Cable



◆ ANALYSIS ◆

The analysis engineer for BLACK◆DIAMOND performed a detailed finite element analysis (FEA) using the program SAP2000v.14[®] (Computers and Structures, 2009) and designed the prestressing system using a spreadsheet in Microsoft Excel. The team set three goals for the project: (1) create a new universal spreadsheet to design longitudinal prestressing, (2) experiment with a transverse prestressing system, and (3) determine the required composite concrete properties of the canoe.

The structural analysis considered multiple criteria to accurately model the canoe. The spreadsheet used an idealized model of the canoe and calculated section properties at 1' intervals along the length of the hull, including center of gravity, cross sectional area, moment of inertia, shear forces, moments, and the pitching angle of the canoe due to rotation in the water. Tendon geometry was established at three key cross sections; a parabolic path was then fit through those points at each of the 16 remaining cross sections. For quality control purposes, the spreadsheet output construction sheets at 1' intervals to provide accurate horizontal and vertical layout lines for each longitudinal tendon.

Next, the spreadsheet results were input into SAP2000v.14[®]. The FEA model used multi-layered shell elements to account for composite material interaction (Biswick, 1999) and tendon elements to model the prestressing system; the geometric coordinates for the model were provided by the Committee on National Concrete Canoe Competition. Preliminary mix design results provided basic material properties for the model. The concrete material model used a unit weight of 58.8 pcf, a Poisson's ratio of 0.2 and a modulus of rupture of 300 ksi (ASTM 947-03). Based on previous experience, the analysis team set allowable stress limits for the concrete at 75 percent of the compressive strength and 15 percent of the modulus of rupture; a load factor of 1.25 was included to account for dynamic load magnification (Paradis, 2006). A uniform 0.5" thickness was assigned to each shell element to model the hull thickness; this included two layers of carbon fiber grid reinforcement with strength properties provided by the manufacturer. The analysis team implemented four transverse ribs, with a cross-sectional area of 1 in², to add stiffening effects to the canoe. Paddling ergonomics influenced the rib locations, while constructability concerns dictated the rib size and aesthetics.

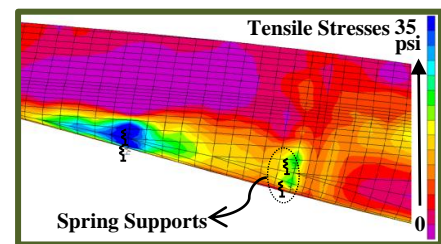


Figure 1: FEA Model with Vertical Restraints.

The analysis team proceeded to determine force effects from six general loading cases: simply supported, inverted simply supported, prestressing only, two paddler race, three paddler race, and four paddler race. Basic boundary conditions included lateral restraints at the bow and stern for model stability and vertical restraints with spring supports, representing paddler loads (Figure 1).

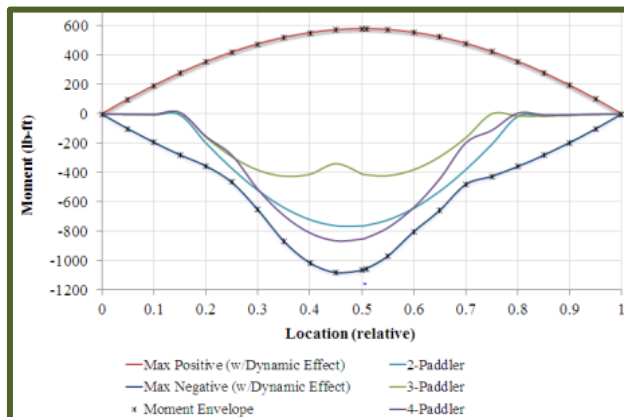


Figure 2: Moment Envelopes.

The FEA model was rotated using the calculated pitching angle to bring the canoe into equilibrium, later discussed in the *Innovation and Sustainability* section. The team also applied a buoyant water force that was modeled as a distributed load that varied with depth, acting orthogonally to the outside of the hull. The vertically restrained nodes at paddler locations generated the effective paddler loads by producing equilibrating reactions. Variations in the water level and spring stiffness factors for each loading case helped to approximate paddler reactions (200 lb in the bow, 150 lb for paddler two, 200 lb for paddler three, and 150 lb in the stern for the four paddler race), producing accurate bending behavior in the canoe model. This year the team determined that the four paddler

loading case controlled with the paddlers tightly grouped in the bow and stern for a more effective paddling reach. A comparison of calculated shear and moment values from the spreadsheet analysis to the results of the FEA provided quality control procedures. Figure 2 shows the maximum and minimum moment envelopes for the canoe, controlled by the simply supported and four paddler race.

Iterative design parameters included total prestressing jacking forces and effective prestress eccentricities, which minimized tensile stresses and ensured compressive stresses were within the allowable limits. Based on AASHTO Bridge Design (2010) specifications, prestressing losses of 25 percent due to creep, shrinkage, steel relaxation, and elastic shortening were included. The final prestressing system required 14 longitudinal steel tendons with a total jacking force of 3,500 lb. In addition, the team considered transverse tendons as an experimental research project to determine if structural ribs could be removed. The system included nine experimental transverse steel tendons, placed every 2', with a total jacking force of 450 lb. Further details are discussed in the *Development and Testing* section.

The analysis yielded quantitative results for material property requirements. The structural concrete mixture needed a minimum compressive strength of 680 psi, a modulus of rupture of 300 psi, and a composite flexural strength of 1,040 psi. With all the strength requirements met, BLACK♦DIAMOND will be able to withstand the rigors of competition.

♦ DEVELOPMENT AND TESTING ♦

The team had two main goals for the composite concrete design: (1) produce a lighter and more workable final concrete mixture, and (2) increase the time allocated for research to optimize mixture constituent selection and improved testing methods while meeting the material property requirements of the structural analysis. Both the mix design and the analysis teams performed intensive investigations of concrete mixture properties while maintaining compliance with 2011 competition rules (ASCE/NCCC, 2010).

The mix design engineers originally set a goal unit weight of 62.0 pcf, the unit weight of **BATTLE BORN** in 2010. A baseline mixture was developed with 0.6 water/cementitious materials (w/cm) ratio, 10 percent design air content, and 400 pcy cementitious materials content. The cementitious materials incorporated 50 percent Type I white portland cement, 40 percent vitro calcium aluminosilicate (VCAS-8™), and 10 percent Komponent®, an expansive cement additive, by weight. This produced a concrete with a unit weight of 62.2 pcf and a 28-day compressive strength of 2,200 psi.

Initial trial mixtures had high w/cm ratios to increase workability; however, several of these batches did not meet the desired unit weight and strength. Improving upon the mixtures involved changing one parameter at a time to obtain the final structural and patch mixtures. The first constituents tested for BLACK♦DIAMOND were the two sustainable aggregates. Poraver® Siscorspheres were selected due to an abundant supply and success from previous years. Selection of the second sustainable aggregate began by batching with several trial aggregates including crushed tile, glass highway spheres, plastic shavings, and plastic airsoft pellets. Iterative batches with crushed tile and glass highway spheres yielded unit weights from 62.0 pcf to 70.0 pcf, which did not meet the team's goal. Snowboard shavings, with a specific gravity of 0.95, were more lightweight but produced an unworkable and non-compactable concrete mixture with rebounding behavior. Finally, used airsoft pellets (Figure 3) were crushed to obtain a desirable gradation and were combined with Poraver® Siscorspheres to produce a well-graded mixture meeting ASTM D6913-04 standards. After several iterations, the airsoft pellets produced satisfactory results in terms of workability, unit weight, and strength.



Figure 3: Used Airsoft Pellets.

Once suitable aggregates were established, admixture selection and corresponding dosage rates were determined. Daravair[®], an air-entraining admixture (AEA), was removed from the structural mixture when the team noticed trial concrete batches with airsoft pellets yielded air contents ranging from 12 to 15 percent and unit weights lower than 55.0 pcf, which is the minimum limit set by the competition rules (ASCE/NCCC, 2010). Rhoplex[®], a polymer modifying admixture (PMA), was used to reduce wet curing from 28 to 14 days while increasing adhesion, water resistance, and workability. A viscosity modifying admixture (VMA) and high range water reducer (HRWR) were used to yield a more fluid and cohesive concrete mixture. The team also added Daraset[®], a set accelerating admixture, during trial batching to increase early compressive strength by 450 psi, which was obtained using ASTM C39-10. Admixture dosage rates were increased in small proportions for each trial batch, eventually exceeding recommended dosages (Table 3) to obtain the desired mixture characteristics. The team contacted manufacturers and confirmed that the increased dosages would have no adverse effects on the concrete properties.

Table 3: Admixture Dosage Rates.

Admixture	Type	Manufacturer's Recommended Dosage	Actual Dosage Used
Daraset [®] 400	Accelerator	10 - 60 fl oz / cwt	15 fl oz / cwt
V-MAR [®] F100	VMA	3 - 12 fl oz / cwt	35 fl oz / cwt
Adva [®] Cast 575	HRWR	2 - 10 fl oz / cwt	45 fl oz / cwt
Rhoplex [®] MC-1834P Emulsion	PMA	N/A	75 fl oz / cwt
Daravair [®] AT60	AEA	0.25 - 3 fl oz / cwt	6 fl oz / cwt

To improve flexural strength and ductility of the concrete, the mix design team incorporated two sizes of polyvinyl alcohol (PVA) fibers (6 mm and 12 mm in length). Excessive clumping of the two sizes in **BATTLE BORN** prompted the team to adjust the amount per volume used in the mixture from 0.4 percent to 0.3 percent to promote better dispersion for improved performance. A fiber dispersing powder, GST 1200 GX, facilitated uniform dispersion as well. The mix design team further strengthened the concrete with chemical prestressing by adding Komponent[®] cement additive to create Type K expansive cement (ASTM C845-04). The expansion in the concrete is restrained by the carbon fiber reinforcement, causing the concrete to develop internal compressive stresses to keep the composite in equilibrium. Type K expansive prestressing added an additional 300 psi of multi-directional prestress to the concrete and caused enough expansion to offset a portion of shrinkage cracking experienced during hydration.

The final structural mixture consisted of 50 percent Type I white portland cement, 40 percent VCAS-8[™], and 10 percent Komponent[®] of the 585 pcy cementitious material content. Aggregates included Poraver[®] Siscorspheres ranging in size from 0.1 mm to 2 mm, totaling 74.3 percent by mass, and airsoft pellets amounting to 25.7 percent by mass, producing a mixture with 100 percent recycled aggregate. To effectively fill in the air voids on the surface of the canoe, a patch mixture incorporated glass highway spheres ranging in size from 0.3 mm to 0.8 mm. Airsoft pellets and fibers were no longer included since the purpose of the patch mixture was solely aesthetic and did not need to meet strength requirements. The final structural and patch mixture proportions are shown in Appendix B.

Table 4: Required and Actual Concrete Properties.

Property	Analysis Requirements	Actual Properties
Unit Weight	62.0 pcf (max)	58.8 pcf
Compressive Strength	680 psi (min)	1,700 psi
Modulus of Rupture	300 psi (min)	300 psi
Composite Flexural Strength	1,040 psi (min)	1,200 psi

For quality control and analysis purposes, the team cast four 2" x 4" cylinders of each trial batch to test the compressive strength at 7 days, 14 days, and 28 days (ASTM C39-10). In addition, ASTM C138-10b was used to calculate the unit weights and gravimetric air contents of each batch. Further quality control testing included casting composite and non-composite concrete beams to determine composite flexural strength and modulus of rupture, respectively. Tensile strengths were obtained through third-point bending tests (ASTM C78-10). The final structural mixture and strength requirements of the analysis are shown in Table 4.



Heat forming reduced cuts and breaks caused by the brittle resin compounds coating the carbon fiber reinforcement during placement. The team tested whether heat treating the carbon fiber grid negatively affected its properties. A heat gun was used to make the grid pliable enough to bend over the rounded chines of the form while being careful not to overheat the product and change its manufactured strength properties. To ensure that any detrimental effect from heating the material was negligible, the analysis team tested the carbon fiber grid using ASTM D6637-10. Results (Figure 4) confirmed that the strength loss is negligible; the deformed carbon fiber grid failed at 263 lb while the original carbon fiber grid failed at 260 lb, indicating a strength loss of only 1.14 percent. Therefore, 1.5" x 1.5" carbon fiber grid reinforcement with 82.6 percent open area was selected for use due to its large open area for monolithic concrete casting and suitable flexural strength properties in the composite structure.

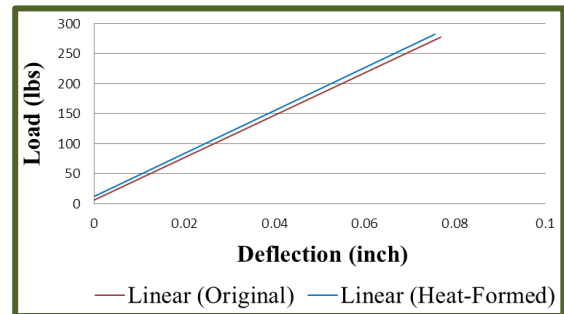


Figure 4: Carbon Fiber Test Results.

Finally, the analysis and mix design engineers discussed the possibility of eliminating structural ribs from the canoe due to construction difficulty and paddler discomfort. The team arbitrarily placed nine transverse prestress tendons spaced at 2' intervals and tensioned to 50 lb each. Due to time constraint in preparation for casting day, the transverse tendons were placed before performing an FEA research, which later indicated a 5 psi reduction in tensile stresses and showed a minor decrease in deflection. Ultimately, elimination of structural ribs seemed unjustifiable because the number of transverse tendons must be increased in order to obtain the desired tensile stress reduction.

◆ PROJECT MANAGEMENT AND CONSTRUCTION ◆

The objectives for project management were to provide a fortified organizational framework, an effective budget appropriation, and a systematic schedule with minimal variances. To achieve these goals, a project manager administered five branches: academics, mix design, construction, paddling, and graphics. Each branch had a lead manager who closely worked with the project manager to maintain the project schedule and certify compliance with 2011 competition regulations (ASCE/NCCC, 2010). Lead managers delegated tasks among team members to effectively appropriate duties and accomplish project tasks. The team was comprised of 25 members, all of whom collaborated closely with division managers to ensure timely progress as shown in the organizational chart on Page 7. In comparison to **BATTLE BORN**, mix design man hours were increased from two to three days per week to experiment with potential aggregates. A total of 6,400 project hours and their respective division contributions are identified in Figure 5.

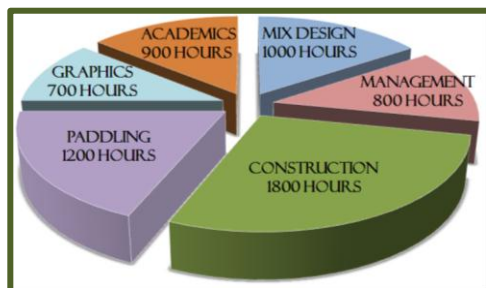


Figure 5: Project Man Hours.

This year's cost analysis excluded perennial materials reused from last year, such as tools and the polyurethane foam mold. A space heater was purchased to maintain a constant temperature during the curing process. Carbon fiber reinforcement, respiration filters, gloves, steel cable, and mix design materials also added to the major expenses. The operational budget for this year's canoe, excluding travel expenses, amounted to \$7,700. The team approached local engineering and non-engineering agencies for monetary and material donations. However, alternative fundraising efforts became necessary due to current economic conditions; these alternative fundraisers included hosting concerts at a local venue, selling promotional t-shirts, and acquiring donations from sales commission at local restaurants, raising approximately \$3,000.

The team determined the 2011 project schedule using **BATTLE BORN** as a baseline. BLACK•DIAMOND's critical path, along with planned and actual dates of completion, is indicated on Page 8. Major milestones included final mixture selection, analysis completion, canoe casting, prestress tendon release, form removal, and canoe completion. Variances of these tasks are presented in Table 5. The project manager notified lead managers three weeks in advance of each task deadline, and weekly team meetings ensured the project schedule stayed on-track. Risk management was implemented by allotting additional time and budget to teach new members appropriate techniques and to account for possible delays. The team discussed proper methods of preparation and safety measures before every task, and the safety lead manager implemented safety standards for each phase of the project and updated Material Safety Data Sheets when necessary.

Table 5: Variances in Major Milestones.

Milestone	Variance	Cause
Final Mix Selection	17 days	Member Inexperience
Canoe Completion	2 days	Delay in Staining



Figure 6: Grade Screw for Depth Control and Tendon

The construction team began the year by assembling the steel work table, made in 2008, and preparing last year's polyurethane foam mold to minimize cost and promote sustainability. The team applied two layers of the mold primer Duratec® and wax to facilitate an easy canoe removal from the form. Reinforcement placement began with securing four threaded rods in the center of each rib location. Grade screws, which doubled as depth control gauges and prestress tendon paths, were drilled into the form (Figure 6). Clear acrylic square

rods were also used as a base for the gunwale and quality control. The team used construction cut sheets, generated by the analysis engineer, to improve tendon placement accuracy. Fourteen longitudinal prestressing tendons were placed on the form, followed by a layer of heat-formed carbon fiber grid on the sidewalls and two layers on the bottom. The team secured nine transverse prestress tendons that were tensioned using compression springs. To complete the reinforcement, steel mesh was used at the bow and stern due to its high malleability.

Monolithic casting of the canoe began by hand-packing concrete through the reinforcement; this technique allowed the team to prestress the canoe, pre-place reinforcement to the required specifications and cast the canoe in a single layer, preventing delamination of the final product. Two experienced mixing teams batched concrete simultaneously and veteran members oversaw the casting process as a quality control measure for a consistent 0.5" thickness. Vibrating trowels, a Nevada innovation, were used to improve consolidation of the concrete. After casting, the canoe was covered with wet sheets and wrapped in Visquine.



Figure 7: Exposed Reinforcement.

Finishing began with iterations of sanding and patching after seven days of curing. Fourteen days after the original casting day, longitudinal and transverse tendons were released and cut, and concrete was cast over the exposed tendon ends. However, the team noticed a transverse crack 6" from the stern of the canoe. After tendon release, the crack propagated into the chine while another crack became evident near the bow. The team investigated possible reasons for the cracking, concluding that either: (1) the wood support underneath the bulkhead at the bow and the stern adhered to the concrete causing tensile stresses; (2) forces were not evenly applied to all sides during form removal; or (3) the parabolic shape of the tendon paths generated stresses at the ends. The team's managers decided to remove the concrete around the crack, exposing the steel mesh reinforcement (Figure 7), and then cast a larger bulkhead to support the area.

Next, the team built a slotted wooden frame to simultaneously place five manufactured plastic cross-sectional templates at 1' intervals over the canoe to administer an average depth control, as discussed in the *Innovation and Sustainability* section. Finally, the team placed a stencil illustrating the winter

Sierras onto the canoe and applied two layers of stain and sealer per the manufacturer's recommendation to finish BLACK♦DIAMOND.

♦ INNOVATION AND SUSTAINABILITY ♦

The 2011 Nevada Concrete Canoe Team focused on developing innovative techniques to optimize work hours for an improved final product and continue to build upon sustainable practices established in previous years. New and efficient techniques were used by the structural analysis, construction and mix design divisions.

Nevada developed an innovative structural analysis spreadsheet to simplify the structural design of **BATTLE BORN** and future Nevada canoes. Using a simple user-interface, the spreadsheet calculates section properties of the canoe at each user-specified cross section, as well as the displaced water line for each user-defined load case. Innovative features include the first known use of a calculated pitching angle in determining the displaced water line. Previous canoe modeling techniques incorporated artificial restraints at the bow and stern to satisfy model equilibrium, resulting in residual shear at the ends of the canoe. Under most loading scenarios, a net pitching moment develops due to the fact that the line of action of the applied loads (paddlers and canoe self-weight) is not coincident with the buoyant force. The line of action of the buoyant load can be changed by permitting the canoe to rotate about the transverse axis. The spreadsheet calculates the pitching angle necessary to bring all external loads coincident with each other, thereby eliminating residual shear and providing more accurate design forces. Once the forces are known, the spreadsheet simplifies the design of the longitudinal prestressing system, and generates construction cut sheets that enables the team to accurately transfer the longitudinal tendon paths onto the canoe form. The use of the cut-sheets reduced a total of 50 construction man hours.

Optimization of construction techniques also became a focal point for innovation. The team constructed a slotted wooden frame, capable of holding five cross-sectional templates (made in 2009 for **FUSION**) as part of canoe casting preparation. In previous years, concrete was often packed in excess on casting day, causing material waste and requiring additional sanding to the desired hull thickness. As a quality assurance measure, the slotted wooden frame was constructed to hold cross-sectional templates with a 0.5" offset from the foam mold. With the new frame, the team cast BLACK♦DIAMOND more uniformly, thus decreasing waste by 15 lb and construction work by 40 hours when sanding to the appropriate canoe dimensions (Figure 8).

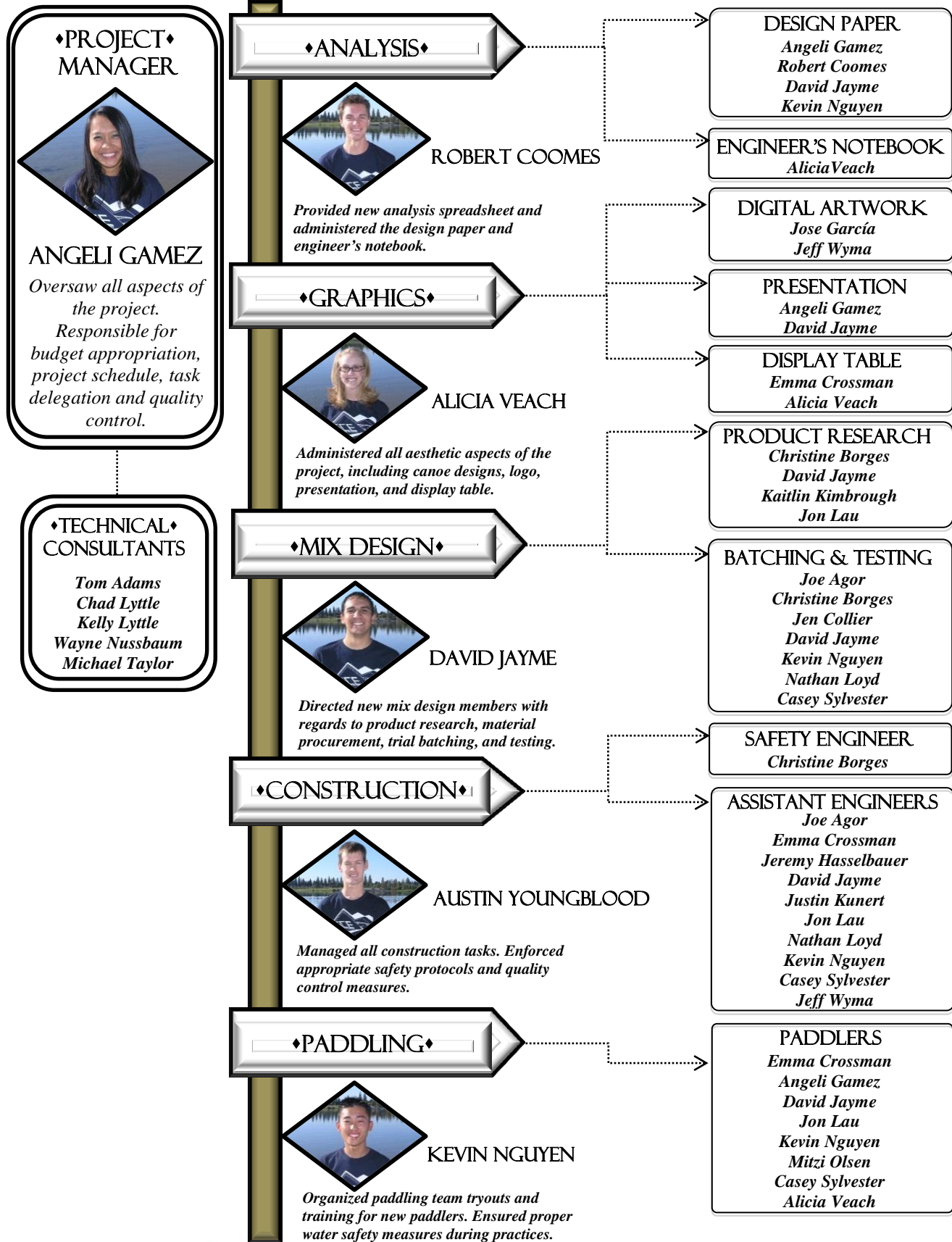


Figure 8: Slotted Wooden

Sustainable mix design measures included the reduction of portland cement, addition of a PMA, and conservation of concrete trial batches. The use of VCAS-8™, a white pozzolan, reduced the amount of portland cement required in the concrete mixture thereby decreasing net greenhouse gas emission and energy consumption; the heat saved during manufacturing is 4.26 million BTU's/ton, which could heat an average home for more than a week (Vitro Minerals, 2005). Rhoplex®, a PMA, reduced wet curing by 50 percent, reducing water consumption by 40 gal, an important practice for the driest state in the nation. A final sustainable practice was to retain trial batches from BLACK♦DIAMOND, totaling 190 lb of concrete as a potential aggregate for next year. Continuing these processes each year will promote the longevity of generating a sustainable project.

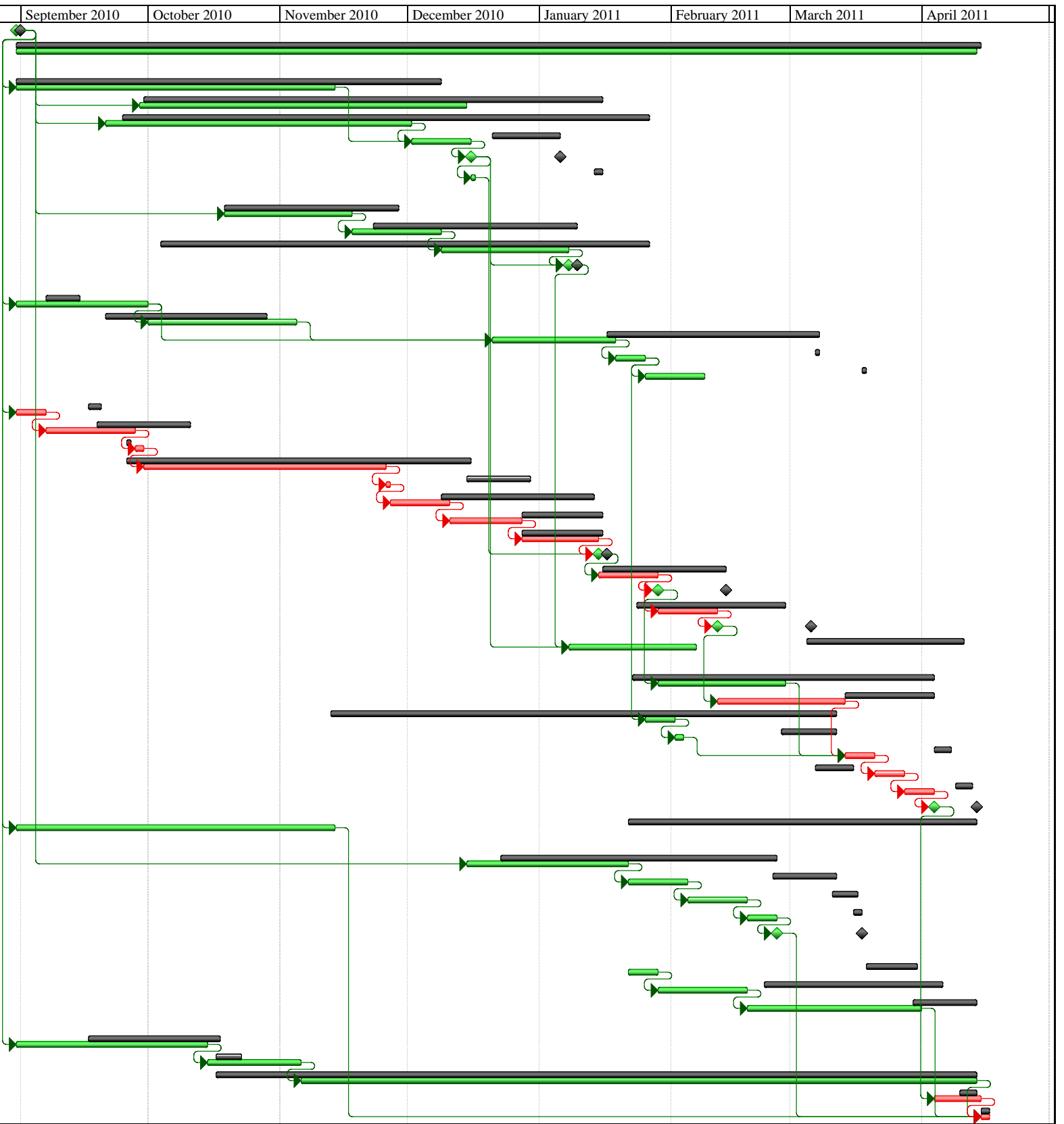
New innovative tools created this year, including the structural analysis spreadsheet, construction cut sheets, and slotted wooden frame, will help future Nevada teams considerably to decrease man hours and the need for new materials. This approach combines sustainable measures developed in previous years with the innovative and environmentally friendly techniques used in BLACK♦DIAMOND – making it the most innovative and sustainable concrete canoe in Nevada's history.

♦ORGANIZATION CHART♦



♦PROJECT SCHEDULE♦

ID	Task Name	Duration	Start	Finish	Baseline Start	Baseline Finish	August 2010	September 2010	October 2010	November 2010	December 2010	January 2011	February 2011	March 2011	April 2011
1	First Meeting and Start	0 days	Tue 8/31/10	Tue 8/31/10	Tue 8/31/10	Tue 8/31/10									
2	Fundraising	226 days	Tue 8/31/10	Thu 4/14/11	Tue 8/31/10	Thu 4/14/11									
3	Concrete Mix Design	108 days	Tue 8/31/10	Fri 12/17/10	Tue 8/31/10	Sat 1/15/11									
4	Research	75 days	Tue 8/31/10	Sun 11/14/10	Tue 8/31/10	Wed 12/8/10									
5	Material Procurement	77 days	Wed 9/29/10	Wed 12/15/10	Thu 9/30/10	Sat 1/15/11									
6	Preliminary Design and Testing	72 days	Tue 9/21/10	Thu 12/2/10	Sat 9/25/10	Wed 1/26/11									
7	Mix Design Refinement	14 days	Thu 12/2/10	Thu 12/16/10	Tue 12/21/10	Wed 1/5/11									
8	Final Mix Selection	0 days	Thu 12/16/10	Thu 12/16/10	Tue 12/21/10	Wed 1/5/11									
9	Pre-Weigh Materials	1 day	Thu 12/16/10	Fri 12/17/10	Fri 1/14/11	Sat 1/15/11									
10	Structural Analysis	81 days	Tue 10/19/10	Sat 1/8/11	Mon 10/4/10	Sun 1/9/11									
11	Longitudinal Tendon Analysis	30 days	Tue 10/19/10	Thu 11/18/10	Tue 10/19/10	Sun 11/28/10									
12	Transverse Tendon Analysis	21 days	Thu 11/18/10	Thu 12/9/10	Tue 11/23/10	Sun 1/9/11									
13	Composite Analysis and Design	30 days	Thu 12/9/10	Sat 1/8/11	Mon 10/4/10	Wed 1/26/11									
14	Analysis Complete	0 days	Sat 1/8/11	Sat 1/8/11	Sun 1/9/11	Sun 1/9/11									
15	Graphic Desgin	162 days	Tue 8/31/10	Wed 2/9/11	Tue 9/7/10	Fri 3/18/11									
16	Theme Brainstorming and Selection	31 days	Tue 8/31/10	Fri 10/1/10	Tue 9/7/10	Tue 9/14/10									
17	Canoe Name Selection	35 days	Fri 10/1/10	Fri 11/5/10	Tue 9/21/10	Thu 10/28/10									
18	Design Sketching	29 days	Tue 12/21/10	Wed 1/19/11	Mon 1/17/11	Mon 3/7/11									
19	Final Graphic Design Selection	7 days	Wed 1/19/11	Wed 1/26/11	Mon 3/7/11	Mon 3/7/11									
20	Submit Stencil Design	14 days	Wed 1/26/11	Wed 2/9/11	Fri 3/18/11	Fri 3/18/11									
21	Construction	165 days	Tue 8/31/10	Sat 2/12/11	Fri 9/17/10	Sun 4/10/11									
22	New Location Move	7 days	Tue 8/31/10	Tue 9/7/10	Fri 9/17/10	Sun 9/19/10									
23	New Location Organization	21 days	Tue 9/7/10	Tue 9/28/10	Sun 9/19/10	Sun 10/10/10									
24	Form Table Construction	2 days	Tue 9/28/10	Thu 9/30/10	Sun 9/26/10	Sun 9/26/10									
25	Form Preparation	57 days	Tue 9/30/10	Fri 11/26/10	Sun 9/26/10	Wed 12/15/10									
26	Grade Screw Installation	1 day	Fri 11/26/10	Sat 11/27/10	Wed 12/15/10	Wed 12/29/10									
27	Tendon Application	14 days	Sat 11/27/10	Sat 12/11/10	Thu 12/9/10	Thu 1/13/11									
28	Tie Reinforcement	17 days	Sat 12/11/10	Tue 12/28/10	Tue 12/28/10	Sat 1/15/11									
29	Christmas Break	18 days	Tue 12/28/10	Sat 1/15/11	Tue 12/28/10	Sat 1/15/11									
30	Canoe Casting Day	0 days	Sat 1/15/11	Sat 1/15/11	Sun 1/16/11	Sun 1/16/11									
31	Initial Concrete Curing	14 days	Sat 1/15/11	Sat 1/29/11	Sun 1/16/11	Sun 2/13/11									
32	Prestress Tendon Release	0 days	Sat 1/29/11	Sat 1/29/11	Sun 2/13/11	Sun 2/13/11									
33	Grade Screw Removal	14 days	Sat 1/29/11	Sat 2/12/11	Mon 1/24/11	Sun 2/27/11									
34	Form Removal	0 days	Sat 2/12/11	Sat 2/12/11	Sat 3/5/11	Sat 3/5/11									
35	Cross-Section Construction	30 days	Sat 1/8/11	Mon 2/7/11	Sat 3/5/11	Sun 4/10/11									
36	Finishing	68 days	Wed 1/26/11	Mon 4/4/11	Sat 11/13/10	Wed 4/13/11									
37	Patching/Sanding Exterior	30 days	Sat 1/29/11	Mon 2/28/11	Sun 1/23/11	Sun 4/3/11									
38	Patching/Sanding Interior	30 days	Sat 2/12/11	Mon 3/14/11	Mon 3/14/11	Sun 4/3/11									
39	Stain Research	7 days	Wed 1/26/11	Wed 2/2/11	Sat 11/13/10	Fri 3/11/11									
40	Stain Selection	2 days	Wed 2/2/11	Fri 2/4/11	Sun 2/27/11	Fri 3/11/11									
41	Staining	7 days	Mon 3/14/11	Mon 3/21/11	Mon 3/21/11	Thu 4/7/11									
42	Sealer Selection	7 days	Mon 3/21/11	Mon 3/28/11	Mon 3/7/11	Tue 3/15/11									
43	Sealing	7 days	Mon 3/28/11	Mon 4/4/11	Sat 4/9/11	Tue 4/12/11									
44	Canoe Finished	0 days	Mon 4/4/11	Mon 4/4/11	Wed 4/13/11	Wed 4/13/11									
45	Display Table	75 days	Tue 8/31/10	Sun 11/14/10	Sat 1/22/11	Wed 4/13/11									
46	Desgin Report	73 days	Wed 12/15/10	Sat 2/26/11	Thu 12/23/10	Thu 3/17/11									
47	Compose Rough Draft	38 days	Wed 12/15/10	Sat 1/22/11	Thu 12/23/10	Fri 2/25/11									
48	Peer/Professional Editing	14 days	Sat 1/22/11	Sat 2/5/11	Fri 2/25/11	Fri 3/11/11									
49	Final Revisions and Review	14 days	Sat 2/5/11	Sat 2/19/11	Fri 3/11/11	Wed 3/16/11									
50	Printing and Binding	7 days	Sat 2/19/11	Sat 2/26/11	Wed 3/16/11	Thu 3/17/11									
51	Design Report Finished	0 days	Sat 2/26/11	Sat 2/26/11	Thu 3/17/11	Thu 3/17/11									
52	Oral Presentation	69 days	Sat 1/22/11	Fri 4/1/11	Wed 2/23/11	Wed 4/13/11									
53	Compose Verbal Presentation	7 days	Sat 1/22/11	Sat 1/29/11	Sat 3/19/11	Wed 3/30/11									
54	Compose Visual Presentation	21 days	Sat 1/29/11	Sat 2/19/11	Wed 2/23/11	Tue 4/5/11									
55	Practice and Critique	41 days	Sat 2/19/11	Fri 4/1/11	Wed 3/30/11	Wed 4/13/11									
56	Paddling	226 days	Tue 8/31/10	Thu 4/14/11	Fri 9/17/10	Wed 4/13/11									
57	Tryouts	45 days	Tue 8/31/10	Fri 10/15/10	Fri 9/17/10	Sun 10/17/10									
58	Team Selection	22 days	Fri 10/15/10	Sat 11/6/10	Sun 10/17/10	Fri 10/22/10									
59	Paddling Practice and Conditioning	159 days	Sat 11/6/10	Thu 4/14/11	Sun 10/17/10	Wed 4/13/11									
60	Mid-Pac Preparation	11 days	Mon 4/4/11	Fri 4/15/11	Sun 4/10/11	Wed 4/13/11									
61	Mid-Pacific Conference	2 days	Fri 4/15/11	Sun 4/17/11	Fri 4/15/11	Sat 4/16/11									

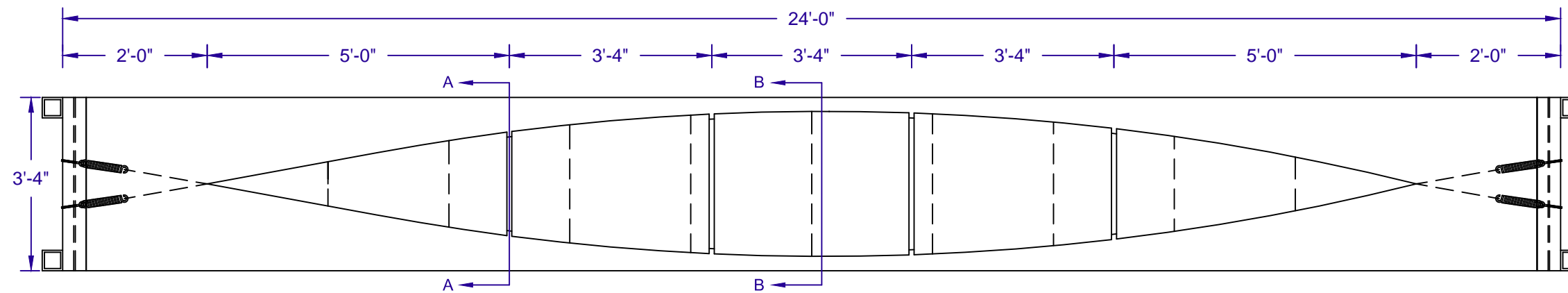


Critical Task — Planned Task — Actual Task — Planned Milestone ◆ Actual Milestone ◆

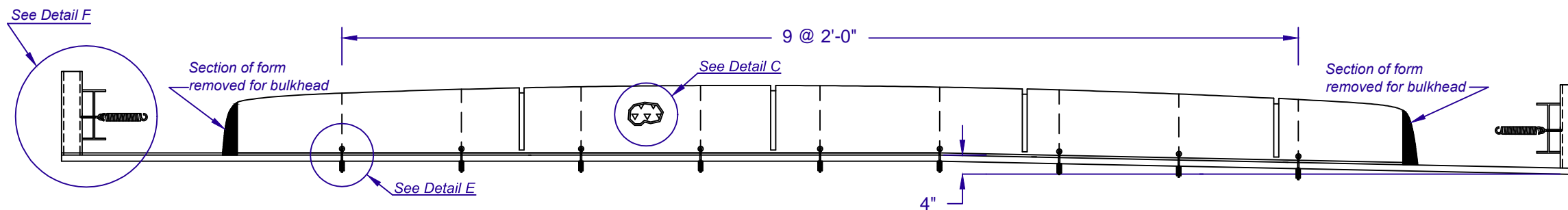




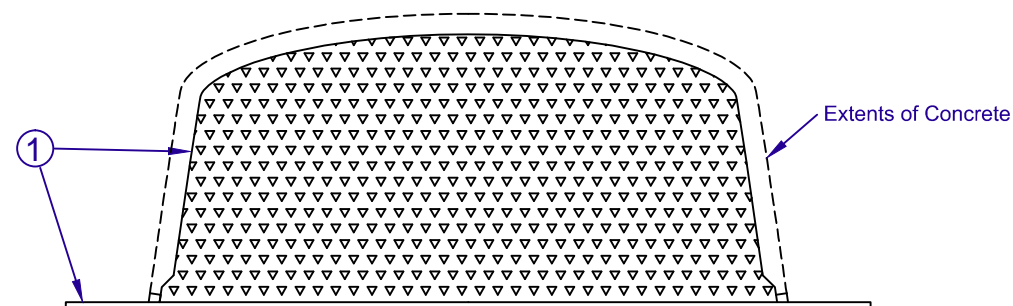
University of Nevada, Reno
Concrete Canoe



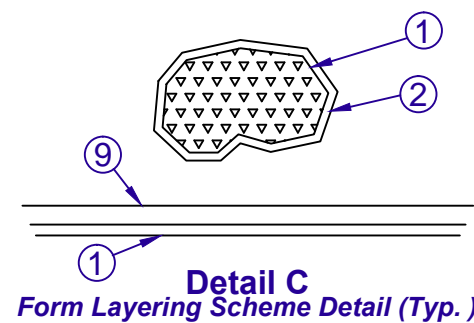
Plan View



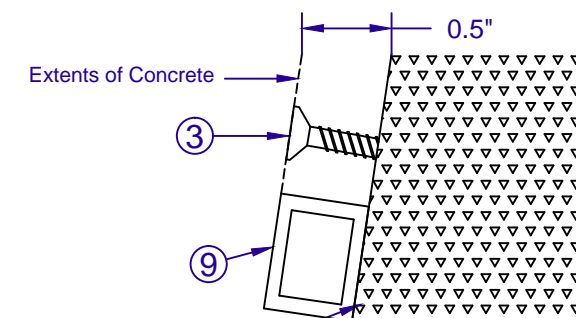
Elevation View



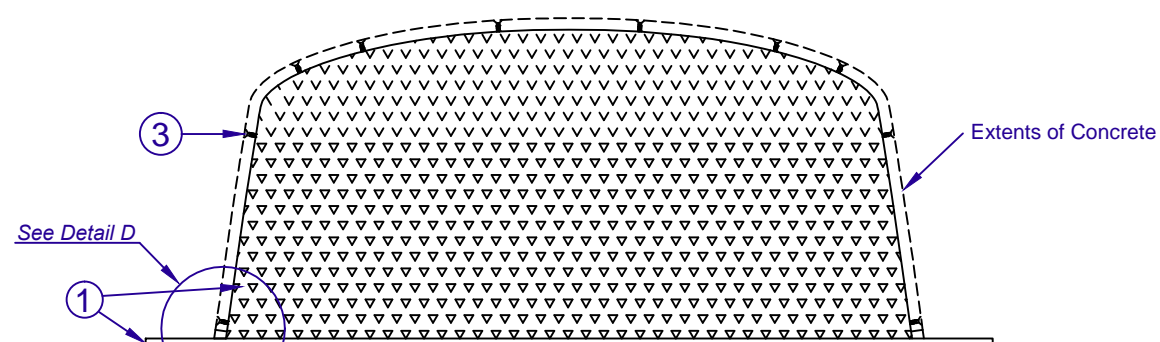
Section A-A (Contains a Rib)
21.6125" (extents of form)



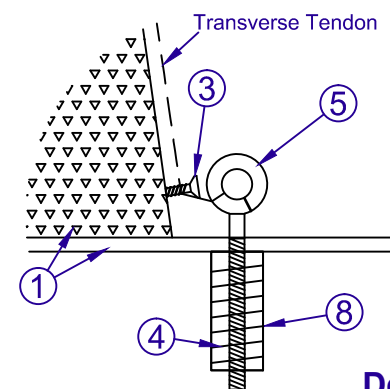
Detail C
Form Layering Scheme Detail (Typ.)



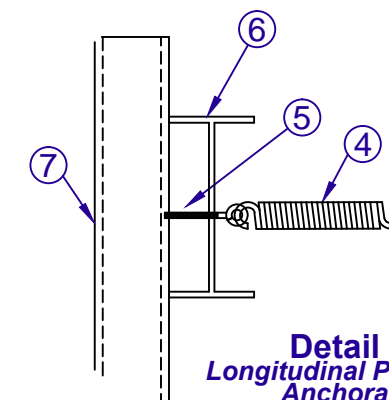
Detail D
Table Edge Detail (Typ.)



Section B-B (Widest Section)
30.1875" (extents of form)



Detail E
Transverse Prestress Anchorage



Detail F
Longitudinal Prestress Anchorage

Bill of Materials

Part	Qty	Description
①	160 cu. ft.	Expanded Polyurethane
②	2 gal.	Duratec® (Surface Treatment)
③	267 ct.	Grade Screws ($\frac{1}{2}$ " protruding into concrete)
④	23 ct.	Steel Spring ($7\frac{5}{8}$ " long, $1\frac{1}{8}$ " dia., $k=300$ lb/in)
⑤	46 ct.	Eye Bolts/Nuts (3" long, $\frac{3}{8}$ " dia.)
⑥	2 ct.	W 12 X 22
⑦	4 ct.	HSS $3\frac{1}{2}$ " X $3\frac{1}{2}$ " X $\frac{3}{8}$ "
⑧	9 ct.	PVC Pipe (4" long, 1" dia.)
⑨	7 ct.	Acrylic Square Rod ($\frac{1}{2}$ " X $\frac{1}{2}$ " X 6')

BLACK DIAMOND
Form Design Drawing

- General Notes:
 1. Drawings not to scale
 2. Only two longitudinal prestress anchorages are shown for clarity
 3. Total Longitudinal Prestressing Force: $P_{jack}=3.5$ kips
 4. Total Transverse Prestressing Force: $P_{jack}=450$ lb

Date: 3/7/2010

Engineer: JAYME

Drawn By: HASSELBAUER

SHEET

9

OF

9

APPENDIX A ♦ REFERENCES

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APPENDIX B ♦ MIXTURE PROPORTIONS
 ♦ STRUCTURAL MIXTURE ♦
 2011 CONCRETE CANOE MIX DESIGN

Mixture ID: BLACK♦DIAMOND Structural Mix					Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions		
Y _D	Design Batch Size (ft ³):				0.15						
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 White Portland Cement				3.15	294.97	1.501	1.64	0.008	292.40	1.488
CM2	VCAS-8™				2.60	235.98	1.455	1.31	0.008	233.93	1.442
CM3	Komponent®				3.10	58.99	0.305	0.33	0.002	58.48	0.302
Total Cementitious Materials:						589.94	3.260	3.28	0.018	584.81	3.232
Fibers											
F1	Nycon® PVA Fibers (6 mm)				1.30	6.74	0.083	0.04	0.000	6.68	0.082
F2	Nycon® PVA Fibers (12 mm)				1.30	6.74	0.083	0.04	0.000	6.68	0.082
Total Fibers:						13.48	0.166	0.07	0.001	13.36	0.165
Aggregates											
A1	Poraver® Siscorspheres 0.1-0.3 mm	Abs:	4%	0.90	47.87	0.852	0.27	0.005	47.45	0.845	
A2	Poraver® Siscorspheres 0.25-0.5 mm	Abs:	4%	0.75	167.55	3.580	0.93	0.020	166.09	3.549	
A3	AirSoft Pellets #8 Retained	Abs:	0%	1.77	181.85	1.646	1.01	0.009	180.27	1.632	
A4	Poraver® Siscorspheres 1-2 mm	Abs:	4%	0.44	301.90	10.996	1.68	0.061	299.27	10.900	
Total Aggregates:						699.17	17.075	3.88	0.095	693.09	16.926
Water											
W1	Water for CM Hydration (W1a + W1b)				1.00	259.57	4.160	1.44	0.023	257.32	4.124
	W1a. Water from Admixtures					44.45		0.25		44.06	
	W1b. Additional Water					215.13		1.20		213.25	
W2	Water for Aggregates, SSD				1.00	20.69		0.11		20.51	
Total Water (W1 + W2):						280.27	4.160	1.56	0.023	277.83	4.124
Solids Content of Latex Admixtures, Dyes, & Solid Admixtures											
S1	Rhoplex® MC-1834P Emulsion (PMA)				1.12	14.33	0.204	0.08	0.001	14.20	0.202
S2	GST 1200 GX				0.33	3.81	0.185	0.02	0.001	3.77	0.183
Total Solids of Admixtures:						18.13	0.389	0.10	0.002	17.98	0.386
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	Rhoplex® MC-1834P Emulsion (PMA)				8.8 lb/gal	47.10	75.00	16.092	2.46	0.089	74.3
Ad2	GST 1200 GX				2.8 lb/gal	100.00	30.00	0.000	0.98	0.000	29.7
Ad3	ADVA® CAST 575 (HRWR)				8.9 lb/gal	40.00	45.00	11.075	1.47	0.062	44.6
Ad4	Daraset® 400 (Accelerator)				11.5 lb/gal	47.10	15.00	4.206	0.49	0.023	14.9
Ad5	V-MAR® F100 (VMA)				8.4 lb/gal	3.50	35.00	13.076	1.15	0.073	34.7
Water from Admixtures (W1a):							44.448		0.247		44.06
Cement-Cementitious Materials Ratio						0.500		0.500		0.500	
Water-Cementitious Materials Ratio						0.440		0.440		0.440	
Slump, Slump Flow, in.						0 +/- 0.25 in.		0 +/- 0.25 in.		0 +/- 0.25 in.	
M	Mass of Concrete, lbs					1600.99		8.89		1587.06	
V	Absolute Volume of Concrete, ft ³					25.050		0.139		24.832	
T	Theoretical Density, lb/ft ³ = (M / V)					63.91		63.91		63.91	
D	Design Density, lb/ft ³ = (M / 27)					59.30					
D	Measured Density, lb/ft ³							58.780		58.780	
A	Air Content, % = [(T - D) / T x 100%]					7.22		8.03		8.03	
Y	Yield, ft ³ = (M / D)					27		0.151		27	
Ry	Relative Yield = (Y / Y _D)							1.009			



♦PATCH MIXTURE♦
2011 CONCRETE CANOE MIX DESIGN

Mixture ID: BLACK♦DIAMOND Patch Mix				Design Proportions		Actual Batched		Yielded Proportions				
Y _D	Design Batch Size (ft ³):			(Non SSD)		Proportions						
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 White Portland Cement			3.15	294.97	1.501	1.64	0.008	262.54	1.336		
CM2	VCAS-8™			2.60	235.98	1.455	1.31	0.008	210.03	1.295		
CM3	Komponent®			3.10	58.99	0.305	0.33	0.002	52.50	0.271		
Total Cementitious Materials:					589.94	3.260	3.28	0.018	525.07	2.902		
Aggregates												
A1	Highway Spheres	Abs:	0%	1.95	203.07	1.669	1.13	0.009	180.74	1.485		
A2	Poraver® Siscorspheres 0.25-0.5 mm	Abs:	4%	0.75	234.33	5.007	1.30	0.028	208.56	4.456		
A3	Poraver® Siscorspheres 0.5-1.0 mm	Abs:	4%	0.56	349.92	10.014	1.94	0.056	311.44	8.913		
Total Aggregates:					787.32	16.690	4.37	0.093	700.75	14.854		
Water												
W1	Water for CM Hydration (W1a + W1b)				259.57	4.160	1.44	0.023	231.03	3.702		
	W1a. Water from Admixtures			1.00	42.50		0.24		37.83			
	W1b. Additional Water				217.07		1.21		193.20			
W2	Water for Aggregates, SSD			1.00	23.37		0.13		20.80			
Total Water (W1 + W2):					282.94	4.160	1.57	0.023	251.83	3.702		
Solids Content of Latex Admixtures, Dyes, & Solid Admixtures												
S1	Rhoplex® MC-1834P Emulsion (PMA)			1.12	14.33	0.204	0.08	0.001	12.75	0.182		
Total Solids of Admixtures:					14.33	0.204	0.08	0.001	12.75	0.182		
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	Rhoplex® MC-1834P Emulsion (PMA)			8.8	lb/gal	47.10	75.00	16.09	2.46	0.09	66.8	14.32
Ad2	ADVA® CAST 575 (HRWR)			8.9	lb/gal	40.00	45.00	11.08	1.47	0.06	40.1	9.86
Ad3	Daravair® AT60 (AEA)			8.6	lb/gal	5.00	6.00	2.26	0.20	0.01	5.3	2.01
Ad4	V-MAR® F100 (VMA)			8.4	lb/gal	3.50	35.00	13.08	1.15	0.07	31.2	11.64
Water from Admixtures (W1a):						42.50		0.24		37.83		
Cement-Cementitious Materials Ratio						0.500		0.500		0.500		
Water-Cementitious Materials Ratio						0.440		0.440		0.440		
Slump, Slump Flow, in.						0.00 +/- 0.25 in.		0.00 +/- 0.25 in.		0.00 +/- 0.25 in.		
M	Mass of Concrete, lbs				1674.53		9.30		1490.40			
V	Absolute Volume of Concrete, ft ³				24.31		0.135		21.64			
T	Theoretical Density, lb/ft ³ = (M / V)				68.87		68.87		68.87			
D	Design Density, lb/ft ³ = (M / 27)				62.02							
D	Measured Density, lb/ft ³						55.200		55.200			
A	Air Content, % = [(T - D) / T x 100%]				9.95		19.85		19.85			
Y	Yield, ft ³ = (M / D)				27		0.169		27			
Ry	Relative Yield = (Y / Y _D)						1.124					

APPENDIX C ♦ BILL OF MATERIALS

MATERIAL	QUANTITY	UNIT COST	TOTAL PRICE
Type I White Portland Cement	47.4 lb	\$0.21/lb	\$9.96
Komponent [®]	9.48 lb	\$0.24/lb	\$2.28
VCAS-8 [™]	37.9 lb	\$0.17/lb	\$6.45
Poraver [®] Siscorspheres (0.1-0.3 mm)	6.90 lb	\$1.12/lb	\$7.73
Poraver [®] Siscorspheres (0.25-0.5 mm)	28.0 lb	\$1.02/lb	\$28.54
Poraver [®] Siscorspheres (0.5-1 mm)	5.70 lb	\$0.98/lb	\$5.59
Poraver [®] Siscorspheres (1-2 mm)	43.5 lb	\$0.96/lb	\$41.79
Airsoft Pellets (2.36 mm)	25.8 lb	\$15.2/lb	\$391.81
Highway Spheres	3.31 lb	\$4.08/lb	\$13.50
Daravair [®] AT60 (AEA)	0.002 lb	\$0.07/fl. oz.	\$0.01
Daraset [®] 400 (Accelerator)	0.18 fl. oz.	\$0.05/fl. oz.	\$0.01
V-MAR [®] F100 (VMA)	0.77 fl. oz.	\$0.12/fl. oz.	\$0.09
Adva [®] Cast 575 (HRWR)	1.34 fl. oz.	\$0.09/fl. oz.	\$0.12
Rhoplex [®] MC-1834P Emulsion (PMA)	3.68 lb	\$1.75/lb	\$6.45
GST 1200 GX Fiber Dispenser	0.54 lb	\$9.98/lb	\$5.43
Nycon [®] PVA Fibers (6mm)	0.97 lb	\$1.31	\$1.28
Nycon [®] PVA Fibers (12mm)	0.97 lb	\$1.28	\$1.25
Carbon Fiber Grid Reinforcement (1.5" x 1.5")	22 sq. ft.	\$13.5/sq. ft.	\$297
Welded Wire Mesh	5 sq. ft.	\$0.64/sq. ft.	\$3.20
Steel Cable	436 ft	\$0.15/ft	\$65.4
Tension Spring	14 units	\$15.0/unit	\$210
Compression Spring	9 units	\$12.2/unit	\$110
Polyurethane Foam Mold	2.5 cu. ft.	\$97.6/cu. ft.	\$244
Clear Acrylic Square Rod (0.5" x 0.5")	40 ft	\$0.98/ft	\$39.2
Foam Mold, complete	Lump sum	\$1,563	\$1,563
Vinyl Lettering	Lump sum	\$61.5	\$61.5
Design Stencil	Lump sum	\$544	\$544
Acid Stain	Lump sum	\$189	\$189
Sealer	96 fl. oz.	\$0.39/fl. oz.	\$37.4
Canoe Finishing, complete	Lump sum	\$917	\$917
TOTAL PRODUCTION COST			\$3,886