5-2014

USU Concrete Canoe, Promontory

Nathaniel Laurence Decker
Utah State University

USU CONCRETE CANOE, PROMONTORY

by

Nathaniel Laurence Decker

Thesis submitted in partial fulfillment
of the requirements for the degree

of

HONORS IN UNIVERSITY STUDIES
WITH DEPARTMENTAL HONORS

in

Civil Engineering
in the Department of Civil and Environmental Engineering

Approved:

Thesis/Project Advisor
Paul Barr, Ph.D., P.E.

Departmental Honors Advisor
Dean Adams, Associate Dean

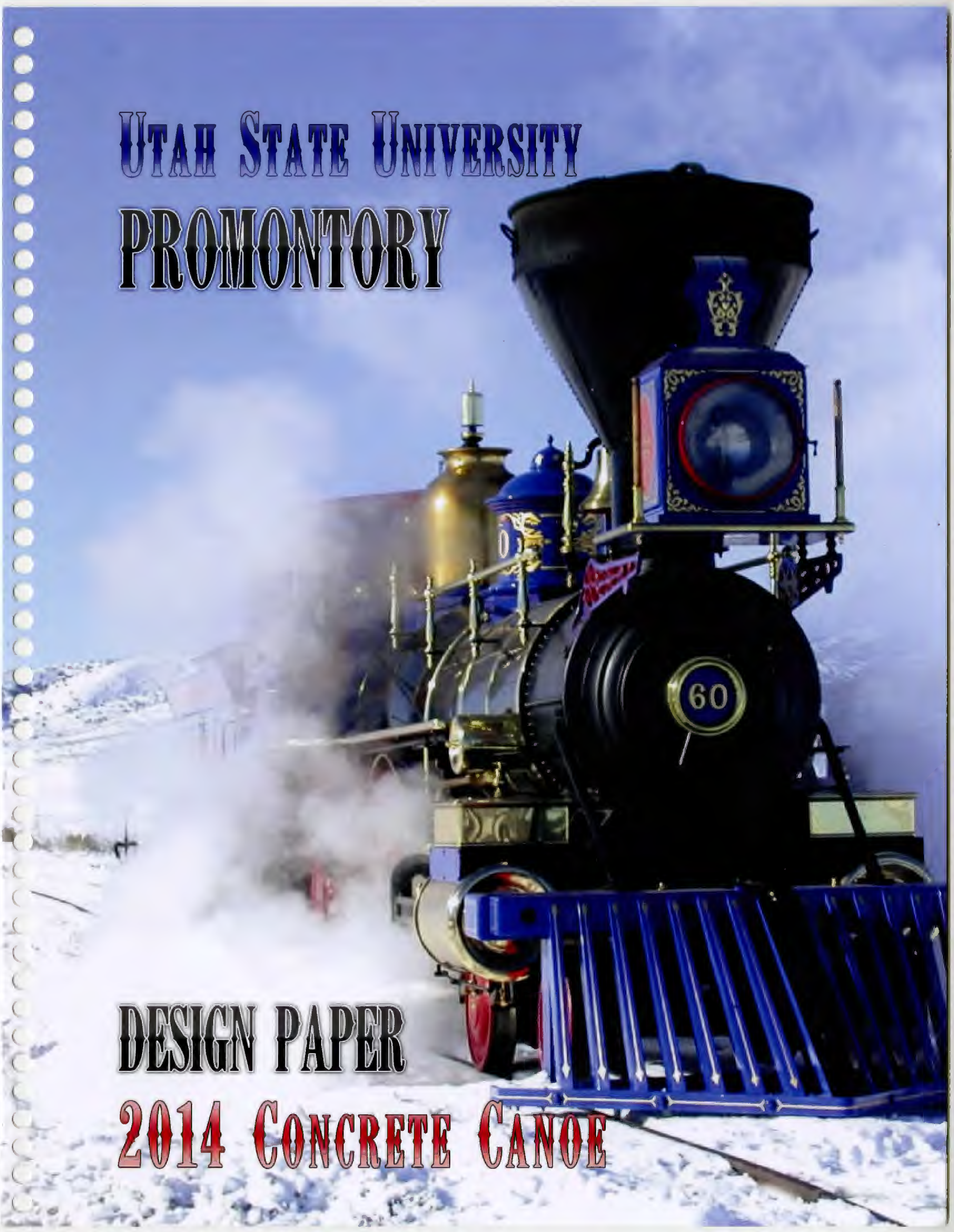
Director of Honors Program
Nicholas Morrison, D.M.

UTAH STATE UNIVERSITY
Logan, UT

Spring 2014

Utah State University

PROMONTORY



DESIGN PAPER

2014 Concrete Canoe

TABLE OF CONTENTS

SECTIONS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

EXECUTIVE SUMMARY

In 1863, while the Civil War was dividing the East, a monumental project began in the West. Plans had been finalized for a railroad that would unify the country in commerce and migration. Two companies accepted the challenge of laying track across over 1700 miles of North American soil, from Sacramento, California to Omaha, Nebraska. The Union Pacific Railroad would come from the East and the Central Pacific Railroad from the West. Governor Leland Stanford of California broke ground for the project on January 8, 1863, and the line was finished at Promontory Summit, UT on May 10, 1869 (NPS, 2013). The 2014 Utah State University (USU) Concrete Canoe Team has honored the engineers and laborers involved in this project by basing this year's canoe, *Promontory*, on this historic achievement of the 19th century.

The Agricultural College of Utah was founded March 8, 1888 in Logan, UT, but was later renamed Utah State University in 1957 (USU, 2010a). Over the past 126 years, USU has changed from a small agricultural college in a remote valley, to a renowned university that offers undergraduate degrees in 168 programs, and graduate degrees in 143. With enrollment of over 27,000, it is the third largest university in Utah (USU, 2010b).

USU's Concrete Canoe Team is a veteran competitor in the Concrete Canoe Competition, competing in the Rocky Mountain Student Conference since the 1980's. In 2011, the team placed first in the conference competition, and appeared at the National Concrete Canoe Competition (NCCC) for the first time, placing 16th with *Tribute*. A second conference win in 2012 led to an 18th place NCCC finish with *Old Ephraim*. For the third straight year, the USU team placed first at the conference competition in 2013 and returned to the NCCC with *Canoebis*, obtaining 5th place and becoming the first university from Utah to place in the top five at the national level. *Canoebis* and *Old Ephraim* were among the lightest canoes at the competition weighing 124 lbs and 108 lbs, respectively.

The team set high expectations this year with new ideas regarding leadership, design, and construction. The team captain was chosen by the team's faculty advisor and the captain from 2013. This was done as an effort to carry over experience and leadership to the new team. Additionally, the design team used 3D printing for the first time to model potential hull designs, improving the hull design by simplifying the modeling process. Since the potential hulls varied greatly, a quantitative design analysis approach was needed for comparison. Turning and drag tests were performed on the models in a hydraulics lab and a hull design was chosen for *Promontory*. Table 1 summarizes *Promontory's* specifications.

Table 1: *Promontory's* Specifications

Design Specifications	
Canoe Name	*Promontory*
Estimated Weight	225 lbs
Length	19'-6"
Max. Width	2'-2"
Hull Thickness	0.375"
Concrete Color	Light Gray
Stain Color	White, Black, Brown, Green
Reinforcement and Composite Details	
Passive Reinforcement	Fiberglass Mesh
Active Reinforcement	Pre-stressed 1/16" steel cable

When planning the construction phase of *Promontory*, the design team saw that new techniques and materials were required to build an intricate inlay and gunwale. To create detailed molds, Sugru® substitute (a type of modeling clay) was used to replicate actual items. The team developed a new finishing mix that could match the high level of detail found in the complex inlay, and would protect the underlying structural mix (See Table 2 for concrete properties).

Table 2: *Promontory's* Concrete Properties

Concrete Mix:	Structural Mix (21-day):	Finishing Mix (21-day):
Unit Weight (Wet)	55.434 pcf	97.442 pcf
Unit Weight (Dry)	50.635 pcf	70.014 pcf
Tensile Strength	160 psi	660 psi
Compressive Strength	1270 psi	2390 psi
Composite Flexural Strength	975 psi @ 14 days	

To honor the unparalleled engineering feat of the Transcontinental Railroad, the USU Concrete Canoe Team has combined precision and ingenuity to create the best canoe produced by Utah State, *Promontory*.

PROJECT MANAGEMENT

At the end of the 2012-13 school year, the 2014 team captain was selected. The faculty advisor met with the 2013 captain and discussed the credentials, leadership ability, and dedication of the applicants, then picked the new captain for 2013-14. The new captain then selected three co-captains from the pool of applicants to oversee hull design, aesthetics, and the concrete mix design. This new selection process ensures that captains are experienced, dedicated, and driven to succeed.

The four captains met in early September to set goals and create the project schedule. To establish the critical path, the captains determined the tasks that needed to be completed on time in order for no delays in the project schedule. The captains included slack between critical path activities to prepare for unforeseen setbacks. The critical path is in gold on the project schedule (Pg. 9). The project manager used milestones to monitor progress and adjust the project schedule as needed (see Table 3). The captains met weekly to prepare for upcoming milestones and resolve delays.

Table 3: Key Milestones

Milestone	Delay	Reason
Mold Completion	None	Proper Scheduling
Cast Fiberglass Canoe	None	Proper Scheduling
Final Mix Selection	1 week	Additional Testing
Final Casting	None	Proper Scheduling

The project was held to a strict construction schedule due to the amount of time that would be spent on form preparation and post-cast work. The team replaced meeting times with construction time to remain on schedule. The team dedicated over 3,000 person-hours to the project. The distribution of these hours is shown in Figure 1.

Figure 1: Distribution of Person-Hours

After selecting a railroad theme, a team trip was taken at the beginning of the 2013-14 academic year to the Golden Spike National Historic Site located at Promontory Summit, UT. The functioning replicas of the original trains and the historical items found at the site inspired the design of *Promontory's* aesthetics, stands, display, and cross section. This trip to Promontory Summit allowed the project to flow smoothly from the concept phase into the design phase.

One of the captains' primary goals was to reduce construction costs to compensate for conference travel costs (see Figure 2). The previous year's budget was used as a starting point for 2013-14. The team developed in-house solutions to lower costs, and recycle materials from previous years.

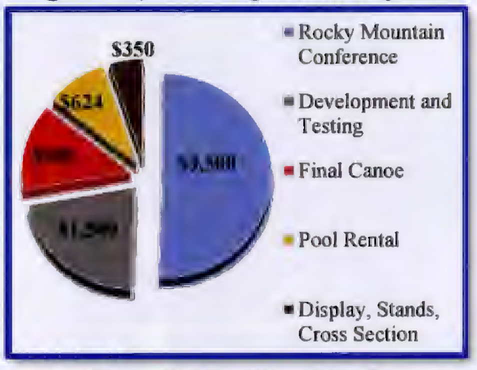


Figure 2: Allocation of Funds

For example, instead of purchasing name brand Sugru®, a homemade substitute was created that had the same molding properties, but reduced costs by 83%. This cost reduction allowed for extensive use of the Sugru® substitute during both the detailed mold testing and form construction phases.

The team captains closely monitored quality control throughout *Promontory's* construction phase. At least one captain was always present to oversee construction and material testing. This ensured testing was performed according to ASTM standards and construction was accurate. Captains delegated specific tasks to individual team members and taught them proper techniques. The individual improvement of these techniques throughout the process ensured high quality in every aspect of the project.

To ensure a safe work environment, captains educated the team on proper materials handling and the correct use of tools and personal protective equipment. A team captain checked that proper safety practices were maintained during the materials testing and construction of the canoe.

ORGANIZATION CHART

NATHAN FOX
Paddling Lead &
General Management

Coordinated paddling practices. Oversaw quality control, safety program, and general project management.

Paddlers
Jenica Hillyard
Kyle Kump
Jean Lawrence
McKenna Lee
Ryan McLeod
Timo Patterson
Jackson Reid
Ploy Samranjit
Breanna Watkins

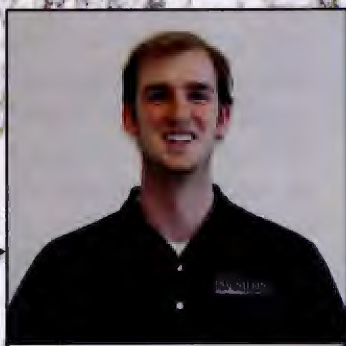
NATE DECKER
Hull Design &
Structural Analysis

Conducted 3D model testing of hull designs. Performed structural analysis on canoe to determine strength requirements of concrete mix.

Design Team
Braden Felix
Ryan McLeod
Tomsen Reed
Nate Rogers
Mark Stenquist

ALLISON ALBERT
Final Product &
Design Aesthetics

Designed aesthetics for canoe, display, stands, and cross section. Applied graphics for finishing of canoe.



TYLER HANSEN
Construction &
Mix Design

Lead and directed all construction tasks including form construction, canoe casting and finishing. Conducted research and development of mix design.

Construction/Aesthetics Team
Tyson Alder
Parker Bassett
Nathan Booth
Jill Debuck
Braden Felix
Kaisa Forsyth
Jenica Hillyard
Austin Hunting
Kyle Kump
Dayton Law
Jean Lawrence
McKenna Lee
Katelyn Madsen
Parker McGarvey
Ryan McLeod
Timo Patterson
Phillip Powelson
Tomsen Reed
Jackson Reid
Nate Rogers
Ploy Samranjit
James Saunders
Robert Spencer
Mark Stenquist
Breanna Watkins

HULL DESIGN

The design team focused on creating a hull design that would maintain tracking without sacrificing maneuverability. Low maneuverability in *Canoebis* indicated that a modified hull design was necessary. *Canoebis* was modeled after a professional racing canoe, the Wenonah Jensen V-1 Pro (Wenonah, 2014), but it was evident in the endurance races that the hull design did not perform as expected. *Canoebis* sat too deep in the water because of the increased weight, resulting in a significant loss of maneuverability. This year the team decided to use the NCCC standard hull design as a baseline (ASCE/NCCC, 2014).

Three 1:15 scale models were 3D printed to compare different hull design modifications (See Figure 3). One was a model of *Canoebis,* and two were new designs the team developed. A model of *Canoebis* was created to serve as a comparison to determine whether these new designs had improved hydrodynamic characteristics to fulfill team goals.

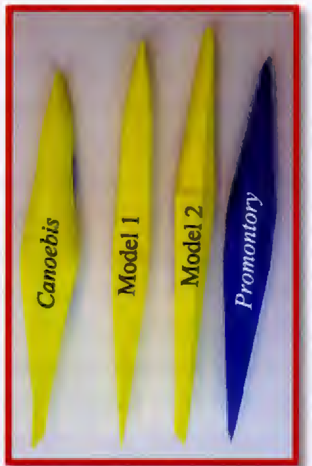


Figure 3: 3D Models used in Testing (Yellow); Final Hull (Blue)

The design team used Froude similitude to scale these models because inertia and gravity forces tend to control in hull design due to wave action. Dynamic similarity was maintained as a result (Finnemore and Franzini, 2002). This allowed the team to determine the weight of the models and velocity of the water required to accurately test the models in a hydraulic flume.

Table 4: Results of Model Testing

Model	Avg. Drag Force	Avg. Turning Time (90°)
Canoebis	0.026 lb	2.44 sec
Model 1	0.016 lb	2.27 sec
Model 2	0.020 lb	2.03 sec
Promontory	0.018 lb	2.21 sec

To begin testing, the design team placed each model in a flume and attached it to an electronic balance to measure the drag force at typical paddling velocities. For the relative maneuverability test, models were placed in a tank and a force acting normal to the length of the canoe was applied at the bow. The design team measured the time required for the model to complete the 90° turn and align with the force. After multiple iterations of these tests, an average turning time was taken; it was determined that Model 1 had the lowest drag forces while Model 2 had the fastest turning times (see Table 4). An initial hull design was created combining these strengths.

This initial hull design was used to create a practice canoe (See Practice Canoe, Pg. 7) and a fiberglass test canoe. During initial float tests, the fiberglass canoe revealed flaws in the hull design. Due to the lack of a rocker and a narrow cross section, the canoe was unstable and maneuvered poorly. To overcome these flaws, the team shortened the canoe by 2', added a 2" linear rocker from midship to the bow and stern, and made the midship section 2" wider. Reducing the length and adding a rocker reduces the resisting forces generated while turning. A full-scale wooden canoe was constructed to ensure that these changes were effective and that the paddlers would have an accurately shaped canoe to practice in. The team qualitatively verified the efficacy of these changes during subsequent practices and feels that *Promontory* meets the original design goals. The team tested a final 3D model (see Figure 3) to provide quantitative results (see Table 4). Table 5 shows the dimensions of *Promontory* compared to the standard hull design and *Canoebis* (see Design Drawing, Pg. 10).

Table 5: Comparison of Canoe Specifications

Specification	*Promontory*	Standard Hull	*Canoebis*
Length	19'-6"	20'	18'-6"
Bow Depth	1'-2.125"	1'-4"	1'-6"
Stern Depth	1'-0.125"	1'-2"	1'-0.2"
Center Depth	1'-2.125"	1'-2"	1'-0.4"
Max. Width	2'-2.75"	2'-7.184"	2'-10"

STRUCTURAL ANALYSIS

The purpose of the structural analysis was to calculate the maximum tensile and compressive stresses that *Promontory* would experience both longitudinally and laterally, in order to develop an adequate concrete mix. Two-dimensional structural analysis techniques were used to determine these stresses. A new lateral analysis was performed because of longitudinal cracking in *Canoebis* during last year's competition.

The longitudinal analysis was performed to determine which loading scenario would generate the largest maximum moment along the length of the canoe. The loading cases consisted of transportation, display, two woman, two man, and co-ed (two men and two women).

Point loads were applied for each paddler on the top of a beam representing the canoe. A trapezoidal distributed load was used to represent the buoyant force based on the amount of displaced water along *Promontory's* length (see Figure 4). The ordinates of

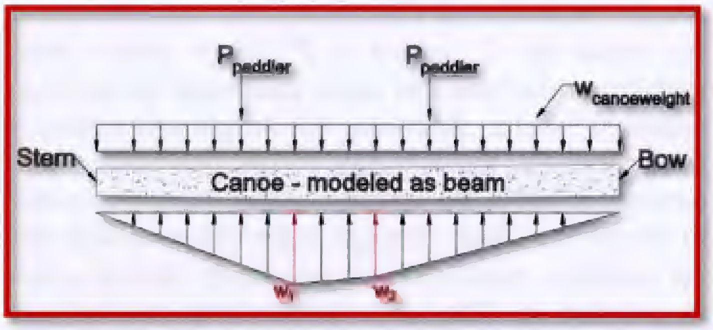


Figure 4: Free Body Diagram Used in Longitudinal Analysis

the trapezoid, w_1 and w_2, were adjusted to ensure equilibrium between the resultant buoyant force and the combined weight for each loading scenario. Accounting for dynamic loading, these weights were assumed to be 225 lbs for male paddlers, 150 lbs for female paddlers, and 225 lbs for *Promontory*. The distributed buoyant load acting on the bottom of the canoe was found for each loading scenario based on this resultant force. During transportation, the beam was supported at one foot increments along its length. While on display, the canoe was modeled as a simply supported beam.

Shear diagrams were created for each loading scenario. Applying Euler-Bernoulli Beam Theory and integrating the shear forces provided the moment values along the canoe (Timoshenko, 1953). Table 6 shows the maximum applied moments. The two man loading scenario is the controlling case, with the maximum moment located 10'-4.3" from the bow of *Promontory*. Using the principle of flexure, the maximum longitudinal tensile and compressive stresses were then found on the cross section at this location (see Development and Testing, Table 7).

Table 6: Loading Cases Examined

Loading Case	Max. Moment	Distance from Bow
Co-Ed Sprint	118.38 lb-ft.	5'-10.7"
Display	548.44 lb-ft.	9'-9"
Transportation	0.96 lb-ft.	9'-9"
Two Man	609.67 lb-ft.	10'-4.3"
Two Woman	509.16 lb-ft.	10'-1.9"

In *Promontory*, tension develops in the gunwale during paddling and in the bottom of the hull while on display. Steel cables are located on either side of *Promontory* in both the gunwale and along the bottom to support this tension. The design team used the maximum tensile stress from each case to calculate the amount of total tensile force needed in the cables. This total tensile force translated to four cables along the gunwale (two on either side) and four cables along the bottom of the hull (two on either side), each pre-tensioned to 150 lbs.

The co-ed loading controls the lateral analysis because *Promontory* displaces the greatest volume of water due to the total combined weight. This displacement causes the largest normal buoyant forces acting on the exterior of the canoe. These hydrostatic forces were calculated by determining the location of the waterline at a cross-section of the midship (see Figure 5). These forces were then multiplied by their lever arms about the keel of the cross-section to determine the moment being applied about the bottom of the canoe. The principle of flexure was again used to determine the maximum stresses on the lateral cross-section.

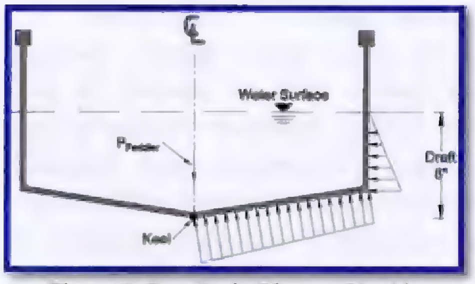


Figure 5: Free Body Diagram Used in Lateral Analysis

Table 7 shows the calculated longitudinal and lateral stresses and indicates that *Promontory* will withstand stresses experienced during competition.

DEVELOPMENT AND TESTING

The mix design team set a goal to create a unique concrete mix that would be economically and environmentally sustainable, workable, strong, and less than 55 pcf. To achieve these goals, the team researched and tested various aspects of the concrete mixture to create a mix design with the strength-to-weight ratio best suited for the canoe. The mix design for *Canoebis* was used as a baseline for *Promontory* and 40 variations were tested.

Testing to create a new mix design began by determining the ideal cementitious material mixture. Varying ratios of Portland cement, fly ash and VCAS™ were cast into 2" mortar cubes and tested in compression following ASTM C109 (2013b). After performing these tests, the team found a base mortar that was 22% stronger than what was used in *Canoebis*. The cementitious material ratio for *Promontory* is 59% white Portland cement, 18% fly ash and 24% VCAS™ 160.

After selecting the mortar mixture, concrete mixes were tested by varying aggregates, using the aggregate gradation of *Canoebis* as a base. *Canoebis'* mix followed a modified Fuller curve with a 0.22 exponent (1906). In order to lower the water-cementitious (w/cm) ratio, the *Promontory* mix was designed to more closely follow the Fuller curve (0.5 Power Curve). This provided a coarser gradation and lowered the w/cm ratio from 0.6 to 0.435.

Figure 6: Breaking Test Cylinders (ASTM

To match the curve, one new aggregate, ceramic spheres, was tested but was too heavy to meet the desired 55 pcf design goal. Two of the finest aggregates, 3M™ IM16K and IM30K, were removed from the mix, which reduced the cost of concrete by 57%.

The aggregates that were chosen for the structural and finishing mix included a mixture of Poraver® microspheres (varying in size from 0.25 - 2.0 mm). These were chosen for their compressive strength, weight, and environmental sustainability. HG75/400 Cenospheres were also used, along with 3M™ K-1 glass bubbles. The *Promontory*, *Canoebis*, and 0.5 Power Curve gradations are shown in Figure 7.

Because the concrete for *Promontory* was to be applied manually to the vertical sides of the male mold, workability was a concern for the design team. Two criteria were used to evaluate workability: (1) 0-0.5" slump per ASTM C143 (2013d), (2) ease of applying a 3/16" layer while maintaining homogeneity. *Promontory's* structural mix had a slump of 0.25".

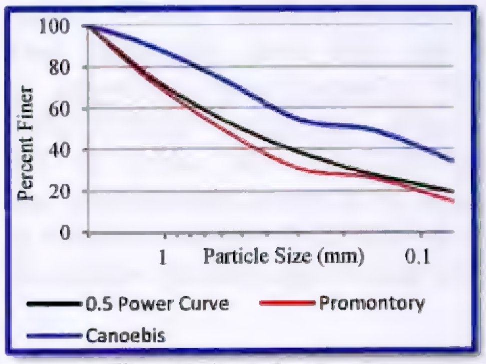


Figure 7: Gradation Curves

Aggregates were moisture-conditioned to a saturated surface dry state – the point where the aggregates would neither discharge into nor absorb water from the concrete mix – prior to mixing. This maintained the workability of the mix by preventing premature drying caused by aggregate water absorption.

After selecting the aggregate gradation, three sizes of polyvinyl-alcohol (PVA) fiber were added to increase tensile strength and cohesion throughout the mix. Splitting tensile tests were performed according to ASTM C496 (2013e) to verify that sufficient fibers were included to meet tensile analysis results (See Table 7).

Table 7: Maximum Stresses

Stress	*Promontory's* Concrete	Required Longitudinally	Required Laterally
Max. Tensile	160 psi	42.8 psi	122.6 psi
Max. Compressive	1270 psi	71.6 psi	122.6 psi

Promontory is approximately 85% structural concrete. Because of this, a high air content was required to decrease the composite density of the canoe. MasterAir® AE 90 air-entraining admixture was used in the structural mix to improve plasticity, workability, water resistance, and increase air content (BASF, 2008a). The admixtures that were included in both structural and finishing mixes were MasterPolyheed® 997 Mid-Range Water-Reducing Admixture and MasterGlenium® 3030 High-Range Water-Reducing Admixture. Both were included to increase workability of the concrete mixtures, increase setting strength, improve the cohesion of the finishing mix, and the finishability (BASF, 2008b and 2008c). For the first time, the team used MasterSet® AC 534, a non-chloride accelerator, to achieve higher early strengths. QUIKRETE® Concrete Bonding Adhesive was added to the finishing mix because it decreases permeability and increases strength. QUIKRETE® was not included in the structural mix because it significantly reduces air content.

TENSILE REINFORCEMENT

Pre-tensioned steel cables and fiberglass mesh provided active and passive reinforcement. Although the analysis indicates that the tensile strength of the concrete is sufficient to withstand the stresses *Promontory* will experience, eight steel cables were used to provide an added safety factor and capture tensile stresses to avoid concrete cracking.

To determine the ultimate tensile strength of the steel cables, a tension test was performed according to ASTM A931 – 08 (2013f). The ultimate tensile strength was desired to ensure that cables would not fail during pre-tensioning or the curing process. The test results concluded that the nominal breaking strength of the cable matched the actual strength of 480 pounds.

In previous canoes, cables lost tension before the concrete had cured. To investigate the cause, the design team performed a relaxation test. The length of a steel cable was measured. The team tensioned the cable to 150 pounds for 28 days. Length measurements were taken at the end of the 28-day test and compared to the initial length. There was no variation in cable length before and after the test.

After eliminating relaxation as a cause of tensile losses, the team determined that the concrete was not bonding to the cables. To remedy this, aluminum stops were placed on each of the eight cables at 3' intervals along the length of the canoe.

The design team performed a modified third-point load test (ASTM C78, 2013c) by casting a 6" x 20" x 3/8" slab that represented a wall section of *Promontory* (see Figure 8). The composite modulus of rupture is 975 psi.

Figure 8: Composite Flexural Test

SUSTAINABILITY

To reduce *Promontory's* environmental impact, the concrete mix contains several recycled aggregates. Poraver® microspheres are made of post-consumer recycled glass and Cenospheres are a byproduct of coal combustion.

Economic sustainability was another goal of the design team for the concrete mix. In addition to seeking admixture donations from companies, the concrete mix was simplified by removing the most expensive aggregates and cementitious materials. Two aggregates and one cementitious material (Xypex) were removed, lowering costs by $100 per cubic ft (see Table 8 for cost comparisons of concrete mixes).

The team reduced waste by decreasing the amount of concrete made for each iteration during the testing phase. On casting day, special care was taken to minimize concrete waste by mixing manageable 0.15 cubic ft batch sizes.

Promontory's mix design achieved the goals of compressive strength, environmental sustainability, and unit weight while saving money on aggregates and cementitious materials. The use of only two mixes reduced concrete waste and streamlined the casting process, resulting in less person hours used towards construction. The development and testing of *Promontory* contributed to a cost effective and durable canoe that is ready for competition.

Table 8: Comparison of *Promontory* and *Canoebis* Mix Designs

Stress	Compressive Strength	Tensile Strength	Cost/Cubic Foot
Promontory	1,270 psi	160 psi	$ 77.00
Canoebis	1,870 psi	270 psi	$ 179.00

Construction

The more maneuverable hull design for *Promontory* provided new and exciting challenges in the construction process. Building on past construction methods, the team constructed the mold and cast the canoe efficiently while maintaining the needed tension in the steel reinforcement cables. This year, the team wanted to achieve a more efficient construction process by decreasing the amount of time needed for finishing the canoe. New construction techniques were added into the mold creation process to achieve the desired final product. Sugru® substitute was used to create intricate inlays and metal forms allowed the gunwales to be cast to perfection.

Practice Canoe

The team builds a practice canoe each year to provide the team captains an opportunity to help new members practice the construction skills needed for a high quality final product.

The concrete practice canoe used the mold construction method of *Canoebis*, where 6" thick pieces of expanded polystyrene were placed between sheet metal cross-sections and cut using a hotwire. A total of 43 cross-sections were cut and assembled to create a male mold (see Figure 9). This process required a significant amount of time to sand, sculpt with drywall mud, and carve to reach the desired shape. To save time, the captains explored more efficient options for constructing *Promontory's* form.

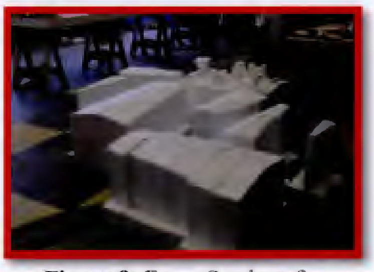


Figure 9: Foam Sections for Practice Canoe

Form Construction

Once the plans for the competition canoe were finalized, construction for *Promontory* began using expanded polystyrene. Rather than cutting individual 6" sections, a professional hotwire company agreed to donate the foam and cutting time. Using a precise hotwire, the form was cut in three separate sections that were glued together after delivery (see Figure 10). This process permitted an extra week of time for final preparations before casting.

For the last three years, USU has included a three-dimensional inlay to emphasize the year's theme (see Finishing, Pg. 8). With the exception of the rails, the bottom interior of the hull consisted primarily of Sugru® substitute, providing detail to the railroad ties and rock textures that decorate the bottom of the hull. The mold side-walls feature hand carved mountains and plains. Once the design inlay was complete, the form was coated with Styropoxy™ to protect the mold during casting and aid with demolding.

Figure 10: Foam Sections for Final Canoe

Reinforcement

Promontory features two reinforcement systems to resist tensile forces associated with the loading scenarios. The team placed two cables in each gunwale and rail (see Design Drawing, pg 10) and pre-tensioned these cables to 150 lbs each using a simple lever and pulley system. A scale was attached to the end of the lever to monitor the tension force throughout the curing process.

To enhance reinforcement throughout the hull and protect against puncture, fiberglass mesh was draped, cut, and formed to the foam mold prior to casting to ensure a snug fit.

Casting

Utilizing the team and a group of volunteers totaling 31 people, Promontory was cast in 3.5 hours. This was done in four steps. First, a thin layer of finishing mix was painted on the foam mold to help preserve the details of the inlay and reduce finishing time. Next, a structural mix was applied to a thickness of $^3/_{16}$" using plywood board as a depth gauge. Third, the pre-fitted fiberglass mesh was placed over the first two layers of concrete. Finally, another $^3/_{16}$" layer of structural mix was applied using the same depth gauge method.

Once the casting was complete, a wet curing process was used to ensure maximum strength. The canoe was covered in wet cloths and then wrapped in plastic to prevent dehydration. An ambient temperature of 75°F was maintained to aid the curing process. Team members soaked the cloths twice a week during the 21-day curing period.

SANDING

In the past, sanding required many person-hours after the canoe was pulled from the mold. In order to allow more finishing time between casting and the conference competition, sanding for *Promontory* began one week after casting. The team completed these early iterations of sanding before demolding. After the initial 21-day cure, the team removed *Promontory* from the form.

FINISHING

Special care was taken in the final finishing steps. The design team developed an extra hard finishing mix to enhance the details of the inlays and shield the structural mix. Two iterations of applying finishing mix and sanding up to 5000-grit were used to create a smooth figure.

Figure 11: Inlay Tracks and Rails

Because finishing mix was painted onto the mold during casting, *Promontory's* interior required only spot-treatment and sanding touch-ups. This significantly reduced finishing time and allowed more time to apply stain.

Team members molded animal figurines using Sugru® substitute to create more detailed three-dimensional figures. These animals were then attached to the inside of the canoe to enhance the hand carved scenery.

The team used acid stain to create a weathered-wood look on the inlaid railroad ties and rails. The skylines on the interior and exterior walls of Promontory were left bare to provide a natural look.

SUSTAINABILITY

Each year the team endeavors to create a quality product, while maintaining a high level of sustainability. The expanded polystyrene from the mold was returned to the manufacturer to be recycled and reused for new products. Team members built the construction table out of leftover wood from previous projects and sealed with paint from the local landfill reuse shed. To reduce hazardous waste, the team used remaining stains from *Canoebis.*

INNOVATION

This year the gunwale is centered on the walls of the canoe to provide a T-shape look. In the past, the gunwales were formed by hand, leaving many flaws. This year, the team used sheet metal sections to cast the gunwale to perfection. Using a Sugru® substitute mold of an HO scale train track, a model track was cast onto the top of the gunwale (see Figure 12).

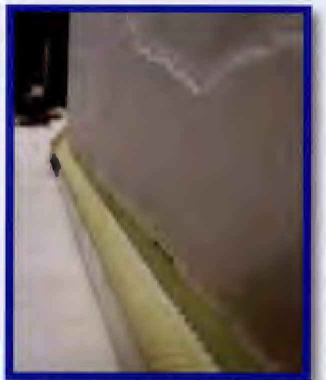


Figure 12: Sheet Metal Sections with Train Track

Bridges were built at the bow and stern to allow the track to run continuously along the gunwale. This allows a working battery-powered model train to travel nonstop around the gunwale. The bridge construction method was inspired by accelerated bridge construction (ABC), a Federal Highway Administration program pioneered by the Utah Department of Transportation where bridges are cast offsite and then transported to location for installation. This method reduces onsite construction time and increases site constructability (Federal, 2013). The bridges on *Promontory* were pre-cast separately from the canoe to precise measurements and added once the canoe was demolded. This allowed more time for finishing around the bridge sites.

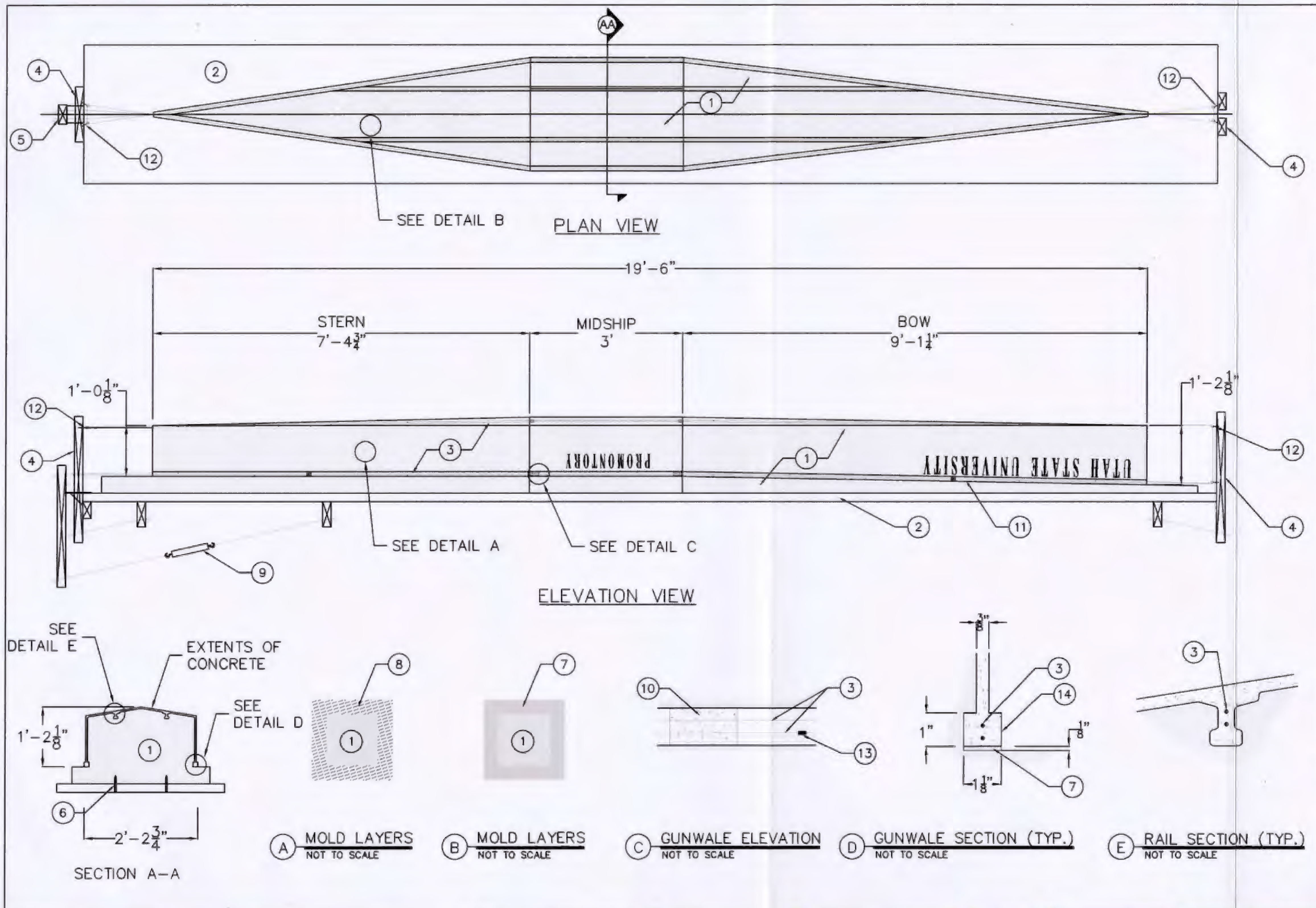
Through precision casting, the Utah State University Concrete Canoe Team has created *Promontory* in memory of a true engineering marvel, the Transcontinental Railroad.

Project Schedule

ID	Task Name	Start	Finish
1	**1 Project Start**	**Mon 26-08-13**	**Sat 28-09-13**
4	**2 Mix Designs**	**Mon 02-09-13**	**Wed 20-11-13**
10	**3 Hull Design**	**Mon 26-08-13**	**Fri 11-10-13**
16	**4 Analysis**	**Mon 28-10-13**	**Sat 01-02-14**
19	**5 Construction Innovations**	**Sat 14-09-13**	**Sat 16-11-13**
22	**6 Fiberglass Canoe**	**Wed 16-10-13**	**Tue 19-11-13**
28	**7 Practice Canoe Constructi**	**Sat 28-09-13**	**Sat 14-12-13**
29	7.1 Gather Materials	Sat 28-09-13	Fri 04-10-13
30	7.2 Form Construction	Sat 05-10-13	Fri 15-11-13
31	7.3 Final Preparations	Sat 16-11-13	Fri 22-11-13
32	7.4 Casting Day	Sat 23-11-13	Sat 23-11-13
33	7.5 Curing	Sun 24-11-13	Fri 13-12-13
34	7.6 Pull From Mold	Sat 14-12-13	Sat 14-12-13
35	**8 Finishing Practice Canoe**	**Sun 15-12-13**	**Wed 22-01-14**
36	8.1 Sanding/Finishing Mix	Sun 15-12-13	Mon 30-12-13
37	8.2 Staining/Sealing	Tue 31-12-13	Wed 22-01-14
38	**9 Final Canoe Construction**	**Mon 06-01-14**	**Wed 05-03-14**
39	9.1 Gather Materials	Mon 06-01-14	Tue 14-01-14
40	9.2 Form Construction	Wed 15-01-14	Sat 01-02-14
41	9.3 Final Preparations	Sun 02-02-14	Fri 07-02-14
42	9.4 Casting Day	Sat 08-02-14	Sat 08-02-14
43	9.5 Curing	Sun 09-02-14	Tue 04-03-14
44	9.6 Pull From Mold	Wed 05-03-14	Wed 05-03-14
45	**10 Finishing Final Canoe**	**Mon 10-02-14**	**Sat 29-03-14**
46	10.1 Sanding/Finishing Mix	Mon 10-02-14	Tue 18-02-14
47	10.2 Staining	Sat 08-03-14	Sat 22-03-14
48	10.3 Sealing	Sun 23-03-14	Sat 29-03-14
49	**11 Paddling**	**Mon 02-09-13**	**Tue 01-04-14**
50	11.1 Initial Practice	Mon 02-09-13	Sat 28-09-13
51	11.2 Tryouts	Wed 25-09-13	Sat 28-09-13
52	11.3 Workouts	Sat 28-09-13	Tue 01-04-14
53	**12 Fundraising**	**Mon 02-09-13**	**Wed 19-02-14**
57	**13 Display**	**Mon 06-01-14**	**Tue 01-04-14**
61	**14 Design Paper**	**Mon 30-12-13**	**Fri 07-03-14**
62	14.1 Rough Draft	Mon 30-12-13	Sat 18-01-14
63	14.2 Initial Review	Sun 19-01-14	Mon 20-01-14
64	14.3 Final Draft	Tue 21-01-14	Tue 11-02-14
65	14.4 Peer Review	Wed 12-02-14	Fri 28-02-14
66	14.5 Final Editing	Sat 01-03-14	Tue 04-03-14
67	14.6 Submission	Wed 05-03-14	Fri 07-03-14
68	**15 Rocky Mountain Conferei**	**Wed 02-04-14**	**Thu 03-04-14**

Project: Promontory Project Sch
Date: Mon 03-03-14

Task | Milestone ◆ | Summary | Critical



PROMONTORY DESIGN DRAWING

BILL OF MATERIALS

ITEM NO.	QTY	DESCRIPTION
1	47 cu.ft.	CUBIC FT. EXPANDED POLYSTYRENE
2	6	4' x 8' PARTICLE BOARD (2 LAYERS)
3	200 ft.	1/16" STEEL CABLE
4	8	2" x 4" WOOD ANCHOR BLOCKS
5	12	STEEL WASHERS
6	15	SCREWS
7	10 lb.	SUGRU SUBSTITUTE
8	.75 gal	STYROPOXY™
9	1	TENSION SCALE
10	8	CABLE GUIDE BLOCKS (CONCRETE)
11	4	CABLE GUIDE BLOCKS (SUGRU SUBSTITUTE)
12	6	PULLEY
13	48	3/32" ALUMINUM STOP
14	48	STEEL GUNWALE MOLD

Notes:

1. Build wood table.
2. Cut 2" rocker on pre-cut bow and stern foam sections.
3. Place three foam sections on table and secure with glue and screws.
4. Apply drywall compound to fill cracks between foam blocks
5. Carve inlay on vertical faces.
5. Place Sugru substitute inlay molds on form. (Not shown)
6. Apply two coats of Styropoxy™.
7. Setup pulley system and place tension cables.
8. Apply tension to 150 lbs. using scale.

UtahStateUniversity

Drawn By:	Nate Decker
Checked By:	Nathan Fox
Date:	Feb. 2, 2014
SCALE: ½"=1'-0"	SHEET 1 OF 1

APPENDIX A: REFERENCES

ASCE/NCCC (2014). "Rules and Regulations." *2014 American Society of Civil Engineers® National Concrete Canoe Competition™*: <http://www.asce.org/concretecanoe/> (Feb. 10, 2014).

American Society for Testing and Materials (ASTM). (2013a). "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." C39/C39M – 12a. ASTM International, West Conshohocken, PA

ASTM. (2013b). "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)." C109/C109M – 13. ASTM International, West Conshohocken, PA

ASTM. (2013c). "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)." C78/C78M – 10e1. ASTM International, West Conshohocken, PA

ASTM. (2013d). "Standard Test Method for Slump of Hydraulic-Cement Concrete." C143/C143M – 12. ASTM International, West Conshohocken, PA

ASTM. (2013e). "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens." C496/C496M – 11. ASTM International, West Conshohocken, PA

ASTM. (2013f). "Standard Test Method for Tension Testing of Wire Ropes and Strand." A931 – 08(2013). ASTM International, West Conshohocken, PA

BASF Corporation. (2008a). "MasterAir® AE 90 (Formerly MB-AE 90)." *Air-Entraining*, <http://www.basf-admixtures.com> *(Jan. 30, 2014).*

BASF Corporation. (2008b). "MasterGlenium® 3030 (Formerly Glenium 3030 NS)." *High-Range Water-Reducing*, <http://www.basf-admixtures.com> *(Jan. 30, 2014).*

BASF Corporation. (2008c). "MasterPolyheed® 997 (Formerly PolyHeed 997)." *Mid-Range Water-Reducing*, <http://www.basf-admixtures.com> *(Jan. 30, 2014).*

Federal Highway Administration. (2013). "Accelerated Bridge Construction." *Bridge Construction.* <http://www.fhwa.dot.gov/Bridge/ABC/> (28 Feb, 2014).

Finnemore, E. John, & Franzini, Joseph B. (2002). "Similitude and Dimensional Analysis." *Fluid Mechanics with Engineering Applications*, McGraw Hill, 10th ed., New York, NY, 237-244.

Fuller, W. B., & Thompson, S. E. (1906). "The Laws of Proportioning Concrete." *Transactions of the American Society of Civil Engineers*, *57*(2), 67-143.

National Park Service (NPS). (2013). *Golden Spike National Historic Site*. Utah: NPS. Print.

Timoshenko, S. (1953). "History of Strength of Materials." McGraw-Hill, New York, NY.

USU (2010a). "History and Tradition." *About USU.* <http://www.usu.edu/about/> (Jan 10, 2014).

USU (2010b). "Utah State University at a Glance." *About USU.* <http://www.usu.edu/about/> (Jan 10, 2014).

USU Concrete Canoe. (2013). "Canoebis." NCCC Design Paper, Utah State University, Logan, UT.

Wenonah Canoe Inc. (2014). "Jensen V-1 Pro." <www.wenonah.com> (Jan. 22, 2014).

APPENDIX B: MIXTURE PROPORTIONS

Mixture ID: 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	White Portland Cement			3.15	325.00	1.653	1.81	0.0092	331.02	1.684
CM2	VCAS™ 160			2.60	130.00	0.801	0.72	0.0045	132.41	0.816
CM3	Jim Bridger Fly Ash			2.15	97.50	0.727	0.54	0.0040	99.31	0.740
Total Cementitious Materials:					**552.50**	**3.181**	**3.07**	**0.018**	**562.73**	**3.24**
Fibers										
F1	PVA RSC15			1.30	8.75	0.108	0.049	0.00060	8.91	0.110
F3	PVA RFS400			1.30	3.25	0.040	0.018	0.00022	3.31	0.041
F4	PVA RF4000			1.30	4.00	0.049	0.022	0.00027	4.07	0.050
Total Fibers:					**16.00**	**0.197**	**0.089**	**0.0011**	**16.30**	**0.201**
Aggregates										
A1	Cenospheres	Abs:	15%	0.60	78.62	2.100	0.44	0.012	80.08	2.139
A2	3M™ K1	Abs:	1%	0.10	14.25	2.284	0.08	0.013	14.51	2.326
A4	Poraver® 0.25-0.5	Abs:	21%	0.88	99.75	1.817	0.55	0.010	101.60	1.850
A5	Poraver® 0.5-1.0	Abs:	18%	0.71	142.50	3.216	0.79	0.018	145.14	3.276
A6	Poraver® 1.0-2.0	Abs:	19%	0.53	142.50	4.309	0.79	0.024	145.14	4.389
Total Aggregates:					**477.62**	**13.725**	**2.65**	**0.076**	**486.47**	**13.980**
Water										
W1	Water for CM Hydration				240.27	3.850	1.33	0.021	244.72	3.922
	W1a. Water from Admixtures			1.00	22.71		0.13		23.13	
	W1b. Additional Water				217.57		1.21		221.59	
W2	Water for Aggregates, SSD			1.00	85.61		0.48		87.19	
Total Water :					**325.88**	**3.850**	**1.81**	**0.021**	**331.91**	**3.922**
Solids Content of Latex, Dyes and Admixtures in Powder Form										
P1	Type S Hydrated Lime			2.50	97.50	0.625	0.54	0.003	99.31	0.637
Total Solids of Admixtures:					**97.50**	**0.625**	**0.54**	**0.003**	**99.31**	**0.637**
Admixtures				% 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	MasterPolyheed® 997	10.6	*lb/gal*	48.00	25.00	5.95	0.77	0.033	25.5	6.06
Ad2	MasterGlenium® 3030	8.7	*lb/gal*	20.00	20.00	6.01	0.61	0.033	20.4	6.12
Ad3	MasterSet® AC 534	11.7	*lb/gal*	53.40	20.00	4.71	0.61	0.026	20.4	4.79
Ad4	MasterAir® AE 90	7.9	*lb/gal*	11.40	20.00	6.04	0.61	0.034	20.4	6.15
Water from Admixtures:						**22.71**		**0.126**		**23.13**
Cement-Cementitious Materials Ratio					0.588		0.588		0.588	
Water-Cementitious Materials Ratio					0.435		0.435		0.435	
Slump, Slump Flow, *in.*					0-0.50		0.25		0.25	
M	Mass of Concrete, *lbs*				1469.50		8.16		1496.72	
V	Absolute Volume of Concrete, *ft^3*				21.580		0.120		21.979	
T	Theorectical Density, *lb/ft^3*				68.10		68.10		68.10	
D	Design Density, *lb/ft^3*				54.43					
D	Measured Density, *lb/ft^3*						55.434		55.434	
A	Air Content, %				20.08		18.60		18.60	
Y	Yield, *ft^3*				27		0.147		27	
Ry	Relative Yield						0.982			

APPENDIX C: BILL OF MATERIALS

Form Construction				
Material	***Quantity***	***Units***	***Unit Cost***	***Total Price***
Expanded Polystyrene Mold	1	Lump Sum	$190.00	$190.00
Sugru Substitute	1	Lump Sum	$155.54	$155.54
Styropoxy™	0.5	gal	$101.71	$50.86
Total Cost of Form Construction				$396.40
Concrete Materials				
Material	***Quantity***	***Units***	***Unit Cost***	***Total Price***
Type I White Portland Cement	79.03	lbs	$0.36	$28.59
VCAS ™ 160	15.17	lbs	$1.32	$19.98
Jim Bridger Fly Ash	11.38	lbs	$0.21	$2.39
PVA RSC15 Fibers	1.15	lbs	$14.00	$16.11
PVA RFS400 Fibers	0.38	lbs	$15.00	$5.69
PVA RFS4000 Fibers	0.47	lbs	$20.00	$9.34
Cenospheres	14.73	lbs	$7.00	$103.14
3M™ K1	1.66	lbs	$10.00	$16.60
Poraver® 0.25-0.5	11.64	lbs	$1.99	$23.16
Poraver® 0.5-1.0	16.63	lbs	$2.01	$33.36
Poraver® 1.0-2.0	16.63	lbs	$2.01	$33.36
Type S Hydrated Lime	11.38	lbs	$0.19	$2.20
MasterPolyheed® 997	24.33	fl oz	$0.05	$1.22
MasterGlenium® 3030	19.06	fl oz	$0.13	$2.48
MasterSet® A C 534	12.89	fl oz	$0.10	$1.29
MasterAir® A E 90	12.89	fl oz	$0.03	$0.39
QUIKRETE® Bonding Adhesive	1.61	gal	$10.32	$16.57
Total Cost of Concrete Materials				$315.86
Reinforcement				
Material	***Quantity***	***Units***	***Unit Cost***	***Total Price***
Fiberglass Mesh	68.5	sq ft	$2.65	$181.53
1/16" Steel Cable	160	ft	$0.09	$14.60
Aluminum Stop	48	pieces	$0.10	$4.80
22 Gauge Galvanized Wire	12	ft	$0.03	$0.34
1/2" x 1/8" Steel Bar	2	ft	$1.50	$3.00
Total Cost of Reinforcement				$204.26
Finishing				
Material	***Quantity***	***Units***	***Unit Cost***	***Total Price***
VIVID™ Acid Stain	0.25	gal	$39.95	$9.99
QuickDye™ Solvent-Based Dye	0.1	gal	$30.00	$3.00
H&C® Concrete Stain	1	gal	$23.47	$23.47
ChemMasters® Crystal Clear	1	gal	$14.00	$14.00
Total Cost of Finishing				$50.46
Total Production Cost of Promontory				$966.98