5-1998

Poseidon American Society of Civil Engineers/Master Builders Rocky Mountain Regional Concrete Canoe Competition

William Spencer Guthrie

POSEIDON

**AMERICAN SOCIETY OF CIVIL ENGINEERS/
MASTER BUILDERS
ROCKY MOUNTAIN REGIONAL
CONCRETE CANOE COMPETITION**

by

William Spencer Guthrie

**Thesis submitted in partial fulfillment
of the requirements for the degree**

of

**UNIVERSITY HONORS
WITH DEPARTMENT HONORS**

in

Civil Engineering

Approved:

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Thesis/Project Advisor **Department Honors Advisor**

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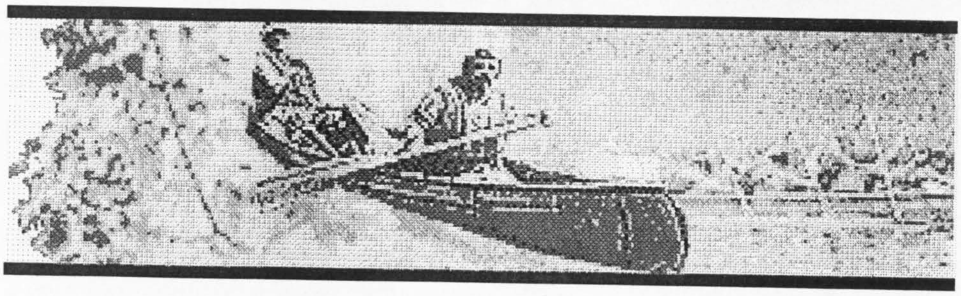
Director of Honors Program

**UTAH STATE UNIVERSITY
Logan, UT**

1998

Proposal for

Competition Concrete Canoe Design



Utah State University

American Society of Civil Engineers

Student Chapter

by

Streamline Technical Systems, Inc.

December 1997

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December 10, 1997

Streamline Technical Systems, Inc.
Utah State University
Logan, UT 84322

Dr. Kevin Womack
Civil Engineering Department
Utah State University
Logan, UT 84322

Dear Dr. Womack:

Thank you for the opportunity to submit this bid proposal in behalf of the Utah State University Student Chapter of the American Society of Civil Engineers. Our proposal addresses the design and construction of Utah State University's entry to the 1998 ASCE Rocky Mountain Regional Concrete Canoe Competition. I am confident that you will be pleased with the academic preparation, work experience, and innovation of our individual team members.

Enclosed herewith please find materials substantiating our design of the concrete canoe. This report details design objectives and methods, cost assessments, and general project management. Specifically included are the techniques of testing and analysis we propose for use in the design of the hull, reinforcement, and concrete mixture.

We are excited to consider this project and look forward to receiving your reply.

Sincerely,

W. Spencer Guthrie
Project Manager

1.0 INTRODUCTION

The concrete canoe team has been selected in behalf of the Utah State University Student Chapter of the American Society of Civil Engineers to prepare an entry for the 1998 ASCE Rocky Mountain Regional Concrete Canoe Competition. This event is co-sponsored by the American Society of Civil Engineers and Master Builders, Inc., and has become a tradition at annual ASCE regional conferences nationwide.

The USU Student Chapter of ASCE needs a team of qualified students to design and build a winning concrete canoe entry. The inherent challenges of this project include maximizing strength while minimizing weight, designing a hull geometry which is both stable and sleek in racing, and producing a finished product which is both durable and aesthetically pleasing. These are the primary objectives in the design and construction of a concrete canoe.

2.0 BACKGROUND

The project background is best traced through the history of the concrete canoe competition with its co-sponsors, the American Society of Civil Engineers and Master Builders, Inc. A short profile of each is given below.

2.1 THE AMERICAN SOCIETY OF CIVIL ENGINEERS

The American Society of Civil Engineers was founded in 1852, making it the oldest national engineering society in the United States. Today, membership exceeds 110,000 with 143 branches and 253 student chapters and clubs. The objective of ASCE is to improve the welfare of the general public by way of the profession of engineering, and this objective is accomplished through literally thousands of members of the organization who serve the nation on various committees. Student chapters of the organization, including the USU Student Chapter of ASCE, are committed to coordinating activities which enrich university curricula through opportunities for service and interaction with professional engineers in the area. Scholarships are available through ASCE to help students with the increasing costs of college educations. The American Society of Civil Engineers hosts the concrete canoe competitions at annual regional conferences to enhance creative design and stimulate student innovation.

2.2 MASTER BUILDERS, INC.

Master Builders, Inc., has become a national leader in developing construction materials and chemicals since its founding in 1909. This prowess in the world of construction materials makes it a perfect sponsor of the concrete canoe competition. It is the headquarters for the Region of the Americas within MBT Holding AG, which is a worldwide network of construction chemical companies. Master Builders, Inc., develops products dedicated to the improvement, protection, and reparation of concrete structures, and thus its interest in student projects such as the concrete canoe are evident. The company is devoted to excellence and, as demonstrated by its years of support of the concrete canoe competition, has always aspired to display the ingenuity of future engineers as well as show the multifaceted advantages of concrete.

3.0 TEAM QUALIFICATIONS

The individual project team members are abundantly qualified to develop Utah State University's entry this year to the ASCE Rocky Mountain Regional Concrete Canoe Competition. Several of the team members have been involved with the project in past years, and this depth of experience offers invaluable benefit toward the final success of the project. The combination of effective design methods and innovations with the ingenuity of the team members will lead to a winning concrete canoe entry.

Furthermore, the team has unrestricted access to the materials laboratory equipment necessary to properly design, analyze, and finally construct a concrete canoe. The team is fully supported by a qualified faculty advisor, Dr. Gilberto Urroz, who will advise in the area of his expertise, fluid mechanics.

The following overview of the team members displays the team's qualifications for this project. Further information may be obtained through reference to individual resumes alphabetized in the appendix at the back of this report.

3.1 SPENCER GUTHRIE, CONCRETE MIXTURE DESIGN AND ANALYSIS, PROJECT MANAGER

The qualifications of Mr. Guthrie to participate in the design and construction of a concrete canoe stem primarily from his two years of experience with the annual ASCE Rocky Mountain Regional Concrete Canoe Competition. Academic instruction in concrete behavior and his attendance at ACI seminars together provide him an understanding of overall mixture design criteria and testing methodologies inherent in a project so sensitive to material strengths and required innovations. Furthermore, his experience with Smithfield City Corporation testing aggregate samples and concrete batch cylinders also substantiates his ability to determine the adequacy of a given concrete mixture as applicable to concrete canoe specifications.

3.2 AARON BUDGE, REINFORCEMENT DESIGN AND ANALYSIS

Mr. Budge is a senior in the Civil Engineering Department at Utah State University and will be graduating with a B.S. degree in the spring. He plans to attend graduate school to further enhance his education in civil engineering. He is currently working at the Utah Department of Transportation Materials Laboratory, and this experience is of great benefit to the concrete canoe team. Also of advantage to the project are the courses he has taken in reinforced concrete design and structural analysis.

3.3 JARED BURGESS, CONCRETE MIXTURE DESIGN AND ANALYSIS

Mr. Burgess currently works at the Utah Technology Transfer Center on a variety of projects primarily relating to the evaluation of pavements. His employment at the Idaho National Engineering Laboratory taught him to work in a team environment. This experience, combined with his knowledge of designing and testing concrete, makes him a valuable asset to the team. His experience with concrete has been obtained through class work, attendance at an ACI seminar on concrete mixing practices, and his previous experience with the materials development of Utah State University's 1997 concrete canoe.

3.4 STEPHANIE CANNON, REINFORCEMENT DESIGN AND ANALYSIS

Through her course work at Utah State University, Miss Cannon has gained a broad background in concrete design. For the past three summers, she has worked for the Utah Department of Transportation as an Engineer in Training. This experience has given her a basic understanding of concrete construction methods. This has been reinforced through her attendance at various concrete and ASCE conferences. She has experience in small project management and record keeping.

3.5 DAVID STEVENS, HULL DESIGN AND ANALYSIS

Mr. Stevens has completed undergraduate course work at Utah State University in statics, dynamics, fluid mechanics, AutoCAD, and spreadsheet utilization. In these courses he mastered concepts such as dimensional analysis, drag forces, and forces affecting stability. As a second-year participant in the ASCE Rocky Mountain Regional Concrete Canoe Competition, Mr. Stevens looks forward to improving on Utah State University's earlier canoe designs and including innovative features to enhance overall performance this year.

3.6 JAMES VANSHAAR, HULL DESIGN AND ANALYSIS

As a senior in civil engineering at Utah State University, Mr. VanShaar has had introductory classes to fluid mechanics, including topics such as dimensional analysis, aerodynamics, and flow patterns. He has also taught elementary fluid mechanics principles and practiced laboratory experimentation as an undergraduate laboratory assistant. Engineering economy has also taught him the Choosing By Advantages decision-making process. Mr. VanShaar has broad experience with microcomputers, including programming, spreadsheets, and mathematical tools.

4.0 HULL DESIGN AND ANALYSIS

The concrete canoe hull design and analysis will be performed by David Stevens and James VanShaar. The results of static and dynamic fluid mechanics analyses will be utilized to determine the actual geometry of the concrete canoe. Extensive modeling will be accomplished to identify effective design characteristics capable of producing desired performance criteria.

4.1 DESIGN CRITERIA

Significant criteria to be considered in the concrete canoe hull design include primary stability, secondary stability, drag forces, and architectural effect. Each of these criteria will be evaluated using both engineering judgment and the principles of fluid mechanics.

Using detailed drawings of the hull shapes to be considered, team members will analyze each shape's primary stability by comparing the relative vertical location of the center of buoyancy above the center of gravity of the canoe-paddler combination. Secondary stability of the hull shape will be determined through detailed evaluation of the cross-sectional area of the canoe which remains under the water as the canoe rolls away from its initial vertical alignment. Dynamic testing on wooden models will utilize the Utah State University water laboratory flume and appropriate instrumentation to evaluate the drag forces on each hull design. The architectural effect of each hull shape will be assessed visually to determine its apparent conformance to standard hydrodynamic geometries. This visual appeal of streamlines, curvatures, angles, and other contour details will supplement the data acquired on each hull design from actual fluids analysis techniques.

4.2 DESIGN OBJECTIVES

Efforts in actual hull design will be directed toward maximizing primary stability, secondary stability, and architectural effect. Drag forces will be minimized.

Examples of competitive hull shapes will be collected from companies and schools experienced in the design of racing canoes. Combinations of desired architectural and performance characteristics of these collected examples will be then used in developing five wooden models built to one-twelfth scale specifications.

Factors affecting primary stability include the specific weight of the concrete mixture, the volume of styrofoam end caps utilized, the placement and weight per area of reinforcement, and the average weight of a paddling team. Design variables addressing these factors include the length and width of the hull and the thickness of the concrete wall panels. These variables will be chosen to maximize the distance of the center of buoyancy above the center of gravity of the canoe-paddler combination. In addition, secondary stability will be maximized by appropriately implementing the combination of tumblehome and flared freeboard geometries. Drag forces will be reduced by designing for effective cutting capability, minimum cross-sectional area below the water line, and low separation zone effects. Maximum architectural effect will be achieved by incorporating aesthetically pleasing streamlines, curvatures, and angles into the hull design. These contours will dually serve to enhance performance.

4.3 COST ASSESSMENT

Table 4.1 below shows the anticipated tasks with the expected labor and material costs associated with hull design and analysis.

Table 4.1 Cost Assessment

Tasks	Hours	Hourly Cost	Labor Cost	Materials Cost	TOTAL COST
Preliminary Research	10	$30	$300	NA	$300
Shape Identification	20	$30	$600	NA	$600
Static Shape Analysis	15	$30	$450	NA	$450
Mathematical Analysis	10	$30	$300	NA	$300
Consultant Review	2	$200	$400	NA	$400
Preparation of Models	10	$30	$300	$30	$330
Model Analysis	15	$30	$450	NA	$450
Final Shape Selection	5	$50	$250	NA	$250
TOTALS	**87**	**NA**	**$3,050**	**$30**	**$3,080**

5.0 REINFORCEMENT DESIGN AND ANALYSIS

Reinforcement for Utah State University's 1998 concrete canoe will be designed by Aaron Budge and Stephanie Cannon. Their purpose will be to determine the strengths and appropriate locations in the canoe structure for the various reinforcement materials being considered for use in the canoe. Both tensile and shear reinforcement will be considered.

5.1 DESIGN CRITERIA

In considering the overall performance of the reinforced concrete composite, several design criteria became immediately apparent. Moment strength, panel shear strength, and weight were chosen as significant criteria in the process of selecting reinforcement materials.

Moment resistance will be evaluated through the use of typical three-point loading tests. Shear strength will also be determined according to standardized ASTM testing procedures to simulate impact response. Materials weights will be precisely measured. In order to obtain a fair representation of each combination, three samples of each composite will be tested.

5.2 DESIGN OBJECTIVES

Given standard canoe geometry and the loading conditions resulting from the position of paddlers in a canoe race, the placement of varying reinforcement combinations becomes critical in maximizing design efficiency and meeting required shear and tensile strengths.

For this project, various combinations of shear and tensile reinforcement materials will be extensively analyzed to determine the capabilities of each to adequately perform at different locations in the canoe structure. Finite element analysis will be utilized to target optimum theoretical reinforcement conditions, and actual reinforcement arrangements will be patterned after these results.

Options for shear reinforcement include one-fourth-inch hardware mesh, one-inch chicken wire, and one-inch geogrid. Tensile reinforcement alternatives include straight steel wire of 37 p.s.i. yield strength and braided wire with a yield strength of 68 p.s.i. The benefits potentially provided by pre-stressed tensile reinforcement, ribs, a partial diaphragm, and other innovations will also receive extensive consideration.

5.3 COST ASSESSMENT

Table 5.1 below shows the anticipated tasks with the expected labor and material costs associated with reinforcement design and analysis. Materials costs include the cost of concrete and reinforcement for all tests.

Table 5.1 Cost Assessment

Tasks	Hours	Hourly Cost	Labor Cost	Materials Cost	TOTAL COST
Preliminary Research	15	$30	$450	NA	$450
Reinforcement Testing	20	$30	$600	$20	$620
Evaluation of Tests	5	$30	$150	NA	$150
AutoCAD Drawing	10	$75	$750	NA	$750
Finite Element Analysis	20	$75	$1,500	NA	$1,500
Final Selection	2	$50	$100	NA	$100
TOTALS	72	NA	**$3,550**	**$20**	**$3,570**

6.0 CONCRETE MIXTURE DESIGN AND ANALYSIS

The concrete mixture for the concrete canoe will be designed by Jared Burgess and Spencer Guthrie. Their purpose will be to identify and quantify the individual ingredients of a concrete mixture which will provide maximum strength and minimum weight.

6.1 DESIGN CRITERIA

The primary criteria in the development of a concrete mixture appropriate for the concrete canoe are the compressive-strength-to-weight ratio and workability of each batch sample.

The compressive strength of each batch sample will be determined through ASTM testing of uniform cast cylinders. The weight will be precisely measured and will complement the compressive stress in calculations evaluating the compressive-strength-to-weight ratio. ASTM slump tests will be performed to rate workability directly.

6.2 DESIGN OBJECTIVES

Acknowledging the innumerable types of aggregates, admixtures, and cements available for concrete mixtures, the design process becomes an essential task in the selection of the concrete mixture ingredients to be utilized in the concrete canoe. Selection of the percentages and types of course and fine aggregates, effective admixtures, and an optimized water-cement ratio will be orchestrated through the iterative process of design, testing, and analysis.

Engineering judgment and past experience are the key players in developing the concrete mixture. Mr. Burgess and Mr. Guthrie are familiar with the inherent properties of common ingredients and are prepared to investigate the effects on concrete mixtures of materials whose properties are not yet well established.

Mr. Burgess and Mr. Guthrie will appraise the value in concrete mixtures of diverse sizes of ceramic beads and other aggregates, water reducers, super-plasticizer, air-entrainers, fly ash and other pozzolans, and different types of cement.

6.3 COST ASSESSMENT

The following Table 6.1 shows the anticipated tasks with the expected labor and material costs associated with concrete mixture design and analysis. Materials costs include only the cost of concrete mixtures required for testing.

Table 6.1 Cost Assessment

Tasks	Hours	Hourly Cost	Labor Cost	Materials Cost	TOTAL COST
Preliminary Research	10	$30	$300	NA	$300
Materials Selection	10	$30	$300	NA	$300
Mixture Development	20	$30	$600	NA	$600
Batch Mixing and Cylinder Casting	40	$30	$1,200	$640	$1,840
Testing and Evaluation	40	$30	$1,200	$10	$1,210
Final Selection	2	$50	$100	NA	$100
TOTALS	**122**	**NA**	**$3,700**	**$650**	**$4,350**

7.0 CONSTRUCTION

The results of all of the team's design and analysis will culminate at the time of construction. Working closely with the members of the hull design team, the structural team will design and coordinate construction of the concrete canoe form. However, as actual construction is a significant task, all members of the USU Student Chapter of ASCE will be invited to assist with construction efforts.

7.1 DESIGN CRITERIA

The primary facet of construction which requires design work is the concrete canoe form. Important criteria include ease of construction and ease of canoe removal after curing.

Past experience will be the key player in the selection of materials and methods to be employed in construction of the form.

7.2 DESIGN OBJECTIVES

Whether a male or female form is used will depend on both the type of reinforcement and the shape of the hull selected for the concrete canoe. Though other restrictions may exist upon evaluation of final analyses, a male form must be utilized if pre-stressed tensile reinforcement is recommended.

Styrofoam, wood, and fiberglass will be considered for form construction. Surfacing will be accomplished with drywall plaster and varnish, plastic heat shrink, or any of a variety of materials, depending on the form's skeletal material. To afford complete concrete coverage and maintain uniformity of depth within the canoe walls, the reinforcement will be appropriately distanced from the form with concrete spacers prior to concrete placement. Means of assuring uniform concrete thickness will also be utilized.

The canoe will be steam cured for one week before full submersion in a water bath for an additional one or two weeks. The extent of the grouting and sanding required afterwards to obtain a smooth, paintable finish will be minimized by meticulous preparation of the form and careful concrete placement.

7.3 COST ASSESSMENT

Table 7.1 below shows the anticipated tasks with the expected labor and material costs associated with general construction of the concrete canoe.

Table 7.1 Cost Assessment

Tasks	Hours	Hourly Cost	Labor Cost	Materials Cost	TOTAL COST
Preliminary Research	5	$30	$150	NA	$150
Form Construction	50	$30	$1,500	$150	$1,650
Reinforcement Placement	40	$30	$1,200	$75	$1,275
Concrete Placement	15	$30	$450	$215	$665
Curing	2	$30	$60	NA	$60
Sanding	20	$30	$600	$30	$630
Painting	10	$30	$300	$300	$600
TOTALS	**142**	**NA**	**$4,260**	**$770**	**$5,030**

8.0 PROJECT MANAGEMENT

Project management will be accomplished by the critical path method. The following Table 8.1 displays the proposed scheduling for design and construction of the concrete canoe.

Table 8.1 Critical Path

DATES	CRITICAL TASKS
15 December 1997	Begin Hull Design, Reinforcement Design, and Concrete Mixture Design
05 January 1998	Select Final Hull and Reinforcement Designs and Begin Form Design
12 January 1998	Begin Form Construction
02 February 1998	Select Final Concrete Mixture Design
06 February 1998	Finish Form Construction
07 February 1998	Place Concrete and Begin Curing
02 March 1998	Begin Sanding
16 March 1998	Finish Curing and Begin Painting
16 April 1998	ASCE Rocky Mountain Regional Conference

9.0 SUMMARY

The concrete canoe team has been selected in behalf of the Utah State University Student Chapter of the American Society of Civil Engineers to prepare an entry for the 1998 ASCE Rocky Mountain Regional Concrete Canoe Competition.

The inherent challenges of this project include maximizing strength while minimizing weight, designing a hull geometry which is both stable and sleek in racing, and producing a finished product which is both durable and aesthetically pleasing.

Careful consideration will be given to the design and analysis of the hull geometry, reinforcement, and concrete mixture to be utilized in the construction of the concrete canoe.

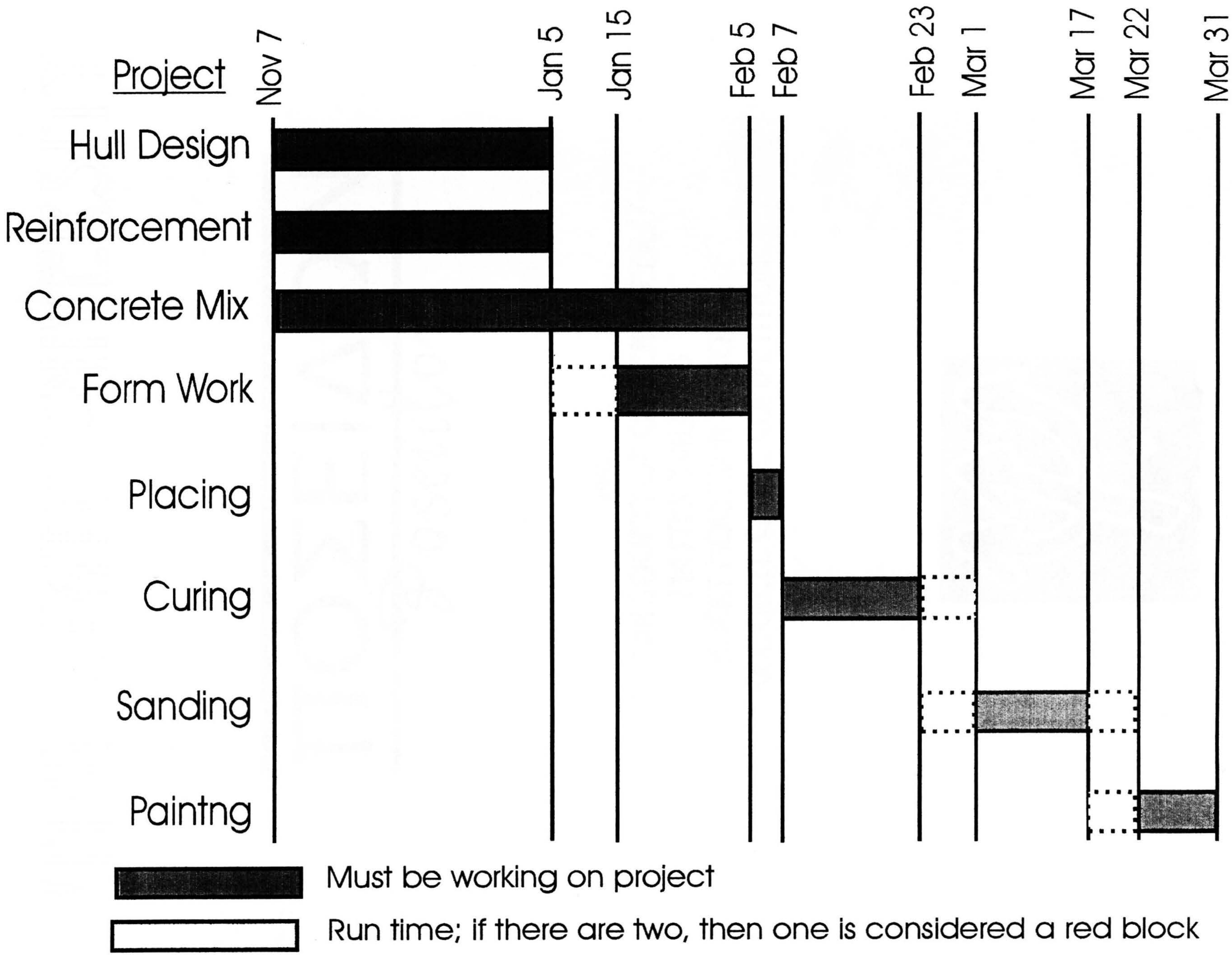
The total projected costs are shown in the following Table 9.1.

Table 9.1 Total Cost Assessment

Tasks	Hours	Labor Cost	Materials Cost	TOTAL COST
Hull Design	87	$3,050	$30	$3,080
Reinforcement Design	72	$3,550	$20	$3,570
Concrete Mixture Design	122	$3,700	$650	$4,350
Construction	142	$4,260	$770	$5,030
TOTAL	**343**	**$14,560**	**$1,470**	**$16,030**

The project team members are confident that their individual academic preparation, work experience, and innovation will effectively combine to develop for Utah State University a winning concrete canoe entry to the ASCE Rocky Mountain Regional Conference.

APPENDIX

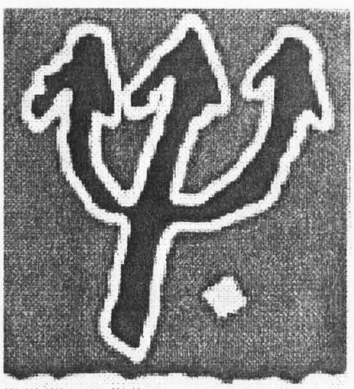

Project
Nov 7
Jan 5
Jan 15
Feb 5
Feb 7
Feb 23
Mar 1
Mar 17
Mar 22
Mar 31
Hull Design
Reinforcement
Concrete Mix
Form Work
Placing
Curing
Sanding
Paintng
Must be working on project
Run time; if there are two, then one is considered a red block

UTAH STATE UNIVERSITY

ΠΟΣΕΙΔΩΝ

Poseidon

1998
AMERICAN SOCIETY OF CIVIL ENGINEERS/
MASTER BUILDERS
ROCKY MOUNTAIN REGIONAL
CONCRETE CANOE COMPETITION



STATEMENT OF CERTIFICATION

This statement of certification assures compliance with the requirements of the American Society of Civil Engineers/Master Builders National Concrete Canoe Competition as stipulated in Section III.A.7 of the rules and regulations of the national competition. Specifically, (1) the construction of the canoe has been performed in complete compliance with the rules and regulations of the national competition, (2) the ten members intended to be registered at the national competition are qualified student members as specified in the rules and regulations of the national competition, and (3) the canoe has been completely built within the current academic year of the competition.

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W. Spencer Guthrie
Concrete Canoe Team Captain
Utah State University

1.0 EXECUTIVE SUMMARY

Utah State University proudly presents its concrete canoe entry, POSEIDON, to the 1998 American Society of Civil Engineers/Master Builders Rocky Mountain Regional Concrete Canoe Competition. POSEIDON weighs 110 lbs (49.9 kg) and measures 17' (5.2 m) in length, 26" (66.0 cm) in width, and 11" (27.9 cm) in depth. The average concrete wall thickness is 0.4" (1.0 cm). The deep blue finish and various highlights were created by utilizing a base coat/clear coat automotive paint system.

Significant design features enhance numerous aspects of the hull shape, reinforcement, and concrete mixture employed in constructing POSEIDON. A hull shape incorporating the simultaneous use of tumblehome geometry and straight sides facilitates both stability and a more efficient paddler position. The aggregate gradation of the concrete mixture is founded on the 0.45 Power Gradation Curve developed by Goode and Luffsey (FHWA) to achieve maximum density. A transverse thrust block (TTB) across the interior of each paddler position offers structural support and affords efficient transfer of momentum from the paddlers to the canoe. These individual design features, balanced with proven design and construction techniques, lend substantial confidence to the success of POSEIDON.

2.0 INTRODUCTION

Utah State University was founded in 1888 as a state land-grant college. Since those early years, USU has gained an international reputation for research and teaching and is recognized as being a Carnegie Foundation Research I institute. Only the top 3% of research institutions in the nation receive this honor. This high level of excellence attracts quality students from around the world to a beautiful campus on the edge of the Rocky Mountains. An enrollment of over 21,000 students during the Fall of 1997 was composed of individuals from each of the 50 American states, Puerto Rico, and 87 foreign countries. This assortment of students leads to great ethnic diversity and an increased cultural understanding.

The College of Engineering, one of eight colleges at Utah State University, is comprised of five departments. These departments consist of Biological and Irrigation Engineering, Civil and Environmental Engineering, Electrical and Computer Engineering, Industrial Technology and Education, and Mechanical and Aerospace Engineering.

The concrete canoe team is comprised of students from the Department of Civil and Environmental Engineering. Academic courses and work experience have been invaluable tools to the team in preparation for the concrete canoe competition this year. Members of the team have experience in fluid mechanics analyses, concrete and reinforced concrete design, and other significant training of great benefit in the design and construction of POSEIDON.

Named after the Greek god of the sea most feared among Olympians, POSEIDON boasts the power to command both waves and winds. The concrete canoe team is proud to represent the Department of Civil and Environmental Engineering at USU at the 1998 ASCE Rocky Mountain Regional Conference. Powerful and persistent, POSEIDON is tenacious in competition.

3.0 HULL DESIGN

The hull design team focused on maximizing stability, tracking, maneuverability, and paddling ease, while minimizing drag and wave forces. Also critical was the task of designing a canoe which could be easily constructed, particularly as complex curvatures are difficult to reinforce.

Literature reviews on the subjects of canoes and hydrodynamics offered guidelines for design. A desired canoe shape exhibits primary stability, or resistance to initial rocking, as well as secondary stability, the resistance to capsizing once tipping begins. At the same time, maneuverability must also be maintained. Optimum longitudinal shape fosters the reduction of skin friction, form drag, and wave forces, as well as promotes fine tracking performance.

Excellent hull design facilitates an efficient paddling motion by affording a closer stroke at a reduced vertical angle from the paddler's body. This translates into a shorter reach and a more powerful, efficient stroke.

3.1 DESIGN OPTIONS

Considering the above design characteristics, the design team pressed forward to create a new and competitive canoe shape for POSEIDON. Five canoe hull designs were developed. Both longitudinal symmetry and asymmetry were thus considered, adding an inventive touch to the aesthetic and practical aspects of the project. Maximum width varied from 26" (66.0 cm) to 28" (71.1 cm), positioned either at midship or at 10% of hull length aft of midship, and was located at 4" (10.2 cm) below the gunwale in every case. Canoe depth and estimated freeboard were constant at 11" (27.9 cm) and 5" (12.7 cm), respectively, for all designs. Also, all designs were 17' (5.2 m) long, a length believed to advocate superior tracking and maneuverability, as well as stability.

The plan view, longitudinal curvature for all canoes was based on estimated positions of paddlers and the required width at these sections. Each design also incorporated a moderate rocker measuring 2" (5.1 cm) in the bow and 1" (2.5 cm) in the stern, ensuring maneuverability and reducing the tendency of the canoe to bow-dip.

A shallow arch bottom was introduced as the typical cross section, reported by canoe manufacturers to be better in overall racing performance than flat or round bottom cross sections.

Some initial stability was thereby forfeited, whereas secondary stability was still expected to be strong. In the paddler areas, slight tumblehome sides were added to each design to maintain paddler efficiency and to reduce tipping induced by leaning during racing.

3.2 METHODOLOGY

Prior to execution of dynamic and static analyses, the geometry for each proposed design was drawn to scale in AutoCAD. In developing the curvature in these drawings, it was evident that the chosen dimensions and positions of paddler sections governed the overall longitudinal shape. As a result, two of the designs with maximum width at midship took on an asymmetrical shape.

For dynamic force analysis, five wooden models were built at a 1:7 scale to be tested in a water flume. These models framed only the lower six inches of each canoe structure, the portion estimated to be submersed during racing. A steel bar instrumented with a strain gage was attached to each model in succession and rigidly fixed in the flume at the proper depth. With the assistance of a strain indicator, the relative magnitude of forces acting on the models was measured. The intent of this exercise was to aid in choosing the hull design which experienced the least composite drag and wave forces.

Though attempts to work with the Reynolds number in dimensionally analyzing the models were frustrated by limitations on fluid velocity in the testing apparatus, Froude number similarity, representative of wave forces, was nonetheless possible. According to experienced professors and various publications on hydrodynamics, wave forces dominated in this situation.

In addition to dynamic analyses of proposed designs, the critical cross sections for each design were evaluated for secondary stability. Cross sections analyzed were the front and back paddler sections, together with the section of maximum width. This was accomplished by manipulating the cross section drawings in AutoCAD. Working with the estimated water line and overall center of gravity for each loaded section, an approximate righting moment, upon tipping, was determined. A positive righting moment for a particular design would indicate that the hull geometry is successful in returning the canoe from tipping to an upright position.

3.3 RESULTS

Experimental dynamic force analysis revealed minimal differences between the five models. The variation in observed forces was very small, and this was attributed primarily to the similarity in model shape and the difficulty of model construction at a 1:7 scale. Static analysis of design cross sections also indicated negligible difference between designs, showing a nearly equal righting moment in all cases. This average righting moment for a 10-degree rotation ranged between 72 in-lbs (8.1 N-m) and 91 in-lbs (10.3 N-m) for the five designs considered.

Based on the theory that a narrower canoe produces less drag and wave forces than a wider one, length being constant, the designs of 26" (66.0 cm) widths were evaluated for construction. By thus eliminating the designs of 28" (71.1 cm) widths, overall weight was minimized, tracking ability was maximized, and compromise in stability was minor. In addition, it was decided to place the maximum width at midship, combined with a forced asymmetrical shape due to pre-determined paddler section criteria. An innovative asymmetrical design would provide a more gradual bow expansion, reducing the effect of the controlling wave forces. By having its maximum width at midship, and thus more capacity for sustaining a relatively long section of increased width through its center, POSEIDON would have significantly better stability than a design with maximum width aft midship.

Key design dimensions for POSEIDON include a 17' (5.2 m) length, 26" (66.0 cm) widest point located at midship, 19" (48.3 cm) width at the front paddler section, 20" (50.8 cm) width at the back paddler section, and a rocker of 2" in the bow and 1" in the stern. Based on geometries of racing canoes studied, paddler sections are strategically placed 5' (1.5 m) from the bow and 3.5' (1.1 m) from the stern. These set positions for paddlers aided in the placement of the TTBs implemented to enhance paddler efficiency.

4.0 CONCRETE MIXTURE DESIGN

The design goals for the concrete mixture were a high strength-to-weight ratio, low specific gravity, adequate workability, and satisfaction of minimum compressive strength requirements. Based on previous finite element analyses performed on concrete canoe geometries, a 28-day compressive strength of approximately 2000 psi (13.8 MPa) was recommended for POSEIDON.

4.1 DESIGN OPTIONS

Many different materials were considered for use in the concrete mixture design for POSEIDON. The three types of aggregate evaluated were Kinetico ceramic spheres, Recyclospheres Bionic Bubble microspheres, and Utelite expanded shale. Previous experience with the use of Mighty, a melamine-based superplasticiser and water reducer, supported the decision to examine its performance in the concrete mixture also. The design team further chose to implement CTS Type III Rapid Set Portland Cement as the binding material. Additional variables included polyolefine fibers and sugar.

4.2 METHODOLOGY

Given the above options, the design team first evaluated the physical properties of the available aggregates. Sieve analyses, specific gravity, and absorption tests were performed on each type in accordance with ASTM C136, C127, and C70, respectively. The 0.45 Power Gradation Curve developed by Goode and Luffsey (FHWA) was employed to determine the required percentages of each size of aggregate necessary to achieve theoretical maximum density. An iterative approach revealed an aggregate gradation structure realizable with available materials. The 0.45 Power Gradation Curve is shown below.

$$P=100(d/D)^{0.45}$$

P=Percent Passing for Particle Diameter d
d=Diameter of Particle Size Being Considered
D=Diameter of Largest Particle Size in Series

A QuattroPro spreadsheet program based on volumetrics was next designed to accept information from sieve analyses and specific gravity tests. Given the preferred aggregate gradation, the desired batch volume, and the volumetric percentages of water and cement under consideration, the spreadsheet provided the required mass of each ingredient, the water-cement ratio, and the overall specific gravity of the proposed concrete mixture. Therefore, by simply varying the volumetric percentages of water and cement for a given batch size, mixture compositions with preferred specific gravity and water-cement ratio combinations were targeted directly. Four such mixture designs are displayed in the following Table 4.1. This method of design further streamlined the actual casting and testing procedures by eliminating mixtures not theoretically sound.

Samples were cast in cylinders 4" (10.2 cm) in length and 2.5" (6.4 cm) in diameter. These were placed in a moisture room at 100% humidity, and the forms were removed after 24 hours to facilitate full hydration. At a 7-day cure, each sample was capped with high strength gypsum and subjected to compression testing. The results were extrapolated to a 28-day strength for evaluation through a factor of 0.69 as determined through research at Cornell University.

By assigning a single person to manage the laboratory work associated with each concrete mixture design, consistency was maintained in all aspects of mixture preparation, cylinder casting, and sample testing.

4.3 RESULTS

Both materials evaluations and mixture compressive strengths played key roles in determining the final concrete mixture design. At 1.75, for example, the specific gravity of the expanded shale made it an unattractive choice among the available aggregates. However, with specific gravities of 0.7 and 0.6, respectively, the ceramic spheres and the microspheres proved valuable in successive concrete mixture designs.

Polyolefine fibers were not selected for use because of their trivial contribution to bending strength in comparison to the ½" (1.3 cm) steel hardware mesh ultimately chosen for primary reinforcement in POSEIDON. Furthermore, loose fiber ends in the surface of concrete samples were difficult to finish. Sugar was found to be an effective retardant and was thus utilized during actual construction. The final concrete mixture design is shown in the following Table 4.1 as mix number one, shaded for identification. The binding material is 100% CTS Type III Rapid Set Portland Cement.

Table 4.1 Concrete Mixture Design

CONCRETE MIXTURE DESIGN								
MIX NUMBER	ONE		TWO		THREE		FOUR	
MIXTURE	AMOUNT		AMOUNT		AMOUNT		AMOUNT	
INGREDIENTS	lb/yd^3	kg/m^3	lb/yd^3	kg/m^3	lb/yd^3	kg/m^3	lb/yd^3	kg/m^3
Ceramic Spheres (ML714)	447	265	438	260	430	255	460	273
Ceramic Spheres (ML1430)	305	181	300	178	293	174	315	187
Ceramic Spheres (ML3050)	137	81	133	79	131	78	140	83
Microspheres (Coal Ash)	74	44	72	43	71	42	76	45
Water Reducing Agent	42	25	19	11	8	5	34	20
Portland Cement (Type III)	769	456	769	456	760	451	602	357
Water	308	183	342	203	384	228	302	179
Sugar	0.59	0.35	0.59	0.35	0.59	0.35	0.59	0.35
Avg. 7-day Comp. Strength	2576 psi	17.8 MPa	2190 psi	15.1 MPa	1937 psi	13.4 MPa	1279 psi	8.8 MPa
Specific Gravity	1.00		1.00		1.00		0.95	
Water/Cement Ratio	0.40		0.45		0.50		0.50	

5.0 REINFORCEMENT

The goal in reinforcement design for POSEIDON was to identify a lightweight, pliable reinforcement which could provide maximum strength with minimum weight. The ability of concrete to bond with the reinforcement and the ease of construction were major factors considered in choosing among reinforcement alternatives.

5.1 DESIGN OPTIONS

Five different reinforcement combinations were considered in the construction of POSEIDON. Geogrid, ½" (1.3 cm) steel hardware mesh, and 1" (2.5 cm) chicken wire were evaluated in combination with braided wire and 18-gauge straight wire as additional longitudinal reinforcement.

The benefits of a TTB along the interior of the canoe at each paddler position were also examined. A TTB would provide greater resistance to failure in the area occupied by the paddlers' knees and would afford greater efficiency in the transfer of momentum from the paddlers to the canoe.

5.2 METHODOLOGY

In order to evaluate the performance of various combinations of reinforcement materials, composite panel tests were performed on the five combinations shown in Table 5.1 below. Metal forms of 11" x 5" x ½" (27.9 cm x 12.7 cm x 1.3 cm) in size were fabricated to ensure uniformity in sample panel dimensions and to effectively model expected performance. A standardized concrete mixture was selected to enable accurate and consistent interpretations of testing results. Three composite panels were then prepared for each combination and allowed to cure for 21 days at 100% humidity. Upon careful removal from the forms, the samples were subjected to a line load applied across the width of each simply supported sample. The failure load and sample weight were recorded for each plate.

5.3 RESULTS

The results of the composite panel testing are displayed in Table 5.1 below. The advantages of each panel were evaluated, and the final decision was based on the strength and pliability characteristics of each type of reinforcement material. Hardware mesh scored well in both these factors and was selected for use as primary reinforcement. Straight wire was selected as secondary reinforcement.

Geogrid was rejected due to its relatively low panel strength, a result attributed to its weak bonding interface with the concrete. Furthermore, geogrid proved too resistant to the necessary shaping required to match the desired curvature of the hull shape. Braided wire was avoided due to its inadequate integrity, as the separation of the numerous strands hindered efficient construction. Chicken wire was eliminated because it required additional straight wire to meet the strength of hardware mesh alone and also proved difficult to shape.

Table 5.1 Results from Reinforcement Panel Testing

Reinforcement Combination	Line Load at Failure (lbs)	Line Load at Failure (N)
Geogrid with 18-Gauge Straight Wire	65	289
1/2" Steel Hardware Mesh with Braided Wire	170	756
1/2" Steel Hardware Mesh with 18-Gauge Straight Wire	164	730
1/2" Steel Hardware Mesh	93	414
Chicken Wire with 18-Gauge Straight Wire	93	414

6.0 CONSTRUCTION

Construction of POSEIDON was founded on techniques proven through experience. A male form was chosen because of the ease and speed of construction. The male form was constructed using 1" (2.5 cm) styrofoam sheeting cut into 12" x 32" (30.5 cm x 81.3 cm) panels. Line drawings on each panel were accomplished through meticulous plotting of coordinates exacted from detailed AutoCAD drawings of the proposed hull shape. Coordinates were recorded at 1" (2.5 cm) vertical increments around the perimeter of each section, and this was repeated through the length of POSEIDON on 2" (5.1 cm) intervals. Individual sections were then trimmed along the desired outline and numbered for proper placement in the form.

Construction adhesive was pressed between adjacent sections to assemble the form, which was then carefully sanded to the desired shape. Sheetrock joint compound was applied over the styrofoam surface and sanded to achieve a smooth finish. Plastic wrap was then glued over the form to protect the joint compound from moisture damage from concrete placement and to facilitate simple removal of the styrofoam for later grouting and finishing.

The ½" (1.3 cm) steel hardware mesh reinforcement was installed by first shaping the hardware mesh to the form. Light blankets were placed over the form to protect the plastic wrap against tearing and punctures. The blankets also effectively spaced the reinforcement sufficiently far from the form that the need for spacers during concrete placement was eliminated. The ability of the hardware mesh to retain its shape also simplified the task of tying the necessary portions together to assure structural continuity throughout the reinforcement. The 18-gauge straight wire to be used for longitudinal reinforcement was additionally utilized to tie the mesh together.

Once the mesh was tied, the blankets and reinforcement were removed, and the shaped reinforcement was again placed on the form. Longitudinal wires were placed along the full length of each gunwale and tensioned to tightly shape the hardware mesh to the form. Additional lateral wires were run under the form between gunwales to further refine the edge contours. Each TTB was reinforced using 18-gauge straight wire.

Placement of the concrete was completed in four sections and required batch mixing of approximately 2.5 ft^3 (0.071 m^3) of concrete. All materials were apportioned, and dry ingredients for each batch were well mixed before placement began. Concrete was hand placed and then vibrated using a half-sheet vibratory sander through a protective plastic interface. Thickness uniformity was monitored using toothpicks marked at 0.4" (1.0 cm). With sugar acting as a retarder in the concrete mixture, the construction team had nearly an hour to finish the concrete surface.

Following the placement of concrete, the entire canoe was encased in plastic sheeting and supplied with a low-pressure steam hose to begin a 7-day steam cure. Upon removal of the form from the partially cured canoe, acrylate polymer was mixed with CTS Type III Rapid Set Portland Cement, Recyclospheres Bionic Bubble microspheres, and water to make the mortar necessary for grouting. The acrylate polymer improved the flexural, compressive, and impact strength of the grout and reduced the possibility of surface cracking and spalling. Further curing of POSEIDON consisted of a 7-day submerged cure, with the remaining 14 days dry (7h/7w/14d). Repeated grouting and sanding prepared the canoe for final painting, which was accomplished with a base coat/clear coat automotive paint system applied with an air sprayer.

7.0 PROJECT MANAGEMENT

Management responsibilities for the design and construction of POSEIDON were decided at the start of the academic year. In consideration of the broad range of requirements for a successful canoe, the various duties were subsequently divided among the members of the team. Five committees were organized, each with a committee head who was accountable to the team captain. The committees addressed hull design, concrete mixture design, reinforcement design, form construction, and paddler conditioning. Each member of the team recorded his or her hours on a standardized time sheet prepared for this purpose.

Each committee head was responsible for reporting the progress of their committee to the team captain in weekly project management meetings. In these meetings, committee heads recounted headway made during the week and also made known to the team captain the specific needs of the committee for the coming week. In this way, the team captain was able to confirm progress and arrange for the necessary volunteers and materials to be present when needed. These meetings were also beneficial for exchanging ideas with respect to the project and for allowing different committees to ensure that their individual ideas for the project were compatible.

The committee heads and team captain employed the Critical Path Method (CPM) to formulate a plan for completing the necessary steps of the project. By referring often to this proposed critical path, progress was measured and actions taken to afford timely completion of the project. The critical path prepared for the construction of POSEIDON is shown below in Figure 7.1.

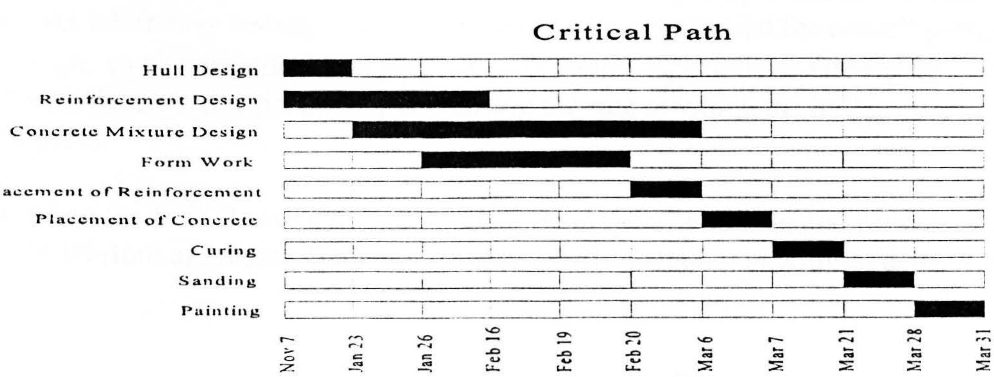


Figure 7.1 Critical Path

8.0 COST ASSESSMENT

A detailed cost assessment was produced using a specialized spreadsheet. The spreadsheet compiled data from the individual time sheets submitted by each team member. Materials and labor costs were calculated using the standard costs stipulated in the rules and regulations of the national competition. Complete materials lists were retained by the project engineer for each group. A generalized cost assessment is shown in Table 8.1 below. Detailed calculations for cost assessment are shown in Appendix A.

Table 8.1 Generalized Cost Assessment

		LABOR	MATERIAL	TOTAL
	Hull	$7,266	$10	$7,276
Design	Concrete	$2,227	$19	$2,246
	Reinforcement	$540	$10	$550
	Form	$1,627	$122	$1,749
	Concrete	$195	$189	$384
Construction	Reinforcement	$910	$1	$911
	Curing and Finishing	$698	$16	$714
	Painting	$75	$377	$452
	Equipment	$100	$20	$120
Competition	Report	$1,395	$24	$1,419
	Display	$120	$39	$159
	Presentation	$1,140	$0	$1,140
Management	Group Meetings	$1,830	$0	$1,830
	Fundraising	$150	$0	$150
	Sub-Totals	$18,273	$826	$19,099
	Overhead	$3,654	$0	$3,654
			TOTAL	**$22,753**

9.0 INNOVATIVE FEATURES

POSEIDON boasts several innovative features contributing to its success as a sleek, stable racing canoe. As laboratory testing revealed that wave forces governed the overall performance of the hull design, an asymmetrical hull shape was designed especially to streamline POSEIDON. This effectively decreased resistance by decreasing the rate at which the hull geometry achieved its widest point.

Founded on the 0.45 Power Gradation Curve developed by Goode and Luffsey (FHWA), the concrete mixture aggregate gradation was designed to attain a maximum density given the limited availability of aggregate materials. This gradation afforded a minimized volume of Portland Cement within the mixture and effectively reduced the overall weight of POSEIDON.

Bending moment testing of sample composite panels served as an innovative method to evaluate the strengths of reinforcement types being considered. Implementation of TTBs across the interior of each paddler position offer structural support and afford efficient transfer of momentum from the paddlers to the canoe.

The use of easily finishable sheetrock joint compound in conjunction with plastic wrap to finish the styrofoam form was an innovative method of form construction. Immediately after concrete placement, POSEIDON was wrapped in plastic sheeting and supplied with a low pressure steam hose to facilitate a 7-day cure. The utilization of acrylate polymer in the grout mixture also proved to be an inventive feature. Further curing was accomplished through a 7-day submerged cure (7h/7w/14d). This method of curing provided excellent hydration and high concrete strength. These innovative features balanced with proven engineering experience lend substantial confidence to the success of POSEIDON.

10.0 SUMMARY

The overall objective of the Utah State University concrete canoe team was to produce a theoretically sound, competitive watercraft for the 1998 American Society of Civil Engineers/Master Builders Rocky Mountain Regional Concrete Canoe Competition. Innovation coupled with engineering experience founded the basis for the design of the hull shape, concrete mixture, and reinforcement.

Combining high-strength, lightweight concrete with a durable reinforcement to fabricate a superior hull design has produced an aesthetically pleasing and dynamically sure craft that will perform at the standard of excellence upheld at Utah State University.

APPENDIX

Table A1. Detailed Labor Cost Assessment

Description of Work Done			Consultants	Principal Engineer	Project Manager	Project Engineer	Foreman	Labor	Computer	COSTS
Design										
Hull:	Research									
		Library Research				7				$210
		Catalog Research				6				$180
		Consultation	2			2				$445
	Design Work									
		Shape Creation			2	15		15	20	$2,268
		AutoCAD Static Analysis				9			9	$945
		Spreadsheet Analysis				2			4	$360
	Dynamic Modeling									
		Materials Collection						1		$15
		Model Construction					18	26		$833
		Model Testing & Analysis		2			6	4		$348
		Experimental Preparation	4			3		1		$905
	Freeboard and Design Finalization									
		AutoCAD Drawing				5			5	$525
		Numerical Value Extraction						12	1	$233
Concrete:	Materials Collection				1			2		$55
	Specific Gravity Testing		1			6		8		$500
	Spreadsheet Concrete Design					11			11	$1,155
	Concrete Testing			1				32		$518
Reinforcement:	Material Research					4				$120
	Materials Collection				1			1		$40
	Sample Preparatior					1	8	6		$320
	Testing							4		$60
Construction										
Obtain Materials								8		$120
Forming:	Form Construction					10		81		$1,508
	Reinforcement Construction						7	49		$910
Concrete Work:	Placement							13		$195
	Curing							9		$128
	Grouting							15		$225
Finishing:	Sanding							23		$345
	Painting/Lettering							5		$75
Competition										
Equipment					2					$100
Reporting (Written)						34			5	$1,395
Display						2		4		$120
Presentation				1		13			9	$1,140
Management										
Group Meetings (Correlation)					9	46				$1,830
Fundraising								5	1	$150
Total Project Hours			7	4	14	176	39	322	65	625
								Labor Sub-total		$18,273
								Overburden (20%)		$3,654.6
								TOTAL LABOR		$21,928

Appendix A
Cost Assessment

Table A2. Detailed Material Cost Assessment

	Task	Item	Rate	Quantity	Total
Design	*Hull Modeling*	Wood (2x4)	$1.39 /M	4 M	$5.56
		Wood Filler	$6.34 /Liter	0.5 Liter	$3.17
		Varnish	$1.32 /Liter	1 Liter	$1.32
	Concrete Testing	Testing Materials	LS		$17.93
	Reinforcement Testing	Testing Materials	LS		$9.57
Construction	*Form*	Sheetrock Joint Compound	$0.47 /Liter	19 Liter	$8.93
		Styrofoam	$1.89 /M^2	54 M^2	$102.06
		Construction Adhesive	$3.50 /Liter	3 Liter	$10.50
		Plastic Wrap	$0.02 /M	8 M	$0.16
	Concrete	Cement	$0.08 /Kg	30.3 Kg	$2.33
		Superplasticizer/Water Reducer	$2.11 /Liter	1.5 Liter	$3.17
		Sugar	$0.01 /Kg	0.0053 Kg	$0.00
		Ceramic Beads (ML 714)	$5.62 /Kg	17.6 Kg	$98.91
		Ceramic Beads (ML 1430)	$4.83 /Kg	12 Kg	$57.96
		Ceramic Beads (ML 3050)	$4.03 /Kg	5.4 Kg	$21.76
		Microspheres (coal ash)	$0.03 /Kg	2.9 Kg	$0.09
		Acrylate Polymer	$5.19 /Liter	1 Liter	$5.19
	Reinforcement	Reinforcing Steel	$0.03 /Kg	0.4 Kg	$0.01
		Welded Wire Mesh	$0.04 /M^2	5 M^2	$0.20
	Curing & Finishing	Sandpaper	$0.40 /Sheet	25 Sheets	$10.00
		Drywall Sanding Screens	$1.50 /Screen	4 Screens	$6.00
	Paint	Resin (Part A)	$23.63 /Liter	5 Liters	$118.15
		Hardener (Part B)	$51.69 /Liter	5 Liters	$258.45
Competition	*Equipment*	Canoe Stand	LS		$20.00
		Paddles and Life jackets	LS		$0.00
	Report	Paper and Copies	$0.05 /Copy	112 Copies	$5.60
		Binding	$3.00 /Report	6 Reports	$18.00
	Display	Photo Developing	$4.50 /Roll	2 Roll	$9.00
		Styrofoam	$1.89 /M^2	8.9 M^2	$16.82
		Cloth Covering	$1.50 /M	9 M	$13.50
		Printing	$0.05 /Copy	10 Copy	$0.50
				Total Materials	$824.84

Table A3. Total Cost

Total Materials	$824.84
Total Labor	$21,928.00
Total Cost	**$22,752.84**

POSEIDON

UTAH STATE UNIVERSITY

DIMENSIONS

Weight	110 lbs (49.9 kg)
Length	17 ft (5.2 m)
Width	26 in (66.0 cm)
Depth	11 in (27.9 cm)
Thickness	0.4 in (1.0 cm)

HULL DESIGN
OBJECTIVES

MAXIMIZE:

- Stability
- Tracking
- Maneuverability
- Hydrodynamic Efficiency
- Paddling Efficiency
- Ease of Construction

HULL DESIGN
METHODOLOGY

- AutoCAD Drafting
- Model Construction
- Dynamic Analysis
- Static Analysis

HULL DESIGN
RESULTS

- Shallow Arch Bottom
- Moderate Rocker
- Assymmetrical Longitudinal Curvature

CONCRETE DESIGN
OBJECTIVES

MAXIMIZE:

- Strength-to-Weight Ratio
- Workability

CONCRETE DESIGN
METHODOLOGY

- Materials Evaluation
  - Sieve Analyses (ASTM C136)
  - Specific Gravity Tests (ASTM C127)
  - Absorption Tests (ASTM C70)
- Aggregate Gradation
  - 0.45 Power Gradation Curve
- Volumetric Design

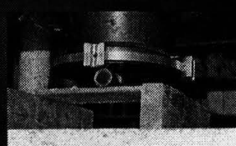
REINFORCEMENT
OBJECTIVES

MAXIMIZE:

- Composite Flexural Strength
- Bonding Ability
- Pliability

REINFORCEMENT
METHODOLOGY

- Construction of 5"x11"x1/2" Composite Panels
- Bending Moment Testing



REINFORCEMENT
RESULTS

- Final Reinforcement Selection

Reinforcement Combination	Line Load at Failure (lbs)	Line Load at Failure (N)
Geogrid with 18-Gauge Straight Wire	65	289
1/2" Steel Hardware Mesh with Braided Wire	170	756
1/2" Steel Hardware Mesh with 18-Gauge Straight Wire	164	730
1/2" Steel Hardware Mesh	93	414
Chicken Wire with 18-Gauge Straight Wire	93	414

- Transverse Thrust Block (TTB)

CONSTRUCTION

- Form
  - 12" x 32" x 1" Styrofoam Panels
  - Joint Compound
  - Plastic Wrap

CONSTRUCTION

- Reinforcement
- Concrete
  - Hand Placed
  - Vibrated
  - Finished

CONSTRUCTION

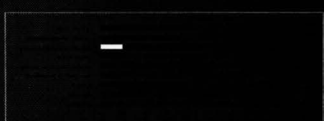
- Curing
  - 7-Day Low-Pressure Steam Cure
  - 7-Day Submerged Cure
  - 14-Day Dry Cure

CONSTRUCTION

- Finishing
  - Acrylate Polymer in Grout
  - Automotive Paint System

PROJECT MANAGEMENT

- Committees
- Weekly Meetings
- Critical Path Method



COST ASSESSMENT

		LABOR	MATERIAL	TOTAL
Design	Hull	$7,266	$10	$7,276
	Concrete	$2,227	$19	$2,246
	Reinforcement	$540	$10	$550
Construction	Form	$1,627	$122	$1,749
	Concrete	$195	$189	$384
	Reinforcement	$910	$1	$911
	Curing and Finishing	$698	$16	$714
	Painting	$75	$377	$452
Competition	Equipment	$100	$20	$120
	Report	$1,395	$24	$1,419
	Display	$120	$39	$159
	Presentation	$1,140	$0	$1,140
Management	Group Meetings	$1,830	$0	$1,830
	Fundraising	$150	$0	$150
	Sub-Totals	$18,273	$826	$19,099
	Overhead (120%)	$21,927	$0	$21,927
			TOTAL	$41,026

INNOVATIVE FEATURES

- Assymmetrical Longitudinal Shape
- 0.45 Power Gradation Curve
- TTBs
- Steam/Submerged Cure
- Acrylate Polymer

POSEIDON