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Mix Design for a Concrete Canoe

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MIX DESIGN FOR A CONCRETE CANOE

by

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Abstract

Each year the American Society of Civil Engineers sponsors a concrete canoe competition. This paper details the work performed by Ryan Christensen for the 2006 concrete canoe competition. His primary focus was on formulating a concrete mix to be used for the Utah State University canoe. Basic information regarding the building and design of concrete canoes is also presented. Finally, general competition results for 2006 are presented for the Utah State University canoe team.

Acknowledgements

To be honest, it is difficult for me to remember a time when I haven't been in school so I suppose it's fortunate for me that my scholastic experience has been good. Over the years I have had many good teachers and they have shaped my view of learning and the hard work that is necessary to excel. Dr. Michael Johnson, Dr. Loren Anderson, and Dr. Laurie McNeill are a few of my favorites. I also owe a great deal to Steve Barfuss for giving me the opportunity to work with him. The greatest thanks of all goes to my wife Amy for love, support, and patience. She has helped me to be a better person than I ever could have been on my own.

Table of Contents

List of Tables

List of Figures

Introduction

Each year the American Society of Civil Engineers sponsors a unique event known formally as the ASCE National Concrete Canoe Competition. Engineering students across the United States are given the opportunity to design, build, and compete with a concrete canoe. Not surprisingly, most people have never heard of, nor considered the possibility of making a concrete canoe. All the same, there are a number of dedicated individuals who just can't seem to get enough. The author, Ryan Christensen was a member of the 2006 Utah State University concrete canoe team. His assignment was to develop the concrete mix to be use in the 2006 USU concrete canoe.

Team Members and Responsibilities

Building a concrete canoe is an extensive project, especially if the canoe is to be used in competition. The 2006 USU concrete canoe team was composed of six members: Jared Bates, Ryan Christensen, Russell Funk, Michael Jardine, John Pace, and Justin Woffinden. Russell Funk was chosen to be the team leader. Russell Funk, Justin Woffinden, and John Pace focused primarily on the construction of the canoe. Jared Bates and Michael Jardine focused on the design of the canoe's hull. Ryan Christensen focused on designing the concrete mix.

Design Constraints

It is no small task to build a concrete canoe. Adding a 76 page rulebook only adds to the intimidation. Because the end goal of this project was to compete in the 2006 western region concrete canoe competition, a brief description of the competition rules will be presented.

Additionally, the major points of the rules regarding the concrete mix will also be explained. Last of all, the process of designing the concrete mix will be described.

The Competition

The 2005 ASCE National Concrete Canoe Competition was made up of four main sections. Each section was worth 25% of the overall score. The first section was the Design Paper. The main portions of the design paper were hull design, analysis of the canoe, testing and development, project management and construction, mixture proportions, and overall presentation. The second portion of the competition was the oral presentation. The oral presentation was judged on the demeanor of the presenters, the presentation quality, and the answers given to the judge's questions. The final academic section of the competition was the judging of the final product. The final product judging was based on following the guidelines and regulations established for building the canoe, a flotation test, and a final product display. Last but not least, were the concrete canoe races. There were two categories of canoe races: sprint and endurance. There were men's, women's, and coed categories for the sprint races. The endurance race consisted of a men's and a women's race.

The Mix Design

Concrete Explained

Concrete is made up of a mixture of several different types of materials. The following is a brief introduction to some of the most common constituents of concrete.

The first category is made up of cementitious materials. Portland cement, fly ash, and a few other products fall into this category. Cementitious materials are defined in the 2006 National Concrete Canoe Competition rules as “cements and pozzolans used in concrete masonry and construction” (ASCE 2005). These are the materials that react with water to form a binding agent. Another material used in concrete is aggregate. Aggregates are inert granular materials such as sand, gravel, and crushed stone (Portland Cement Association, 2006). Cement, aggregate, and water are combined to form the most basic type of concrete.

Many different additives are used with concrete in order to enhance specific characteristics of the concrete. One such additive is fibers. Fiber materials range from very common substances like polyester to the more exotic Kevlar. Fibers help give strength, particularly tensile strength, to concrete. Admixtures are the final common concrete ingredient. The American Concrete Institute (ACI) defines admixtures as “a material other than water, aggregates, hydraulic cement, and fiber reinforcement, used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing” (ACI 2000). Due to the complex and varied nature of admixtures, an in depth discussion of admixtures is beyond the scope of this work.

Mix Requirements

There were three primary limitations imposed on the design of concrete mix:

1. Cementitious materials had to be used in one of the following proportions:
    a. Minimum of 70% of cementitious maters must be portland cement and 15% minimum fly ash

b. Minimum of 70% of cementitious maters must be portland cement and 25% slag cement
c. Minimum of 50% of cementitious maters must be portland cement, 15% minimum fly ash and 25% slag cement

2. Aggregate must fall within the range of "fine aggregate" as defined by Paragraph 6.1 of ASTM C 33 (see appendix for specific requirements) and must be a minimum of 25% of the weight of the concrete mixture.
3. The water to cement ratio must not exceed 0.5.
4. An air-entraining admixture must be used.

Additionally, our mix needed to be very flowable in order to meet the needs of construction through the use of a male-female mold.

Mix Design

In order to have a starting point in designing the mix for the canoe, concrete mixes developed for canoes used in previous years were analyzed. Two canoes had been built by USU students for the 2005 competition. The first, "Frank the Tank" utilized a new polymer based air-entrainment admixture called Miracon (Miracon Technologies 2006). Miracon has an appearance similar to shaving cream and allows a much higher degree of air entrainment because of the small size of the air bubbles and the uniform distribution of the voids. Through the use of Miracon, very light weight concrete was obtained even when using conventional concrete aggregates. Unfortunately, the design group was unable to maintain satisfactory contact with the developers of Miracon and subsequently was unable to utilize it as a design material. As a result, the canoe team was required to select a different baseline canoe mix. The other USU entry in the 2005 competition was "Down Periscope". The details for the mix design of Down Periscope are included in Table 1.

Table 1: Mix Design of Down Periscope

	Amount (lb/yd^3)
ASTM 150 Cement Type I / II (Cementitious Material)	520.2
Latex Emulsion Polymer (Admixture)	299.5
Class F Fly Ash (Cementitious Material)	126.2
Sand (Aggregate)	377.6
Duralite Plastic (Aggregate)	88.5
NyconRC fibers (fiber reinforcement)	1.85

Though not as strong or light weight as the Miracon based mix, this mix was still very good. The category of each ingredient is listed below the ingredient.

In developing the mix the 2006 canoe team started with these primary ingredients and then adapted the mix through trial and error to obtain the necessary strength while still meeting the construction guidelines. The light weight of the concrete was obtained by utilizing very fine glass bubbles as the largest portion of the concrete by volume. After comparing the physical properties of many different types of glass bubbles Sil-Cell 32 was selected to be used as the light weight aggregate in the 2006 canoe. Though Sil-Cell 32 was not the lightest of the glass beads considered, it was still very light with a unit weight of 12 lb/ft^3. Sil-Cell 32 was one of the strongest lightweight beads found with a compressive strength of 1800 psi. Perhaps the most important reason Sil-Cell 32 was chosen for use as an aggregate was because of its shape. Figure 1 compares a magnified view Sil-cell with standard glass bubbles.

Figure 1: Sil-Cell

Source: Silbrico, 1998

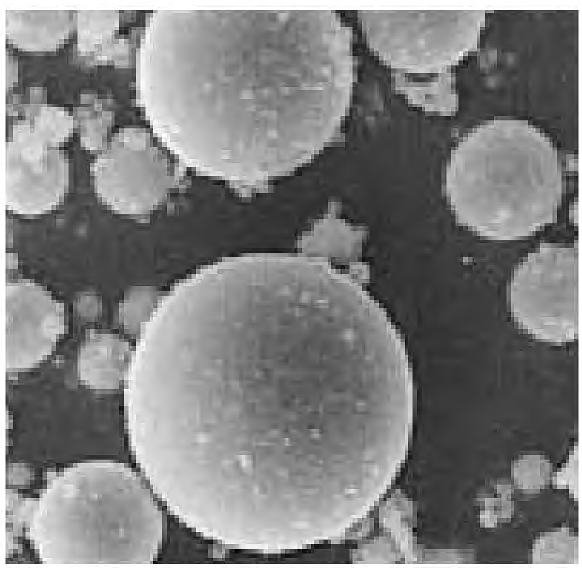

Figure 2: Standard glass bubble

Source: 3M, 2006

It can be seen that the standard glass bubble has a very spherical shape. The Sil-cell is much more irregularly formed. The irregular shape of the Sil-cell allows for mechanical interlocking of the individual particles in addition to the cohesion provided by cement. The mechanical interlocking increases the strength of the concrete as compared with a concrete using standard glass bubbles.

Sand meeting the gradation requirements of ASTM C 33 was chosen for use as the remainder of the aggregate. The main concern in meeting the ASTM C 33 gradation standard is a result of the very small size of Sil-cell 32. Nearly 100% of the Sil-cell will pass the No. 100 sieve but the maximum percent finer allowed is 10%. Pre-sifting of the sand to reduce the amount of sand passing the No. 100 sieve was considered as an option for reducing the percent finer than 0.15 mm. However, tests indicated that the Sil-cell was light enough, and the sand was sufficiently low in fines that removing the fines from the sand was found to be unnecessary.

Using a male-female mold to construct the canoe required a very flowable concrete mix. In order to have a flowable mix and meet the requirement of a 0.5 water-cement ratio Glenium 3030 NS, a high range water reducer, was used to reduce the amount of water required. The manufacturer's recommended dosage is 6-18 fluid ounces per 100 pounds of cementitious material. Exceeding the manufacturer's recommendation results in a mix that will quickly lose workability. Additionally, a mix that is too thin may separate.

The second admixture used was Micro-Air, an air entrainment admixture. Micro-Air was added in order to improve workability as well as decrease the unit weight of the concrete. The recommended dosage for Micro-Air is 0.5-1.5 fluid ounces per 100 pounds of cementitious material. In general, entraining air in concrete decreases the overall strength of the concrete while increasing durability. The recommended dosage provides enough air entrainment to provide better durability without sacrificing a large amount of strength. Increasing the dosage beyond the manufacturer's specifications will result in a relatively large reduction in concrete strength.

Laticrete was the final concrete additive used. Laticrete was added in order to increase the flexibility of the concrete. There was not a manufacturer's recommended dosage available for Laticrete. Laticrete is weaker then cement but much more flexible. Adding Laticrete can increase the strength of the composite concrete mixture because of the added flexibility it provides. However, when too much Laticrete is added to a concrete mix, strength will decline.

Two types of reinforcement were used. The first was Forta Fiber. Forta Fiber was dispersed throughout the concrete mix. The second reinforcement used was composite metal rods. The rods were located along each side and along the keel of the canoe. The reinforcement was located in order to strengthen the areas of maximum stress.

In summary, the final mix was similar to the baseline mix and is shown in Table 2.

Table 2: 2006 USU Concrete Canoe Mix

	Amount (lb/yd^3)
ASTM C150 Portland Cement	660
Fly Ash	141
Forta Fiber	0.0684
ASTM C 33 Sand	376
Sil-cell 32	109
Batched Water	355
Air Entrainment: Micro-Air	2.54
Glenium 3030 NS	18.5
Laticrete 330	141

Notwithstanding the similarity to the baseline mix several adjustments were made. The water cement ratio was increased in order to allow for the use of the male-female mold. The admixture proportions were also adjusted. A more detailed description of the 2006 canoe mix has been included in the appendix. The final unit weight for the concrete mix was 66 lb/ft^3 and the compressive strength was measured to be 530 psi. It was difficult to further lower the unit weight of the concrete as a result of the limitations on the water to cement ratio and the requirement to meet the ASTM C 33 gradation requirements.

Challenges/Lessons

The best canoe teams have built canoes together for several years. This was a learning experience for each member of the canoe team because none had previous concrete canoe experience. One of our primary difficulties occurred when the option to use Miracon was lost. The 2006 canoe team invested time in developing a mix based on Miracon. When that option was lost it became necessary to develop a completely new mix in a very short period of time. One of the results was that the canoe team was not able to perform the testing necessary to ensure that the canoe mix was optimized for the design constraints. The primary result of this was that the canoe mix experienced separation while it cured. This separation can be seen in Figure 3.

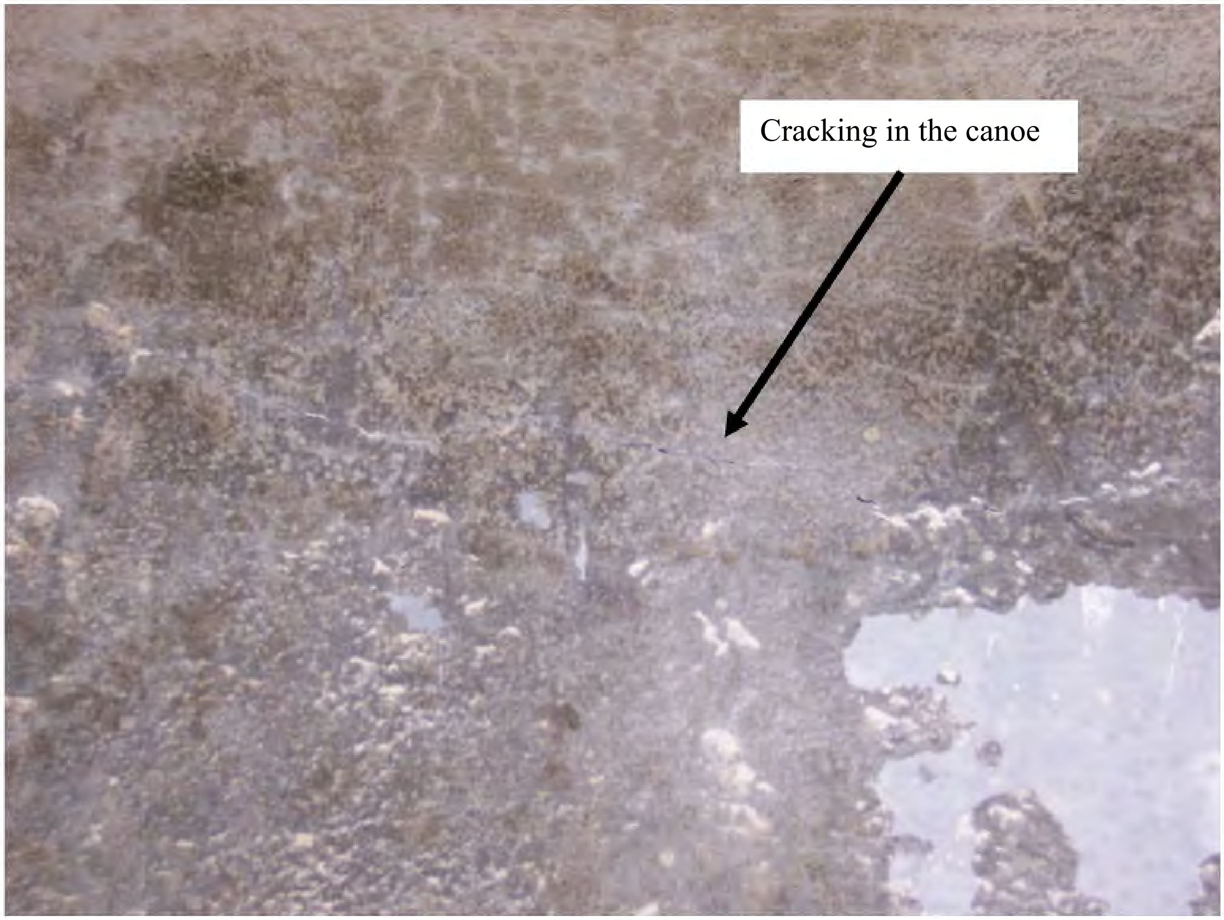

Figure 3: Photograph of Canoe

Notice the white grainy substance on the outside of the canoe. The white grainy substance is Sil-cell that separated out of the concrete mix during the process of curing. Also notice the crack. Separation of the mix resulted in weak areas that were particularly susceptible to cracking. More time spent in testing the canoe mix could have eliminated this difficulty.

Competition Results

In spite of the difficulties, the cracks were repaired and the canoe was transported to Rapid City, South Dakota to compete in the regional concrete canoe competition. Figure 4 is a picture taken the morning of the swamp test. The canoe had to be fully submerged and still float.

Figure 4: Swamp Test in South Dakota (That is snow in the background)

Later in the day the canoes were taken to a local lake for the races. Figure 5 was taken while preparing the canoes to race.

Figure 5: Preparing the Canoe for Racing

The 2006 canoe team finished 5th overall out of the nine competing teams. Their highest ranking was achieved in the oral presentation category where they finished in 3rd place. The 2006 canoe generally finished in the middle of the pack for the races. It was just too long and heavy to maneuver and accelerate with the best canoes. Much was learned through the course of building and competing. Perhaps most importantly, lessons were learned that will provide a foundation for future years of competition.

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Appendix

Table 3: ASTM C33-03 Gradation Specifications for Fine Aggregate

Source: ASTM, 2003

Sieve (Specification E 11)	Percent Passing
9.5-mm (3/8-in.)	100
4.75-mm (No. 4)	95 to 100
2.36-mm (No. 8)	80 to 100
1.18-mm (No. 16)	50 to 85
600-µm (No. 30)	25 to 60
300-µm (No. 50)	5 to 30
150-µm (No. 100)	0 to 10

Table 4: Detailed Concrete Mix for 2006 Canoe

Mixture: The 2006 canoe mix

Batch Size (ft^3): 1.5 ft^3

		Proportions as Designed		Batched Proportions		Yielded Proportions	
Cementitious Materials	Specific Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb)	Volume (ft^3)
1. ASTM C150 Portland Cement Type: I/II	3.15	660	3.36	36.7	0.186	651	3.31
2. Fly Ash	2.20	141	1.03	7.86	0.0572	140	1.02
Total of All Cemetitious Materials		801	4.39	44.5	0.244	790	4.33
Fibers							
1. Forta Fiber	0.90	0.0684	0.00122	0.00380	6.77E-05	0.067494	0.00120
Aggregates							
1. ASTM C 33 Sand Absorption, 2.7 % Batched Moisture Content, 4.3 %	2.40	376	2.51	20.9	0.140	371	2.48
2. Sil-Cel 32 Absorption, 0 % Batched Moisture Content, 0 %	0.18	109	9.67	6.03	0.537	107	9.54
Total of All Aggregates		485	12.2	26.9	0.677	478	12.0
Water							
Batched Water	1.00	355	5.68	19.7	0.316	350	5.61
Total Free Water from All Aggregates	1.00	5.87	0.0940	0.326	0.00522	5.79	0.0928
Total Water from All Admixtures	1.00	108	1.73	5.99	0.0960	106	1.70
Total Water		468	7.51	26.0	0.417	462	7.40
Admixtures	% Solids	Amount (fl oz/cwt	Water in Admixture (lb/yd^3)	Amount (fl oz)	Water in Admixture (lb/yd^3)	Amount (fl oz/cwt	Water in Admixture (lb/yd^3)
1. Air Entrainment: Micro-Air	12.6	4.82		2.147		4.82	
2. Glenium 3030 NS	20.3	33.8	14.0	15.026	0.780	33.8	13.9
3. Laticrete 330	31.0	260	93.8	115.876	5.21	260	92.5
Cement-Cementitious Materials Ratio		0.823		0.823			0.823
Water-Cementitious Materials Ratio		0.585		0.585			0.585
Slump, in.		11.0		11.0			11.0
Air Content, %		7.97		9.00			9.20
Density (Unit Weight), lb/ft^3		67.0		66.1			66.1
Gravimetric Air Content, %				9.20			
Yield, ft^3		27.0		1.52			27.00

Author's Biography

Ryan Christensen grew up on a potato farm in Firth, Idaho. He performed well scholastically while attending Firth High School. He graduated Valedictorian of the class of 1999 while being President of the National Honor's Society and on the State Champion basketball team. His work ethic and accomplishments continued throughout college at Utah State University where he was awarded a 4-year Presidential Non-Resident Scholarship. As a sophomore he was awarded the Outstanding Pre-professional in Civil and Environmental Engineering. The Outstanding Senior award in Civil Engineering was also bestowed upon Ryan.

Ryan spent two years in the Philippines serving a mission for the Church of Jesus Christ of Latter-day Saints. He married his wife, Amy in 2003 and has an adorable 3 month old boy named Thomas.

Ryan enjoys the outdoors, particularly hunting and fishing. His other hobbies include basketball, reading, cross-country skiing, and playing with his son.