euphoria

2006
University of Nevada, Reno
Concrete Canoe Design Report
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Executive Summary

Founded in 1887, the University of Nevada, Reno (UNR) served as the original land-grant institution in the Silver State, offering higher education in mining and agriculture, as well as in the mechanical and liberal arts. Since its creation, the University has expanded to accommodate 14 collegiate disciplines, and a student population of over 16,000. Housing one of the top earthquake simulation facilities in the nation, the Civil and Environmental Engineering Department has earned the Network for Earthquake Engineering Simulation Award from the National Science Foundation. Only 14 other schools in the United States share this distinction. The 250 students in the Civil and Environmental Department at UNR are proud to be associated with some of the finest in the nation.

Expertise passed down from distinguished professors and fellow students has developed into a skill set necessary for success in the demanding engineering field. The University of Nevada, Reno Concrete Canoe Team members are dedicated to applying these skills to excel in every facet of the canoe program. Striking back from a seven-year absence, the 2005 team paddled its vessel, All In, to a fifth place finish at the Mid-Pacific Regional Conference. This respectable effort inspired the 2006 successors to maintain the momentum necessary to be highly competitive.

Table 1: Canoe Details

<table>
<thead>
<tr>
<th>euphoria Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>217 lbs</td>
</tr>
<tr>
<td>Length</td>
<td>21'-11&quot;</td>
</tr>
<tr>
<td>Depth</td>
<td>13&quot;</td>
</tr>
<tr>
<td>Width</td>
<td>30&quot;</td>
</tr>
<tr>
<td>Thickness</td>
<td>1/2&quot;</td>
</tr>
<tr>
<td>Color</td>
<td>Burgundy/Grey</td>
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</table>

<table>
<thead>
<tr>
<th>Concrete and Reinforcement</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Reinforcement</td>
<td>1/4&quot; Fiberglass Scrim</td>
</tr>
<tr>
<td>Rib Reinforcement</td>
<td>1/4&quot; All Thread</td>
</tr>
<tr>
<td>Gunwale Reinforcement</td>
<td>1/16&quot; Steel Cable</td>
</tr>
<tr>
<td>Unit Weight</td>
<td>61.2 lbs/ft³</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>2300 psi</td>
</tr>
<tr>
<td>Modulus of Rupture</td>
<td>375 psi</td>
</tr>
<tr>
<td>Composite Flexural Strength</td>
<td>850 psi</td>
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</table>

Extensive research and a broad range of concrete mix testing began in August 2005 to successfully yield low unit weights and high compressive strength for a new hull designed with outstanding maneuverability. A primary focus on aesthetic improvements led to the addition of sheer to the gunwale profile as well as more uniform concrete placement for a smooth finish. Construction members developed many new tools and techniques in order to meet budget demands and ensure build completion in accordance with critical path dates.

It is with great pride and a well-founded sense of elation that the Concrete Canoe Team of the University of Nevada, Reno presents the 2006 entry… euphoria.
Hull Design

Many hull design characteristics of *All In* contributed to the success of the 2005 team in the Mid-Pacific Regional races; adequate straight-line-speed, maneuverability, stability, and tracking all resulted from specific design elements. The design team for the 2006 entry, *euphoria*, felt significant improvement in each of these areas was possible. To improve the design of *All In* and achieve all performance goals, research into naval architecture began in early September. Application of this research yielded an entirely new hull design.

Straight-line-speed and maneuverability are generally considered to be inversely proportional, but hull elements applied to *euphoria* improve both. Composed of arc lengths of varying radius, *euphoria* has a rounded appearance in plan view. This shape results in a full-ended canoe, generating two advantages: first, paddlers can be positioned toward the ends of the canoe which improves torque during turns; second, the canoe has a shallow draft, which reduces resistance, ultimately improving straight line speed and turning. Although a flatter keel and hard chine create more wetted surface area and increase friction drag, it was deemed necessary to reduce the profile area of the canoe in order to improve turning. The increase in friction drag is offset by a narrow beam to reduce wave drag while maintaining a sufficient stability as indicated by the moment-righting arm GZ (Gilmer and Johnson, 1982). Comparative dimensions are illustrated in Table 2, below.

To further improve turning, the team designed *euphoria* with six inches of rocker at the bow that tapers seven feet into the length of the canoe. Stern rocker is slightly less, only three feet of taper with a four inch height variance. Since no definitive methods to evaluate the turning resistance of various hull designs were found through research, the engineering team developed a method based on simple hydrodynamics. During a turn, the bow and stern pivot about the center of the canoe, with resistance to the turn coming from pressure under the waterline. This resistance is proportional to the submerged profile area of each section of the canoe multiplied by its distance from the pivot point. Thus the most resistance to turning comes from the bow and stern, verifying that rocker increases maneuverability. The hull design team termed this “turning moment” (units of feet cubed), and modeled it with a Taylor series. Using this model, *euphoria* will have 15 percent less resistance to turning than *All In* for coed loading.

<table>
<thead>
<tr>
<th>Property</th>
<th>All In</th>
<th>Euphoria</th>
</tr>
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<tbody>
<tr>
<td>Co-ed Waterline Length</td>
<td>20’-3”</td>
<td>21’-0”</td>
</tr>
<tr>
<td>Co-ed Waterline Beam</td>
<td>28”</td>
<td>26”</td>
</tr>
<tr>
<td>Co-ed Draft</td>
<td>7.2”</td>
<td>6.7”</td>
</tr>
<tr>
<td>Submerged Area</td>
<td>31 in²</td>
<td>32 in²</td>
</tr>
<tr>
<td>Turning Moment</td>
<td>54.8 ft³</td>
<td>46.6 ft³</td>
</tr>
</tbody>
</table>

Many other subtle changes influence both the aesthetic appeal and performance characteristics of *euphoria*. Three inches of sheer was added at both the bow and stern, primarily to increase the overall aesthetic appeal. Additionally, sheer limits the amount of water taken on as the canoe rocks during racing. *euphoria* is asymmetric with the widest cross section 63 percent of the canoe’s length aft of the bow. This design characteristic is important in full-ended canoes as it narrows the entrance angle, thereby improving straight line speed. To assist in the design and analysis of these various hull design characteristics, *Prolines 98* was used for its advanced features and versatility.
Analysis

The primary goal of the hull analysis was to verify the structural capacity of *euphoria* based on the ultimate strength of the concrete mix and the dimensions of the canoe. Using a concrete compressive strength of 1,500 psi, a composite flexural strength of 500 psi, and a total canoe weight of 230 lbs, the canoe was analyzed using SAP2000 [a finite element analysis (FEA) program] and an Excel-based analysis spreadsheet. The engineering team developed the spreadsheet to be used as an alternative method of analysis to FEA to relieve the dependence on computer analysis. Past experience has shown that there is generally a large factor of safety between the capacity of a concrete canoe and the imposed external loads; consequently, a precise FEA is not necessary to conservatively predict critical stresses.

The team employed its analysis spreadsheet to determine the principle stresses in the canoe using concepts of basic engineering mechanics. Learning from experience gained during the construction of *All In*, the design team concluded that hull thicknesses less than ½ inch raise certain constructability issues. Therefore a ½ inch hull thickness was used as a parameter in the spreadsheet to determine the stresses. Three load cases were used to generate a moment envelope for the canoe, shown in Figure 1. In Load Case 1 the canoe was simply supported from either end and subjected to its self weight. Load Case 2 included two 180 lb paddlers with a distributed buoyant force, and Load Case 3 added two 140 lb paddlers to Load Case 2. In Load Cases 2 and 3 the locations of the paddlers were adjusted to maximize the moment on the canoe.

The analysis team also sought help from professionals in the community to develop a FEA model to verify the results of the spreadsheet and to justify the need to include structural elements such as integral ribs and a larger gunwale section. The results of the FEA (see Figure 2, left) showed a 28 percent reduction in principle stresses with the inclusion of four transverse ribs and a 1 inch x 2 inch gunwale section for the worst loading case (simply supported under its own weight).

The spreadsheet analysis showed maximum compressive and tensile stresses of 230 psi and 215 psi, respectively, while the FEA yielded 170 psi and 150 psi. This comparison of the two methods confirms that the spreadsheet conservatively predicted stresses, and that *euphoria* has sufficient capacity to resist the applied loads in each load case.
Development & Testing

Mix Design

One fundamental way the Nevada Concrete Canoe Team built upon the success of All In was by focusing on the concrete mix design. The mix design members set two primary goals during the development phase of euphoria. The first was to develop a mix with a 28-day compressive strength of 1,500 psi while maintaining a workable consistency. The second was to develop a mix with a maximum unit weight of 62 lbs/ft³.

The first steps toward achieving mix design goals began with the research and testing of several aggregates. The team located samples of two different brands of ceramic beads in addition to microspheres and lightweight natural aggregates. Two baseline mixtures helped to evaluate the ceramic beads, which comprised the bulk volume of the aggregates used in mixing. Both baseline mixtures shared a water/cement ratio of 0.45, a cementitious materials content of 655 lbs/yd³ (70% Type I/II Portland Cement, 15% Fly Ash, 15% Silica Fume), and appropriate quantities of microspheres and natural sand to ensure the blended aggregates met the gradation specification of ASTM C33. Six 2 inch x 4 inch cylinders were made from each mix, and tested at 7, 14, and 28 days using the test method prescribed by ASTM C39. Mix NCC0501, made with Macrolite ceramic beads, exhibited a 28-day compressive strength of 3,400 psi and a unit weight (determined by ASTM C138) of 69.9 lbs/ft³. Mix NCC0502, made with Siscor glass spheres, exhibited a 28-compressive strength of 1,450 psi and a unit weight of 54.09 lbs/ft³.

Based on these baseline mixtures, the team decided to use Macrolite ceramic beads, which offered superior strength to the Siscor glass spheres. The team then studied other aggregates to maximize the strength of the mix while minimizing the unit weight. 3M K20 Microspheres were selected for their low specific gravity (0.2), and Fillite SG 500 provides a lightweight replacement for natural sand used to fill the gap in the gradation between the microspheres and Macrolite Aggregates.

After determining the aggregate blend, the mix team selected appropriate cement and air contents to achieve the unit weight and strength goals. This phase of mix development included testing of water-reducing admixtures to develop a mix with the proper consistency for concrete placement and consolidation. Because all the aggregates used in the mix are spherical, a large demand is imposed on the cement paste to ensure a uniform coating on the aggregate surfaces. Additionally, the abundance (by volume) of particles passing the #100 sieve yields a harsh concrete; the use of high-range water reducers (HRWR) proved to be vital in achieving the proper consistency. The mix design team experimented with various HRWR including those classified as ASTM Type F and ASTM Type G, ultimately selecting a Type F Admixture (Adv 140.)

The team batched and tested twenty additional mixes before selecting the final design. A cementitious materials content of 631.8 lbs/yd³ with a w/c ratio of 0.5 yielded a concrete with strengths that met the mix design goals. Testing showed that using 9 fl oz/cwt of cement (manufacturer recommends 6-16 fl oz/cwt of cement) of Adv 140 yielded a concrete with a slump of 1/8”, adequate for placement and consolidation. As recommended by the manufacturer, the dosage of the air entrainer, Darex II, was
dependent on testing in order to achieve the desired air content. After several trial batches, a final dosage of 2.3 fl oz/cwt of cement was selected, yielding a target air content of 2.5% (ASTM C 138). Testing with various polypropylene fibers was the last step in the mix design process. Verfi fibers, a micro polypropylene fiber suspended in a water based gel, were selected as they proved to be superior to normal micro-fibers with respect to their dispersion upon batching. The final mix design exhibited a 28-day compressive strength of 2,350 psi, with a unit weight of 61.2 lbs/ft$^3$, thereby surpassing the goals set by the mix team at the beginning of the project. The final mix design can be found in Appendix B.

Reinforcement

Various reinforcement types were reviewed to establish comparisons of cost, strength, availability and ease of application. Samples of steel, fiberglass, Kevlar® and carbon fiber composed the base for initial consideration. Kevlar® was immediately eliminated because of high expense. Carbon fiber has high theoretic tensile strength; however, the tightly woven composition gave rise to concerns regarding delamination and reinforcement compliance. Removing strands from the carbon fiber cloth weave thinned the structure to allow for sufficient bonding between lifts, but proved too labor intensive. In preliminary tests of 12 inch x 3 inch x 1 inch beams, steel hardware cloth and three different fiberglass products were analyzed for composite flexural strength. Table 3 (left) displays the performance of composite beams reinforced with these products.

Although steel hardware-cloth provided sufficient strength, rigidity proved to be problematic. The stiff structure was difficult to fashion around the three-dimensional curve of the hull. Fiberglass with $\frac{3}{16}$ inch square grid was ultimately selected because of its high strength and low cost. In addition, team members concluded that the superior flexibility of fiberglass would allow for easy placement during the concrete application process. Final composite testing by third point loading (ASTM C78) resulted in a flexural strength of 850 psi.

Preliminary composite testing of the fiberglass revealed that the greatest benefit to tensile strength occurs when the scrim reinforcement is placed as close to the outer surface as possible; when applied directly to the canoe this helps to reduce point load fractures from paddlers’ knees and feet. Because aggregate size and concrete placement techniques would not allow for shallow depth reinforcement schemes, the reinforcement was placed between two $\frac{1}{4}$ inch concrete lifts throughout the entire length of the vessel. Four transverse strands were removed at the end of each section of the fiberglass reinforcement, to allow for two inches of overlap at all joints. As a result of further testing, the team concluded that a 1/16 inch steel cable in the gunwale was necessary to hold high tensile stresses of certain loading conditions. Upon completion, the alkali-resistant fiberglass and other reinforcement in euphoria was a substantial improvement over the semi-rigid steel hardware-cloth used on All In.

<table>
<thead>
<tr>
<th>Type of Reinforcement</th>
<th>Composite Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>865</td>
</tr>
<tr>
<td>fiberglass (coarse)</td>
<td>480</td>
</tr>
<tr>
<td>fiberglass (medium)</td>
<td>865</td>
</tr>
<tr>
<td>fiberglass Scrim</td>
<td>315</td>
</tr>
<tr>
<td>Control (no reinforcement)</td>
<td>230</td>
</tr>
</tbody>
</table>

Fiberglass with $\frac{3}{16}$ inch square spacing, and $\frac{1}{4}$ inch steel hardware-cloth exhibited almost identical strengths, creating the need for further evaluations.
Project Management & Construction

Project Management

The Project Manager of the UNR Canoe Team is ultimately responsible for two main tasks: the continuation of the program and the proper coordination of time, resources, and finances to ensure complete construction of a competitive concrete canoe.

Prior-year comparison was used to develop a critical path for project tasks. To begin, the team discussed the intuitive order of all crucial construction elements with key 2005 members. The order of events from last year was altered to include a full-scale concrete practice vessel, and a time line was established for individual tasks. To develop this new time line, a one month buffer period was applied before starting a reverse order countdown to the starting date of the first task (completed hull design). A critical path of major milestone elements was manually organized using Microsoft Excel. Major milestones consist of hull design completion, form construction, mix selections, practice construction, race boat construction, and product completion. Practice construction included the manufacture of a complete concrete canoe to reduce the risk of mistakes inherent to one-off builds, and to practice every step from material placement to paddling. Table 4 (above) displays critical completion dates, and Table 5 (below) illustrates a breakdown of total man hours. Ultimately, by referencing the 2005 design report and consulting team members, an aggressive time schedule was established that allocated sufficient time to complete all core objectives by April 28th, even in the event of unforeseen delays.

Table 4: Schedule Variances

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Completion Date</th>
<th>Variance</th>
<th>Reason</th>
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<tr>
<td>Final Hull Design</td>
<td>10/15</td>
<td>0 days</td>
<td>None</td>
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<tr>
<td>Form Construction</td>
<td>12/19</td>
<td>13 days</td>
<td>Schedule Reassessment</td>
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<tr>
<td>Final Mix Design</td>
<td>2/6</td>
<td>68 days</td>
<td>Contaminated Materials</td>
</tr>
<tr>
<td>Practice Canoe Construction</td>
<td>12/10</td>
<td>7 days</td>
<td>Member Availability</td>
</tr>
<tr>
<td>Race Canoe Construction</td>
<td>2/11</td>
<td>35 days</td>
<td>Final Mix Variance</td>
</tr>
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</table>

Table 5: Milestone dates and variances

<table>
<thead>
<tr>
<th>Phase</th>
<th>Man-Hours</th>
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<tr>
<td>Design</td>
<td>150</td>
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<tr>
<td>Testing</td>
<td>322</td>
</tr>
<tr>
<td>Canoe Construction†</td>
<td>751</td>
</tr>
<tr>
<td>Paddling</td>
<td>270</td>
</tr>
<tr>
<td>Total</td>
<td>1493</td>
</tr>
</tbody>
</table>

†Time noted includes two canoes

Finance management is yet another project element based on experience. After reviewing an itemized record of all 2005 material purchases, project members compared planned changes with earlier quantities in order to compile a detailed list of materials, from wood screws and mold release wax to tire chains and fuel. A slight inflation was added before the list of all needed materials was translated to a categorized total project cost of $7,400. Fundraising efforts focused on monetary as well as material procurement; organizations in the Reno area were encouraged to help with finances, materials, and professional knowledge.

Team structure was intended to be as democratic as possible. The Project Manager had one graduate advisor to help facilitate decisions made by the team as a whole. Tasks such as hull design, construction, mix design, and analysis were assigned to team members who showed the most knowledge
and interest in each particular area. Weekly meeting topics coincided with class schedules and critical path completion dates to keep the project on task, and to continually familiarize team members with structure laboratory safety practices. Fall practices, held for two hours every Sunday, are responsible for faster paddling than any other UNR canoe team. Other biweekly events, such as running, bicycling, and ball games, have created a comfortable unity in team euphoria.

Construction

Current team members created numerous goals and fabrication advancements prior to constructing euphoria. To guarantee significant time and money savings, many innovations were applied to build-table and form construction as well as concrete placement and finishing. Various materials were salvaged from the 2005 project further reducing ultimate cost. A humidity controlled curing environment was one of the first concepts developed; in the long run, it reduced the time demands on team members.

The build-table design included several new characteristics, such as a logarithmically curved build-surface intended to create aesthetically correct gunwale sheer. The team also designed the build-table shape to exceed that of the hull layout by exactly ½ inch to produce gunwale thickness uniformity. Support platforms were incorporated into the table top surface for quick form and table separation, and ⅛ inch thick by ¾ inch steel angle, attached to the curved table edge, served as a guide runner for hand fabricated gunwale forming tools. Due to these advancements, the finishing time of certain hull characteristics was drastically reduced and required little experience to yield nearly perfect results.

New foam materials and manufacturing techniques were investigated in an attempt to eliminate the need for a sealer coat on the form before resin is applied. However, because of cost and time restraints, the mold construction reverted to a simple refinement of the polystyrene cross-section method used for the construction of All In. A hot-wire apparatus was constructed to cut cross-sections in a scroll-saw configuration, and joint compound placed on the assembled form covered imperfections. To help with removal and increase durability, the manufacture of the five piece form included over 80 man hours of hand sanding, three Elmer’s glue sealer caps, four separate polyester resin coats, a mold release wax application, and a polyvinyl alcohol film.

Concrete application by the rolled sheet method remained nearly unchanged, as substantial improvements in workability resulted from the introduction of High Range Water Reducer to the concrete mix. To increase product quality, construction members fashioned vibrating trowels from dual action pneumatic sanders. The pneumatic trowels consolidated and smoothed all joints and inconsistencies in the hand placed concrete sheets. These, along with other advancements in material placement, have yielded a uniform finish that requires minimal final sanding.

To gain as much ultimate strength from the concrete as possible, a curing tent fashioned from sheet plastic and PVC pipe misted 24 hours a day. A closed-loop pressure system circulated water for four full weeks. After curing and form removal, team members sponged acid stain into the surface of the canoe according to manufacturer suggestions and brushed on two coats of concrete sealer. Canoe titles airbrushed in industrial enamel completed the final construction step of the euphoric concrete vessel built with Nevada pride.
Project Manager
Chad Lyttle

Directed all project logistics while maintaining a strong focus on aesthetics and quality

Faculty Advisor
Dr. David Sanders

Graduate Student Advisor
Michael Taylor

Design & Analysis

Hull Design Engineer
Corbin McFarlane

Designed an all new hull with superior maneuverability based on extensive research

Mix Design Engineer
Michael Taylor

Directed all mix design elements from aggregate selection to composite reinforcement testing

Analysis Consultant
Elliot Goodwin
FEA Hull Analysis

Reinforcement Chair
Kara Bymers
Research and Test Reinforcement

Quality Assurance/Quality Control
Matt Pontoni

Construction

Construction Engineer
Adam McNutt

Facilitated all hands on construction from the buildable to final canoe construction

Form Construction
McNutt / Lyttle

Stand Construction
Lyttle

Cutaway Section
McNutt

Construction Academics & Administration

Hull Design Engineer
Mix Design Engineer
Construction Engineer

Academics & Administration

Fundraising Coordinator
Nick Maxon
Organize and Manage Fundraising

Design Paper
Lyttle / Taylor / McFarlane

Oral Presentation
Lyttle / Doyle

Paddling Chair
Bryan Truce
Coordinate Paddling Practices, Instruct Paddlers

Paddlers
Chad Lyttle
Kelly Doyle
Adam McNutt
Brittany Miller
Brian Fitzgerald
Kara Bymers
Bryan Truce
Christine Harms
Corbin McFarlane
Jessica Dennis

Analysis Consultant
Elliot Goodwin
FEA Hull Analysis

Reinforcement Chair
Kara Bymers
Research and Test Reinforcement

Quality Assurance/Quality Control
Matt Pontoni

Facilitated all hands on construction from the buildable to final canoe construction

Directed all mix design elements from aggregate selection to composite reinforcement testing

Form Construction
McNutt / Lyttle

Stand Construction
Lyttle

Cutaway Section
McNutt
Euphoria Project Schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Planned Start</th>
<th>Planned Finish</th>
<th>Actual Start</th>
<th>Actual Finish</th>
<th>Summary (Planned)</th>
<th>Summary (Actual)</th>
<th>Critical Path</th>
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<tr>
<td>1</td>
<td>First Meeting &amp; Start</td>
<td>8/28/05</td>
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<td>Fundraising</td>
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<td>4/27/06</td>
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<td>8/28/05</td>
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<td>Research &amp; Modeling</td>
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<td>10/16/05</td>
<td>1/16/06</td>
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<td>10/15/05</td>
<td>0 days</td>
<td>0 days</td>
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<td>7</td>
<td>Materials Research</td>
<td>9/2/05</td>
<td>9/24/05</td>
<td>9/2/05</td>
<td>9/24/05</td>
<td>22 days</td>
<td>0 days</td>
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<td>8</td>
<td>Preliminary Designs &amp; Testing</td>
<td>9/26/05</td>
<td>10/24/05</td>
<td>9/26/05</td>
<td>10/24/05</td>
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<td>0 days</td>
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<td>9</td>
<td>Refinement Designs &amp; Testing</td>
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<td>11/30/05</td>
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<td>2/6/06</td>
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<td>68 days</td>
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<td>10</td>
<td>Final Mix Selection (Practice)</td>
<td>9/2/05</td>
<td>12/1/05</td>
<td>9/2/05</td>
<td>12/1/05</td>
<td>0 days</td>
<td>0 days</td>
</tr>
<tr>
<td>11</td>
<td>Final Mix Selection (Race Canoe)</td>
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<td>1/1/06</td>
<td>2/6/06</td>
<td>2/6/06</td>
<td>0 days</td>
<td>36 days</td>
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<td>Research Design Schemes</td>
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<td>10/15/05</td>
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<td>10/16/05</td>
<td>10/23/05</td>
<td>7 days</td>
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<td>14</td>
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<td>10/28/05</td>
<td>10/23/05</td>
<td>10/28/05</td>
<td>5 days</td>
<td>0 days</td>
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<td>15</td>
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<td>12/2/05</td>
<td>9/2/05</td>
<td>12/2/05</td>
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<td>13 days</td>
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<td>4/28/6</td>
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<td>0 days</td>
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</table>
Appendix A: References


ASTM (2004). “Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).” C78, West Conshokocken, PA.


<http://members.cox.net/concretecanoe/index.shtml>


<http://www.greenval.com/jwinters.html>
### Appendix B: Mixture Proportions

#### Final Concrete Mixture

**2006 Concrete Canoe Mix Design**

<table>
<thead>
<tr>
<th>Batch Size (ft$^3$): 0.212</th>
<th>Proportions as Designed</th>
<th>Batched Proportions</th>
<th>Yielded Proportions</th>
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<tbody>
<tr>
<td><strong>Cementitious Materials</strong></td>
<td>Specific Gravity*</td>
<td>Amount (lb/yd$^3$)</td>
<td>Volume (ft$^3$)</td>
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<tr>
<td>1. Cement (Type I/II)</td>
<td>3.15</td>
<td>439.31</td>
<td>2.235</td>
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<tr>
<td>2. Fly Ash, Class F</td>
<td>2.35</td>
<td>94.08</td>
<td>0.642</td>
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<tr>
<td>3. Silica Fume</td>
<td>2.25</td>
<td>94.12</td>
<td>0.670</td>
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<td>3.547</td>
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<td><strong>Fibers</strong></td>
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<td></td>
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<tr>
<td>1. Verfi (Fibers)$^1$</td>
<td>1.00</td>
<td>1.52</td>
<td>0.024</td>
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<td><strong>Aggregates</strong></td>
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<td></td>
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<td>1. Macrolite ML 714</td>
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</tr>
<tr>
<td></td>
<td>Absorption: 8.5%</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Batched Moisture Content: 0.0%</td>
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<td></td>
<td>Amount</td>
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<td>2. Macrolite ML 1430</td>
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<tr>
<td></td>
<td>Absorption: 8.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Batched Moisture Content: 0.0%</td>
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</tr>
<tr>
<td></td>
<td>Amount</td>
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<td>254.29</td>
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<tr>
<td>3. Fillite SG 500</td>
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</tr>
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<td></td>
<td>Absorption: 0.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Batched Moisture Content: 0.0%</td>
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</tr>
<tr>
<td></td>
<td>Amount</td>
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<td>108.19</td>
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<td>4. 3M K20</td>
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<td></td>
<td>Absorption: 0.0%</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Batched Moisture Content: 0.0%</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Amount</td>
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<td>70.21</td>
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<td><strong>Total of All Aggregates</strong></td>
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<td>663.04</td>
<td>17.691</td>
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<tr>
<td><strong>Water</strong></td>
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<tr>
<td>Batched Water</td>
<td>1.0</td>
<td>348.07</td>
<td>5.578</td>
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<tr>
<td>Total Free Water from All Aggregates</td>
<td>1.0</td>
<td>-41.20</td>
<td>-0.660</td>
</tr>
<tr>
<td>Total Water from All Admixtures$^2$</td>
<td>1.0</td>
<td>9.02</td>
<td>0.145</td>
</tr>
<tr>
<td><strong>Total Water</strong></td>
<td>315.90</td>
<td>5.063</td>
<td>2.49</td>
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<tr>
<td><strong>Admixtures</strong></td>
<td>% Solids</td>
<td>Amount (fl oz/cwt)</td>
<td>Amount (fl oz)</td>
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<td>1. Adva 140 (HRWRA)</td>
<td>60.0%</td>
<td>9.27</td>
<td>1.8</td>
</tr>
<tr>
<td>2. Darex II (AEA)</td>
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<td>2.32</td>
<td>1.1</td>
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<td>3. Verfi (Fibers)$^1$</td>
<td>20.0%</td>
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<td>6.1</td>
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<td><strong>Cement-Cementitious Materials Ratio</strong></td>
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<td>0.070</td>
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<tr>
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<td>0.51</td>
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<td><strong>Slump, in.</strong></td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
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<td><strong>Air Content, %</strong></td>
<td>2.5</td>
<td>4.0</td>
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<tr>
<td><strong>Density (Unit Weight), lb/ft$^3$</strong></td>
<td>61.18</td>
<td>60.47</td>
<td>60.47</td>
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<td><strong>Gravimetric Air Content, %</strong></td>
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<tr>
<td><strong>Yield, ft$^3$</strong></td>
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<td>0.215</td>
<td>27.0</td>
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* For aggregates provide ASTM C 127 saturated, surface-dry bulk specific gravity.

$^1$ Water content of admixture

$^2$ If impact on water-cementitious materials ratio is less than 0.01, enter zero.

$^3$ Verfi fibers are dispersed within a water based gel solution (20% Fibers & 80% water)
Appendix C: Gradation Curves & Tables

Concrete Aggregate:  *Macrolite ML 714*

Sample Weight:  **672.9 g**

Specific Gravity (Gs):  **0.77**

Finess Modulus:  **4.33**

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<th>Weight Retained (g)</th>
<th>Cumulative Weight Retained (g)</th>
<th>Percent Finer (%)</th>
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<td>3/8 inch</td>
<td>9.50</td>
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<td>100.0%</td>
</tr>
<tr>
<td>No. 4</td>
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<td>0.0</td>
<td>0.0</td>
<td>100.0%</td>
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<tr>
<td>No. 8</td>
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<td>223.1</td>
<td>223.1</td>
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<tr>
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<td>425.4</td>
<td>648.5</td>
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<tr>
<td>No. 30</td>
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<td>2.3</td>
<td>650.8</td>
<td>0.2%</td>
</tr>
<tr>
<td>No. 50</td>
<td>0.30</td>
<td>0.4</td>
<td>651.2</td>
<td>0.1%</td>
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<tr>
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<td>0.0</td>
<td>651.2</td>
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<tr>
<td>Pan</td>
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<td>651.8</td>
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Concrete Aggregate:  *Macrolite ML 1430*

Sample Weight:  **672.9 g**

Specific Gravity (Gs):  **0.85**

Finess Modulus:  **3.22**

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<tr>
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<td>0.0</td>
<td>100.0%</td>
</tr>
<tr>
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<td>0.0</td>
<td>0.0</td>
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<tr>
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<td>673.7</td>
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Appendix C: Gradation Curves & Tables

Concrete Aggregate: *Fillite SG 500*

**Sample Weight:** 281.2 g

**Specific Gravity (Gs):** 0.70

**Fineness Modulus:** 1.02

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<tr>
<td>3/8 inch</td>
<td>9.50</td>
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<td>100.0%</td>
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<tr>
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<td>0.0</td>
<td>100.0%</td>
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<td>0.0</td>
<td>100.0%</td>
</tr>
<tr>
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<td>0.0</td>
<td>0.0</td>
<td>100.0%</td>
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<tr>
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Concrete Aggregate: *3M K20*

**Sample Weight:** 672.9 g

**Specific Gravity (Gs):** 0.20

**Fineness Modulus:** 0.00

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<th>Percent Finer (%)</th>
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<tbody>
<tr>
<td>3/8 inch</td>
<td>9.50</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0%</td>
</tr>
<tr>
<td>No. 4</td>
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<td>0.0</td>
<td>0.0</td>
<td>100.0%</td>
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<tr>
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<td>0.0</td>
<td>0.0</td>
<td>100.0%</td>
</tr>
<tr>
<td>No. 16</td>
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<td>0.0</td>
<td>0.0</td>
<td>100.0%</td>
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<td>0.0</td>
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<td>100.0%</td>
</tr>
<tr>
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<tr>
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<td>156.0</td>
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<td>76.8%</td>
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</table>
Appendix C: Gradation Curves & Table

**Macrolite ML 714 Gradation**

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<th>Percent Finer (% by weight)</th>
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<td>10.0%</td>
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<tr>
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<td>50.0%</td>
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<tr>
<td>0.80</td>
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<td>90.0%</td>
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<tr>
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**Macrolite ML 1430 Gradation**

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<th>Percent Finer (% by weight)</th>
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<td>0.0%</td>
</tr>
<tr>
<td>0.20</td>
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<tr>
<td>0.30</td>
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<tr>
<td>0.40</td>
<td>30.0%</td>
</tr>
<tr>
<td>0.50</td>
<td>40.0%</td>
</tr>
<tr>
<td>0.60</td>
<td>50.0%</td>
</tr>
<tr>
<td>0.70</td>
<td>60.0%</td>
</tr>
<tr>
<td>0.80</td>
<td>70.0%</td>
</tr>
<tr>
<td>0.90</td>
<td>80.0%</td>
</tr>
<tr>
<td>1.00</td>
<td>90.0%</td>
</tr>
<tr>
<td>1.10</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Legend:
- Macrolite ML 714
- Upper Limit
- Lower Limit

C-3
Appendix C: Gradation Curves & Table

**Fillite SG 500 Gradation**

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Percent Finer (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>10.00</td>
<td>10.00</td>
</tr>
</tbody>
</table>

**Upper Limit**

**Lower Limit**

**3M K20 Gradation**

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Percent Finer (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>10.00</td>
<td>10.00</td>
</tr>
</tbody>
</table>

**Upper Limit**

**Lower Limit**
Appendix C: Gradation Curves & Table

Concrete Aggregate:  Composite Aggregate Gradation

Fines Modulus:  2.95

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Percentage of Total Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macrolite ML 714</td>
<td>36%</td>
</tr>
<tr>
<td>Macrolite ML 1430</td>
<td>39%</td>
</tr>
<tr>
<td>Fillite SG 500</td>
<td>15%</td>
</tr>
<tr>
<td>3M K20</td>
<td>10%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>3/8 inch</th>
<th>No. 4</th>
<th>No. 8</th>
<th>No. 16</th>
<th>No. 30</th>
<th>No. 50</th>
<th>No. 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macrolite ML 714</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Macrolite ML 1430</td>
<td>65.8%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>87.9%</td>
<td>87.9%</td>
</tr>
<tr>
<td>Fillite SG 500</td>
<td>0.5%</td>
<td>76.8%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>55.7%</td>
<td>55.7%</td>
</tr>
<tr>
<td>3M K20</td>
<td>0.2%</td>
<td>0.9%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>25.8%</td>
<td>25.8%</td>
</tr>
<tr>
<td>Composite</td>
<td>0.1%</td>
<td>0.2%</td>
<td>0.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>10.0%</td>
<td>10.0%</td>
</tr>
</tbody>
</table>

Composite Aggregate Gradation