



A PRODUCT OF THE 2007-2008
UNIVERSITY OF MICHIGAN
CONCRETE CANOE TEAM





TABLE OF CONTENTS

Report: Executive Summary i
 Hull Design..... 1
 Analysis..... 2
 Mix Development and Testing 3
 Project Management and Construction 5
 Organizational Chart 7
 Project Schedule 8
 Formwork Design Drawing 9
 Canoe Design Drawing 10

Appendices: References..... A
 Mixture Proportions B
 Gradation Curves and Tables C

EXECUTIVE SUMMARY

Since its inception in 1854, the University of Michigan’s Civil Engineering department has taught students to be on the cutting edge of technology and advancements, driving young engineers to lead and achieve. As the first engineering department to be created, the University of Michigan’s Civil Engineering education has been refined to a nationally resound caliber. Participation in the A.S.C.E. North Regional Conference is the Michigan Concrete Canoe Team’s (MCCT) opportunity to exhibit this distinguished education. Though small, the team is dedicated and determined, comprised of leading individuals who enjoy the challenge of creating something paradoxical in nature.

Presenting MCCT’s 2008 concrete creation, **Maizin’ Race**, named for our teams’ race-like enthusiasm. To ensure overall structural integrity, the hull design includes two thin layers of concrete encompassing a sheet of fiberglass mesh. In comparison with years past, the mix includes lesser amounts of Silica Fume and increased amounts of Fly Ash Types C and F. These changes were made to decrease the overall unit weight and increase the overall strength of the canoe. The resulting 57.9 pounds per cubic foot (pcf) mix has a 28-day compressive strength of 2200 pounds per square inch (psi) and has an average residual compressive strength of 1000 psi through a strain of 2.5 percent.

Table 1: <i>Maizin’ Race</i>	
Weight	225 lbs.
Length	19' 9"
Maximum Width	30-1/4"
Maximum Depth	1' 1/2"
Average Thickness	3/4"
Color	Blue, Maize, Grey
Fiberglass Mesh Thickness	0.023"
PVA Fiber Length	3/8"



HULL DESIGN

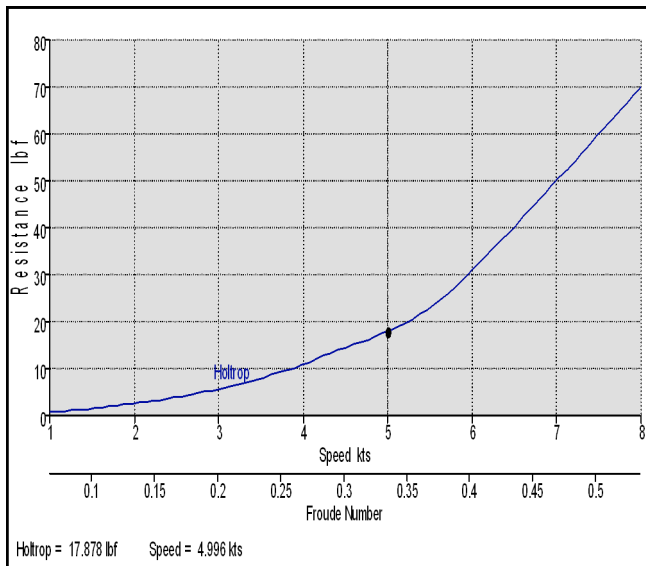
The goal of the new design of **Maizin' Race** was to increase the maneuverability and stability of the canoe over past designs, while increasing the ergonomics of the canoe. The hull design of **Maizin' Race** incorporates many design features to meet its goals of a slight rocker, a shallow vee hull form, and an asymmetrical or swede hull.

In order to improve maneuverability of the hull, a rocker of 2 inches at the bow and 0.5 inches were used to reduce the inertia of the hull. Further, the rocker was designed to be asymmetrical in order to assist in turning about the pivot point, by decreasing the lateral area towards the bow of the hull. By using an increased beam at the waterline of 30.5 inches the amount of torque needed to turn was reduced compared to previous designs.

A shallow vee hull shape was chosen for its increased stability when moving. The hull was chosen as it provides a compromise between a flat bottom and a rounded bottom. This design gives good secondary stability while compromising little of its initial stability. The increased stability is due to the two planes of stability that the shallow vee shape provides. To increase the GM_T of the hull a shallower angle for the deadrise was used to place as much weight as possible below the waterline without compromising the benefits of the shallow vee design.

Several design features were built into **Maizin' Race** to allow the paddler a comfortable experience. A small amount of tumblehome was added to assist the paddlers in their paddling motion. To further assist the ergonomics of the hull the freeboard of the design waterline was reduced to allow a more natural paddling motion. Maxsurf, software was used to predict the resistance of the hull and the components of the resistance using the Holtrop method, with the goal of reducing the resistance of the hull to

increase paddler speed. Maxsurf was also used to find the hydrostatics of the hull. The canoe was modeled three dimensionally using Rhinoceros.



The shallow vee design has more wetted area than a flat bottom thus increasing the frictional resistance. To reduce the wetted area a rounded chine was used. The hull also incorporates an asymmetric/swede waterplane area to improve tracking and reduce the wave resistance versus other hull shapes. The length of **Maizin' Race** was maximized in order to increase the hull speed.

FIGURE 1: MAXSURF OUTPUT FOR MAIZIN' RACE AT 1050LB LOAD



ANALYSIS

Analysis of the 2008 canoe began by examining a few basic load cases through a rational hand calculation approach. Load Case 1 had the canoe simply supported at both ends, which may occur when the canoe is lifted. A load of 150 percent the dead weight of the canoe was applied as a uniform load increasing toward the center of the canoe. The additional 50 percent accounted for any weight increase if the canoe is wet when being moved or acceleration forces from lifting of the canoe.

An allowable stress design analysis was performed in both the upright and upside-down positions. The analysis was completed under the assumption that one layer of fiberglass mesh reinforcement will be used. The actual and allowable stresses are given in Table 2. The tension stress was calculated by transforming the actual tensile stress. The allowable concrete stress was calculated assuming a safety factor of 2.5 and a concrete compressive strength of 2000 psi. Both the reinforcement and concrete allowable stresses were greater than the actual stresses. The actual area of reinforcement was greater than the calculated required area.

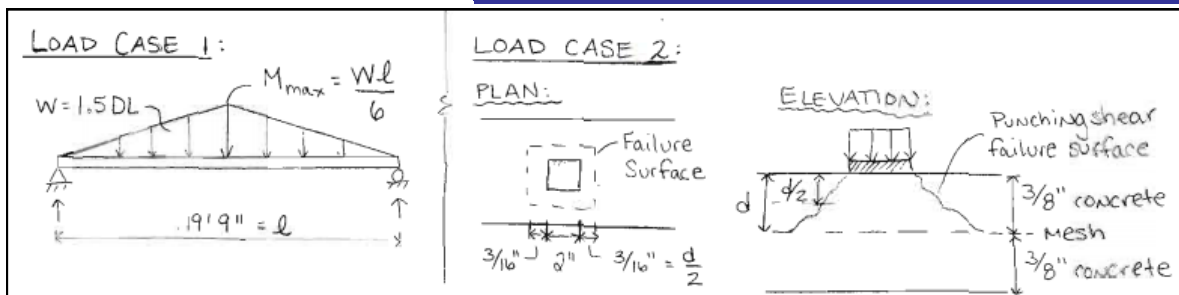
Load Case 2 examined the capacity of the canoe to resist punching shear from a paddler's knee. The knee contact area was modeled as a 2-by-2 inch square acted on by a force equal to a paddle stroke. Using the provisions in ACI Code 11.11.2.1, a concrete shear stress of 84 psi was calculated. Using a strength reduction factor of 0.75, the nominal shear capacity was found to be 113 lb. The canoe will not fail in punching shear since the ultimate shear of 96 lb (found using a live load factor of 1.6) is greater than the nominal shear. Figure 2 shows examples of the load drawings associated with the hand calculations for Load Cases 1 and 2.

Load Case 3 examined the forces from the male sprint race assuming paddler weights of 250 pounds each. The buoyant force was calculated and distributed across the length of the canoe approximately proportional to the width. Using a beam model in RISA, the critical moment in the canoe was 2856 lb-in located near the first paddler. The minimum required strengths during bending were 90 psi in compression and 150 psi in tension. Since the reinforcement was conservatively neglected during this load case, it will provide secondary rigidity.

Table 2: Load Case 1 - Simply supported upright canoe

Actual Tensile Stress	115 psi
Actual Reinforcement Tensile Stress	474 psi
Allowable Reinforcement Stress	7800 psi
Actual Compressive Stress	227 psi
Allowable Concrete Stress	800 psi

FIGURE 2: LOAD CASE 1 & 2 LOAD DRAWINGS





MIX DEVELOPMENT

The baseline mix for the 2008 canoe was the mix used for the 2007 canoe, Rushin' Blue. The baseline mix included the following items:

Cementitious Material: Portland Cement Type I, Fly Ash Types C and F, Silica Fume
Aggregates: 3M S38, 3M G3500, expanded polystyrene, Poraver Spheres 1-2 mm, Haydite A expanded slate

The challenge of this year's mix was to replace the large amount of expanded polystyrene (EPS) that the MCCT used the previous two years with another comparably low-density material. Since EPS had a specific gravity of only 0.05, a small volumetric percentage lowered the specific gravity of the concrete significantly. Another goal was to decrease the amount of silica fume since it partially attributed to last year's stiff mix, and a less stiff mix was needed for this year's male mold.

To offset the removal of EPS, another gradation of Poraver was investigated. Batches were made using 0.5-1 mm and 1-2 mm. The specific gravity of the aggregate composite was reasonable, but a smoother gradation was desired. Previously, MCCT had selectively used only the Haydite collected on the No. 30 and 50 sieves. This year we added No. 100 sieve sized particles, and a combination of the three sizes was selected that provided the smoothest gradation curve. A balanced gradation was achieved according to ASTM C33 using a mix of three different sizes of Haydite and two different sizes of Poraver. Although the rule for proportioning aggregates according to ASTM C33 was deleted this year, MCCT still wanted to stay within these standards to ensure quality finishing.

This year's mix was developed through testing several separate mixes with different combinations of cementitious material and aggregates. For example, identical batches were made varying only the use of either 3M K15 glass spheres or 3M S38 glass spheres. A decision was made to use K15 in the final mix because MCCT was willing to trade a slight decrease in crush strength for the lower specific gravity of K15.

After each batch was mixed, cylinders were made according to ASTM C31. These cylinders were then tested for compressive strength according to ASTM C109. Examples of the compressive strength for two batches are shown in Figure 3. Batch 1 had larger percentages of Poraver than Haydite, whereas Batch 2 contained the opposite. The compressive strengths were comparable even though Batch 1 had more Poraver which has a lower crush strength (300 psi) than Haydite (2000psi).

Admixtures

In the creation of *Maizin' Race*, MCCT used admixtures to help the concrete achieve the desired finishing characteristics. One of the admixtures used was superplasticizer to reduce water and help disperse fibers. More was used than the recommended amount of 18 floz/cwt to ensure a workable mix without increasing the required water. In addition, liquid latex modifier was used for its ability to provide strong adhesion



between the concrete and its reinforcing materials. Based on previous year's experience with this product, a sufficient dosage was used to ensure uniform concrete/mesh reinforcement bonding. More admixture was required than the recommended amount for the desired results due to the less dense cementitious materials. The dosages are given in Appendix B.

Reinforcing

Based on previous experience, MCCT decided that one layer of 4.3oz fiberglass mesh (POA of ~75%) between two 3/8 inch layers of concrete would provide the hull with the required flexural strength. In addition to providing the strength required, one layer of reinforcing allowed the hull to be constructed more easily as it is difficult to consistently place layers thinner than 3/8 of an inch. Additionally, polyvinyl alcohol (PVA) fibers were used to allow the canoe to maintain its structural strength and still absorb energy if damaged or cracked. The PVA fibers chemically bond to the matrix of the cementitious material, controlling small local cracking.

Final Results

The cementitious materials in the final mix for *Maizin' Race* were the same as the baseline mix with a partial redistribution of cementitious materials from Silica Fume to Fly Ash. The aggregates used were K15, Poraver, and Haydite. Figure 3 shows the compressive response (including the residual strength) of our final mix. The decrease in strength of the final batch is attributed to the use of the less dense Fly Ash Type F, which replaced a portion of the stronger Type C. Type F had not been included in previous batches but was used in the final batch to ensure a low overall unit weight. The final batch satisfied all structural requirements determined from analysis.

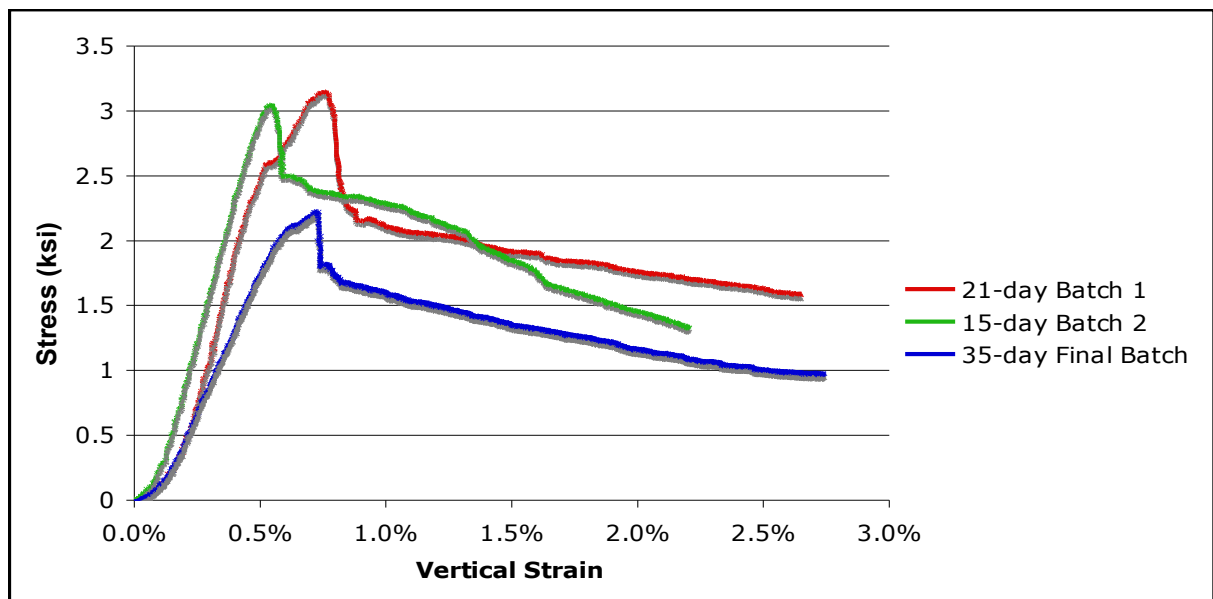


FIGURE 3: COMPRESSIVE STRENGTH BATCH COMPARISON



PROJECT MANAGEMENT AND CONSTRUCTION

The MCCT continued recruiting efforts in both the fall and winter semesters and accumulated nine active members. Breaking our team into sub-teams (hull-design, construction, and research and development) allowed members to display and develop their leadership skills while insuring that all members participated in activities that best suited their skills. The two team captains organized weekly team meetings, allowing the sub-teams the opportunity to update the team on progress, to ask questions, and to make suggestions. The smaller teams were led by second year students, who delegated tasks and ensured tasks were completed on schedule.

During the team orientation phase, the team captains dispensed a rough timeline and budget sheet for the new year. The formwork, concrete components, team travel expenses, food, and miscellaneous were designated a target budget summing to \$2500. Of this construction was estimated to cost \$500 and aggregate was estimated to cost \$500, and the actual prices were closely reflected by the estimates. Reuse of aggregates from the previous year maintained material procurement costs while use of male formwork decreased material costs.

Critical Path Items

Milestones for the year were set using the previous year's schedule as a reference. MCCT's goal to finish mix design was scheduled for beginning of January and was completed by the research and development team by that time. Another critical path item was the formwork routing because it had to be completed within the beginning of January due to scheduling constraints in the CNC routing lab. Formwork was cut January 15, and then assembled and finished by February 13. On the "big day", February 16, the whole team gathered and poured **Maizin' Race**. This critical path date was selected to assure adequate time for curing and finishing. The construction team followed up by sanding, staining and painting through out March, leaving time for practice before the competition. Completing the canoe mid-March was a major goal in order for rowers to practice rowing. If facilities for rowing practice can be found, members will practice two weeks prior to competition. For the technical presentation the captains selected representatives, who practiced for two weeks up to the competition.

The breakdown of man hours for the main project phases were 80 man-hours for mix design and development, 30 man-hours for hull design, 40 hours for formwork design, 30 hours for formwork construction, 60 man-hours for canoe pouring, 40 hours for finishing and 10 hours for paddling practice (if practice facilities are found.)

Construction

MCCT's canoe placement plan deviated from the previous year, as a male routed-foam mold was used rather than a female mold. This change was intended to reduce the overall cost of foam, as well as improve the ease of the pouring process. Last year a stiff concrete mix was required to pour in a female mold. We felt a smoother overall

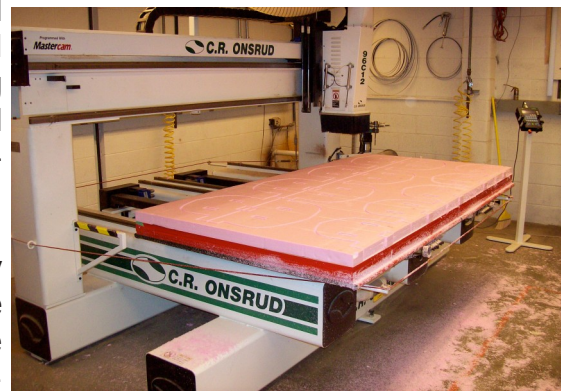


exterior would result with a less stiff mixture placed in a male mold because we would control the exterior surface finish during placement. Foam cutting and gluing techniques similar to previous years was followed, since the methods were effective and the required cost and time management was known.

Once the final **Maizin' Race** hull design was finished, the three dimensional file in Rhino was converted into two dimensional contours for CNC routing. The two dimensional contours in Rhino were taken at 2 inches on center since the formwork would be constructed with 2 inch insulation board. To capture the complex contours of the ends, the last 18 inches of the stern and bow were cut into three dimensional two inch sections. To ensure the foam was used as efficiently as possible, the width of the formwork varied along the length of the canoe. Key holes were cut into the foam sections and were fit with 2x4's to maintain alignment during the gluing process. Sections of approximately equal width were glued together in three to four foot sections. Then, the entire form body was sanded until the formwork was acceptably smooth, and dry-wall mud was applied to the foam surface for a smooth finish.

Four foot fiberglass reinforcing sheets were cut to fit the mold with 3 inches of overlap between sheets and 1-1/2 inches below the rough gunwale height. During pouring, concrete was placed in a 3/8 inch layer and finished from above by compacting by hand and with trowels. Reinforcement was then placed, and an additional crew followed behind, placing the final 3/8 inch layer of concrete. The exterior of the canoe was smoothed with damp towels and sponges. The canoe was covered by moist burlap and left to cure for two weeks. After demolding, the exterior and interior surfaces were coated with a slurry mix and the entire hull was thoroughly sanded. (Refer to pages 9 and 10 for formwork sections and gunwale finishing details.) The canoe was then sealed and stained according to manufacturer's recommendations.

Proper safety training was required before any work or research could be conducted in the U-M laboratory facilities. Each member of the team was responsible for attending safety training by the beginning of October, so that he/she could proceed with individually assigned tasks. Furthermore, protective equipment, such as gloves, masks, and safety glasses, were used during the application of drywall mud, the sanding of the foam and concrete, and during concrete mixing.



FIGURES 4 & 5: CNC ROUTING OF THE FORMWORK AND PLACEMENT OF MAIZIN' RACE



ORGANIZATIONAL CHART





APPENDIX A– REFERENCES

ACI 318-08, "Building Code Requirements for Structural Concrete," American Concrete Institute. (copyright 2008).

ASTM C 31/C 31M, "Standard Practice for Making and Curing Concrete Test Specimens in the Field," ASTM International Book of Standards vol.04.02. (copyright 2005)

ASTM C33-03, "Standard Specification for Concrete Aggregates," ASTM International Book of Standards vol.04.02. (copyright 2005).

ASTM C109/C109M-02, "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars," ASTM International Book of Standards vol.04.01. (copyright 2005).

ASTM C150-04ae1, "Standard Specification for Portland Cement," ASTM International Book of Standards vol.04.01. (copyright 2005).

ASTM C947-03, "Standard Test Method for Flexural Properties of Thin-Section Glass-Fiber-Reinforced Concrete," ASTM International Book of Standards vol.04.05. (copyright 2005).

"Ferrocement and Laminated Cementitious Composites," Antoine E. Naaman. (copyright 2000).

"Glossary of Nautical Terms" <http://en.wikipedia.org/wiki/Nautical_term> (accessed January 2007)

"Poraver Product Specifications" (copyright Poraver North America, 2006) <http://www.poraver.com/02rohstoff/pdf/product_specifications.pdf> (accessed October 2006)

"Rhino3D, NURBS Modeling for Windows." (copyright Robert McNeel & Assoc. 2003). <<http://www.rhino3d.com>> (accessed October 2006).

"Shell Element Internal Forces/Stresses Output Convention" (copyright Computers & Structures, Inc., 2006) <<c:\program files\SAP2000\help\20105.html>> (accessed November 2006)

"Tecfil T300 Product Specifications" (copyright Dirk Corp., 2006) <<http://www.pozzocrete.co.in/index.php?id=47>> (accessed December, 2006)

"3M Scotchlite Glass Bubbles: K and S series Product Information." (copyright 3M 2006). <http://www.3m.com/microspheres/s_k_1.html> (accessed October 2006).



APPENDIX B / TABLE 3.1 – MIXTURE PROPORTIONS

TABLE 3.1 - SUMMARY OF MIXTURE PROPORTIONS		Proportions as Designed		Batched Proportions		Yielded Proportions	
Batch Volume: 0.35 cubic ft	Specific Gravity	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
Cementitious Materials							
Portland Cement Type III	3.15	520	2.65	6.29	0.03	540	2.75
Fly Ash Type C	2.40	80	0.53	0.97	0.01	83	0.55
Tecfil	0.70	120	2.75	1.45	0.03	125	2.85
Norchem Silica Fume	2.30	80	0.56	0.97	0.01	83	0.58
C.M. Totals:		800	6.48	9.68	0.08	831	6.73
Fibers							
PVA Fiber	1.30	13	0.16	0.2	0.00	13	0.16
Aggregates							
K15	0.15	26	2.82	0.3	0.03	27	2.93
Absorption < 0.1%							
Batched Moisture < 0.1%							
Haydite 30	1.85	53	0.46	0.6	0.01	55	0.48
Absorption 1-2%							
Batched Moisture < 0.1%							
Haydite 50	1.85	43	0.37	0.5	0.00	45	0.39
Absorption 1-2%							
Batched Moisture < 0.1%							
Haydite 100	1.85	70	0.60	0.8	0.01	72	0.63
Absorption 1-2%							
Batched Moisture							
Poraver 0.5-1mm	0.47	120	4.09	1.5	0.05	125	4.25
Absorption = 7%							
Batched Moisture = 12.1%							
Poraver 1-2mm	0.39	168	6.90	2.0	0.08	174	7.17
Absorption = 7%							
Batched Moisture = 12.1%							
Aggregate Totals:		480	15.25	6	0.18	499	15.84
Water							
Batched Water	1.00	295	4.73	3.6	0.06	306	4.91
Total Free Water - Aggregates	1.00	0	0.00	0.0	0.00	0	0.00
Total Water - Admixtures	1.00	25	0.40	0.3	0.00	26	0.42
Total Water:		320	5.13	3.9	0.06	332	5.33
Admixtures							
	% Solids	Amount (fl oz/cwt)	Water in Admixture (lb/yd ³)	Amount (fl oz)	Water in Admixture (lb)	Amount (fl oz/cwt)	Water in Admixture (lb/yd ³)
Master Builders Glenium 3030	5%	23.0	11.00	2.4	0.15	23	10.00
Master Builders AE90	5%	0.0	0.00	0.0	0.00	0	0.00
Dow Liquid Latex Modifier	50%	54.0	14.00	5.6	0.17	54	14.54
Cement-CM Ratio		0.65			0.65		0.65
Water-CM Ratio		0.40			0.40		0.40
Slump, in.		0.2			0.2		0.2
Air Content, %		6%			3%		3%
Density (Unit Weight), lb/ft ³		58.4			57.9		57.9
Gravimetric Air Content, %					1%		
Yield, L		28.9			0.34		28.9



APPENDIX C / TABLE 3.2- GRADATION CURVES FOR INDIVIDUAL AND COMPOSITE AGGREGATES

Composite	Composite											
	K15		Haydite 30		Haydite 50		Haydite 100		P0.51		P12	
100.0	5.5	11.0	9.0	14.5	25.0	35.0						
100.0	5.5	11.0	9.0	14.5	25.0	35.0						
100.0	5.5	11.0	9.0	14.5	25.0	35.0						
71.3	5.5	11.0	9.0	14.5	25.0	6.3						
33.6	5.5	0.0	9.0	14.5	4.6	0.0						
20.4	5.5	0.0	0.0	14.5	0.4	0.0						
5.0	5.0	0.0	0.0	0.0	0.0	0.0						
Weight Factor:	5.5%	11.0%	9.0%	14.5%	25.0%	35.0%	100%					
cm ³ per Kilo:	367	59	49	78	532	899	1984					
Grams per Kilo:	55	110	90	145	250	350	1000					
Spec. Grav.	0.15	1.85	1.85	1.85	0.47	0.39						

Sieve No.	K15		Haydite 30		Haydite 50		Haydite 100		P0.51		P12	
	% Fin.	% Ret.	% Fin.	% Ret.	% Fin.	% Ret.	% Fin.	% Ret.	% Fin.	% Ret.	% Fin.	% Ret.
3/8"	100	0	100	0	100	0	100	0	100	0	100	0
4	100	0	100	0	100	0	100	0	100	0	100	0
8	100	0	100	0	100	0	100	0	100	0	100	0
16	100	0	100	0	100	0	100	0	100	0	18	82
30	100	0	0	100	100	0	100	0	18	82	0	100
50	100	0	0	100	0	100	100	0	2	98	0	100
100	90	10	0	100	0	100	0	100	0	100	0	100

Spec. Grav.	0.15	1.85	1.85	1.85	0.47	0.39
-------------	------	------	------	------	------	------

Composite SG
0.504

