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Executive Summary:

Following ten months of research, extensive testing, innovative construction, and physical training, the Clemson Concrete Canoe Team, 3CT, returns to the National Concrete Canoe Competition to introduce and compete with ACES WILD. Clemson University is located in the foothills of western South Carolina. Founded in 1889, Clemson University is a public, land grant university of approximately 14,000 undergraduate and 3,000 graduate students. The team is comprised of 16 civil engineering students, a quality control advisor, and a faculty advisor. 3CT has successfully taken the Carolina’s Conference title in the concrete canoe competition every year since 1993. These regional titles have led to 11 top ten finishes, including three national titles in the National Concrete Canoe Competition (’99, ’00, and ’02).

Table 1: Canoe Dimensions

Length: 21.4 ft. (6.5 m)
Weight: 202 lb (91.6 kg)
Thickness: 0.4 in. (1.02 cm)
Depth: 12 in. (30.5 cm)
Beam at Gunwale: 29 in. (73.7 cm)
Beam at Waterline: 26 in. (66.0 cm)
Color: Black

ACES WILD is a swift, maneuverable, and reliable canoe that is constructed of an ultra thin, lightweight concrete and reinforced with polypropylene mesh and high strength pretensioned polyethylene tendons (Table 1). The canoe is the product of economical construction, thorough planning, and continuous attention to detail. Parameters such as straight line speed and maneuverability were used in evaluating the hull design of the canoe. Material standards were created through analysis to prevent failure under static and dynamic

conditions. This analysis included Finite Element Analysis, strain gage testing, and transverse stress analysis. ACES WILD has excellent flexibility and strength due to the combination of lightweight aggregates and dispersed fibers in the concrete mixture (Table 2). The team used thermal imagery for concrete quality control and time-lapse photography to demonstrate methods of construction during placement. A new computer simulation project management program was utilized to ensure 3CT would meet all deadlines and show potential areas for adjustment in the project schedule. All of these construction and analytical techniques have made 3CT ready to join in the game with ACES WILD.

Table 2: Concrete Properties

	<u>English</u>	<u>SI</u>	<u>ASTM Standard</u>
Concrete Unit Weight	71.2 lb/ft ³	1,141 kg/m ³	C138 28 Day
Concrete Compressive Strength	846 psi	5.83 MPa	C109 28 Day
Concrete Flexural Strength	349 psi	2.41 MPa	C78 28 Day



Hull Design:

3CT took many important factors into consideration during the development of the hull design for ACES WILD. High performance racing canoes require a delicate balance between speed and maneuverability. Straight line speed is needed for the straight-aways in both the sprint and endurance races, while maneuverability is needed for the slalom portion of the endurance race. Stability at the start of the race and during turns is also important. It is difficult to maximize one parameter without affecting another. Finding a balance between these factors requires both creativity and innovative engineering.

The team's goal for this year's design was to maximize paddler performance by producing a fast, maneuverable, and stable canoe. Evaluation of the hull design began by obtaining feedback from veteran paddlers. Feedback showed that last year's canoe was easier to turn and more stable than previous years. Freeboard was also low enough to allow for full range of motion while paddling.

Utilizing the hull design software program GODZILLA, several hull designs were generated. Designs from past years were used as references for comparison to new hull designs. This program worked by using an iterative process to create hull designs based on user inputs. User variables of beam, length, and draft were varied in the development of each new design. A flat bottom with hard chines was also incorporated into the design to maintain stability.

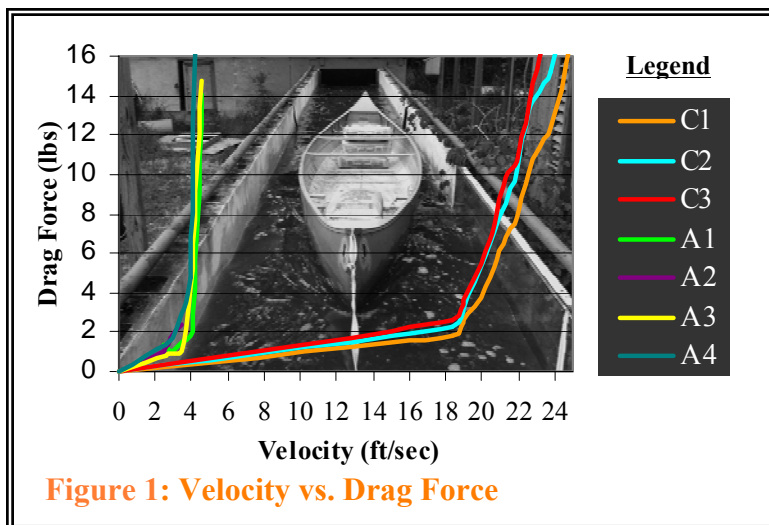


Figure 1: Velocity vs. Drag Force

The software program calculated the total theoretical drag force for each canoe. 3CT decided to validate these results with data from experimental testing. To do this, several canoes were tested in a flume to determine the drag force on each canoe at various velocities. The results from the flume test showed the same trend as the theoretical results; however, much higher drag forces were obtained during the flume testing. This was expected because the computer program assumes "ideal" conditions which were difficult to create in a flume. The fastest canoe is represented by the

computer program design "C1" and the flume testing design "A1" (Figure 1). This optimal design was a 21.4 ft. (6.5 m) canoe with a 26 in. (66.0 cm) beam at the waterline.

Since the computer program only designs below the waterline, further dimensions had to be determined. Past experience showed that an 8 in. (20.3 cm) freeboard was optimal to both keep water from entering the canoe and to allow paddlers a free range of motion. The beam at the gunwale was chosen as 29 in. (73.7 cm). A narrow beam helps to maximize speed by reducing drag and giving paddlers more freedom of motion. With these parameters established, the team's focus turned toward maneuverability. The design was modified by adding 2.5 in. (6.35 cm) of rocker in the bow and 1.5 in. (3.81 cm) in the stern. Rocker increases maneuverability during turns by slightly elevating the bow and stern in the water, thus reducing the surface area of the canoe in the water. This new design for ACES WILD was found to be very similar to a previous year's canoe. The team examined an old form and decided making modifications to this form would be more cost effective than constructing a new form.

After the final concrete mixture was created, 3CT found that flotation would be required. Bulkheads in the bow and stern were incorporated into the design to cover the foam flotation. The size of the bulkheads was minimized to reduce additional weight and provide maximum space for the paddlers. With the old form properly modified 3CT was ready to collect its cards and begin the game with ACES WILD.



Analysis:

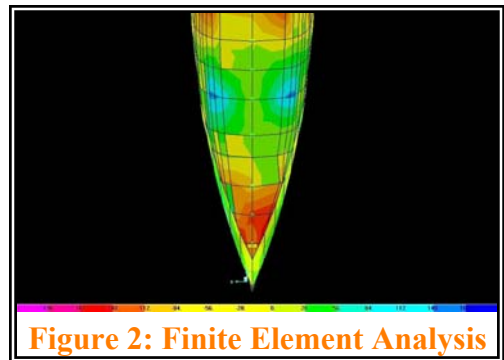
After the hull design was completed, 3CT needed to establish the structural design requirements needed to prevent ACES WILD from cracking under extreme stress. To achieve the target values for the concrete mixture, reinforcement, and composite, the team used theoretical and experimental procedures to determine the different stresses the canoe would undergo.

Theoretical analysis began by creating a structural model of the canoe in order to determine the maximum shear and moment experienced and the location of these forces. Paddlers were treated as 180 lb (81.65 kg) point loads for the two person loading with 140 lb (63.50 kg) loads added for the four person loading. The self weight of the canoe and the buoyancy force of water were calculated based on the width of the canoe at one-inch intervals. The model enabled 3CT to determine the maximum shear and moment occurred during the two person loading. The maximum moment was determined to be 680.6 ft-lb (922.6 N-m), located at the center of the canoe, while the maximum shear was 166.2 lb (739.3 N), located under each paddler. These loading conditions were used as design loads in the concrete design program CONCAD. This program was used to calculate the minimum required compressive strength of the concrete based on strength of reinforcement. When using the program, the sides of the canoe were treated as reinforced beams with a factor of safety (FS) of 1.75. The team determined a reinforcement with a modulus of elasticity of 7,000 ksi (48.07 GPa) should be used in conjunction with a minimum compressive concrete strength of 700 psi (4.81 MPa). Prior experience suggested 3CT use 300 psi (2.07 MPa) as a minimum flexural strength.

The last step of theoretical analysis was to perform a Finite Element Analysis (FEA) to determine the required composite strength of the canoe (Figure 2). The canoe was modeled in SAP 2000[®] using 512 shell elements, each 0.4 in. (10.2 mm) thick, with concrete compressive strength of 700 psi (4.81 MPa). Nine roller supports were placed along the canoe with a pin support at the stern for stability. After applying the paddler loads and the buoyancy force of water, the FEA showed a maximum compressive stress of 325 psi (2.23 MPa) occurred under the paddler's knees near the chines. After applying the FS, the minimum composite strength was 570 psi (3.91 MPa). The FEA ignored the effect of bulkheads to increase the maximum composite strength computed by the FEA.

Next, 3CT examined maximum stresses experimentally. First, 3CT examined longitudinal stresses experienced in the canoe under a dynamic loading. This involved outfitting a similarly designed canoe with nine linear strain gages and having two paddlers use the canoe under race conditions. Results indicated a maximum strain occurred at the center of the canoe along the gunwales. The maximum strain was converted into the maximum longitudinal stress. The maximum stress was determined to be 299 psi (2.06 MPa). This value was multiplied by the FS to obtain a minimum composite strength due to longitudinal stress of 525 psi (3.60 MPa).

The final step in the experimental analysis was to establish the maximum transverse stress experienced in the chines. 3CT equipped the same canoe with a displacement measuring device at the points that experience deflection during turns. This displacement was compared to an equivalent force creating the same deflection and converted into the maximum transverse stress experienced by the canoe, determined to be 431 psi (2.97 MPa). After applying the same FS, the minimum composite strength of the canoe due to transverse stresses was calculated as 755 psi (5.19 MPa). Using this analysis, 3CT established a minimum compressive strength of 700 psi (4.81 MPa), a minimum flexural strength of 300 psi (2.07 MPa), a minimum composite strength of 755 psi (5.19 MPa), and a minimum reinforcement modulus of elasticity of 7000 ksi (48.07 GPa). With that, 3CT was ready to shuffle the cards and deal away with ACES WILD.



Development and Testing:

Concrete canoes are subject to various loads that require them to be very structurally sound. The concrete and reinforcement must work together effectively as a composite to endure the rigors of transporting and racing. The team's main concern was the possibility of cracking in ACES WILD. 3CT began development for this year's canoe by first examining last year's canoe, Cast Away. The results of this examination showed that negotiating buoys during the races caused cracks to form in the chines of the canoe. In order to reduce the delamination cracking in the chines, 3CT needed to develop a mixture with greater resistance to stress during the races. 3CT focused its efforts on developing a mixture with the lowest possible unit weight while maintaining optimum compressive and flexural strength to reduce cracking. The team also wanted to maximize workability for ease of construction.

The targets set for this year's canoe, based on structural analysis, included a concrete mixture design with a maximum unit weight of 75 lb/ft³ (1,201 kg/m³) while maintaining a minimum compressive strength of 700 psi (4.83 MPa) and a minimum flexural strength of 300 psi (2.07 MPa). To attain these goals and develop such a concrete mixture, 3CT divided material research into five phases: aggregate, lightweight aggregate, binders, admixtures, and fibers. In each phase, the team utilized standard tests. Compressive strength was measured with 2 in. (50.8 mm) cubes in accordance with ASTM C109. Flexural strength was calculated according to ASTM C78 by applying a load at the third points of an 8 in. (203.2 mm) long, 1.25 in. (31.8 mm) wide, and 2 in. (50.8 mm) deep beam.

Phase one began by developing a spreadsheet used to determine the amount of aggregate needed to comply with ASTM C33 based on known specific gravities and a desired volume of concrete. 3CT sieved Ottawa Sand (OS), Perlite (Pe), Pumice (Pu), Stalite (St), and Vermiculite (Vm) for testing purposes. The team tested these five aggregates to determine a base aggregate for the construction of ACES WILD. These aggregates were tested for compressive and flexural strength. Although mixtures containing Ottawa Sand were heavier by 12%, these mixtures were higher in compressive strength and lighter in color (Table 3). This base aggregate mixture was used as the baseline for remaining tests.

Table 3: Aggregate Testing

Aggregate	Compressive Strength (psi)
OS	2,080
Pe	1,946
Pu	1,491
St	1,861
Vm	1,775

Ottawa Sand is also easily pigmented and was used to enhance the appearance of the interior of ACES WILD. The pigmented sand had no significant affect on the material properties of the concrete and did not result in coloration of the concrete mixture.

Phase two was designed to determine the optimum blend of glass bubbles for a lightweight concrete aggregate.

The team started by using the baseline mixture, established in phase one, to test six individual glass bubble aggregates in order to decrease the unit weight of the concrete. Next, different types of glass bubbles were blended together to capture each glass bubble's key properties creating an optimum blend of lightweight aggregate. This allowed the team to reduce unit weight while maximizing compressive strength. K15 and K25 glass bubbles were added to the baseline mixture and resulted in a compressive strength of 992 psi (6.84 MPa) and a unit weight of 77.7 lb/ft³ (1,245 kg/m³). This new baseline mixture was used as the control for the remaining tests.

In phase three, different types of polymer based binders were tested to help increase flexural strength. 3CT experimented with two varieties of latex at 14 days using ASTM C78. Both latexes, L1 and L2, were tested at 5, 10, and 15% by weight of binder. The tests showed a decrease in the unit weight by 8.5% for L1 and 5.6% for L2; however, only the use of L1 increased the compressive strength. In addition, L1 provided the mixture with a flexural strength of 201.6 psi (1.39 MPa). This latex was ultimately incorporated into the mixture at 15% by weight of binder. The team also tested the non-polymer based binder fly ash. Mixtures containing class C and class F fly ash were tested at 28 days. The team selected class C fly ash for its light gray color since there was no substantial difference in compressive or flexural strength and workability was constant between the two types.



Phase four included the testing of admixtures. 3CT tested shrinkage reducer (SR), high-range water reducer (HRWR), and super plasticizer (SP). Mixtures containing these admixtures (tested at 1% and 2% by weight of binder) were tested for flexural and compressive strength. The results, in general, indicated that the use of these admixtures were not beneficial (Table 4).

Admixture	Compressive Strength	Flexural Strength
HRWR 1%	35.1	17.1
HRWR 2%	23.4	31.0
SR 1%	22.3	27.4
SR 2%	31.7	30.9
SP 1%	27.9	15.3
SP 2%	19.2	13.9

Phase five of the project included research of fiber reinforcement. 3CT tested five types of fibers to act as secondary reinforcement to increase the flexural strength by bridging micro-cracks and redistributing internal strains in the concrete. The testing included two polypropylene fibers, two other synthetic fibers, and carbon fibers. Carbon fibers increased the peak flexural strength of the concrete while the polypropylene and synthetic fibers increased the post peak performance of the concrete mixture (Figure 3). All of the fibers had no affect on the

compressive strength or the unit weight of the concrete. Carbon fibers were combined with the best synthetic fiber at the most efficient ratio of 1:4.6 in the final mixture. The final concrete mixture has a unit weight of 71.2 lb/ft³ (1,141 kg/m³), compressive strength of 846 psi (5.83 MPa), and a flexural strength of 349 psi (2.41 MPa), all meeting the team’s criteria.

While experimenting with different concrete mixtures, 3CT tested four types of primary reinforcement. Reinforcement materials should have high modulus and strength to allow the stress in the concrete to be transferred to the reinforcement. The reinforcements tested were two types of polypropylene mesh, R1 and R2, and two types of glass fiber mesh, R3 and R4. All reinforcements met the minimum target modulus of elasticity values. Each reinforcement was tested using ASTM C293 on plates 0.4 in. (10mm) deep, 3 in. (76 mm) wide and 12 in. (305mm) long. Samples containing glass fiber mesh had a 29% greater strength than the polypropylene meshes; however, both glass fiber meshes were eliminated from further testing due to lack of post peak strength. The glass fiber meshes completely failed upon reaching a maximum load. In the event of cracking in the chins, the polypropylene meshes would continue to ensure structural integrity and were used in the construction of the canoe. Specimens made with R1 resulted in a strength of 617 psi (4.25 MPa) where specimens containing R2 had a strength of only 400 psi (2.76 MPa); therefore, R1 was chosen for construction.

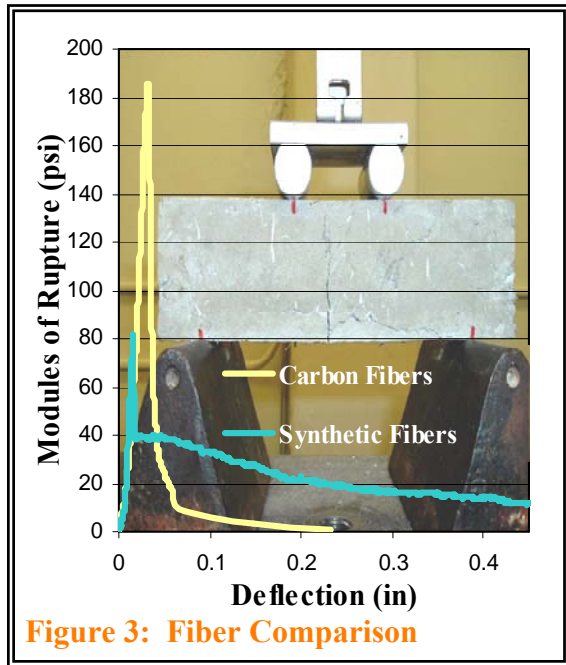


Figure 3: Fiber Comparison

Next, the effects of pretensioned tendons placed in the gunwales above the neutral axis of the canoe were tested using polyethylene tendons. Pretensioning was evaluated using ASTM C1018 on beams 3 in. (76 mm) deep, 1 in. (25 mm) wide, and 10 in. (254 mm) long with four pretensioned strands. An increase in the pretension force in each strand resulted in an increase in composite strength. The final reinforcement scheme contains 12 pretensioned polyethylene tendons, each with 40 lb (177.9 N) of force, spaced 0.5 in. (13 mm) apart in alternating layers within the inner two concrete layers. When integrated with the pretensioned tendons, the final composite yields a first crack flexural strength of 349 psi (2.41 MPa) and an ultimate composite flexural strength of 782 psi (5.39 MPa), both meeting the team’s criteria. After all material testing was completed, 3CT was ready to raise the stakes with ACES WILD.



Project Management and Construction:

Completing a project of great magnitude on time and under budget constraints requires detailed planning and constant communication. Two project managers were selected at the beginning of the fall semester. Team leaders were assigned to each activity and new recruits worked in their areas of interest (Figure 5). The two project managers and key returning personnel worked together to establish a work breakdown structure (WBS). Individual activities in the WBS were treated as work packages and incorporated into a preliminary schedule. 3CT tested this schedule with an innovative computer simulation program, ABC-SIM, to model the project schedule and control variances in the milestone activities. Stochastic durations were used in the model to account for the variability associated with the construction activities. The range of durations for each activity was determined by examining previous team's schedules. The results of the simulation showed the team's preliminary schedule had a 13.1% chance of overrun. The team modified this schedule to reduce the risk of overrun to less than 2%. The modified schedule was incorporated into the scheduling software Primavera and shown in Figure 6 with deterministic durations. Items in the critical path are located in red. These activities were considered critical because the delay of any one item would delay the completion of the project. Milestone activities included hull design, concrete mixture, and placement. Team leaders made use of email, message boards, and team meetings to assure all aspects of these projects were being completed properly. Research, testing, and construction hours were documented with weekly progress reports. All together, the time spent on ACES WILD was approximately 490 man-hours. After all activities and critical paths were determined, 3CT was ready to begin the construction phase of the project.

The construction phase began with prepackaging dry components of the concrete mixture to reduce the time of construction. Next, an existing wooden male form was sanded, patched, and covered with 0.4 mil plastic to act as a release agent. On the day of placement, alternating layers of concrete and reinforcement were placed onto the male form (Figure 4). Twelve pretensioned polyethylene tendons were placed in the middle two layers of the concrete along the gunwales. A 40 lb (177.9 N) force in each tendon was kept constant by measuring the extension of a calibrated spring.

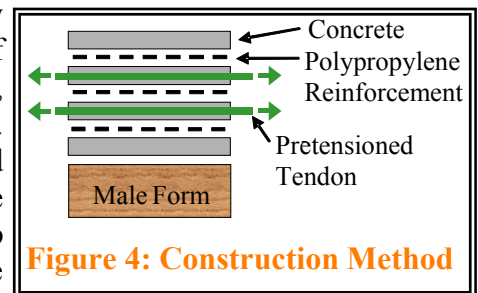


Figure 4: Construction Method

To maintain quality control between layers of concrete, 3CT made use of thermal photography (Figure 5). This technique monitored the surface temperature of the concrete to ensure constant heat of hydration throughout the construction of ACES WILD.

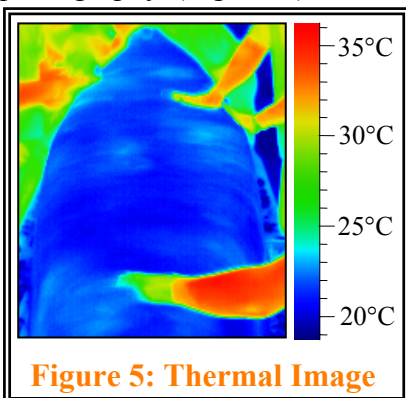


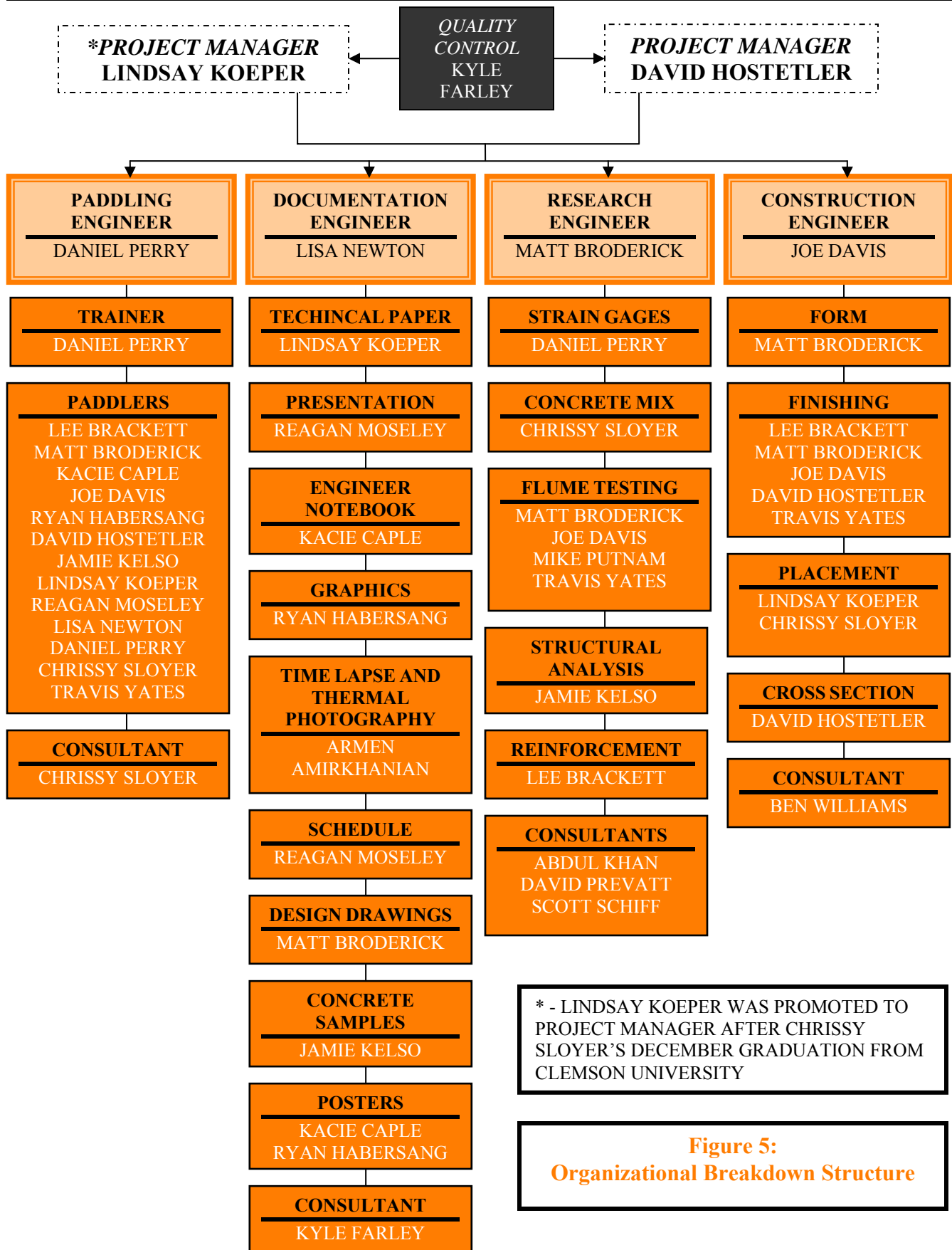
Figure 5: Thermal Image

Last year's canoe construction included a new acrylic finishing method. This method resulted in concrete pulling away from the outer layer of reinforcement and inconsistencies in the thickness of the outer layer. This year, 3CT researched different methods of finishing for the exterior of the canoe. A new "poly-surfacing" method was used for its simplicity and low cost. This new method covered the entire canoe with a large sheet of 4 mil plastic and rollers were then used to smooth out the concrete surface. This method resulted in a smooth surface that reduced sanding and patching time. Finally, the canoe was covered with plastic and allowed to cure.

To help prevent shrinkage cracking due to rapid water loss, the canoe was sprayed with water twice a day for 14 days and stored in a temperature controlled environment. After curing, the exterior of the canoe was sanded and patched. Next, the canoe was removed from the form and the interior was sanded and patched. Concrete sealer and stain was then applied to the exterior of the canoe in accordance with the manufacturer's recommendations. Finally, vinyl decals were adhered. With all organization and construction under the table, ACES WILD was ready to place a bet and show its hand.



CLEMSON CONCRETE CANOE TEAM



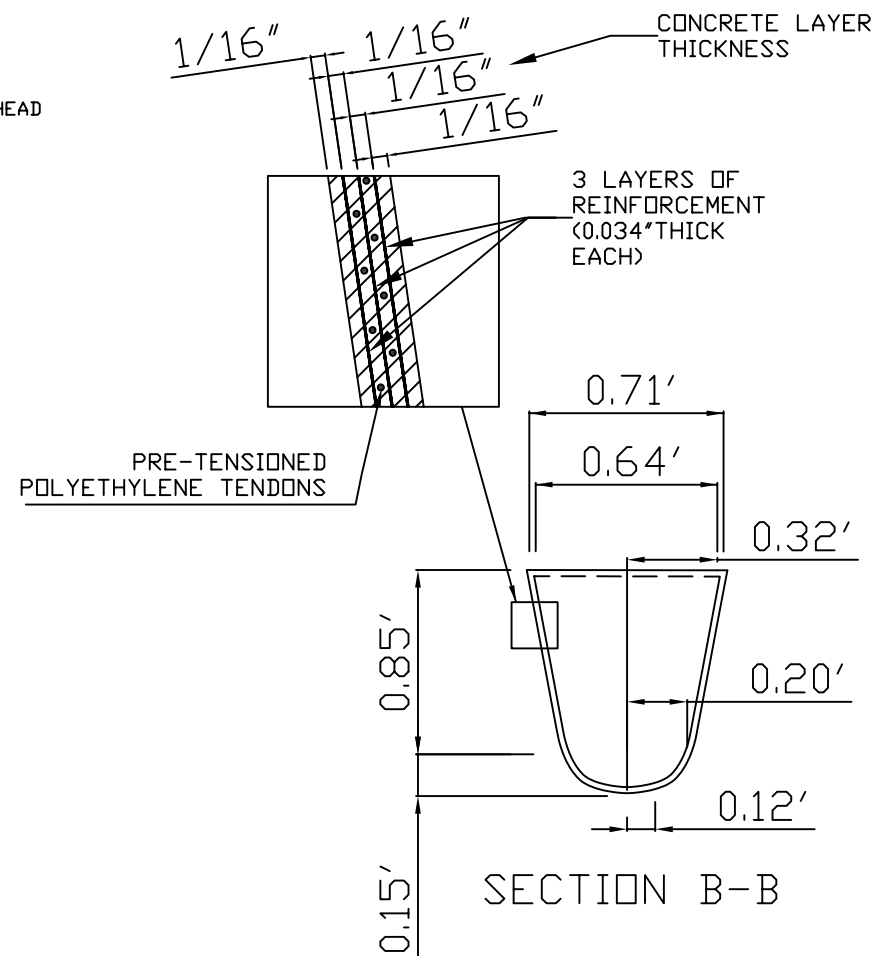
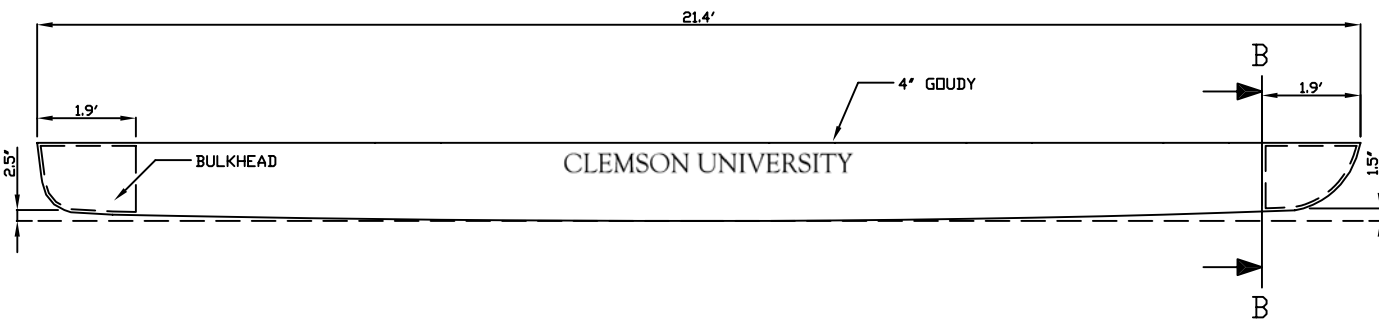
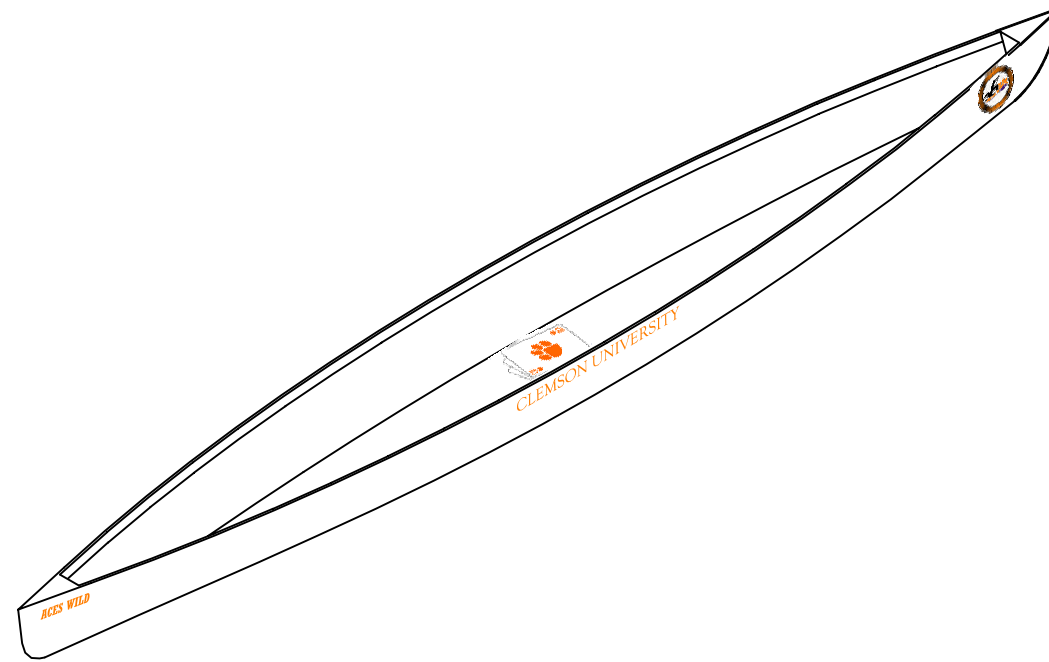
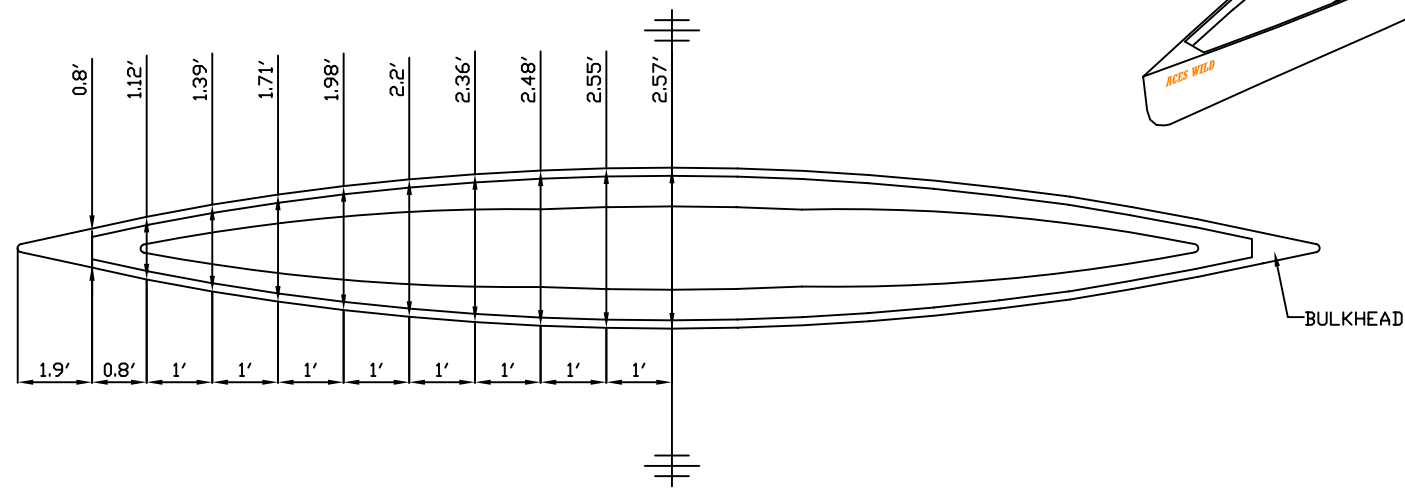
* - LINDSAY KOEPER WAS PROMOTED TO PROJECT MANAGER AFTER CHRISSY SLOYER'S DECEMBER GRADUATION FROM CLEMSON UNIVERSITY

Figure 5:
Organizational Breakdown Structure





ITEM NO	QTY	UNIT	DESCRIPTION
1	2.5	CF	CONCRETE
2	256	SF	POLYPROPYLENE MESH
3	520	LF	POLYETHYLENE TENDONS
4	0.37	CF	POLYSTYRENE FOAM



REV. DATE	REV	DESCRIPTION
5/9/05	1	FORMATTING

ENGINEER: MATT BRODERICK
 DRAWN BY: MRB DATE: 3/6/05
 CHECKED BY: LNK DATE: 3/6/05
 PROJECT: **ACES WILD**

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CLEMSON CONCRETE CANOE TEAM

Table 3.1-1: Summary of Final Mixture Proportions

AIR AND CEMENTITIOUS MATERIALS				
Air Content of Concrete		Amount: 13.9 (%)	Volume: .139 (m ³)	
Cementitious Material		Specific Gravity	Amount (kg/m ³)	Volume (m ³)
ASTM C 150 Cement Type I White		3.150	247.975	0.079
2: Class C Fly Ash		2.200	53.138	0.024
3: Quikrete Concrete Acrylic Fortifier		1.100	53.138	0.048
Σ(all cementitious materials)			<i>cm</i> : 354.251	Vol _{cm} : 0.151
Cement-to-Cementitious Materials Ratio			<i>c/cm</i> : 0.7	
AGGREGATES				
Aggregate #	Amount (kg/m ³)	ASTM C 127/128 BSG (SSD)	Volume (m ³)	Batch Weight (kg/m ³)
1: Sand-Size No. 16 Sieve	<i>W_{SSD,1}</i> : 90.922	2.650	0.034	<i>W_{stk,1}</i> : 90.922
2: Sand-Size No. 30 Sieve	<i>W_{SSD,2}</i> : 151.537	2.650	0.057	<i>W_{stk,2}</i> : 151.537
3: Sand-Size No. 50 Sieve	<i>W_{SSD,3}</i> : 181.844	2.650	0.069	<i>W_{stk,3}</i> : 181.844
4: Sand-Size No. 100 Sieve	<i>W_{SSD,4}</i> : 121.229	2.650	0.046	<i>W_{stk,4}</i> : 121.229
5: 3M K25 Glass Bubbles	<i>W_{SSD,5}</i> : 30.307	0.250	0.121	<i>W_{stk,5}</i> : 30.307
6: 3M K15 Glass Bubbles	<i>W_{SSD,6}</i> : 30.307	0.150	0.202	<i>W_{stk,5}</i> : 30.307
Combined	<i>W_{SSD,agg}}</i> : 606.146		0.529	<i>W_{stk,agg}}</i> : 606.146
FIBERS				
Fiber #	Volume Fraction (%)	Specific Gravity	Volume (m ³)	Batch Weight (kg/m ³)
1: Diced Carbon Fibers	0.018	2.900	0.00018	0.533
2: Synthetic Fibers	0.272	0.910	0.00272	2.472
Σ(all fibers)	0.290		0.0029	3.005
WATER				
Water		<i>W</i> : 177.125	<i>w_{batch}</i> : 4.145	kg/m ³
vol of admixture #1:		<i>x</i> ₁ :		mL/m ³
vol of admixture #2:		<i>x</i> ₂ :		mL/m ³
vol of admixture #3		<i>x</i> ₃ :		mL/m ³
water from Quikrete Concrete Acrylic Fortifier			<i>w_{admix,1}</i> : 172.980	kg/m ³
water from admixture #2			<i>w_{admix,2}</i> :	kg/m ³
water from admixture #3			<i>w_{admix,3}</i> :	kg/m ³
total of free (surplus) water from all aggregates			Σ <i>w_{free}</i> : 172.980	kg/m ³
total water		<i>w</i> : 177.125	<i>w</i> : 177.125	kg/m ³
concrete density	1,140.50			kg/m ³
water to cement ratio	<i>w/c</i> : 0.714			
water to cementitious material	<i>w/cm</i> : 0.500			



CLEMSON CONCRETE CANOE TEAM

Table 3.1-2: Summary of Patch Mixture Proportions

AIR AND CEMENTITIOUS MATERIALS				
Air Content of Concrete		Amount: 13.6 (%)	Volume: .136 (m ³)	
Cementitious Material		Specific Gravity	Amount (kg/m ³)	Volume (m ³)
ASTM C 150 Cement Type I White		3.150	249.678	0.079
2: Class C Fly Ash		2.200	53.502	0.024
3: Quikrete Concrete Acrylic Fortifier		1.100	53.502	0.049
Σ(all cementitious materials)			<i>cm</i> : 356.682	<i>Vol_{cm}</i> : 0.152
Cement-to-Cementitious Materials Ratio			<i>c/cm</i> : 0.7	
AGGREGATES				
Aggregate #	Amount (kg/m ³)	ASTM C 127/128 BSG (SSD)	Volume (m ³)	Batch Weight (kg/m ³)
1: Sand-Size No. 16 Sieve	<i>W_{SSD,1}</i> : 91.546	2.650	0.035	<i>W_{stk,1}</i> : 91.546
2: Sand-Size No. 30 Sieve	<i>W_{SSD,2}</i> : 152.577	2.650	0.058	<i>W_{stk,2}</i> : 152.577
3: Sand-Size No. 50 Sieve	<i>W_{SSD,3}</i> : 183.093	2.650	0.069	<i>W_{stk,3}</i> : 183.093
4: Sand-Size No. 100 Sieve	<i>W_{SSD,4}</i> : 122.062	2.650	0.046	<i>W_{stk,4}</i> : 122.062
5: 3M K25 Glass Bubbles	<i>W_{SSD,5}</i> : 30.515	0.250	0.122	<i>W_{stk,5}</i> : 30.515
6: 3M K15 Glass Bubbles	<i>W_{SSD,6}</i> : 30.515	0.150	0.204	<i>W_{stk,6}</i> : 30.515
Combined	<i>W_{SSD,agg}</i> : 610.308		0.534	<i>W_{stk,agg}</i> : 610.308
FIBERS				
Fiber #	Volume Fraction (%)	Specific Gravity	Volume (m ³)	Batch Weight (kg/m ³)
1: Diced Carbon Fibers	0.000	2.900	0	0.000
2: Synthetic Fibers	0.000	0.910	0	0.000
Σ(all fibers)			0	0
WATER				
water		<i>W</i> : 178.342	<i>w_{batch}</i> : 4.174	kg/m ³
vol of admixture #1:		<i>x</i> ₁ :		mL/m ³
vol of admixture #2:		<i>x</i> ₂ :		mL/m ³
vol of admixture #3		<i>x</i> ₃ :		mL/m ³
water from Quikrete Concrete Acrylic Fortifier			<i>W_{admix,1}</i> : 174.168	kg/m ³
water from admixture #2			<i>W_{admix,2}</i> :	kg/m ³
water from admixture #3			<i>W_{admix,3}</i> :	kg/m ³
total of free (surplus) water from all aggregates			<i>Σw_{free}</i> : 174.168	kg/m ³
total water		<i>w</i> : 178.342	<i>w</i> : 178.342	kg/m ³
concrete density	1,145.32			kg/m ³
water to cement ratio	<i>w/c</i> : 0.714			
water to cementitious material	<i>w/cm</i> : 0.500			



CLEMSON CONCRETE CANOE TEAM

Table 3.1-3: Summary of Pigmented Mixture Proportions

AIR AND CEMENTITIOUS MATERIALS				
Air Content of Concrete		Amount: 15.4 (%)	Volume: .154 (m ³)	
Cementitious Material		Specific Gravity	Amount (kg/m ³)	Volume (m ³)
ASTM C 150 Cement Type I White		3.150	243.796	0.077
2: Class C Fly Ash		2.200	52.242	0.024
3: Quikrete Concrete Acrylic Fortifier		1.100	52.242	0.048
Σ(all cementitious materials)			<i>cm</i> : 348.280	<i>Vol_{cm}</i> : 0.149
Cement-to-Cementitious Materials Ratio			<i>c/cm</i> : 0.7	
AGGREGATES				
Aggregate #	Amount (kg/m ³)	ASTM C 127/128 BSG (SSD)	Volume (m ³)	Batch Weight (kg/m ³)
1: Sand-Size No. 16 Sieve	<i>W_{SSD,1}</i> : 89.390	2.650	0.034	<i>W_{stk,1}</i> : 89.390
2: Sand-Size No. 30 Sieve	<i>W_{SSD,2}</i> : 148.983	2.650	0.056	<i>W_{stk,2}</i> : 148.983
3: Sand-Size No. 50 Sieve	<i>W_{SSD,3}</i> : 178.779	2.650	0.067	<i>W_{stk,3}</i> : 178.779
4: Sand-Size No. 100 Sieve	<i>W_{SSD,4}</i> : 119.186	2.650	0.045	<i>W_{stk,4}</i> : 119.186
5: 3M K25 Glass Bubbles	<i>W_{SSD,5}</i> : 29.797	0.250	0.119	<i>W_{stk,5}</i> : 29.797
6: 3M K15 Glass Bubbles	<i>W_{SSD,6}</i> : 29.797	0.150	0.199	<i>W_{stk,6}</i> : 29.797
Combined	<i>W_{SSD,agg}</i> : 595.932		0.520	<i>W_{stk,agg}</i> : 595.932
FIBERS				
Fiber #	Volume Fraction (%)	Specific Gravity	Volume (m ³)	Batch Weight (kg/m ³)
1: Diced Carbon Fibers	0.018	2.900	0.00018	0.524
2: Synthetic Fibers	0.267	0.910	0.00267	2.431
Σ(all fibers)	0.285		0.00285	2.955
WATER				
water		<i>W</i> : 174.140	<i>w_{batch}</i> : 4.076	kg/m ³
vol of admixture #1:		<i>x</i> ₁ :		mL/m ³
vol of admixture #2:		<i>x</i> ₂ :		mL/m ³
vol of admixture #3		<i>x</i> ₃ :		mL/m ³
water from Quikrete Concrete Acrylic Fortifier			<i>W_{admix,1}</i> : 170.064	kg/m ³
water from admixture #2			<i>W_{admix,2}</i> :	kg/m ³
water from admixture #3			<i>W_{admix,3}</i> :	kg/m ³
total of free (surplus) water from all aggregates			<i>ΣW_{free}</i> : 170.064	kg/m ³
total water		<i>w</i> : 174.140	<i>w</i> : 174.140	kg/m ³
concrete density	1,121.29			kg/m ³
water to cement ratio	<i>w/c</i> : 0.714			
water to cementitious material	<i>w/cm</i> : 0.500			



Table 3.1-4: Summary of Orange Concrete Mixture Proportions

AIR AND CEMENTITIOUS MATERIALS				
Air Content of Concrete		Amount: 17.4 (%)	Volume: .174 (m ³)	
Cementitious Material		Specific Gravity	Amount (kg/m ³)	Volume (m ³)
ASTM C 150 Cement Type I White		3.150	251.842	0.080
2: Class C Fly Ash		2.200	53.966	0.025
3: Fox Industries 338 Latex		1.100	53.966	0.049
Σ(all cementitious materials)			<i>cm</i> : 359.775	<i>Vol_{cm}</i> : 0.154
Cement-to-Cementitious Materials Ratio			<i>c/cm</i> : 0.7	
AGGREGATES				
Aggregate #	Amount (kg/m ³)	ASTM C 127/128 BSG (SSD)	Volume (m ³)	Batch Weight (kg/m ³)
1: Sand-Size No. 16 Sieve	<i>W_{SSD,1}</i> : 70.733	2.650	0.027	<i>W_{stk,1}</i> : 70.733
2: Sand-Size No. 30 Sieve	<i>W_{SSD,2}</i> : 117.888	2.650	0.045	<i>W_{stk,2}</i> : 117.888
3: Sand-Size No. 50 Sieve	<i>W_{SSD,3}</i> : 141.465	2.650	0.053	<i>W_{stk,3}</i> : 141.465
4: Sand-Size No. 100 Sieve	<i>W_{SSD,4}</i> : 94.310	2.650	0.036	<i>W_{stk,4}</i> : 94.310
5: 3M K1Glass Bubbles	<i>W_{SSD,5}</i> : 47.155	0.125	0.377	<i>W_{stk,5}</i> : 47.155
Combined	<i>W_{SSD,agg}}</i> : 471.551		0.538	<i>W_{stk,agg}}</i> : 471.551
FIBERS				
Fiber #	Volume Fraction (%)	Specific Gravity	Volume (m ³)	Batch Weight (kg/m ³)
1: Diced Carbon Fibers	0.000	2.900	0	0.000
2: Synthetic Fibers	0.000	0.910	0	0.000
Σ(all fibers)	0		0	0
WATER				
Water		<i>W</i> : 170.546	<i>w_{batch}</i> : 27.628	kg/m ³
vol of admixture #1:		<i>x</i> ₁ :		mL/m ³
vol of admixture #2:		<i>x</i> ₂ :		mL/m ³
vol of admixture #3:		<i>x</i> ₃ :		mL/m ³
water from FX 338			<i>w_{admix,1}</i> : 63.351	kg/m ³
water from admixture #2: Quikrete Liquid Color			<i>w_{admix,2}</i> : 79.567	kg/m ³
water from admixture #3:			<i>w_{admix,3}</i> :	kg/m ³
total of free (surplus) water from all aggregates			<i>Σw_{free}</i> : 142.918	kg/m ³
total water		<i>w</i> : 170.546	<i>w</i> : 170.546	kg/m ³
concrete density	1,001.872			kg/m ³
water to cement ratio	<i>w/c</i> : 0.677			
water to cementitious material	<i>w/cm</i> : 0.474			



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Table 3.1-5: Summary of Black Concrete Mixture Proportions

AIR AND CEMENTITIOUS MATERIALS				
Air Content of Concrete		Amount: 19.5 (%)	Volume: .195(m ³)	
Cementitious Material		Specific Gravity	Amount (kg/m ³)	Volume (m ³)
ASTM C 150 Cement Type I White		3.150	238.555	0.076
2: Class C Fly Ash		2.200	51.119	0.023
3: Fox Industries 338 Latex		1.100	51.119	0.046
Σ(all cementitious materials)			<i>cm</i> : 340.793	Vol _{<i>cm</i>} : 0.146
Cement-to-Cementitious Materials Ratio			<i>c/cm</i> : 0.7	
AGGREGATES				
Aggregate #	Amount (kg/m ³)	ASTM C 127/128 BSG (SSD)	Volume (m ³)	Batch Weight (kg/m ³)
1: Sand-Size No. 16 Sieve	<i>W_{SSD,1}</i> : 67.001	2.650	0.025	<i>W_{stk,1}</i> : 67.001
2: Sand-Size No. 30 Sieve	<i>W_{SSD,2}</i> : 111.668	2.650	0.042	<i>W_{stk,2}</i> : 111.668
3: Sand-Size No. 50 Sieve	<i>W_{SSD,3}</i> : 134.002	2.650	0.051	<i>W_{stk,3}</i> : 134.002
4: Sand-Size No. 100 Sieve	<i>W_{SSD,4}</i> : 89.334	2.650	0.034	<i>W_{stk,4}</i> : 89.334
5: 3M K1 Glass Bubbles	<i>W_{SSD,5}</i> : 44.667	0.125	0.357	<i>W_{stk,5}</i> : 44.667
Combined	<i>W_{SSD,agg}</i> : 446.672		0.509	<i>W_{stk,agg}</i> : 446.672
FIBERS				
Fiber #	Volume Fraction (%)	Specific Gravity	Volume (m ³)	Batch Weight (kg/m ³)
1: Diced Carbon Fibers	0.000	2.900	0	0.000
2: Synthetic Fibers	0.000	0.910	0	0.000
Σ(all fibers)	0		0	0
WATER				
water		<i>W</i> : 165.631	<i>w_{batch}</i> : 68.042	kg/m ³
vol of admixture #1:		<i>x</i> ₁ :		mL/m ³
vol of admixture #2:		<i>x</i> ₂ :		mL/m ³
vol of admixture #3:		<i>x</i> ₃ :		mL/m ³
water from FX 338			<i>w_{admix,1}</i> : 60.009	kg/m ³
water from admixture #2: Quikrete Liquid Color			<i>w_{admix,2}</i> : 37.580	kg/m ³
water from admixture #3			<i>w_{admix,3}</i> :	kg/m ³
total of free (surplus) water from all aggregates			Σ <i>w_{free}</i> : 97.589	kg/m ³
total water		<i>w</i> : 169.631	<i>w</i> : 169.631	kg/m ³
concrete density	953.095			kg/m ³
water to cement ratio	<i>w/c</i> : 0.694			
water to cementitious material	<i>w/cm</i> : 0.486			



Figure 3.1-1: Composite Gradation Curve

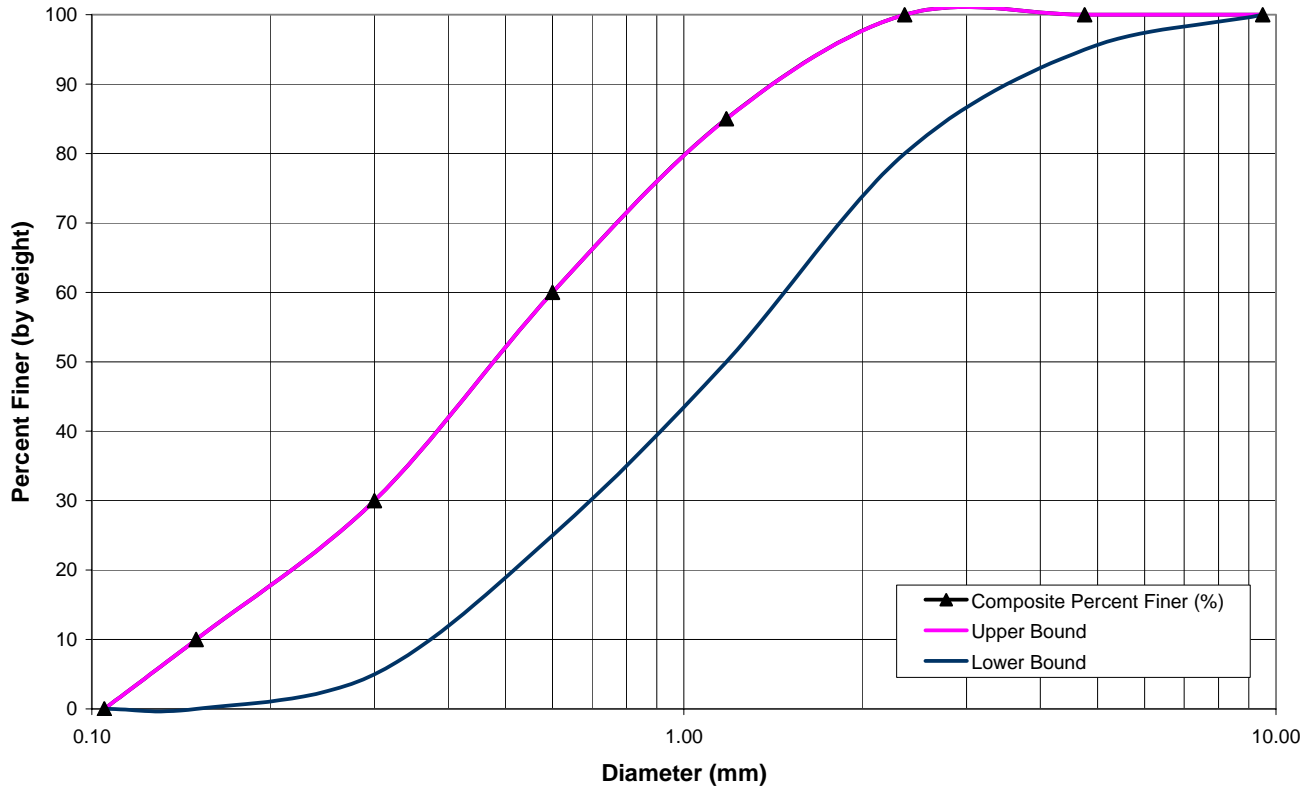


Table 3.2-1: Composite Gradation Chart

Concrete Aggregate: Composite
 Sample Weight: 500 grams
 Specific Gravity (G_s): -

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.00	0.00	100.00
No. 4	4.75	0.00	0.00	100.00
No. 8	2.36	0.00	0.00	100.00
No. 16	1.18	165.49	165.49	85.00
No. 30	0.60	275.82	441.31	60.00
No. 50	0.30	330.99	772.30	30.00
No. 100	0.15	220.66	992.96	10.00
Fines	0.11	110.33	1103.29	0.00



Figure 3.1-2: Silica Sand Gradation Curve

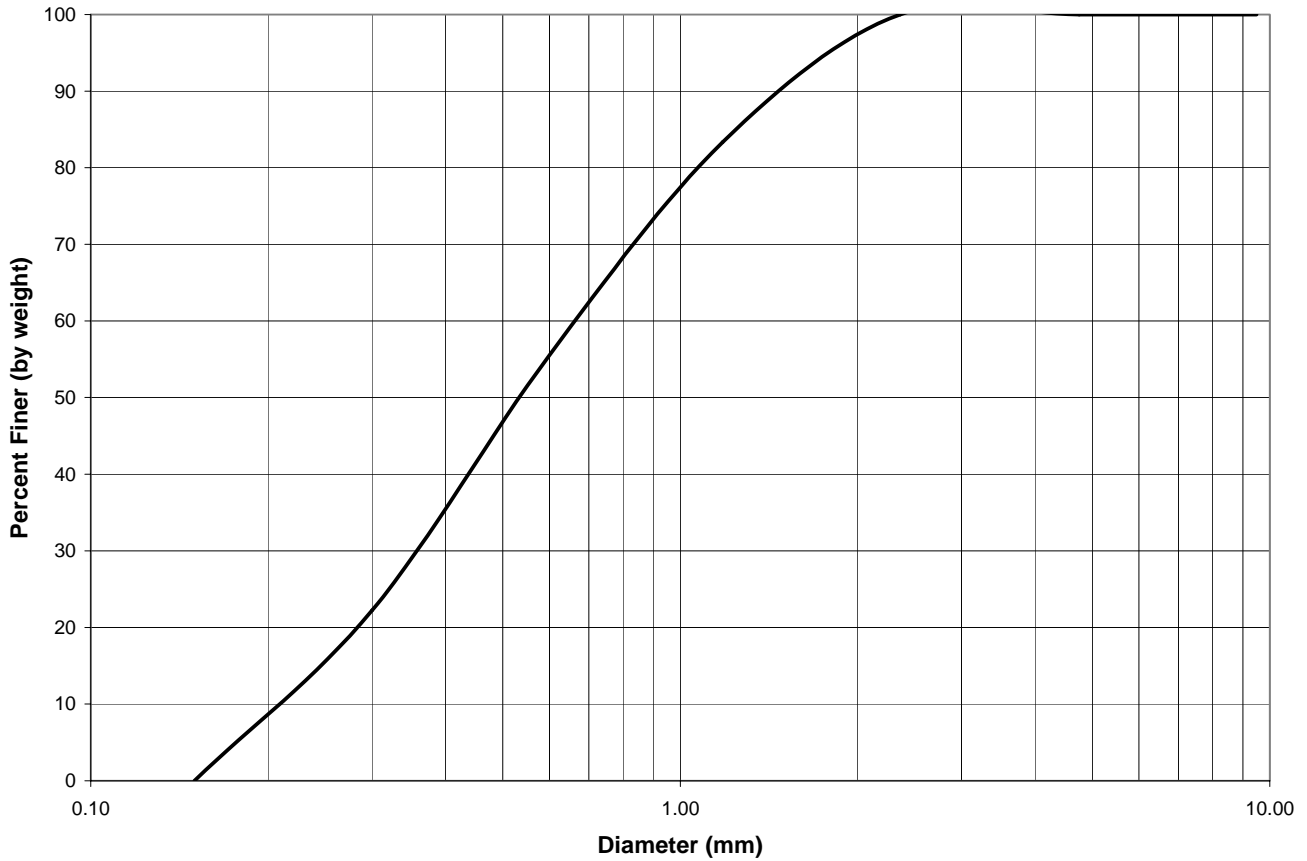


Table 3.2-2: Silica Sand Gradation Chart

Concrete Aggregate: Silica Sand
 Sample Weight: 500 grams
 Specific Gravity (G_s): 2.650

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.00	0.00	100.00
No. 4	4.75	0.00	0.00	100.00
No. 8	2.36	0.00	0.00	100.00
No. 16	1.18	165.49	165.49	83.33
No. 30	0.60	275.82	441.31	55.56
No. 50	0.30	330.99	772.30	22.22
No. 100	0.15	220.66	992.96	0.00



Figure 3.1-3: K15 Glass Bubbles Gradation Curve

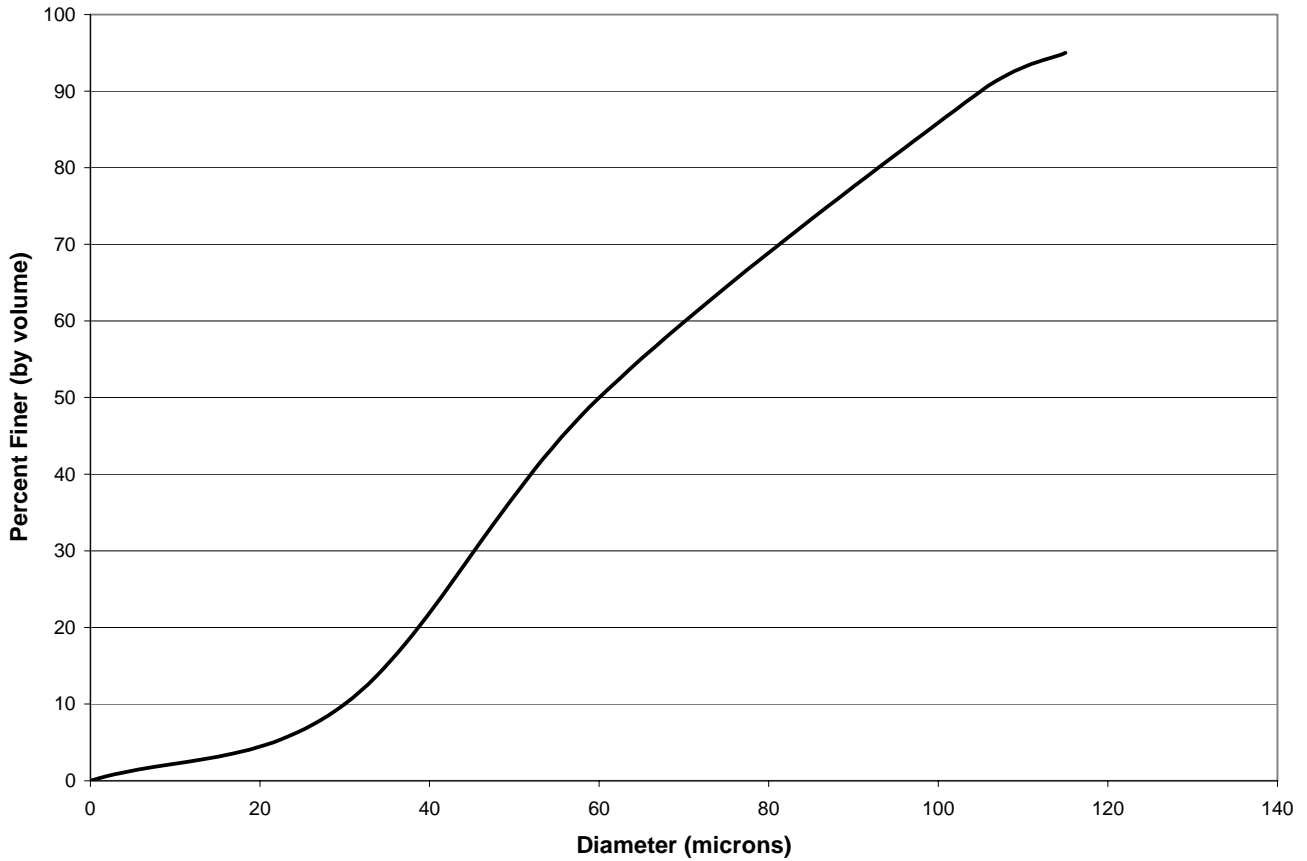


Table 3.2-3: K15 Bubbles Gradation Chart

Concrete Aggregate: K15 Glass Bubbles
 Sample Weight: 500 grams
 Specific Gravity (G_s): 0.150

Diameter (mm)	Cumulative Percent Finer (%)
0	0
0.03	10
0.06	50
0.105	90
0.115	95

*Data based on 3M Scotchlite Glass Bubbles
 Product Information Sheet



Figure 3.1-4: K25 Glass Bubbles Gradation Curve

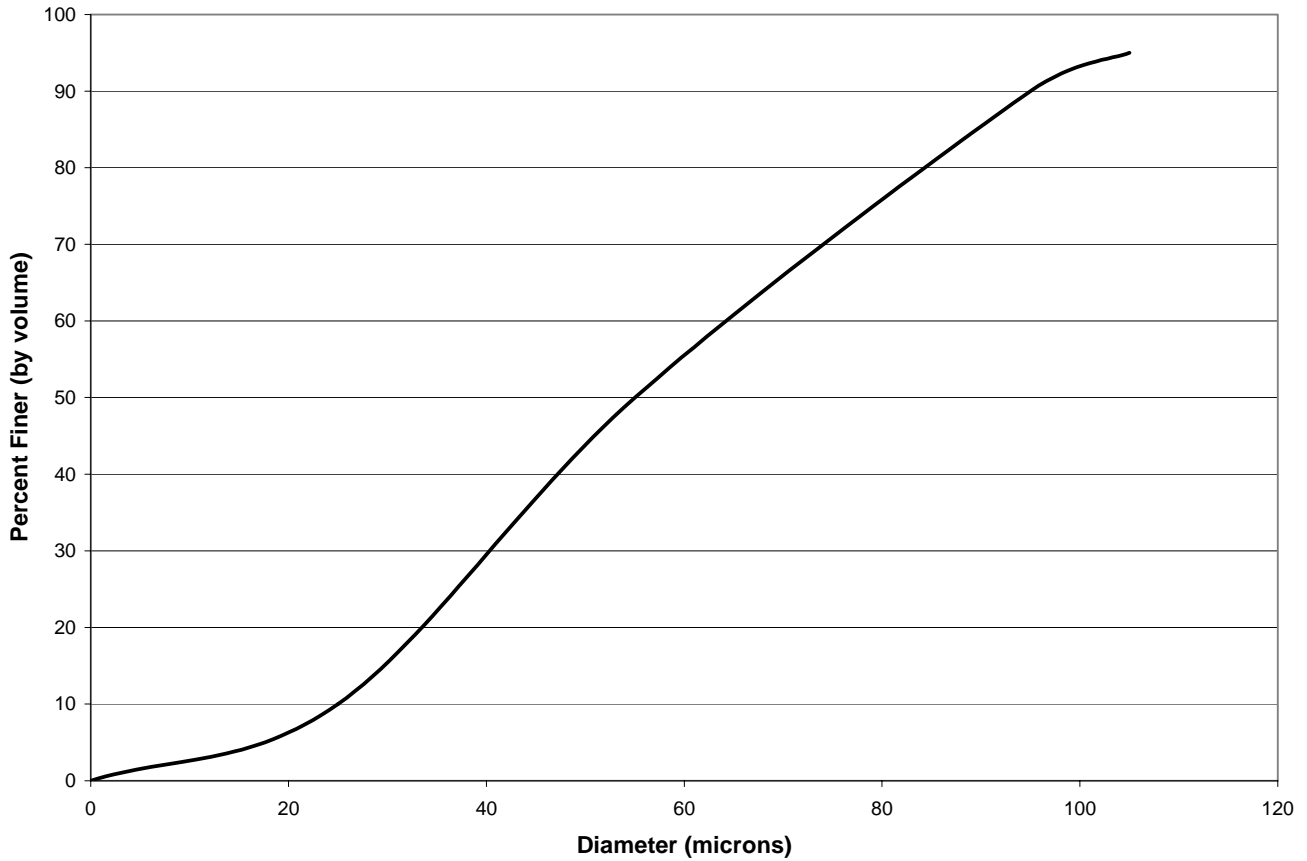


Table 3.2-4: K25 Bubbles Gradation Chart

Concrete Aggregate: K25 Glass Bubbles
 Sample Weight: 500 grams
 Specific Gravity (G_s): 0.250

Diameter (mm)	Cumulative Percent Finer (%)
0	0
0.025	10
0.055	50
0.095	90
0.105	95

*Data based on 3M Scotchlite Glass Bubbles
 Product Information Sheet

