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Wolverine Specifications	
Length	20ft
Maximum Width	31.2 in
Maximum Depth	14 in
Hull Thickness	¾ in
Weight	280 lb
Unit Weight	66.74 pcf
14-Day Compressive Strength	1486 psi
14-Day Split Tensile Strength	305 psi
Main Reinforcement	Fiberglass
Color	Blue

EXECUTIVE SUMMARY

When the University of Michigan expanded into the versatile field of engineering in 1854, Civil Engineering was the first department to be created. Since then, the department has been at the forefront of engineering advancements and education. The Michigan Concrete Canoe Team's (MCCT) participation in the A.S.C.E. North Central Regional Conference is a chance to demonstrate the quality of this education. Each year, veteran MCCT members come together to seek out new recruits, share their knowledge and experiences, and encourage further involvement in extra-curricular engineering activities. Driven by a young leadership team and numerous new recruits, MCCT 2010 sought not only to achieve a strong and durable concrete composite, but to educate and involve all members every step of the way.

Throughout the year MCCT focused on optimizing design and construction of the 2010 canoe to ensure a competitive performance at the regional conference. New structural members were introduced into the canoe design, higher percentages of recycled and sustainable materials were incorporated into the final concrete mix and innovative research and construction methods were employed to ensure an increase in product quality. MCCT is proud to present its 2010 canoe ***Wolverine***.

ANALYSIS

MCCT 2010 began the analysis process by outlining calculations to be performed, analyzing the canoe in hydrostatic equilibrium, and evaluating the vessel as an idealized beam to calculate stresses. Using this information, MCCT was able to determine minimum compressive and tensile strength requirements for the final concrete mix design.

Volume distribution functions were estimated in Excel using station areas obtained in AutoCAD in conjunction with Simpson's Rule Approximation. Hydrostatic forces were analyzed at five evenly distributed waterlines. Concrete volume distribution, neutral axis location, and sectional moments of inertia were estimated using the same technique. These distribution functions were used to evaluate longitudinal and vertical centers of gravity and buoyancy, and the net force acting on the canoe per unit length.

Total passenger loads were determined by examining the remaining buoyancy force at each waterline, with passenger positions established to ensure sufficient space to paddle while maintaining an even keel. It was decided that waterline three (8.4" submerged) best approximated the four passenger loading case of the co-ed medley, and that waterline two (5.6" submerged) best approximated the two passenger loading case of the men's or women's sprints. These two cases were taken to be the two extreme loading scenarios. Waterline three allowed for four passengers of 206 lbs each, whereas waterline two allowed for two passengers of 185 lbs each. These cases were accepted as the most accurate, if not significantly conservative, loading scenarios. Passengers were treated as point loads at their prescribed positions, and shear forces and curves were established for each case by subtracting the distributed canoe weight and point loads from the distributed buoyancy function. Using Riemann sums, the moments for both cases were calculated from the shear force curve. Finally, the discretized moment curve, moments of inertia, and distances from the gunwales and keel to the neutral axis were used to determine the most extreme values of total stress. The canoe was also examined as upright and simply supported to simulate resting on the display stands.

Based on the results for the co-ed medley, two person loading, and simply supported cases, the final concrete must have a compressive yield strength no lower than 136 psi, while the concrete and mesh combined must have a composite tensile yield strength no lower than 81 psi. These requirements include a safety factor of two, selected based on experience from previous analyses. MCCT is confident that the canoe will not suffer from local failures, an assumption also based on previous years' calculations.

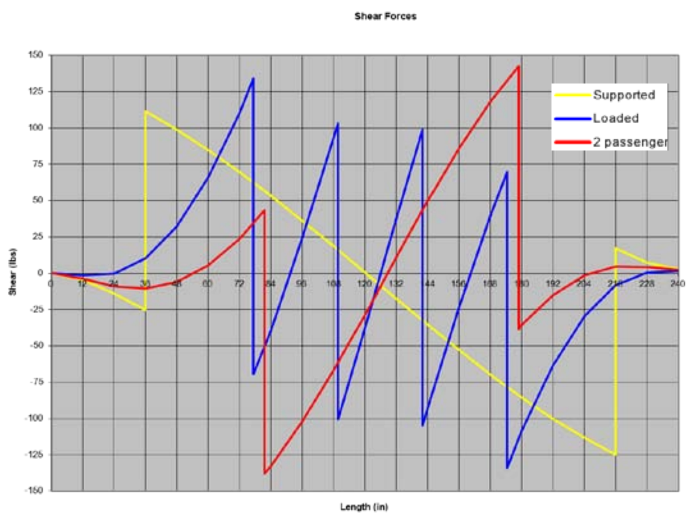

Figure 1: Shear Forces vs. Position

DEVELOPMENT AND TESTING

Research

This year MCCT's R&D team decided to focus on improving the team's organization and research methods, rather than purely focusing on technical results. We decided to take a systematic approach to research by studying the reports of previous successful teams for starting points and seeking out guidance from the department and local manufacturers. This shifted the focus of the group to assessing the properties of the materials that were available rather than searching through academic literature for "ideal" aggregates that could not be obtained.

In terms of technical results, the team was interested in improving the workability of the mix to simplify construction, increasing the tensile strength to prevent cracking, and reflecting the overall team's transition to more environmentally friendly design and construction. After preliminary research to find available materials, the team began evaluating possible components of the mix and comparing them to last year's final mix (Table 1), which was used as a baseline.

Category	**2009 Final Mix**	**2010 Final Mix**
Hydraulic cement	Portland Cement, Type I, standard	White Portland cement, Type I
Pozzolan(s)	Fly Ash (Type C), Norchem Silica Fume	GGBFS
Very fine aggregate	K-15 glass bubbles	Same
Synthetic aggregate	Poraver	Same
Natural aggregate	Solite, expanded slate	------
Fibers	3/8" PVA	Same
Admixtures	Superplasticizer, air entrainer, latex modifier	Same
Coloring	Black and yellow pigment	EnviroStain

Table 1: Baseline Mix and Final Mix Components

Working from this baseline mix, MCCT determined that Poraver was an ideal material to be used again in this year's mix due to the range of available sizes, low specific gravity (ranging from 0.39-0.55 depending on diameter), and the fact that it is a recycled product. Poraver sizes ranging from 0.25mm to 2mm were used in varying proportions to minimize voids and ensure a smooth gradation. In order to meet this year's requirement of two recycled aggregates, MCCT replaced its natural aggregate with crushed recycled concrete. This material was chosen not only because it reused concrete that would otherwise be wasted, but because it was locally accessible, meaning fewer resources were consumed in transportation. The crushed concrete required selective sieving to remove particles passing the No. 200 sieve.

In its study of past successful teams, MCCT found that many teams had used very fine ceramic spheres rather than glass ones, which MCCT has used in the past. After further research, MCCT decided to order a small sample of Extendospheres ceramic spheres to compare to the similarly sized K-15 glass spheres. MCCT also considered adjustments to several other components of the mix. Granulated Ground Blast Furnace Slag (GGBFS), a by-product of steel production, was chosen to replace last year's pozzolans due to its faster reaction time and lighter color. Finally, since one of the team's goals was to improve the canoe's aesthetic value, the team researched possible coloring compounds. With the lighter colored mix, we decided that light colored stains would be acceptable, and chose EnviroStain as a more environmentally friendly option to the typical acid stain.

Testing

MCCT performed two rounds of mix design testing. Having already decided on incorporating crushed concrete and Poraver, these tests were used to determine whether K-15 or ceramic ExtendoSpheres should be the final aggregate, and what proportion of aggregates would produce the best workability, strength, and unit weight values.

Figure 2: Compression Test Specimens

In the first round, four different mixes were formed into test specimens: two mixes containing different proportions of ExtendoSpheres and two corresponding mixes for K-15. Specimens underwent compressive and split-tensile testing, in accordance with ASTM C39 and ASTM C496 respectively. Testing showed that the batches containing the K-15 had higher strengths (average 7-day compressive strength of 1350psi), so it was chosen over the Extendospheres (average 7-day compressive strength of only 840 psi).

In the second round of testing MCCT prepared three mixes containing the K-15; one with an increased m_{agg}/m_{cem}, one with an increased amount of latex modifier, and an original K-15 mix from the first round of testing. The mix with increased m_{agg}/m_{cem} ratio showed no noticeable increase in strength compared to the original mix, but did show a slight decrease in unit weight. The mix with increased latex showed increased strength and plasticity compared to the original, and was ultimately chosen as the structural mix for the canoe. An average 7-day compressive strength of approximately 1600 psi was found for this mix.

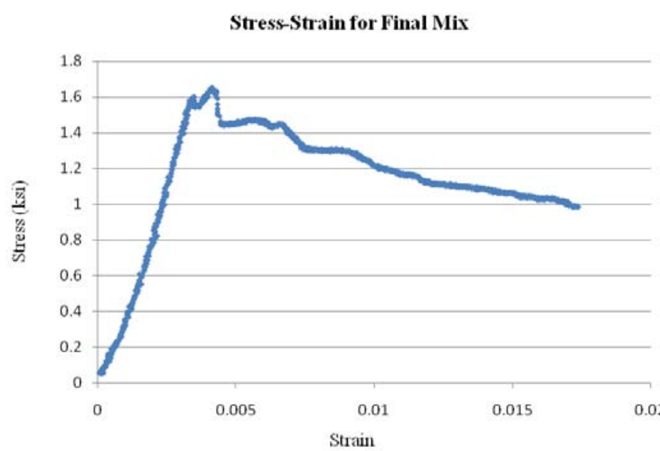

Figure 3: Stress-Strain Curve for Final Mix

Reinforcement

Numerous types of reinforcement meshes were considered for use in the MCCT 2010 canoe ***Wolverine***. Our goals for improving mesh performance included maintaining an opening size and POA similar to last year’s mesh, but increasing mesh flexibility for ease of construction. These criteria were used to evaluate the three main material options established from preliminary research: fiberglass, carbon fiber, and plastic. Fiberglass was ultimately chosen for its high strength to weight ratio and flexibility, and mesh with approximately 50% open area was ordered and used during fabrication of the canoe.

Admixtures

The final admixture selection changed very little from the baseline mix. However, there was an increase in the amount of Latex modifier; neither the MSDS nor the latex product information sheet provided a recommended dosage. Super-plasticizer was used according to the manufacturer recommended dosage range of 195-390mL/100kg of cement, while the air entraining agent used the dosage recommended to achieve 6% air content.

PROJECT MANAGEMENT AND CONSTRUCTION

Project Management

The team had a budget of $3700 for the total cost of the project. An additional amount of $1000 was set aside to take care of unforeseen and emergency expenses. The total cost of the project can be broken down into the following constituents: concrete materials, construction materials, reinforcement material, recruiting, transportation, food and beverages, and miscellaneous. The projected expenses for the team are estimated at $3500. Thus the team is $200 within budget. However, this is not yet a final figure as some of the expenses are still categorized as 'potential' and have yet to be incurred. On account of stronger sponsorship support and stricter budget controls, MCCT finds itself in a much stronger financial position than in previous years.

The project had a start date of September 4th 2009. This was the first official recruitment drive by the team. Prior to this, continuing team members met over the summer break and chalked out a comprehensive plan for having a more successful project than the previous year, while taking a learning cue from the previous year's experiences. The project will have an anticipated end date of March 28th 2010. After this, there will be an end-of-year meeting for the entire team to draw conclusions from the project and take notes to be used in the following year. The date for this final meeting is yet to be decided.

The scope of work was divided into 3 main sub-groups: Research and Development, Construction, and Publicity/Recruitment. Experienced team members were responsible for supervision of these 3 departments and had the added duty of guiding new-recruits and training them to be future team leaders. Within these sub-groups, the work was further divided by the team leaders as they deemed fit. The composition of these groups was flexible, as senior members felt it necessary for new recruits to gain experience in several aspects of the project. Working on multiple parts of the team was not overwhelming for members since typically the R&D group has its maximum workload during the early part of the project and the Construction group has its heaviest workload later in the project.

The team identified the major risk areas by going over notes from previous years. It was felt that placing concrete, testing specimens, and paddling were areas that the team could significantly improve on. For concrete placing, the team held a practice placement session so all members could get comfortable with the techniques used. For testing, a more structured approach was adopted, and three times as many sample mixes were tested than were last year. Team members were expected to attend designated testing times and were familiarized with testing machines and ASTM standards. These efforts ensured that the team was not overly dependent on a few individuals and that new members gained experience. The team also held a canoeing/paddling practice early in the year, which doubled as a team bonding activity.

MCCT balanced high quality production with teaching and learning by getting experienced team members to work closely with new recruits. This strategy also had the added benefit of making the team more cohesive, which increases member involvement and drive. Like all successful teams, MCCT also referred to notes and observations from previous years to avoid repeating mistakes and to successfully build upon those experiences.

Milestone and Critical Path Activities

In the case of this project, it was observed that the milestone activities typically occurred at the end of a series of critical activities or at a point that signaled a change in the project from one phase to the next. The following were identified as such:

- Mass meeting
- Starting test batches
- Registering the team with NCRC
- Pour canoe
- Finished canoe
- Competition details finalized
- Competition

The critical activities for this project were constrained by availability of facilities or due to completion time required by successors. The critical path activities for our project were the following:

- Hold Mass Meeting
- Cut Foam Mold
- Practice Placement
- Pour canoe
- Submit Technical Paper

Among these activities, the activity “Cut Foam Mold” had to be completed on the scheduled date due to lack of CNC Router availability on any subsequent days. Similarly the activity “Pour Canoe” had to be marked down as critical and having zero total float as any further delay would push this activity to after the University’s spring break, leaving insufficient time for the concrete to cure or for the team to complete the activities such as “Finish Canoe”. The total number of man-hours is split into the 3 major sub-groups and is summed up to the total man-hours spent by the team on the project.

- Research and Development (includes aggregate, mesh, pigments and plasticizer research, testing, preparing test cylinders, documenting research findings): <u>400 hours.</u>

- Construction (includes creating 3-D model of canoe, preparing cut-paths, scheduling Foam cutting router, Cutting Foam sheets, Assembling and finishing the mold, pouring the canoe and finishing-testing): <u>350 hours.</u>

- Recruitment and publicity (includes work done during summer and prior to school re-opening, creating team website, scheduling MCCT’s presence in college events, editing sending out sponsorship letters, arranging team-bonding events): <u>150 hours.</u>

Construction

Building on past design concepts and construction processes, formwork construction began by deciding between a male and female mold. A female mold was ultimately chosen because it yields a smoother exterior. A three-dimensional model of this year's standardized hull was created using Nx5, then sliced into 120 two inch thick sections along its length. These contours were then optimally oriented to fit 8' by 4' foam insulation sheets, and cut using a CNC router. In addition to the exterior mold pieces, gunwale, rib molds and interior support pieces (similar to male mold sections) were also cut to improve structural integrity, ensure interior surface quality and aesthetics. Key holes were also routed in the sections so 2x4s could be used for alignment during assembly. To ensure a smoother final product, 3D routing was used at the bow and stern sections of the hull; the remainder of the mold was cut in 2D.

Once cut, the 120 cross-sections were aligned using 2x4s, glued into four sections using wood glue, and compressed using cinder blocks. These four sections were later glued together to create the whole form, and sanded smooth. Drywall compound was used to fill in imperfections, and then the entire interior of the form was coated with duct tape to ease the demolding process and give a smooth exterior finish.

On pour day, approximately fourteen batches of concrete (10L per batch) were mixed, and placed in two 3/8 inch layers. To ensure the thickness of each layer, specially constructed rolling tools with a 3/8 inch indentation were used to compact the concrete. Toothpicks marked at 3/8 inch and 3/4 inch were also used for quality control. The concrete was placed in the mold by hand, with the first layer receiving little compaction to ensure sufficient bonding between concrete layers once the mesh was laid. Between the concrete layers, 2' long sheets of fiberglass mesh, with six inches of overlap, were placed. The length of these sheets was chosen for ease of workability and to avoid cold joints between concrete layers. The second layer of concrete was then placed and rolled smooth to lessen the need for interior sanding during finishing.

Figure 4: Layered Placement

After pouring, the canoe was wet-cured for fourteen days. Once cured, it was carefully demolded – the mold was saved to be used during transportation – and floatation material was added at the bow and stern. A swamp test was performed before the canoe was thoroughly sanded, stained and sealed.

MCCT considers safety to be of utmost importance, and members were required to attend safety training classes prior to working in laboratory facilities, so that they could safely proceed with individually assigned tasks. Furthermore, members were required to use personal protective equipment, such as safety-glasses, masks, and gloves during all mixing, placement and sanding. OSHA was contacted prior to sanding to ensure the safest working conditions.

INNOVATION AND SUSTAINABILITY

This year was one of innovation for MCCT. The team functioned much more efficiently on an all new leadership system, surpassed previous "green" efforts in all aspects of the project, and explored new avenues for construction. ***Wolverine*** is the product of new members and fresh leadership with common goals of education, sustainability, and fun.

The use of environmentally benign materials was an integral part of making the canoe "green". MCCT made a conscious effort to exceed the mandated recycled materials content in the concrete mix for this year's canoe. Fly ash used last year was replaced with Ground Granulated Blast Furnace Slag (GGBFS), a bi-product of industrial steel production. Recycled aggregate content was increased from 72% to 95%. Poraver, a spherical product composed of 100% recycled glass which has won numerous awards for its environmental and ecological sensitivity, comprises 70% of the aggregates in the final mix design. Locally obtained, recycled crushed concrete comprises another 25% of the aggregate.

Innovative construction methods and new structural members were also integral parts of MCCT's fabrication process. In order to minimize local cracking, gunwale and rib molds were cut and used during placement to give the canoe a 1 ½ inch thick gunwale and ½ inch center rib. These additions not only improved the aesthetics of the canoe, but greatly improved its structural integrity. The thicker gunwale significantly reduces the stress carried through the top of the canoe, by increasing moment of inertia by 9.88% and the cross sectional area by 2.21%. The rib counteracts the effects of the thicker gunwales on the neutral axis, lowering the center of gravity from a 4.35% raise to only a 2.63% raise, while further adding to the moment of inertia and cross-sectional area, resulting in a more stable canoe.

Figure 5: Gunwale Mold Pieces and Center Rib

Mold construction is a large part of MCCT's fabrication process, and with sustainability as a top priority, significant steps were taken to reduce mold production waste. Last year, sixteen sheets of insulating foam were used in mold construction – this year the team decreased this amount by roughly 20%. MCCT also considered ways to reuse/recycle the mold once the canoe was finished. The team noted that, in the past, transportation was a major cause of cracking due to vibration and lack of continuous support, and therefore resolved to salvage the mold in hopes of remedying the issue. This effort began by researching de-bonding agents to be used in the mold. Bond-O was considered but ruled out due to high cost and caustic nature. Duct tape was chosen as an inexpensive alternative. It was applied to the interior of the mold, preventing bonding of the concrete directly to the foam, greatly simplifying de-molding, and leaving the mold intact and able to support the canoe during transportation.

Figure 6: Applying Duct Tape

Appendix A – References

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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)

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ASTM C496, “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens” ASTM International Book of Standards vol. 04.03 (copyright 2005)

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

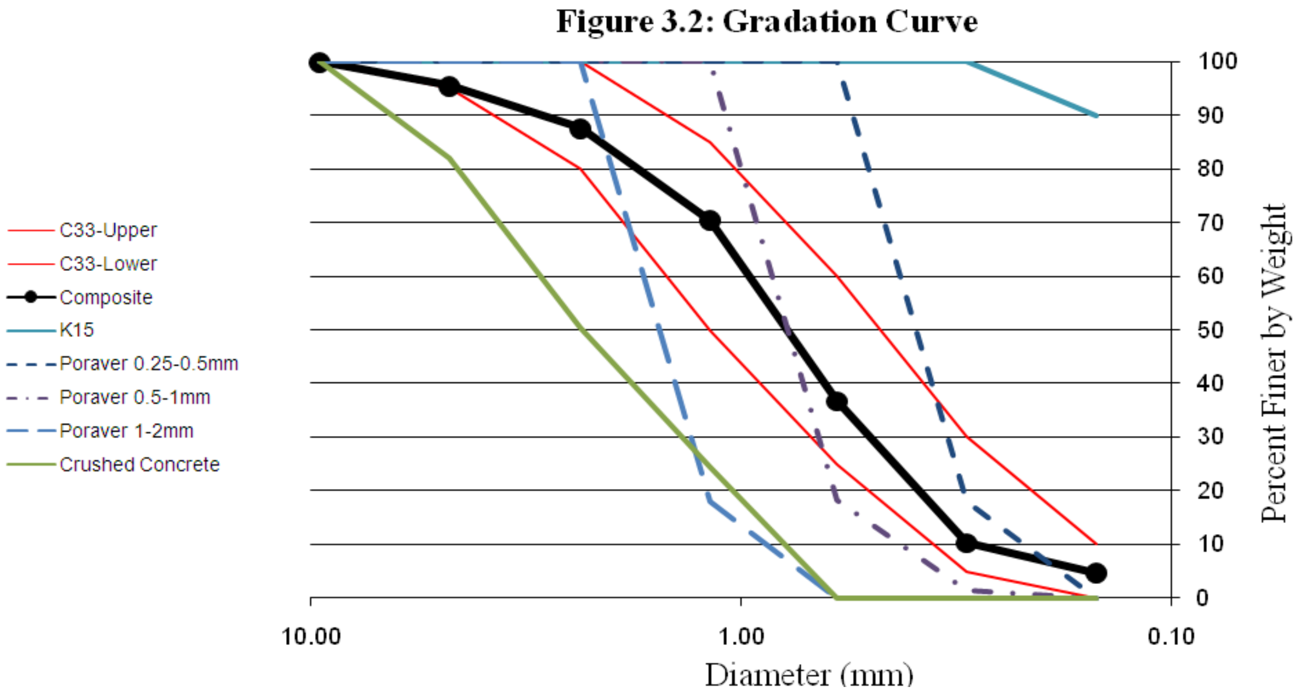
“Poraver Product Specifications” (copyright Poraver North America, 2006) < http://www.poraver.com/02rohstoff/pdf/product_specifi cations.pdf> (accessed October 2009)

“3M Scotchlite Glass Bubbles: K and S series Product Information.” (copyright 3M 2006). <http://www.3m.com/microspheres/s_k_1.html> (accessed October 2009).

Appendix B – Mixture Proportions

Table 3.1 : Summary of Mixture Proportions		Proportions as Designed		Batched Proportions		Yielded Proportions	
Batch Volume: 10 L	Specific Gravity	Amount (g)	Volume (L)	Amount (g)	Volume (L)	Amount (g)	Volume (L)
Cementitious Materials							
Portland Cement Type I	3.15	430	0.14	2359.5	0.75	431	0.14
GGBFS	2.50	570	0.23	3127.8	1.25	572	0.23
C.M. Totals:		**1000**	0.36	5487.3	2.00	1003	0.37
Fibers							
PVA Fiber	1.30	14	0.01	78.0	0.06	14	0.01
Aggregates							
<u>K15</u> Absorption < 0.1% Batched Moisture < 0.1%	0.15	23	0.15	126.2	0.84	23	0.16
<u>Crushed Concrete</u> Absorption 5% Batched Moisture < 0.1%	2.70	115	0.04	631.0	0.23	116	0.04
<u>Poraver 1-2mm</u> Absorption 3% Batched Moisture < 0.1%	0.39	60	0.15	328.1	0.84	60	0.16
<u>Poraver 0.5-1mm</u> Absorption 3% Batched Moisture < 0.1%	0.47	120	0.25	656.3	1.40	121	0.26
<u>Poraver 0.25-0.5mm</u> Absorption 3% Batched Moisture < 0.1%	0.55	143	0.26	782.5	1.42	144	0.26
Aggregate Totals:		460	0.86	2524	5	465	0.87
Water							
Batched Water	1.00	375	0.37	2055.7	2.06	375	0.37
Total Free Water - Aggregates	1.00	-14	-0.01	-76.8	-0.08	-14	-0.01
Total Water - Admixtures	1.00	39	0.04	216.0	0.22	39	0.04
Total Water:		400	0.40	2194.9	2.19	400	0.40
Admixtures	% Solids	Amount (g)	Volume (L)	Amount (g)	Volume (L)	Amount (g)	Volume (L)
Master Builders Glenium 3030	5%	2.5	0.00	13.7	0.01	2.5	0.00
Master Builders AE90	5%	2.1	0.00	11.5	0.01	2.1	0.00
Dow Liquid Latex Modifier	50%	70.0	0.07	384.1	0.38	70.0	0.07
Cement-CM Ratio		0.43			0.43		0.43
Water-CM Ratio		0.40			0.40		0.40
Slump, in.		1.0			0.6		1.0
Air Content, %		6%			6%		6%
Density (Unit Weight), g/L		1069			1069		1069
Gravimetric Air Content, %					8%		
Yield, L		1.8			10.0		1.8

Appendix C – Gradation Curve and Table



Composite	Table 3.2 : Gradation Analysis				
	K15	Crushed Concrete	P.25.5	P0.51	P12
100.0	5.0	25.0	26.0	31.0	13.0
95.5	5.0	20.5	26.0	31.0	13.0
87.6	5.0	12.6	26.0	31.0	13.0
70.4	5.0	6.1	26.0	31.0	2.3
36.7	5.0	0.0	26.0	5.7	0.0
10.2	5.0	0.0	4.7	0.5	0.0
4.5	4.5	0.0	0.0	0.0	0.0
WeightFactor:	5.0%	25.0%	26.0%	31.0%	13.0%
cm^3 per Kilo:	333	93	473	660	334
(g) per Kilo:	50	250	260	310	130
SG:	0.15	2.70	0.55	0.47	0.39

No.	K15	Ret.	Crushed Concrete	Ret.	P.25.5	Ret.	P0.51	Ret.	P12	Ret.
3/8"	100	0	100	0	100	0	100	0	100	0
4	100	0	81.9	18.1	100	0	100	0	100	0
8	100	0	50.31	49.69	100	0	100	0	100	0
16	100	0	24.322	75.678	100	0	100	0	18	82
30	100	0	0.062	99.938	100	0	18	82	0	100
50	100	0	0	100	18	82	2	98	0	100
100	90	10	0	100	0	100	0	100	0	100
S.G.	0.15		2.70		0.55		0.47		0.39	

PROJECT SCHEDULE

DESIGN DRAWING & BILLOF MATERIALS