



New Mexico State University Concrete Canoe

2008-2009



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Specifications for Resurrección

- Weight: 197 lb
- Length: 20 ft 0 in
- Width: 2 ft 7-3/16 in
- Depth: 1 ft 4 in
- Thickness: 1/2 in

Specifications for Concrete Mixtures

Structural Black Mixture

- Unit Weight: 58 lb/ft³
- Comp. Strength: 1,187 lb/in²
- Reinforcement: Fiberglass mesh and Kevlar post-tensioned strands

White Inlay Mixture

- Unit Weight: 58 lb/ft³
- Comp. Strength: 1,059 lb/in²
- Reinforcement: Polypropylene Fibers

Colored Inlay Mixture

- Unit Weight: 57 lb/ft³
- Comp. Strength: 912 lb/in²
- Reinforcement: Polypropylene Fibers

Executive Summary

New Mexico State University (NMSU) has been a landmark in Las Cruces, New Mexico for over 130 years. NMSU (then known as Las Cruces College) opened the doors of its two-room building in the fall of 1888 with a total student population of 35, when New Mexico was still a territory (New Mexico became the 47th State in

1912). Today NMSU has a student enrollment of greater than 17,000 students. NMSU has a long history of competing in concrete canoe competitions and has advanced to the National Competition four times in the past six years. The NMSU team placed 2nd in the Rocky Mountain Conference in 2008, but attended the National Competition to stay current with the latest and most effective techniques and applications.

Inspiration for the 2009 canoe *Resurrección* came from “Día de los Muertos”. Día de los Muertos, or Day of the Dead, is a celebration based on European and Pre-Hispanic traditions. The celebration includes honoring the departed with family reunions, special foods, and commemorative altars. The 2009 NMSU Team created *Resurrección* to commemorate past canoes and members. This includes the snake skeletons on *Resurrección*’s exterior, which are a tribute to the 2008 canoe “*Quetzalcóatl*”.

The NMSU team includes returning members who are skilled in the use of finite element modeling. The effective use of finite element modeling allowed the team to perform detailed structural analysis to identify problem areas prior to construction. *Resurrección* reflects the knowledge gained from past canoes and encompasses innovative techniques; to include some that have not been used in NMSU’s, or other teams’ past canoes. The NMSU team’s most notable innovative technique is the post-tensioning system that used Kevlar strands and parflex sheathing to counteract longitudinal tensile stresses in the gunwale. The NMSU team also mitigated potential cracking in the floor of the canoe, a past problem, by adding one full rib and six partial ribs, highlighted aesthetically with the skeleton.

Resurrección also incorporates aspects of sustainable construction. The NMSU team used the Leadership in Energy and Environmental Design for New Construction (LEED-NC) criteria certification program. The NMSU team’s initial goal was to obtain a Silver rating for the canoe, but once innovative recycling programs were implemented in each area of construction, *Resurrección* achieved a Gold rating.



Analysis

Past NMSU teams used several methods for structurally analyzing their canoes. One method is the flexural formula: stress = moment \times distance to the extreme fiber/moment of inertia ($\sigma = Mc/I$), which gives reasonable estimates for maximum stresses. However, its use is limited due to the changes in the cross-section over the length of the canoe and it does not identify stress concentration locations. The NMSU teams have used the beam flexure formula [ACI 318 (2008)], which assumes that the maximum moments are known, to determine reinforcement requirements. Additionally, the NMSU teams also used ACI 318 to check reinforcement requirements determined by other methods. NMSU teams successfully performed direct measurement of strains over a range of loading conditions by embedding strain gauges into past years canoes.

With the improvement of user-friendly software to perform finite element analysis (FEA), it has become more effective for NMSU to pursue this method for determining the structural requirements of the canoe. With several years of past data obtained from other methods it is easy to validate the findings from the FEA and take advantage of its power to identify problem areas. Numerous loading conditions, transportation scenarios and “accidents” (e.g., improper carrying, entering and exiting) can be modeled using FEA in a relatively short amount of time. Innovations, such as post-tensioning, can be modeled well in advance of constructing models or prototypes to determine potential effectiveness.

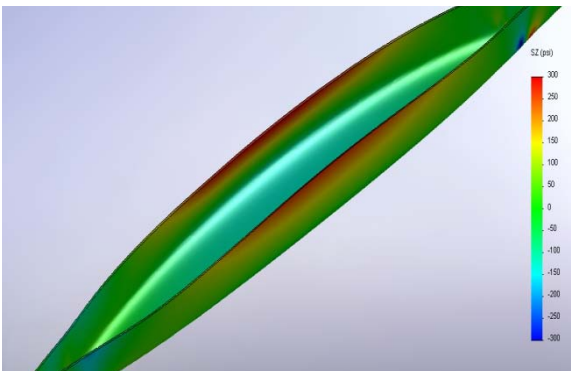


Figure 1 Longitudinal stresses on un-reinforced canoe from two paddler loading case.

The SolidWorks Design Suite was chosen to perform the FEA on this year's *Resurrección*, because software improvements have made modeling more straight forward. In previous versions of the software it was necessary to model the canoe using only surfaces. The latest version allows for solid modeling producing more consistent results. The advantage of this is the canoe can be drawn, the mold produced, and the FEA performed, all with the same set of software. Perhaps most importantly, the team members in charge of the analysis have become more skilled in the use of FEA, and faculty advisors are also more proficient in verifying the methods used. As one faculty advisor put it, “Using finite element analysis is like playing guitar: it’s easy to do it badly and have the result be mostly garbage.”

After this year’s mandated canoe shape was “drawn” in SolidWorks using the provided spreadsheet coordinates, various methods were evaluated to model the rather unique structural situation of a canoe sitting in the water. The support is continuous and yielding, so a variety of techniques were tried including using springs to model the water. Ultimately, it was decided to model the water as a two-dimensional varying load and the paddlers would act as hinge supports. This upside-down approach allowed the many loading conditions to be modeled by simply changing the depth that the canoe sat in the water as determined by the weight and positioning of the paddlers.

Of the three static loading scenarios that the canoe experiences during competition, the most critical is an exaggerated case of two 250 pound paddlers placed 24 inches from the fore and aft ends of the canoe. The longitudinal and transverse normal stresses are shown in Figures 1 & 2, respectively.

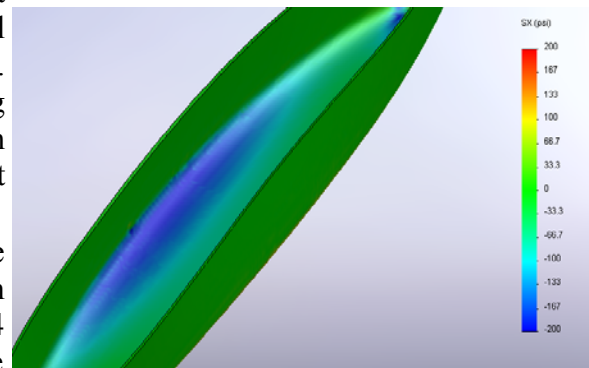


Figure 2 Transverse stresses on un-reinforced canoe from two paddler loading case.

Critical areas as indicated from the various FEA's include the center portion of the gunwale, the center portion of the floor, the area of the chine, and stress concentrations produced by the paddlers themselves (feet and knees). From these critical areas the maximum tensile stress produced was 298 psi and the maximum compressive stress was 182 psi.

As shown in Figure 1, the maximum longitudinal stresses are tensile in nature and occur in the area of the gunwale. *Resurrección* was reinforced in this area of the gunwale. *Resurrección* was reinforced in this area using post-tensioned strands of Kevlar (discussed in detail under the Development & Testing section). An advantage of using post-tensioning is that it can be easily modeled using FEA. The model was used to determine required tensioning of the strands as well as the effect that the post-tensioning system has on the rest of the canoe. The model showed a reduction of longitudinal tensile stress in the area of the gunwale to an acceptable 100 psi with 75 pounds of tension in each of the six post-tensioning strands (Figure 3).

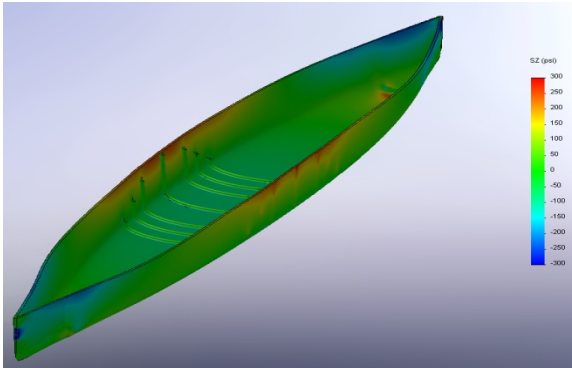


Figure 3 Longitudinal stresses after post-tensioning.

Particularly troubling were the transverse stresses in the area of the chine (Figure 2). In past years, NMSU canoes have suffered longitudinal cracks in the floor and chine of the canoe following continued use. These cracks correspond to the areas of high stresses shown in the FEA. To counteract these stresses, ribs were modeled in various positions along the length of the canoe in an effort to minimize the transverse stresses while also taking into account paddler positioning. Ultimately, one main structural rib was placed in the center of the interior of the canoe. Three additional ribs were placed on each side of center for aesthetic purposes, but they also added structural integrity. Figure 4 indicates the FEA of this arrangement. Note the drastic reduction in compressive stress in the area of the chine from 182 psi (Figure 2) to essentially zero after the placement of the ribs (Figure 4). The ribs themselves, however, do continue to experience compressive stresses of approximately 200 psi. The tensile stresses on the outside of the canoe are reduced from 180 psi to 100 psi.

With the inclusion of ribs, the necessary property values for the concrete are as follows: 200 psi compressive strength, 100 psi composite strength in the areas where Kevlar post-tensioning is used, and 100 psi composite strength in the area where fiberglass mesh is used. Using a factor of safety of three, the goal of the mixture design team is to produce a concrete with a 600 psi compressive strength and 300 psi composite strength.

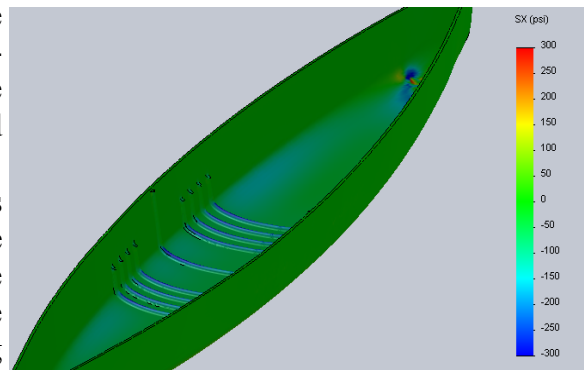


Figure 4 Transverse stresses after placement of structural and aesthetic ribs.

Development & Testing

Concrete Mixture Development

The goal for the mixture design of *Resurrección* was to formulate a sustainable, high strength, low unit-weight concrete with the acceptable workability, which meets or exceeds competition specifications. The structural concrete for *Resurrección* was to be black in color, while the aesthetic concrete for inlays, outlays and relief features was to be designed in various colors including white, blue, red and yellow. Twelve different mixtures were developed before settling on three that gave *Resurrección* its contrasting, colorful and vibrant appeal.

Mixture designs were developed with the aid of two Excel© spreadsheets. The spreadsheets were linked together through cell formulas that addressed the many factors regarding mixture proportioning. One spreadsheet contained the sieve analysis for each constituent aggregate, and the other contained mixture proportions and calculations, described by ACI 211.1(ACI 1991) and Kosmatka, Kerkhoff & Paranes (2002). The amounts of the aggregates were adjusted in the mixture proportions spreadsheet, and a gradation curve was automatically generated indicating if the aggregate for the proposed design

Table 1 ASTM tests used in mixture development.

ASTM No.	Specific Use
ASTM C 33	Conformity of Chosen Aggregates
ASTM C 39	Compressive Strength
ASTM C 78	Composite Tensile Strength
ASTM C 128	Specific Gravity & Absorption of Aggregates
ASTM C 136	Gradation of Aggregate
ASTM C 138	Unit Weight & Air Content of Concrete (gravimetric)
ASTM C 143	Slump of Concrete
ASTM C 173	Air Content of Concrete (volumetric)
ASTM C 469	Concrete Modulus of Elasticity
ASTM C 496	Splitting Tensile Strength
ASTM C 5035	Kevlar & Fiberglass Mesh Tensile Strength

would conform to ASTM C 33. Specific gravity and absorption values (ASTM C 128 testing) for each aggregate in the mixture were included in the linked spreadsheet, allowing the development team to predict unit weight and air content values. A list of all ASTM testing standards used in evaluating the various mixture designs are listed in Table 1. The water-cementitious materials requirements proved to be a challenge. To comply with the mandated 0.4 water to cementitious materials ratio, the water reducer dosage was increased. As in previous years, air entraining was obtained by using latex admixture. Dosages of latex were held at manufacturer’s recommendations but air content was controlled by increasing the mixing time.

Aggregates

The primary aggregates in *Resurrección* were recycled glass spheres ranging in size from 0.25 mm to 1.0 mm, K36 glass microspheres, and grey ceramic spheres of 1.0 mm to 3.0 mm. The grey ceramic spheres replaced the recycled glass spheres of 1.0 mm to 2.0 mm used in *Quetzalcòatl*. Their dark color and structural properties made them ideal for the structural black mixture. The glass microspheres were the only aggregate that passed the #100 sieve thus was the only aggregate whose quantity was controlled by the rules (5% by weight).

Cementitious Materials

In developing mixture proportions, a ratio of 50% Type I/II cement ($G_s = 3.15$), 40% fly ash ($G_s = 2.50$) and 10% silica fume ($G_s = 2.35$) was held constant. This combination provided workability and consistent compressive strength results.

Admixtures

Water reducer and latex were included in the design as admixtures. The water reducer assisted in achieving the required 0.40 water-cementitious material ratio (w/c + p), in conjunction provided sufficient workability to the mix. After conducting numerous test batches it was determined the dosage needed to meet the water-cementitious material ratio and to sustain workability, proved to be slightly higher than the manufacturer’s recommended dosage (26 oz. per cwt vs. 18). Research was conducted to discover why the extra amount of water reducer was needed. It was determined that the use of silica fume usually requires dosages outside the normal range. The relatively high percentage of silica fume used in this year’s mixture design would account for the increased need for water reducer.

Latex is used as an additive in concrete to decrease permeability, increase tensile strength and workability, and to entrain air. The percent of latex by weight affects the permeability, tensile strength and workability and the mixing time determines the amount of entrained air produced. Manufacturers recommend latex contents by weight that range from 1% to 5% of the cementitious materials. Based



on testing, the team determined that the optimum latex content to meet permeability, tensile strength, and workability goals was 2%. The team also conducted experiments on the mixing time to meet the air entrainment specification. Based on the experiments, at a latex content of 2%, the mixing time to obtain the specified 6% air entrainment was four minutes. To control the latex mixing time, the team added the latex last to each batch of concrete, which was then mixed for four minutes.

The primary color in the concrete mixture is black, but red, yellow, and blue pigments were also utilized for the inlays, outlays and reliefs. The white inlay mixture was made with Type I white cement and brown fly ash.

Reinforcement

Several methods of reinforcement were chosen for the construction of *Resurrección*, which included post tensioning with Kevlar, polypropylene micro fibers, and fiberglass mesh. Finite element analysis conducted on SolidWorks revealed transverse tensile stresses acting on the canoe floor, which could be mitigated by installing one structural rib with an effective area of 0.4 in² in the center of the vessel. An additional six ribs were installed for aesthetic purposes, providing additional structural integrity.

To enhance tensile strength without a significant increase in weight, a single layer of fiberglass mesh was placed between *Resurrección's* two layers of concrete. The tensile strength of the mesh is 58,000 psi and the 0.25 inch x 0.40 inch openings produced a percent of open area (POA) of 76%.

Post tensioning methods were researched and analyzed to determine the best way to minimize longitudinal tensile stresses acting on the gunwale. In normal post-tensioning applications, steel tendons are stressed and anchored using hydraulic jacks and wedges. Stresses in the tendons are calculated from their elongation. The stressed tendons impart a compressive force on the concrete, counteracting tensile forces while increasing the load-carrying capacity of the concrete.



Figure 5 Post-tensioning system installation.

In place of steel tendons, NMSU chose Kevlar strands for the post-tensioning of *Resurrección*, because of its high tensile strength of 138,000 psi. The strands were encased in parflex tubing and placed in three rows along the gunwale, as shown in Figure 5. Knots, screws, clamps and washers were considered to secure the strands in *Resurrección*. After much experimentation, NMSU decided to tension the strands by twisting them with small steel rods. Forces in the strands were determined by direct measurement using a load cell. The Kevlar strands were post-tension to 75 lb per strand, reducing the longitudinal tensile stress by 70%.

Table 2 Structural Concrete Properties Summary.

Property	Analysis Requirements	Actual Value
Unit Weight	59 pcf	58.4 pcf
Slump	4 in.	6 in.
Air Content	>6%	6.6%
Compressive Strength*	200 psi	1187 psi
Composite Strength*	300 psi	435 psi
Tensile Strength*	N/A	157 psi

*Strength values are at 7-days

Another component of the reinforcement system was polypropylene fibers, primarily used to minimize tensile cracks in the concrete. The manufacturer's recommendation for fiber content in concrete is 0.5 lb/yd³ to 1 lb/yd³. Dosages of 0.5 lb/yd³ and over proved to decrease workability, and increase problems with bonding between the two concrete layers and the fiberglass mesh. Ultimately a concentration of 0.5 lb/yd³ was used. Many hours were spent separating the fibers, and hand mixing them into the dry portion of each batch to ensure a relatively consistent dispersion concentration of 0.5 lb/yd³ was used.



Project Management & Construction

Project Management

The planning for *Resurrección* began May 2008 under new leadership of a new generation of returning members. Knowledge of past successes at national and regional competition has encouraged and motivated the team to strive for a rewarding year. The organizational planning process was initiated with the formation of committees based on the milestones: hull conformity/analysis, construction and testing, and finishing. Senior members of the team evaluated each of the returning members’ strengths to select leaders for the different committees. This was done to promote efficient work and to increase interaction between new and experienced members. Decisions were based on general consensus with the intentions of facilitating growth as a team, while exposing members to the entirety of the developmental process. Meetings were conducted twice a week for decision making, canoe development, and documentation. In addition, weekly paddling practices were held. Project hours dedicated to the project were as follows: 300 hours for canoe development (hull conformity and analysis), 1500 hours for testing and construction, 250 hours for finishing activities, 200 hours for documentation (report, presentation and engineer’s notebook) and 210 hours for paddling.

Scheduling

Previous years’ experiences aided in the determination of the four major milestones and the critical path (Table 3). The major milestones served as a guide, aiding committees with the scheduling of tasks to achieve the desired final product. Also shown in Table 3 are the variations from the expected deadlines. Hull conformity was delayed by challenges to incorporating the mandated dimensional constraints into the CAD software used by the NMSU team. Mold construction was delayed as the team grew accustomed to using recycled foam pieces from last year’s canoe. Canoe construction was delayed simply because of its place on the critical path. Earlier delays were reflected in a postponed placement day. Canoe finishing was similarly delayed; however the milestone was completed due to the hard deadline of regional competition.

Table 3 Milestones.

Milestones	Variation
Hull Conformity/Analysis	+10 days
Mold Construction	+36 days
Canoe Construction	+36 days
Canoe Finishing	+18 days

Financial Allocation

Expenditures for the construction of *Resurrección* were reviewed from previous years to calculate a budget. Contributions from the Engineering Departments, New Mexico State University Student Government, and external fund-raising were used to cover these costs.

Safety Precautions

Prior to start of each activity, safety meetings conducted by veteran members were held to inform the team of risks associated with the task (e.g., concrete mixing, materials handling, concrete application, and paddling). Dust masks and safety glasses were worn during sanding and the mixing process to minimize exposure to hazardous particles. Gloves were mandatory for handling concrete, staining, and painting. Caution tape also marked the perimeter of the construction site to alert people of potential risks in the vicinity.

Construction

Practice cross- sections were built with the intention of assisting the team in the development of construction techniques. These cross-sections determined if the ideas associated with post-tensioning, rib location, and the placement of aesthetic elements were plausible. BlueBoard styrofoam was chosen to construct this year’s male mold. This styrofoam has high strength and can be easily sanded. The styrofoam has a two inch nominal thickness with a measured thickness of 1.94 inches. SolidWorks was employed to print templates for the 124 cross-sections forming the canoe length. Templates were



glued to a piece of styrofoam and cut using a hot wire. A drill press was utilized to bore four holes in the base of each section for the insertion of PVC pipes to align the pieces of the mold. After every sixth (approximately 11.5 inches) BlueBoard cross-section, a galvanized metal cross-section was inserted to ensure quality control during sanding. The complete mold was anchored using a wooden I-beam and sanded to a uniform smoothness. Structural ribs and other aesthetic elements were carved into the mold using half round PVC pipes and Dremmel tools (Figure 6). Joint compound was used to fill any imperfections prior to the final sanding. Press N'Seal acted as a release agent to prevent concrete from adhering to the mold. Inlay designs were cut from 1/8 inch foam and glued to the top of the mold. Finally, 1/2 inch by 3/4 inch boards were placed on the mold to provide a smooth finish for the gunwale, which also aided with the uniform placement of each layer of concrete.



Figure 6 Aesthetic reliefs on the canoe mold.

Placement and Reinforcement

Four days prior to placement, the mixture design team convened to weigh all the dry ingredients for the fifteen 0.3 ft³ batches needed to complete the canoe, testing cylinders and the cutaway section. One day prior to the placement, all the liquid ingredients were measured and placed into individual containers. Members were positioned to apply the concrete to the entire mold at once, and each member was issued a quality assurance gauge to ensure uniform layered thickness. Preparing the ingredients in advance and locating the mixer in close proximity of the mold allowed for the minimization of the mixing team to three members. As a result, the remaining members could dedicate themselves to helping with the concrete placement. This allowed the team to streamline production of the canoe, finishing the placement a full three hours ahead of schedule, conserving resources and providing maximum quality.

Concrete was applied using trowels and hands. After the first 1/4 inch layer was applied, a role of the fiberglass mesh that had been cut out to fit the canoe like a blanket was placed, producing continuity within the reinforcement. Strands of Kevlar encased in parflex sheathing were placed along the each side of the canoe. Six of these strands would later be post-tensioned at 7 and 14 days after the concrete placement. The second 1/4 inch layer of concrete was then applied followed by the outlay mold pieces. These pieces were cut from 1/8 inch foam and worked into the fresh concrete. After 10 days the outlay pieces were removed and filled with the colored concrete mixture.

Concrete Curing and Finishing

Immediately after the placement of the concrete, several saturated pieces of burlap were placed over the canoe, followed by a curing blanket. Between the burlap and the curing blanket, a re-circulating soaker hose system was inserted. This system consisted of a large tarp placed under the tables supporting the canoe, forming a reservoir; in which a pump was placed to transport water through the soaker hose to the top of the canoe. Excess water dripped off the canoe and into the reservoir under the table. This allowed the water to be continuously recycled.

After 14 days, the center mold pieces from the canoe were dislodged. Removal of these pieces allowed for the rest of the segments to be removed. Inlay mold pieces were then removed and the voids were filled with the colored concrete mixture. Curing continued for another 16 days after the removal of the mold, provided a total curing time of 30 days. The inside of the canoe was dry sanded first, and then wet sanded. Afterwards, the canoe was flipped over and the outside was dry and wet sanded. Once sanding was complete, the canoe name and school name were painted on the outside of the canoe followed by two coats of sealant.

Innovation and Sustainability

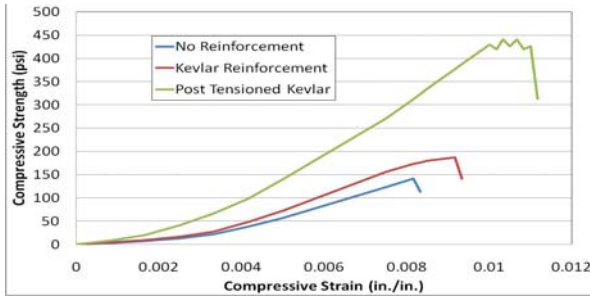


Figure 7 Splitting tensile stress comparison.

The NMSU team’s most notable innovation is the post-tensioning system in *Resurrección* that used Kevlar strands and parflex sheathing to counteract longitudinal tensile stresses in the gunwale, which causes cracking in the gunwale of a canoe. Past NMSU teams have used pre-tensioned Kevlar to strengthen the gunwale, but it has the potential for slipping or relaxing. Kevlar, unlike reinforcing bars, does not bond well with concrete and does not provide tensile strength until there is a load (people)

in the canoe. Figure 6 shows the comparison of several splitting tensile tests using various reinforcement techniques. The Post-Tensioning Institute (1990) offered numerous case studies of post-tensioning thin shells. Anderson (2001) presented a practical guide for the installation, construction, and pre-compression of post-tension members. After studying these concepts, the NMSU team decided to try post-tensioned instead of pre-tensioned Kevlar, which had not previously been done. Three strands of Kevlar on each side of the canoe were tensioned to 75 pounds. The post-tensioning was very successful, and reduced the longitudinal stress in the gunwale from 298 psi to approximately 100 psi.

Sustainability was a priority with *Resurrección* and the NMSU team decided to use the Leadership in Energy and Environmental Design (LEED) standards as guidelines for building the canoe. LEED is the predominant building assessment tool in the U.S. developed through the U.S. Green Building Council’s (USGBC) LEED suite of rating systems (Kibert 2008). There are four levels of certification under LEED. In ascending order they are Certified, Silver, Gold, and Platinum. *Resurrección* was constructed to satisfy all prerequisites and was scored using the LEED New Construction Version 2.2 Standard (LEED-NC 2.2). The LEED-NC 2.2 credit checklist was filled out periodically to help track requirements for certification. Silver certification was the NMSU team’s goal.

The checklist prompted the NMSU team to implement new procedures including the recycling of waste, purchasing materials made from recycled material, and reusing materials. Over half of the paper, plastic, cardboard, and concrete generated during construction was recycled through the recycling center on campus. Paper, cardboard, and plastic were bailed and sold, while waste concrete was ground and used as base coarse for paving projects around the NMSU campus. This year’s canoe design was much narrower than *Quetzalcòatl*, which allowed 35% of the mold to be reused from the previous year. Water was conserved by designing a closed loop system to allow excess water to be captured and re-circulated through a drip line.

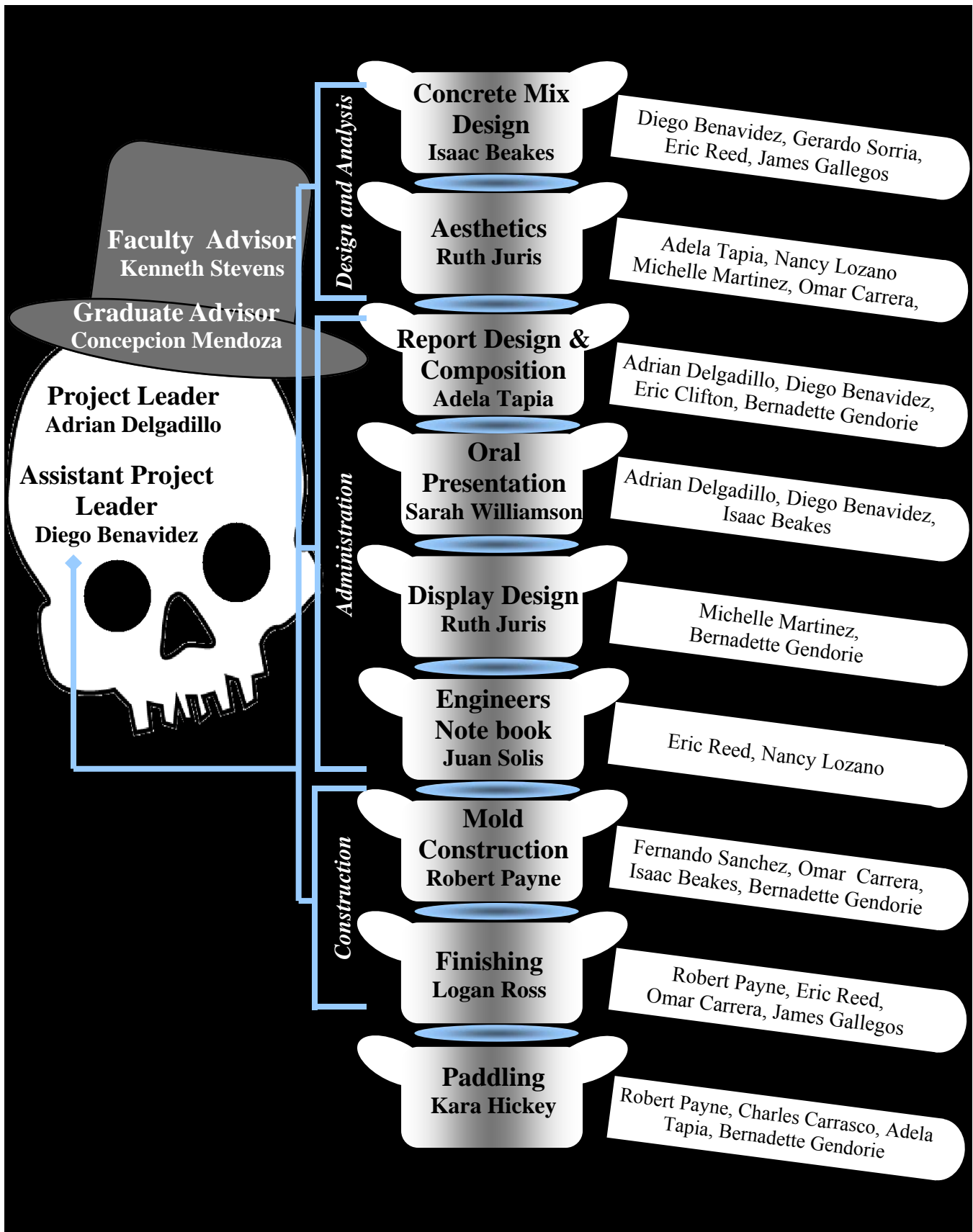
Table 4 LEED for New Construction v2.2.

Registered Project Checklist	
Sustainable Sites (SS)	
Points Possible: 14	Points Earned: 10
Water Efficiency (WE)	
Points Possible: 5	Points Earned: 5
Energy & Atmosphere (EA)	
Points Possible: 17	Points Earned: 17
Materials & Resources (MR)	
Points Possible: 13	Points Earned: 7
Indoor Environmental Quality (EQ)	
Points Possible: 15	Points Earned: 8
Innovation in Design (ID)	
Points Possible: 5	Points Earned: 2
Point Totals	
Possible: 69	Earned: 49
Certification Level: GOLD	

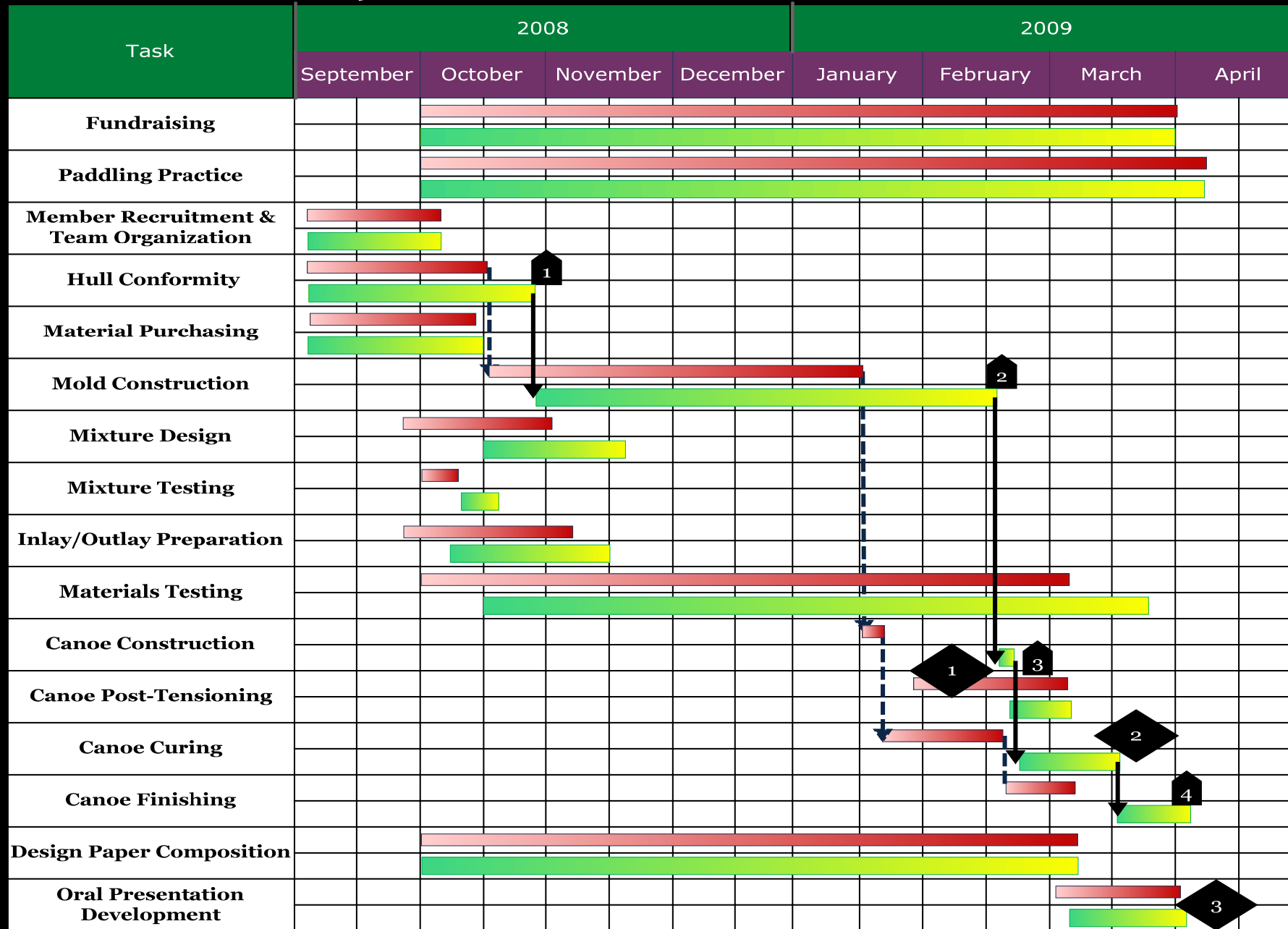
Resurrección’s mixture design incorporated materials that were traditionally land filled before their usefulness in producing concrete was discovered. To make certain the cementitious material met the 50% portland cement by mass requirement, 40% fly ash and 10% silica fume were added for their pozzolanic value. Fly ash is a byproduct of coal fired power generation plants, and silica fume is a residue resulting from the production of silicon or ferrosilicon alloy. Inorganic lightweight round spheres manufactured from 100% recycled glass made up 64% of *Resurrección’s* total aggregate. Upon completion of the project, the LEED-NC 2.2 credit checklist was evaluated and the points earned were tabulated, to reveal *Resurrección* had attained a LEED Rating of Gold (Table 4).



Organizational Chart



Schedule 2008 - 2009



Legend	
	Milestone
	Expected Path
	Actual Path
	Expected Critical Path
	Actual Critical Path

Milestones		
10/24/08	Completion of Hull Conformity	
2/21/09	Completion of Mold Construction	
2/23/09	Completion of Canoe Construction	
3/31/09	Completion of Canoe Finishing	

Key Dates		
2/22/09	Canoe Placement Day	
3/20/09	Swamp Test	
4/2/09	Rocky Mountain Regional Competition	

Critical Path Comparison

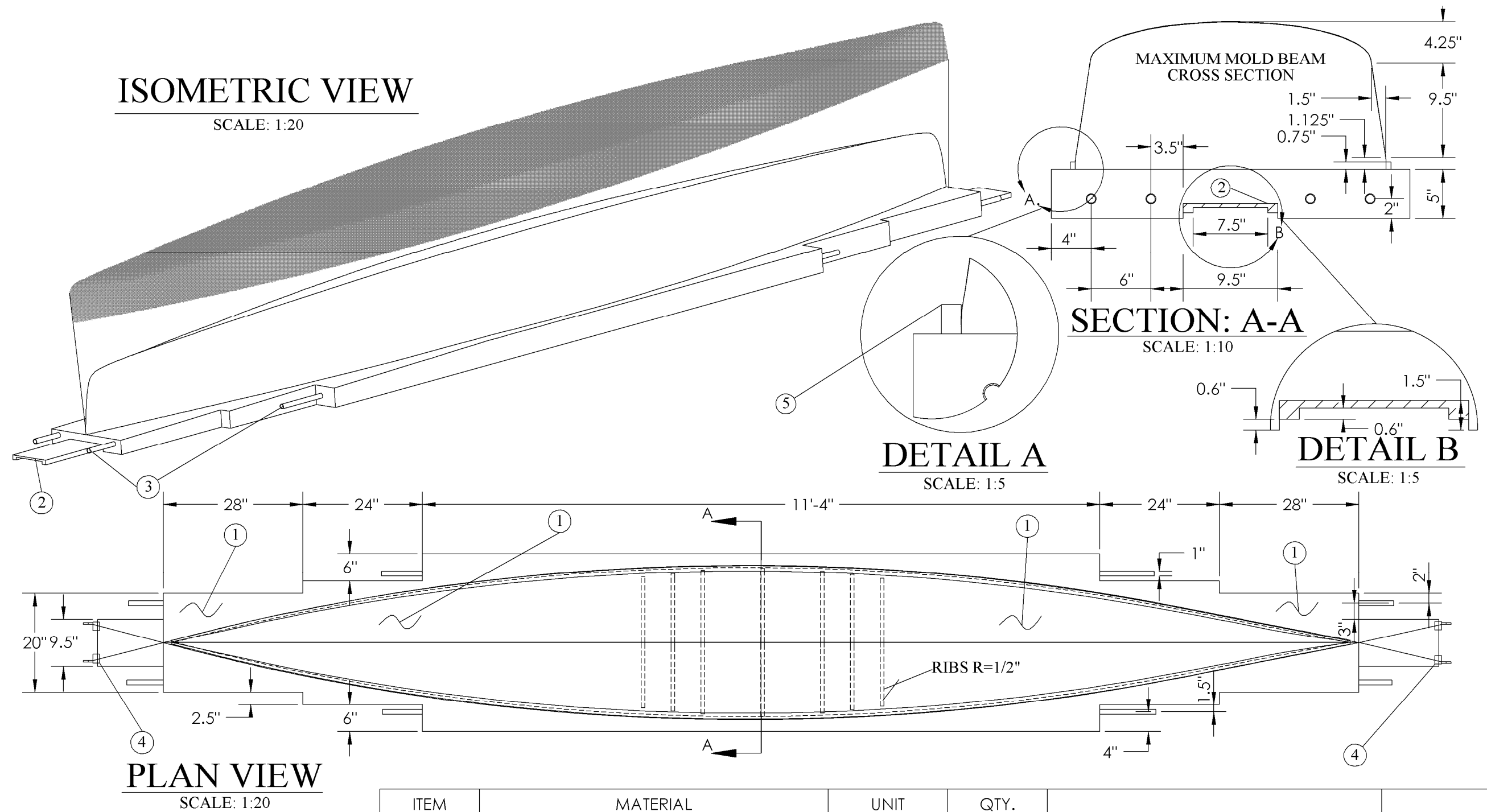
Hull Conformity			Hull Conformity		
41 Days	ES 9/4/08	EF 10/14/08	51 Days	AS 9/4/08	AF 10/24/08
Mold Construction			Mold Construction		
94 Days	ES 10/15/08	EF 1/16/09	120 Days	AS 10/25/08	AF 2/21/09
Canoe Construction			Canoe Construction		
2 Days	ES 1/17/09	EF 1/18/09	2 Days	AS 2/22/09	AF 02/23/09
Canoe Curing			Canoe Curing		
32 Days	ES 1/19/09	EF 2/19/09	29 Days	AS 2/23/09	AF 3/23/09
Canoe Finishing			Canoe Finishing		
22 Days	ES 2/20/09	EF 3/13/09	9 Days	AS 3/23/09	AF 3/31/09

Total = 191 Days

Total = 211 Days

RESURRECCIÓN





ITEM	MATERIAL	UNIT	QTY.
1	DOW BOARD INSULATION - 4 FT.X8 FT.X2 IN.	SHEET	20
2	ALIGNMENT BEAM - 1 IN.X9.5 IN.	FOOT	24
3	SCH. 40 PVC PIPE - 3/4 IN.	FOOT	42
4	POST-TENSIONING DEVICE	EACH	2
5	GUNWALE BOARD - 1/2 IN.X3/4 IN.	FOOT	80
6	FORM RELEASE FILM	SQ. FOOT	85

**NEW MEXICO STATE UNIVERSITY
FORM DESIGN DRAWING**

ENGINEER: ADRIAN D.
DRAWN BY: ERIC C.

PROJECT NAME:
RESURRECCIÓN


 03-07-09 2008-2009 SCALE: AS SPECIFIED ON SHEET PAGE 10



Appendix A-References

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Appendix B-Summary of Mixture Proportions

Mixture ID: Structural Black

Batch Size (ft³): 0.3

Cementitious Materials		Specific Gravity*	Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
			Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
1. ASTM C150 Portland Cement Type 1		3.15	350.0	1.781	3.9	0.020	350.0	1.781
2. Silica Fume		2.35	70.0	0.477	0.8	0.005	70.0	0.477
3. Fly Ash Type F		2.50	280.0	1.795	3.1	0.020	280.0	1.795
Total of All Cementitious Materials			700.0	4.053	7.8	0.045	700.0	4.053
Fibers		Specific Gravity*	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
1. Polypropelene Micro fibers								
Total of All Fibers			0.5	0.008	0.0	0.000	0.5	0.008
Aggregates		Specific Gravity*	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
1. Ceramic Spheres 7-14 mm Abs.: 3.8 % ; MC: 0.2 %								
2. Glass Spheres 0.5-1 mm Abs.: 12 % ; MC: 0.1 %		0.47	188.0	6.068	2.1	0.071	182.8	6.233
3. Glass Spheres 0.5-1 mm Abs.: 12 % ; MC: 0.1 %		0.59	188.0	4.848	2.1	0.057	182.8	4.965
4. K36 Glass Bubbles Abs.: 0.0 % ; MC: 0.0 %		0.38	25.4	1.010	0.3	0.0	24.8	1.044
Total of All Aggregates			589.4	15.124	6.5	0.177	573.2	15.497
Water		Specific Gravity*	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
1. Batched Water [^]								
2. Water added for Aggregate Absorption		1.00	51.5	0.784	0.6	0.009	50.1	0.803
3. Total Water form All Admixtures [§]		1.00	10.5	0.168	0.1	0.002	21.0	0.337
Total water			279.6	4.481	3.1	0.050	242.1	3.880
Solids Content of Latex Modifiers		Specific Gravity*	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
1. Latex								
Total Latex Solids			0.3	0.002	0.1	0.000	0.5	0.004
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)
1. Air Entrainment	lb/gal: N/A	0.00	0.0		0.0		0.0	
2. High Range Water Reducer	lb/gal: 8.76	0.00	26.0	0.0	2.0	0.0	26.0	0.0
3. Latex	lb/gal: 8.72	40.00	38.4	10.5	5.0	0.1	76.8	21.0
		Specific	Amount	Volume	Amount	Volume	Amount	Volume
4. Concrete Dye		0.50	25.0	0.8	0.3	0.0	50	1.6
Cement-Cementitious Materials Ratio			0.50		0.50		0.50	
Water-Cementitious Materials Ratio			0.40		0.40		0.35	
Slump, Slump Flow, in. (Flow Table %)			4.00		3.00		6.00	
Design Air Content, %			6.00					
Density (Unit Weight), lb/ft ³			59.29		60.10		58.41	
Gravimetric Air content, %					4.68		6.60	
Yield, ft ³			27.0		0.3		27.0	

Abs. = Absorption; MC = Batched moisture concrete;

[‡]Water content of admixture.

[^] Including water added for aggregate absorption;

[§] if impact on w/cm is less than 0.01 enter zero

* For aggregates, provide ASTM C 127 oven-dry bulk specific gravity.



Appendix B-Summary of Mixture Proportions

Mixture ID: Colored Inlay

Batch Size (ft³): 0.3

Cementitious Materials		Specific Gravity*	Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
			Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
1. ASTM C150 Portland Cement Type 1		3.15	350.0	1.781	3.9	0.020	350.0	1.781
2. Silica Fume		2.35	70.0	0.477	0.8	0.005	0.0	0.000
3. Fly Ash Type F		2.50	280.0	1.795	3.1	0.020	350.0	2.244
Total of All Cementitious Materials			700.0	4.053	7.8	0.045	700.0	4.024
Fibers								
1. Polypropelene Micro fibers		1.00	0.5	0.008	0.0	0.000	0.5	0.008
Total of All Fibers			0.5	0.008	0.0	0.000	0.5	0.008
Aggregates								
1. Ceramic Spheres 7-14 mm Abs.: 3.8 % ; MC: 0.2 %		0.90	188.0	3.178	2.1	0.037	0.0	3.255
2. Glass Spheres 0.5-1 mm Abs.: 12 % ; MC: 0.1 %		0.47	188.0	6.068	2.1	0.071	0.0	6.233
3. Glass Spheres 0.5-1 mm Abs.: 12 % ; MC: 0.1 %		0.59	188.0	4.848	2.1	0.057	471.5	12.808
4. K36 Glass Bubbles Abs.: 0.0 % ; MC: 0.0 %		0.38	25.4	1.010	0.3	0.0	24.8	1.044
Total of All Aggregates			589.4	15.124	6.5	0.177	496.3	13.852
Water								
1. Batched Water [^]		1.00	320.0	5.096	3.6	0.057	304.0	4.872
2. Water added for Aggregate Absorption		1.00	51.5	0.784	0.6	0.009	56.1	0.899
3. Total Water form All Admixtures [§]		1.00	10.5	0.168	0.1	0.002	31.5	0.505
Total water			279.6	4.481	3.1	0.050	279.4	4.477
Solids Content of Latex Modifiers								
1. Latex		40.00	0.3	0.002	0.1	0.000	0.8	0.005
Total Latex Solids			0.3	0.002	0.1	0.000	0.8	0.005
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)
1. Air Entrainment	lb/gal: N/A	0.00	0.0		0.0		0.0	
2. High Range Water Reducer	lb/gal: 8.76	0.00	26.0	0.0	2.0	0.0	26.0	0.0
3. Latex	lb/gal: 8.72	40.00	38.4	10.5	5.0	0.1	115.1	31.5
		Specific Gravity	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
4. Concrete Dye		0.50	25.0	0.8	0.3	0.0	50.0	1.6
Cement-Cementitious Materials Ratio			0.50		0.50		0.50	
Water-Cementitious Materials Ratio			0.40		0.40		0.40	
Slump, Slump Flow, in. (Flow Table %)			4.00		3.00		6.00	
Design Air Content, %			6.00					
Density (Unit Weight), lb/ft ³			59.29		60.10		57.30	
Gravimetric Air content, %					4.68		9.92	
Yield, ft ³			27.0		0.3		27.0	

Abs. = Absorption; MC = Batched moisture concrete;

[‡]Water content of admixture.

[^]Including water added for aggregate absorption;

[§] if impact on w/cm is less than 0.01 enter zero

* For aggregates, provide ASTM C 127 oven-dry bulk specific gravity.



Appendix B-Summary of Mixture Proportions

Mixture ID: White Inlay

Batch Size (ft³): 0.3

Cementitious Materials		Specific Gravity*	Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
			Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
1. ASTM C150 Portland Cement Type 1		3.15	350.0	1.781	3.9	0.020	350.0	1.781
2. Silica Fume		2.35	70.0	0.477	0.8	0.005	0.0	0.000
3. Fly Ash Type F		2.50	280.0	1.795	3.1	0.020	350.0	2.244
Total of All Cementitious Materials			700.0	4.053	7.8	0.045	700.0	4.024
Fibers								
1. Polypropelene Micro fibers		1.00	0.5	0.008	0.0	0.000	0.5	0.008
Total of All Fibers			0.5	0.008	0.0	0.000	0.5	0.008
Aggregates								
1. Ceramic Spheres 7-14 mm Abs.: 3.8 % ; MC: 0.2 %		0.90	188.0	3.178	2.1	0.037	0.0	3.255
2. Glass Spheres 0.5-1 mm Abs.: 12 % ; MC: 0.1 %		0.47	188.0	6.068	2.1	0.071	0.0	6.233
3. Glass Spheres 0.5-1 mm Abs.: 12 % ; MC: 0.1 %		0.59	188.0	4.848	2.1	0.057	557.3	15.138
4. K36 Glass Bubbles Abs.: 0.0 % ; MC: 0.0 %		0.38	25.4	1.010	0.3	0.0	29.3	1.234
Total of All Aggregates			589.4	15.124	6.5	0.177	586.6	16.372
Water								
1. Batched Water [^]		1.00	320.0	5.096	3.6	0.057	314.3	5.036
2. Water added for Aggregate Absorption		1.00	51.5	0.784	0.6	0.009	66.3	1.063
3. Total Water form All Admixtures [§]		1.00	10.5	0.168	0.1	0.002	31.5	0.505
Total water			279.6	4.481	3.1	0.050	279.4	4.478
Solids Content of Latex Modifiers								
1. Latex		40.00	0.3	0.002	0.1	0.000	0.5	0.004
Total Latex Solids			0.3	0.002	0.1	0.000	0.5	0.004
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)
1. Air Entrainment	lb/gal: N/A	0.00	0.0		0.0		0.0	
2. High Range Water Reducer	lb/gal: 8.76	0.00	26.0	0.0	2.0	0.0	26.0	0.0
3. Latex	lb/gal: 8.72	40.00	38.4	10.5	5.0	0.1	115.1	31.5
		Specific Gravity	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
4. Concrete Dye		0.50	25.0	0.8	0.3	0.0	0.0	0.0
Cement-Cementitious Materials Ratio			0.50		0.50		0.50	
Water-Cementitious Materials Ratio			0.40		0.40		0.40	
Slump, Slump Flow, in. (Flow Table %)			4.00		3.00		6.00	
Design Air Content, %			6.00					
Density (Unit Weight), lb/ft ³			59.29		60.10		57.58	
Gravimetric Air content, %					4.68		8.49	
Yield, ft ³			27.0		0.3		27.0	

Abs. = Absorption; MC = Batched moisture concrete;

[‡]Water content of admixture.

[^]Including water added for aggregate absorption;

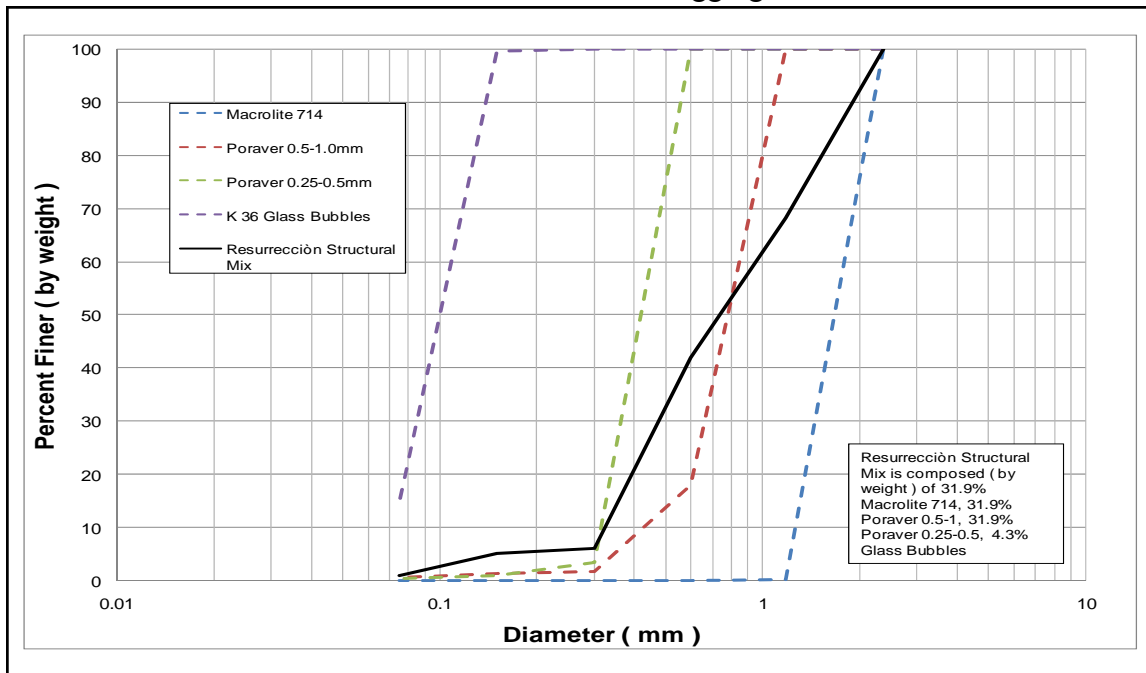
[§] if impact on w/cm is less than 0.01 enter zero

* For aggregates, provide ASTM C 127 oven-dry bulk specific gravity.



Appendix C-Aggregate Gradation Curves and Tables

Gradation Curve for the Structural Black Concrete Aggregate



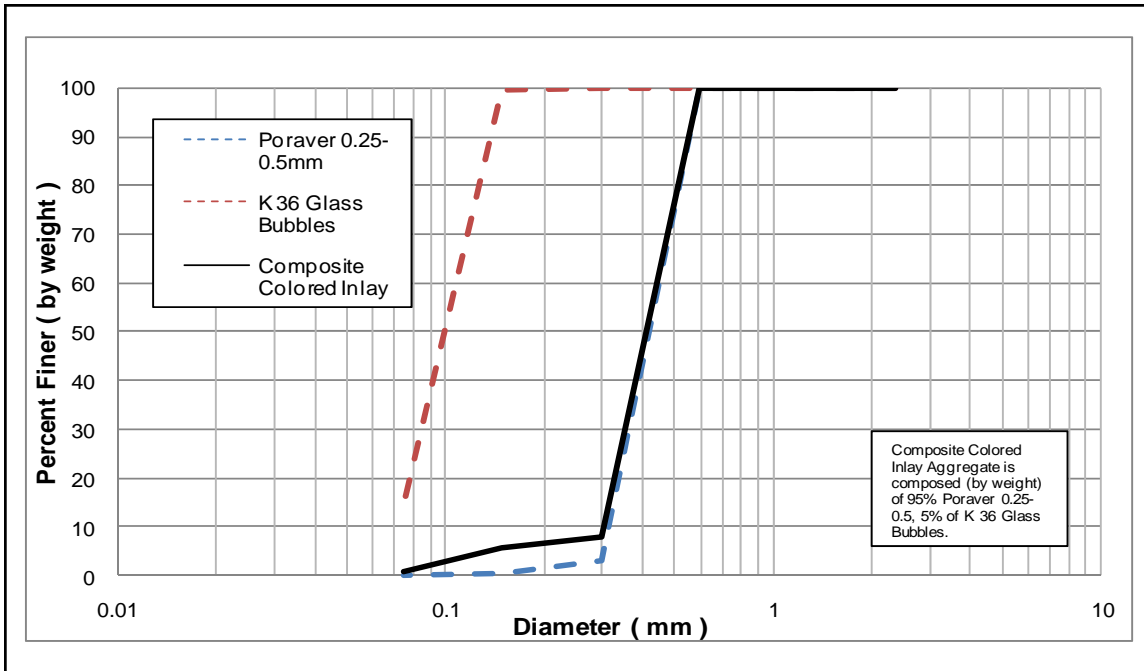
Concrete Aggregate: Composite Structural Black
 Sample Weight: 298.0 g
 Specific Gravity (G_s): 0.64
 Fineness Modulus: 2.79

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
No. 8	2.26	0.0	0.0	100.0
No. 16	1.18	94.9	94.9	68.1
No. 30	0.60	78.2	173.1	41.9
No. 50	0.30	107.3	280.4	5.9
No. 100	0.15	4.8	285.2	4.3



Appendix C-Aggregate Gradation Curves and Tables

Gradation Curve for White Inlay Aggregates



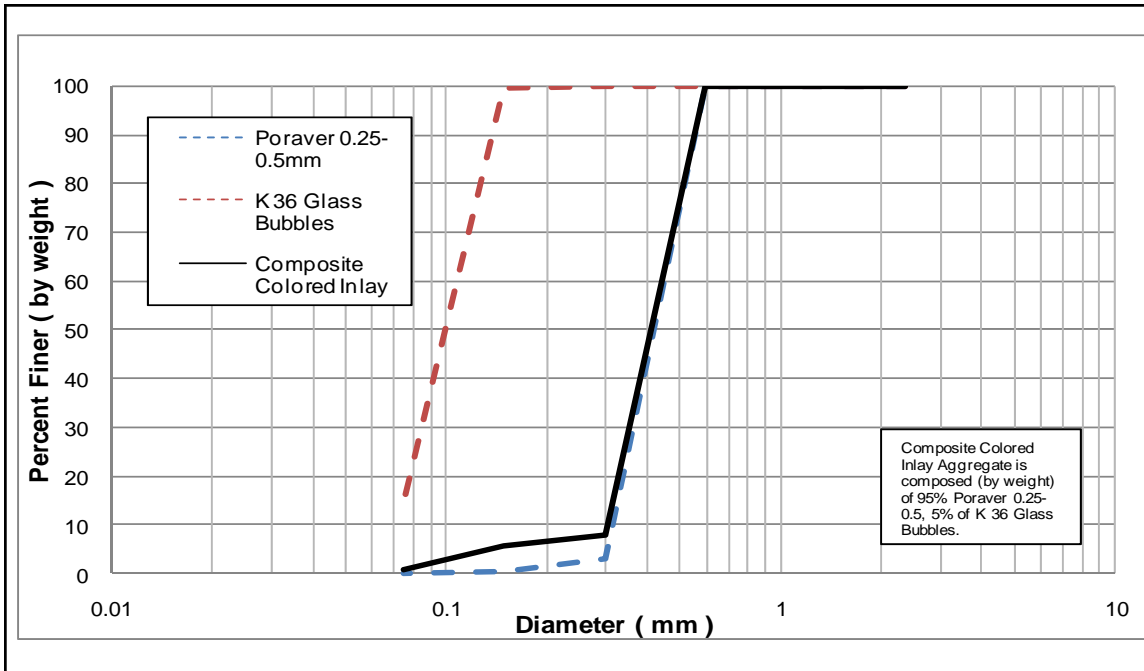
Concrete Aggregate: Composite White Inlay
 Sample Weight: 349.1 g
 Specific Gravity (G_s): 0.58
 Fineness Modulus: 1.87

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	0.0	0.0	100.0
No. 30	0.60	0.1	0.1	99.9
No. 50	0.30	320.2	320.3	8.2
No. 100	0.15	12.0	332.3	4.8



Appendix C-Aggregate Gradation Curves and Tables

Gradation Curve for Colored Inlay Aggregates



Concrete Aggregate: Composite Colored Inlay
 Sample Weight: 349.1 g
 Specific Gravity (G_s): 0.58
 Fineness Modulus: 1.87

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	0.0	0.0	100.0
No. 30	0.60	0.1	0.1	99.9
No. 50	0.30	320.2	320.3	8.2
No. 100	0.15	12.0	332.3	4.8



Appendix C-Aggregate Gradation Curves and Tables

Concrete Aggregate: Macrolite 7.0-14.0 mm

Sample Weight: 165.2 g

Specific Gravity (G_s): 0.90

Fineness Modulus: 4.00

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	164.9	164.9	0.2
No. 30	0.60	1.2	165.1	0.1
No. 50	0.30	0.1	165.2	0.0
No. 100	0.15	0.0	165.2	0.0

Concrete Aggregate: Poraver Recycled Glass 0.5-1.0 mm

Sample Weight: 183.1 g

Specific Gravity (G_s): 0.47

Fineness Modulus: 2.79

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	0.4	0.4	99.9
No. 30	0.60	150.4	150.4	17.8
No. 50	0.30	29.7	180.1	1.6
No. 100	0.15	0.6	180.7	1.3

Concrete Aggregate: Poraver Recycled Glass 0.25-0.5 mm

Sample Weight: 227.8 g

Specific Gravity (G_s): 0.59

Fineness Modulus: 1.96

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	0.0	0.0	100.0
No. 30	0.60	0.1	0.1	99.9
No. 50	0.30	220.0	220.1	3.4
No. 100	0.15	5.8	225.9	0.9



Appendix C-Aggregate Gradation Curves and Tables

Concrete Aggregate: K36 Glass Bubbles

Sample Weight: 105.3 g

Specific Gravity (G_s): 0.38

Fineness Modulus: 0

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	0.0	0.0	100.0
No. 30	0.60	0.0	0.0	100.0
No. 50	0.30	0.0	0.0	100.0
No. 100	0.15	0.3	0.3	99.7

