CONCRETE
CHARLIE

2006

- NAVAL ARCHITECTURE
- STRUCTURAL RELIABILITY
- CONCRETE TECHNOLOGY
- ADVANCED CONSTRUCTION
- TRADITION

Drexel

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SuCCess with Self-Consolidating Concrete

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EXECUTIVE SUMMARY

Founded by Philadelphia financier and philanthropist Anthony J. Drexel in 1891, Drexel University consists of ten colleges and three schools with an enrollment of 14,000 and operates one of the country's oldest and largest mandatory co-operative education programs. Located in the University City area of Philadelphia, Drexel is ideally situated for its valuable relationship with the business and industry of the nation's fifth largest metropolitan area.

Drawing upon the knowledge accumulated over the last decade in the production of concrete racing hulls, Drexel proudly unveils its 2006 entry, ***Concrete Charlie*.** This year marks our ninth consecutive (and tenth overall) appearance at the national competition as the representative of the Mid-Atlantic Region. Drexel has several top-ten finishes to its credit, and now looks to improve upon last years' 11th place national finish.

The Original "Concrete Charlie"

Named in honor of Philadelphia Eagle Hall of Famer Chuck Bednarik who was given the nickname by sportswriter Hugh Brown because he is "as hard as the concrete he sells," ***Concrete Charlie*** represents the integration of state-of-the-art concrete technology with naval architecture. Seeking to revolutionize the canoe construction process, our team focused its efforts on the incorporation of ***self-consolidating concrete*** (SCC) – a fluid, non-segregating mixture that spreads through dense reinforcement and complex formwork under its own weight with minimal mechanical consolidation. Given that each SCC formulation is based on available materials and performance specifications, nearly every aspect of production is evaluated to fully capitalize on its advantages (Neuwald 2004).

The well-balanced hull design is based on the principles of naval architecture, while its structural integrity is evaluated through a probability-based design approach. The precision formwork for the dual mold system was fabricated with the use of a computer numerical controlled (CNC) mill. The 0.75-inch thick hull is a moderate strength SCC composite reinforced with a single layer of 0.5-inch square welded-wire mesh comprised of 16-gauge galvanized steel strands. The fluidity and stability of the tertiary blend of Type III Portland cement, slag cement, and Class C fly ash and two (2) low-density aggregates is achieved through a combination of viscosity modifying, air-entraining, and next generation synthetic high-range water-reducing admixtures. For enhanced aesthetics, a powder color-conditioning admixture gives ***Concrete Charlie*** its French Gray color.

In order to quantify our results, newly adopted test procedures such as *slump flow* and *visual stability index* are used alongside the more traditional tests for unit weight and strength. The Chace Air Indicator was used for the expedient and reliable determination of concrete air content, allowing our team to overcome the limitations associated with more commonly used air meters.

A hierarchical management scheme allowed the team to capitalize on the experience of seasoned veterans while training young recruits for future success. New facets in the quality management process include the use of external quality oversight, namely in the development of the SCC, and third-party technical reviews.

- Concrete Charlie Specifications -

Overall Length:	**20.75 ft.**	**(6.32 m)**
Maximum Beam:	**26.40 in.**	**(67.06 cm)**
Center Depth:	**12.0 in.**	**(30.5 cm)**
Rocker (bow):	**3.50 in.**	**(8.89 cm)**
(stern):	**1.50 in.**	**(3.81 cm)**
Hull Thickness:	**0.75 in.**	**(1.90 cm)**
Estimated Weight:	**250 lbs.**	**(113 kg)**

- Concrete & Composite Properties -

Plastic Density:	**59 pcf**	**(945 kg/m^3)**
Compressive Strength:	**450 psi**	**(3.10 MPa)**
Tensile Strength:	**125 psi**	**(0.86 MPa)**
Flexural Capacity:	**840 psi**	**(5.79 MPa)**

HULL DESIGN

Concrete Charlie features a well-balanced, structurally efficient design that embodies naval architecture, engineering judgment, and on-the-water experience (Table 1, Design Drawing C-002). Drawing upon a decades' worth of knowledge in the production of concrete racing hulls, our 2005 team conducted an evaluation of our past national-qualifying hulls and established the best match between personnel and canoe (Drexel 2005). That study ultimately led to the selection of our 2004 model and a female mold was milled for the construction of last year's canoe. With this year's strategy of incorporating self-consolidating concrete, a dual-mold system is required. Given the investment already made in the female mold, the decision to fabricate the complimentary male plug was simple to make.

The streamlined design of ***Concrete Charlie*** is obtained through the optimization of two (2) naval ratios: length/beam (L/B) and displacement/length (D/L). Combined with the proper selection of hull shape and rocker, a good balance of speed, tracking, maneuverability and stability is achieved.

A common specification of top national contending canoes (e.g., Clemson 2001, Team UAH 2004 and Wisconsin-Madison 2004) is a waterline length between 20 and 21.5 ft. Canoes significantly less than 20 ft. are more maneuverable but tend to lack adequate straight-line speed. Theoretically, the potential speed of a hull increases with length; however, this comes at the expense of maneuverability (Jensen 1993a). While these lengths do not appear to be a major factor for paddlers making the 180° hairpin turn in the sprints, past performances in the distance slalom tend to indicate a practical threshold limit in the range of 22 to 23 ft. for the current race configuration (Drexel 1999, Team UAH 1999).

Most sophisticated racing hulls are long and asymmetrical, having their fullness shifted slightly to the stern resulting in a design that tracks straighter, travels faster, and has increased capacity (Jensen 1993b). ***Concrete Charlie*** maintains a sharp bow at the entry line and widens slowly and smoothly until it reaches its maximum beam of 26.40 in. just aft of amidships. The narrow beam and low entry angle at the bow section significantly reduces wave resistance. The corresponding L/B ratio, a parameter that is inversely proportional to the wave resistance, is 9.36. This L/B ratio is the lowest of all Drexel designs, is comparable to other national-caliber canoes (e.g., Université Laval 2003, Wisconsin-Madison 2004), and results in a hull that possesses excellent speed and tracking ability.

Along with narrow beams, high speeds for canoes are only made possible by having excellent D/L ratios (Winters 2001a). Typical D/L values range from 25 to 30 for marathon racers, the classification of racing hulls that most concrete canoes resemble. For a given canoe, the semi-empirical ratio will vary as a function of loading. ***Concrete Charlie***'s designed displacement (e.g., the displacement intended for best performance) is based on the tandem loading conditions and results in a D/L of 27 for women and 30 for men.

The shallow arch cross section of ***Concrete Charlie*** combines the maneuverability and stability of a flat-bottom section with the speed and tracking of a circular section. The low surface-to-volume ratio of this section decreases the wetted surface area thereby reducing skin friction (Gillmer and Johnson 1982). The gunwale beam is narrow enough to allow efficient paddling, but wide enough for ergonomics. Near the stern, the sidewalls of the shallow arch flare out forming a "whale tail" allowing paddlers to sit further back in the canoe for better overall handling. The whale tale is above the waterline in all the races except the 4-person co-ed when minimum freeboard occurs; therefore, it does not impact the hull's hydrodynamic performance in most cases.

The small amount of rocker (Table 1) incorporated in the bow and stern sections results in a slight decrease in tracking, but it is essential for the quick negotiation of the slalom and turning buoys. The depth provides adequate freeboard during the maximum loading condition of the 4-person co-ed race, and is proven by the fact that this design has never been submerged during the course of any race.

Table 1 – Hull Geometry and Hydrostatic Properties

Length Overall	20.75 ft.
Length at 5" Waterline (L)	20.60 ft.
Beam at 5" Waterline (B)	26.40 in.
L/B Ratio	9.36
Rocker (Bow / Stern)	3.5 in. / 1.5 in.
Center Depth	12.0 in.
Designed Displacement*	530 to 590 lbs.
D/L Ratio**	27 to 30

* *Range based on weight of canoe and tandem loading*

** $D/L = (D/2240\ \text{lbs}) / (0.01L)^3$ *(Winters 2001b)*

ANALYSIS

Since the late 1980's, 3D finite element methods have been employed by various concrete canoe teams including Drexel (1989) and remain one of the most commonly used techniques today. However, a review of design reports over the years has revealed that large discrepancies remain (e.g., hull geometries, loading conditions, and applied factors of safety). As such, reported stresses vary from as low as 130 psi (Team UAH 2004) to those that easily exceed 1000 psi. Other techniques using more simplistic 2D analyses appear to corroborate the values determined by the 3D methods. Given that 2D methods are commonly used by naval architects (Platt 1999), such an analysis is an adequate approach for designing concrete canoes (Rutledge and McKaskle 2002).

Various loading scenarios were considered in the analysis of ***Concrete Charlie*** including the simply-supported case (display), in transport, male and female tandems, male and female trios, and four-person loading combinations. The 250 lbs canoe self-weight is based on a 0.75-inch thick hull with a composite density of 67 pcf. Paddlers are modeled as 180 lbs point loads (men) and 140 lbs point loads (women.). This results in a slightly conservative analysis since paddlers will typically distribute their weight over some area (knees or seats). Buoyant forces are approximated as a 2D pressure, parabolic in shape, equal to the weight of the canoe and paddlers. From the various loads, shear and bending moments are determined.

Given that the canoe is placed in a coffin-like container and continuously supported, the stresses induced under normal transportation conditions are minimal. Under the simply-supported loading condition a maximum positive moment of 650 ft-lb occurs 10.4 feet away from the bow. Based on pure bending, a tensile stress of 82 psi occurs in the bilge and chines and a compressive stress of 176 psi occurs in the gunwale. A reversal of stresses will occur when the canoe is turned upside down (this may occur while the canoe is on display or during judge's inspection).

The critical race condition was determined to be that of the male tandem with the paddlers situated 6 feet from the bow and 4 feet from the stern. A maximum negative moment of 656 ft-lb, resulting from the buoyant force, occurs approximately 11 feet from the bow and results in a tensile stress of 185 psi in the gunwale and a compressive stress of 85 psi in the bilge.

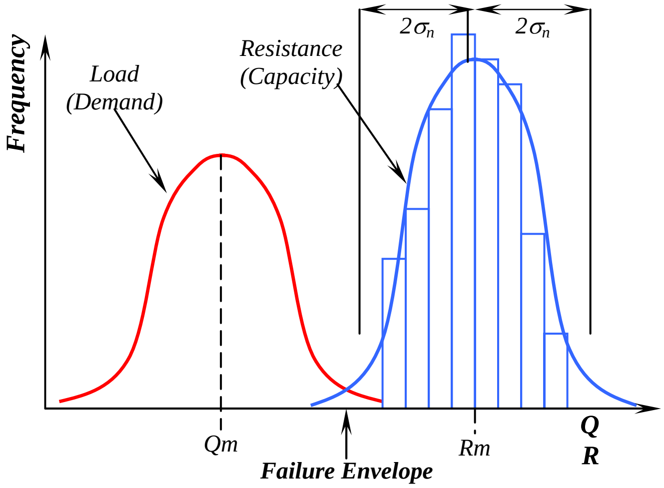


Figure 1 – Frequency Distribution of Load, Q, and Resistance, R

Rather than arbitrarily applying a factor of safety to the compressive and flexural strengths, our designers took a probabilistic design approach (Figure 1) based on the concept of structural reliability. Given the known and controlled loading, the deterministic demand of the hull is a compressive stress of 176 psi and a tensile stress of 185 psi. As discussed in the *Development and Testing* section, test data collected in the laboratory investigation is used to estimate the mean (M_n), standard deviation (σ_n), and 95% confidence level (M_n - $2\sigma_n$) values of the capacity of the reinforced composite. Using this information, the probability of failure (i.e., the probability that capacity will be less than the demand) is calculated and compared to the average code value of 1/10,000 (i.e., one-in-ten thousand chance of failure) (Moon 2006).

Given that steel was the selected reinforcement (see *Development and Testing*), the area of steel (A_s) required to withstand flexure was determined to be 0.10 in^2 (f_y = 60 ksi). Based on 16-gauge (0.063 in) diameter strands, a total of 34 are needed. The 0.5-inch square spacing of the selected welded-wire mesh results in nearly double the amount required along the bilge. The minimum spacing is based on being three (3) times the maximum aggregate particle size.

Since the reinforced composite is not inherently buoyant, flotation tanks are necessary. When completely submerged, the canoe has 17 lbs of negative buoyancy. Given a flotation material with a buoyant force per unit volume of nearly 57 pcf, the minimum volume of 0.30 ft^3 is required to achieve neutral buoyancy. To account for the possible increase in composite density and overall weight, nearly 1.0 ft^3 of flotation is used.

DEVELOPMENT AND TESTING

Following the structural analysis, our focus shifted towards the development of a reinforced concrete composite that has a probability of failure of 1-in-10,000 or better. A secondary goal was to significantly decrease the concrete density from last year's 78 pcf. More importantly, our designers sought to revolutionize the canoe construction process by implementing self-consolidating concrete (SCC).

SCC is defined as a highly flowable, non-segregating concrete that can spread through densely reinforced or geometrically complex formwork to adequately fill voids under its own weight with little to no mechanical consolidation. This is achieved by designing a mix that has a low-yield stress (minimal force to initiate flow) and an increased plastic viscosity (cohesion between the constituents to ensure uniform flow and resistance to segregation and bleeding) (Neuwald 2004).

SCC Mixture Design

Upon the decision to use SCC, designers contacted local Degussa Admixtures, Inc. (Degussa) representatives who agreed to provide consultation and oversight in its development. During initial consultation, recommendations for tertiary blends, admixture dosage, and testing were provided. Our team then followed the "simple and rationale" mix design procedure of Okamura and Ozawa (Neuwald 2004) where aggregate content is fixed and adjustments are made to water, cementitious material and dosage rates until the specified fresh and hardened properties are met.

Several lightweight aggregates, including expanded shale, perlite and glass/ceramic spheres, were evaluated in order to meet weight and gradation requirements (ASCE 2005). Given that the expanded shale used last year resulted in a high density, it was immediately eliminated from consideration. Perlite's absorptive nature proved to be problematic and was subsequently dismissed. Ultimately, our team developed a blend comprised primarily of *Siscor*® glass spheres with a limited amount of *Q-Cel*® microspheres. These aggregates were selected based on their strength, low densities (SG = 0.34 to 0.64) and low absorption properties. This aggregate blend constituted approximately 30% (by weight) of all trial mixture designs.

During initial testing, a baseline mixture was created using a recommended 800 pcy of cementitious material (cm), with a breakdown (percent by weight) of 50% Portland cement (ASTM C150), 30% slag (ASTM C989), and 20% Class C fly ash (ASTM C618), and a baseline 0.38 w/cm ratio (Philips 2005). Slag and fly ash are used because their fine particle size enhances the concrete viscosity (Vachon 2002), increases strength and reduces density. Finely ground Type III Portland cement was used to obtain high-early strength as well as to increase viscosity, while silica fume was excluded in order to lower the water demand and reduce shrinkage cracking.

The workability of SCC is measured by slump flow (Figure 2) rather than the conventional slump test (ASTM C143), and is quantified by a *visual stability index* (VSI) that ranges from 0 (highly stable) to 3 (highly unstable). The fluidity is achieved through the use of synthetic polycarboxylate-based high-range water-reducing admixtures (HRWR) and our baseline tests were based on a recommended dosage of 8 fl oz /cwt of *Glenium*® *3400 NV HRWR*.

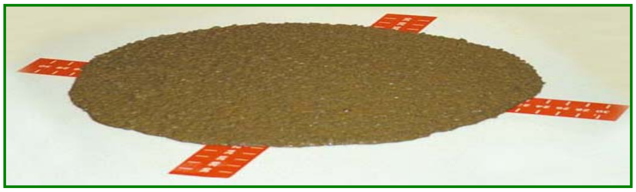


Figure 2 – Slump Flow (Daczko & Attiogbe 2003)

Preliminary findings were promising as unit weight and strength were achieved (60 pcf; 700 psi). However, the 20-inch spread was less than the desired 30 inches and the mixture was unstable as segregation and bleeding did occur (VSI = 2). To modify the slump flow, incremental increases in the HRWR dosage, up to the recommended 12 fl oz/cwt maximum, were made. The stability issues resulting from the low-density aggregates were addressed by incorporating a thickening-type, viscosity-modifying admixture, *Rheomac*® *VMA 362*. The final 8.5 fl oz/cwt VMA dosage is within the recommended range of 2-14 fl oz/cwt giving our designers the flexibility to modify dosages during production of larger batches. *MicroAir*® air-entraining admixture further enhanced the flowability and stability as prescribed 0.125-1.5 fl oz/cwt dosages where used in trial mixtures.

Finally, *Chromix*® color-conditioning powder admixture gives ***Concrete Charlie*** its French Gray color (dosage of 3.2 lbs/cwt). Since *Chromix*® is also water-reducing, additional slump flow tests were conducted; however, results indicated that no adjustments to the other admixtures were needed.

Taking into account the water attributed from the admixtures, a w/cm ratio of 0.42 was obtained. The end result is a highly stable, moderate strength design with a 32-inch spread that is 24% lighter than last year's mixture (Table 2). Final SCC mixture proportions are provided in Appendix B.

Table 2 – Select Design Goals & Final SCC Properties

	Goals	"Gifford"
Plastic Density	62.4 pcf	59 pcf
Compress. Strength*	176 psi	450 psi
Aggregate Weight**	25% (min)	29%
w/cm ratio	0.50 (max)	0.42
VSI	0 to 1	0

* *7-day strengths* ***In relation to concrete unit weight*

Reinforcement Selection

Glass-fiber reinforced concrete (GFRC) has been a hallmark of all Drexel canoes since 1996. The pliable mesh used was well suited for the hand placement construction techniques employed by previous teams. However, the use of the dual mold system required a re-evaluation of the reinforcement scheme. The criteria for the selection were the ability to maintain a minimal amount of layers to facilitate the proper flow of concrete, the material's engineering properties, and the ability to be formed and retain its shape.

Fiber meshes were quickly eliminated because their close-knit weaves restrict flow resulting in inadequate encapsulation of the reinforcement. Several fiber reinforced plastic (FRP) grids were considered an attractive alternative given their light weight and high strength. However, FRP cannot hold the desired shape without stiffening them with resins or an additional rigid frame and therefore were eliminated from consideration.

Although heavier than the aforementioned reinforcement products, a single layer of steel welded-wire mesh (WWM) was found to provide sufficient strength. With the ability to maintain its shape once formed and the predictability of steel with respect to its properties, WWM proved to be the reinforcement of choice. The particular WWM used is a 0.5-inch square mesh comprised of 16-gauge galvanized steel strands.

Concrete & Composite Testing Program

SCC mixture proportions were formulated using the Absolute Volume Method (ACI 211.1) and all tests were performed in accordance with commonly accepted industry standards (e.g., ASTM, AASHTO). To assure the uniform quality of the aggregates, numerous gradation (ASTM C136) and moisture content tests (ASTM C128) were conducted. Concrete densities (ASTM C138), compressive (ASTM C39) and tensile strengths (ASTM C496) were obtained from 2-inch diameter cylinders (ASTM C192) taken from all trial batches and as part of construction quality control. Final yielded mixture proportions were determined by following ASTM C138 guidelines.

Slump flow and VSI quantification, per ASTM C1611, were performed with the assistance of Degussa personnel. To further evaluate the flowability of the concrete within the mold, small scale tests were conducted that allowed designers to view the encapsulation of the reinforcement and the concrete's thixotropic reaction to vibration.

The w/cm ratios were determined by using the microwave oven per AASHTO T318. The Chace Air Indicator (AASHTO T199) was used in determining air content given that the pressure method (ASTM C231) is not acceptable for lightweight concrete (Frank 2003) and the recommended volumetric air meter (ASTM C173) is hampered by the buoyant aggregate obscuring the reading lens, giving no clear measurement of air content. The Chace Air Indicator takes a much smaller sample of only the cementitious paste, thereby eliminating the aggregate. Five (5) tests were conducted on each batch since the average of five provides the same statistical accuracy as one (1) pressure meter test (AASHTO T199).

The compressive capacity (95% confidence) of the final mix design, based on 7-day tests, is 450 psi (M_n = 618 psi; σ_n = 85.5 psi). Given the compressive demand of only 176 psi, the probability of failure was determined to be significantly less than the 1-in-10,000 requirement.

Reinforced composites were evaluated based on tests conducted on 12 in. by 12 in. by 0.75 in. plates following the methodology of ASTM C78 (Figure 3). The composite's flexural capacity (95% confidence) was determined to be 840 psi (M_n = 1088 psi; σ_n = 123 psi). Given the demand of 185 psi, the probability of flexural failure is found to be several orders of magnitude less than the 1-in-10,000 value.

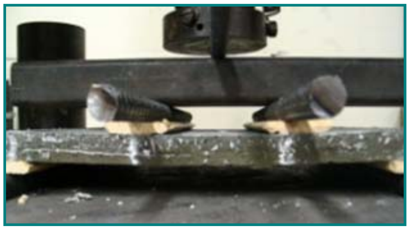


Figure 3 – Flexural Testing

PROJECT MANAGEMENT AND CONSTRUCTION

Project Management

Our management hierarchy was broken down into five (5) areas: *Engineering*, *Construction*, *Quality Assurance/Quality Control*, *Competition*, and *Administration* (Figure 5). Task managers were delegated responsibilities for their respective areas of concentration and reported to the project manager who coordinated all efforts to ensure the timely completion of the project. The managers assigned tasks; scheduled meetings and work sessions; coordinated with consultants and suppliers; and provided weekly progress updates. This organizational structure allowed new members to be given tasks while at that same time being supervised and trained for future success.

Milestones and Critical Path

Starting with the posting of the 2006 Rules and Regulations, the critical path activities were hull design, structural analysis, development of the reinforced SCC composite, mold assembly, canoe casting, and ended with the Mid-Atlantic regional competition. Major milestones and minor objectives, based on the teams' previous experience and deadlines for items such as design paper submissions, are shown on the project schedule (Page 8) and contain the proposed, actual, and remaining timeframes leading up to the national competition in Stillwater, OK. Slight variances in task completion, generally on the order of one to two weeks, occurred but did not adversely affect the overall schedule (Table 3).

Table 3 – Critical Path Activities

Critical Path Activities	Scheduled Completion	Actual Completion
Hull Selection	5 October	20 October
Structural Design	20 October	5 November
Composite Design	28 January	14 February
Mold Assembly	26 February	16 March
Canoe Construction	26 February	18 March
Regional Event	28 April	28 April

Financial and Resource Allocation

Financial support is provided by the university and is supplemented through the sponsorship of the engineering and construction industry. Items such as cementitious materials, aggregates, admixtures, and sealers are donated by local suppliers. Other purchases, such as equipment rentals, construction supplies, personal protective equipment (PPE), and reinforcement are made with donated funds. Outside of transportation costs, the most expensive project line item was the off-site fabrication of the male plug (~$4,000). It was the opinion of the team that this investment would reduce construction time and allow future teams to further advance the SCC casting process.

Quality Assurance/Quality Control (QA/QC)

The senior-most team member served as the QA/QC officer and, with the project manager, was responsible for ensuring quality products that adhered to competition regulations. The focal point of the QA program is the systematic process that included the development of a submittal register and a set of procedures that included submittal transmission, compliance review, and final certification. The major feature of the QC program was the extensive testing performed during the development of the reinforced composite and canoe construction. A new facet in total quality management was the use of external quality oversight. This includes the technical assistance provided by Degussa personnel in the development of the SCC and independent third-party reviews of test results and design report drafts.

Risk Management

Throughout the project's duration, our team utilized an informal process of identifying, assessing, and developing strategies to manage risks. Techniques such as transfer, avoidance, reduction and acceptance (Dorfman 1997) were used as appropriate to minimize consequences. For example, the team fully accepted the risk of implementing SCC in order to introduce an innovative concrete technology, while the outsourcing of the CNC milling of the mold (risk transfer) and the use of external QA/QC measures to supplement our internal quality process (risk reduction) helped mitigate the risk undertaken.

Health and Safety (H&S)

Maintaining the safety of all team members is of paramount concern. Our H&S program ensures that all team members abide by the university's lab safety policies, are familiar with the products they are using by making MSDS readily available, are provided with the appropriate PPE (masks, gloves, life jackets, etc.), and maintain a clean working environment. As a result of these efforts, there have been no lost time injuries or accidents.

Mold and Canoe Construction

One of the project goals is the use of a construction technique that would result in the ease and speed of concrete placement, as well as an improved surface quality that would dramatically reduce finishing efforts. With the selection of SCC came the automatic requirement of a dual mold system. While SCC addresses the concrete placement, precision formwork ensures consistent thickness and impeccable finish.

The dual mold system was fabricated out of expanded polystyrene foam via CNC milling machine (Figure 4). The female formwork consists of five (5) segments, and the male plug, which is offset by 0.75 inches, consists of three (3) segments as shown on Design Drawing C-001.


Figure 4 – Milling of Plug

The segmented pieces were assembled and finished by applying drywall compound and a layer of latex paint, creating a smooth, uniform surface. Using 0.75-inch thick foam spacers, the plug was inserted into the female form and a wooden frame was constructed around the assembly to ensure proper alignment during casting. Since the shear line rises slightly in the bow, 2-inch high foam board was attached to the lip of the female mold so that the concrete could rise above the final gunwale elevation.

The plug was also used in the construction of the reinforcement cage as sections of WWM were cut and placed on 0.25-inch O.D. plastic tubing spacers on top of the plug. Sections of reinforcement overlapped one another by six (6) inches and were tied with plastic ties. The cage extended several inches above the canoe shear line so that it could be later attached to the male mold

Prior to concrete placement, vegetable shortening was applied to all formwork as a release agent. The reinforcement cage was then placed inside the female mold. To control the placement of the reinforcement, lengths of 0.25-inch O.D. plastic tubing were placed between the female mold and the cage, while lengths of 0.50-inch O.D. plastic tubing were placed on top of the cage.

As work on the form and reinforcement progressed, several batches of SSC were prepared. To ensure that the bottom of the canoe was free of any voids, concrete was filled to a predetermined level in the female mold. The plug was then placed into the assembly displacing the very fluid mix to the point that it could be seen coming up the sidewalls. The remainder of the concrete was then poured on either side of the mold and allowed to flow to the other end filling up the sidewalls.

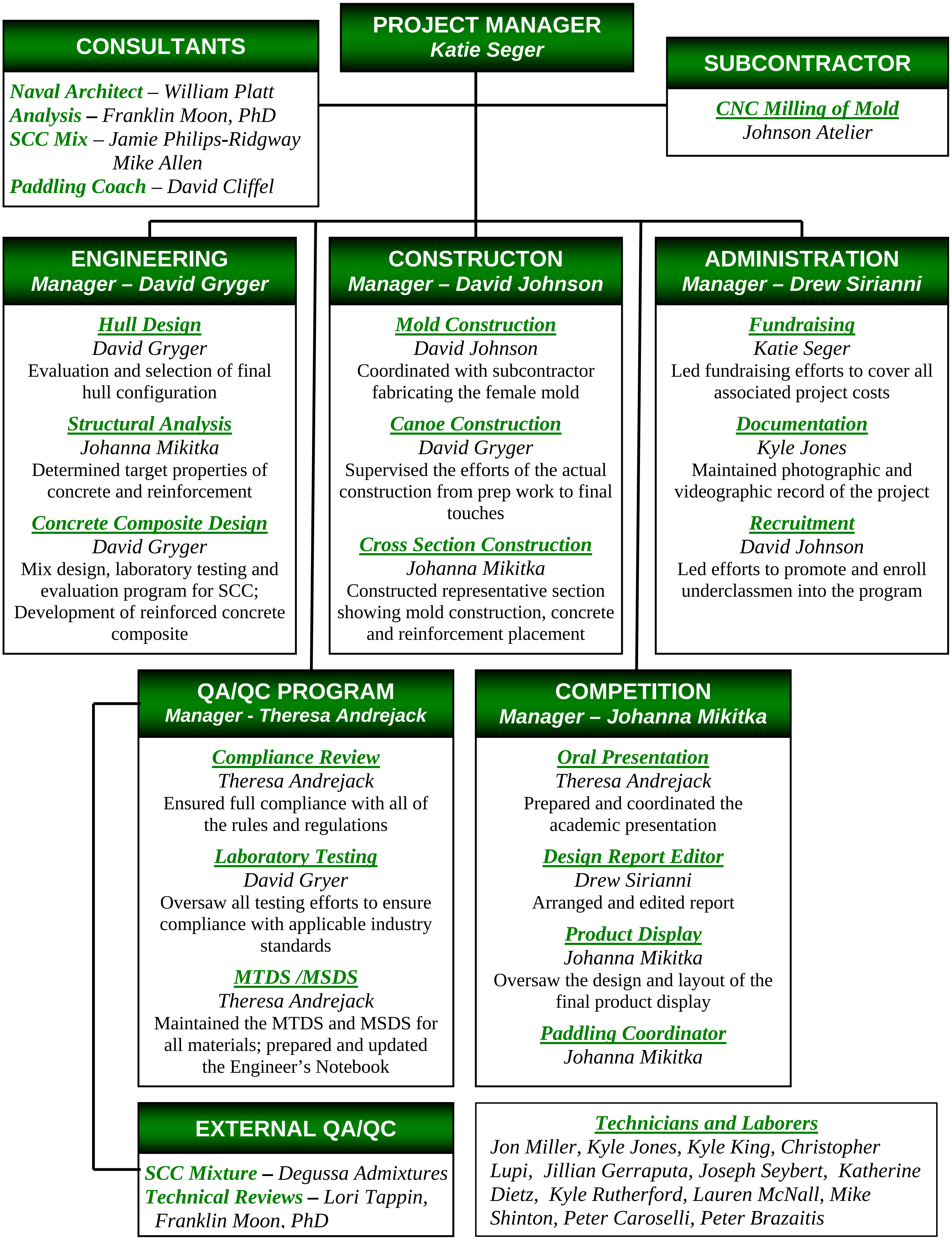
The QC program during construction included the determination of the density, slump flow, and air content of the fresh concrete and the collection of numerous cylinders and plates for both testing and product display purposes.

The canoe remained in the mold for three (3) days under plastic, relying on water that has been absorbed into the porous structure of the low-density aggregate for internal curing (Frank 2003). The plug was removed after the third day in order to cure the concrete with saturated towels under plastic. Following its removal, a large void along one of the sidewalls was discovered. To repair this void, the reinforcement was first cleared of slush concrete, the plug was inserted back into the canoe, and a batch of SCC was poured into the void. Three (3) days after the repair was made, the plug was again removed and the canoe was allowed to continue to cure.

Seven (7) days after the repair, the excess concrete and reinforcement that extended above the designed shear line were cut flushed with the gunwale and wet sanding of the canoe's interior commenced. The canoe was released from the female mold 21 days after casting and sanding of the exterior surface began. Flotation tanks were constructed by placing expanding spray foam and then using temporary formwork to encase it in concrete. Two (2) uniform coats of Dress and Seal™ acrylic cure and sealer (ASTM C309 and ASTM C1315) were applied with a roller to the canoe surface. The coatings were applied 5 hours apart per the manufacturer's specifications. Finally, vinyl lettering of the canoe and school names were adhered to the sealed concrete surface.

Summary of Hours

To date, 985 man-hours have been committed to the design and construction of the canoe (630 for research and development; 355 for construction) with an additional 315 hours devoted to other aspects of the competition such as design paper, oral presentation, display and fundraising. Paddling training has been limited to approximately 50 hours for each paddler.



PROJECT MANAGER
Katie Seger

CONSULTANTS

Naval Architect *– William Platt*
Analysis *– Franklin Moon, PhD*
SCC Mix *– Jamie Philips-Ridgway*
Mike Allen
Paddling Coach *– David Cliffel*

SUBCONTRACTOR

CNC Milling of Mold
Johnson Atelier

ENGINEERING
Manager – David Gryger

Hull Design
David Gryger
Evaluation and selection of final hull configuration

Structural Analysis
Johanna Mikitka
Determined target properties of concrete and reinforcement

Concrete Composite Design
David Gryger
Mix design, laboratory testing and evaluation program for SCC; Development of reinforced concrete composite

CONSTRUCTON
Manager – David Johnson

Mold Construction
David Johnson
Coordinated with subcontractor fabricating the female mold

Canoe Construction
David Gryger
Supervised the efforts of the actual construction from prep work to final touches

Cross Section Construction
Johanna Mikitka
Constructed representative section showing mold construction, concrete and reinforcement placement

ADMINISTRATION
Manager – Drew Sirianni

Fundraising
Katie Seger
Led fundraising efforts to cover all associated project costs

Documentation
Kyle Jones
Maintained photographic and videographic record of the project

Recruitment
David Johnson
Led efforts to promote and enroll underclassmen into the program

QA/QC PROGRAM
Manager - Theresa Andrejack

Compliance Review
Theresa Andrejack
Ensured full compliance with all of the rules and regulations

Laboratory Testing
David Gryer
Oversaw all testing efforts to ensure compliance with applicable industry standards

MTDS /MSDS
Theresa Andrejack
Maintained the MTDS and MSDS for all materials; prepared and updated the Engineer's Notebook

COMPETITION
Manager – Johanna Mikitka

Oral Presentation
Theresa Andrejack
Prepared and coordinated the academic presentation

Design Report Editor
Drew Sirianni
Arranged and edited report

Product Display
Johanna Mikitka
Oversaw the design and layout of the final product display

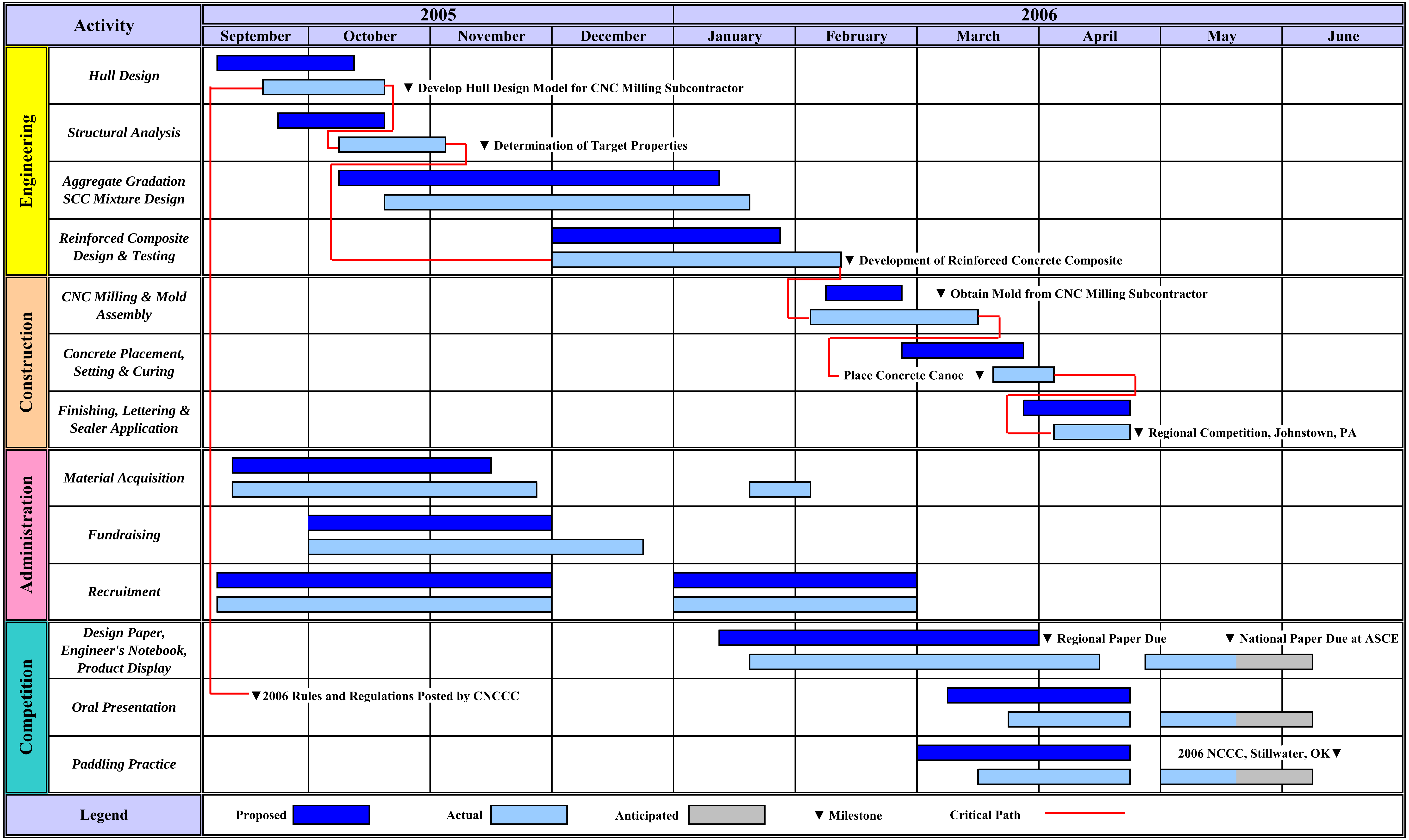
Paddling Coordinator
Johanna Mikitka

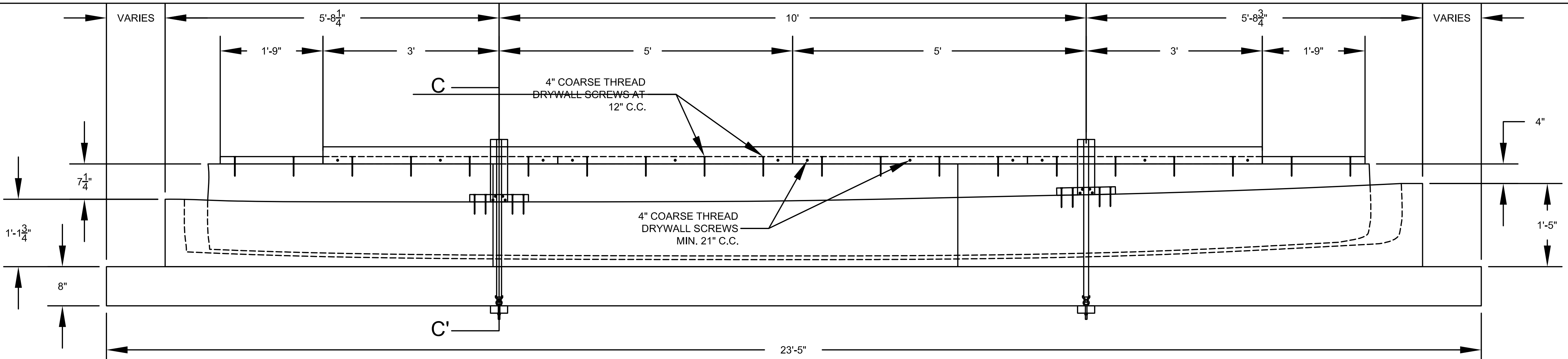
EXTERNAL QA/QC

SCC Mixture *– Degussa Admixtures*
Technical Reviews *– Lori Tappin, Franklin Moon, PhD*

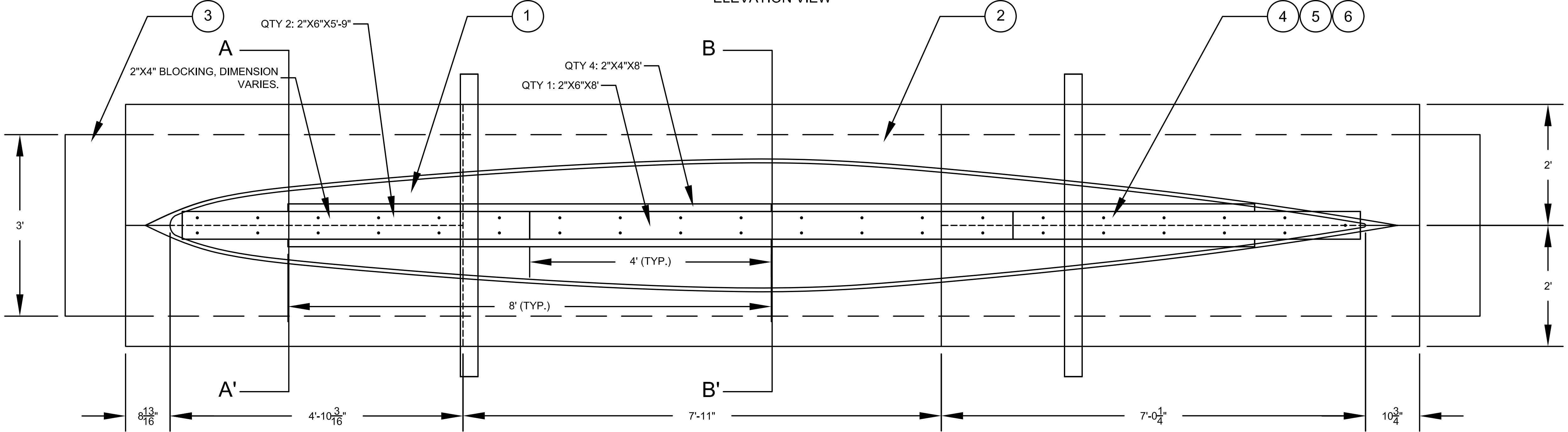
Technicians and Laborers
Jon Miller, Kyle Jones, Kyle King, Christopher Lupi, Jillian Gerraputa, Joseph Seybert, Katherine Dietz, Kyle Rutherford, Lauren McNall, Mike Shinton, Peter Caroselli, Peter Brazaitis

Figure 5 – Organizational Chart of 2006 Drexel University Concrete Canoe Team

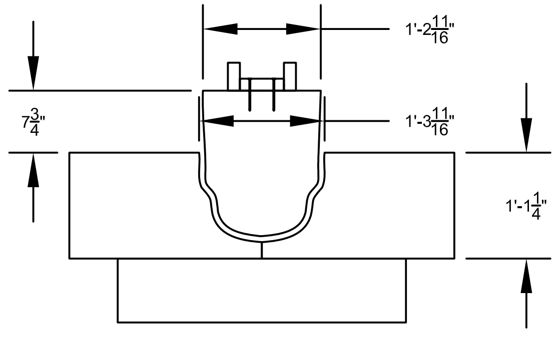

Activity
2005
2006
September
October
November
December
January
February
March
April
May
June
Engineering
Hull Design
▼ Develop Hull Design Model for CNC Milling Subcontractor
Structural Analysis
▼ Determination of Target Properties
Aggregate Gradation
SCC Mixture Design
Reinforced Composite
Design & Testing
▼ Development of Reinforced Concrete Composite
Construction
CNC Milling & Mold
Assembly
▼ Obtain Mold from CNC Milling Subcontractor
Concrete Placement,
Setting & Curing
Place Concrete Canoe ▼
Finishing, Lettering &
Sealer Application
▼ Regional Competition, Johnstown, PA
Administration
Material Acquisition
Fundraising
Recruitment
Competition
Design Paper,
Engineer's Notebook,
Product Display
▼ Regional Paper Due
▼ National Paper Due at ASCE
Oral Presentation
▼2006 Rules and Regulations Posted by CNCCC
Paddling Practice
2006 NCCC, Stillwater, OK▼
Legend
Proposed
Actual
Anticipated
▼ Milestone
Critical Path



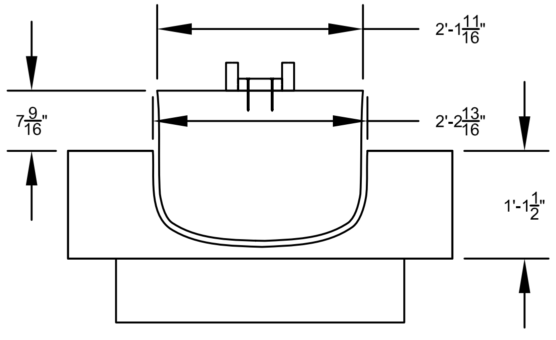
ELEVATION VIEW



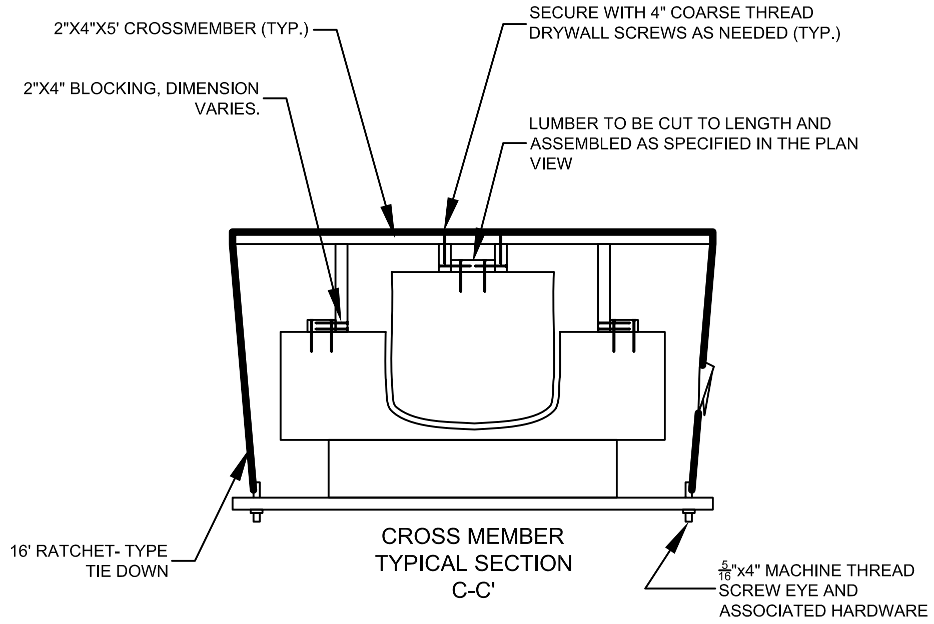
PLAN VIEW



CROSS SECTION A-A'



CROSS SECTION B-B'



CROSS MEMBER
TYPICAL SECTION
C-C'

NOTES:

1. EPS FORMWORK FABRICATED BY CONTRACTOR USING CNC MILLING MACHINE
2. DUAL MOLD SYSTEM USED SPECIFICALLY FOR SELF-CONSOLIDATING CONCRETE (SCC)
3. REINFORCEMENT CAGE (NOT SHOWN) FABRICATED USING MALE PLUG AS GUIDE.
4. CANOE PLACING BY POURING SCC AT BOTTOM OF CANOE TO PREDETERMINED LEVEL, FOLLOWED BY THE INSERTION OF THE MALE PLUG, AND THEN PLACING SCC ALONG SIDEWALLS UNTIL FILLED.

BILL OF MATERIALS

NO.	ITEM DESCRIPTION	QTY.	UNIT
1	3-PIECE EPS MALE MOLD	1	EA.
2	5-PIECE EPS FEMALE MOLD	1	EA.
3	WOOD STRONGBACK TABLE (MIN. 3'x20'-5")	1	EA.
4	LATEX PAINT	1	GAL.
5	DRYWALL COMPOUND	5	GAL.
6	VEGETABLE SHORTENING	5	LB
	2"x4" DIMENSIONAL LUMBER	40	L.F.
	2"x6" DIMENSIONAL LUMBER	24	L.F.
	MISCELLANEOUS HARDWARE - AS NEEDED		

DATE:
MARCH 29, 2006

SCALE:
0 2'

SHEET NUMBER:
C-001

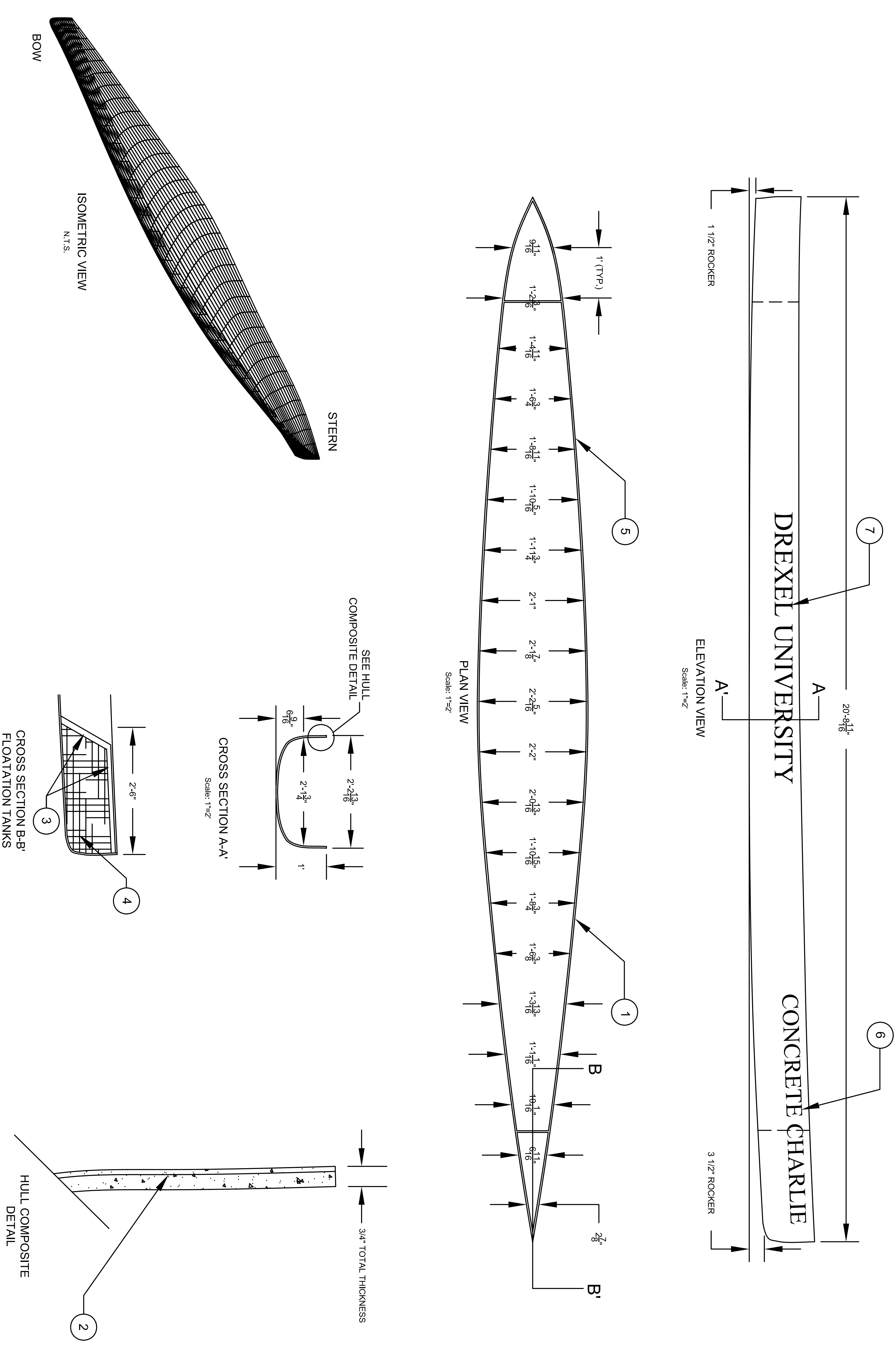
TITLE:
CANOE FORMWORK
SCHEMATIC

DREXEL UNIVERSITY ASCE STUDENT CHAPTER
ASCE CONCRETE CANOE COMPETITION

CONCRETE CHARLIE

	DATE:
DESIGNED BY: DAVE GRYGER	03/16/06
DRAWN BY: DREW SIRIANNI	03/29/06
QA REVIEW BY: THERESA ANDREJACK	03/30/06
APPROVED BY: KATIE SEGER	03/31/06

NOTES:
1. REPAIR MADE TO SIDE WALLS OF CANOE FOLLOWING THE COMPLETION OF REGIONAL COMPETITION. REFER TO APPENDIX D FOR REPAIR PROCEDURE REPORT.



BILL OF MATERIALS

NO.	ITEM DESCRIPTION	QTY.	UNIT
1	CONCRETE (PER SPEC)	4	FT^3
2	WWM REINFORCEMENT: 16 GAUGE GALV. STEEL, 0.5" OPENING	75	FT^2
3	3/4" EXTRUDED FOAM INSULATION BOARD	4.5	FT^2
4	EXPANDING FOAM	1	FT^3
5	ACRYLIC WATER SEALANT (2 COATS)	240	FT^2
6	3 25/32" VINYL LETTERING (CANOE NAME)	2	EA.
7	4 5/16" VINYL LETTERING (SCHOOL NAME)	2	EA.

DATE:
MARCH 29, 2006

SHEET NUMBER:
C-002

SCALE:
SEE DETAILS

TITLE:
CANOE HULL
DESIGN SCHEMATIC

DREXEL UNIVERSITY ASCE STUDENT CHAPTER
ASCE CONCRETE CANOE COMPETITION

CONCRETE CHARLIE

	DATE:
DESIGNED BY: DAVE GRYGER	02/10/06
DRAWN BY: DREW SIRIANNI	03/29/06
QA REVIEW BY: THERESA ANDREJACK	03/30/06
APPROVED BY: KATIE SEGER	03/31/06

Drexel
UNIVERSITY

APPENIDX A – REFERENCES

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APPENDIX B – SUMMARY OF MIXTURE PROPORTIONS

Mixture Designation: ***Gifford***

Done By: DJG
Checked By: TLA

Trial Batch Size = 1.0 ft^3

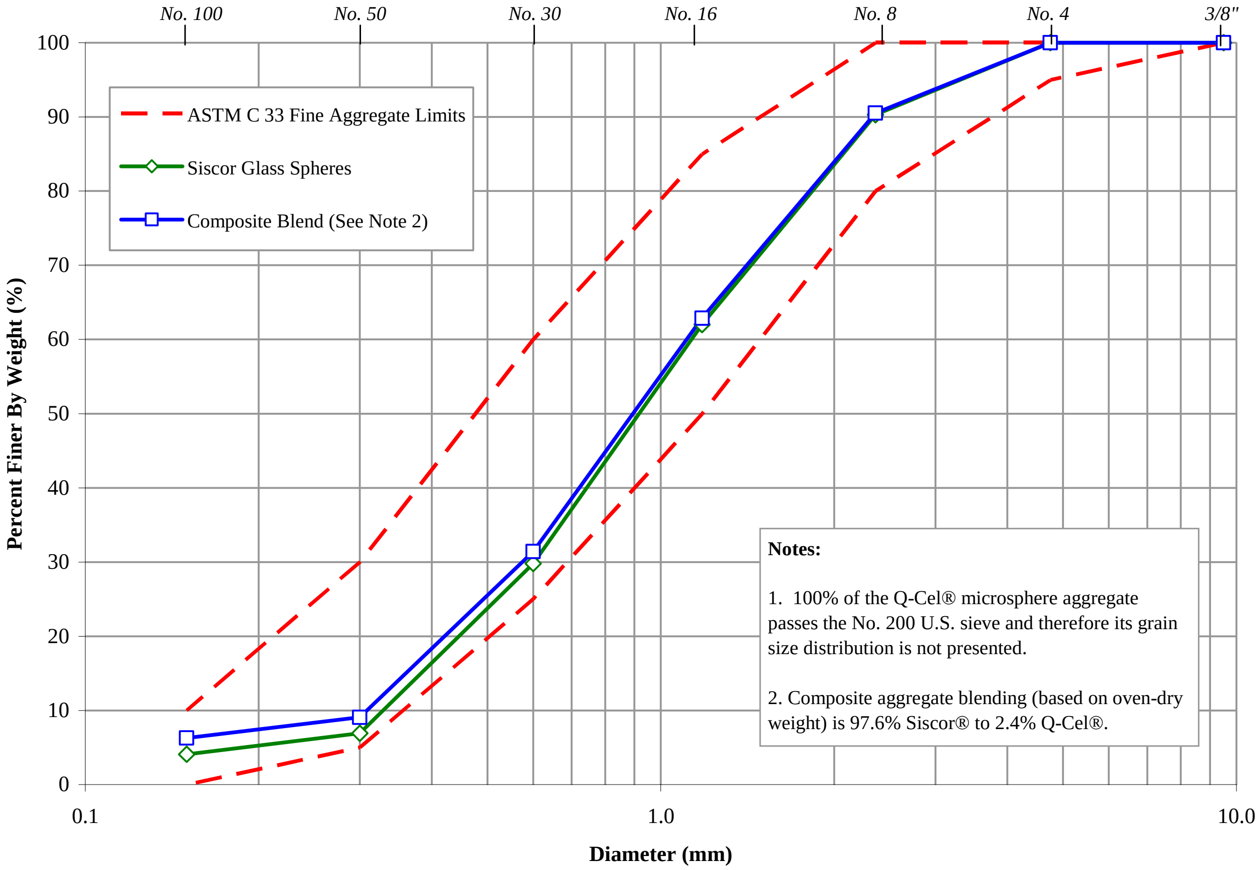
		Proportions as Designed		Batched Proportions		Yielded Proportions	
Cementitious Materials	Specific* Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
ASTM C150 Portland Cement Type III	3.15	405	2.06	15.0	0.08	402	2.05
Class C Fly Ash	2.62	162	0.99	6.0	0.04	161	0.98
Slag Cement	2.60	243	1.50	9.0	0.06	241	1.49
Total of All Cementitious Materials		**810**	**4.55**	**30.0**	**0.17**	**805**	**4.52**
Aggregates							
Siscor® Glass Spheres (2 - 4 mm dia.) Absorption, **4%** Batched Moisture Content, **4%**	0.34	48.0	2.26	1.78	0.08	47.7	2.25
Siscor® Glass Spheres (1 - 2 mm dia.) Absorption, **4%** Batched Moisture Content, **4%**	0.40	131.8	5.28	4.88	0.20	130.9	5.24
Siscor® Glass Spheres (0.5 - 1 mm dia.) Absorption, **3%** Batched Moisture Content, **3%**	0.46	173.2	6.03	6.41	0.22	172.0	5.99
Siscor® Glass Spheres (0.25 - 0.5 mm dia.) Absorption, **3%** Batched Moisture Content, **3%**	0.64	90.4	2.26	3.35	0.08	89.8	2.25
Q-Cel® 6014 Microspheres Absorption, **>0.1 %** Batched Moisture Content, **0%**	0.48	11.3	0.38	0.42	0.01	11.2	0.37
Total of All Aggregates		**454.7**	**16.22**	**16.84**	**0.60**	**451.6**	**16.11**
Water							
Batched Water	1.00	328.3	5.26	12.16	0.19	326	5.226
Total Free Water from All Aggregates	1.00	0	0.00	0.00	0.00	0	0.000
Total Water from All Admixtures[§]	1.00	9.1	0.15	0.34	0.01	9	0.146
Total Water		**337.4**	**5.41**	**12.50**	**0.20**	**335.2**	**5.371**
Admixtures	% Solids	Amount (fl oz/cwt) *lbs/cwt	Water[‡] in Admixture (lb/yd^3)	Amount (fl oz) *lbs	Water[‡] in Admixture (lb)	Amount (fl oz/cwt) *lbs/cwt	Water[‡] in Admixture (lb/yd^3)
MicroAir® AE	14.0	1.0		0.04		1.0	
Glenium® 3400 NV HRWR	40.0	12.0	4.88	0.44	0.18	11.9	4.8
Rheomac® VMA 362	0.7	8.5	4.27	0.31	0.16	8.4	4.2
Chromix® Color-Conditioning Admix.*	100.0	3.2	0.0	0.12	0.00	3.2	0.0
Cement-Cementitious Materials Ratio		0.50		0.50			**0.50**
Water-Cementitious Materials Ratio		0.42		0.42			**0.42**
Slump Flow, in. (per ASTM C1611)		28		32			**32**
Air Content, %		3.1		4.5			**3.8**
Density (Unit Weight), lb/ft^3		59.3		58.9			**58.9**
Gravimetric Air Content, %				3.8			
Yield, ft^3		27.0		1.007			**27.0**

*** For aggregates provide ASTM C127 saturated, surface-dry bulk specific gravity.*

[‡] *Water content of admixture.*

[§] *If impact on water-cementitious materials ratio is less than 0.01 enter zero.*

APPENDIX C – GRADATION CURVES AND TABLES



Notes:

1. 100% of the Q-Cel® microsphere aggregate passes the No. 200 U.S. sieve and therefore its grain size distribution is not presented.

2. Composite aggregate blending (based on oven-dry weight) is 97.6% Siscor® to 2.4% Q-Cel®.

Concrete Aggregate: ***Composite Aggregate Blend (97.6% Siscor® / 2.4% Q-Cel®)*** ***Done By: DJG***

Sample Weight: *1000 grams* ***Checked: TLA***

Specific Gravity (SG): *0.34 to 0.64* *(varies)*

Fineness Modulus: *2.998*

Note: *Percentage listed is based on oven-dry weights of the individual aggregate sources.*

U.S. Standard Sieve Size	***Diameter (mm)***	***Weight Retained (g)***	***Cumulative Weight Retained (g)***	***Percent Finer (%)***	***ASTM C 33 Fine Aggregate Limits***
3/8 inch	9.50	0.0	0.0	100.0	**100**
No. 4	4.75	0.0	0.0	100.0	**95 - 100**
No. 8	2.36	95.0	95.0	90.5	**80 - 100**
No. 16	1.18	276.3	371.3	62.9	**50 - 85**
No. 30	0.60	314.5	685.7	31.4	**25 - 60**
No. 50	0.30	223.6	909.3	9.1	**5 - 30**
No. 100	0.15	27.7	937.0	6.3	**0 - 10**

Concrete Aggregate:	***Siscor$^{®}$ Glass Sphere Aggregate***	***Done By: DJG***
Sample Weight:	*500 grams*	***Checked: TLA***
Specific Gravity (SG):	*0.34 to 0.64* *(varies)*	
Fineness Modulus:	*3.069*	

U.S. Standard Sieve Size	***Diameter (mm)***	***Weight Retained (g)***	***Cumulative Weight Retained (g)***	***Percent Finer (%)***
3/8 inch	9.50	0.00	0.00	100
No. 4	4.75	0.00	0.00	100
No. 8	2.36	48.60	48.60	90.3
No. 16	1.18	141.40	190.00	62.0
No. 30	0.60	160.93	350.93	29.8
No. 50	0.30	114.42	465.35	6.9
No. 100	0.15	14.19	479.53	4.1

Concrete Aggregate:	***Q-Cel$^{®}$ Microsphere Aggregate***	***Done By: DJG***
Sample Weight:	*200 grams*	***Checked: TLA***
Specific Gravity (SG):	*0.48*	
Fineness Modulus:	*N/A*	

Note: *All material passed the No. 200 U.S. Standard sieve.*

U.S. Standard Sieve Size	***Diameter (mm)***	***Weight Retained (g)***	***Cumulative Weight Retained (g)***	***Percent Finer (%)***
3/8 inch	9.50	0.00	0.00	100
No. 4	4.75	0.00	0.00	100
No. 8	2.36	0.00	0.00	100
No. 16	1.18	0.00	0.00	100
No. 30	0.60	0.00	0.00	100
No. 50	0.30	0.00	0.00	100
No. 100	0.15	0.00	0.00	100

REPAIR PROCEDURE REPORT

School Name: Drexel University

Canoe Name: ***Concrete Charlie***

Team Captain(s): Theresa Andrejack, Johanna Mikitka

Date of Request: May 4, 2006

Description of Cause:

See Attachment A.

Description of Repair:

See Attachment B.

Materials used in Repair:

We are planning on using our original mix design, without adding the HRWR. These materials include Type III Portland cement, slag cement, Class C fly ash, Siscor® glass spheres, Q-Cel ® microspheres, MicroAir® AE, Rheomac® VMA, and Chromix® Color-Conditioning Admixture. Two coats of water sealer will be applied as well as new vinyl lettering.

Description of Supporting Documentation:

Attachment A and B

Michael Carnivale III

CNCCC Disposition		
Date:	*8 May 2006*	
Request to Repair Canoe:	☒ **Granted**	☐ **Declined**
Reason for Disposition: *The damage sustained by Drexel University (DU) is the direct result of an accident following the conclusion of the Regional Competition and not the result of inadequate design or construction. The CNCCC has reviewed the Repair Procedure Report and grants DU permission to repair their canoe in accordance with the methodology outlined in the report. Unfortunately, DU will be assessed the 25-point deduction for the repairs that need to be made.*		

This report, CNCCC disposition, and supporting documentation shall be included in Appendix D of the Design Paper. Failure to do so will result in a 25-point deduction from the Design Paper final score.

Filing this report does not guarantee the school will be granted permission to conduct repairs to their canoe. The ability to do so is a function of the reason for the request and the supporting documentation. Under no circumstances should a school consider a verbal disposition permission to repair their canoe.

If the school is permitted to conduct repairs, that school will receive a 25-point penalty for doing so. The maximum final product points will be reduced to 75 out of 100 points. This penalty may be waived at the discretion of the CNCCC on a case by case basis.

ATTACHMENT A

Drexel University Concrete Canoe Team

Description of Incident and Resulting Failure

We loaded the canoe into our coffin just as we have done for the past 9 years. We place the canoe inside the coffin, a 24'x 4'x 3' crate lined with foam and other packing materials, secured the lid, and secured it in the trailer using ratchet straps and blocking to secure it in place. We secured the steel bridge alongside the coffin in the approximate location of the failure, which happens to be above the axle.

While pulling out of the parking lot, Dr. Martin (our faculty advisor), hit a tree on the broadside of the trailer while performing a sharp turn. This caused the trailer to rise on one side, inducing a torsional force along the longitudinal axis of the trailer. This torsion caused the tie downs to come loose enough to allow the blocking to slide from underneath the coffin, and the coffin than became loose. When the trailer came back down, the resulting force was too much to be taken up by the suspension system as would be the case when hitting a pothole. This force transmitted up into the coffin, causing the canoe to shift inside and break.

After hitting the tree, we opened the trailer and coffin to discover that the coffin had shifted and the canoe broke at the location of the failure in a manner consistent with being compressed transversely along the top of the gunwale. We repacked the canoe as best as possible to stabilize the cracking and returned to Philly.

Damage to passenger side of trailer

(Left: Bent rain gutter above door indicating point of impact. Right: Damage to fender indicating additional impact)

Failure on port side of canoe

(Left to right: top of gunwale, interior)

Failure on starboard side of canoe

(Left to right: exterior, top of gunwale, interior)

ATTACHMENT B

Description of Repair Process

We would like to repair the failure in the sidewalls following the same methodology that we utilized upon discovering the void present from the initial pour. We will remove the damage/loose concrete from the reinforcement. We will then inspect the condition of reinforcement for any damage from removal of the concrete and repair any damage that is found, and if necessary additional reinforcement will be added to the affected area. This is subject to the judgment of the Engineering Manager at time of inspection.