OHIO NORTHERN UNIVERSITY

CONCRETE CANOE TECHNICAL PAPER
2007

NORTHERN EDGE

Table of Contents

EXECUTIVE SUMMARY

Ohio Northern University (ONU), located in Ada, Ohio, was founded in 1871 as a private, comprehensive, liberal arts university. Known for its solid undergraduate educational programs and professional degrees including engineering, pharmacy, and law, ONU has excellent networking connections with employers. Ohio Northern currently has 3,202 undergraduate students with approximately 100 students enrolled as Civil Engineering majors.

ONU has been active in concrete canoe competitions for over 25 years and currently competes as part of the North Central Regional Conference. Over the past five years, ONU has continued to improve upon past designs, placing second at the 2006 regional competition and 13th in its debut at the 2006 national competition. The American Concrete Institute acknowledged last year's innovative prestress system and presented ONU with the 2006 Award for Excellence in Design, which recognizes the use of basic design principles for unconventional applications. Building upon the performance of the 2006 season, Ohio Northern proudly unveils its 2007 entry, ***NORTHERN EDGE*** (Table 1).

One of the team's focuses this year was improving racing performance. Shortening the length of the canoe provided better maneuverability and weekly paddling practices improved paddling techniques and paddler endurance.

Improving upon last year's design, a combination of ten 1/16-inch diameter prestress cables each tensioned to 325 pounds; and a sequence of three concrete mixtures, structural, inlay and finishing, were used in the construction of ***NORTHERN EDGE***. The inlay mix displays a sword and the cardinal directions. Tests were run according to the ASTM standards measuring tensile, compressive, and flexural strength characteristics for each of the 21 structural concrete mixtures that were considered for use in this year's canoe.

Table 1: ***Northern Edge*** Properties

Dimensions and Properties	
Name	***Northern Edge***
Color	Black
Weight	170 lbs
Length	19'-7"
Width	2'-6 1/2"
Depth	1'-1 3/8"
Thickness	0'-1/2"
Reinforcement	Fiberglass Mesh
Composite Concrete Mixture	
Unit Weight	53.95 pcf
Flexural Strength	960 psi
Structural Concrete Mixture	
Unit Weight	52.92 pcf
Compressive Strength	2048 psi
Tensile Strength	268 psi
Inlay Concrete Mixture	
Unit Weight	56.25 pcf
Finishing Concrete Mixture	
Unit Weight	51.88 pcf

This year a new officer position, Assistant Project Manager, was added to the management scheme, which allows an experienced veteran to train a younger team member for future success.

Built within the allotted time and proposed budget, this year's determined team hopes that several months of hard-work will give ***NORTHERN EDGE*** the edge it needs to succeed in the 2007 Concrete Canoe Competition.

HULL DESIGN

To begin this year's hull design, the 2006 canoe, *American Pride*, was utilized as the template, due to its stability and straight-line speed. From the comments of last year's paddlers, it was decided that there needed to be adjustments to increase the maneuverability of the canoe. The two most important adjustments were made to the depth of the rocker and the length of the hull.

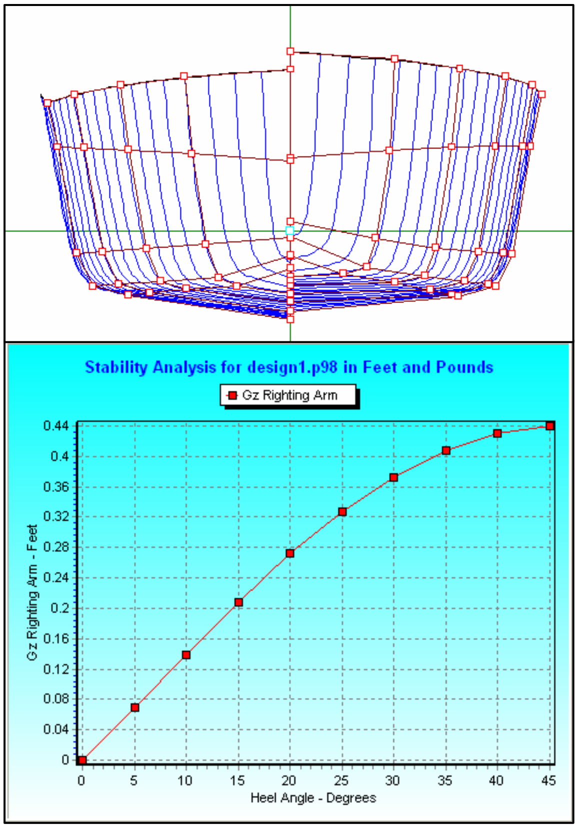


Fig. 1: Cross-section of hull & graph of righting arm

To determine the correct depth of the rocker, engineering reports were consulted from past competitions and various dimensions were analyzed within the hull design program, Prolines 98®. The design engineers desired canoe dimensions that would optimize speed and maneuverability without sacrificing safety and stability. Throughout the tests, the engineers focused on the rotating/righting arm, which provides for stability within the canoe. The larger the rotating arm, the more stability the canoe will have. Upon consulting the paddling engineer, Audrey Seals, a larger rocker was designed for this year's hull. This increased rocker allows the paddlers to have more freedom to turn the canoe quickly and easily. The design engineers investigated the effect of varying depths for the rocker and found 3.5 inches to be an optimal value. This increased rocker depth on ***NORTHERN EDGE*** should provide for easier turns compared to the 1.5 inch rocker on last year's *American Pride*.

The other major adjustment from last year's design was the length of the hull. Although this year's rules only allow for a maximum canoe length of 20 feet, the design engineers had previously decided that the 21.5-foot length of *American Pride* was too long because it made the slalom section of the endurance race very difficult. Therefore, this year's design has a 19.5-foot hull length. This length adjustment, coupled with the increased rocker, should provide the additional maneuverability needed for the paddling team to be more competitive in this year's races.

NORTHERN EDGE still boasts the same hard chines of *American Pride* that provide an increased righting arm for stability of the hull during turns (see Fig. 1). A hard chine also allows the paddlers to sit closer to the bow and stern. This is advantageous for turning and maneuverability because it provides for a longer moment-arm between the paddlers and the mid-ship. Therefore, this hull design choice allows the paddlers to efficiently turn and have adequate stability.

By optimizing maneuverability, and providing adequate speed and stability based on paddler feedback, research, and computer modeling, the hull design team created the ***NORTHERN EDGE*** canoe (Table 2). Compared to previous Ohio Northern canoes, it is the design team's hope that this year's canoe will be the most successful on raceday and throughout the entire competition.

Table 2: Hull Geometry Comparison

Canoe Name	Northern Edge	American Pride
Length	19'-7"	21'-6"
Beam	2'-6 1/2"	2'-6 1/2"
Depth	1'-1 3/8"	1'-1"
Rocker	3 1/2"	1 1/2"
Surface Area	69 ft^2	71 ft^2

CANOE ANALYSIS

The main goal during the analysis stage was to determine accurate values for the structural requirements of the canoe considering all possible loading conditions. This data was used to implement numerous structural elements into the design of the canoe.

Research was performed on the possible benefits of incorporating a thickened gunwale and ribs into the design. Five loading cases (two male, two female, three male, three female, and coed) were used to determine the maximum possible stress at any given point on the hull. Male and female paddlers were assigned a generalized weight of 180lb and 150lb, respectively. The buoyancy force/hydrostatic pressure was determined by locating the waterline that was created by each loading condition. A finite element analysis (FEA) model in SAP 2000® was used to determine the maximum stress location throughout the canoe. The hull was analyzed as a shell under all five conditions using over 3600 elements in order to maintain accurate results. The results indicated that the controlling case for compressive, tensile, and shear stresses was the two male loading scenario (see Fig. 2). The FEA analysis yielded a maximum stress of 82 psi in compression, 95 psi in tension, and 23.5 psi in shear. This information was necessary to determine the placement and dimensions of the ribs and thickened gunwale. The ribs were placed at four feet and eight feet from the tips of the canoe. These ribs have dimensions of 3/4 inch by 3/4 inch to prevent transverse cracking due to tension and shearing forces within the concrete. The gunwale was found to have optimal performance with dimensions of 1.25 inches thickness and 1.25 inches depth. The thickened gunwale provides for additional torsional rigidity and allows for the developed stresses to be spread out over a larger cross-sectional area. These structural elements are vital during racing conditions and help reduce the extra level of stress created by the critical two male race loading scenario.

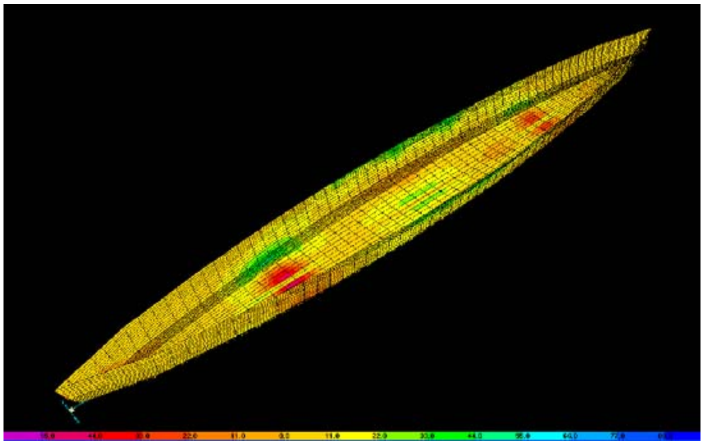


Fig. 2: Maximum Stress Condition (Two Male Load Case)

After significant research, it was determined that a prestress system directly implemented into the hull would dramatically increase the strength of ***NORTHERN EDGE***. This system is designed to reduce any tensile force by creating a compressive force in the longitudinal direction of the canoe. Based on data obtained from SAP 2000®, it was determined that 10 prestress wires would be required to eliminate the tension. After an iterative process within a developed spreadsheet for the prestress design, the necessary force in each wire was found to be 325 lbs. Four wires are located in the base of the canoe under the paddlers and three wires are located along each of the sides of the hull. The areas and moments of inertia for each of the 38 cross-sections were determined using AutoCAD 2007®. These values were used to calculate stresses using fundamental principles of mechanics of materials. The wires were located such that the net moment about the neutral axis due to the eccentricities of the wires was nearly zero. The initial stresses created upon the transfer of prestress from the wires to the canoe were analyzed along with the ultimate stresses created once in the loaded paddling scenarios.

Structural analysis of the canoe was performed with the aid of SAP 2000®, AutoCAD 2007® and a spreadsheet for prestress calculations. The results of the analysis were used to determine the size and placement of various structural elements and prestress wires, which ultimately resulted in the strong, rigid design of ***NORTHERN EDGE***.

DEVELOPMENT AND TESTING

The primary goal of the mix design team was to create a lightweight concrete mixture that met the necessary compression, tension, and flexural strengths determined during structural analysis. Mix engineers researched new concrete components, developed an aggregate gradation, created a structural mix, and selected the reinforcement used to create the composite concrete mixture. Research and testing was conducted on five different elements: cementitious materials, aggregate, latex, admixtures, and fibers. Twenty-one test mixtures were investigated using cylinders and cubes subjected to compressive and tensile tests at 7, 14 and 28 days (ASTM C109, ASTM C496/C469M). Composite plates were also made to test the flexural strength of the final mixes.

Phase one involved testing various cementitious materials including Class C fly ash, slag cement, and silica fume. A baseline mix was developed for each of the three options. Within these mixes the ratios of the cementitious materials were varied. The results indicated that Option 3, which specified a minimum of 50% portland cement, 15% fly ash and 25% slag cement provided the superior combination of binders. Further testing indicated that the addition of silica fume to this mixture increased strength. As a result, a baseline mix consisting of 50% portland cement, 15% fly ash, 25% slag cement, and 10% silica fume was developed. This mix met the goal of 175 psi tensile strength, but significantly exceeded the compressive strength goal and had a high unit weight.

Phase two consisted of research on two possible aggregate compositions. Proper selection of aggregate type and particle size distribution affects the main properties of concrete: workability, mechanical strength, and durability. Complying with the gradation requirements as specified in ASTM C 33, the team's goal was to find the correct aggregates that would achieve the desired strength and unit weight. Additional tests to determine the density, specific gravity, and absorption for the fine aggregates were conducted per ASTM C 128. Glass microspheres and Poraver® glass granulates were selected as the aggregates based on their low unit weights and strength properties. To optimize the aggregate gradation, a modified Fuller's curve was developed and plotted against the ASTM C 33 grading requirements. Two aggregate proportions were then developed that closely matched this curve, and the proportion with higher strength was ultimately chosen (see Fig. 3).

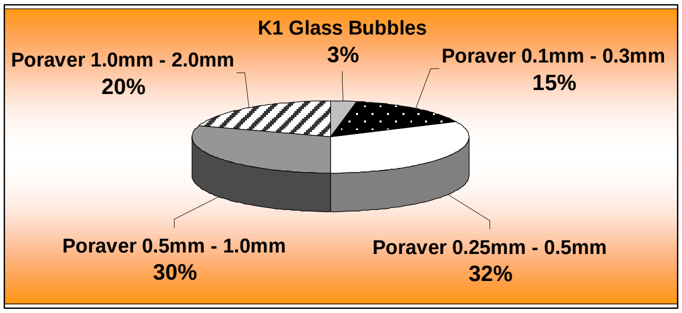


Fig. 3: Aggregate Proportions in Structural Mix

Phase three entailed varying latex and batched water amounts to find a balance between workability and strength. Latex reduces the amount of water required for the mixture, which results in higher compressive and flexural strength and reduces the formation of hairline cracks during the curing stage. Mixtures that contained low amounts of latex demonstrated low strength, while mixtures with large amounts of latex had a concrete setting time that was too fast. Therefore, the mix design team compromised on a ratio that satisfied both workability and strength.

Phase four involved the consideration of chemical admixtures including high range water reducer, air entrainment, and *Chromix*® coloring admixture. High range water reducer was added in the concrete mixes to increase the workability, slump, compressive strength and flexural strength. The mix engineers tested doses below and above the manufacturer's recommendation of 18 fl oz/cwt, while noting that the data sheet states the use of silica fume may require higher doses. However, tests revealed that higher doses resulted in an excessively high slump, while lower doses resulted in reduced strength. Therefore, the manufacturer's recommended dose was used. Air entrainment was utilized to lower the unit weight even though it has negative effects on the strength and the finish. The mix engineers tested ranges of air entrainment within and above the manufacturer's recommended dosage (between ¼ and 4 fl oz/cwt). Test results indicated that a dose slightly higher than recommended was necessary to achieve the desired unit weight without losing significant strength. Finally, a suitable amount of black *Chromix*® coloring admixture needed to properly color the mix was found through trial and error of several batches.

Finally, during phase five the 2006 *American Pride* mix design was employed as a baseline for fiber testing. As a result, chopped polypropylene fibers and carbon fibers were incorporated into the structural mixture. Results of tensile tests (ASTM C 496) revealed that mixtures with carbon fibers could resist failure at higher loads than those with only polypropylene, but would fail more suddenly. The polypropylene fibers were found to improve the ductility of the concrete. Therefore, a combination of both carbon fibers and polypropylene fibers was selected. The amount of each fiber in the mix was derived from the *American Pride* design, as this type and amount of secondary reinforcement was successful in resisting cracks in last year's canoe.

Three different materials were tested for use as the reinforcement in the canoe. A carbon fiber mesh was investigated, however, due to the high cost it was ruled out for possible use in this year's design. Polypropylene fiber meshes were also considered but were ruled out because they were found to prevent crack propagation, but provided minimal improvement to initial flexural strength. The design team then researched fiberglass mesh with a higher tensile strength than the polypropylene. Two different fiberglass meshes were studied. Flexural test plates (ASTM C 293) using the structural mix were made with the fiberglass meshes to determine which reinforcement provided the necessary strength. Ultimately, the 6 oz/yd^2 fiberglass mesh being considered was chosen for use as the main reinforcement of ***NORTHERN EDGE*** due to its adequate bonding capabilities and flexural strength. This reinforcement has a thickness of 0.0409 in (1.04 mm) and a percent open area of 50.95%.

NORTHERN EDGE will be comprised of three layers of structural concrete with two layers of fiberglass mesh between the concrete layers. The inside and outside layers are 1/8 inch thick, and the middle layer is 1/4 inch thick. The prestress wires will be in the center of the middle layer at 1/4 inch depth.

Table 3: Final Properties

Final Structural Concrete – 28 Day	
Compressive Strength (psi)	2048
Tensile Strength (psi)	268
Unit Weight (pcf)	52.92
Composite Results – 28 Day	
Flexural Strength (psi)	960
Percent Open Area (%)	50.95

When the chosen fiberglass mesh was integrated into the final composite mix, it yielded an ultimate composite flexural strength of 960 psi, exceeding the strength requirement established in the FEA analysis. The compressive strength of 2048 psi and tensile strength of 268 psi are about the same as *American Pride's* structural strength and exceed the necessary strengths determined from all stress analyses (Table 3). The final unit weight of 52.92 pcf is over 10% lighter than *American Pride*, which will enhance performance during the races. Therefore, the mix design team's goal of reducing the weight of the canoe while maintaining similar strength was achieved.

Finally, to reinforce ***NORTHERN EDGE'S*** aesthetics, an inlay mixture and finishing coat mixture were created using the final structural mixture as a baseline. The inlay mixture will be used to fashion the inlaid sword and cardinal directions. The finishing coat mixture was designed as a slurry mixture that is easily workable. This mixture has no fibers, has a high water-cementitious materials ratio, and has minimal aggregate content to allow for maximum workability in order to smooth the surface of the canoe.

After successful completion of the testing and analysis, the team was ready to construct ***NORTHERN EDGE***.

PROJECT MANAGEMENT AND CONSTRUCTION

The project manager and assistant project manager led the ***NORTHERN EDGE*** team and directed a staff of seven engineers, each specializing in a different area of expertise. This organizational structure allowed for the most effective and efficient use of resources and was formed based upon past experience.

The project was divided into six specialization areas: mix design, hull design, administration, quality control, construction, and paddling. An engineer led a team assigned to each specialty area. The engineers met on a weekly basis to discuss the progress of the past week, and develop goals and tasks for the coming week. At the beginning of the project, time was devoted by the administrative engineer to develop relationships with sponsors and donors. The project manager developed a budget for the project and discussed it with the civil engineering department. Sponsor letters were sent to supporting companies and industries to obtain the necessary funds.

The project schedule included a critical path of four major milestones chosen as the activities with the least amount of float in the schedule: hull design, mix design and testing, form construction, and casting day. Using risk management theory, each of these milestones included one week of float as a factor of safety in anticipation of unforeseen events. Therefore, four weeks of total float were incorporated into the project schedule.

The hull design and analysis proved to be more complicated than expected because of the extensive research into various designs and the in-depth computer analysis. This caused a delay in the entire project. Due to the sophisticated prestress cable system being used, the form construction was also completed at the late finish date. However, with the four weeks of float in the schedule, all tasks were completed within the proposed time frame.

The quality control engineer implemented a safety and quality control plan. Every test and procedure was conducted according to ASTM specifications. On casting day, each batch of concrete was mixed for a constant duration so that each mix would be consistent before applying it to the canoe form. Six 2 inch by 4 inch cylinders and six 2 inch cubes were made for testing the strength of the concrete to verify that the concrete behaved as tested in the lab.


Fig. 4: Foam and plywood cross-sections

The main goal of this year’s construction team was to develop a form that would easily accommodate hull features such as the gunwale and to simplify the construction and form removal process. Construction was divided into five sections: mold construction, prestress cable system, concrete placement, mold removal, and finishing.

Form construction began with the exportation of 38 cross sections from Prolines 98® to AutoCAD 2007®, where they were modified for the form. The cross-sections were then laser-milled onto 3/8 inch hardboard. These served as guides to cut the 6 inch thick foam sections using a hotwire knife. A notch for the strongback was also cut into each foam cross-section. The strongback is a 4 inch by 4 inch support running the entire length of the canoe mold that provides stability and straightness. The gunwale, included on the cross-sections, was cut directly into the foam thereby making construction of the form easier. Eleven 3/4 inch plywood cross-sections were cut and placed equally between foam cross sections to anchor the prestress screws that support the cables and keep them at the required depth of 1/4 inch. The foam that had adjacent plywood sections were then trimmed to account for the width of the plywood. These foam and plywood cross-sections were then glued together, forming the male mold (see

Fig. 4). Drywall compound was applied to the foam and plywood mold to create a smooth finish. The drywall was then sanded and sealed with three coats of varnish. Vegetable oil was applied to the mold on casting day to act as a release agent when it came time to remove the mold.

The prestress cable system was another major challenge for the construction team. Tubular steel was used to create a welded angle bracket end support system. At each plywood cross-section, fabricated pins were placed at precise locations to guide and support the cables above the first layer of concrete. Stiff springs and turnbuckles were used to create the required tension of 325 lbs in each prestress wire. The springs were stretched to the desired displacement using the spring's initial tension, Hooke's law, and the given spring constant. After testing the prestress system in a dry run, it was apparent that the table which supported the form needed some extra reinforcement to remain safe and operational. This issue was efficiently resolved by the project manager and the night before casting day.

One week before casting day, the concrete canoe engineers organized a practice casting day for everyone involved with the project. During this training session, each member of the team was given their own task to perform on casting day. Mixes were made and everyone practiced applying the concrete to the canoe sectional model. This session was very beneficial as it enabled the real casting day to run efficiently.

On casting day, stations were set up for a smooth assembly line of production and application of the concrete. All dry aggregates, cementitious materials, and fibers were pre-weighed during the week prior to casting day. Latex and water were weighed, while air entrainer and high range water reducer were measured using burets at the weigh station. At the mix station, the dry materials and liquids were mixed together for 2.5 minutes in a machine blender. Then, concrete was formed into sheets of 1/8 inch thickness on sheets of wax paper, controlled by precut rectangular borders with the required thickness.

Before placement on the main form, concrete was first spread into the gunwale and the four ribs along the length of the canoe to a thickness of 3/4 inch. The first 1/8 inch thick layer of concrete was then applied to the form in pre-formed sheets. Fiberglass reinforcement was applied to this first layer of concrete. A second 1/8 inch layer was then applied over the reinforcement. Once the first two layers of concrete and the fiberglass reinforcement were in place, the ten prestress cables were applied and tightened to the desired tension of 325 lbs (see Fig. 5). The third 1/8 inch thick layer of concrete was then applied over the cables. A second layer of fiberglass reinforcement was placed on the canoe and, finally, the fourth 1/8 inch thick layer of concrete was applied over the reinforcement. This assembly line technique greatly increased the speed of the casting, yet issues arose with the bonding of the concrete to the reinforcement. Layers were sprayed with water at some places in order for sufficient bonding to occur.


Fig. 5: Tensioning of the prestress wires

After cutting the wires and removing the form, finishing was the last step in the construction process. A finishing mixture was applied to fill in cavities and then sanded to remove any imperfections. The sword and cardinal directions inlays were formed with the proper inlay concrete mixtures. Finally, a high-gloss concrete sealer was applied to the entire canoe according to the manufacturer's recommendation.

A total of 1215 man-hours (315 on design and analysis, 780 on testing and construction, and 120 on paddling) were spent on ***NORTHERN EDGE***. The team is confident that this year's canoe will continue Ohio Northern's recent success.

ORGANIZATIONAL CHART

Faculty Advisor
Farhad Reza
Ph.D., P.E.

Design Engineers
Ruth Bickel
Sara McDonald
Researched canoe design, analyzed loading cases, developed final hull design.

Quality Control Engineer
Mindy Moser
Ensured compliance with rules and regulations, monitored quality of casting.

Construction Engineer
Anna Santino
Coordinated male mold construction, stand design and canoe casting.

Project Manager
Mike Brown
Coordinated all engineers, organized meetings, advised team on engineering concepts, committed to entire project.

Administrative Engineer
Brandon Strohl
Organized fundraising, managed finances, handled logistics, and team communication.

Mold Construction
Luisa Chinchilla
Ryan Mahle
Sara McDonald
Mindy Moser
Matt Pierce
Drew Richards
Kevin Ring
Chris Shearer
Lindsey Staley

Assistant Project Manager
Brad Barber
Assisted the project manager and shared the same responsibilities, committed to entire project.

Design Paper
Brad Barber
Ruth Bickel
Mike Brown
Sara McDonald
Mindy Moser
Chris Shearer

Casting
Entire Team

Finishing
Entire Team

Paddling Engineer
Audrey Seals
Researched paddling techniques, coordinated paddling practices.

Mix Design Engineer
Chris Shearer
Analyzed and developed concrete mixes.

Oral Presentation
Brad Barber
Mike Brown
Mindy Moser
Chris Shearer

Engineer's Notebook
Mike Brown
Audrey Seals
Chris Shearer

Paddling Team
Brad Barber
Mike Brown
Luisa Chinchilla
Eric Lange
Ryan Mahle
Sara McDonald
Mindy Moser
Anna Santino
Audrey Seals
Brandon Strohl

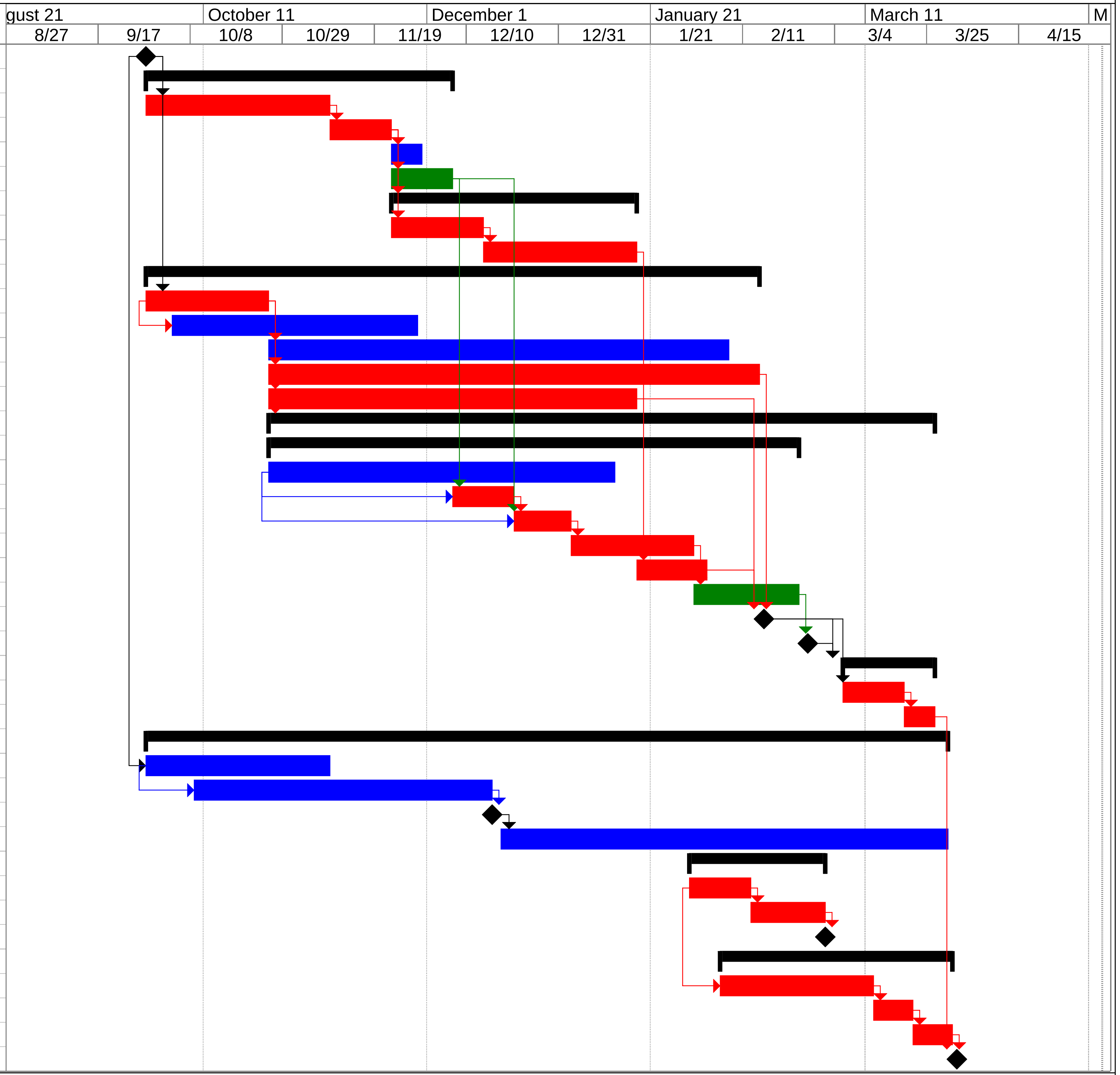
Testing
Lydia Buehrer
Josh Casto
Kelly Cholewa
Chris Dohner
Kevin Gilbert
Kevin Mangan
Jake Meinerding

OHIO NORTHERN UNIVERSITY

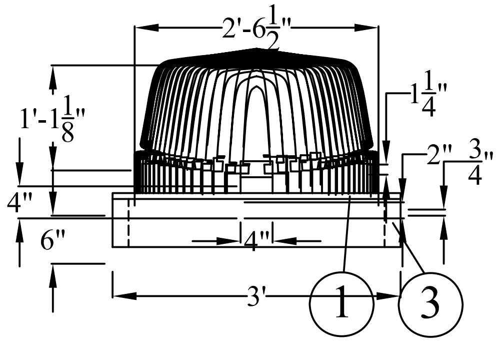
PROJECT SCHEDULE

Northern Edge

ID	Task Name	Duration	Start	Finish
1	Release of 2007 Rules	0 days	Thu 9/28/06	Thu 9/28/06
2	**Hull Design**	**50 days**	**Thu 9/28/06**	**Wed 12/6/06**
3	Research	30 days	Thu 9/28/06	Wed 11/8/06
4	Computer Modeling	10 days	Thu 11/9/06	Wed 11/22/06
5	Finalize Design Planned	5 days	Thu 11/23/06	Wed 11/29/06
6	Final Design Actual	10 days	Thu 11/23/06	Wed 12/6/06
7	**Analysis**	**40 days**	**Thu 11/23/06**	**Wed 1/17/07**
8	2-Dimensional	15 days	Thu 11/23/06	Wed 12/13/06
9	FEA Analysis	25 days	Thu 12/14/06	Wed 1/17/07
10	**Mix and Reinforcement**	**100 days**	**Thu 9/28/06**	**Wed 2/14/07**
11	Goals	20 days	Thu 9/28/06	Wed 10/25/06
12	Material Acquisition	40 days	Wed 10/4/06	Tue 11/28/06
13	Structural Mix Design Planned	75 days	Thu 10/26/06	Wed 2/7/07
14	Structural Mix Design Actual	80 days	Thu 10/26/06	Wed 2/14/07
15	Reinforcement Design	60 days	Thu 10/26/06	Wed 1/17/07
16	**Construction**	**108 days**	**Thu 10/26/06**	**Mon 3/26/07**
17	**Form Construction**	**87 days**	**Thu 10/26/06**	**Fri 2/23/07**
18	Material Acquisition	57 days	Thu 10/26/06	Fri 1/12/07
19	Build Strongback	10 days	Thu 12/7/06	Wed 12/20/06
20	Cut Foam	9 days	Thu 12/21/06	Tue 1/2/07
21	Prepare Mold for Concrete	20 days	Wed 1/3/07	Tue 1/30/07
22	Prestress System Planned	12 days	Thu 1/18/07	Fri 2/2/07
23	Prestress System Actual	18 days	Wed 1/31/07	Fri 2/23/07
24	Pour Day Planned	0 days	Fri 2/16/07	Fri 2/16/07
25	Pour Day Actual	0 days	Mon 2/26/07	Mon 2/26/07
26	**Finishing**	**15 days**	**Tue 3/6/07**	**Mon 3/26/07**
27	Sanding	10 days	Tue 3/6/07	Mon 3/19/07
28	Apply Stain and Decals	5 days	Tue 3/20/07	Mon 3/26/07
29	**Paddling**	**131 days**	**Thu 9/28/06**	**Thu 3/29/07**
30	Recruit Members	30 days	Thu 9/28/06	Wed 11/8/06
31	Fall Practice	50 days	Mon 10/9/06	Fri 12/15/06
32	Declare 2006 Paddlers	0 days	Fri 12/15/06	Fri 12/15/06
33	Winter and Spring Practice	74 days	Mon 12/18/06	Thu 3/29/07
34	**Design Paper**	**23 days**	**Tue 1/30/07**	**Fri 3/2/07**
35	Rough Draft	10 days	Tue 1/30/07	Mon 2/12/07
36	Revise and Edit	13 days	Tue 2/13/07	Thu 3/1/07
37	Paper Due	0 days	Fri 3/2/07	Fri 3/2/07
38	**Presentation**	**39 days**	**Tue 2/6/07**	**Fri 3/30/07**
39	Design Theme	25 days	Tue 2/6/07	Mon 3/12/07
40	Review and Revise	7 days	Tue 3/13/07	Wed 3/21/07
41	Rehearsals	7 days	Thu 3/22/07	Fri 3/30/07
42	North Central Regional @ Michigan Tech	0 days	Sun 4/1/07	Sun 4/1/07

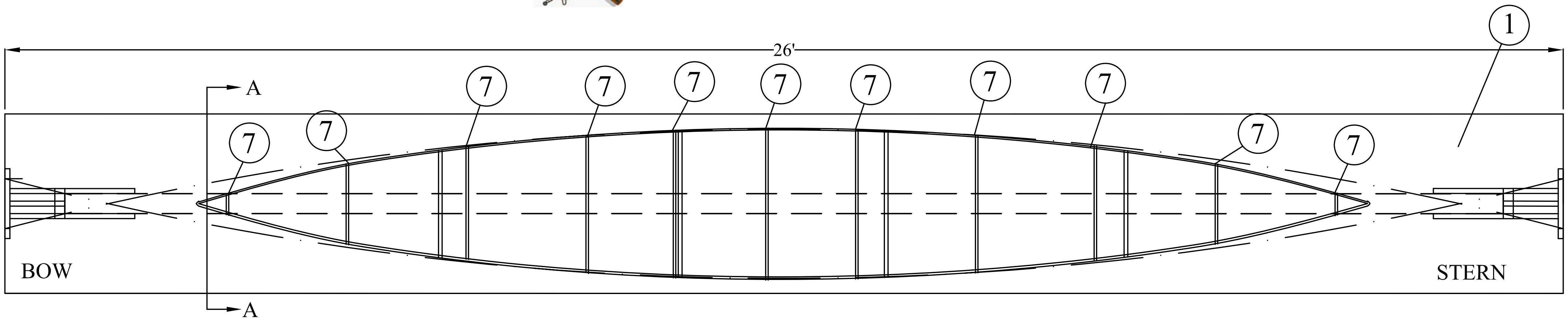


Task	🟦	Critical Path	🟥	Summary	▬	Actual Excecution	🟩	Milestone	◆

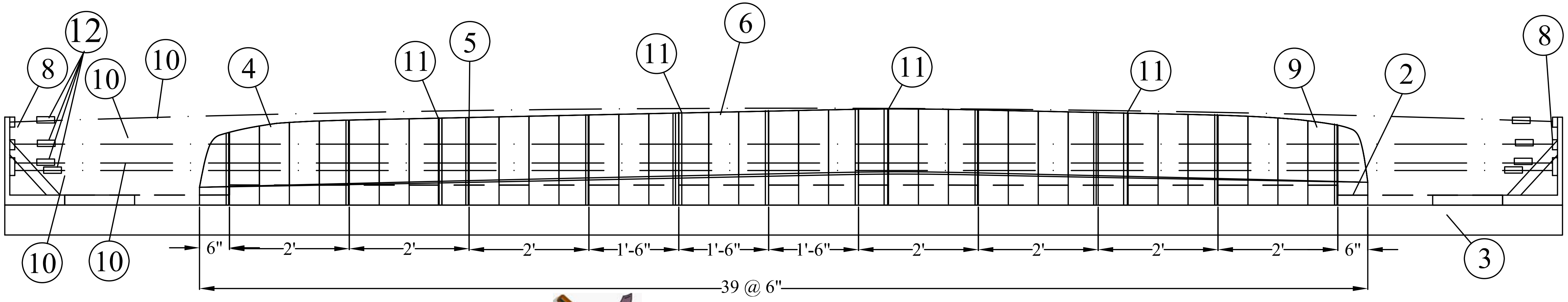


Cross-Section View

Section A-A



Plan View



Elevation View

NORTHERN EDGE

Form Design

Bill of Materials

No.	Qty.	Description
1	3.25	$\frac{3}{4}$" x 3' x 8' Plywood Sheet
2	1	4" x 4" x 22' Strongback
3	2	2" x 6" x 26' Support
4	39	Styrofoam Fills
5	N/A	Glue
6	N/A	Drywall Compound
7	11	3/4" Plywood Cross-sections
8	2	Steel Stand
9	N/A	Spar Varnish
10	240'	1/16" S.S. Wire
11	4	3/4" x 3/4" Rib
12	10	500 lb. Springs

Northern Edge Facts

Length: 19'-7"
Depth: 1'-1 3/8"
Deck Beam: 2'-6 1/2"
Hull Thickness: 0'- 1/2"
Color: Black
Weight: 170 lbs

Ohio Northern University
College of Engineering
ASCE Concrete Canoe
Ada, OH 45810

Project Name: *Northern Edge*
Date: February 12, 2007
Scale: 1/2" = 1'

Sheet
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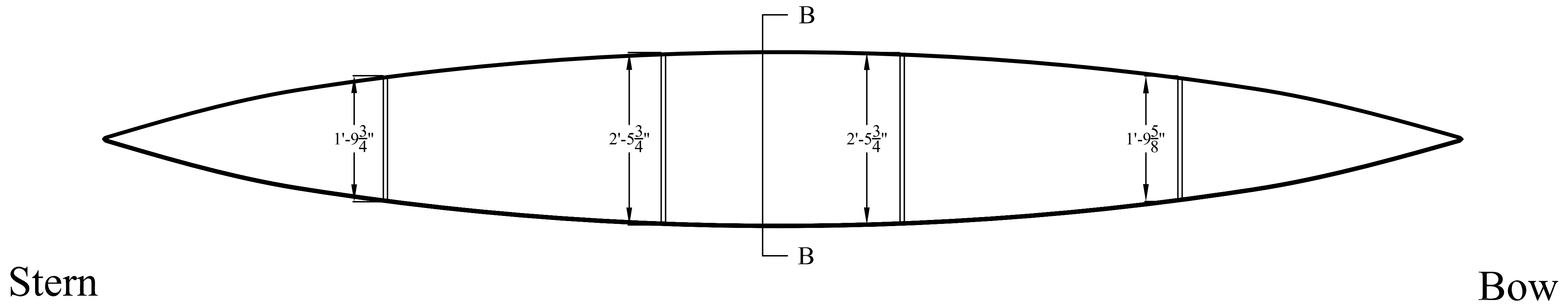
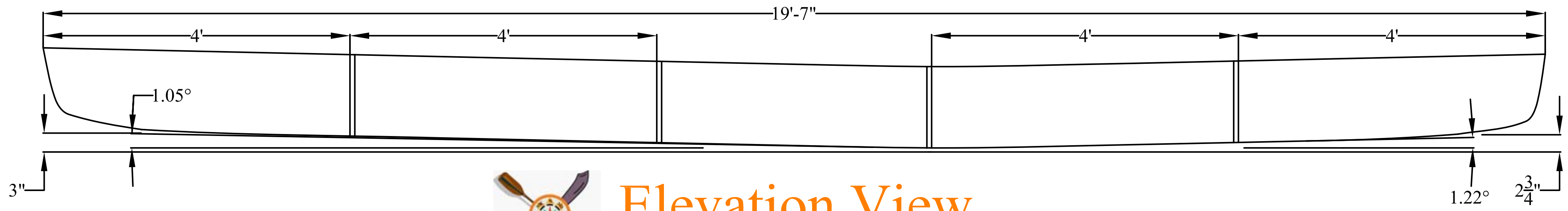
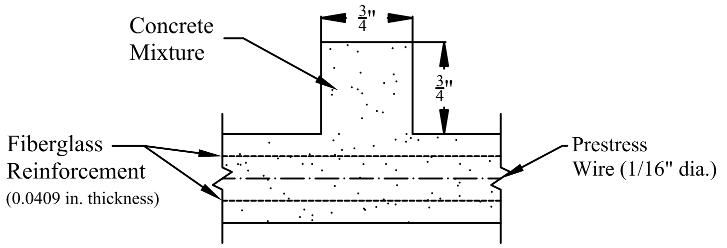


Plan View

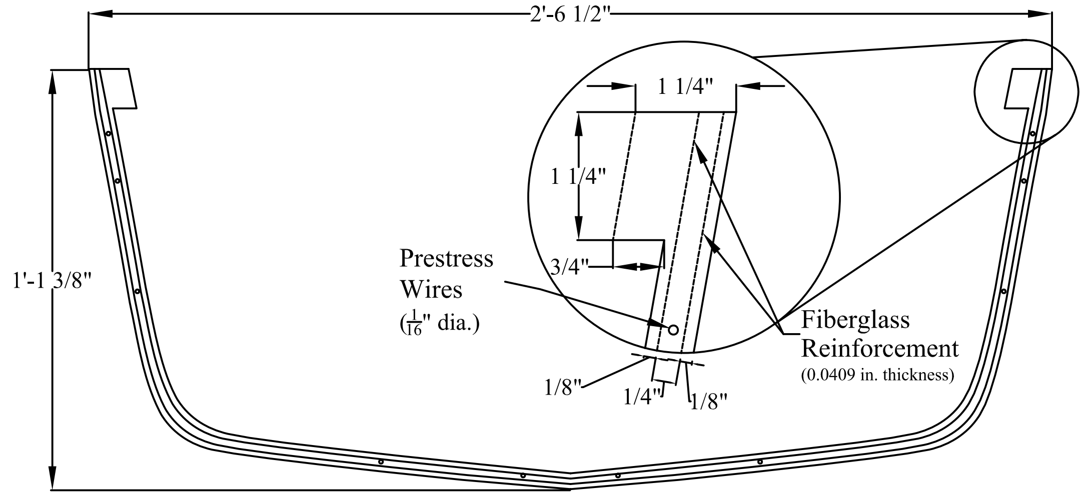


Elevation View



Typical Rib Detail

Not to Scale



Cross Section

SECTION B-B

Not to Scale

NORTHERN EDGE

Hull Design

Bill of Materials

No.	Qty.	Description
1	10	$\frac{1}{16}$" S.S. Wires @ 24'
2	2	6 OZ/SQ YD Fiberglass Mesh Reinforcement 69 SQ FT.
3	3 cu. ft.	Structural Concrete Mixture
4	0.10 cu. ft.	Finishing Mixture
5	0.03 cu. ft.	Inlay Mixture
6	0.5 gal	Concrete Sealer

Northern Edge Facts

Length: 19'-7"
Depth: 1'-1 3/8"
Deck Beam: 2'-6 1/2"
Hull Thickness: 0'- 1/2"
Color: Black
Weight:170 lbs

Ohio Northern University
College of Engineering
ASCE Concrete Canoe
Ada, OH 45810

Project Name: *Northern Edge*
Date: February 12, 2007
Scale: 1/2" = 1'

Sheet
10

APPENDIX A – REFERENCES

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APPENDIX B – MIXTURE PROPORTIONS

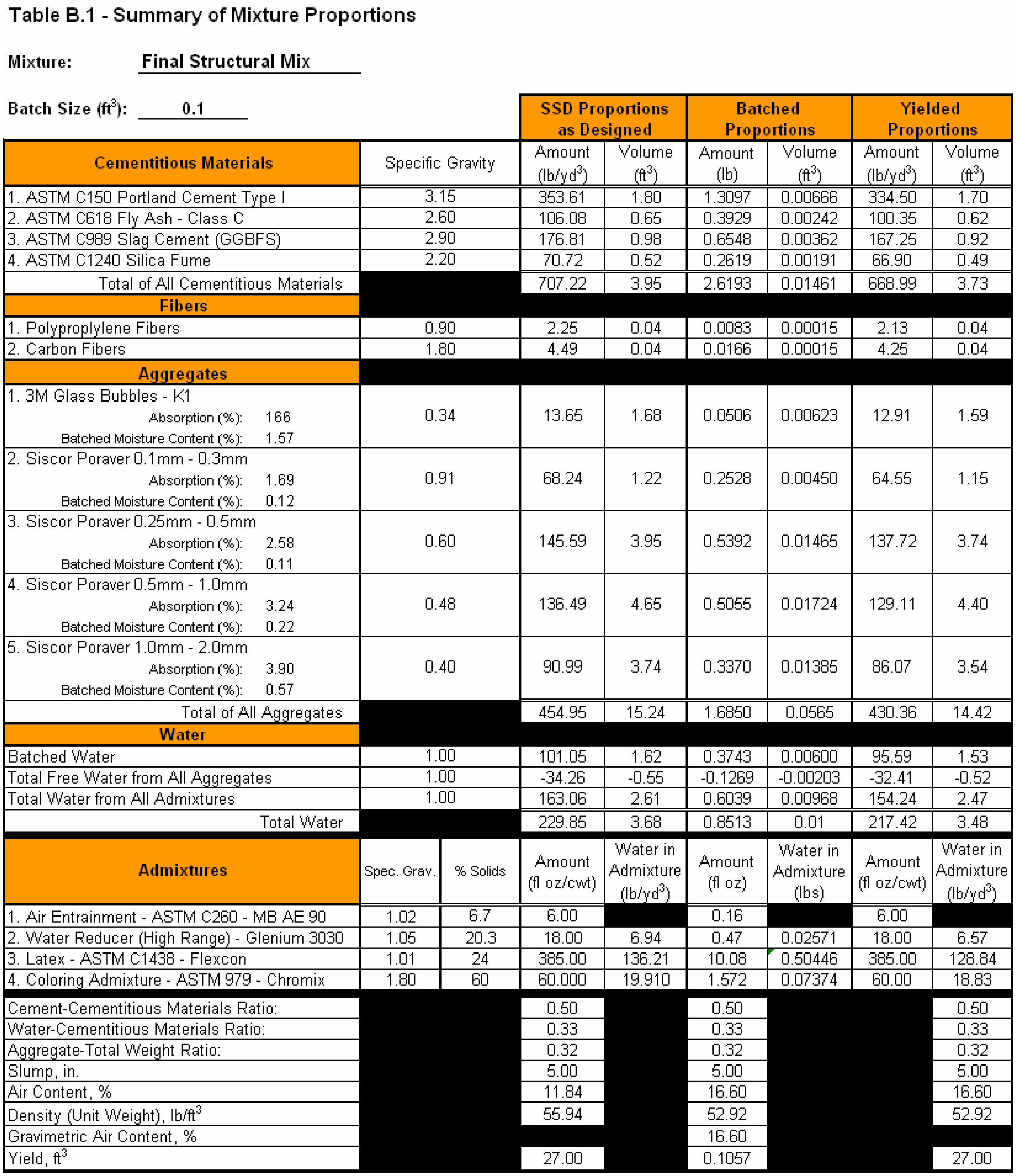


Table B.1 - Summary of Mixture Proportions

Mixture: Final Structural Mix

Batch Size (ft³): 0.1

		SSD Proportions as Designed		Batched Proportions		Yielded Proportions	
Cementitious Materials	Specific Gravity	Amount (lb/yd³)	Volume (ft³)	Amount (lb)	Volume (ft³)	Amount (lb/yd³)	Volume (ft³)
1. ASTM C150 Portland Cement Type I	3.15	353.61	1.80	1.3097	0.00666	334.50	1.70
2. ASTM C618 Fly Ash - Class C	2.60	106.08	0.65	0.3929	0.00242	100.35	0.62
3. ASTM C989 Slag Cement (GGBFS)	2.90	176.81	0.98	0.6548	0.00362	167.25	0.92
4. ASTM C1240 Silica Fume	2.20	70.72	0.52	0.2619	0.00191	66.90	0.49
Total of All Cementitious Materials		707.22	3.95	2.6193	0.01461	668.99	3.73
Fibers							
1. Polyproplylene Fibers	0.90	2.25	0.04	0.0083	0.00015	2.13	0.04
2. Carbon Fibers	1.80	4.49	0.04	0.0166	0.00015	4.25	0.04
Aggregates							
1. 3M Glass Bubbles - K1 Absorption (%): 166 Batched Moisture Content (%): 1.57	0.34	13.65	1.68	0.0506	0.00623	12.91	1.59
2. Siscor Poraver 0.1mm - 0.3mm Absorption (%): 1.69 Batched Moisture Content (%): 0.12	0.91	68.24	1.22	0.2528	0.00450	64.55	1.15
3. Siscor Poraver 0.25mm - 0.5mm Absorption (%): 2.58 Batched Moisture Content (%): 0.11	0.60	145.59	3.95	0.5392	0.01465	137.72	3.74
4. Siscor Poraver 0.5mm - 1.0mm Absorption (%): 3.24 Batched Moisture Content (%): 0.22	0.48	136.49	4.65	0.5055	0.01724	129.11	4.40
5. Siscor Poraver 1.0mm - 2.0mm Absorption (%): 3.90 Batched Moisture Content (%): 0.57	0.40	90.99	3.74	0.3370	0.01385	86.07	3.54
Total of All Aggregates		454.95	15.24	1.6850	0.0565	430.36	14.42
Water							
Batched Water	1.00	101.05	1.62	0.3743	0.00600	95.59	1.53
Total Free Water from All Aggregates	1.00	-34.26	-0.55	-0.1269	-0.00203	-32.41	-0.52
Total Water from All Admixtures	1.00	163.06	2.61	0.6039	0.00968	154.24	2.47
Total Water		229.85	3.68	0.8513	0.01	217.42	3.48

Admixtures	Spec. Grav.	% Solids	Amount (fl oz/cwt)	Water in Admixture (lb/yd³)	Amount (fl oz)	Water in Admixture (lbs)	Amount (fl oz/cwt)	Water in Admixture (lb/yd³)
1. Air Entrainment - ASTM C260 - MB AE 90	1.02	6.7	6.00		0.16		6.00	
2. Water Reducer (High Range) - Glenium 3030	1.05	20.3	18.00	6.94	0.47	0.02571	18.00	6.57
3. Latex - ASTM C1438 - Flexcon	1.01	24	385.00	136.21	10.08	0.50446	385.00	128.84
4. Coloring Admixture - ASTM 979 - Chromix	1.80	60	60.000	19.910	1.572	0.07374	60.00	18.83

Cement-Cementitious Materials Ratio:	0.50	0.50	0.50
Water-Cementitious Materials Ratio:	0.33	0.33	0.33
Aggregate-Total Weight Ratio:	0.32	0.32	0.32
Slump, in.	5.00	5.00	5.00
Air Content, %	11.84	16.60	16.60
Density (Unit Weight), lb/ft³	55.94	52.92	52.92
Gravimetric Air Content, %		16.60	
Yield, ft³	27.00	0.1057	27.00

Table B.1 - Summary of Mixture Proportions (cont.)

Mixture: Inlay Mix (grey, black, & orange)

Batch Size (ft^3): 0.1

		SSD 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)
1. ASTM C150 Portland Cement Type I	3.15	335.00	1.70	1.2407	0.00631	352.48	1.79
2. ASTM C618 Fly Ash - Class C	2.60	100.50	0.62	0.3722	0.00229	105.74	0.65
3. ASTM C989 Slag Cement (GGBFS)	2.90	167.50	0.93	0.6204	0.00343	176.24	0.97
4. ASTM C1240 Silica Fume	2.20	67.00	0.49	0.2481	0.00181	70.50	0.51
Total of All Cementitious Materials		670.00	3.74	2.4815	0.01384	704.95	3.93
Fibers							
1. Polyproplylene Fibers	0.90	2.25	0.04	0.0083	0.00015	2.37	0.04
2. Carbon Fibers	1.80	4.49	0.04	0.0166	0.00015	4.72	0.04
Aggregates							
1. 3M Glass Bubbles - K1 Absorption (%): 166 Batched Moisture Content (%): 1.57	0.34	17.24	2.13	0.0639	0.00787	18.14	2.24
2. Siscor Poraver 0.1mm - 0.3mm Absorption (%): 1.69 Batched Moisture Content (%): 0.12	0.91	56.03	1.00	0.2075	0.00370	58.95	1.05
3. Siscor Poraver 0.25mm - 0.5mm Absorption (%): 2.58 Batched Moisture Content (%): 0.11	0.60	150.85	4.10	0.5587	0.01518	158.72	4.31
4. Siscor Poraver 1.0mm - 2.0mm Absorption (%): 3.90 Batched Moisture Content (%): 0.57	0.40	206.89	8.50	0.7662	0.03149	217.68	8.94
Total of All Aggregates		431.01	15.72	1.5963	0.0582	453.50	16.54
Water							
Batched Water	1.00	99.97	1.60	0.3703	0.00593	105.19	1.69
Total Free Water from All Aggregates	1.00	-39.84	-0.64	-0.1476	-0.00236	-41.92	-0.67
Total Water from All Admixtures	1.00	157.62	2.53	0.5838	0.00936	165.84	2.66
Total Water		217.75	3.49	0.8065	0.01	229.11	3.67

Admixtures	Spec. Grav.	% Solids	Amount (fl oz/cwt)	Water in Admixture (lb/yd^3)	Amount (fl oz)	Water in Admixture (lbs)	Amount (fl oz/cwt)	Water in Admixture (lb/yd^3)
1. Air Entrainment - ASTM C260 - MB AE 90	1.02	6.7	6.00		0.15		6.00	
2. Water Reducer (High Range) - Glenium 3030	1.05	20.3	18.00	6.58	0.45	0.02436	18.00	6.92
3. Latex - ASTM C1438 - Flexcon	1.01	24	385.00	129.04	9.55	0.47791	385.00	135.77
4. Coloring - Chromix (grey, balck, & orange)	1.80	60	70.000	22.006	1.737	0.08151	70.00	23.15
Cement-Cementitious Materials Ratio:			0.50		0.50			0.50
Water-Cementitious Materials Ratio:			0.33		0.33			0.33
Aggregate-Total Weight Ratio:			0.33		0.33			0.33
Slump, in.			2.00		2.00			2.00
Air Content, %			11.65		7.04			7.04
Density (Unit Weight), lb/ft^3			53.46		56.25			56.25
Gravimetric Air Content, %					7.04			
Yield, ft^3			27.00		0.0950			27.00

Table B.1 - Summary of Mixture Proportions (cont.)

Mixture: Finishing Mixture

Batch Size (ft^3): 0.1

			SSD 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)
1. ASTM C150 Portland Cement Type I	3.15		383.00	1.95	1.4185	0.00722	330.04	1.68
2. ASTM C618 Fly Ash - Class C	2.60		114.90	0.71	0.4256	0.00262	99.01	0.61
3. ASTM C989 Slag Cement (GGBFS)	2.90		191.50	1.06	0.7093	0.00392	165.02	0.91
4. ASTM C1240 Silica Fume	2.20		76.60	0.56	0.2837	0.00207	66.01	0.48
Total of All Cementitious Materials			766.00	4.27	2.8370	0.01583	660.07	3.68
Fibers								
Aggregates								
1. 3M Glass Bubbles - K1 Absorption (%): 166 Batched Moisture Content (%): 1.57	0.34		11.38	1.40	0.0422	0.00520	9.81	1.21
2. Siscor Poraver 0.1mm - 0.3mm Absorption (%): 1.69 Batched Moisture Content (%): 0.12	0.91		56.91	1.01	0.2108	0.00375	49.04	0.87
3. Siscor Poraver 0.25mm - 0.5mm Absorption (%): 2.58 Batched Moisture Content (%): 0.11	0.60		121.41	3.30	0.4497	0.01221	104.62	2.84
4. Siscor Poraver 0.5mm - 1.0mm Absorption (%): 3.24 Batched Moisture Content (%): 0.22	0.48		113.82	3.88	0.4216	0.01437	98.08	3.34
5. Siscor Poraver 1.0mm - 2.0mm Absorption (%): 3.90 Batched Moisture Content (%): 0.57	0.40		75.88	3.12	0.2810	0.01155	65.39	2.69
Total of All Aggregates			379.40	12.71	1.4052	0.0471	326.93	10.96
Water								
Batched Water	1.00		219.64	3.52	0.8135	0.01304	189.27	3.03
Total Free Water from All Aggregates	1.00		-28.57	-0.46	-0.1058	-0.00170	-24.62	-0.39
Total Water from All Admixtures	1.00		176.61	2.83	0.6541	0.01048	152.19	2.44
Total Water			367.68	5.89	1.3618	0.02	316.83	5.08
Admixtures	Spec. Grav.	% Solids	Amount (fl oz/cwt)	Water in Admixture (lb/yd^3)	Amount (fl oz)	Water in Admixture (lbs)	Amount (fl oz/cwt)	Water in Admixture (lb/yd^3)
1. Air Entrainment - ASTM C260 - MB AE 90	1.02	6.7	6.00		0.17		6.00	
2. Water Reducer (High Range) - Glenium 3030	1.05	20.3	18.00	7.52	0.51	0.02785	18.00	6.48
3. Latex - ASTM C1438 - Flexcon	1.01	24	385.00	147.53	10.92	0.54639	385.00	127.12
4. Coloring Admixture - ASTM 979 - Chromix	1.80	60	60.000	21.565	1.702	0.07987	60.00	18.58
Cement-Cementitious Materials Ratio:			0.50		0.50			0.50
Water-Cementitious Materials Ratio:			0.48		0.48			0.48
Aggregate-Total Weight Ratio:			0.25		0.25			0.25
Slump, in. (for SCC concrete, see footnote)*			25.00		31.50			31.50
Air Content, %			11.85		24.04			24.04
Density (Unit Weight), lb/ft^3			60.21		51.88			51.88
Gravimetric Air Content, %					24.04			
Yield, ft^3			27.00		0.1160			27.00

*The slump flow given is the diameter of the spread using the testing method for self-consolidating concrete.

APPENDIX C – GRADATION CURVES AND TABLES

Table C.1 - Gradation Curves

Concrete Aggregate: K1 Glass Bubbles

Sample Weight: 70.9 g

Specific Gravity (G_s): 0.13

Fineness Modulus: 0.18

Sieve Size	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.5	0.0	0.0	100.00%
#4	4.75	0.0	0.0	100.00%
#8	2.38	0.0	0.0	100.00%
#16	1.18	0.0	0.0	100.00%
#30	0.6	0.0	0.0	100.00%
#50	0.3	0.0	0.0	100.00%
#100	0.15	13.0	13.0	81.66%
#200	0.074	57.9	70.9	0.00%
Pan	0.0	0.0	70.9	0.00%

Concrete Aggregate: Siscor 0.1mm - 0.3mm

Sample Weight: 291.8 g

Specific Gravity (G_s): 0.90

Fineness Modulus: 0.56

Sieve Size	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.5	0.0	0.0	100.00%
#4	4.75	0.0	0.0	100.00%
#8	2.38	0.0	0.0	100.00%
#16	1.18	0.0	0.0	100.00%
#30	0.6	0.0	0.0	100.00%
#50	0.3	1.1	1.1	99.63%
#100	0.15	165.2	166.3	44.55%
#200	0.074	125.5	291.8	2.70%
Pan	0.0	0.0	299.9	0.00%

Table C.1 - Gradation Curves (cont.)

Concrete Aggregate: Siscor 0.25mm - 0.5mm

Sample Weight: 448.4 g

Specific Gravity (G_s): 0.59

Fineness Modulus: 1.99

Sieve Size	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.5	0.0	0.0	100.00%
#4	4.75	0.0	0.0	100.00%
#8	2.38	0.0	0.0	100.00%
#16	1.18	0.0	0.0	100.00%
#30	0.6	0.1	0.1	99.98%
#50	0.3	443.1	443.2	1.16%
#100	0.15	4.6	447.8	0.13%
#200	0.074	0.6	448.4	0.00%
Pan	0.0	0.0	448.4	0.00%

Concrete Aggregate: Siscor 0.5mm - 1mm

Sample Weight: 372.0 g

Specific Gravity (G_s): 0.47

Fineness Modulus: 2.76

Sieve Size	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.5	0.0	0.0	100.00%
#4	4.75	0.0	0.0	100.00%
#8	2.38	0.0	0.0	100.00%
#16	1.18	0.1	0.1	99.97%
#30	0.6	307.7	307.8	17.26%
#50	0.3	49.9	357.7	3.84%
#100	0.15	4.7	362.4	2.58%
#200	0.074	9.6	372.0	0.00%
Pan	0.0	0.0	372.0	0.00%

Table C.1 - Gradation Curves (cont.)

Concrete Aggregate: Siscor 1mm - 2mm

Sample Weight: 434.5 g

Specific Gravity (G_s): 0.39

Fineness Modulus: 3.81

Sieve Size	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.5	0.0	0.0	100.00%
#4	4.75	0.0	0.0	100.00%
#8	2.38	0.2	0.2	99.95%
#16	1.18	359.1	359.3	17.31%
#30	0.6	71.7	431	0.81%
#50	0.3	1.9	432.9	0.37%
#100	0.15	0.6	433.5	0.23%
#200	0.074	0.4	433.9	0.14%
Pan	0.0	0.6	434.5	0.00%

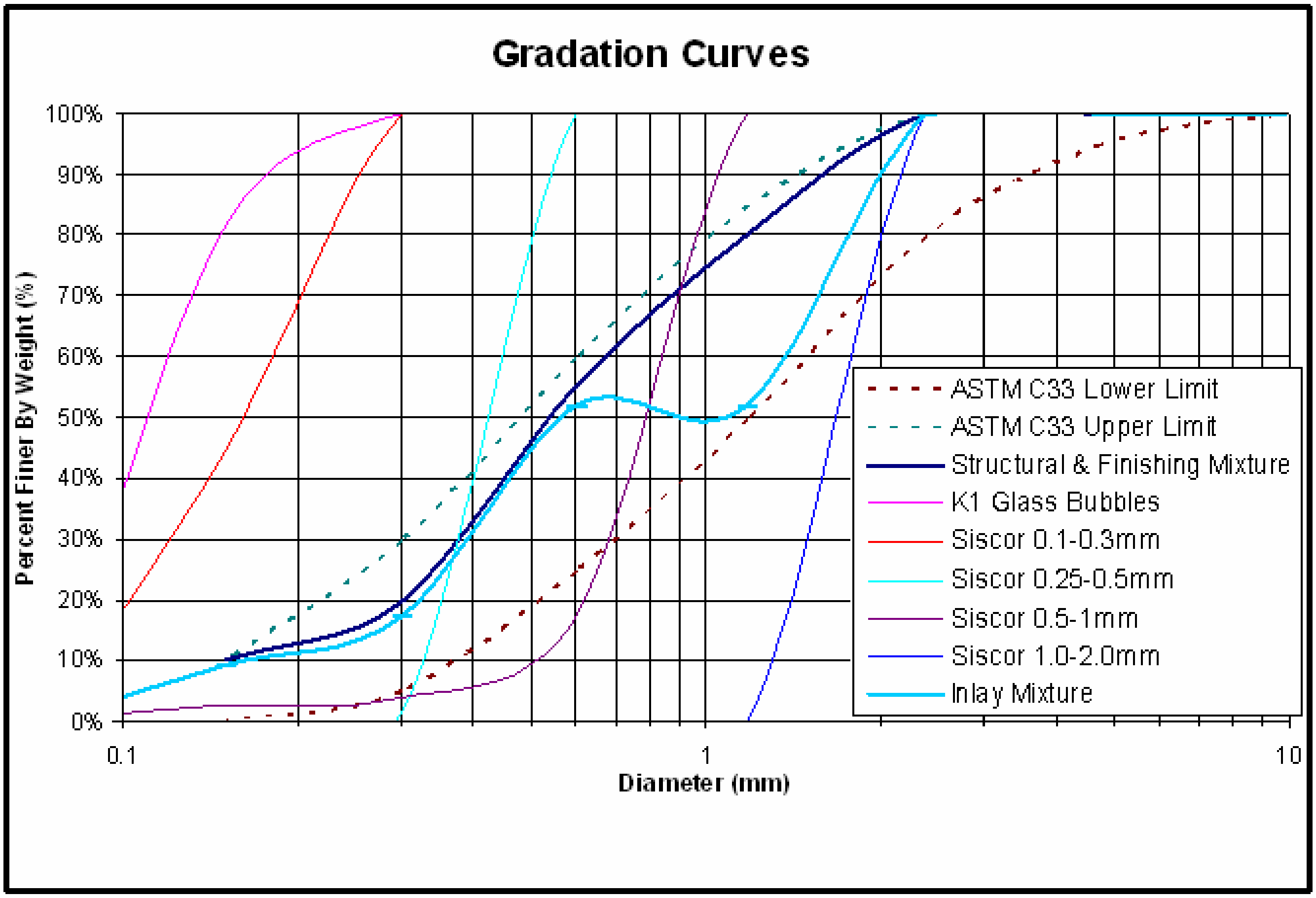
Composite Aggregate for Structural and Finshing Mixtures

Blending Ratio:		3.00%	15.00%	32.00%	30.00%	20.00%			ASTM C-33 Standards	
Sieve Size	**Diameter (mm)**	**Percent Finer (Glass Bubbles)**	**Percent Finer (Siscor .1-.3mm)**	**Percent Finer (Siscor .25-.5mm)**	**Percent Finer (Siscor .5-1mm)**	**Percent Finer (Siscor 1-2mm)**	**Composite Percent Finer %**	**Cum. % Retained**	**Cum. % Retained Upper Limit**	**Cum. % Retained Lower Limit**
3/8 inch	9.5	3.00%	15.00%	32.00%	30.00%	20.00%	100.00%	0.00%	0.00%	0.00%
#4	4.75	3.00%	15.00%	32.00%	30.00%	20.00%	100.00%	0.00%	0.00%	5.00%
#8	2.38	3.00%	15.00%	32.00%	30.00%	19.99%	99.99%	0.01%	0.00%	20.00%
#16	1.18	3.00%	15.00%	32.00%	29.99%	0.00%	79.99%	20.01%	15.00%	50.00%
#30	0.6	3.00%	15.00%	31.99%	5.18%	0.00%	55.17%	44.83%	40.00%	75.00%
#50	0.3	3.00%	14.94%	0.37%	1.15%	0.00%	19.47%	80.53%	70.00%	95.00%
#100	0.15	2.45%	6.68%	0.04%	0.77%	0.00%	9.95%	90.05%	90.00%	100.00%
#200	0.074	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
Pan	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	-	-

Composite Aggregate for Inlay Mixture

Blending Ratio:		4.00%	13.00%	35.00%	48.00%			ASTM C-33 Standards	
Sieve Size	**Diameter (mm)**	**Percent Finer (Glass Bubbles)**	**Percent Finer (Siscor .1-.3mm)**	**Percent Finer (Siscor .25-.5mm)**	**Percent Finer (Siscor 1-2mm)**	**Composite Percent Finer %**	**Cum. % Retained**	**Cum. % Retained Upper Limit**	**Cum. % Retained Lower Limit**
3/8 inch	9.5	4.00%	13.00%	35.00%	48.00%	100.00%	0.00%	0.00%	0.00%
#4	4.75	4.00%	13.00%	35.00%	48.00%	100.00%	0.00%	0.00%	5.00%
#8	2.38	4.00%	13.00%	35.00%	47.97%	99.97%	0.03%	0.00%	20.00%
#16	1.18	4.00%	13.00%	35.00%	0.00%	52.00%	48.00%	15.00%	50.00%
#30	0.6	4.00%	13.00%	34.99%	0.00%	51.99%	48.01%	40.00%	75.00%
#50	0.3	4.00%	12.95%	0.41%	0.00%	17.36%	82.64%	70.00%	95.00%
#100	0.15	3.27%	5.79%	0.05%	0.00%	9.10%	90.90%	90.00%	100.00%
#200	0.074	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
Pan	0	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	-	-

Figure C - Concrete Aggregate Gradation Curve



*Note: Please Note Blending Ratios for Composite Mix in above Composite Tables