Northern Arizona University
2015 Concrete Canoe Design Report

Dreadnoughtus

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Executive Summary

Northern Arizona is known for its many natural wonders. From the heights of the San Francisco Peaks, to the depths of the Grand Canyon, from the colorful splendor of the Petrified Forest, to the powerful, lonely spires of Monument Valley, the beauty of this region is apparent. Northern Arizona is also known for its rich history of fossils, including those of dinosaurs. *Dreadnoughtus schrani*, discovered in Patagonia, Argentina, and published in 2014, is the largest land dinosaur ever documented. It weighed in at over 65-tons and was about 85-feet long (Ewing 2014). *Dreadnoughtus* means "fear nothing" and it was with this motto in mind that the Northern Arizona University (NAU) 2015 Concrete Canoe Team approached the canoe project.

Table 1: *Canoe Specifications*

Canoe Name: *Dreadnoughtus*		
Dimensions		
Length	251.0-in	
Maximum Depth	13.0-in	
Maximum Beam/Width	27.0-in	
Avg. Wall Thickness	0.5-in	
Weight (est.)	180-lbs	
Reinforcement		
Fiberglass Mesh	Post-tensioning Cables	Fibers
Color		
Stain Color	Tan, Blue, Green	

NAU is located at 7,000-ft above sea-level in the picturesque mountain town of Flagstaff, at the base of the 12,000-ft San Francisco Peaks. Founded in 1899, NAU counts over 23,000 undergraduates and 351 Civil Engineering students among its student population spread over seven colleges.

NAU competes in the Pacific Southwest Conference (PSWC), which is considered by many to be the most competitive conference in the nation. It consists of 18 schools from Arizona, California, Nevada, and Hawaii. NAU's placement in the canoe competition at PSWC has included 10th place in 2012, a move up to 6th in 2013, and a 13th place ranking in 2014.

Table 2: *Concrete Properties*

Structural Mix	
Plastic Unit Weight	65.5-pcf
Dry Unit Weight	57.4-pcf
28 Day Compressive Strength	2,150-psi
28 Day Tensile Strength	225-psi
28 Day Flexural Strength	725-psi
Patch Mix	
Plastic Unit Weight	60.2-pcf
Dry Unit Weight	52.1-pcf
28 Day Compressive Strength	1000-psi

Sustainability was a major focus for this year's team. Reuse and environmental impact was considered during every design decision. The team investigated, found, and was approved for the use of a 100% fly ash based cement. EkkoMAXX™ cement by CeraTech not only has a significantly lower carbon impact (compared to traditional Portland mixes), it has reduced water demands, reduced shrinkage, and is more resistant to chemical attack. It was exciting to implement one of the greenest concrete products on the market and to experience and overcome the challenges of using an all-new material. Our concrete mix aggregates and reinforcement were leftover materials from past canoe teams that would have otherwise been disposed. We were able to use all of our plastic concrete cylinders multiple times during testing and we constructed our foam mold to be reusable.

This year, *Dreadnoughtus* was cast using a shotcrete/spray method for the first time in NAU's history to increase construction speed and to improve quality control. This method reduced pour day man-hours significantly compared to previous years. The team incorporated post-tensioning for only the second time in school history. The hull design used this year is longer and narrower than previous NAU canoes and presents a balance of speed, stability, and maneuverability (Table 1). A primary goal of our concrete design was to significantly reduce the unit weight, compared to last year's 98-pcf mix (*Spirit*). The results of this intensive concrete design process can be seen in Table 2. A wet concrete polishing system was also used for the first time to dramatically improve the final finish of *Dreadnoughtus.*

Many hours were committed to this challenging and rewarding project, and while NAU has only a small group of dedicated students and a small budget, we have created a beast. *Dreadnoughtus* is ready to compete with nothing to fear!

Project Management

The project manager set the objective to apply the "Fear Nothing" principle across the entire project and to improve on the past success of NAU teams. Future teams will benefit from the established project framework and the improved equipment and practices. This program focused on maximizing sustainability and improving construction, structural analysis, concrete mix design, reinforcement design, safety, and paddling performance.

Initial project planning began over the summer, and it was quickly determined that past canoe budgets of approximately $2-3,000 would not be able to support the desired improvements. An increased fundraising campaign was implemented. As a result, over $6,000 was directly raised. Combined with additional donations of materials, the team was equipped with the resources to enact the desired changes. The allocation of these resources is shown in Figure 1.

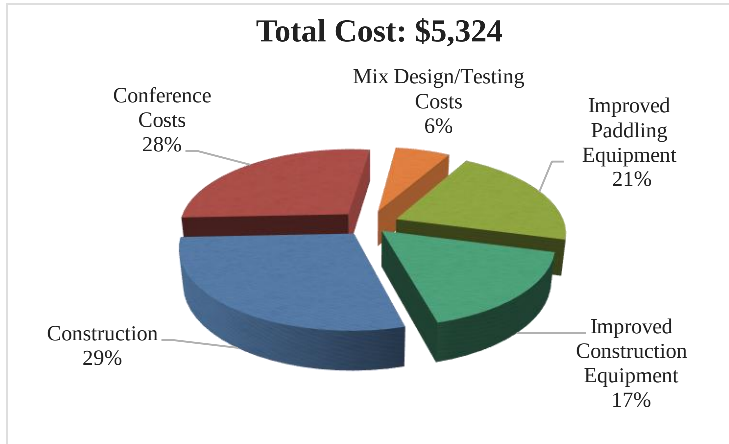


Figure 1: *Allocation of Resources*

The team consisted of five members and four mentees. The mentee program, in its second year, allows a group of students to shadow the project, help out, and potentially be leaders on the following year's canoe team. Three members of this year's team were previously mentees. Because of the team's small size, efficient management of time and resources were critical. A project schedule was created in early September and twice-weekly meetings ensured that critical tasks were on schedule and appropriately supported. Over 2 weeks of float were built into the schedule to account for unknown complications. Major milestones and principal critical path tasks are found in Table 3.

Table 3: *Critical Path Tasks*

Critical Path Activities	Variance	Reason
Hull Design	None	Proper Planning
Mix Design Finalized	+3 Weeks	Additional Testing
Mold Completion	None	Proper Planning
Canoe Casting	+3 weeks	Additional Testing

A total of 2437 man-hours (Figure 2) were needed to complete *Dreadnoughtus*. This is 562 hours more than *Spirit* and reflects time needed to implement significant changes.

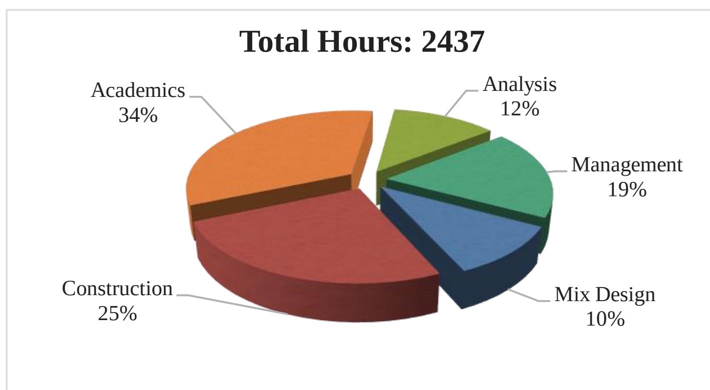


Figure 2: *Allocation of Hours*

Our quality control and safety officer ensured that each team member completed safety training courses, reviewed all necessary Material Safety Data Sheets (MSDS), and was equipped and properly using required personal protective equipment (PPE). As a result of this safety program, no reportable injuries occurred during this project. Quality Assurance/Quality Control (QA/QC) was achieved through constant checks of calculations by outside sources, tests of systems and materials to confirm results and practicality, and proper training in construction procedures. Maintaining a clean working environment and providing standard operating procedure training for all tools helped to keep the project on schedule and safe. Team members were assigned specific tasks to help regulate quality, and constant checks were performed to verify the desired objectives were being achieved. This allowed the team to be more efficient and produce a high quality canoe.

Organizational Chart

Project Manager

Jeremy DeGeyter

Directed project and delegated tasks. Responsible for budget planning, fundraising, mold construction, material procurement, and paddling program. Assisted other tasks as needed.

Structural Analysis Lead

Matt Snyder

Conducted structural analysis on hull using hand calculations and computer programs. Selected and analyzed hull design.

Reinforcement Design Lead

Cynthia Alvarez

Researched, tested and selected reinforcement. Designed post-tensioning system.

Concrete Design Lead

Kristin Van Sciver

Researched materials and developed mix designs. Tested concrete properties.

Quality Control and Safety Officer

Ramon Aguilar

Developed safety plan, provided and checked PPE usage compliance. Designed transportation unit.

Table 4: *Registered Participants*

Name	Class	Years Participating	Registered Participant, Yrs.
Jeremy DeGeyter	Senior	4	3
Kristin Van Sciver	Senior	3	3
Matt Snyder	Senior	1	1
Ramon Aguilar	Senior	2	1
Cynthia Alvarez	Senior	2	1
Jacob Hood	Senior	1	1
Chelsie Kekaula	Junior	1	1
Emily Melkesian	Junior	1	1

Table 5: Mentee Involvement

Name	Tasks
Chelsie Kekaula	T-shirt Logo
Emily Melkesian	Paddling
Evan Kaichi	Construction
Brent Lipar	Display
Jacob Hood	Paddling, Construction

Hull Design and Structural Analysis

In order to structurally "Fear Nothing," hull design decisions had to start from scratch. The team completed extensive research on hull handling characteristics and past top performing concrete canoes. Seminars with canoe experts were arranged, and seven different canoes were tested in the field. The team determined that a long canoe with a round-bottom and moderate rocker has tracking and speed for straight-a-ways, as well as the maneuverability required to slalom and make 180° turns. The hull envisioned was akin to the NAU 2011 Concrete Canoe, *Ponderosa*, which still remains with NAU today. During Concrete Canoe Competitions of 2009-2012, all participants were required to use a standardized hull shape which featured a relatively long canoe with flared sides, a round bottom, and moderate rocker. *Ponderosa* was 20-ft long and 31-in wide. Using *Ponderosa* as a benchmark, *Dreadnoughtus* was designed to be faster while sacrificing some stability by having a length of 21-ft and a maximum width of 27-in. The rocker increased slightly at 5-in at bow and 3-in at stern. Having the ability to practice races in *Ponderosa* during construction of *Dreadnoughtus* supported the team's final hull decision.

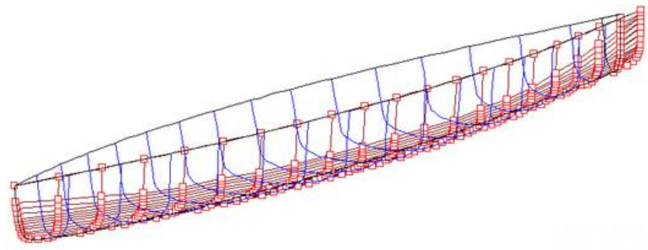


Figure 3: *Prolines Hull Model*

Using the hull design program Prolines, the team modeled *Dreadnoughtus* (Figure 3) and conducted hydraulic analyses to determine speed, drag, stability, and waterline (Table 6). Prolines revealed *Dreadnoughtus* as being the fastest NAU canoe in the past four years. *Dreadnoughtus* traded stability for speed by being relatively narrow and long but showed greater stability than the 2013 NAU concrete canoe *Night Fury*. Stability is measured by the righting arm of a ship, or the horizontal separation between the center of gravity and the center of buoyancy. A larger righting arm is more stable. Every member of the team paddled *Night Fury* and was assured that the stability of *Dreadnoughtus* would be sufficient. Waterline analysis revealed 13-in maximum height would be sufficient. Although the concrete mix design of *Dreadnoughtus* is light enough to stay afloat on its own, foam flotation was incorporated in bulkheads to meet swamp test requirements. During the swamp testing this year, participating canoes must hold 50-lbs in addition to being completely filled with water. The canoe plus bulkheads will provide 110-lbs of buoyancy which is greater than the 50-lb requirement.

Table 6: *Prolines NAU Comparison*

Parameter	Scenario	Dreadnoughtus (2015)	Night Fury (2013)	Ponderosa (2011)
Waterline (in)	2-Person	5.5	8.5	5.1
	4-Person	8.6	11.6	7.52
Optimal Speed (knots)	2-Person	5.4	4.8	5.0
	4-Person	5.6	5.0	5.5
Righting Arm (ft)	2-Person	0.34	0.22	0.47
	4-Person	0.14	0.05	0.25

The team completed preliminary 2-D stress analyses first so concrete design could begin. Two bending scenarios were accounted for: longitudinal bending between two paddlers and transverse folding where paddlers are located. *Dreadnoughtus* was designed to have reinforcements acting in both directions: ribs and reinforcement mesh for transverse strength and post-tensioning for longitudinal resistance. For bending stress calculations, a simplified rectangular cross-section was used to find centroid and moment of inertia. The longitudinal bending analysis was modeled as a simply-supported beam. The longitudinal moment envelope is shown in Figure 4.

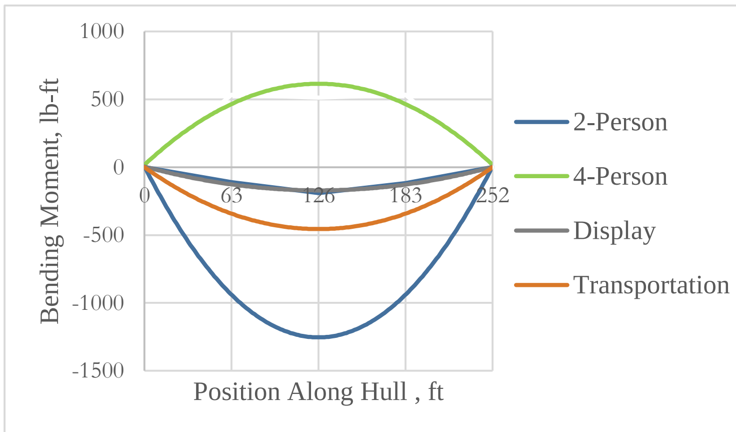


Figure 4: *Moment Envelope*

RISA 2-D was utilized to investigate different paddler orientations and loading scenarios (Figure 5). The transverse stress was estimated by considering a free-body diagram of a simplified rectangular section with triangular distributed loads pushing inwards on the sides to represent the waterline in the four-person scenario (Figure 6). A one inch section cut was taken to estimate the maximum transverse moment is 4-lbin/in. Applying principles from Reinforced Concrete classes and following the ACI 318-11 design code, singly and doubly-reinforced sections were analyzed. By adding one layer of reinforcement, the flexural capacity is 30-lbin/in. The factor of safety of 7.5 is conservative because the actual transverse moment experienced will be greater than the 4-lbin/in approximation.

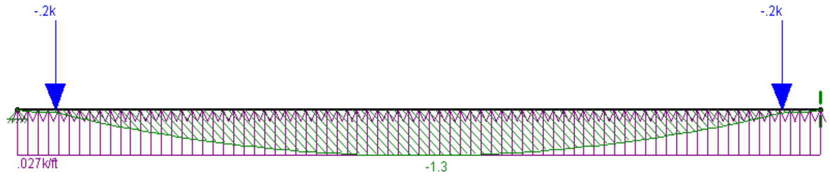


Figure 5: *RISA 2-D Simply-Supported Beam*

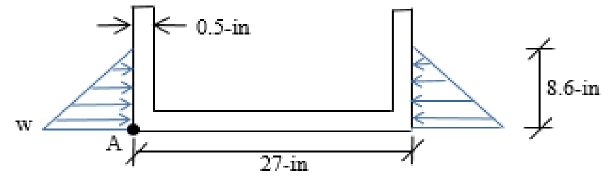


Figure 6: *Transverse Free-Body Diagram*

Ribs were not required for strength, but for aesthetic display and conservatism, life-like dinosaur bone ribs were incorporated. Ribs were sized using T-Beam construction methods by guessing rib sizes and calculating the effective overhanging flange width from the canoe geometry. By adding 3-in by 0.5-in ribs, the flexural factor of safety increased an additional 3.5 at paddler locations. *Dreadnoughtus* will experience an estimated maximum of 340-psi of compression and 120-psi of tension in the longitudinal direction and 74-psi of compression and 92-psi of tension in the transverse direction. Our concrete compressive strength of 2150-psi and tensile strength of 225-psi is sufficient for this loading. Detailed calculations are shown in Appendix D. The conservation safety factors are to account for cross-section approximations, unknowns such as the de-molding process, and collisions.

The “Fear Nothing” initiative took on the challenge of post-tensioning because it is an effective way to reinforce concrete and has been done only once in NAU concrete canoe history with mixed results. The post-tensioning system (PTS) was designed by following methods from the Post-Tensioning Institute’s (PTI) Post-Tensioning Manual.

The PTS (Figure 7) provides 690-lbs of axial compression to increase the flexural cracking load. The team decided six galvanized steel tendons would work best in the cross-section geometry. Each tendon was spaced symmetrically about the centroid to reduce eccentric loading. AutoCAD was used to locate the centroid of each cross-section. The tensile stress in *Dreadnoughtus* was limited to $3\sqrt{f'c}$ when fully loaded, a conservative value for post-tensioning. While a fully loaded 0-psi tensile stress was desired, the team restricted the stresses because the PTS would require more tension then the team felt comfortable putting into the canoe. As result, each strand was designed to have 115-lbs of tension versus 447-lbs in the ideal 0-psi system.

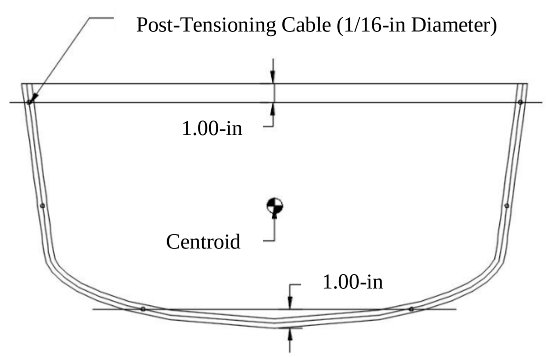


Figure 7: *Post-Tensioning System*

To achieve the desired 115-lbs per wire, each wire was over-tensioned to account for post-tension losses. The initial losses considered were friction, seating, and elastic shortening of the concrete. Time dependent losses considered were shrinkage of the concrete. 15-lbs of anchorage seating loss, 10-lbs of friction loss, and 13-lbs of elastic shortening was estimated using PTI equations and constants. After the tensioning system was experimentally verified, 35-lbs of additional seating loss (button-stopper slippage) occurred from limited swaging space. EkkoMAXX™ cement has very little shrinkage compared to Portland cement. *Dreadnoughtus* shrank 0.08 inches in length over 28-days, resulting in PTS loss of 2-lbs per cable versus 9-lbs per cable if using Portland cement. The first tendon was tensioned to 190-lbs and each subsequent tendon after was tensioned 2.5-lb less to account for elastic shortening losses.

Development and Testing

The focus for *Dreadnoughtus* was on sustainability. Two alternatives to Portland cement were researched: EkkoMAXX™ cement from CeraTech and Geopolymer concrete. Geopolymer concrete was removed from consideration since it is not commercially available yet and requires harsh chemicals. EkkoMAXX™ has similar strength and rheological characteristics to typical Portland cement. The lightweight aggregates considered for use in this year's mix were Poraver® P051, 3M K1 and S32 Glass Bubbles, White Pozzolans (VitroMinerals), and Cenospheres. To decrease waste, surplus materials: Poraver® P051 and 3M K1 Glass Bubbles from past NAU canoes were selected.

EkkoMAXX™ is a "carbon neutral cement technology" which "utilizes a non-portland, activated fly ash system" (CeraTech 2014). EkkoMAXX™ provides a "green" alternative to the traditional Portland cement since it is 100% fly ash based. EkkoMAXX™ is also commercially available and ready to work with as soon as it is received. The two proprietary liquid additives used in conjunction with EkkoMAXX™ have insignificant hazards based on the National Fire Protection Association (NFPA) hazard rating system. These additives help to chemically control the set time and strength development. EkkoMAXX™ has not been used in previous concrete canoes.

When utilizing the K1 Glass Bubbles, the resulting compressive strength was not as high as desired (250-psi to 1485-psi) when in the desired range of unit weights (50-pcf to 70-pcf). S32 bubbles were selected as an alternative since they had an increased isostatic crush strength of 2000-psi compared to 250-psi for the K1 bubbles (Table 7). This increased crush strength nearly doubled the compressive strength of the concrete mixes but only slightly increased the unit weight. Both Poraver® and S32 Glass Bubbles are smaller than 1-mm, creating a finish that allows for easy sanding and smoothing. Prior to the mixing, the aggregates were saturated-surface-dry. The only chemical admixture used in the concrete mix was the air entraining liquid (AEA) MasterAir AE 90. Another additive to the concrete mix was MasterFiber M 100 Individual Fibers. The 0.75-in long fibers, made of monofilament homopolymer polypropylene, increase crack resistance of the concrete.

Table 7: *Aggregate Properties*

Material	Poraver® 	S32 Glass Bubbles 
Size (mm)	0.50 to 1.00	0.105
Specific Gravity	0.44	0.32
Absorption (by Mass)	20%	1%
Isostatic Crush Strength (psi)	290	2000
Volume in Mix	36%	22%

A total of 25 mixtures were developed and tested in order to determine the optimum use of the selected materials for various ASTM industry standard tests. The developed mixes varied the proportions of AEA, Poraver®/S32, and EkkoMAXX™ one at a time while holding other constituents constant. The ideal amount of AEA for our mix was determined to be 3-oz/cwt. When comparing the aggregates only, the best ratio of light weight to compressive strength was a mix where Poraver® made up approximately two-thirds of the aggregate volume, and the S32 Glass Bubbles made up one-third of the aggregate volume. The amount of EkkoMAXX™ was adjusted until a sufficient compressive strength was reached according to ASTM C319 methods. During this adjustment process, a trend appeared (Figure 8) where unit weights that fell below 60-pcf had compressive strengths ranging from 300 to 1000-psi and those above 60-pcf ranged from 1500- to 2200-psi. This trend occurred when using both the K1 and the S32 glass bubbles. Based off this trend, our concrete required a density greater than 60-pcf to reach a minimum of 1200-psi.

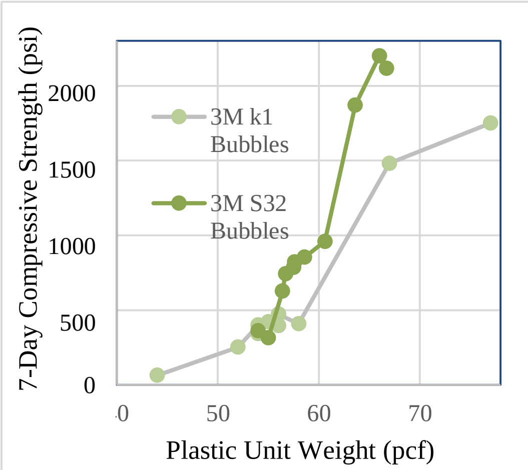
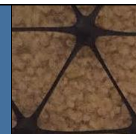
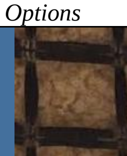
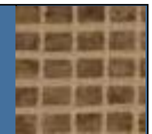


Figure 8: *EkkoMAXX™ Trend*

A spray test for each mix developed was performed by modeling the side of our mold with leftover materials (Figure 9). A desired slump of 6 to 8-in was identified through these tests (ASTM C1611). Shrinkage was tested (Figure 10), with a 1-in x 1-in x 10-in bar mold (ASTM C157). The shrinkage for the final mix was found to be 0.03%, which was less than the 0.05% observed in the same mix using Portland cement. The final mix selected (Appendix B) provides a 28-day compressive strength of 2150-psi and a 65.5-pcf plastic unit weight, as determined according to ASTM C138. A decrease to 57.4-pcf was demonstrated with oven-dried cylinders. The final mix had an air content of 2.8% (ASTM C138) and tensile strength of 225-psi (ASTM C496).

To further the sustainability initiative, reinforcement was selected from left-over NAU materials while considering one material from an outside source, TriAx Geogrid (TX140). The team tested four materials, shown in Table 9, for tensile strength and elongation using an Instron 3885 H screw driven machine. Glasgrid Pavement Reinforcement System was the strongest and elongated the least but had poor workability because of its size and high percent open area (POA). Parex Glass Fiber Reinforcing Mesh was chosen because of its relatively high strength and satisfactory bonding behavior. The POA of Parex Glass Fiber Reinforcing Mesh was calculated to be 61%.

Table 8: *Reinforcement Options*

Material	 TriAx Geogrid (TX140)	 Parex Glass Fiber Reinforcing Mesh	 Glasgrid Pavement Reinforcement System	 Dryvit Reinforcing Mesh
Strength (lb-ft/in)	72	135	181	102
Elongation (in)	0.62	0.08	0.04	0.07

The flexural strength of the composite concrete and reinforcement was tested with a third point loading test similar to ASTM C78/C78M (Figure 11). This test was conducted by applying a gradual load until failure for the four samples. The modulus of rupture of the composite material was found to be 725-psi. Development lengths of the reinforcement were tested to determine the required overlap length at splices. Three different samples were created with varying development lengths of two, four, and six inches. It was determined that the three different development lengths were sufficient to meet application needs because they all failed in the reinforcement rather than pulling out. Although a two inch overlap was successful, a four inch overlap was chosen due to uncertainties in overlap length where actual failure might occur.

Two post-tensioning systems were selected for testing. Using a turnbuckle and pull-force gauge, a single ball-shank system and button-stop system were tested by putting a tendon in tension, swaging both ends, and observing the losses that occurred after releasing the turnbuckle. Initial tests showed that the single ball-shanks were difficult to swage and would break if swaged too much. Additional testing showed that using two button-stops would eliminate approximately 50% of the slippage losses experienced using only one button-stop. The button-stop system was selected and two button-stops were used at the live end to minimize slippage losses due to the difficulty of swaging in a tight area (Figure 12). The dead end received one button-stop because proper swaging could occur.

Figure 9: *Spray Testing*

Figure 10: *Shrinkage Testing*

Figure 11: *Third Point Loading Test*

Figure 12: *Button-Stop System*

Construction

The *Dreadnoughtus* hull shape is most closely related to *Ponderosa* (2011), which was constructed in a wood strip female mold. The most recent canoe to incorporate post-tensioning was *Night Fury* (2013) which experienced constructability difficulties installing and tensioning the system within their wooden female mold. *Dreadnoughtus* decided to use a male foam mold (Figure 13) to ease post-tensioning implementation and to save time on mold construction compared to the labor intensive process to create a wood strip mold.

Figure 13: *Foam Male Mold*

The canoe is post-tensioned with six steel wires threaded through nylon tubing. A post-tensioning “net” (Figure 14) was created by wrapping the nylon encased steel tendons with thin wire at regular intervals creating a net that could be draped over the canoe mold placing the tendons at the correct spacing. This year 3-D elements were incorporated into the canoe. Two dinosaur fossil models were built into the bulkheads and dinosaur rib bones were cast for the four structural ribs (Figure 15). These elements were created using silicone molds that had been cast from the desired shapes. This is the first time NAU has incorporated such features.

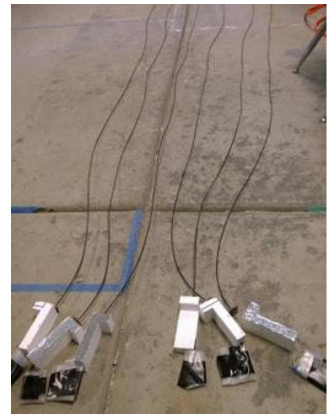


Figure 14: *Post-Tensioning Net*

On pour day, concrete mixing was done constantly to prevent any cold joints from occurring between layers. Concrete mixes were pre-batched to reduce the chance of batching errors on pour day. QA/QC tests were performed on each batch to ensure slump and other critical properties were correct. Form release oil was brushed onto the mold to prevent the concrete from bonding with the mold and to help the de-molding process. A shotcrete/spray method was used for the first time in NAU history (Figure 16) to increase concrete placement speed, while also ensuring that a consistent thickness of concrete was applied. Previous teams had experienced quality control issues with large groups of people applying concrete in varying thicknesses and this year’s team sought to avoid this problem. This method also limited the number of person-hours needed on pour day and ultimately saved time and improved the quality of the final product. While *Spirit* took over 12-hrs to construct on pour day with a team of around 20-people, *Dreadnoughtus* was cast in less than 10-hrs with around 10-people. Two pour day walkthroughs were conducted in the week leading up to pour day to ensure that everyone was familiar with the construction process and techniques in advance.

Figure 15: *3-D Elements*

The previous four NAU concrete canoe teams have used female wood strip molds. This year a male foam mold was used primarily to make post-tensioning installation easier. The foam mold was created in house by printing canoe cross sections, transferring these dimensions to plywood and cutting out the shapes needed for our canoe. Using a hot wire cutter, foam was cut between two wooden cross sections and glued together to create the male mold. Steel stands were built that allowed the canoe mold to be rotated to multiple angles and a wooden strong back or platform was constructed to support the canoe mold. The mold was secured to the strong back so the canoe could not shift during pour day. The foam mold was assembled in four sections to facilitate removal after the canoe was cast (Figure 17), and these sections were covered with shrink-wrap to provide a smooth interior surface. This covering allowed the mold to be removed after pour day without having to destroy it and makes the mold reusable for future canoe

Figure 16: *Shotcrete Spray Method*

teams. Gunwale edges were formed using ½ in PVC piping cut to create a semi-circular cap. Wood and metal forms were constructed to shape the bow and stern ends.

Figure 17: *Mold Sections*

Bulkheads were wrapped with the Parex Reinforcement prior to pour day and were among the first items installed. 12-in strips of Parex were installed at each structural rib location and all reinforcement was pre-cut to speed installation on pour day. Canoe layer details can be seen in Figure 18. Seven days after the construction was completed, *Dreadnoughtus* was post-tensioned. The six tendons were tensioned in a star pattern, similar to tightening a car tire, to minimize unbalanced bending stresses. The first cable was tensioned to 190 lbs, the second to 187 lbs, and so on to account for elastic shortening of the canoe while the load was applied. After losses and shortening, an estimated 115-lbs of tension remained in each cable. Jacking force was measured directly with an inline force scale (Figure 19).

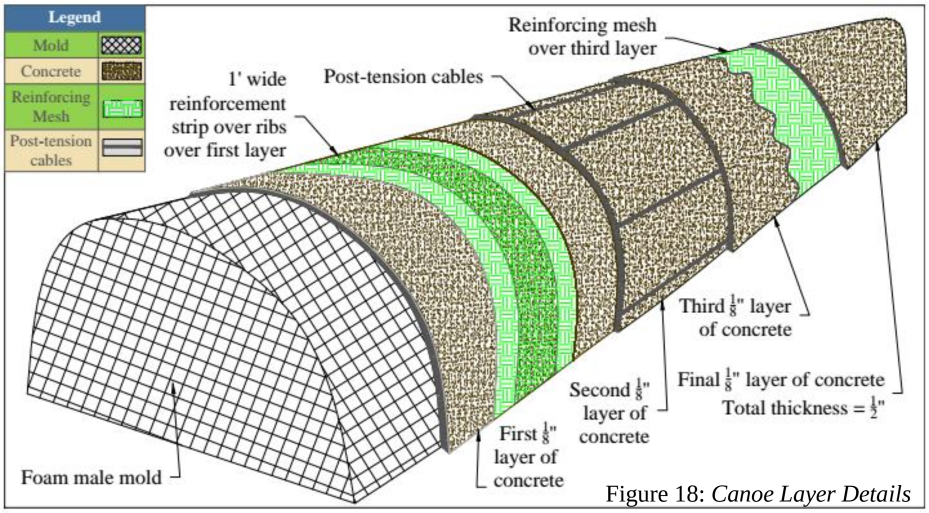


Figure 18: *Canoe Layer Details*

Immediately following final finishing on pour day, an evaporation retarding membrane was applied and a curing enclosure was built around the canoe (Figure 20). Two humidifiers were placed inside the plastic enclosure and filled twice daily to maintain a humidity of 99% for 14 days. The day after casting, the mold was released from the strong back and a foam key was removed from the center of the mold allowing the canoe to shrink unrestrained. Previous teams have experienced problems with cracking as the canoe was restrained from shrinking during curing. The 14-day moist cure was followed with a gradual transition to air curing, where humidity levels were slowly reduced and finally removed altogether.

Once initial curing was complete and the mold removed, finishing commenced. Using sanders and diamond polishing equipment, the canoe surface was smoothed and prepared for staining. Solid color and semi-transparent acrylic concrete stains were used to decorate the canoe. Two layers of a cure-sealing compound were used to provide the glossy finish and to reduce water absorption.

Throughout the construction of the canoe, safety was a primary goal. A safety briefing with all participating members was conducted at the start of pour day. During this briefing proper PPE usage, such as safety glasses, masks and gloves was emphasized. The safe and proper use of all equipment was demonstrated. Everyone had to be aware of their surroundings to prevent any injury. Because of this attention to safety, this project was completed with no injuries.

Figure 19: *Post-Tensioning with Inline Force Gauge*

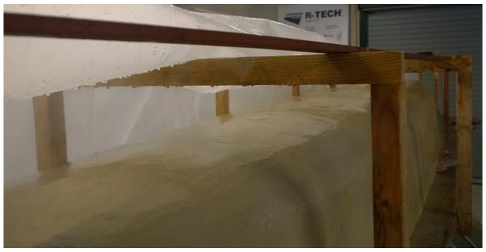
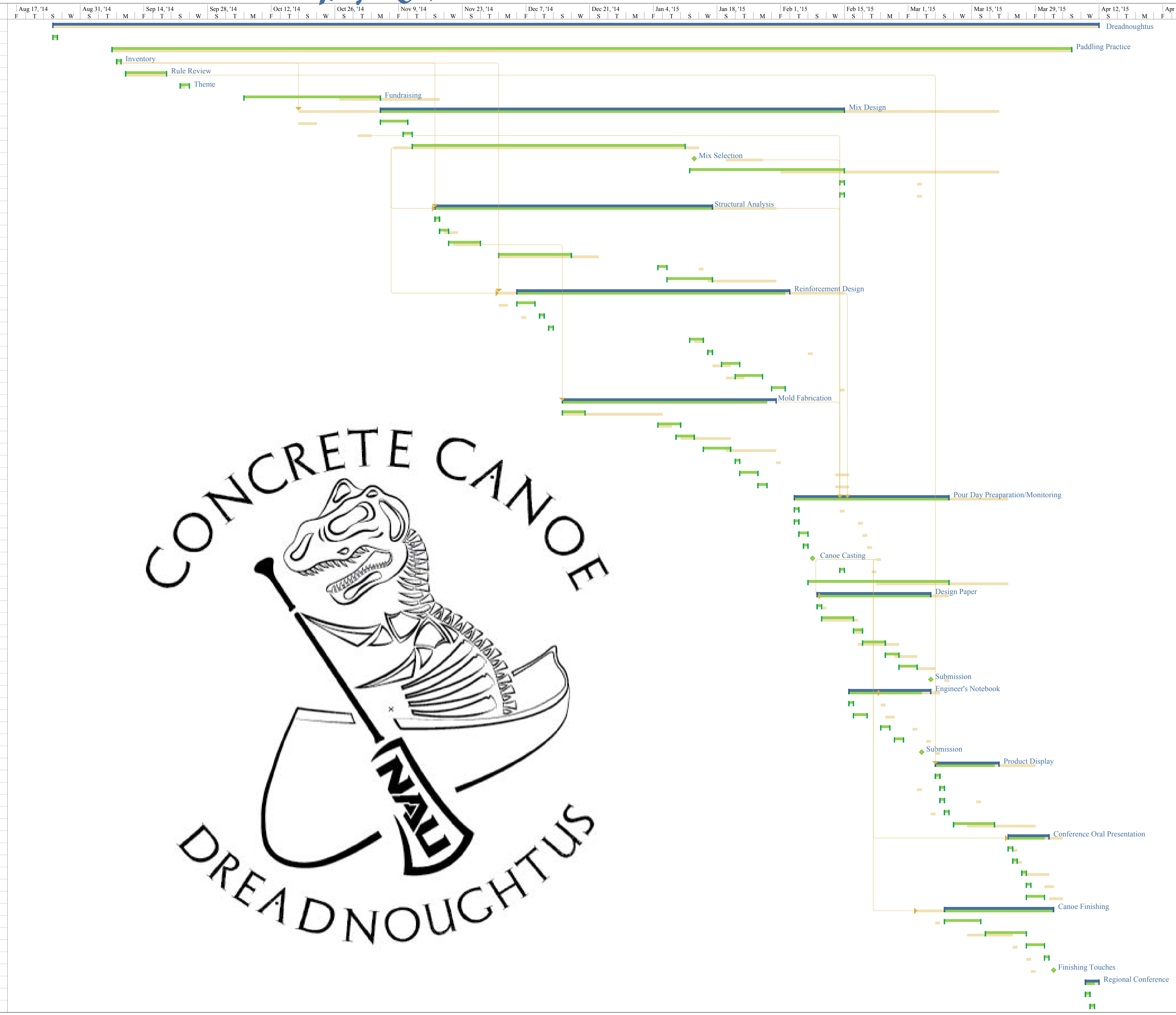


Figure 20: *Curing Enclosure*

Project Schedule

ID	Task Name	Duration	Start	Finish	Predecessors	Baseline Start	Baseline Finish
0	**Dreadnoughtus**	**165 days**	**Mon 8/25/14**	**Sat 4/11/15**		**Mon 8/25/14**	**Sat 4/11/15**
1	**1 Project Initiation**	**1 day**	**Mon 8/25/14**	**Mon 8/25/14**		**Mon 8/25/14**	**Mon 8/25/14**
2	**2 Paddling Practice**	**152 days**	**Sun 9/7/14**	**Sun 4/5/15**		**Sun 9/7/14**	**Sun 4/5/15**
3	**3 Inventory**	**1 day**	**Mon 9/8/14**	**Mon 9/8/14 Wed**		**Mon 9/8/14**	**Mon 9/8/14**
4	**4 Rule Review**	**7 days**	**9/10/14 Thu**	**9/18/14 Mon**		**Wed 9/10/14**	**Thu 9/18/14**
5	**5 Theme**	**2 days**	**9/22/14 Tue 9/23/14**			**Mon 9/22/14**	**Mon 9/22/14**
6	**6 Fundraising**	**22 days**	**Mon 10/6/14**	**Tue 11/4/14**		**Mon 10/27/14**	**Mon 11/17/14**
7	**7 Mix Design**	**74 days**	**Wed 11/5/14**	**Sat 2/14/15**	**3**	**Sat 10/18/14**	**Fri 3/20/15**
8	7.1 Research and Determine Final Materials	4 days	Wed 11/5/14	Mon 11/10/14		Sat 10/18/14	Tue 10/21/14
9	7.2 Acquire Materials	2 days	Mon 11/10/14	Tue 11/11/14		Fri 10/31/14	Sun 11/2/14
10	7.3 Cylinder Testing	44 days	Wed 11/12/14	Sat 1/10/15		Sat 11/8/14	Tue 1/13/15
11	7.4 Mix Selection	1 day	Mon 1/12/15	Mon 1/12/15		Tue 1/20/15	Tue 1/27/15
12	7.5 Shrinkage Test	26 days	Mon 1/12/15	Sat 2/14/15		Sun 2/1/15	Fri 3/20/15
13	7.6 Flexural Testing	1 day	Sat 2/14/15	Sat 2/14/15		Tue 3/3/15	Tue 3/3/15
14	7.7 Tensile Testing	1 day	Sat 2/14/15	Sat 2/14/15		Tue 3/3/15	Tue 3/3/15
15	**8 Structural Analysis**	**45 days**	**Mon 11/17/14**	**Fri 1/16/15**	**3,10SS**	**Mon 11/17/14**	**Fri 1/30/15**
16	8.1 Identify Design Standards	1 day 2	Mon 11/17/14	Mon 11/17/14		Mon 11/17/14	Mon 11/17/14
17	8.2 Determine Minimum f'c required	days	Tue 11/18/14	Wed 11/19/14		Wed 11/19/14	Fri 11/21/14
18	8.3 Determine optimal hull dimensions	5 days	Thu 11/20/14	Wed 11/26/14		Fri 11/21/14	Wed 11/26/14
19	8.4 2D/3D Analysis	12 days	Mon 12/1/14 Tue 12/16/14			Mon 12/1/14	Mon 12/22/14
20	8.5 Rib Design	2 days	Mon 1/5/15	Tue 1/6/15		Wed 1/14/15	Wed 1/14/15
21	8.6 Post Tensioning Design	8 days	Wed 1/7/15	Fri 1/16/15		Fri 1/16/15	Fri 1/30/15
22	**9 Reinforcement Design**	**42 days**	**Fri 12/5/14**	**Mon 2/2/15**	**3,10SS**	**Mon 12/1/14**	**Sat**
23	9.1 Research Materials	2 days	Fri 12/5/14	Mon 12/8/14	**2/14/15**	Mon 12/1/14	Tue 12/2/14
24	9.2 Determine Percent Open Area 9.3	1 day	Wed 12/10/14	Wed 12/10/14		Sat 12/6/14	Sat 12/6/14
25	Tensile Testing	1 day	Fri 12/12/14	Fri 12/12/14		Sat 12/19/15	Fri 12/19/14
26	9.4 Determine Layers and Placement	3 days	Mon 1/12/15	Wed 1/14/15		Tue 1/13/15	Wed 1/14/15
27	9.5 Development Length Testing	1 day	Fri 1/16/15	Fri 1/16/15		Sat 2/7/15	Sat 2/7/15
28	9.6 Research Post Tensioning Methods	4 days	Mon 1/19/15	Thu 1/22/15		Sat 1/17/15	Tue 1/20/15
29	9.7 Aquire Materials	4 days	Thu 1/22/15	Tue 1/27/15		Tue 1/20/15	Fri 1/23/15
30	9.8 Test Post Tensioning Anchorage System	2 days	Fri 1/30/15	Sun 2/1/15		Sat 2/14/15	Sat 2/14/15
31	**10 Mold Fabrication**	**35 days**	**Mon 12/15/14**	**Fri 1/30/15**	**18**	**Mon 12/15/14**	**Sat 1/24/15**
32	10.1 Construct Stands	5 days	Mon 12/15/14	Fri 12/19/14		Mon 12/15/14	Mon 1/5/15
33	10.2 Construct Strongback 10.3	5 days	Mon 1/5/15	Fri 1/9/15		Mon 1/5/15	Wed 1/7/15
34	Cut Wooden Cross Sections 10.4	2 days	Fri 1/9/15	Mon 1/12/15		Sat 1/10/15	Tue 1/20/15
35	Cut Foam Cross Sections 10.5	4 days	Thu 1/15/15	Tue 1/20/15		Tue 1/20/15	Fri 1/30/15
36	Shrink Wrap Mold	1 day	Thu 1/22/15	Thu 1/22/15		Sat 1/31/15	Sat 1/31/15
37	10.6 Construct Ribs	2 days	Fri 1/23/15	Mon 1/26/15		Fri 2/13/15	Sun 2/15/15
38	10.7 Construct 3D Elements	2 days	Tue 1/27/15	Wed 1/28/15		Fri 2/13/15	Sun 2/15/15
39	**11 Pour Day Preparation/Monitoring**	**24 days**	**Wed 2/4/15**	**Mon 3/9/15**	**9,15,22,31,11**	**Sat 2/14/15**	**Sun 3/22/15**
40	11.1 Appoint Personnell	1 day	Wed 2/4/15	Wed 2/4/15		Sat 2/14/15	Sat 2/14/15
41	11.2 Acquire Materials	1 day	Wed 2/4/15	Wed 2/4/15		Wed 2/18/15	Wed 2/18/15
42	11.3 Practice Shotcrete Method	2 days	Thu 2/5/15	Fri 2/6/15		Thu 2/19/15	Thu 2/19/15
43	11.4 Final Mix Preparation 11.5	1 day	Fri 2/6/15	Fri 2/6/15		Fri 2/20/15	Fri 2/20/15
44	Canoe Casting	1 day	Sat 2/7/15	Sat 2/7/15		Sun 2/22/15	Sun 2/22/15
45	11.6 Post-Tensioning Anchorage	1 day	Sat 2/14/15	Sat 2/14/15		Sat 2/21/15	Sat 2/21/15
46	11.7 Curing & Daily Monitoring	22 days	Sat 2/7/15	Mon 3/9/15		Sun 2/22/15	Sun 3/22/15
47	**12 Design Paper**	**19 days**	**Mon 2/9/15**	**Thu 3/5/15**	**44SS**	**Tue 2/10/15**	**Mon 3/9/15**
48	12.1 Rules	1 day	Mon 2/9/15	Mon 2/9/15		Tue 2/10/15	Tue 2/10/15
49	12.2 First Draft 12.3	5 days	Tue 2/10/15	Mon 2/16/15		Tue 2/10/15	Tue 2/17/15
50	Peer Review 12.4	2 days	Tue 2/17/15	Wed 2/18/15		Tue 2/17/15	Wed 2/18/15
51	Second Draft 12.5	3 days	Thu 2/19/15	Mon 2/23/15		Wed 2/18/15	Thu 2/26/15
52	Faculty Review 12.6	3 days	Tue 2/24/15	Thu 2/26/15		Thu 2/26/15	Mon 3/2/15
53	Final Draft 12.7	2 days	Fri 2/27/15	Mon 3/2/15		Tue 3/3/15	Fri 3/6/15
54	Submission	1 day	Thu 3/5/15	Thu 3/5/15		Mon 3/9/15	Mon 3/9/15
55	**13 Engineer's Notebook**	**14 days**	**Mon 2/16/15**	**Thu 3/5/15**	**44SS**	**Mon 2/23/15**	**Sat 3/7/15**
56	13.1 Rules 13.2	1 day	Mon 2/16/15	Mon 2/16/15		Mon 2/23/15	Mon 2/23/15
57	First Draft	3 days	Tue 2/17/15	Thu 2/19/15		Tue 2/24/15	Wed 2/25/15
58	13.3 Second Draft	2	Mon 2/23/15	Tue 2/24/15		Mon 3/2/15	Mon 3/2/15
59	13.4 Final Draft	days	Thu 2/26/15	Fri 2/27/15		Thu 3/5/15	Thu 3/5/15
60	13.5 Submission **14**		Tue 3/3/15	Tue 3/3/15		Sat 3/7/15	Sat 3/7/15
61	**Product Display**	**11 days**	**Sat 3/7/15**	**Fri 3/20/15**	**4**	**Sat 3/7/15**	**Sat 3/28/15**
62	14.1 Cutaway Section 14.2	1 day	Sat 3/7/15	Sat 3/7/15		Sat 3/7/15	Sat 3/7/15
63	Tested/Split Cylinders 14.3	1 day	Sun 3/8/15	Sun 3/8/15		Tue 3/3/15	Tue 3/3/15
64	Material Samples 14.4	1 day	Sun 3/8/15	Sun 3/8/15		Mon 3/16/15	Mon 3/16/15
65	Engineer's Notebook 14.5	1 day	Mon 3/9/15	Mon 3/9/15		Fri 3/6/15	Fri 3/6/15
66	Canoe Stands	7 days	Wed 3/11/15	Thu 3/19/15 **Mon**		Sat 3/14/15	Sat 3/28/15
67	**15 Conference Oral Presentation**	**7 days**	**3/23/15**	**Tue 3/31/15**	**44SS** Mon	**Mon 3/23/15**	**Fri 4/3/15**
68	15.1 Rules	1 day	3/23/15	Mon 3/23/15		Tue 3/24/15	Tue 3/24/15
69	15.2 First Draft	1 day	Tue 3/24/15	Tue 3/24/15		Tue 3/24/15	Wed 3/25/15
70	15.3 Second Draft	1 day	Thu 3/26/15	Thu 3/26/15		Thu 3/26/15	Tue 3/31/15
71	15.4 Final	1 day	Fri 3/27/15	Fri 3/27/15		Tue 3/31/15	Wed 4/1/15
72	15.5 Practice	2 days	Fri 3/27/15	Mon 3/30/15		Wed 4/1/15	Fri 4/3/15
73	**16 Canoe Finishing**	**18 days**	**Mon 3/9/15**	**Wed 4/1/15**	**44SS**	**Tue 3/3/15**	**Sat 3/28/15**
74	16.1 Sanding	6 days	Mon 3/9/15	Mon 3/16/15		Sat 3/7/15	Sat 3/7/15
75	16.2 Staining	7 days	Wed 3/18/15	Thu 3/26/15		Sat 3/14/15	Mon 3/23/15
76	16.3 Lettering	2 days	Fri 3/27/15	Mon 3/30/15		Tue 3/24/15	Tue 3/24/15
77	16.4 Sealing	1 day 1	Tue 3/31/15	Tue 3/31/15		Fri 3/27/15	Fri 3/27/15
78	16.5 Finishing Touches	day **3**	Wed 4/1/15	Wed 4/1/15		Sat 3/28/15	Sat 3/28/15
79	**17 Regional Conference**	**days** 1	**Thu 4/9/15**	**Sat 4/11/15**		**Thu 4/9/15**	**Sat 4/11/15**
80	17.1 Display Day and Oral Presentation	day 1	Thu 4/9/15	Thu 4/9/15		Thu 4/9/15	Thu 4/9/15
81	17.2 Canoe Races	day	Fri 4/10/15	Fri 4/10/15		Fri 4/10/15	Fri 4/10/15



Northern Arizona University

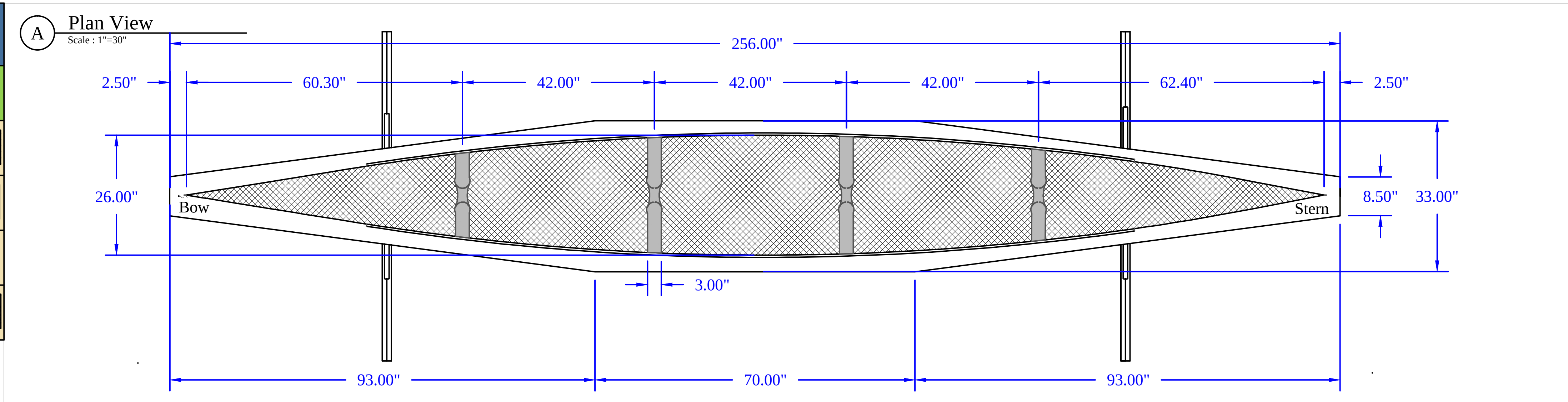
Planned — Milestone — Critical Path

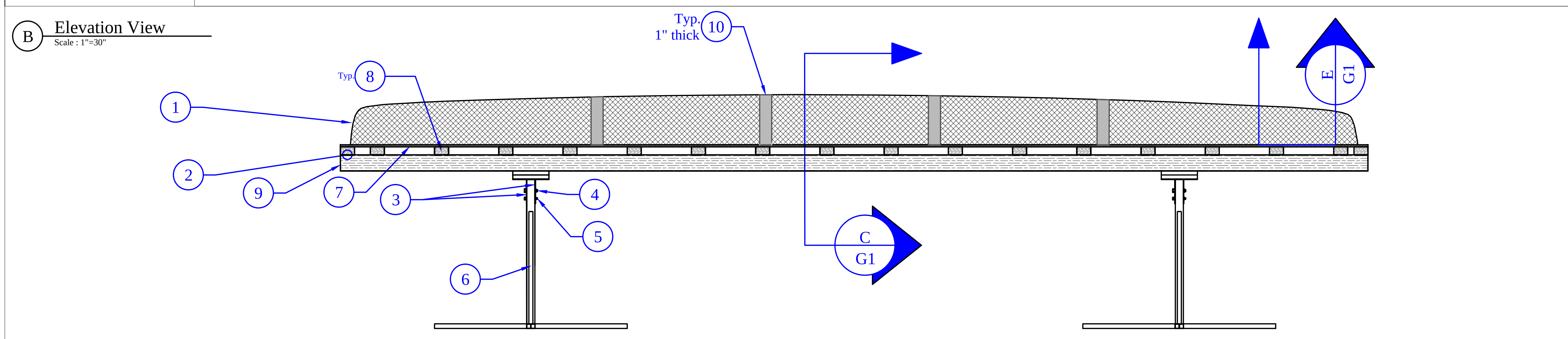
Actual — Summary Task

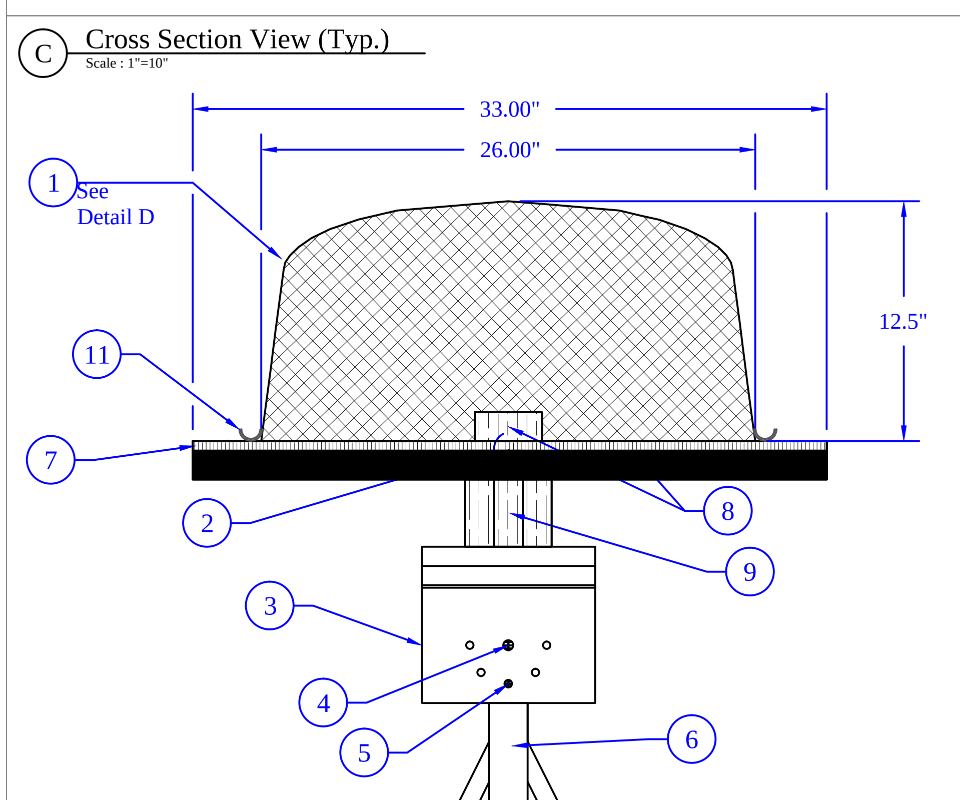
Design Drawing

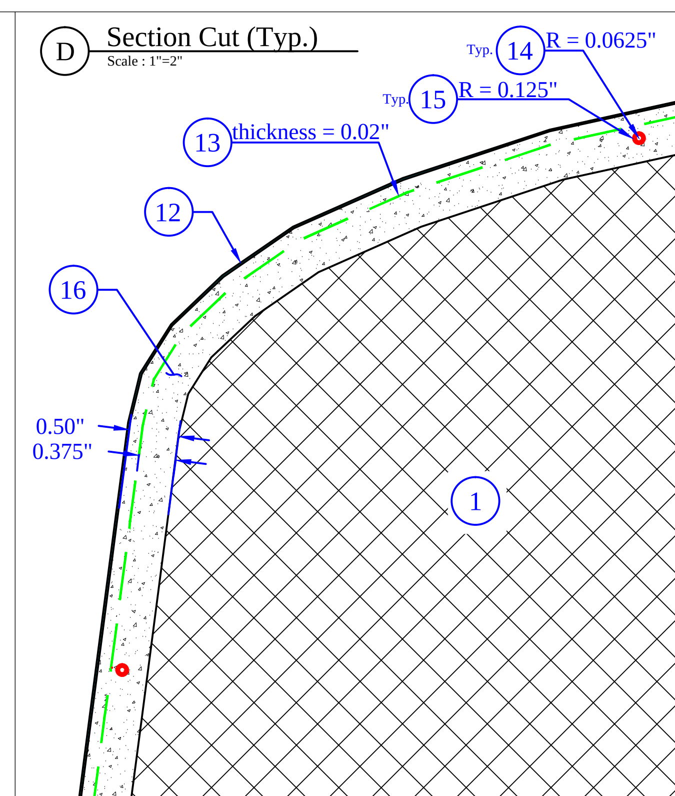
Legend

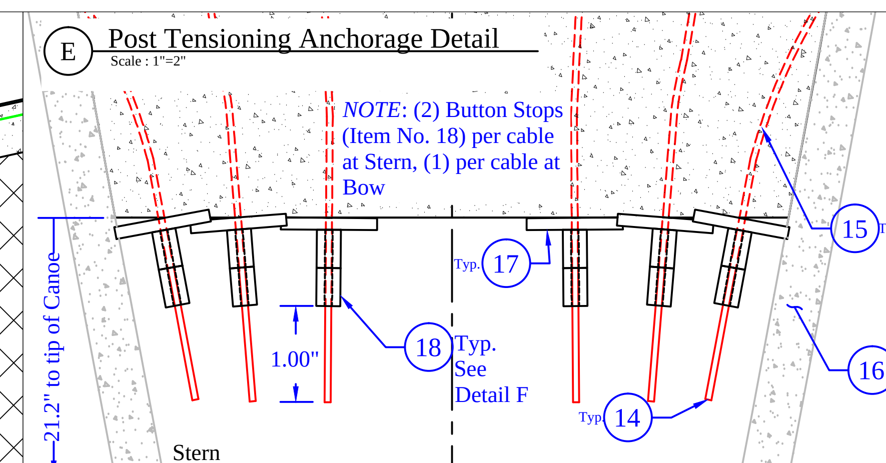
Description	Item No.	Hatching
Foam Mold	1	
Plywood	7	
2x4 and 2x6	8 / 9	
Concrete	16	

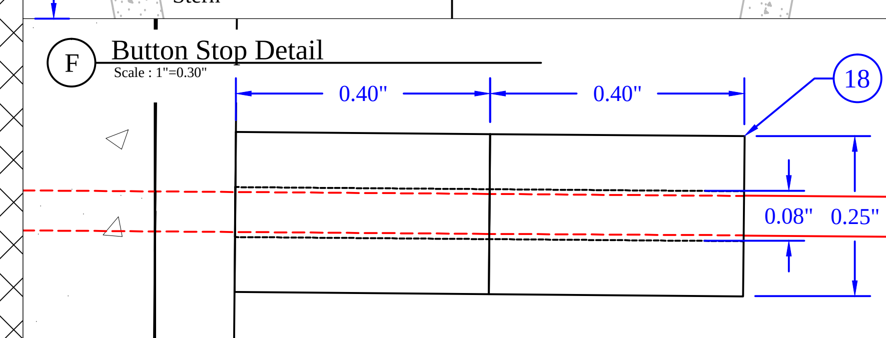












CONCRETE CANOE
DREADNOUGHTUS

Bill of Materials

Item No.	Item Description	Quantity	Unit
1	Foam Male Mold	1	EA
2	Wood Alignment System	1	EA
3	Rotating Steel Plate	4	EA
4	$\frac{1}{2}$" Bolt	2	EA
5	$\frac{3}{8}$" Bolt	2	EA
6	Steel Stand	2	EA
7	$\frac{1}{2}$" Plywood	64	FT^2
8	Wood 2x4 (1.5"x3.5")	120	LF
9	Wood 2x6 (1.5"x5.5")	64	LF
10	Silicone Rib Molds	0.30	FT^3
11	$\frac{1}{2}$" PVC Tubing for Gunwales	28	LF
12	Shrink Wrap with Form Oil	80	FT^2
13	Parex Glass Fiber Reinforcing Mesh	105	FT^2
14	Post-Tension Galvanized Steel Tendon ($\frac{1}{16}$")	126	LF
15	Post-Tension Plastic Tube ($\frac{1}{8}$")	124	LF
16	Concrete (Per Appendix B Mix Design)	2.55	FT^3
17	0.125" x 1" x 1" Steel Plate	12	EA
18	Button Stop	18	EA

Dreadnoughtus

Form Design Drawing

Drawn By: Kristin	Date: 02/15/15		
Checked By: Mark	Date: 03/03/15		
Scale: As Shown	Sheet: 1 of 1	Drawing Number: G1	
Rev. Date	Rev. No.	Details of Revision	By
2/16/2015	1	Corrections	KVS
3/1/2015	2	Change PT Set up	KVS

Appendix A – References

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Appendix B – Mixture Proportions

Mixture ID: Structural Mix			Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft³):	1						
Cementitious Materials		SG	Amount (lb/yd³)	Volume (ft³)	Amount (lb)	Volume (ft³)	Amount (lb/yd³)	Volume (ft³)
CM1	EkkoMAXX™ (Flyash)	2.78	1040.83	6.00	38.55	0.222	1056.71	6.092
	Total Cementitious Materials:		**1040.83**	**6.00**	**38.55**	**0.22**	**1056.71**	**6.09**
Fibers								
F1	MasterFiber M 100 (0.75")	0.91	0.50	0.009	0.02	0.0003	0.51	0.009
	Total Fibers:		**0.50**	**0.01**	**0.02**	**0.0003**	**0.51**	**0.01**
Aggregates								
A1	Poraver® (0.5-1.0 mm) Abs: 20.0%	0.44	267.17	9.731	9.90	0.360	271.25	9.879
A2	3M S32 Glass Bubbles Abs: 1.0%	0.32	118.59	5.939	4.39	0.220	120.40	6.030
	Total Aggregates:		**385.76**	**15.67**	**14.29**	**0.58**	**391.65**	**15.91**
Water								
W1	Water for CM Hydration (W1a + W1b)	1.00	260.21	4.17	9.64	0.15	264.18	4.23
	W1a. Water from Admixtures		1.98		0.07		2.01	
	W1b. Additional Water		258.23		9.57		262.17	
W2	Water for Aggregates (SSD)	1.00	54.62		2.02		55.45	
	Total Water *(W1 + W2)*:		**314.83**	**4.17**	**11.66**	**0.15**	**319.63**	**4.23**
Admixtures (including Pigments in Liquid Form)		% Solids	Dosage (fl oz/cwt)	Water in Admixture (lb/yd³)	Amount (fl oz)	Water in Admixture (lb)	Dosage (fl oz/cwt)	Water in Admixture (lb/yd³)
Ad3	MasterAir AE 90 *8.51 lb/gal*	6.00	3.00	1.98	1.16	0.072	3.05	2.01
	Water from Admixtures *(W1a)*:			**1.98**		**0.07**		**2.01**
Cement-Cementitious Materials Ratio			0.00		0.00		0.00	
Water-Cementitious Materials Ratio			0.25		0.25		0.25	
Slump, Slump Flow, *in.*			7 ± 1		8.00		8.00	
M	Mass of Concrete. *lbs*		1741.93		64.52		1768.50	
V	Absolute Volume of Concrete, *ft³*		25.84		0.96		26.24	
T	Theorectical Density, *lb/ft³ = (M / V)*		67.41		67.39		67.39	
D	Design Density, *lb/ft³ = (M / 27)*		64.52					
D	Measured Density, *lb/ft³*				65.5		65.5	
A	Air Content, *% = [(T - D) / T x 100%]*		4.3%		2.8%		2.8%	
Y	Yield, *ft³ = (M / D)*		**27.0**		0.985		**27.0**	
Ry	Relative Yield *= (Y / Y_D)*				0.985			

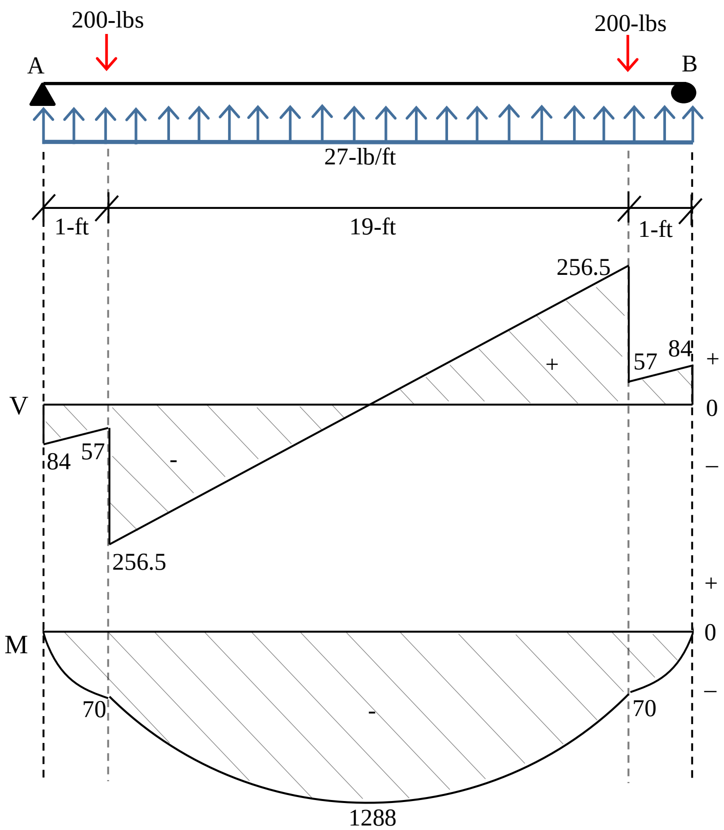
Mixture ID: Patching Mix			Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3):	1						
Cementitious Materials		SG	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	EkkoMAXX™ (Flyash)	2.78	1040.83	6.00	38.55	0.222	1046.19	6.031
	Total Cementitious Materials:		**1040.83**	**6.00**	**38.55**	**0.22**	**1046.19**	**6.03**
Aggregates								
A1	3M S32 Glass Bubbles Abs: 1.0%	0.32	312.90	15.670	11.59	0.580	314.51	15.751
	Total Aggregates:		**312.90**	**15.67**	**11.59**	**0.58**	**314.51**	**15.75**
Water								
W1	Water for CM Hydration (W1a + W1b)		260.21	4.17	9.64	0.15	261.55	4.19
	W1a. Water from Admixtures	1.00	0.00		0.00		0.00	
	W1b. Additional Water		260.21		9.64		261.55	
W2	Water for Aggregates (SSD)	1.00	3.13		0.12		3.15	
	Total Water *(W1 + W2)***:**		**263.34**	**4.17**	**9.75**	**0.15**	**264.69**	**4.19**
	Cement-Cementitious Materials Ratio		0.00		0.00		0.00	
	Water-Cementitious Materials Ratio		0.25		0.25		0.25	
	Slump, Slump Flow, *in.*		7 ± 1		6.00		6.00	
M	Mass of Concrete. *lbs*		1617.07		59.89		1625.40	
V	Absolute Volume of Concrete, ft^3		25.84		0.96		25.97	
T	Theorectical Density, lb/ft^3 = (M / V)		62.58		62.58		62.58	
D	Design Density, lb/ft^3 = (M / 27)		59.89					
D	Measured Density, lb/ft^3				60.2		60.2	
A	Air Content, *%* = [(T - D) / T x 100%]		4.30		3.80		3.80	
Y	Yield, ft^3 = (M / D)		**27.0**		0.995		**27.0**	
Ry	Relative Yield = (Y / Y_D)				0.995			

Appendix C – Bill of Materials

Material	Quantity	Unit Cost	Total Price
Cementitious Materials			
EkkoMAXX	197.55 lbs	$0.77/lb	$152.11
Admixtures			
MB AE 90	.034 gal	$7.00/gal	$0.24
Aggregates			
Poraver Expanded Glass	50.0 lbs	$1.76/lb	$88.00
3M S32 Glass Bubbles	22.57 lbs	$9.80/lb	$221.27
Reinforcing Materials			
Post Tensioning Tendons	132 ft	$0.14/ft	$18.48
Parflex Nylon Tubing	108 ft	$0.42/ft	$45.36
Button Stoppers	18	$0.42/each	$7.56
Bearing Plates	6 sq. in	$0.12/sq in	$0.72
Parex Glass Fiber Reinforcing Mesh	105 sq. ft	$0.18/sq. ft.	$18.98
MasterFiber M 100	0.103 lbs	$1.88/lb	$0.19
Male Mold and Associated Items			
Foam Male Mold	Lump Sum	$300.00	$300.00
3D Elements Silicone Molds	Lump Sum	$362.50	$362.50
Nox-Crete Pro-Release Agent	0.5 gal.	$9.45/gal	$4.73
Wooden Strongback	Lump Sum	$250.00	$250.00
Steel Mold Stands	Lump Sum	$100	$100
Sealer and Stain			
Pro-Release Sealer	2 gal.	$35.00/gal	$70.00
Behr Concrete Stain (Solid and Translucent)	2 gal.	$25.96/gal	$51.92
Total Production Cost			**$1,692.06**

Appendix D – Example Structural Calculation

Longitudinal Internal Stress



Assume:

- Self-weight of the canoe (SW_{canoe}) = 170-lbs
- Self-weight of the paddlers ($SW_{paddlers}$) = 200-lbs each
- Canoe length = 21-ft

Determine Buoyant Force, F_B:

$$F_B = SW_{canoe} + SW_{paddlers} = 170\ lbs + 200\ lbs = 570\ lbs$$

∴ Water will push upwards at 570-lbs per 21-ft or **27-lb/ft**

Find Reactions:

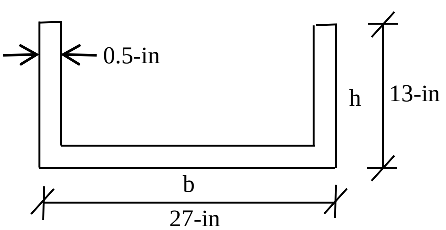
$$\curvearrowright^{+} \Sigma M_A = 0 = (200\ lbs)(1\ ft) + (200\ lbs)(20\ ft) - 27\frac{lb}{ft}(21\ ft)(10.5\ ft) + R_B(21\ ft)$$

$R_A = R_B =$ **83.5-lbs (↓)**

Drawing Shear & Moment Diagrams:

M_{max} = 1288-lbft or **15456-lbin**

Simplified Cross-Section:



$$\bar{y} = \frac{\Sigma A_i y_i}{\Sigma A_i} = \frac{(27\ in)(0.5\ in)(0.25\ in) + 2(12.5\ in)(0.5\ in)(6.75\ in)}{(27\ in)(0.5\ in) + 2(12.5\ in)(0.5\ in)} = \mathbf{3.375 - in}$$

$$I = \Sigma(I_i + A_i d_i^2) = \left[\frac{(0.5\ in)^3(27\ in)}{12} + (0.5\ in)(27\ in)(3.375\ in - 0.25\ in)^2\right] + 2\left[\frac{(27\ in)^3(0.5\ in)}{12} + (0.5\ in)(12.5\ in)(3.375\ in - 6.75\ in)^2\right] = \mathbf{437.3 - in^4}$$

- $\bar{y}$ = Centroid of cross-section
- A_i = Area of individual rectangular segment
- y_i = centroid of individual segment
- I_i = Moment of inertia = $\frac{bh^3}{12}$
- $d_i = y_i - \bar{y}$

Flexural Formula:

$$\sigma = \frac{My}{I}$$

- σ = Normal stress
- M = Moment
- y = Distance from centroid to stress face
- I = Moment of Inertia

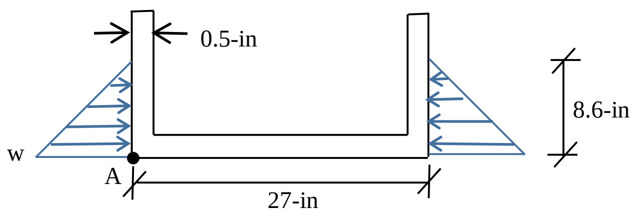
$$\sigma_{compression} = \frac{(15456\ lbin)(13\ in - 3.75\ in)}{437.3\ in^4} = \boxed{\mathbf{340 - psi}}$$

$$\sigma_{tension} = \frac{(15456\ lbin)(3.75\ in)}{437.3\ in^4} = \boxed{\mathbf{119 - psi}}$$

Transverse Internal Stress

Assume:

- Density of water = 62.4-pcf
- Waterline = 8.6-in (From Prolines waterline analysis)



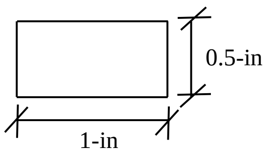
Find Force of Water, w:

$$w = 62.4\frac{lb}{ft^3}\left(\frac{1\ in}{12\ ft}\right)^3 (8.6\ in)(1\ in) = \mathbf{0.311 - \frac{lb}{in}}$$

$$\curvearrowleft + \sum M_A = 0 = \left(0.311\frac{lb}{in}\right)(8.6\ in)(0.5)\left(\frac{1}{3}\right)(8.6\ in)$$

$$\boldsymbol{M = 3.83 - \frac{lbin}{in}}$$

One-inch Section-Cut at A:



$$I = \frac{bh^3}{12} = \frac{(1\ in)(0.5\ in)^3}{12} = \mathbf{0.0104 - in^4}$$

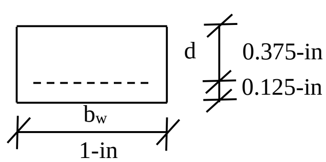
Flexural Formula:

Conventional to use 0.1(h) for compression face

$$\sigma_{compression} = \frac{(3.83\frac{lbin}{in})(0.20\ in)}{0.0104} = \boxed{\mathbf{73.5 - psi}}$$

$$\sigma_{tension} = \frac{(3.83\frac{lbin}{in})(0.25\ in)}{0.0104\ in^4} = \boxed{\mathbf{92 - psi}}$$

Single Layer of Reinforcement:



Assume:

- Compressional Strength of Concrete, f'c = 2150-psi (from concrete mix)
- Tension force, T = 135-lb/in (from mesh reinforcement testing)
- Neutral axis depth factor, β_1 = 0.85
- Strength reduction factor, ϕ = 0.65

Depth to Compression Zone, c:

$$c = \frac{T}{0.85f'c\beta_1 b_w} = \frac{\left(135\frac{lb}{in}\right)(1\ in)}{0.85(2150\ psi)(0.85)(1\ in)} = \mathbf{0.0869 - in}$$

Nominal Flexural Capacity, ϕM_n:

$$\emptyset M_n = \emptyset\left[T(d - \frac{\beta_1 c}{2}\right] = 0.65\left[135\ lbs(0.375\ in - \frac{0.85(0.0869\ in)}{2}\right] = \mathbf{29.6 - \frac{lbin}{in}}$$

$\emptyset M_n \gg M$ **Factor of Safety ≈ 7.5**