GAME OF STONES

2018

WENTWORTH INSTITUTE OF TECHNOLOGY

CONCRETE CANOE DESIGN REPORT

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Table 1: *Game of Stones* Canoe Specifications	
Max Length	20' - 0"
Max Width	2' - 3"
Max Depth	1' - 3.5"
Avg. Thickness	0' - 5/8"
Est. Weight	285 lbs.
Color	Grey

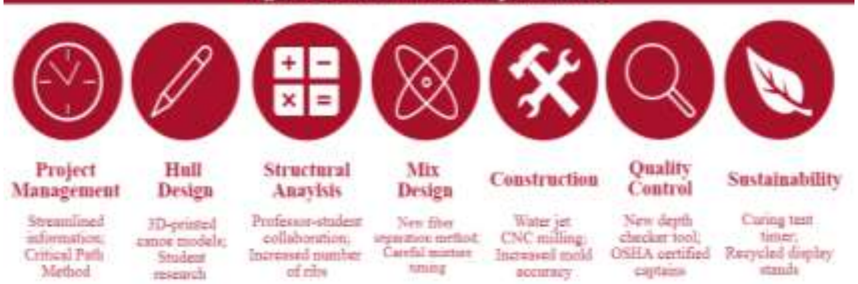
The Iron Islands is one of the seven kingdoms existing in the popular television series, "Game of Thrones." Unlike the northern and southern kingdoms, those who live in Ironman's Bay experience the harsh climate of windswept, treacherous waters. Despite the odds, Ironborns use resilience and determination to create an unmatched naval force. Wentworth will draw inspiration from these tenacious people and use *Game of Stones* to create an unstoppable force in the waters in the upcoming 2018 ASCE Concrete Canoe Competition.

Founded in 1904 and located in Boston, Wentworth Institute of Technology strives for greatness. This university provides career-focused curriculums for 20 different bachelor programs including applied mathematics, design, engineering, and business management. Wentworth consists of 3,711 undergraduates and 124 graduate students, who achieve excellence in academic courses, cooperative programs, and extracurricular activities. Since 1981, Wentworth's Concrete Canoe Team has participated in the American Society of Civil Engineers' New England Regional Conferences. The concrete canoe team received 11th place overall in the 2017 Regional Conference with *Free WITty*. Preceding designs include *Urban Leopard* (6th, 2016) and *Olympus* (6th, 2015).

Table 2: *Game of Stones* Mixture Proportions	
Concrete Density	0.044 pci
Concrete Plastic Weight	4.45 pci
Est. Compressive Strength	2,506.70 psi
Tensile Strength	7,500 psi
Air Content	10 %
Concrete Slump	6 in.
Reinforcement	
Concrete Color	Dark Grey
Primary Reinforcement	Fiberglass Mesh
Secondary Reinforcement	Polypropylene Fibers

With the desire to achieve redemption from poor rankings, the 2018 Concrete Canoe Team implemented a variety of new innovations. Straying away from previous designs, *Game of Stones* was created with a longer, wider, more angled hull design (Table 1). Alterations were made not only to canoe dimensions but also mixture proportions, as there was an increase in testing methods. As it can be observed in Table 2, mixture proportions used in *Game of Stones* was carefully analyzed and developed for efficiency.

Figure 1: Innovations & Improvements



The 2018 canoe team was set up for more success due to higher member counts and experienced managerial staff. Many new innovations and improvements were explored, which will ensure Wentworth's competition success. To improve canoe testing and design, ASCE members used 3D printed canoe models, and collaborated with professors on testing-related research projects. Innovations such as a water jet cut foam mold, new method of fiber separation, and depth checker tools brought precision via uniformity to the canoe shape, mix design, and concrete placement, respectively. The Wentworth concrete canoe team will rock the waters with *Game of Stones*.

PROJECT MANAGEMENT

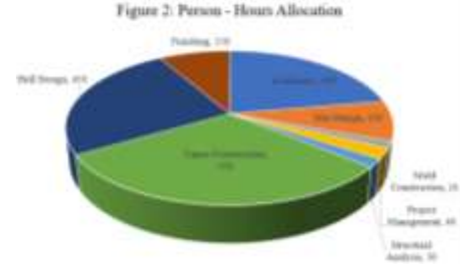
This year, *Game of Stones* faced challenges as many of the previous captains had graduated. To ease this transition, leadership positions were elected in spring. While all elected captains had minimally attended one competition, only one captain previously held a leadership position. The summer was spent preparing for the new positions and early September meetings occurred. Such meetings followed a critical path project management method (CPM), as online shared storage spaces and linked calendars developed a clear understanding of task-list breakdowns, varying responsibilities, and upcoming assignments.

Table 3: Major Milestone Activities

Milestone	Variance	Reason
First Meeting	None	-
Fundraising	-7	Internal school miscommunication
Concrete Mix Design	None	-
3D Printing Canoe Models	-21	New software & techniques
Pour Day	-	Proper scheduling
Design Report	None	Deviation of tasks

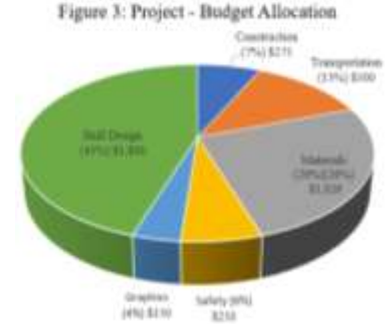
Upon the beginning of team meetings, elected officials faced new and returning members with an informed, strategic approach. Through streamlined information, advising partnerships, organized schedules, and effective communication, student-professor collaboration, task deviation, younger membership, and construction quality were all improved. This chapter cohesion allowed *Game of Stones* to be constructed with a new caliber of quality. Part of this cohesion as a club was due to clear project schedules and major milestones, made evident by club discussion and shared calendar events. This year, major milestones include fundraising, concrete mix design, 3D printing canoe models, pour day, and design report (Table 3). While fundraising was delayed due to internal school miscommunication, all events were successful. New resources resulted in use of 3D printed canoe models, which occurred behind schedule due to the newness of software and techniques. However, invested time and effort will continue beyond *Game of Stones*. No variance occurred in the concrete mix design, pour day and design report milestones.

Figure 2: Person - Hours Allocation



Because of successful PM techniques, *Game of Stones* significantly decreased person hour allocations throughout all categories (Figure 2). These low, yet effective hour breakdowns allowed for additional times for academics, hull design, and finishing, leading to a higher quality canoe and report. In a similar fashion, the budget breakdown experienced new success. While a budget of $4,001 was drafted, many expenses for materials and services were generously donated (Figure 3). The donation of CNC water-jet milling services decreased project expenses by 45%, allowing the team to allocate resources for safety equipment, graphics, and work benches.

Figure 3: Project - Budget Allocation



Safety was dramatically improved as all three captains held Occupational Safety and Health Administration (OSHA) 30-hour certifications. By creating a safety manager position, the leadership team created a new safety program that informed other members about proper personal protective equipment (PPE). All members were required to wear gloves, goggles, and face masks. Those involved in material pouring and dry batching followed a heightened safety plan, requiring gas masks with increased ventilation. An extra layer of precaution was added by the presence of a certified campus lab technician, who was present at all meetings and work sessions.

QUALITY CONTROL & QUALITY ASSURANCE

Due to poor quality control and quality assurance used in 2017, *Free WITty* faced many challenges with mix design, testing results, hull design, and pour day. To ensure that *Game of Stones* wouldn't face any boulders, advanced research methods and techniques were used.

Figure 4: Flume Testing Setup

To ensure the quality assurance of experimental mix designs, a certified lab technician was present to guarantee that experimental mix testing was completed according to the standards of the American Society for Testing and Materials (ASTM). Despite using dry batching techniques and involving first year students, lab technicians and senior members ensured quality controlled mix design. To ensure the quality of the hull design, students collaborated with professors on research projects, introducing a new layer of quality assurance. For the first time, Wentworth students used 3D printers to create tangible models of different canoe designs. Research projects analyzed flume testing methods by using 3D canoe models to understand fluid dynamics and efficient canoe body styles (Figure 4).

Figure 5: Physical Breakaway Mold Depiction

Last year, the largest source of error was *Free WITty's* uneven mold. This unbalanced teardrop shape came from 103 different 2-inch hand-cut sections. This year, *Game of Stones* was created from 80 3-inch sections that were professionally cut with water jet milling services. To ensure uniform section placement, a hole was designed in CAD to be included within the sections. This hole allowed for metal pipes to run along the entire canoe length, ensuring uniform placement. Other techniques used to improve hull design and decrease labor requirements included pre-assembled 5-foot sections and breakaway mold sections (Figure 5).

In preparation for pour day, quality control precautions were taken related to work spaces and material batching. A protective polyethylene sheeting was placed across the work areas, preventing concrete from sticking to the foam and table. The mold was also lubricated with Crisco, to guarantee easy foam removal. Throughout the measuring, batching, mixing, and constructing, team members followed according safety plans. Luckily, the concrete canoe team was composed of a high quantity of returning members, who had attended at least one previous pour day. Because of this experience, it was advised to create smaller concrete batches with hand-powered drills, so as to create work flow efficiency.

Figure 6: Depth Checking on Pour Day

To ensure controlled concrete thickness and placement, depth checkers were created. The first marking on the depth checker was the concrete thickness prior to the glass fiber mesh, and the second depth checker marking was the final 5/8-inch thickness. All team members had depth checkers, and used them periodically throughout laying the concrete. In between the different layers, smoothing and troweling was a large focus, so that the canoe would be produced with an even external layer of cement. This systematic layer via smoothing with trowels furthered improved canoe quality, as it required less coarse sanding.

HOUSE: WENTWORTH

Co-Captain

Chris Drussell (So.)

Responsible for developing hull design and completing structural analysis

Captain

Savannah Reynolds (Sr).

Responsible for managing concrete canoe team and developing mix design

Co-Captain

Amanda Siciliano (So.)

Responsible for managing projects related to regional competition

Asthetics

Nina Collins (Fr.)

Responsible for managing aesthetics related to paper and canoe design

Assistants

- Sam Devincentis (Sr.)
- Deanna Kondek (Jr.)
- Michael Tortora (So.)
- Zach Visser (So.)
- Marina Schmid (Fr.)

Construction

Jim Sullivan (So.)

Responsible for managing mold and canoe construction

Assistants

- Hussein Alhady (Sr.)
- Brendan Briggs (Sr.)
- Joe Bianchi (So.)
- Brian Burns (Fr.)
- Emma Loughlin (Fr.)

Safety

Matt Medeiros (So.)

Responsible for creating safety programs

Assistants

- Tom O'Donnell (Sr.)
- Matt Tirocchi (Sr.)
- Matt Sylvia (Jr.)
- Evan Dimatteo (So.)
- Brannon McMullen (So.)

Indicates Registered Paddler

HULL DESIGN

While it was thought that this this circular, tapered design would allow the canoe to swim through the waters with ease, this did not prove to be the case. This year, captains drew hull design influence from racing canoes, racing shells, on-campus resources, and previous dimensions. As seen in Table 4, captains analyzed the correlation between previous dimensions and canoe success to discover the most optimal canoe design. The final product of *Free WITty* had a 17-foot length, 23.5-inch maximum width, and 21.5-inch maximum depth. This teardrop was ineffective and was unable to race in the regional competition.

Table 4: Previous Canoe Specifications

Canoe	*Free WITty (2017)*	*Urban Leopard (2016)*	*Olympus (2015)*	*Transcontinental (2014)*	*Redneck Yacht Club (2013)*
Max Length	17'-1"	17'- 0"	18' - 6"	18'-0"	19' - 6"
Max Width	1' - 11.5"	2' - 3.89"	2' - 4"	2' - 8"	2' - 9"
Max Depth	1' - 9.5"	1'-4"	1' - 4"	1' - 4"	1' - 3"

Initially, a canoe with a longer body and smaller width was chosen to mimic sleek racing shells. However, this design was evolved as it was not stable enough for competition requirements. Captains considered a wider, shallower design in attempt to decrease overall canoe weight. Once again, this canoe lacked the necessary stability for success. To combat this necessary aspect, a v-shaped hull design with sharper angles and increased stability was explored (Figure 7). To better explore hull design development, captains used Wentworth 3D MakerBot services and SolidWorks to 3D print 1:25 canoe models. New small-scale flume testing methods were explored with these 3D printed models.

Figure 7: CAD Cross-Section of Breakaway Mold

Through flume testing, captains explored canoe dynamics and associated water drags. A long flume testing apparatus was used, as it met the general needs of research due to its ability to create differing flow rates. Model canoes were made with square nut inserts to allow for PASCO load cell attachments. After testing, drag forces were low in nature due to the small-scale of the models. Analysis indicated that the v-shaped hull on this small-scale model reacted well to the water and differing flows, as the sharply-angled body prevented rocking with little drag. Ultimately, captains determined the optimal design would include a longer body, average width, and minimal depth. *Game of Stones* was created to be 20 feet long, 27 inches wide and 15.5 inches deep.

These carefully selected dimensions for *Game of Stones* complies with Wentworth's goals of improving resistance and reducing rocking. The longer body shape of *Game of Stones* allows for its slim and shallow nature, without compromising buoyant forces and negative volume change. While *Free WITty* was heavy due to its whale-like weight, the team was hoping to have a lighter, yet stable canoe. In attempt to decrease weight, the depth and width of *Game of Stones* was reduced from initial designs by 1.5-inches and 3-inches, respectively. Reducing the concrete thickness from the previous 3/4-inch thick layer to a 5/8-inch thick layer also helped to create a lighter canoe. With these helpful weight reduction techniques, captains researched ways to improve structural integrity. Previously, *Free WITty* and other designs incorporated three canoe ribs. However, *Game of Stones* was given an extra rib to improve structural integrity since weight reduction was already a consideration. With four ribs in total, a maximum-length gunwale was also added, improving tensile strength. Through these combined efforts, *Game of Stones* can endure the rocky journey throughout competition travel and canoe races.

STRUCTURAL ANAYLSIS

Figure 8: 2-Paddler Moment Diagram

The structural analysis of *Game of Stones* was completed with the goals of avoiding cracking and validating stress locations through testing results and RISA 2D software. Structural analysis began with determining necessary buoyancy forces to keep the canoe and paddlers afloat. Average estimated weights were 140 lbs. for female racers, 180 lbs. for male racers, and 285 lbs for the canoe. These values were calculated from SolidWorks, using a concrete with a specific weight of 0.04 lbs. / cu.in. and an estimated surface area of 23,207.20 sq. in. To evaluate maximum moment, tensile, and compressive strengths, standard structural analysis equations and beam modeling methods are used.

The least buoyant force, of 565 lbs., is required in the 2 female paddlers race, and the greatest buoyant force, of 925 lbs, is needed during the co-ed 4 paddler race. There is an estimated volume of displacement of 15,646 cu.in. needed for the former scenario and a displaced volume of 25,615 cu. in. needed for the latter scenario. The canoe's underside will have a surface area of 4,758 sq.in. The heaviest scenario loading caused a canoe sit of 5.4 in. into the water while the lightest scenario loading caused a canoe sit of 3.3 in. into the water. If no additional weight is applied, calculations indicated that *Game of Stones* will sink 1.7 in. into the water. The pressure to be applied to the underside of the canoe was then determined to be an estimated 0.119 lbs/ sq. in. for the 2-person scenario and 0.194 lbs / sq. in. for the 4-person load.

The download force of the canoe on the water acts over the center, with point loads representing paddler combinations. In the two-person female race, point loads are applied at the 8-foot and 12-foot markings, which are measured from the front of the canoe. In the four-person co-ed race, point loads are applied at the 6-foot, 8.5-foot, 11.5-foot, and 14-foot markings, which are measured from the front of the canoe. These locations were determined by using two reaction forces. These reaction forces aimed to represent the upwards buoyant forces of the water acting against the canoe. A moment of -506.2 foot-pounds is calculated during the light 2-person female race, while a maximum moment of 657.8 foot-pounds is calculated during the heavy 4-person race.

Due to the success of *Free WITty's* structural calculations, *Game of Stones* followed a similar technique in assuming equivalent T-shaped beams along the canoe cross section to determine compressive and tensile forces. Because of this assumption, the neutral axis location allows for structural analysis to be completed using standard equations (Appendix C). Calculations indicate that the vertical bar of this T-beam was 2-inches by 15.5-inches, while the horizontal bar was 27-inches by 5/8-inch. By using this T-beam interpretation of the canoe's cross section, it was found that the neutral axis was located at an estimated 5.533-inches above the bottom of the canoe.

A factor of safety of 1.5 was used to ensure that the canoe could hold the amount necessary for safe competition practices. As shown in Figure 8 for the 2-person race, the positive moment and neutral axis locations show how material above this axis will experience compression, while materials below the axis will experience tension. However, as depicted in Figure 9, analysis of the 4-person race will be different. With these produced negative moments, the material above the neutral axis will experience tension, while material below will experience compression. Tension stress values are calculated to be 64.36 psi below the neutral axis, while compression stress values have been calculated to be 73.63 psi. However, in the two-person scenario, the material above the neutral axis exhibits a tensile stress of 33.02 psi, while the material below the neutral axis exhibits a compressive stress of 19.38 psi.

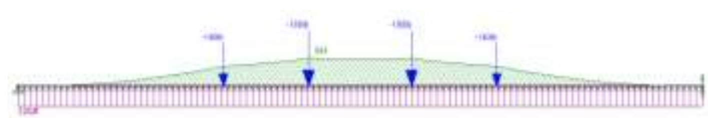


Figure 9: 4-Paddler Moment Diagram

DEVELOPMENT & TESTING

Table 5: Select Properties of Aggregates	
3M Glass Bubbles	
Specific Gravity (g/cm^3)	0.2
Absorption of oil (gram)	0.4
Poraver 0.1-0.3 mm	
Specific Gravity (g/ cm^3)	0.9
Absorption	35
Poraver 0.25-0.5 mm	
Specific Gravity (g/ cm^3)	0.75
Absorption	28
Poraver 1.0-2.0 mm	
Specific Gravity (g/ cm^3)	0.44
Absorption	20
Perlite	
Specific Gravity	2.2
Absorption of oil (gram)	50-100

To test and finalize this year's lightweight mix design for *Game of Stones*, captains combined forces with members, volunteers, and Wentworth professors. This year, *Game of Stones* aimed to increase the mix workability, discover efficient superplasticizer amounts, and determine the most effective application method of placing concrete onto the mold.

Free WITty's mix had inconsistent workability and produced an unstable, uneven canoe. Initially, last year's mix showed little viscosity, which prompted team members to add more cement with the goal of soaking up some of the free liquid. Later, it was realized that the decreased amount of superplasticizer was creating the lack of viscosity. Since inconsistent batches were created during last year's pour day, the final canoe was lopsided. Once placed in the water, it was discovered that *Free WITty* floated at nearly a 45-degree angle. Because of the desire to avoid such mistakes, *Game of Stones* was created with more careful considerations.

To create an enhanced mix, there was a need to discover a more efficient and time-saving way to break up the fibers. While these polypropylene fibers have worked well in previous mixes, their separation and homogenous dispersion has often been tedious, as fibers were separated by hand. This year, captains discovered a more efficient yet uncomplex method: an air compressor. By placing clumps of fibers into a bucket and inserting the nozzle into a small hole, the fibers were separated quickly and evenly. While this method may seem simple, it was a crucial factor in the success of pour day, as it saved unnecessary labor time.

Similar to previous years, the baseline concrete and reinforcement materials included Type I White Portland Cement, Silica Fume, Class F Fly Ash, K20 Glass Bubbles, three different sizes of Poraver, SIKA 2100 Viscocrete, and SIKA AEA 14. Polypropylene fibers and glass fiber mesh were useful reinforcing methods that improved concrete tensile strength. Because of the success of these reinforcing methods with *Free WITty*, the concrete canoe team decided to repeat such processes in the creation of *Game of Stones*. However, *Game of Stones* did experience other changes such as a decreased water-to-cement ratio from 0.9 to 0.6, which aimed to improve workability. To improve the strength of the canoe, the amount of cement was increased while the amount of silica fume was decreased. Since superplasticizer acts indirectly with workability and durability, superplasticizer amounts were decreased. As a result, *Game of Stones* experienced improved concrete workability and higher quantity of light weight aggregates, resulting in improved durability. Overall, this canoe was composed of 34% aggregate by volume, with 48% of the aggregates composed of lightweight aggregate.

Because of the sustainable nature of Poraver, three variations were used in the mix: 0.1-0.3 mm, 0.25-0.5 mm, and 1-2 mm. Poraver, a versatile recycled glass, is a known lightweight, sustainable material that improves mix workability. As it can be observed from the Table 5, this material is desirable because of its specific gravity and absorption values. All lightweight aggregates were tested in accordance to ASTM C136 (Appendix A). A new material, Perlite, was introduced in the mix due to its lightweight and insulation-like properties. Since this material had never been used, extensive research and development was conducted. It was discovered that Pearlite had good absorption properties and was large enough to act like a coarse aggregate. Despite having a much higher specific gravity than other materials, the Pearlite created one of the lightest mixes and had high workability.

Mix	Compressive Strength (psi)		Mass (Lbs.)		Split (psi)	Tensile
	Day 7	*Day 28*	*Day 7*	*Day 28*	*Trial 1*	*Trial 2*
Mix A: Pulverized Rubber	2351.5	1909.1	4.22	4.05	3740.0	2480
Mix B: Pulverized Rubber w/ Reduced Super Plasticizer	2907	2549.7	4.10	3.93	3240.0	3430
Mix C: Volcanic Ash w/ Tap Water	7434.9	4539.9	5.29	5.23	-	3380
Mix D-1: Volcanic Ash w/ Clean Salt Water	3135.4	-	4.20	-	1010.0	-
Mix D-2: Volcanic Ash w/ Non-Clean Salt Water	2970.6	-	3.91	-	2900.0	-
Mix E: Cork	2189.2	2194.0	3.57	3.49	3000.0	-
Mix F: Pearlite	3285.0	2813.9	4.24	4.05	4440.0	4310

Table 6: Test Results of Experimental Mix Designs

A total of six experimental mixes were created, made into 4-inch by 8-inch cylinders, and cured for 28 days in accordance to ASTM C192 (Appendix A). To further research, new materials were included in each mixture to find an optimal mix design. Some of the varying materials include combinations of pulverized rubber, perlite, volcanic ash, pulverized cork, water types, and admixtures.

Pulverized rubber was tested in two different mixes because of its lightweight nature, availability, and previous success in *Urban Leopard*. Using recycled pulverized rubber from Wentworth's turf fields, Mix A, used 0.38 pounds of pulverized rubber with 0.24 pounds of super plasticizer while Mix B used 0.38 pounds of pulverized rubber with a decreased amount of 0.10 pounds of super plasticizer. Three different volcanic ash mixtures were creating for experimental testing. Mix C was created from 0.50 pounds of volcanic ash with potable water. However, Mix D-1 and D-2 were slightly different in order to test the effects of clean and non-clean salt water. Mixes D-1 and D-2 were both created from ¾ gallon batches, different than the usual 1.5-gallon batch. Together, these batches used 2.38 pounds of salt water in place of potable water. To cleanse the salt water for sample D-1, captains mixed 1 mL of chlorine per 1 mL of water, which was stirred every 8 hours until the chlorine order evaporated. Mix E and F used 0.33 pounds of pulverized cork and 0.33 pounds of perlite, respectively. The only variations between Mixes A, C, E, and F are the highlighted material.

Cylinders were measured in both compression, in accordance with ASTM C39, and tension, in accordance with ASTM C496. Wet and dry unit weights were also recorded, as cylinders were randomly selected to be tested after 7, 14, or 28-day curing times (Table 6). When examining testing results, weight, workability, compressive, and tensile strength were all factors used to determine the most efficient mix design. Mix A was indeed workable, but resulted in a medium-weighted cylinder. Mix B proved to be too dry for canoe application, effectively ruling out pulverized rubber as a new material. Mixes C and D created heavy and crumbly cylinders, respectively. Because these heavy, yet weak results did not align with the goals of the team, volcanic ash was also ruled out. Test results from Mix E proved that while it was workable and lightweight, it did not possess the desired strength. When examining Mix F, results were interesting. If this material was spread too thinly, the mixture was too rough. However, once crushing created smaller particle sizes, this material created a very workable mixture.

After testing all six materials, it was determined that the final mix design would follow Mix F. Made from Perlite, this mix demonstrated the most desirable properties of upper-level compressive strength, maximum tensile strength, and moderate weight. Wet unit weights were calculated at the 28-day mark and recorded to be 68.50 lbs./ft³, while dry unit weights, completed in accordance to ASTM C138 with an oven drying time of three days, was recorded to be 64.68lbs./ft³. The compressive strength of this mix was recorded as 2813.9 psi on the 28-day mark, significantly lower than the 7-day value of 3285.0 psi.

When reviewing the results from experimental mix testing and the design used for *Free WITty*, significant developments were made to *Game of Stones*. The w/c ratio was decreased from 0.9 to 0.6. Cement content increased, while silica fume content decreased. Knowing the drastic effects of super plasticizer in a mix design, captains conducted extensive research with proper proportions. Four conducted trials, with super plasticizer amounts varying from 0.2 to 0.24, discovered that 0.23 was the perfect amount (Appendix B). This value created a mix that was viscous yet wet enough to properly stick to the canoe mold. Aggregate contents were altered to comply with the new ASCE competition rules. While the rule required 25% aggregate volume, with 25% of this volume being comprised of lightweight aggregate, *Game of Stones* was created from 34% aggregate volume, with 48% of this value as lightweight aggregate.

Polypropylene fibers and fiberglass mesh acted as primary and secondary reinforcement to increase the strength of the canoe. This fiberglass mesh acted as the primary reinforcement, and was placed between the two layers of concrete. While only one later of this material was used, tensile strength was greatly improved due to the surface area of the mesh. The fiberglass mesh has a calculated percent open area of 69%, a value in compliance with the recent 40% ASCE competition rule. Evenly dispersed ½-inch fibers acted as a second layer of reinforcing, which improved mix tensile strength due to the avoidance of clumping in wet concrete.

Throughout the Wentworth's participation in the ASCE concrete canoe competition, new and innovative ideas have been utilized to increase efficiency. In previous years, some methods related to construction included cutting 6-inch foam sections to create a 17-foot foam mold. This year, *Game of Stones* used new tools and techniques to expand mix design development. Some of these newly implemented ideas include air compressors, dry batching, design tools, and cutting mechanisms, which all work to decrease labor time requirements. In the past, fibers had to be separated by hand to achieve the desired consistency. At times, this laborious task could have taken days to complete. However, this year's use of an air compressor to separate fibers saved a preparation time.

Recent dry batching techniques also ensured a smooth pour day. Materials were pre-measured and pre-mixed prior to pour day during a canoe work session. These 1.5-gallon smaller batches required only two people for creation; one person mixed the materials while another person added in the liquid. *Game of Stones* attempted to utilize drums instead of buckets in attempt to make larger batches of concrete. However, this method proved to only be efficient for large concrete batches, as fibers would easily stick to the internal wall, reducing reinforcement efforts. Another attempted innovation included using an electric mixture. While this new method seemed hopeful, as it would require only one additional person to add in liquids and materials, it proved to be ineffective due to its small size and short supply.

Figure 10: Dry Batching Technique

CONSTRUCTION

In attempt to mimic the unmatched naval force of the Iron Islands and survive the harsh, rocky waters, *Game of Stones* was created with careful construction. By paying particular attention to mold precision, quality control, pour day preparation, and work flow analyses, *Game of Stones* will crush its competition. Last year, *Free WITty's* construction resulted in a lopsided, whale shape due to human error in creating 108 cross-sections. *Game of Stones* followed new methods that aimed to ensure a uniform, accurate mold.

Thanks to the generous donations of closed cell foam and cutting services, captains explored other means of mold construction. Through research and outreach, the canoe team contacted alumni in hopes of achieving an external collaboration. One Wentworth alum worked for a leading foam fabrication company, specializing in custom flexible foam products. Wentworth reduced project expenses by 45% and increased the quality of the mold through this charitable donation of waterjet CNC milling services. Through collaboration, captains created a new hull shape and reduced the number of cross sections. Rather than using 103 two-inch thick sections similar to *Free WITty*, *Game of Stones* used 80 three-inch thick sections. This reduction in the number of cross-sections and increase in the quality of cutting had a significant impact on the construction and success of *Game of Stones*.

Other changes made to this year's canoe include the introduction of a singular hole throughout the different foam pieces and breakaway mold pieces (Figure 5). These pre-cut holes allowed for easy assembly and uniform construction. Breakaway sections were introduced to allow for easy foam removal. After these changes were added, the black closed cell foam was cut, pre-glued with 3M super 77 materials, and delivered in 5-foot preassembled sections. Captains took sustainable efforts in using recycled steel pipes as a means of aligning the different foam sections. Once assembled, Elmer's contact cement was used to glue the different sections, creating a very promising mold for *Game of Stones*. To route reinforce ribs into the mold, the construction lead, equipped with power tool experience due to woodworking knowledge, completed the necessary cuts. Ribs were cut two-inches wide and one-inch deep to create a balanced, strong, and lightweight canoe.

Due to the success with previous sanding, plastering, and painting techniques, captains and members followed similar methods when preparing *Game of Stones* for pour day. As discussed earlier, OSHA certified captains instructed team members about different safety plans. To begin, *Game of Stones* was sanded with both electric and hand sanders. Electric sanders smoothed out larger sections of the canoe and used grit sizes from 80 to 100. After, hand sanding was utilized to smooth out smaller imperfections, ranging in grit size from 100 to 200. Next, a quick setting Diamond Plaster layer was applied using hand placing and troweling techniques. This layer was included to smooth out small imperfections in the foam. This simple layer helped *Game of Stones* by eliminating the potential for excess concrete to fill in uneven spots. Afterwards, electric and hand sanders were again utilized to ensure a high-quality finish. Next, a coat of rust-oleum latex paint was applied to seal the concrete from the plaster, as plaster would absorb moisture from the concrete. Without this sealing, incomplete hydration of the cement would occur along the mold-concrete surface.

Figure 11: Diamond Plaster Layer

This year a yellow latex paint was used, due to its high contrasting color in relation to the white plaster covered mold. This small variation to the construction of *Game of Stones* from *Free WITty* allowed for a much more complete paint layer. Afterwards, a Crisco layer was applied to ensure easy form removal, concrete application, and clean up time. When this layer was first applied it was done quite thick with the hopes that a deeper coating would allow for easier mold separation. However, once the concrete was applied to the mold, it was discovered that the Crisco layer was too thick for the concrete to stay in place. Paper towels were used to remove excess Crisco, which was recycled for future use.

Due to the lack of success in *Free WITty's* pour day, extra precautions were taken. Prior to pour day, material preparation occurred for both dry and wet materials to ensure proper mix designs. An assembly line was created, where dry batches were initially mixed, wet materials were added, and electric mixes were used to create the necessary concrete batches. To ensure mix consistency, a timer was used to track the duration of electric mixing. This timer began once wet ingredients were added to the already-mixed dry batches, and was stopped within a designated period, avoiding both over and under mixing.

After being fully mixed, the concrete would sit for a few minutes so that it would gain some initial strength prior to mold application. Once ready, the application team used hand placement and troweling techniques to ensure successful concrete-to-mold cohesion. Depth checkers were created prior to pour day to ensure that the concrete would be applied with uniform depth (Figure 6). The initial marking on these quality control checkers acted as the midway point of the desired canoe thickness. At this half-thickness, a layer of glass fiber reinforcing mesh was applied. After this mesh layer, more concrete was applied, where the full length of the depth checker marked the desired 5/8-inch concrete canoe thickness.

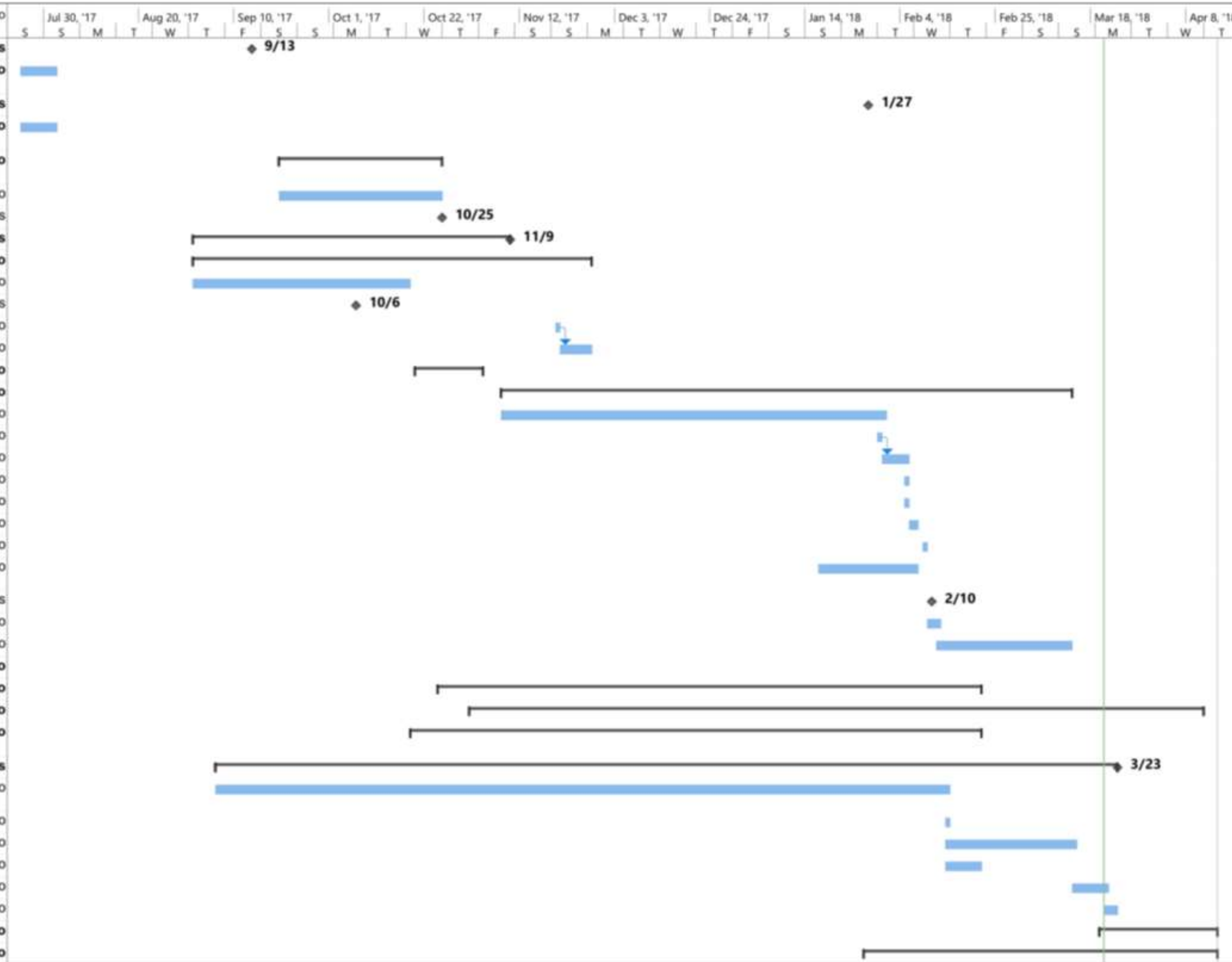
Figure 12: Pour Day

After casting, the canoe was left to air dry for 3 days. Then, a curing tent was constructed to surround the canoe and ensure a moist, proper environment. This tent was constructed from PVC piping with a pitched roof. This pitched roof was a critical component to curing, as it removed water drip, ensured proper misting, and was directly angled towards the canoe. A heavy-duty polyethylene sheet was used to form the tent walls, ensuring a moisture-rich, humid curing environment. The canoe was air-cured for 3 days, wet-cured for 35 days, and dry-cured for an additional 35 days, totaling in an overall cure time of 70 days. To further sustainability efforts, a smart timer was used on the misting system connected to the curing tent. This timer saved water by spraying for fifteen minutes every four hours. Additionally, gutters were installed on either side of the work bench, allowing for proper drainage and avoiding lab flooding.

After successful casting and curing, new form removal techniques were used to decrease the time and labor required. As mentioned earlier, a new breakaway technique was designed into the original mold to ensure easy removal. Due to the difficulty of *Free WITty's* mold removal, this innovation was a crucial aspect in the success of *Game of Stones*, as it allowed time re-distribution. Instead, more time was spent in areas with a direct effect on canoe performance such as hull finished. The canoe was then sanded using similar techniques to mold sanding, and coated with layers of Behr concrete sealer. To display Wentworth's pride, layer decals were added, with the *Game of Stones* title in large decals.

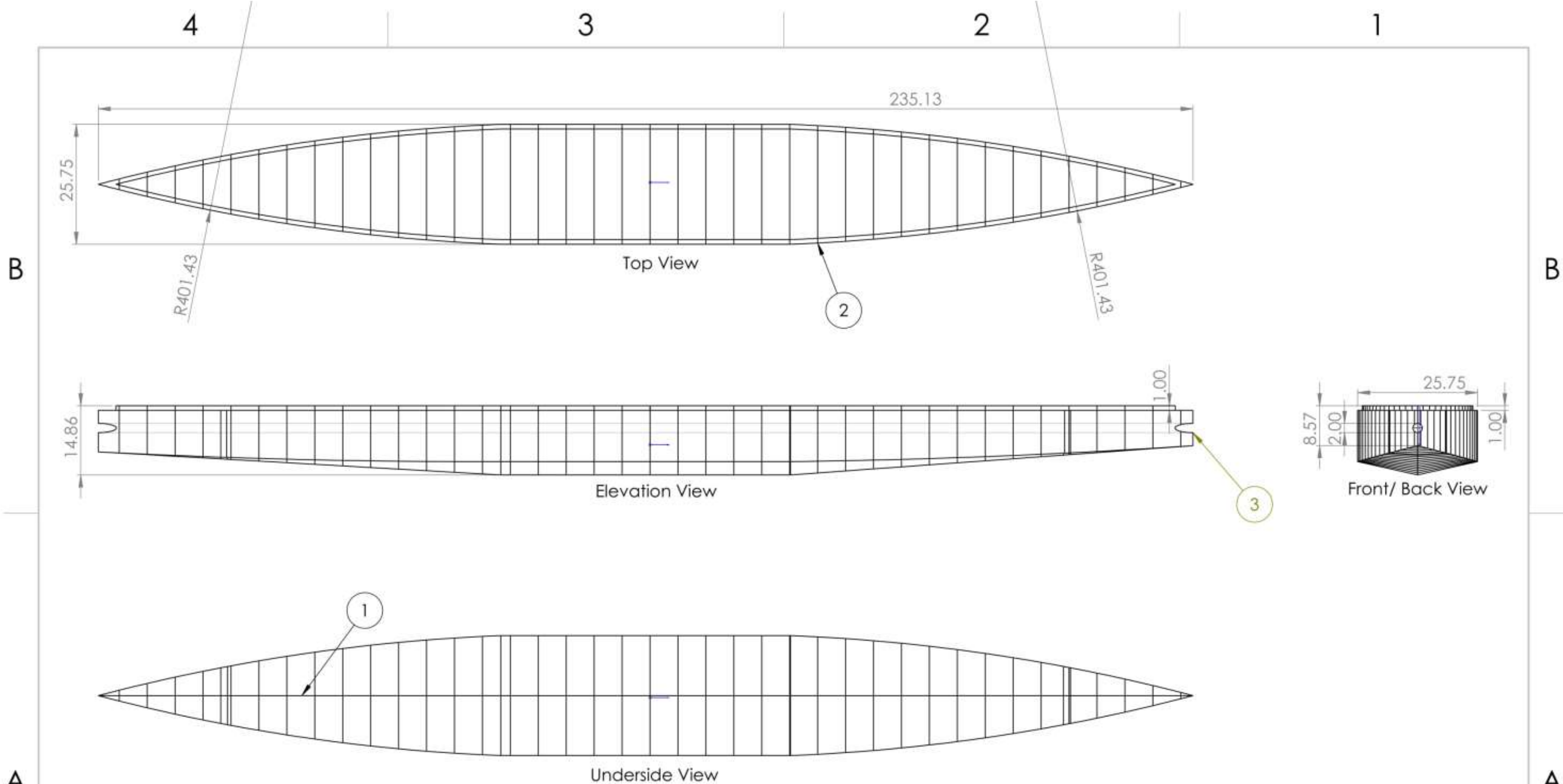
Wentworth Institute of Technology - Game of Stones

ID	Task Name	Duration	Start	Finish	Milesto
1	**First Meeting**	**1 day**	**Wed 9/13/17**	**Wed 9/13/17**	**Yes**
2	**Projected Budget & Spending Breakdoen**	**6 days**	**Tue 7/25/17**	**Tue 8/1/17**	**No**
3	**Fundraising**	**81 days**	**Wed 10/11/1**	**Sat 1/27/18**	**Yes**
4	**Projected Budget and Spending Breakdown**	**6 days**	**Tue 7/25/17**	**Tue 8/1/17**	**No**
5	**Theme Research and Selection**	**26 days**	**Wed 9/20/17**	**Wed 10/25/17**	**No**
6	Theme Brainstroming	26 days	Wed 9/20/17	Wed 10/25/1	No
7	Final Theme Vote	1 day	Wed 10/25/1	Wed 10/25/1	Yes
8	**Concrete Mix Design**	**50 days**	**Fri 9/1/17**	**Thu 11/9/17**	**Yes**
13	**Hull Design**	**62 days**	**Fri 9/1/17**	**Mon 11/27/1**	**No**
14	Hull Design Research	34 days	Fri 9/1/17	Wed 10/18/1	No
15	3D Printing Canoe Models	5 days	Mon 10/2/17	Fri 10/6/17	Yes
16	Hull Design Final Selection	1 day	Mon 11/20/17	Mon 11/20/17	No
17	Shop Drawing of Hull	5 days	Tue 11/21/17	Mon 11/27/17	No
18	**Structural Analysis**	**11 days**	**Fri 10/20/17**	**Fri 11/3/17**	**No**
22	**Construction**	**95 days**	**Wed 11/8/17**	**Tue 3/13/18**	**No**
23	Contact with external collabora	65 days	Wed 11/8/17	Wed 1/31/18	No
24	Final meeting before foam cut	1 day	Tue 1/30/18	Tue 1/30/18	No
25	Cut Foam with CNC Machine	4 days	Wed 1/31/18	Mon 2/5/18	No
26	Assemble foam sections	1 day	Mon 2/5/18	Mon 2/5/18	No
27	Cut Gunwale and Ribs	1 day	Mon 2/5/18	Mon 2/5/18	No
28	Sand and Plaster	2 days	Tue 2/6/18	Wed 2/7/18	No
29	Paint and Apply Crisco	1 day	Fri 2/9/18	Fri 2/9/18	No
30	Pre-mix dry materials for Pour Day	19 days	Wed 1/17/18	Wed 2/7/18	No
31	Pour Day	1 day	Sat 2/10/18	Sat 2/10/18	Yes
32	Trowel Exterior	2 days	Sat 2/10/18	Mon 2/12/18	No
33	Construct tent and cure canoe	22 days	Mon 2/12/18	Tue 3/13/18	No
34	**Finising**	**38 days**	**Wed 2/22/17**	**Fri 4/14/17**	**No**
41	**Stand Construction**	**91 days**	**Wed 10/25/1**	**Wed 2/21/18**	**No**
46	**Table Top Display**	**121 day**	**Wed 11/1/17**	**Wed 4/11/18**	**No**
52	**Project Overview and Technical Addendum**	**95 days**	**Thu 10/19/17**	**Wed 2/21/18**	**No**
56	**Design Report**	**148 day**	**Wed 9/6/17**	**Fri 3/23/18**	**Yes**
57	Aquire Information for Required Sections	121 days	Wed 9/6/17	Wed 2/14/18	No
58	Deviate Tasks	1 day	Wed 2/14/18	Wed 2/14/18	No
59	Write sections & create tables	21 days	Wed 2/14/18	Wed 3/14/18	No
60	Incorprate Theme into Graphic	6 days	Wed 2/14/18	Wed 2/21/18	No
61	Final Editing	6 days	Wed 3/14/18	Wed 3/21/18	No
62	Copy, Bind, and Mail Report	3 days	Wed 3/21/18	Fri 3/23/18	No
63	**Oral Presention**	**20 days**	**Tue 3/20/18**	**Sat 4/14/18**	**No**
69	**Paddling**	**59 days**	**Sat 1/27/18**	**Sat 4/14/18**	**No**



WIT ASCE Project Schedule 2018 Concrete Canoe Competition

Task	Project Summary	Manual Task	Start-only	Deadline					
Split	Inactive Task	Duration-only	Finish-only	Progress					
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress					
Summary	Inactive Summary	Manual Summary	External Milestone						



Note one	Typical Section Cut
Note two	Precut Gunwale
Note three	2" diameter hole for reinforcement

School: Wentworth IT

TITLE: Game of Stones Mold Design

SIZE B | Drawn By: C.M. Drussell Jr. Checked By: APS, J. Sullivan S. Reynolds | REV

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APPENDIX A - REFERENCES

Martin, George R. (2011). *Game of Thrones,* New York: Bantam Books, Print.

Bates, Bruce R. (2002). *RISA 2D Educational Software*, Risa Technologies, Version 1.0.

WIT ASCE. (2017). *Free WITty Concrete Canoe Design Paper*, Wentworth Institute of Technology, Boston, Massachusetts.

ASTM Standards Referenced in Report:

ASTM C39: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C125: Standard Terminology Relating to Concrete and Concrete Aggregates

ASTM C128: Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate

ASTM C138: Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

ASTM C150: Standard Specification for Portland Cement.

ASTM C173: Air Content of Freshly Mixed Concrete by the Volumetric Method

ASTM C260: Standard Specification for Air-Entraining Admixtures for Concrete

ASTM C494: Standard Specification for Chemical Admixtures for Concrete

ASTM C496 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

ASTM C618: Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

ASTM C1116: Standard Specification for Fiber-Reinforced Concrete and Shotcrete

ASTM C1240: Standard Specification for Silica Fume Used in Cementitious Mixtures

APPENDIX B – MIXTURE PROPORTIONS

CEMENTITIOUS MATERIALS				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Portland Cement Type III	3.15	2.44	*c*: 480.00	*Mass of all cementitious materials, cm* ___*800.00*___ lb/yd^3 *c/cm ratio* ___*0.60*___
Silica Fume Class C	2.53	0.76	m_1: 120.00	
Silica Fume	*2.20*	*1.46*	m_2: 200.00	

FIBERS			
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*
Polypropylene Fibers	1.30	0.04	f_1: 3.2

AGGREGATES							
Aggregates	*Abs (%)*	*MC_{stk} (%)*	*SG*	*Base Quantity (lb/yd^3)* OD	*Base Quantity (lb/yd^3)* SSD	*Volume, SSD (ft^3)*	*Batch Quantity (at MC_{stk}) (lb/yd^3)*
3M Glass Bubbles K-20	A_1: 22.00	0	0.2	$W_{OD,1}$: 74.32	$W_{SSD,1}$:	*5.95*	$W_{stk,1}$:
Poraver 0.1 to 0.3	A_2: 21.00	0.5	0.9	$W_{OD,2}$: 70.94	$W_{SSD,2}$:	*1.26*	$W_{stk,2}$:
Poraver 0.25 to 0.5	A_3: 19.00	0.5	0.75	$W_{OD,3}$: 64.18	$W_{SSD,3}$:	*1.37*	$W_{stk,3}$:
Poraver 1 to 2	A_4: 25.00	0.5	0.44	$W_{OD,4}$: 84.45	$W_{SSD,4}$:	*3.08*	$W_{stk,4}$:
Perlite	A_5: 13.00	0	2.2	$W_{OD,5}$: 43.91	$W_{SSD,5}$:	*0.32*	$W_{stk,5}$:

ADMIXTURES					
Admixture	*lb/gal*	*Dosage (fl.oz/cwt)*	*% Solids*	*Water in Admixture (lb/yd^3)*	
AEA	*0.005*	x_1: 0.0174	s_1: 2.00	$w_{admx,1}$: 0.96	*Total Water from All Admixtures* ___*5.27*___ lb/yd^3
Superplasticizer	*0.16*	x_2: 0.44	s_2: 4.00	$w_{admx,2}$: 4.31	

WATER			
	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		*w*: 320.00	*5.13*
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$:	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: 5.27	
Batch Water, lb/yd^3		w_{batch}:	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb, for1 yd^3)	800.0	20.0	337.8	-	320.0	*M: 1,4778*
Absolute Volume of Concrete, V, (ft^3)	4.66	*0.04*	*11.99*	-	*5.13*	*V: 21.82*
***Theoretical Density, T,** (= M / V)*	171.67	lb/ft^3	*Air Content [= (T – D)/D x 100%]*			*10.0 %*
Measured Density, D	0.044	*lbint^3*	***Slump, Slump flow***			6 *in.*
water/cement ratio, w/c:	0.60		***water/cementitious material ratio, w/cm:***			0.40

APPENDIX C – EXAMPLE STRUCTURAL CALCULATIONS

Buoyant Force

$F_B = w_C + (w_p\ x\ n_p)$

F_B → Buoyant Force

w_C → Weight of the unloaded canoe

w_p → Weight of the paddler

(140lb for female or 180lb for male)

n_p → Number of paddlers present in the canoe

$F_{B1} = 285lb + (140lb\ x\ 2) = 565lb$

$F_{B2} = 285lb + (140lb\ x\ 2) + (180lb\ x\ 2) = 925lb$

$V_d = \frac{F_B}{\gamma} = \frac{925}{62.4}\ x\ 1728 = 25{,}615\ \text{in}^3$

V_d → Volume Displaced

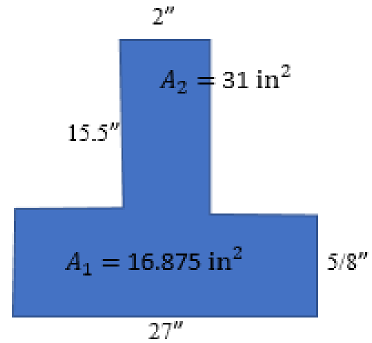
$x_d = \frac{v_d}{SA}$

x_d → distance in the water

SA → Surface Area

$x_d = \frac{25{,}615\ \text{in}^3}{4{,}758\ \text{in}^2}$=5.4in

T-Beam Calculations



$\bar{y} = \frac{A_1 y_1 + A_2 y_2}{A_1 + A_2}$

$= \frac{(16.875 * \frac{5}{16}) + (31 * (7.75 + 0.625))}{16.875 + 31}$=5.533"

$\bar{y}$= Centroid or the Neutral Axis

$$I = \frac{1}{3}[(27)(15.5)^3 - 2(12.5)(15.5)^3 + 2(12.5)(\frac{5}{8})^3$$

I → Moment of inertia

$I = 1017.95\ \text{in}^4$

$\sigma = \frac{M\bar{y}}{I}$, Where σ is the stress and M is the max moment from the RISA 2D analysis

$Factor\ of\ Safety = 1.5$

$$\sigma = \frac{M\bar{y}}{I} = \frac{657.8 * 12 * 5.533}{1017.95} = 42.91psi$$

F_t= 1.5*$42.91psi = 64.36psi$

F_t=7.5*$\sqrt{F_c'}$

$F_c' = \left(\frac{F_t}{7.5}\right)^2 = \left(\frac{64.36psi}{7.5}\right)^2$=73.63psi

F_t → Tensile stress

F_c' → Compressive stress

APPENDIX D- BILL OF MATERIALS

Material	Quantity	Unit Cost	Total Price
Cementious Material			
Portland Cement Type III	124.6 lbs.	$0.10 / lbs.	*Donated*
Fly Ash Class C	31.15 lbs	$0.03 / lbs.	*Donated*
Silica Fume	52.15 lbs.	$0.25 / lbs	*Donated*
Aggregates			
3M Glass Bubbles K-20	19.25 lbs	$6.99 / lbs.	$134.56
Poraver	57.4 lbs	$1.50 / lbs.	$86.10
Perlite	11.55 lbs	$10.00 / lbs	$115.50
Admixtures			
Sikament 686	8.4 lbs	$27.27 / Gallon	*Donated*
Sika AEA-14	0.35 lbs	$18.67 / gallon	*Donated*
Polypropylene fibers	0.7 lbs.	$2.50 / lbs.	*Donated*
Reinforcement			
Fiberglass Mesh	100 sq. ft.	$0.25 / sq. ft.	$25.00
Mold			
Closed cell foam	20 sheets	$50 / sheet	*Donated*
PVC Pipe	20 ft.	$1.25 / ft.	$25.00
Rubber Cement	4 oz.	$0.50 ea.	$2.00
Finishing			
Sealant	2 gallons	$12.00 / gallon	$24.00
Plaster	50 lbs.	$0.15 / lbs	$7.50
Racings			
Racing Paddles	4	$25.00 ea.	$100.00
Protective Foam	17 ft.	$0.39 / ft.	$6.63
Wetsuit Rentals	10	$20.00 ea.	$200.00
Adult Waders	3	$99.99 ea.	$199.98