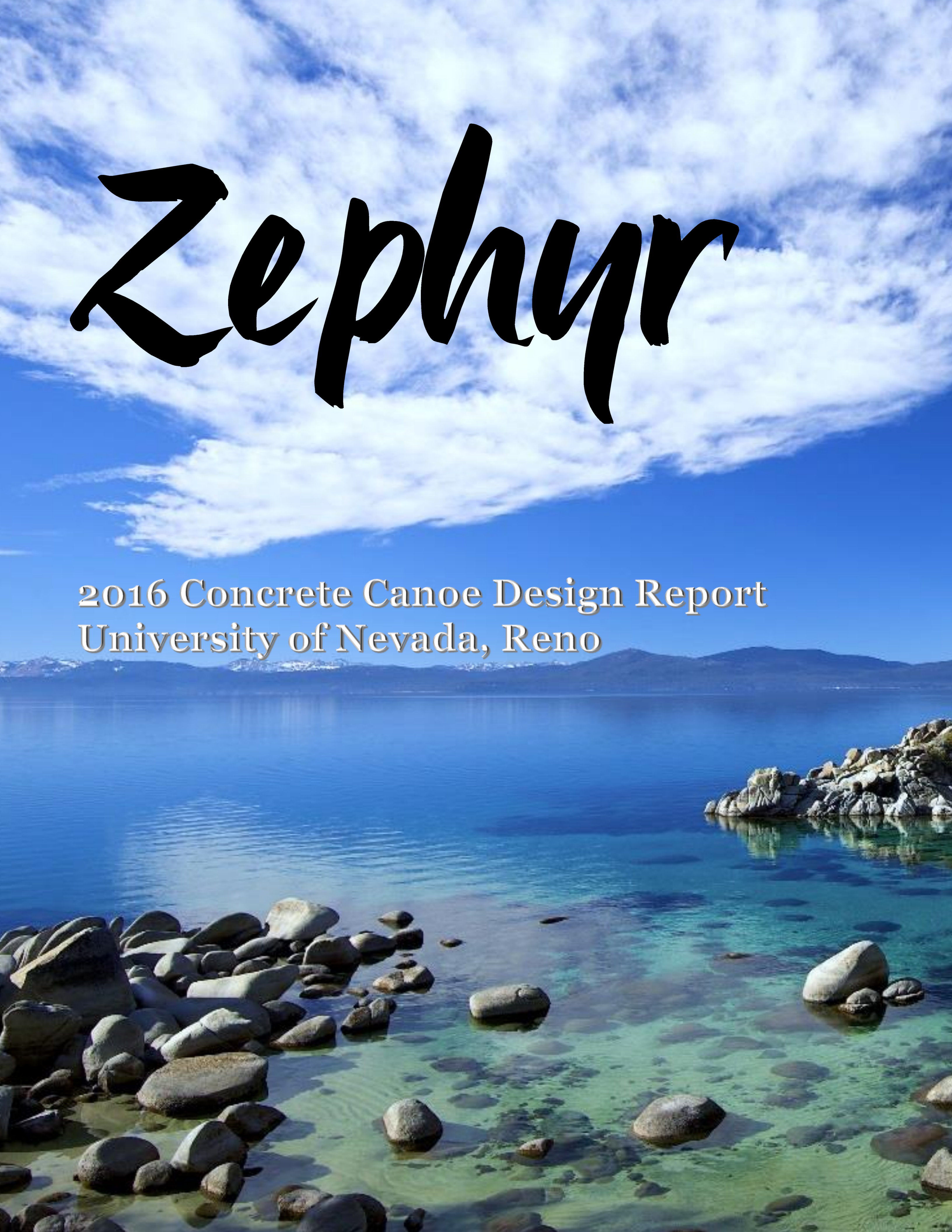
Zephyr

2016 Concrete Canoe Design Report
University of Nevada, Reno



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Executive Summary

Distinguished as the "Jewel of the Sierra", Lake Tahoe is world renowned for its unique ecological surroundings and extraordinary water clarity (Tahoe Fund 2016). In recent years, the lake's gradual decline in water quality has become more severe across the basin, especially at one of Tahoe's most prominent destinations, Zephyr Cove. With increased development and insufficient erosion control measures that continue to degrade Lake Tahoe's water, corrective restoration endeavors have been put in place to reinstate the clarity (CEPA 2006). The perseverance and improvement efforts to restore the lake to its original qualities accurately reflect the determination and dedication of the University of Nevada, Reno's 2016 Concrete Canoe Team.

The University of Nevada, Reno, located in Reno, Nevada, is positioned 37 miles downstream the Truckee River from Lake Tahoe and Zephyr Cove. The University is comprised of nearly 21,000 students, 394 of which are within the College of Civil and Environmental Engineering (UNR 2016). The Nevada Concrete Canoe Team participates in the Mid-Pacific Conference alongside a range of highly competitive schools. After earning their first trip to the National Concrete Canoe Competition (NCCC) in 2006, the team continues to excel at both the regional and national level competitions, with most recent submissions *Aquatone* (6th, 2015), *Alluvium* (1st, 2014), and *Dambitious* (2nd, 2013).

Led by junior division managers from the preceding year, the 2016 team met design goals of a structurally sufficient and aesthetically pleasing canoe through the formation of two individual concrete mixes (Table 1). The implementation of pigmented concrete required a slow, more precise casting process, which threatened the structural integrity of the concrete. Based on these foreseen challenges, team members performed innovative testing procedures simulating the presence of cold-joints to verify the concrete could withstand a newly proposed two-day casting period. The inclusion of hollow microspheres and Type S hydrated lime created the desired aesthetic properties for interior and exterior surfaces. Pigmented concrete allowed the team to create an aesthetically pleasing finish with an array of colors representing the deep blue water and turbidly green shallow shoreline of Zephyr Cove.

Table 1: Concrete Properties

Mix Design	Unit Weight Wet/Dry (pcf)	28-Day Compressive Strength (psi)	28-Day Composite Flexural Strength (psi)	14-Day Tensile Strength (psi)	Air Content (%)
Structural	52.2/48.9	1940	1240	870	9.8
Patch	54.4/43.5	2060	N/A	580	17.3

Supplementary research and acquisition of new materials increased sustainability of canoe composite properties. Replacing steel tendons with Kevlar® exhibited a much higher load capacity, reducing the amount of tendons necessary and time spent to place the canoe into tension. This new material's improved durability decreased overall cost and reduced construction hours. Alterations to the canoe's hull included a decrease in overall length and increase in rocker height, improving maneuverability and minimizing turning time. Final canoe specifications are shown in Table 2.

Table 2: Final Canoe Specifications

Dimensions	
Colors	Grey, Blue, Green
Weight (lbs.)	142
Length (max)	18 ft. 11 in.
Width (max)	23 in.
Depth (max)	12.5 in.
Thickness (avg.)	0.5 in.
Reinforcement (Primary)	
0.125 in. dia. Kevlar® Cable	
1.5 in. Carbon Fiber Mesh	
0.25 in. Steel all Thread	
0.5 in. Galvanized Steel All Hardwear Cloth	
Reinforcement (Secondary)	
6 mm and 12 mm PVA Fibers	

Managers sought out a local firm to assist with the major modifications to a previous year's form, decreasing overall costs of production. Additionally, the team reduced environmental impacts through the construction of a more efficient curing system, reducing excess water during the 28-day process.

The unique challenges encountered by the scientific and engineering communities in preserving the region's most valuable natural resource inspired the innovative approach to the research, construction, and aesthetical presentation for the University of Nevada, Reno's 2016 canoe: *Zephyr*.

Project Management

In order to complete the project efficiently, the project managers (PMs) developed a project schedule in which they defined the major milestones needed to complete the project. To determine these milestones, the PMs first compiled a list of goals needed to compete in the regional conference. In addition, a list of subtasks was created and a duration was assigned to each subtask. The PMs planned a new design of the hull, as well as the repair and use of a previous Nevada canoe mold to achieve an innovative new design while maintaining sustainable practices. Additional time was appropriated towards Development and Testing to further research how to best overcome the challenge of using pigmented concrete, a task that no previous Nevada team had done. This additional time placed the casting date in the spring, reducing finishing time in order to complete the canoe on time. A later casting date also meant that early construction would have more float than initially planned, and more time could be allocated towards hull design and structural analysis research. After establishing these milestones and task durations, the PMs identified the critical path and established a year-long schedule (“Project Schedule”; Page 11).

The PMs delegated critical path completion to managers who assumed leadership over separate divisions of the project. Each division manager accounted for individual man-hours and created schedules to efficiently reach the pre-determined milestones. Managers identified tasks from the schedule that had a higher likelihood to delay the completion of a milestone. The managers mitigated these risks by employing quality control and quality assurance practices throughout their divisions. Communication of these procedures to team members occurred through weekly team meetings, safety meetings, and group-messaging applications.

To better approximate the amount of time and material needed for Development and Testing research, a spreadsheet implementing a Monte Carlo statistical analysis was compiled that evaluated each stage of the research process (RiskAmp 2016). The analysis defined the maximum and minimum number of mixes each step of the Development and Testing research process required, then determined the total number of mixes for each step. This process was repeated 500 times to improve its statistical accuracy. Using a 90 percent confidence interval, the PMs determined that 68 mixes would be needed to complete the desired Development and Testing research. The design team referenced this number when ordering materials and establishing the schedule. The actual number of tests needed to complete the research was in fact 68 tests As a result, no excess material was procured for testing, resulting in both financial and environmental sustainability.

The management team prioritized financial sustainability to procure materials needed for a quality product. The team decided to reuse a previous Nevada canoe mold and saved over $1,000 in mold preparation costs. The Construction division redirected the savings towards purchasing Kevlar® prestressing tendons which cost more than conventional steel tendons. In addition, new springs were purchased to tension the prestressing tendons. Funds were also redirected to the Development and Testing division, to purchase Q-Cels®, a more expensive aggregate. By achieving financial sustainability in material acquisition, the development and construction divisions purchased all the additional material required for the adjusted research process.

The safety officer ensured that strict safety protocol was kept during both material testing and construction throughout the project. Following material testing activities, the safety officer disposed of all chemical and industrial wastes in compliance with university Environmental Health and Safety regulations. During construction, the safety officer implemented the use of Activity Hazard Analysis sheets to be completed at every construction session. The construction and mix design divisions followed the safety procedure circuit created by the safety manager. This process made all participants aware of the dangers of a task and the appropriate methods to mitigate them. Use of appropriate Personal Protective Equipment was enforced by all managers. By following these measures, there were zero reported injuries for the 2016 year, maintaining Nevada’s exceptional record of workplace safety.

Project Management Resource Allocation

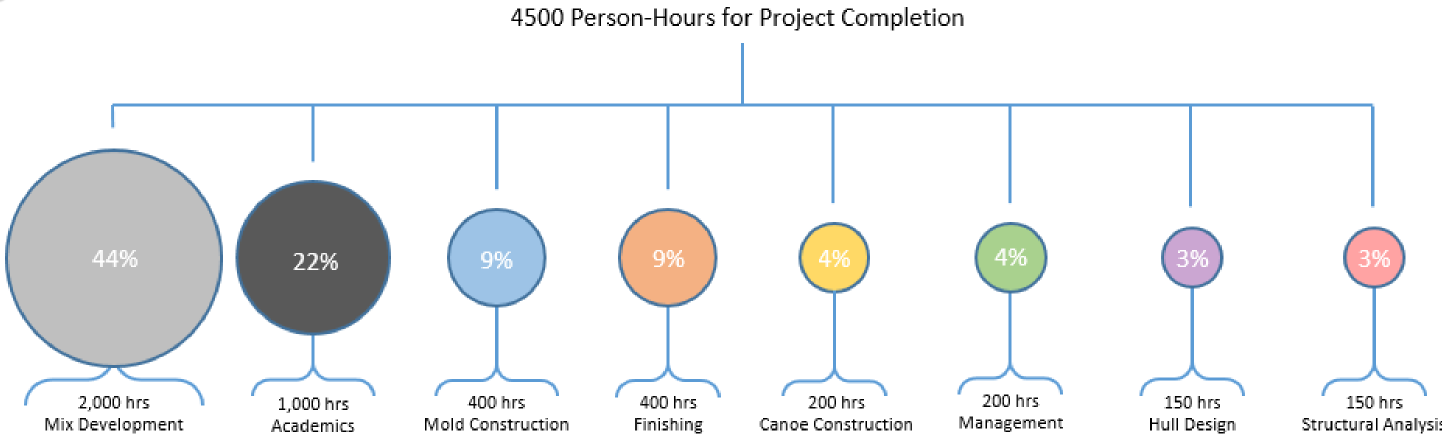


Figure 1: Allocation of Man-Hours

Table 3: Notable Variations in Project Schedule

Task	Variance	Reason
Computer Software Learning	23 Days	More Hours for Hull Design
Form CNC	17 Days	Broken Form
Canoe Casting Complete	29 Days	Cold-Joint Testing

Table 4: Identification of Major Milestones

Major Milestones	
Project Start	Canoe Casting Complete
Competition Rules Release	Canoe Finished
Hull Design Complete	Paper Complete
Analysis Complete	Final Mix Selection
Mid-Pacific Conference	

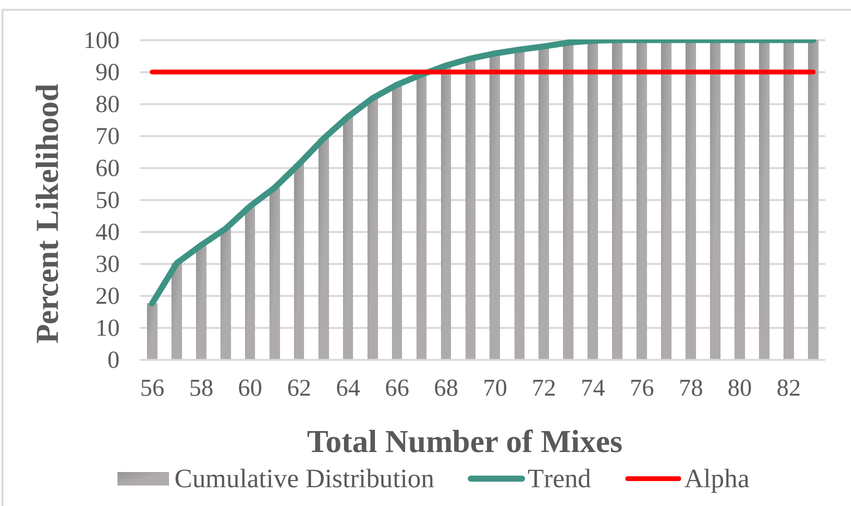


Figure 2: Monte Carlo Probability for Development and Testing

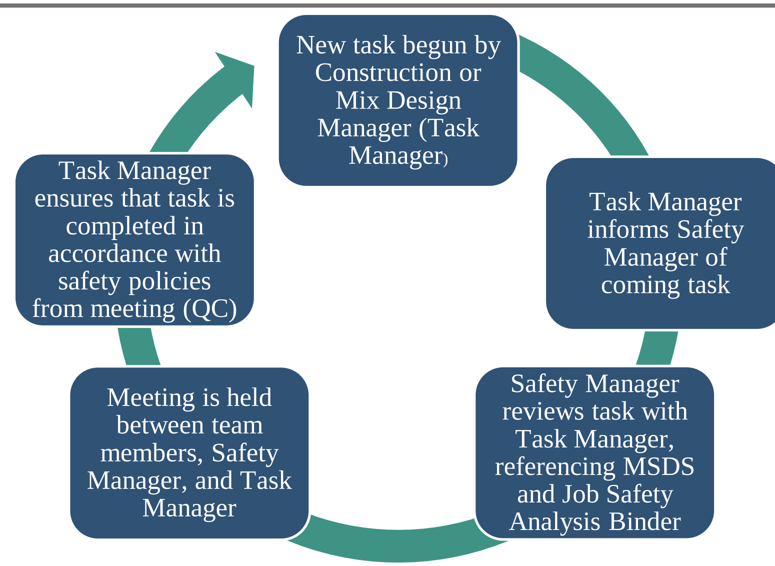
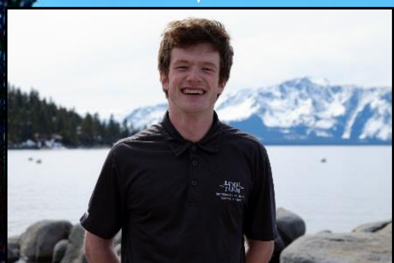


Figure 3: Safety Procedure Circuit

Organization Chart

Danielle Palffy (Jr.) & Evan Jordan (Jr.)
Project Managers

Directed all project tasks and oversaw quality control practices. Responsible for budget appropriation, schedule formation, and tasks delegation.

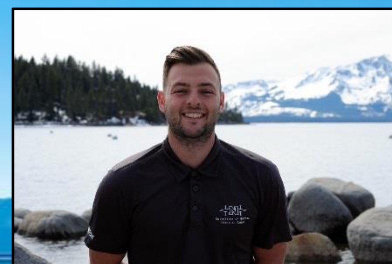


Sandy Cumming (Jr.)
Mix Design Manager

Directed mix design members in product research, material procurement, trial batching, and testing

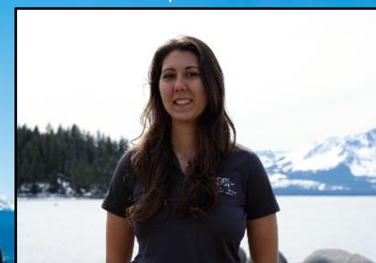
Olivia Dillon (Sr.)
Safety Manager

Updated MSDS and Job Safety Analysis binders, demonstrated safety techniques, and worked with EH&S for compliance with all inspections.



Ryen Blair (Jr.)
Construction Manager

Directed construction from form preparation, concrete casting, and canoe finishing.



Janae Johnston (Jr.)
Aesthetics Manager

Conceptualized artwork for project including canoe theme, colors, pattern, display table, and canoe stand.

Assistants

MIX	CONSTRUCTION		AESTHETICS
Katelyn Kramer (So.)	Guillermo Munoz (Sr.)	Devin Larson (Sr.)	Tanya Flint (Jr.)
Alex Hansen (So.)	Peter Margaretich (Sr.)	Joyce Belen (Sr.)	Janae Johnston (Jr.)
Tanya Flint (Jr.)	Katelyn Kramer (So.)	Irene Serrano (Sr.)	Joyce Belen (Sr.)
Joyce Belen (Sr.)	Johnathan Wagner (Sr.)	Janae Johnston (Jr.)	Katelyn Kramer (So.)
Irene Serrano (Sr.)	Otto Tang (So.)	Dallas Babcock (Fr.)	

Paddling Team

Ryen Blair (Sr.)	Danielle Palffy (Jr.)
Devin Larson (Sr.)	Joyce Belen (Sr.)
Guillermo Munoz (Sr.)	Tanya Flint (Jr.)
Peter Margaretich (Sr.)	Katelyn Kramer (So.)
Evan Jordan (Jr.)	Irene Serrano (Sr.)

Hull Design and Structural Analysis

Managers used the previous year's canoe *Aquatone* as the baseline for its hull design (UNRCC 2015c). *Aquatone* had features that emphasized straight-line speed but was difficult to turn. The primary goal of *Zephyr's* hull design was to increase maneuverability of the canoe while retaining straight-line speed and paddler stability.

Managers redesigned three main components of the hull to enhance maneuverability: the waterline length, the rocker, and the keel. The waterline length was decreased from 22 ft. to 20 ft. Managers reduced the length due to its beneficial impact on turning by decreasing the resistance to turning. This resistance is caused by the turning moment; this moment is dictated by the distance from the center of turning and the wetted surface area.
Rocker is the vertical distance from the lowest point of the canoe to the bottom of the bow or stern. Increasing the rocker height in the bow by 15 percent and in the stern by 20 percent shifts the ends of *Zephyr* upwards, reducing the turning moment and decreasing the effective length.

The final turn-based design consideration was the keel. The keel resists horizontal translation of the canoe, impeding turning (Winters 2005). *Zephyr's* hull design reduced the vertical slope of Aquatone's keel for increased maneuverability (Figure 4). The two designs exhibit similar displacements; however, *Zephyr's* shallower slope causes a more lateral shape. By distributing the buoyant force over a greater lateral area, *Zephyr's* submerged depth is lower in magnitude, decreasing tracking yet improving turning time.

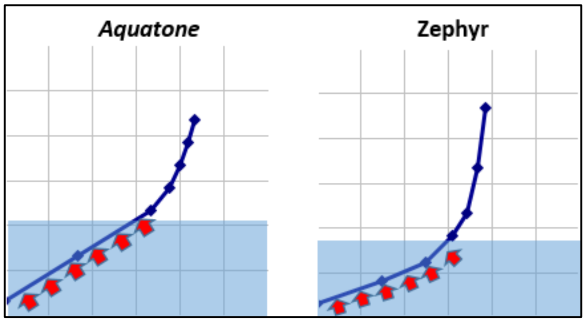


Figure 4: Profile Views of the Keel for Aquatone and Zephyr

Managers estimated maneuverability through the use of a proven hull design spreadsheet created by the Nevada team (UNRCC 2008). The spreadsheet calculates the time to complete a 180° turn. At 1-ft. intervals, the hull design team calculated turning time in seconds using Equation (1):

$$t = \sqrt{\sum Ad * (1 + 2sin\theta)} \tag{1}$$

where A is the submerged profile area of each interval, d is the distance from the center of turning, and θ is the angle of the keel in degrees. Data collected in past competitions shows good correlation (+/- 10 percent) between measured turning times and times predicted by the equation, justifying its use. The analysis proved that maneuverability increased by calculating *Zephyr's* turning time to be 2.5 percent faster than *Aquatone's* time.

The hull design team retained straight-line speed by maintaining a similar length-to-beam ratio to *Aquatone*. Straight-line speed is quantified using the spreadsheet's implementation of KAPER, an analysis program that estimates the drag on watercraft. The total calculated drag on *Zephyr* is 2.5 percent less than that of *Aquatone*, indicating that it will be faster on straight sections of the races.

After conducting the above changes in *Zephyr's* hull design, the team achieved their goals of lowering the turning time and retaining the overall speed. With a reduced length and width, however, the new hull design compromises freeboard relative to *Aquatone*, lowering stability. Additional side wall height was added to account for the estimated 32 percent reduction in freeboard. The final hull design of *Zephyr* achieves all the goals of the design team, with turning times and total drag being improved by 2.5 percent, all while maintaining stability.

Unfortunately, the CAD file used during machining was incorrect. The CNC (Computer Numerical Control) model was scaled five percent smaller than the intended final product. Once this error was identified, managers updated the analysis with the new dimensions, including *Zephyr's* new 18 ft. 11-inch length. With new dimensions established, the next task was to analyze the canoe and perform the structural design. The goal of *Zephyr's* structural analysis was to ensure that the design loads would not exceed the stress capacities of the concrete. The team analyzed four different load cases to determine the demands on the canoe. Modeling the canoe was performed using a spreadsheet created by the Nevada team, assuming the canoe to be a 2-dimensional beam (UNRCC 2008).

The analysis process began with the input of canoe dimensions, the material properties of the concrete, and the location and magnitude of paddler loads. Using the spreadsheet, relevant structural parameters were calculated at 1-ft. intervals along the longitudinal length of the canoe. These parameters included the moments of inertia, centroids, and cross-sectional areas. The team then calculated the location discrepancy between the resultant forces of the non-uniformly distributed buoyancy forces, self-weight, and the concentrated paddler loads. These calculations assured rotational and vertical equilibrium by solving for the pitching angle and water line for each paddler loading scenario.

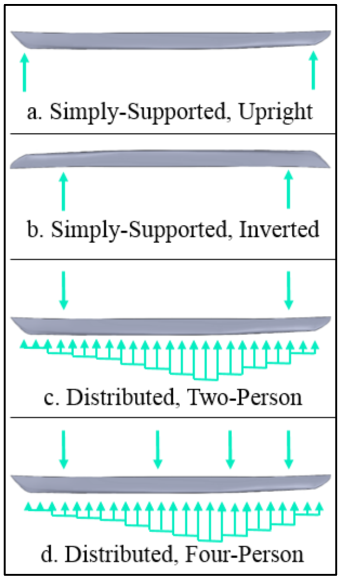


Figure 5: Loading Cases

Four idealized loading cases, shown in Figure 5, were considered for *Zephyr's* analysis: transportation, display, male sprint, and co-ed. The structural analysis team calculated transportation and display as simply-supported beams using the non-uniformly distributed self-weight of the canoe as the only applied loads. The transportation loading case (Figure 5a) modeled the canoe being carried on either end by two people. This case was found to have the maximum positive moment at 305 lb-ft. The display scenario (Figure 5b) was analyzed inverted with point supports acting at 36 and 192 in. from the bow. The display case was found to have no governing moments. Paddler loading cases all were analyzed as being supported by non-uniformly distributed hydrostatic reactions, based on the calculated water-line elevation and water-line angle relative to the canoe. The male paddler scenario (Figure 5c) had two concentrated loads of 225 lbs located 36 in. and 192 in. from the bow for conservative analysis. The co-ed scenario (Figure 5d) had 225 lbs located 36 in. and 108 in. from the bow, and 150 lbs located at 156 in. and 192 in. The male paddler loading scenario had the maximum negative moment of -777.1 lb-ft. To consider load amplification due to the dynamic loading (Paradis and Gendron 2006), a load factor of 1.25 was applied to the calculated moments to obtain a maximum positive moment of 382 lb-ft. and a maximum negative moment of -971 lb-ft.

The prestress system was designed to bring the flexural stresses caused by the moments the loading conditions to within allowable limits. The total prestress load was determined to be 4,800 lbs distributed across 12 tendons each tensioned 400 lbs The assumed losses in the tendons due to relaxation, elastic shortening, shrinkage, and creep in the concrete were assumed to be 25 percent in accordance with AASHTO LRFD Bridge Design Specification (AASHTO 2016), serving as a conservative estimate. Three tendons were situated along the gunwale of the canoe in order to reduce the negative moment experienced during paddler loads. However, this increased the flexural tensile stress towards the bottom and three more tendons were subsequently placed along the chine and bottom to lessen the tensile stresses.

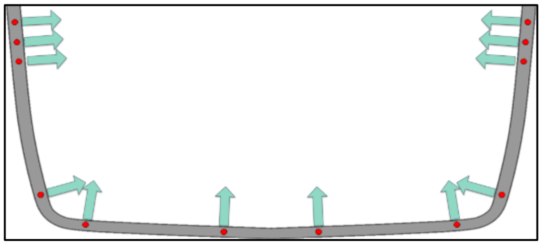


Figure 6: Profile View of Out-of-Plane Forces

Additional innovative analysis was conducted to determine the in and out-of-plane forces caused by the tendons in accordance with AASHTO 5.10.4.3 (AASHTO 2016). Prestressing forces were idealized as concentrated loads acting radially (Figure 6). The out-of-plane force was determined by dividing the tensile load of the tendon by the product of the radius of curvature at that point and pi, the largest magnitude being 177 lbs The in-plane force along a seven-inch transfer length was determined to be 965 lbs using a representative pull-out test based off of ASTM C900 (ASTM C900). The test indicated that negligible slippage would occur between the tendons and the concrete.

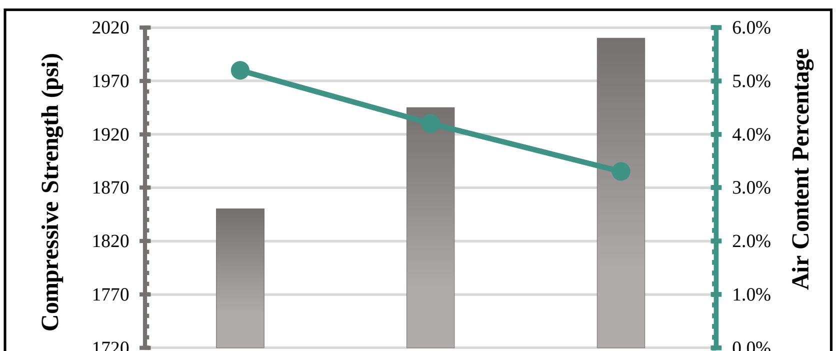
Accounting for all internal moments and shear at 1-ft. intervals, the structural analysis team determined the path and force required for the prestressing tendons to prevent cracking of the concrete. Four ribs were added as stiffeners against the large magnitude of prestressing forces, and a dual-layer carbon-fiber reinforcement scheme raised the composite flexural strength of the canoe. Compiling all factors, the analysis determined *Zephyr's* minimum required concrete compressive strength of 910 psi and minimum Modulus of Rupture of 140 psi.

Development and Testing

The design team set goals to explore new mix constituents and enhance overall canoe aesthetics while meeting structural analysis requirements. In order to achieve the determined goals, design managers allocated time towards testing of individual mix components and primary reinforcement, resulting in a re-evaluation of the single day casting period custom to previous years. Through the development of additional flexural strength tests, managers evaluated the capabilities of the composite concrete properties, resulting in the construction of a competitive final product.

Aquatone's structural mix provided an optimal baseline mix due to its sufficient flexural strength and low unit weight (UNRCC 2015b). Cementitious materials contained ground-granulated blast furnace slag (GGBFS), Type 1 white portland cement, and vitreous calcium aluminosillicate (VCAS™) in proportions of 10 percent, 30 percent, and 60 percent, respectively. The aggregate gradation consisted of recycled glass Poraver® Siscorspheres, ranging in size from 0.1 to 4 mm in diameter, and engineered polymeric spheres Syntheon® Elemix™, helping reduce the total unit weight. Inclusion of polyvinyl alcohol (PVA) fibers at 0.87 percent by volume aided in an optimum flexural strength. Admixtures ADVA® Cast 575, a high range water reducer (HRWR), improved the workability of the concrete, while V-MAR® F100 (V-MAR), a viscosity modifier, and Rhoplex® MC-1834P, a polymer modifying admixture (PMA) improved adhesion of the concrete to the male mold. The addition of Hycrete® X1002, a permeability-reducer, decreased moisture absorption and Daravair®, an air entraining admixture (AEA), achieved an air content of nine percent. Following an initial trial batch, the design team implemented quality control measures by conducting compressive strength tests on 2 in. by 4 in. cylindrical samples at 7, 14, and 28-day intervals and found a 28-day compressive strength of 1,900 psi (ASTM C39) and a dry unit weight of 49.8 pcf (ASTM C138).

Restrictions from using concrete stain prompted design managers to include powdered pigment for physical application and determine required changes needed to the baseline mix properties. The design team tested the baseline mix with pigment dosages ranging from 0.5 to 10.0 percent mass of cement (ASTM C979). Initial inspection of the freshly batched concrete resulted in non-uniform coloration throughout the mix due to Elemix™, contradicting with the team's goal of a quality final product. Design managers concluded that Elemix™ could not consistently combine with the powdered pigments, which led to the removal of the polymeric spheres to enhance the finishing qualities of the concrete.



	6% Q-Cel	8% Q-Cel	10% Q-Cel
Compressive Strength	1850	1945	2010
Air content	5.2%	4.2%	3.3%

Figure 7: Compressive Strength by Air Content for Q-Cel® Integration

Design managers researched and tested alternative aggregates to Elemix™ to create a concrete mix capable of meeting structural requirements and with improved finishing characteristics when mixed with the powdered pigment. The design team sought the possible benefits of adding a new aggregate constituent, Q-Cel® 6019S hollow spheres. The team performed a proper sieve analysis on the new material to determine the gradation curve of the new aggregate (ASTM C136). The spheres were then integrated into the mix at six percent, eight percent, and 10 percent by volume. Design managers observed an inversely proportional relationship in compressive strength and air content, represented between Figure 7. The 150 micron diameter hollow microspheres exceeded required strength values while also creating a smooth finish at a six percent addition. Several trial batch iterations helped managers determine the final optimum aggregate proportion of six percent by volume, balancing a sufficient compressive strength with the lowest unit weight achieved during testing.

Integration of Q-Cel® microspheres created a uniform surface finish, but it produced a mix with decreased workability. The concrete's low plasticity prompted design managers to investigate possible alterations and additional mix components to increase workability. Hydrated Lime Type S assisted with creating a more cohesive and plastic mix, and it was an ideal choice due to its low density and white appearance. Consisting of less than one micron in size, the lime greatly increased the degree of bonding, making it ideal for improving the plasticity of the mix.

An effort to improve upon sustainability prompted the design team to test optimal cementitious proportions by reducing the least sustainable material, portland cement, and increasing supplementary materials, VCAS™ and GGBFS, to compensate. Compressive strength tests at 7, 14, and 28-days proved insufficient compared to required values from the structural analysis. Subsequent strength testing by the design team led to a reduction in the material consisting of the largest supplementary cementitious proportion, VCAS™. However, time constraints for development and testing determined a total reduction of five percent of VCAS™ from the baseline met strength values required by analysis. To avoid compromising additional project goals, managers made the executive decision to continue the development period without further testing of the cementitious components.

The design team continued with the development process by testing altered admixture dosages to optimize concrete properties. Maintaining the dosage of Rhoplex® improved adhesion to both the polyurathane mold and structural mix, while the inclusion of ADVA® Cast and V-MAR® aided in cohesion and prevented segregation. Daravair® assisted in creating an air content of approximately seven percent. The incorporation of lime, which reduces the potential for absorption, led to the omission of Hycrete® from the final mix design. Testing demonstrated no adverse effects or loss of strength with the removal of Hycrete®. Table 5 summarizes the final admixture dosage rates. The team consulted previous managers due to increased dosages of admixtures compared to the manufacturer's recommendations, and based on testing procedures and previous years' applications, larger dosages were deemed necessary for the desired workability. Integrated at an equal volume to the baseline, PVA fibers of 6 mm and 12 mm in size provided an optimal flexural strength based on structural analysis requirements. Test results of 28-day samples surpassed structural analysis requirements (Table 6), yielding a compressive strength of 1,940 psi, an acceptable unit weight of 52.2 pcf, and a modulus of rupture of 300 psi. In addition, a 14-day split tension test of 6 in. x 12 in. cylinders resulted in a tensile strength of 870 psi (ASTM C496). Appendix B outlines the final structural mix.

Table 5: Admixture Dosages

Admixture	Type	Recommended Dosage	Actual Dosage
ADVA® Cast 575	HRWR	2-10 fl. oz./cwt	45 fl. oz./cwt
Daravair® AT30	AEA	0.25-3 fl. oz./cwt	12 fl. oz./cwt
Hydrated Lime	S	N/A	31.5 lb/yd^3
Rhoplex® MC-1834P	PRAH	N/A	90 fl. oz./cwt
V-MAR® F100	VMA	3-12 fl. oz./cwt	35 fl. oz./cwt

Due to the effectiveness of previous reinforcement use, design managers incorporated carbon fiber mesh to provide additional flexural strength to the composite structure. The fiber's low unit weight, high elastic modulus, and superior bonding to concrete made it exemplary for creating a canoe capable of handling forces endured during competition. The 1.5 in. x 1.5 in. apertures in the carbon fiber mesh resulted in an 82.6 percent open area, providing sufficient space for packing concrete. The adoption of a two tier layering scheme produced results surpassing structural analysis requirements. Design managers also sought possible alternatives to steel tendons with a goal of increasing sustainability while maintaining structural analysis requirements. Managers tested Kevlar® synthetic fiber as a replacement to steel tendons due to its resistance to corrosion and high tensile capacity (DuPont 2016). Representative tests for the pull-out strength of hardened concrete, with Kevlar® as the embedded insert, occurred after a 14-day cure of the concrete and resulted in a pull-out strength value of 965 lbs, surpassing force requirements by more than 40 percent. Kevlar's® high load capacity led to a reduction in the number of tendons from the previous year's value of 18 to 12. In addition,

Table 6: Final Concrete Properties

Property	Analysis Requirements	Actual Results
Compressive Strength (psi)	910	1940
Modulus of Rupture (psi)	140	300
Flexural Strength (psi)	N/A	1240

managers observed improved bonding between the Kevlar® and concrete mix compared to steel tendons. Team members calculated values and reported that the use of synthetic fiber tendons reduced the total weight of prestressing material by approximately 80 percent, verifying Kevlar® as an exceptional replacement to steel tendons.

Previous experience with a single day casting process determined this year would require additional packing time as a result of the detailed aesthetics. Due to these observations, the team elongated the casting period from one to two days for additional quality control during casting. A two day casting period required additional flexural strength testing due to the creation of multiple cold-joints in the canoe. Rigorous testing of concrete and composite capabilities evaluated the feasibility of an extended pour day based on additional flexural strength demands. Design members tested cold-joints with a delay of 12 hours by packing 3 in. x 9 in. beams in the horizontal (Figure 8a), vertical (Figure 8b), and diagonal directions (Figure 8c). Packing of the first half of the beam occurred at zero hours and began curing according to ASTM C192 standards. After 12 hours of initial curing, team members packed the second half of the beam, creating a cold-joint at the intersection. Design managers quantified flexural strength results through third-point beam loading tests. After results were calculated at 7, 14, and 28-days, managers determined that with a 12 hour cold-joint the horizontal separation produced the lowest modulus of rupture values (ASTM C78). The team continued cold-joint testing with horizontal beams to represent the highest risk of failure under expected loading conditions (“Structural Analysis”; Page 5). These tests included additional cold-joint packing times of 16, 20, and 24 hours. Test results concluded the concrete met the required modulus of rupture with a horizontal cold-joint of up to 20 hours after a 28-day cure.

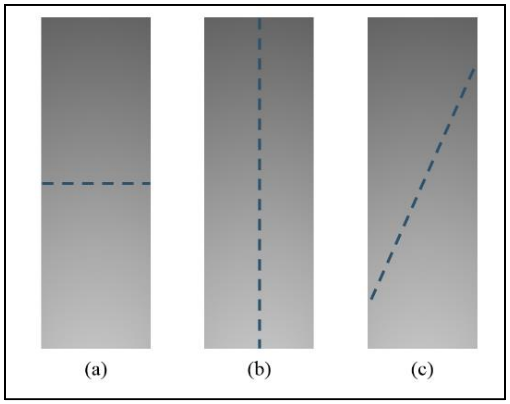


Figure 8: Three Cold-Joint Packing Directions

To create a more accurate representation of the final product, team members performed strength testing using the same delayed packing process with reinforced beam specimens. Each beam contained two layers of carbon fiber mesh with the concrete mix packed horizontally. Team members batched additional concrete at 12 and 24 hours to create the horizontal cold-joint and compared results to a regular flexural strength test without a cold-joint. Analysis of the values determined a 40 percent decrease in flexural strength, compared to a standard beam test, after implementing a 12 hour cold-joint. The strength of the composite samples decreased as cold-joint iterations increased, yet values remained sufficiently greater than the required modulus of rupture, even at 24 hours. The loss in strength with increase in cold-joint delay for both concrete and composite tests as compared to the modulus of rupture required by analysis is illustrated in Figure 9. With the quantitative data available, design managers advanced with the decision to extend the casting period and create intentional cold-joints in the final product.

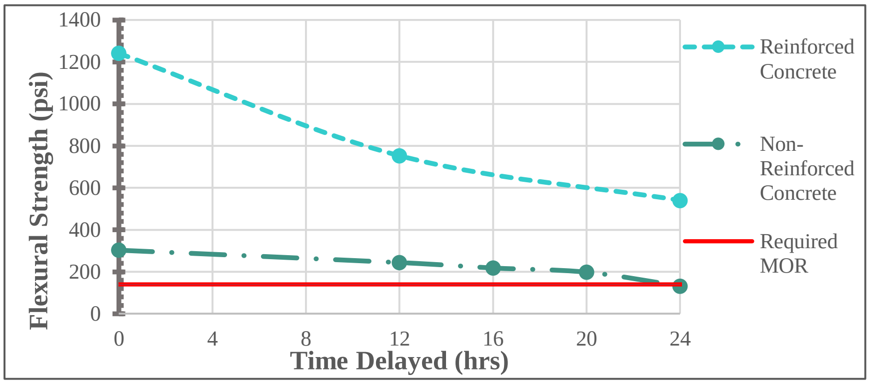


Figure 9: 28-Day Concrete and Composite Strength Results with a Horizontal Cold-Joint

The design team also developed a patch mix to fill surface imperfections while maintaining pigment consistency (Appendix B). A water-to-cementitious ratio of 0.45 and increased admixture dosages created an extremely workable consistency. Removal of aggregate sizes greater than 1 mm, along with PVA fibers, created a smooth finish. *Zephyr’s* design team efficiently structured the development period to allow for additional research into structurally beneficial and sustainable components, providing the Nevada team with a high-quality final product.

Construction

The goal of *Zephyr's* construction team was to retain the streamlined efficiency of *Aquatone's* construction process while incorporating more sustainable materials. To fulfill this standard, the construction team implemented a schedule that utilized previously-used methods but included additional time to accommodate diverse approaches.

A primary component of sustainability was the reuse of a previous two-piece male mold from the 2012 canoe, *Ducimus*. The foam was dense (12 pcf) and required no additional reinforcement to maintain its rigidity. Two problems with the mold prevented its immediate reuse: the majority of the gunwale was damaged and a large cavity in the middle had been dug out for a previously installed air-pressure mold-release system.

Figure 10: Repaired Male Mold

The construction team addressed the problems beginning with the gunwale. Team members removed any structurally incompatible edges of the mold (grey) and replaced them with pieces of foam donated from the local CNC operator (tan). Pieces were cut and placed such that the new gunwale would retain a continuous, uninterrupted perimeter. The team then addressed the cavity in the mold by filling it with contoured foam blocks (Figure 10). Unfortunately, the mold broke when first loaded into the CNC machine. The section containing the repaired hole was not filled properly and could not withstand its own weight when simply supported. The entire cavity was then replaced with a solid block of foam and was subsequently CNC machined.

Following machining, Bondo© body filler was applied to fill locations where chips, depressions, and other small concavities were present. After setting, these repaired areas were sanded down to a desired elevation and shape. The ends of the form were then cut one foot from the bow and stern in order to form the bulkheads during casting. The corners of the bulkheads were heavily sanded using 80-grit sand paper. The bulkhead shape alterations are highlighted in Figure 11. This new circular shape reduces stress on the corners adjoining the bow and stern on the inside of the canoe where cracking was present in *Aquatone*.

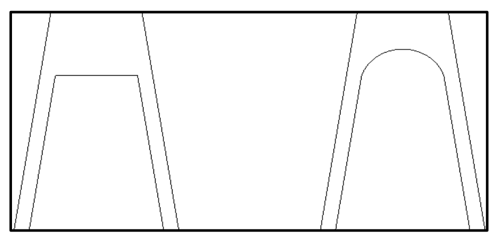


Figure 11: Previous Bulkhead Construction (left) vs. New Bulkhead Construction (right).

The mold was then sealed with eight coats of an industrial primer called Duratec® filling any additional voids and providing a smooth finishing surface that prevented chemical bonding between the concrete and the foam. The team sanded the primer with 1500-grit sand paper after setting. The mold was then waxed with 12 layers of form release wax to ensure easy form removal.

Ribs were placed at various intervals longitudinally along the length of the canoe, providing additional support against transverse bending (“Construction Drawing”, Page 12). Then, ¼ in. diameter steel reinforcements were positioned within the ribs. *Zephyr's* ribs were also made larger than *Aquatone's* to mitigate any risks associated with higher jacking loads from the pre-stress tendons, including radial tear-out.

The coordinates for the tendon path of the pre-stressing system were calculated based on the modified dimensions from the new mold. A series of grade screws were drilled along this path for two reasons: to hold the pre-stress system in place and to serve as depth indicators when packing concrete. An initial layer of carbon fiber reinforcement was then placed between the screws and mold, thus creating an inside layer of reinforcement further mitigating the risk of radial tear-out.

The construction team chose to use Kevlar® cables to prestress the canoe. Pre-tensioned Kevlar® cables have a higher breaking strength than steel cables, and are subsequently safer for the prestressing process. Figure 12 shows the application process of these tendons. The 12 pre-stressing tendons were tensioned up to 400 lbs, a 160 percent increase in the loads applied to each tendon from *Aquatone*. The team utilized tension springs to apply the necessary load, and used Hooke's law to find each spring's displacement to yield the desired force. Placing plastic spacers between the tendons and the form accommodated for concrete packing beneath the tendons.

Figure 12: Kevlar® Tendon Application.

On top of the tendons, team members added an additional layer of carbon fiber mesh to the reinforcement scheme. The team tied the reinforcement layers together to prevent any possible protrusions. This dual-layer system ensured the reinforcement was placed identical to the scheme used during concrete mix development and testing.

Figure 13: Casting the Canoe

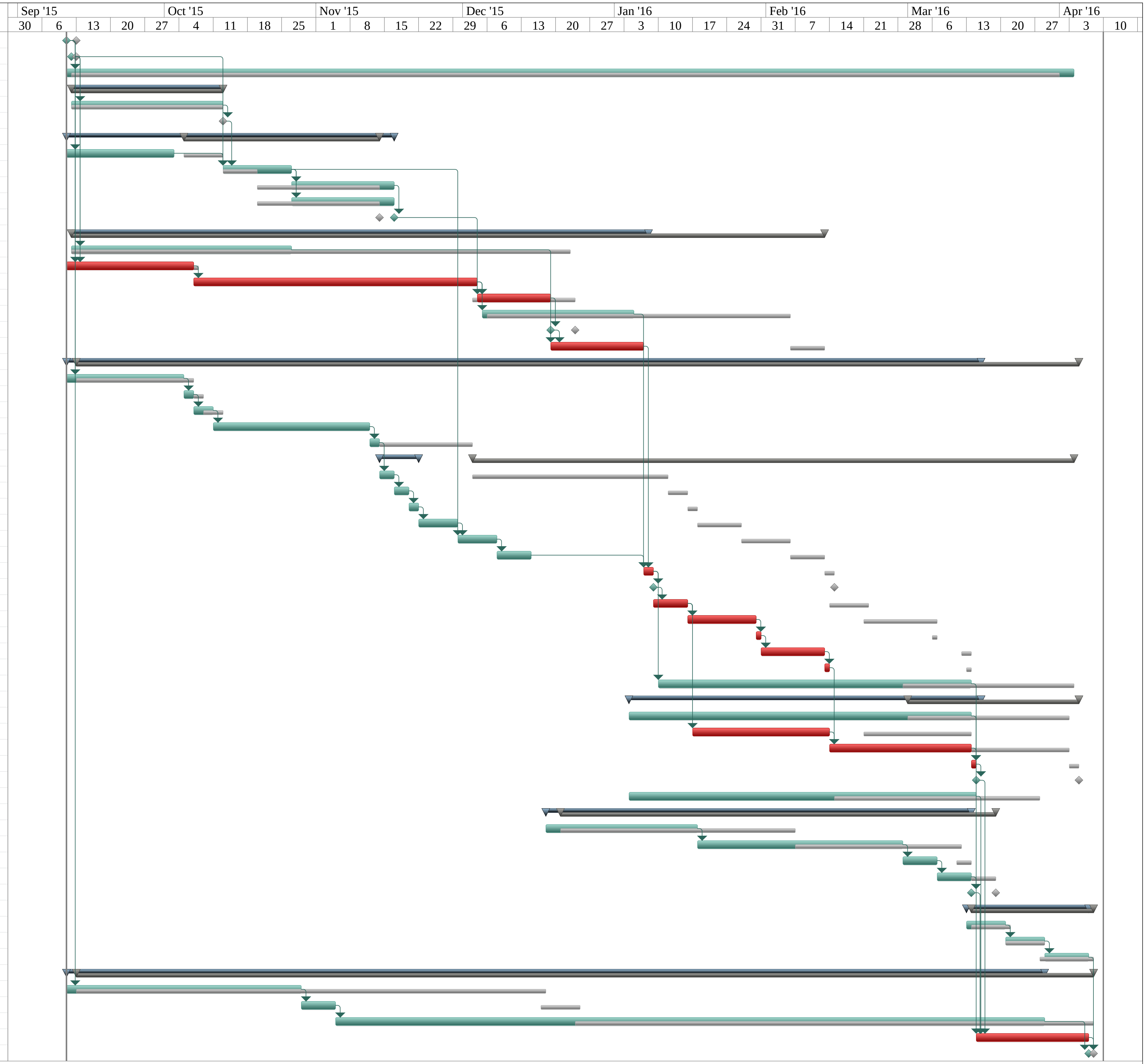
Prior to the casting date, canoe graphics were arranged and areas on the form were shaded with varying ink colors to indicate where colors deviated. Hand-packing the concrete (Figure 13) extended for 17.25 hours over a two-day period, an increase in total casting time of 73 percent from 2015 (UNRCC 2015a). The additional time increased the need for consistently monitoring the concrete thickness and graphics arrangement. Team members upheld quality control throughout the casting process with depth indicators and by following the pre-determined design layout. The increased time allocated for casting day preparation, quality control monitoring, and casting day placement ultimately resulted in a reduced finishing time of four weeks, compared to *Aquatone*.

Figure 14: Team Members Sanding Zephyr

A 28-day cure of the concrete proceeded underneath tightly bound plastic sheeting ensuring optimal strength. The team hand-watered the canoe using spray bottles for seven days following casting. An automated watering system was then used for the remaining cure time. During curing, colored pigments leaked down the sides of the form and accumulated on the bottom of the gunwale. The team began wet sanding the canoe after seen days, as shown in Figure 14. During sanding, the pigments also filled pores in other sections, resulting in color-crossing among sections. To prevent this, extraneous colors were removed with sandpaper and were covered with appropriately colored patch mix. The construction team also made sure to sand within one colored area at a time to prevent the smearing of color across sections and additional use of patch mix.

After the team finished sanding the outside of the canoe, they removed the form by attaching wood planks to pre-embedded steel rods within the foam mold. The team then removed all the spacers and patched the inside and only sanded it down to 400-grit to retain traction for paddlers. The outside was sanded to 1,500-grit to ensure minimal surface-to-water friction and provide the desired aesthetic finish. The canoe was then sealed and made ready for competition. By emphasizing sustainable materials and maintaining an efficient construction schedule, *Zephyr's* construction team created both a reliable and superior product that stands apart from the rest of the competition.

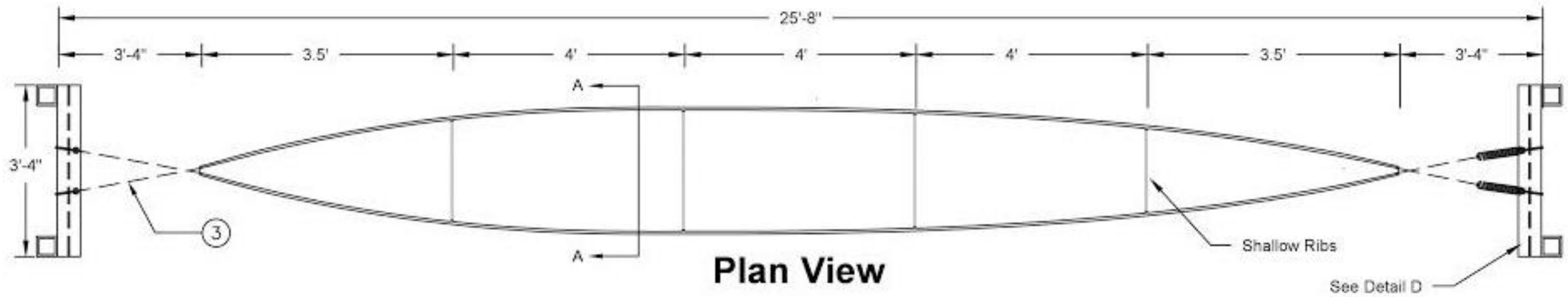
ID	Task Name	Duration	Start	Finish	Actual Start	Actual Finish
1	**Project Start**	**0 days**	**Fri 9/11/15**	**Fri 9/11/15**	**Sat 9/12/15**	**Sat 9/12/15**
2	**Competition Rules Release**	**0 days**	**Sat 9/12/15**	**Sat 9/12/15**	**Sat 9/12/15**	**Sat 9/12/15**
3	**Fundraising**	**206 days**	**Fri 9/11/15**	**Sun 4/3/16**	**Sat 9/12/15**	**Thu 3/31/16**
4	Hull Design	31 days	Sat 9/12/15	Mon 10/12/15	Sat 9/12/15	Mon 10/12/15
5	Hull Design Research	31 days	Sat 9/12/15	Mon 10/12/15	Sat 9/12/15	Mon 10/12/15
6	Hull Design Complete	0 days	Mon 10/12/15	Mon 10/12/15	Mon 10/12/15	Mon 10/12/15
7	Structural Analysis	67 days	Fri 9/11/15	Mon 11/16/15	Mon 10/5/15	Fri 11/13/15
8	Computer Software Learning	22 days	Fri 9/11/15	Fri 10/2/15	Mon 10/5/15	Mon 10/12/15
9	Longitudinal Tendon Analysis	14 days	Tue 10/13/15	Mon 10/26/15	Tue 10/13/15	Mon 10/19/15
10	Composite Analysis and Design	21 days	Tue 10/27/15	Mon 11/16/15	Tue 10/20/15	Fri 11/13/15
11	Kevlar Tendon Testing	21 days	Tue 10/27/15	Mon 11/16/15	Tue 10/20/15	Fri 11/13/15
12	Analysis Complete	0 days	Mon 11/16/15	Mon 11/16/15	Fri 11/13/15	Fri 11/13/15
13	Concrete Mix Design	118 days	Sat 9/12/15	Thu 1/7/16	Sat 9/12/15	Fri 2/12/16
14	Material Procurement	45 days	Sat 9/12/15	Mon 10/26/15	Sat 9/12/15	Tue 12/22/15
15	Research	26 days	Fri 9/11/15	Tue 10/6/15	Sat 9/12/15	Wed 10/7/15
16	Preliminary Design and Testing	58 days	Wed 10/7/15	Thu 12/3/15	Thu 10/8/15	Wed 12/2/15
17	Final Material Testing	15 days	Fri 12/4/15	Fri 12/18/15	Thu 12/3/15	Wed 12/23/15
18	Cold-Joint Testing	31 days	Sat 12/5/15	Mon 1/4/16	Sun 12/6/15	Fri 2/5/16
19	Final Mix Selection	0 days	Sat 12/19/15	Sat 12/19/15	Wed 12/23/15	Wed 12/23/15
20	Pre-Weigh Materials	19 days	Sat 12/19/15	Wed 1/6/16	Sat 2/6/16	Fri 2/12/16
21	Construction	187 days	Fri 9/11/15	Tue 3/15/16	Sun 9/13/15	Mon 4/4/16
22	Laboratory Organization	24 days	Fri 9/11/15	Sun 10/4/15	Sun 9/13/15	Tue 10/6/15
23	Form Table Construction	2 days	Mon 10/5/15	Tue 10/6/15	Wed 10/7/15	Thu 10/8/15
24	Fiberglass Practice Canoe Repair	4 days	Wed 10/7/15	Sat 10/10/15	Fri 10/9/15	Mon 10/12/15
25	Form Repair	32 days	Sun 10/11/15	Wed 11/11/15	Thu 10/13/16	Fri 11/13/15
26	Form CNC	2 days	Thu 11/12/15	Fri 11/13/15	Sat 11/14/15	Wed 12/2/15
27	Form Preparation	8 days	Sat 11/14/15	Sat 11/21/15	Thu 12/3/15	Sun 4/3/16
28	Bondo	3 days	Sat 11/14/15	Mon 11/16/15	Thu 12/3/15	Mon 1/11/16
29	Duratec	3 days	Tue 11/17/15	Thu 11/19/15	Tue 1/12/16	Fri 1/15/16
30	Wax	2 days	Fri 11/20/15	Sat 11/21/15	Sat 1/16/16	Sun 1/17/16
31	Grade Screw Installation	8 days	Sun 11/22/15	Sun 11/29/15	Mon 1/18/16	Tue 1/26/16
32	Tendon Application	8 days	Mon 11/30/15	Mon 12/7/15	Wed 1/27/16	Fri 2/5/16
33	Tie Reinforcement	7 days	Tue 12/8/15	Mon 12/14/15	Sat 2/6/16	Fri 2/12/16
34	Canoe Casting	2 days	Thu 1/7/16	Fri 1/8/16	Sat 2/13/16	Sun 2/14/16
35	Canoe Casting Complete	0 days	Sat 1/9/16	Sat 1/9/16	Sun 2/14/16	Sun 2/14/16
36	Concrete Preliminary Curing	7 days	Sat 1/9/16	Fri 1/15/16	Sun 2/14/16	Sun 2/21/16
37	Concrete Final Curing	14 days	Sat 1/16/16	Fri 1/29/16	Sun 2/21/16	Sun 3/6/16
38	Prestress Tendon Release	1 day	Sat 1/30/16	Sat 1/30/16	Sun 3/6/16	Sun 3/6/16
39	Grade Screw Removal	13 days	Sun 1/31/16	Fri 2/12/16	Sat 3/12/16	Sun 3/13/16
40	Form Removal	1 day	Sat 2/13/16	Sat 2/13/16	Sun 3/13/16	Sun 3/13/16
41	Cross-Section Construction	64 days	Sun 1/10/16	Sun 3/13/16	Mon 2/29/16	Sun 4/3/16
42	Finishing	72 days	Mon 1/4/16	Tue 3/15/16	Tue 3/1/16	Mon 4/4/16
43	Sealer Research & Testing	70 days	Mon 1/4/16	Sun 3/13/16	Tue 3/1/16	Sat 4/2/16
44	Patching/Sanding Exterior	28 days	Sun 1/17/16	Sat 2/13/16	Sun 2/21/16	Sun 3/13/16
45	Patching/Sanding Interior	29 days	Sun 2/14/16	Sun 3/13/16	Mon 3/14/16	Sat 4/2/16
46	Sealing	1 day	Mon 3/14/16	Mon 3/14/16	Sun 4/3/16	Mon 4/4/16
47	Canoe Finished	0 days	Tue 3/15/16	Tue 3/15/16	Mon 4/4/16	Mon 4/4/16
48	**Display Table**	**71 days**	**Mon 1/4/16**	**Mon 3/14/16**	**Mon 2/15/16**	**Sun 3/27/16**
49	Design Report	87 days	Fri 12/18/15	Sun 3/13/16	Mon 12/21/15	Fri 3/18/16
50	Compose Rough Draft	31 days	Fri 12/18/15	Sun 1/17/16	Mon 12/21/15	Sat 2/6/16
51	Peer/Professional Editing	42 days	Mon 1/18/16	Sun 2/28/16	Sun 2/7/16	Fri 3/11/16
52	Final Revisions and Review	7 days	Mon 2/29/16	Sun 3/6/16	Fri 3/11/16	Sun 3/13/16
53	Print Design Paper	7 days	Mon 3/7/16	Sun 3/13/16	Mon 3/14/16	Fri 3/18/16
54	Paper Complete	0 days	Sun 3/13/16	Sun 3/13/16	Fri 3/18/16	Fri 3/18/16
55	Oral Presentation	25 days	Sun 3/13/16	Wed 4/6/16	Mon 3/14/16	Thu 4/7/16
56	Compose Verbal Presentation	8 days	Sun 3/13/16	Sun 3/20/16	Mon 3/14/16	Mon 3/21/16
57	Compose Visual Presentation	8 days	Mon 3/21/16	Mon 3/28/16	Mon 3/21/16	Mon 3/28/16
58	Practice and Critique	9 days	Tue 3/29/16	Wed 4/6/16	Mon 3/28/16	Thu 4/7/16
59	Paddling	200 days	Fri 9/11/15	Mon 3/28/16	Sun 9/13/15	Thu 4/7/16
60	Tryouts	48 days	Fri 9/11/15	Wed 10/28/15	Sun 9/13/15	Thu 12/17/15
61	Team Selection	7 days	Thu 10/29/15	Wed 11/4/15	Thu 12/17/15	Thu 12/24/15
62	Paddling Practice and Conditioning	145 days	Thu 11/5/15	Mon 3/28/16	Thu 12/24/15	Thu 4/7/16
63	Project Float	23 days	Tue 3/15/16	Wed 4/6/16	NA	NA
64	**Mid-Pacific Conference**	**0 days**	**Thu 4/7/16**	**Thu 4/7/16**	**Thu 4/7/16**	**Thu 4/7/16**



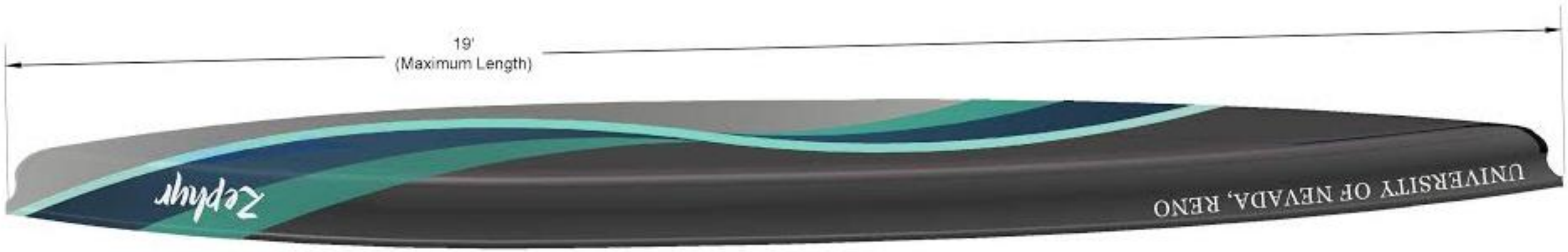
Project: Project Schedule Final
Date: Tue 5/3/16

Projected Task | Projected Milestone | Actual Task | Actual Milestone | Projected Summary | Actual Summary | Critical Task

Construction Drawing



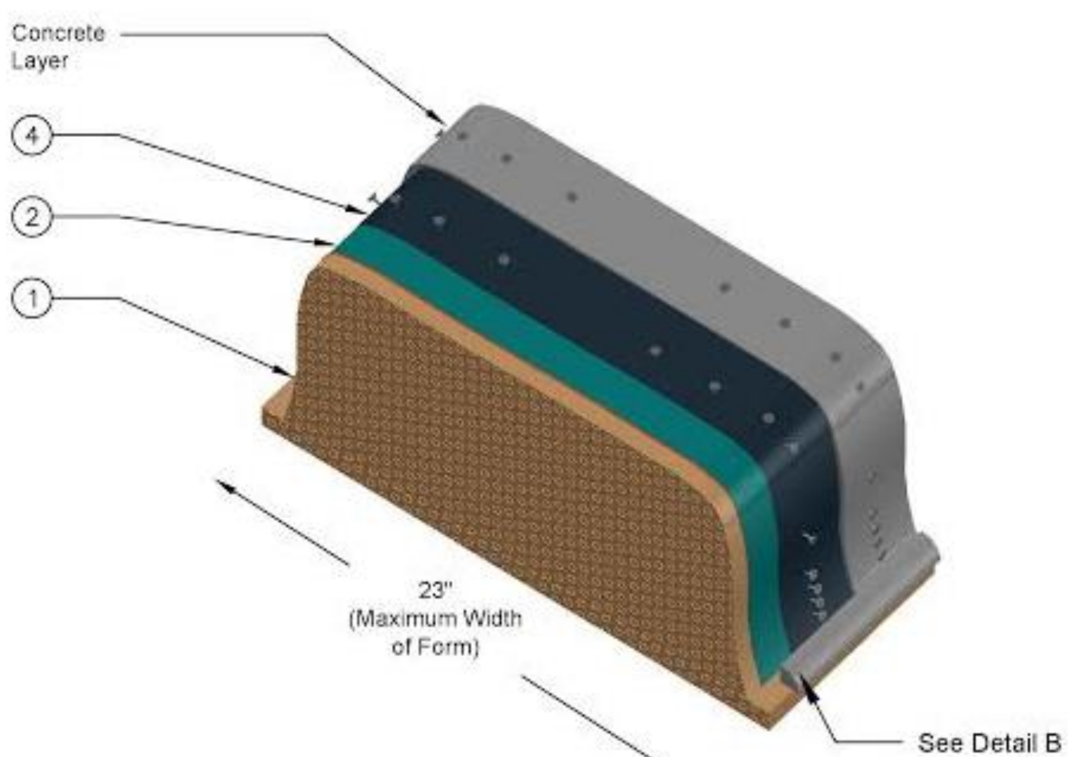
Plan View



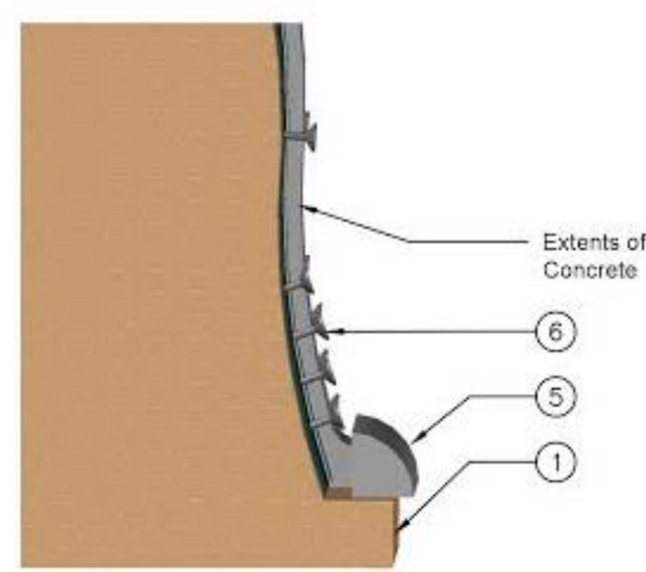
Elevation View

General Notes:

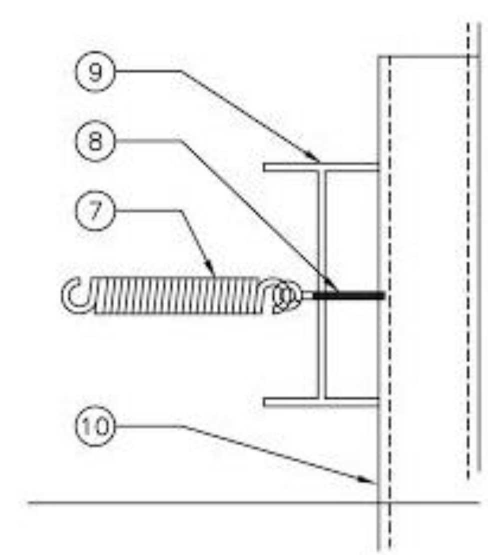
1. Drawings not to scale
2. Only two longitudinal prestress anchorages are shown for clarity
3. Total longitudinal prestressing force: P_{jack}=4.8 kips



Section A - A
Widest Section



Detail B
Gunwale



Detail C
Longitudinal Prestress Anchorage

University of Nevada, Reno
Concrete Canoe

Bill of Materials

	Qty	Description
	21 lbs.	Type 1 White Portland Cement
	39 lbs.	VCAS-140™
	7 lbs.	NewCem® Slag Cement
	1 lb.	Q-Cel® 6019S
	8 lbs.	Poraver® Siscorspheres (0.1-03mm)
	9 lbs.	Poraver® Siscorspheres (0.25-0.5mm)
	13 lbs.	Poraver® Siscorspheres (0.5-1mm)
	12 lbs.	Poraver® Siscorspheres (1-2mm)
	11 lbs.	Poraver® Siscorspheres (2-4 mm)
	4 lbs.	Hydrated Lime Type S
	21 fl. oz.	ADVA® Cast 575 (HRWR)
	40 fl. oz.	Rhoplex® MC-1834P Emulsion (PMA)
	5 fl. oz.	Daravair® AT30 (AEA)
	15 fl. oz.	V-MAR® F100 (VMA)
	1 lb.	Nycon® PVA Fibers (6 mm)
	1 lb.	Nycon® PVA Fibers (12 mm)
	5 lbs.	Powdered Pigment
	90 fl. oz.	Sealer
	1 unit	Vinyl Lettering
	24 units	Ferrule and Stopper
	4 units	Transverse Threaded Steel Rod
	37 sq. ft.	CT 272 Carbon Fiber Grid
	4 sq. ft.	Steel Mesh
1	24 cu. Ft.	Expanded Polyurethane
2	2 gal.	Bondo©
3	228 ft.	Kevlar® Tendons
4	3 gal.	Duratec® (Surface Treatment)
5	34 ft.	Quarter Round Molding (3/4" x 3/4")
6	320 ct.	Grade Screws
7	12 ct.	Steel Spring (L; 6" W; 1.5" k=0.2 k/in)
8	24 ct.	Eye Bolts/Nuts (L; 3" Dia: 3/8")
9	2 ct.	W 12 x 22
10	4 ct.	HSS 3-1/2" x 3-1/2" x 3/8"

Zephyr
Design Drawing

Date: 3/13/2016
Engineers: E. JORDAN, D. PALFFY
Drawn By: J. GUANTONE, A. HANSEN

Appendix A: References

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Appendix B: Mixture Proportions

MIXTURE DESIGNATION: STRUCTURAL MIX

Cementitious Materials

Component	Specific Gravity	Volume (ft^3)	Amount (mass/volume) (lb/yd^3)		
Type 1 White Portland Cement	3.15	0.965	c:	189.6	Mass of all cementitious materials, cm **600.5** lb/yd^3
VCAS-140™	2.60	2.143	m_1:	347.6	
NewCem® Slag Cement	2.60	0.390	m_2:	63.2	c/cm ratio **0.32**

Fibers

Component	Specific Gravity	Volume (ft^3)	Amount (mass/volume) (lb/yd^3)	
Nycon® PVA (6 mm)	1.30	0.117	f_1:	9.52
Nycon® PVA (12 mm)	1.30	0.117	f_1:	9.52

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)
Q-Cel® 6019S	A_1: 2	0.00	0.19	$W_{OD,1}$: 11.8	$W_{SSD,1}$: 12.0	0.995	$W_{stk,1}$: 12.0
Poraver® Siscorspheres 0.1-0.3 mm	A_2: 4	0.00	0.94	$W_{OD,2}$: 73.0	$W_{SSD,2}$: 76.0	1.295	$W_{stk,2}$: 76.0
Poraver® Siscorspheres 0.25-0.5 mm	A_3: 4	0.00	0.78	$W_{OD,3}$: 76.1	$W_{SSD,3}$: 79.1	1.626	$W_{stk,3}$: 79.1
Poraver® Siscorspheres 0.5-1.0 mm	A_4: 4	0.00	0.58	$W_{OD,4}$: 113.6	$W_{SSD,4}$: 118.2	3.265	$W_{stk,4}$: 118.2
Poraver® Siscorspheres 1-2 mm	A_5: 4	0.00	0.46	$W_{OD,5}$: 107.1	$W_{SSD,5}$: 111.4	3.881	$W_{stk,5}$: 111.4
Poraver® Siscorspheres 2-4 mm	A_6: 4	0.00	0.31	$W_{OD,6}$: 97.4	$W_{SSD,6}$: 101.3	5.236	$W_{stk,6}$: 101.3

Admixtures

Admixture	lb/gal	Dosage (fl.oz/cwt)	% Solids	Water in Admixture (lb/yd^3)	
Rhoplex® MC-1834P Emulsion (PMA)	8.8	x_1: 90	s_1: 47.1	$w_{admx,1}$: 19.65	Total Water from All Admixtures <u>44.54</u> lb/yd^3
V-Mar® F100 (VMA)	8.5	x_2: 35	s_2: 35.0	$w_{admx,2}$: 9.07	
ADVA® Cast 575 (HRWR)	8.9	x_3: 45	s_3: 40.0	$w_{admx,3}$: 11.27	
Daravair® AT30 (AEA)	8.5	x_4: 12	s_4: 5.0	$w_{admx,4}$: 4.55	

Solids (Latex, Dyes and Powdered Admixtures)

Component	Specific Gravity	Volume (ft^3)	Amount (mass/volume) (lb/yd^3)	
Rhoplex® MC-1834P Emulsion (PMA)	1.12	0.249	S_1:	17.40
Hydrated Lime Type S	2.60	0.194	S_2:	31.47
Powdered Pigment	1.35	0.042	S_3:	3.54

Water

	Amount (mass/volume) (lb/yd^3)		Volume (ft^3)
Water, lb/yd^3	w:	240.20	3.849
Total Free Water from All Aggregates, lb/yd^3	$\sum W_{free}$:	-18.16	
Total Water from All Admixtures, lb/yd^3	$\sum w_{admx}$:	44.54	
Batch Water, lb/yd^3	w_{batch}:	214.58	

Densities, Air Content, Ratios and Slump

	cm	fibers	aggregates	solids	water	Total
Mass of Concrete, M, (lb, for1 yd^3)	600.5	19.04	498.0	52.41	240.20	M: 1410.15
Absolute Volume of Concrete, V, (ft^3)	3.498	0.235	16.298	0.485	3.849	V: 24.365
Theoretical Density, T, (= M / V)	57.88	lb/ft^3	Air Content [= (T – D)/T x 100%]			9.8 %
Measured Density, D	52.23	lb/ft^3	Slump, Slump flow			1 in.
water/cement ratio, w/c:	1.267		water/cementitious material ratio, w/cm:			0.40

*Powdered Pigment colors vary

Appendix B: Mixture Proportions

MIXTURE DESIGNATION: PATCH MIX

CEMENTITIOUS MATERIALS				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Type 1 White Portland Cement	3.15	0.965	*c*: 189.6	*Mass of all cementitious materials, cm* **600.5** lb/yd^3
VCAS-140™	2.60	2.143	m_1: 347.6	
NewCem® Slag Cement	2.60	0.390	m_2: 63.2	*c/cm ratio* **0.32**

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)*
Q-Cel® 6019S	A_1: 2	0	0.19	$W_{OD,1}$: 18.6	$W_{SSD,1}$: 19.0	1.601	$W_{stk,1}$: 19.0
Poraver® Siscorspheres 0.1-0.3 mm	A_2: 4	0	0.94	$W_{OD,2}$: 73.4	$W_{SSD,2}$: 76.3	1.359	$W_{stk,2}$: 76.3
Poraver® Siscorspheres 0.25-0.5 mm	A_3: 4	0	0.78	$W_{OD,3}$: 183.6	$W_{SSD,3}$: 191.0	3.924	$W_{stk,3}$: 191.0
Poraver® Siscorspheres 0.5-1.0 mm	A_4: 4	0	0.58	$W_{OD,4}$: 246.8	$W_{SSD,4}$: 256.7	7.092	$W_{stk,4}$: 256.7

ADMIXTURES					
Admixture	*lb/gal*	*Dosage (fl.oz./cwt)*	*% Solids*	*Water in Admixture (lb/yd^3)*	
Rhoplex® MC-1834P Emulsion (PMA)	8.8	x_1: 100	s_1: 47.1	$w_{admx,1}$: 21.84	*Total Water from All Admixtures* **50.04** lb/yd^3
V-Mar® F100 (VMA)	8.5	x_2: 40	s_2: 35.0	$w_{admx,2}$: 10.37	
ADVA® Cast 575 (HRWR)	8.9	x_3: 50	s_3: 40.0	$w_{admx,3}$: 12.53	
Daravair® AT30 (AEA)	8.5	x_4: 14	s_4: 5.0	$w_{admx,4}$: 5.30	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)			
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*
Rhoplex® MC-1834P Emulsion (PMA)	1.12	0.277	S_1: 19.36
Hydrated Lime Type S	2.60	0.194	S_2: 31.47
Powdered Pigment	1.35	0.042	S_3: 3.54

WATER		
	Amount (mass/volume) (lb/yd^3)	*Volume (ft^3)*
Water, lb/yd^3	*w*: 270.23	4.331
Total Free Water from All Aggregates, lb/yd^3	$\sum W_{free}$: -20.52	
Total Water from All Admixtures, lb/yd^3	$\sum W_{admx}$: 50.04	
Batch Water, lb/yd^3	w_{batch}: 240.71	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb, for1 yd^3)	600.5	0.00	543.0	54.37	270.23	*M*: 1468.1
Absolute Volume of Concrete, V, (ft^3)	3.498	0.000	13.976	0.513	4.331	*V*: 22.318
Theoretical Density, T, (= M / V)	65.78	lb/ft^3	*Air Content [= (T – D)/D x 100%]*			17.3 %
Measured Density, D	54.40	lb/ft^3	*Slump, Slump flow*			3 in.
water/cement ratio, w/c:	1.425		*water/cementitious material ratio, w/cm:*			0.45

**Powdered Pigment colors vary*

Appendix C: Example Structural Calculation

① INITIAL ASSUMPTIONS

- 2-DIMENSIONAL BEAM
- NON-UNIFORMLY DISTRIBUTED WEIGHT
- NON-UNIFORMLY DISTRIBUTED SUPPORT
- CO-ED SPRINT RACE LOADING CASE
- BUOYANT FORCE IS THE PRODUCT OF THE SUBMERGED SECTION VOLUME OF THE CANOE AND THE UNIT WEIGHT OF WATER. THE SUBMERGED SECTION VOLUME IS CALCULATED BY NEVADA'S STRUCTURAL ANALYSIS SPREADSHEET FROM THE SELF-WEIGHT AND APPLIED LOADS.

② DEFINE VARIABLES

- W = SELF-WEIGHT (lbs.)
- P = APPLIED FORCE (lbs.)
- F = BUOYANT FORCE (lbs.)
- R = RESULTANT (lbs.)
- V = SHEAR (lbs.)
- M = MOMENT (lb-ft.)
- L = LONGITUDINAL INTERVAL (ft.)

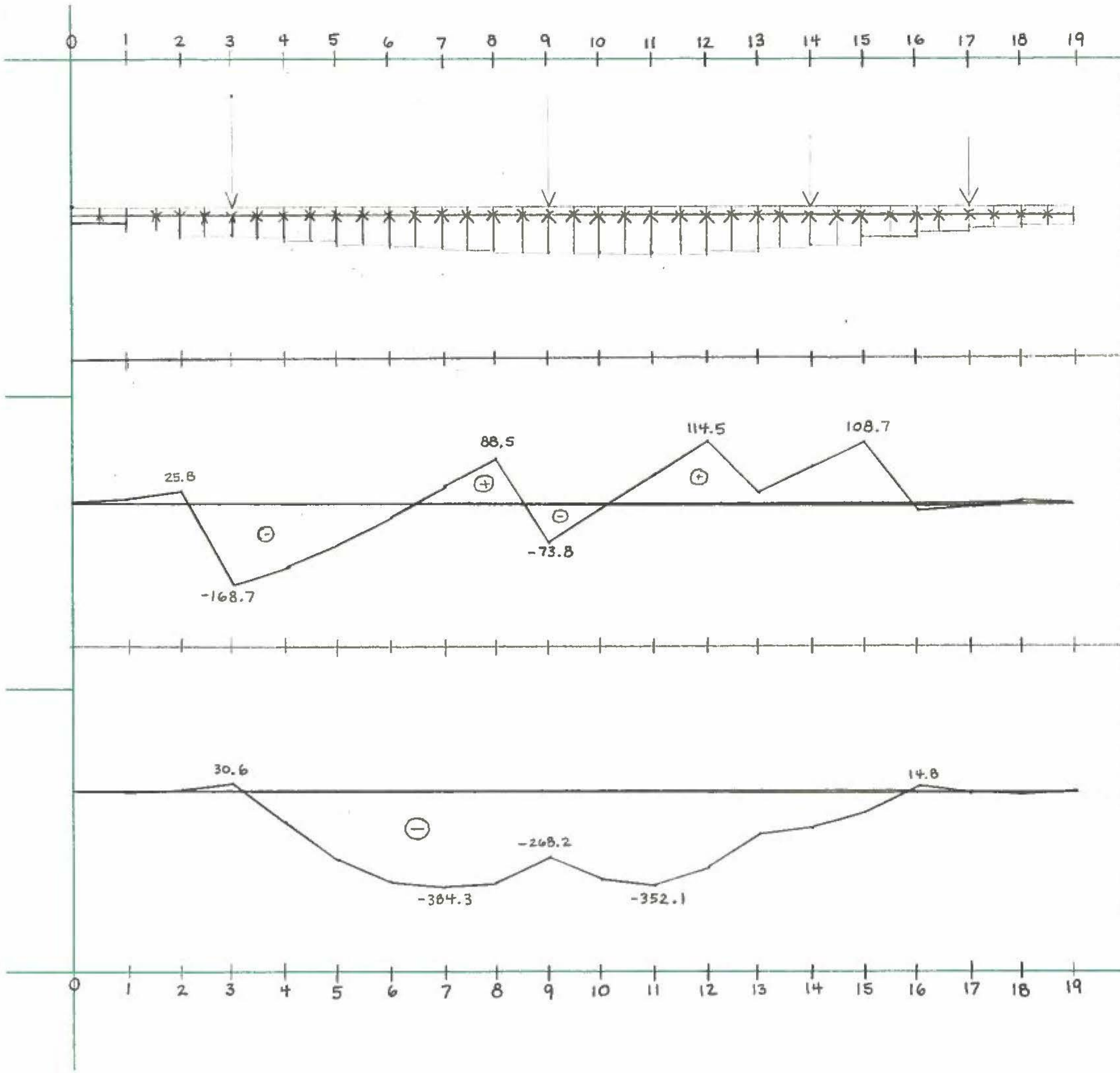
③ TABULATED VALUES

L	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
W	0.0	3.9	4.4	5.0	5.4	5.9	6.5	6.9	7.2	7.3	7.5	7.6	7.6	7.4	7.1	6.6	5.9	5.1	4.4	0.0
P	0.0	0.0	0.0	225.0	0.0	0.0	0.0	0.0	0.0	225.0	0.0	0.0	0.0	150.0	0.0	0.0	150.0	0.0	0.0	0.0
F	0.0	-11.8	-24.0	-35.5	-43.2	-52.2	-60.5	-65.1	-68.2	-70.0	-71.3	-70.8	-68.9	-63.8	-55.9	-45.5	-32.2	-18.8	-7.7	0.0
R	0.0	-7.9	-19.6	194.5	-37.9	-46.3	-53.9	-58.2	-61.0	162.4	-63.8	-63.2	-61.3	93.6	-48.8	-39.0	123.7	-13.7	-3.2	0.0
V	0.0	6.1	25.8	-168.7	-130.9	-84.6	-30.7	27.5	88.5	-73.8	-10.0	53.2	114.5	20.9	69.7	108.7	-15.0	-1.3	2.0	0.0
M	0.0	-1.3	4.8	30.6	-138.2	-269.0	-353.6	-384.3	-356.8	-268.2	-342.1	-352.1	-298.9	-184.5	-163.6	-93.9	14.8	-0.2	-1.5	0.0

④ SHEAR AND MOMENT EQUATIONS

$V = V_{i-1} - R_i$ (lbs.)

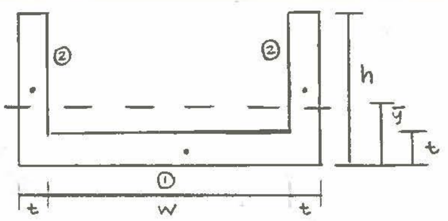
$M = V_{i-1}(L_i - L_{i-1}) + M_{x-1}$ (lb-ft.)



⑤ FREE – BODY DIAGRAM
- DISTRIBUTED LOADS
  - CANOE SELF-WEIGHT
  - BUOYANCY FORCES
- APPLIED LOADS
  - PADDLER LOADS
  - 1/5" VERTICAL = 50 lbs. OF FORCE
  - 2/5" HORIZONTAL = 1 ft. OF LONGITUDINAL LENGTH

⑥ SHEAR FORCE DIAGRAM
- 1 BLOCK VERTICAL = 50 lbs. OF SHEAR
- 2 BLOCKS HORIZONTAL = 1 ft. OF LONGITUDINAL LENGTH

⑦ BENDING MOMENT DIAGRAM
- 1 BLOCK VERTICAL = 100 lb-ft. OF MOMENT
- 2 BLOCKS HORIZONTAL = 1 ft. OF LONGITUDINAL LENGTH



⑧ DEFINE CROSS-SECTION VARIABLES

$t = 0.5\ in$

$h = 11.93\ in$

$w = 20.33\ in$

⑨ DEFINE M AND V AT L = 9.5 ft

$$V_{9.5} = \frac{V_{10} + V_9}{2} = -41.92\ lbs.$$

$$M_{9.5} = \frac{M_{10} + M_9}{2} = -305.16\ lb\text{-}ft.$$

⑩ SAFETY FACTOR CALCULATIONS

APPLYING DYNAMIC LOADING FACTOR (PARADIS AND GENDRON, 2006)

$V_{9.5} = (-41.92\ lbs.)(1.25) = -52.41\ lbs.$

$M_{9.5} = (-305.16\ lb\text{-}ft.)(1.25) = -381.45\ lb\text{-}ft.$

⑪ CALCULATE AREAS

$A_1 = w \cdot t = 20.33\ in \cdot 0.5\ in = 10.625\ in^2$

$A_2 = 2[0.5\ in \cdot 11.93\ in] = 11.93\ in^2$

$A_{tot.} = A_1 + A_2 = 10.625\ in^2 + 11.93\ in^2$

$= 22.56\ in^2$

⑫ NEUTRAL AXIS CALCULATIONS

$$\bar{y} = \frac{\sum y_i A_i}{\sum A_i} = \frac{(10.625\ in^2)(0.25\ in) + (11.93\ in^2)(5.965\ in)}{(10.625\ in^2 + 11.93\ in^2)} = 3.34\ in$$

$$d_1 = \bar{y} - t = 3.34\ in - 0.5\ in = 2.84\ in$$

$$d_2 = \left(\frac{h}{2}\right) - \bar{y} = \left(\frac{11.93\ in}{2}\right) - 3.27\ in = 2.63\ in$$

$$y_t = h - \bar{y} = 11.93\ in - 3.27\ in = 8.59\ in$$

$$y_b = -\bar{y} = -3.34\ in$$

⑬ MOMENTS OF INERTIA

$$I_1 = \frac{wt^3}{12} = \frac{(20.33\ in)(0.5\ in)^3}{12} = 0.212\ in^4$$

$$I_2 = \frac{th^3}{12} = \frac{(0.5\ in)(11.93\ in^2)}{12} = 70.74\ in^4$$

$$I = (I_1 + A_1 \cdot d_1^2) + 2(I_2 + A_2 d_2^2)$$

$$= (0.212\ in^4 + 10.625\ in^2 (2.84\ in)^2) + (70.74\ in^4 + 11.93\ in^2 (2.63\ in)^2)$$

$$= 235.17\ in^4$$

⑭ INTERNAL STRESSES WITHOUT PRESTRESS

$$\sigma_{top} = \frac{-M \cdot y_t}{I} = \frac{-(-381.45\ lb\text{-}ft.)\left(\frac{12\ in}{1\ ft.}\right)(8.59\ in)}{235.17\ in^4} = 167.28\ psi\ (\text{TENSION})$$

$$\sigma_{bottom} = \frac{-M \cdot y_b}{I} = \frac{-(-381.45\ lb\text{-}ft.)\left(\frac{12\ in}{1\ ft.}\right)(-3.34\ in)}{235.17\ in^4} = -64.93\ psi\ (\text{COMPRESSION})$$

$$Q = (A_1 \cdot d_1) + 2(A_2 \cdot d_2) = (10.625\ in^2 \cdot 2.84\ in) + 2(11.93\ in^2 \cdot 2.63\ in) = 91.56\ in^3$$

$$\tau = \frac{V \cdot Q}{I \cdot 2t} = \frac{(-52.41\ lbs)(91.56\ in^3)}{(235.17\ in^4)(2)(0.5\ in)} = -20.40\ psi$$

⑮ PRESTRESS FORCES

$e = 2.025$

TENDON LOAD = $-4800\ lbs$ (COMPRESSION)

TENDON LOAD ACCOUNTING LOSSES (AASHTO 2016)

$$\frac{-4800\ lbs}{1.25} = -3840\ lbs\ (\text{COMPRESSION})$$

⑯ MODIFICATION WITH PRESTRESS

$$\sigma_{top} = \frac{P}{A_{tot.}} + \frac{Pey_t}{I} + \frac{-My_t}{I}$$

$$\sigma_{top} = \frac{-3840\ lbs}{22.56\ in^2} + \frac{(-3840\ lbs)(2.025)(8.59\ in)}{235.17\ in^4} + \frac{-(-381.45\ lb\cdot ft.)(8.59\ in)\left(\frac{12\ in}{1\ ft.}\right)}{235.17\ in^4} = \underline{\underline{-443.4\ ps}}$$

$$\sigma_{bot} = \frac{P}{A_{tot}} + \frac{Pey_b}{I} + \frac{-My_b}{I}$$

$$\sigma_{bot} = \frac{-3840\ lbs}{22.56\ in^2} + \frac{(-3840\ lbs)(2.025)(-3.27\ in)}{235.17\ in^4} + \frac{-(-381.45)(-3.34}{235.17\ in^4}$$

$$\sigma_{bot} = \underline{\underline{-69.15\ psi}}$$