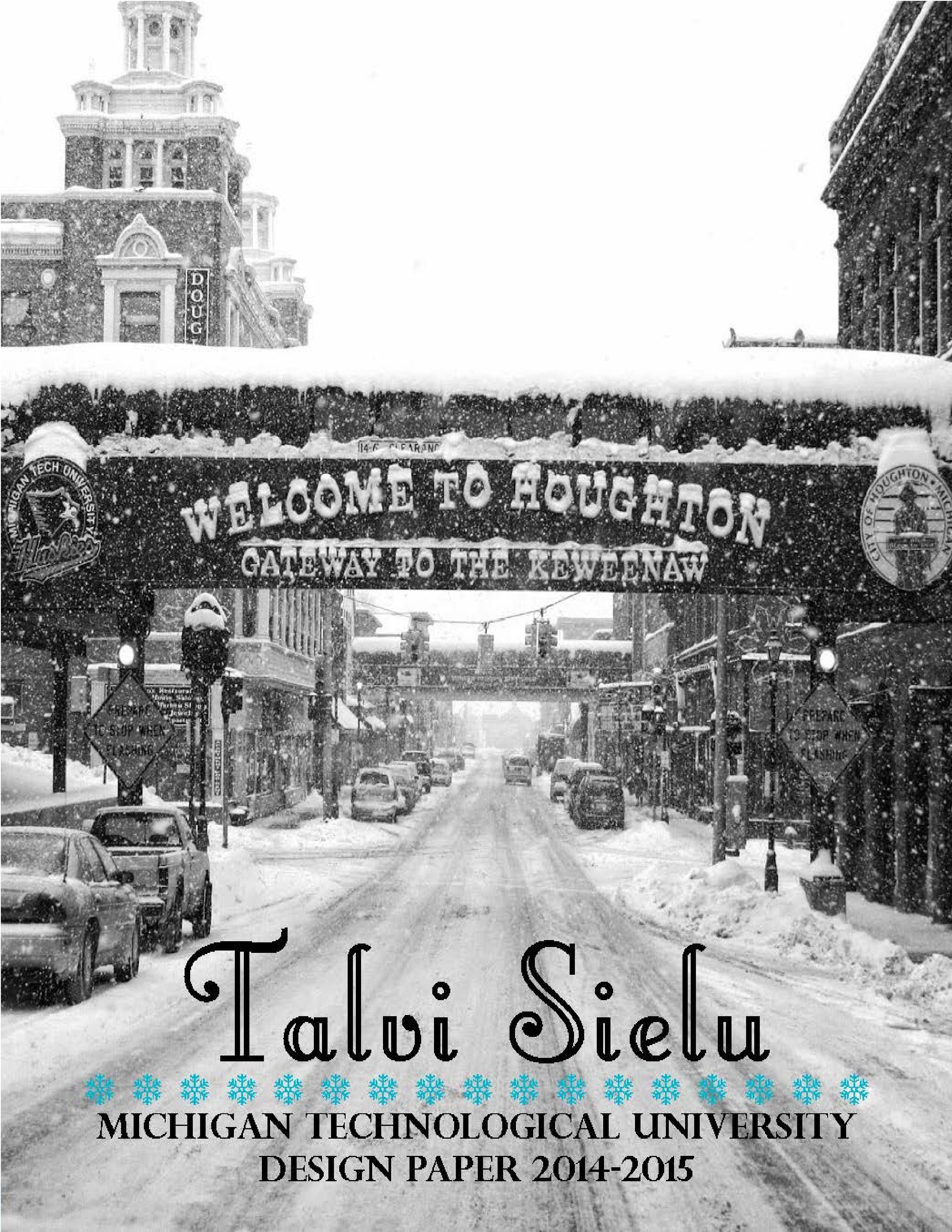

Talvi Sielu

MICHIGAN TECHNOLOGICAL UNIVERSITY

DESIGN PAPER 2014-2015

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Executive Summary

Michigan's Upper Peninsula is known for being a winter wonderland. Michigan Technological University (Michigan Tech) embraces all that this frigid season has to offer due to its location in the heart of the Upper Peninsula. Within sight of the campus, students can lose themselves cross-country skiing or snowshoeing, playing a riveting game of broomball (a favorite Michigan Tech pastime), or snowboarding for hours on end. Winter can truly be a paradise, and Michigan Tech's concrete canoe team developed their 2015 canoe to celebrate this theme. *Talvi Sielu*, Finnish for "winter soul", is a tribute to the lifestyle of students at Michigan Tech and those in the surrounding town of Houghton, Michigan.

The university started in 1885 as the Michigan Mining School with four faculty members and 23 students. Today, this snowy campus is home to over 7,000 undergraduate and graduate students who are enrolled in a variety of programs. The concrete canoe team takes pride in the nine different educational majors represented this year. After 130 years, Michigan Tech continues to provide educational excellence while preparing students to create the future.

Michigan Tech's Concrete Canoe team is a veteran member of the North Central Conference, making its first appearance in 1992. The team has placed first at the conference for the past five years and has continued on to the national level 15 times. A summary of the team's recent placement is presented in Table 1. The 2014-2015 team was determined to build upon this long running success by implementing innovations and increasing sustainable practices.

Table 1: Summary of Michigan Tech's team

Michigan Tech Statistics
9 The 31-member team is comprised of six engineering majors and three non-engineering majors.
15 of 27 Michigan Tech has attended 15 of the 27 ASCE National Concrete Canoe Competitions.
3rd, 7th, and 8th The team placed in the top ten at the past three National Competitions in 2012, 2013, and 2014.

The engineering committee bettered the canoe's turning performance with modifications to 2013's *Mesektet*. A two-dimensional structural model was created to establish material requirements. The research and development (R&D) committee identified areas for sustainability improvements. An alternative material was introduced to replace portland cement and reduce the environmental impact of the final mixture. After initial casting, unrepairable structural damage became apparent. Construction modifications were made and a second canoe was cast using portland cement concrete. Despite the obstacles, Michigan Tech was able to successfully create this year's canoe, *Talvi Sielu*, summarized in Tables 2 and 3.

Table 2: Properties of the 2014-2015 canoe

***Talvi Sielu* Properties**	
Weight:	140 pounds
Length:	19 feet
Maximum Beam:	27.9 inches
Depth:	15.6 inches
Nominal Thickness:	0.375 inch
Main Color:	White
Complimentary Colors:	Blue, Purple, Grey
Continuous Reinforcement:	Kevlar® 4009-1
Fiber Reinforcement:	Nycon-PVA RECS15 Nycon-PVA RF4000

Table 3: Properties of the 2014-2015 concretes

	Unit Weight (pcf)		Compressive Strength (psi)	Tensile Strength (psi)
	Wet	Dry		
Structural	53.9	51.5	1520	340
Finishing	70.0	67.6	1250	225

Project Management

Michigan Tech's Concrete Canoe team established an organizational structure (Page 2) to distribute workload and maintain communication, guaranteeing successful project completion. The team is led by three Captains, each serving a two-year term, who are responsible for overseeing major milestones and daily tasks, as well as managing the team's resources. A Safety Chairperson ensures proper safety procedures throughout the project. Additionally, a Compliance Officer is responsible for verifying that project aspects are completed according to all rules and regulations and to provide overall quality control and assurance.

The Captains, Safety Chairperson, and Compliance Officer work directly with the leaders of five committees to plan and monitor tasks, track labor hours, and identify all safety practices for project aspects. The committee leaders act as supervisors for their assigned components, while mentoring newer members expressing interest in their specific areas. To create a collaborative effort that utilizes individual skills and backgrounds, members were encouraged to participate as part of the five committees to develop a foundation for continued success.

The leadership team set goals at the beginning of the academic year and identified critical milestones to be accomplished by each committee as shown in Table 4. Using past experience and documentation, as well as conference deadlines, a timeline of events was developed. The critical path method was implemented to create the final project schedule (Page 10).

Table 4: Critical milestones

Task	Planned	Actual
Mix Selection	10/31/2014	12/26/2014
Mold Procurement	11/30/2014	12/13/2014
Casting	12/6/2014	2/20/2015
Demolding	12/20/2014	3/6/2015

The initial casting of *Talvi Sielu* was delayed by six weeks due to mold procurement, mix selection and winter recess. After a two-week curing period, significant structural damage was discovered upon demolding. The final canoe was cast on February 20th, creating a total project delay of eleven weeks.

Alterations were made to the mix design and aesthetic details were simplified to maintain a high-quality product. The schedule was adjusted by adding work sessions during spring break and condensing finishing processes. Overall, the final completion of the project accounted for 2,400 labor hours, as shown in Figure 1.

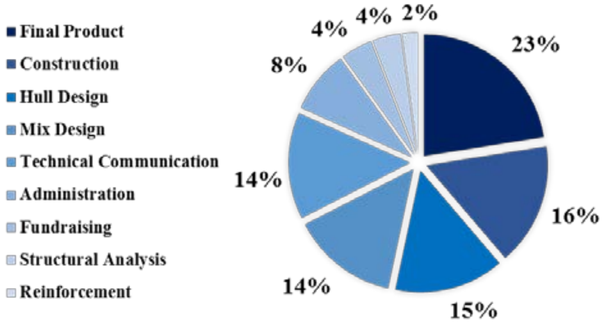


Figure 1: Distribution of labor hours

This year, the team allocated approximately $10,000. These funds were used for the development and construction of the canoes, final product components, and regional conference travel expenses, as shown in Figure 2. The final cost of *Talvi Sielu* are presented in Appendix C. Funds for the project were obtained through donations and fundraising, as well as support from the Michigan Tech academic departments represented.

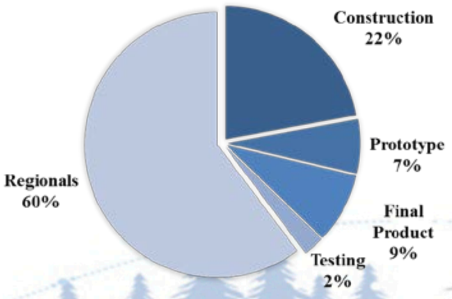


Figure 2: Project cost distribution

Organization Chart

Co-Captain
Karl Schlicker, Sr, 4, 3

Co-Captain
Kathrine Cipriano, Jr, 3, 3

Co-Captain
Philip Doederlein, Jr, 3, 1

Safety Officer
Jerrid Burdue, So, 2, 0

Compliance
Sarah Reed, Gr, 5, 0

Engineering
Sean Kuchta, Sr, 3, 2

Hull Design
Sean Kuchta*

Structural Analysis
Patricia Andersen, Jr, 3, 2

Casting
Logan Pickruhn, Jr, 3, 0

QC/QA Monitors

Chelsea Dubreuil*
Nick Shaieb*
Sylvana Finkbeiner, Fr, 1, 0
Andy LeBeau, Jr, 1, 0

Trowelers

Kathrine Cipriano*
Jerrid Burdue*
Sean Kuchta*
Taylor Wiegand*
Mitchell Finnegan*
Violet Thole*
Luke Cinader, Jr, 1, 0
Robert Herrick, Fr, 1, 0

Aesthetics
Kathrine Cipriano*

Stands
Taylor Hoenshеid, Sr, 3, 1

Display
Nick Shaieb, Sr, 3, 0

Cross Section
Taylor Wiegand, So, 2, 1

Technical Communication
Madie Martin, Sr, 4, 0

Oral Presentation
Chelsea Dubreuil, Sr, 3, 2

Engineer's Notebook
Alicia Homeszyn, Jr, 3, 0

Research & Development
Natalie Parker, Jr, 3, 0

Structual Mix Design
Natalie Parker*

Finishing Mix Design
Peter Winegar, So, 2, 0

Reinforcement
Peter Winegar*

Sustainability
Madie Martin*

Paddling
Karl Schlicker*

Competing Members

Karl Schlicker*
Kathrine Cipriano*
Philip Doederlein*
Sean Kuchta*
Chelsea Dubreuil*
Taylor Hoensheid*
Patricia Andersen*
Taylor Wiegand*
Violet Thole, So, 2, 1
Mitchell Finnegan, So, 2, 1

Key
Name, Class Standing, Years on Team, Years as Registered Member
*Listed Above

Hull Design and Structural Analysis

Talvi Sielu's engineering committee set out to develop a hull design that would improve the turning performance and paddler ergonomics as compared to previous designs. A structural model was created to represent and assess the material strength requirements for various loading scenarios.

Hull Design

The design of *Talvi Sielu* began with an analysis of last year's canoe, *Katsuo Maru* (MTU 2014), by examining race performances and identifying areas for potential improvement. One particular concern was the canoe's narrow bow and stern restricted the paddlers' position, creating a significant impact on turning ability. *Katsuo Maru* also experienced water splashing over the bow at peak race speeds. Following these observations, hull design goals were established to improve paddler ergonomics, optimize interior space, and enhance turning.

The design of the 2013 canoe, *Mesektet* (MTU 2013), was chosen as a baseline for its combination of straight-line tracking, turning ability, and paddler comfort. PROLINES software was used to modify *Mesektet* and create *Talvi Sielu*'s final hull geometry. This progression is detailed in Table 5. The canoe was shortened by one foot to decrease weight and improve turning performance. The beam width was reduced by 4.7 inches, increasing the length to beam (L/B) ratio. This increased ratio indicates a slimmer hull, meaning less wave-making resistance and more efficient paddling.

To eliminate water entry over the bow, additional modifications were made to the hull design, as shown in Figure 3. The resulting geometry acts as a natural spray deflector, pushing waves away from the bow. These changes move the center of buoyancy forward in the canoe, allowing the bow to naturally rise when paddlers are evenly distributed.

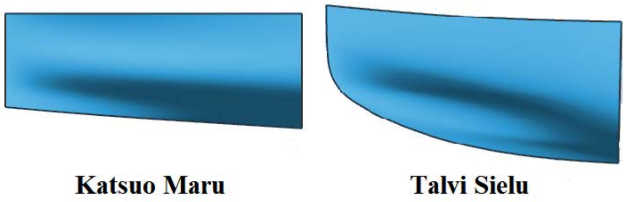


Figure 3: Bow alterations made to improve *Talvi Sielu*

This year's committee used the prismatic coefficient (C_p) to quantify the design goals. Prismatic coefficient determines the fullness or fineness of the hull's ends using Equation 1 shown below.

$$C_p = \frac{\text{Canoe Volume}}{\text{Maximum Cross Sectional Area} \cdot \text{Length}} \qquad \text{(Equation 1)}$$

This coefficient represents a combination of geometry that slips through the water while maintaining balance and turning ability. For a displacement hull design, the optimum C_p is 0.63 (McClary 2014). Table 5 shows the advancement towards this goal over the past three years.

A luan wood prototype was constructed to perform a qualitative analysis of the new hull design. Combining observations from PROLINES and prototype assessments, the bow was narrowed by one inch to optimize paddler positioning, wave drag, and surface area. With this final modification, the goals of improving paddler ergonomics, interior space, and turning ability were achieved.

Table 5: Hull design modifications from 2013-2015

	Length (ft)	Beam Width (in)	L/B Ratio (ft/ft)	Center of Buoyancy (% length from bow)	Rocker (in)		C_p
					Bow	Stern	
Mesektet	20	32.6	7.4	53.5	6.0	2.5	0.46
Katsuo Maru	20	31.9	7.9	52.5	6.1	2.2	0.46
Talvi Sielu	19	27.9	8.2	49.0	4.0	3.0	0.52

Structural Analysis

To establish design strengths required by mixture and reinforcement designs, hand calculations were performed and later iterated in MATLAB and Excel. The maximum flexural and shear stresses were determined for six loading cases: transportation, display stands, a simply supported beam, women's races, men's races, and the coed race. Each race loading case was modeled using four possible combinations of paddlers sitting and kneeling. A safety factor was then applied to determine *Talvi Sielu*'s minimum compressive and tensile design strengths.

Several assumptions were made to complete the structural analysis. First, stresses were calculated assuming straight-line dynamic loading conditions. Male and female paddler weights at 200 and 170 pounds, respectively, were increased by 20% to account for dynamic loading. Each paddler was represented by two linear distributive loads; the seated load was split 83%-17% and the kneeling load was split 63%-37% between the front and rear contact lengths, respectively. *Talvi Sielu* was modeled with a nominal thickness of 3/8 inch and a unit weight of 58 pcf. For this analysis, the canoe and the water were assumed to be in equilibrium, and the canoe was allowed to pitch depending on the paddler location.

Refining previous years' analyses, Michigan Tech utilized spline curve control points in NX to better discretize the hull profile. Figure 4 illustrates the advancement of hull representation over the past three years between the theoretical (blue) and physical (red) cross-sections.

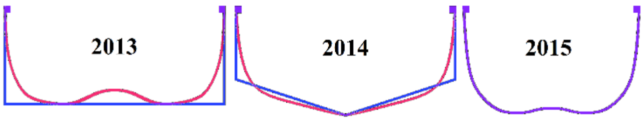


Figure 4: Refinement of modeled hull shape

Rectangles were formed between adjacent control points at each cross-section. Overlap and gaps between rectangles were accounted for in the analysis. Gunwale caps were then added to the model. Areas, centroids, and second area moments of inertia were then calculated based on this shape. This process was iterated for cross sections taken at one inch increments along the canoe. Points of interest were identified and stresses were computed at these locations. Sample calculations are presented in Appendix D.

Bending moment and shear calculations over the length of the canoe were performed using the cross-sectional properties and loading cases. Bending moment diagrams are depicted below.

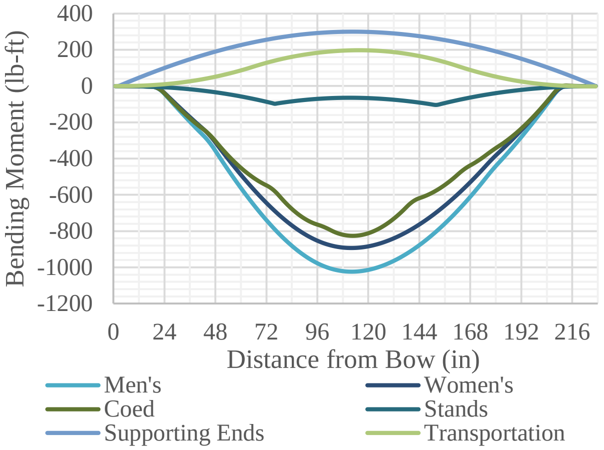


Figure 5: Bending moment diagrams

Maximum flexural stresses were calculated and are summarized in Table 6. The maximum compressive stress of 132 psi was found along the keel 12 feet from the bow, while the maximum tensile stress of 126 psi was found along the gunwale caps 11.6 feet from the bow. *Talvi Sielu* was engineered with a minimum safety factor of 2, resulting in concrete mixture design strengths of 264 psi compressive and 252 psi tensile.

Table 6: Maximum stresses by loading case

	Compressive (psi)	Tensile (psi)
Men's	132	126
Women's	114	110
Coed	98	96
Stands	17	16
Transportation	24	25
Simply Supported	39	43

Development and Testing

Michigan Tech's R&D committee reviewed past research, testing, and innovations to establish goals for this year's canoe. The committee developed a mixture that met the strength demands set by structural analysis, while improving upon previous mixture designs and introducing new materials. From previous years of experience, the committee recognized the need for continuous reinforcement to provide adequate punching shear strengths. Additionally, placement schemes were explored to determine the best method of incorporating gunwale cap reinforcement. These material tests were combined to finalize the design of *Talvi Sielu.*

Mixture Design

The mixture design committee began the year with three main goals: optimize aggregate blends, research and test non-portland binders, and create a lightweight structural mixture.

The first goal, optimizing aggregate blends, began by looking at previous Michigan Tech mix designs. Based on past performance, the team decided to first find an ideal blend of Poraver® 1-2 mm, 0.5-1 mm, and 0.25-0.5 mm expanded glass spheres. Upper and lower limits for each grade were chosen based on the percent by volume used in previous years as shown by the white region in Figure 6.

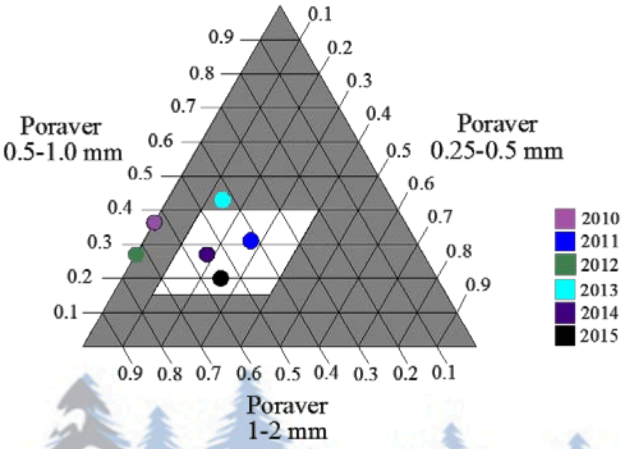


Figure 6: Poraver® blends used from 2010-2015

JMP® Pro 11, a statistical analysis software, was used to select 10 test batches within these limits. The 7 and 14 day compressive (ASTM C39) and split tensile (ASTM C496) strengths, as well as unit weights (ASTM C138), were recorded for each batch. These results were entered in the program, and a blend that optimized these three attributes was computed and represented by the black point in Figure 6.

Once a Poraver® blend was chosen, 3M™ K1 was introduced. K1 has been demonstrated in previous testing to increase strengths while decreasing unit weight. Four batches with varying amounts of K1 were tested to balance its benefits and detriments as the fourth aggregate in the mixture design. Although K1 is not produced from post-consumer recycled glass like Poraver®, 10% K1 by volume was chosen to limit the environmental impacts while increasing strength.

As aggregate testing continued, the committee began researching alternative binders to replace portland cement. Portland cement is the binder typically used in the construction industry despite the associated environmental footprint. Cement production accounted for the second-highest source of greenhouse gases in industrial processes for the United States in 2012 (EPA 2014). Traditionally, Michigan Tech has limited the amount of portland cement by incorporating materials derived from recycling processes such as slag cement or VCAS™ pozzolans. Michigan Tech aimed to completely replace Portland cement in *Talvi Sielu* to improve the sustainability of the design.

After much consideration, CeraTech USA's ekkomaxx™ was selected as the non-portland replacement that would be tested. ekkomaxx™ is a low carbon concrete that uses additives to activate Class C fly ash, a by-product of coal combustion. This low carbon concrete was compared to an equivalent portland cement concrete (PCC) to determine if ekkomaxx™ would be an adequate substitute. The binder proportions for the PCC were the same as those used in Hayate, *Katsuo Maru's* structural mix. Once all testing concluded, strengths and unit weights were compared. A table showing these preliminary 14-day results can be seen below.

Table 7: 14-Day strength results

	Split Tensile Strength (psi)	Compressive Strength (psi)
Portland	340	1520
ekkomaxx™	260	1340

Strengths alone would not justify a final decision in regards to the concrete mixture used. Table 8 highlights the benefits and costs associated with using either ekkomaxx™ or PCC in regards to environmental impact, strengths, and the effect of finishing practices.

Table 8: Comparison of ekkomaxx^{TM} and PCC

	PCC	ekkomaxx™
Benefits	• Increased strength • Decreased finishing time	• Low carbon-footprint concrete
Costs	• Environmental impact	• Decreased strength • Increased finishing time

CeraTech USA's ekkomaxx™ produced strengths that met the requirements set forth by the structural analysis. Due to the tan color of the ekkomaxx™ concrete, a finishing mixture would be require and was developed using white pigment to create a cleaner palate for the aesthetic committee. To ensure an even color on the canoe, two weeks were scheduled for curing before staining could commence. As long as *Talvi Sielu* was cast before February 1st, the finishing process could be completed. Given this, the mixture committee was confident that ekkomaxx™ could be used in *Talvi Sielu.*

The chosen fibers for *Talvi Sielu* were a 50/50 blend of Nycon-PVA RF4000 and Nycon-PVA RECS15; this blend has increased the tensile strength of the mixture in previous years. The only additives included were those needed to activate the fly ash. By combining all results from testing, an environmentally friendly structural mixture was created.

During demolding on February 1st, significant structural damage to the canoe occurred. This damage is discussed in further later in this report. Casting a new canoe was required; necessary materials were reordered. To meet the deadlines imposed by finishing processes, the committee moved forward with the PCC mixture for the second canoe. This would produce a white surface and would eliminate the two weeks required to prepare the ekkomaxx™ concrete for staining.

Loska, the final structural mixture for *Talvi Sielu*, is a combination of all portland cement testing efforts. Xypex® Xycrilic and BASF Glenium® 3030NS were included as admixtures to increase strength and workability. A finishing mixture, modeled after Loska, was developed with finer aggregates. Final mix proportions are presented in Appendix B.

Although the primary binding agent in Loska is portland cement, 50% of the cementitious materials and 90% of the aggregates are production by-products or recycled materials, thus attaining the committee's sustainability goals. Figure 7 depicts the final environmental composition of Loska.

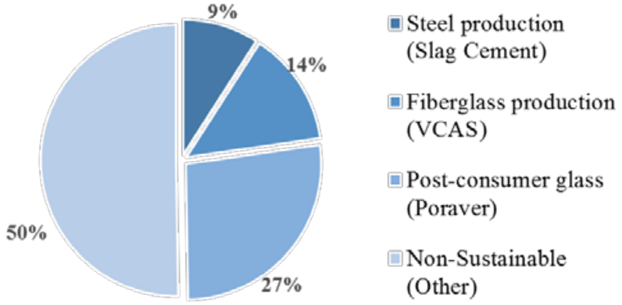


Figure 7: Percent by mass environmental composition

Continuous Reinforcement

In recent years, Kevlar® 4009-1 has been tested to determine the best reinforcement configuration within the canoe. One layer of reinforcement in the walls and two layers in the bottom were deemed adequate for all loading scenarios. Kevlar® was placed in *Talvi Sielu* using this arrangement.

Michigan Tech tested the placement of reinforcement in the gunwale caps, supplementing past testing. These tests identified a correlation between reinforcement placement and moment capacity of the gunwales.

Gunwale beams were cast with a length of 16 inches. Three arrangements of reinforcement in the gunwale caps, including one-fold, two-fold, and detached, were tested and compared to a straight wall control. Schematics of the reinforcement and cross-sectional dimensions of beams can be seen in Figure 8.

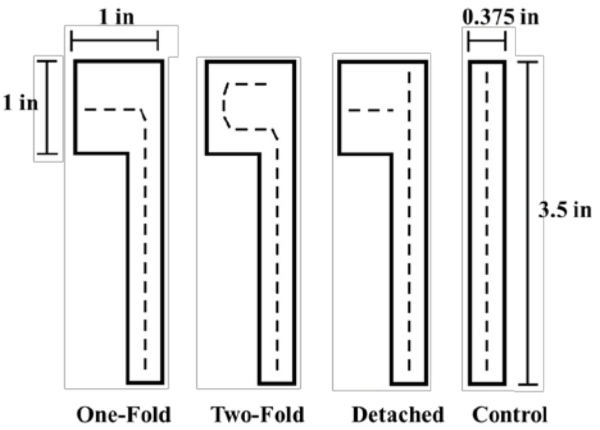


Figure 8: Reinforcement scheme diagram

A wooden gunwale cap testing apparatus was constructed to anchor the samples, preventing horizontal movement. Beams were placed into the apparatus with 4 inches unsupported, as shown in Figure 9. Weights were incrementally added to the exposed beam until it was unable to support the load. Three specimens of each configuration were tested for this quantitative analysis.

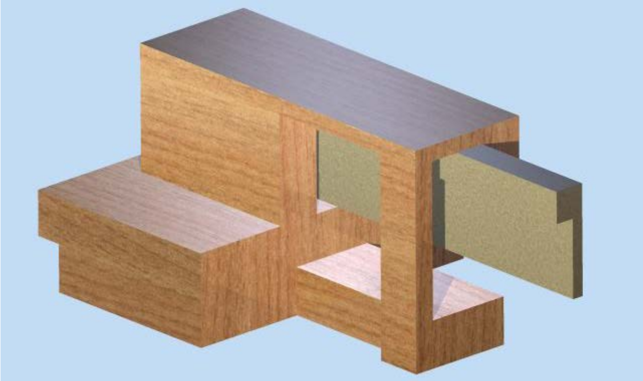


Figure 9: Gunwale beam testing apparatus

The failure load of each cap was recorded and used to determine the average bending moment for each arrangement, as shown in Table 9. The folded reinforcement gunwale caps were able to support a higher load before failure when compared to the control specimen. The detached arrangement yielded results comparable to the control. This identified that folding the reinforcement provided additional strength. The one-fold gunwale caps produced the highest moment capacity with greater quality relative to the two-fold. Therefore, the one-fold gunwale cap was used in *Talvi Sielu*.

Table 9: Gunwale cap reinforcement testing results

Test Plate Description	Average Applied Load (lb)	Average Bending Moment (lb*in)
Control	31.0	186.0
One-Fold	56.3	337.8
Two-Fold	47.3	238.8
Detached	26.7	160.2

Composite flexural strength was calculated using the rule of mixtures. Final material properties of *Talvi Sielu* and the structural analysis demands are compared in Table 10 below.

Table 10: Final properties comparison

Strengths (psi)	Analysis Requirements	Actual Results
Compressive	264	1520
Tensile	252	340
Composite Flexural	N/A	1460

Construction

Construction of the canoe was completed in three major phases: preparation, casting, and finishing. The team incorporated safe and environmentally friendly practices to increase the team's morale and enthusiasm, leading to a high-quality final product. Collaborative efforts were made between the Captains, Safety Chairperson, and committee leaders to improve construction methods, introduce innovations, and overcome construction obstacles. Through these efforts, *Talvi Sielu* was successfully created.

Preparation

During the design and analysis of the canoe, the engineering committee held mock casting sessions using a quarter mold from *Mesektet.* The sessions introduced team members to the casting process in which concrete is hand troweled up the walls of a female mold. More importantly, the sessions were used to improve techniques and select the final casting team, which included eight trowelers and four QC/QA monitors.

Once the final hull design for *Talvi Sielu* was selected, the team ordered a CNC-milled mold made from 10% recycled high-density polystyrene foam. The mold was received in six sections as shown in the design drawing (Page 10). The sections were assembled using adhesive and bolts. Plywood squares were attached along the exterior joints to prevent separation. The mold was then secured to a rigid frame using bolts and wooden supports. Layers of epoxy were applied to prevent water loss and to enhance the surface for concrete placement.

Prior to casting day, mixture ingredients were weighed and placed in individual containers. End caps were cut and assembled from polystyrene foam to increase floatation. Kevlar® reinforcement was sized for the two layers that would be placed within *Talvi Sielu.* These steps were taken to guarantee an efficient casting process.

Casting

On casting day, the Captains divided the team to work on three specific assignments. The mixture team prepared each batch of concrete and ensured consistency throughout the process. The casting team placed concrete and monitored layer thickness. The reinforcement team laid reinforcement and cast gunwale caps. The Captains oversaw the operations to facilitate safety and efficacy throughout casting.

Talvi Sielu was cast with three 1/8 inch layers of structural concrete, one continuous layer of reinforcement throughout the canoe, and an additional layer of reinforcement along the bottom. This process can be seen in Figures 10 and 11.

Figure 10: Concrete placement within *Talvi Sielu*

Figure 11: Reinforcement placement in the canoe

The team added end caps after the body of the canoe was cast. Extruded polystyrene foam sections, coated with epoxy and release aid, were then used as placement guides for the gunwale caps. The continuous layer of reinforcement from the walls was folded in after a 1/2 inch layer of concrete was placed in the guides as shown in Figure 12. The gunwale caps were filled, thus completing *Talvi Sielu.*

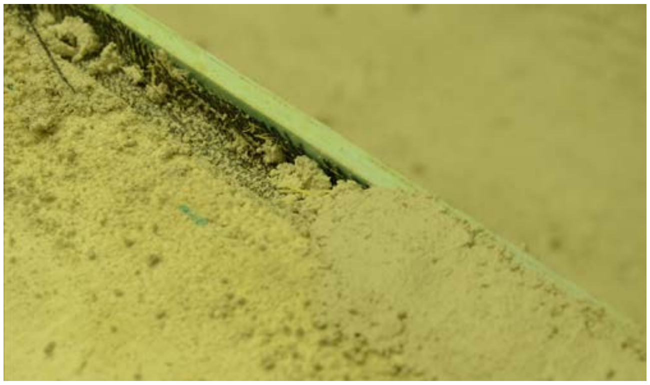


Figure 12: Reinforcement within gunwale caps

After a two week curing period, the canoe was removed from the mold to apply the finishing mixture and aesthetic details. During demolding of the initial canoe made with ekkomaxx™, the team discovered unrepairable structural damage. As a result, the team cast a second canoe. Improvements were made to the mold, and the mix design was altered for successful completion of *Talvi Sielu*. On February 20th, the second canoe was cast using the same construction methods as the first casting.

Finishing

Due to the delay in the final casting, the aesthetic committee made adjustments to the finishing schedule. These adjustments will be greatly assisted by innovative techniques that are being implemented to create a safer, more efficient finishing process for the canoe.

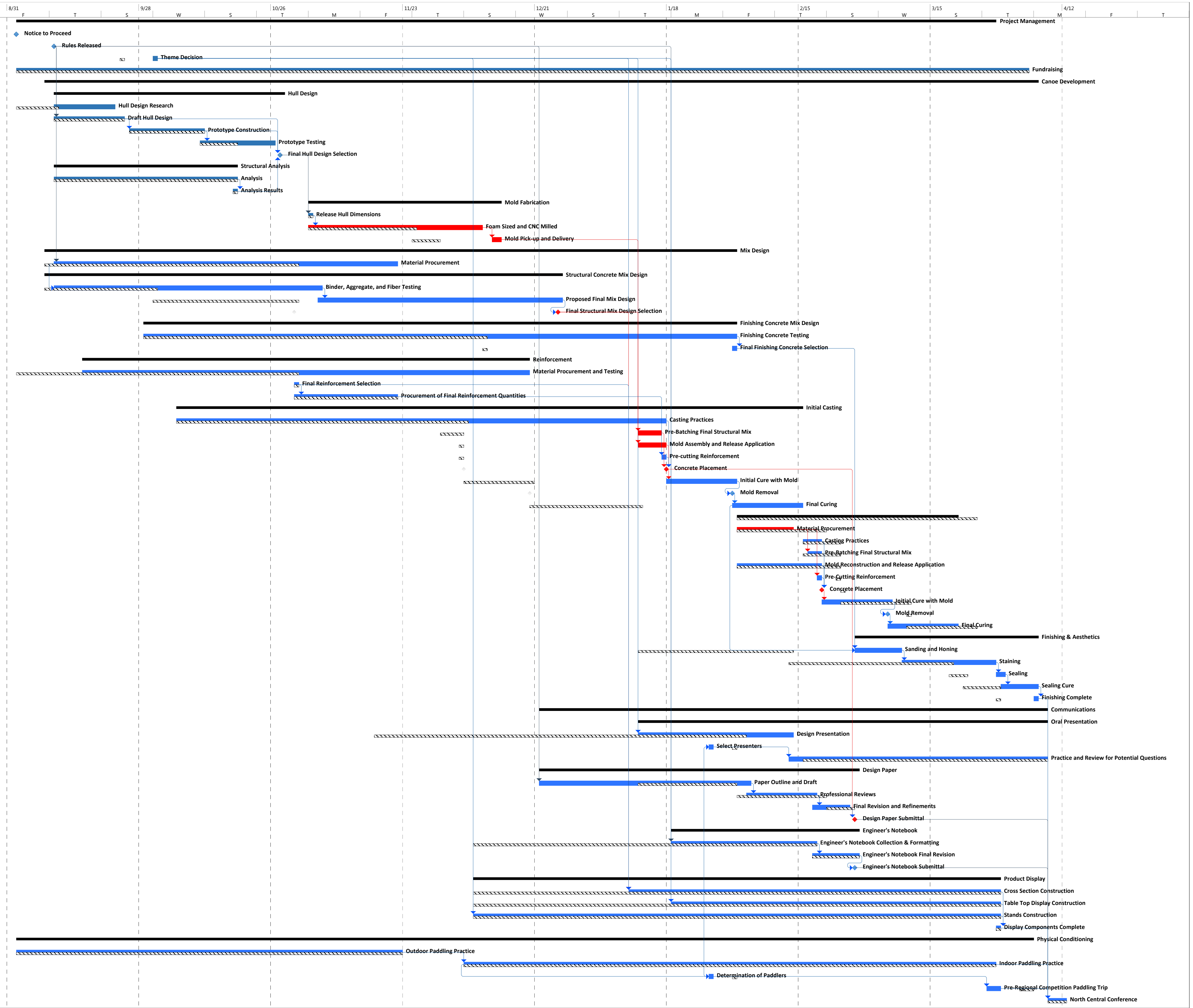
Sanding will be completed using a combination of honing and hand-sanding methods to create a smooth surface, as well as maintain a nominal thickness of 3/8 inch. Honing is a wet sanding technique, shown in Figure 13, which largely reduces the risk of silica exposure. By wetting the concrete, fine particles do not become airborne, but instead flow directly into the facility's drainage system. Honing produces a smoother product while decreasing sanding time. Therefore, honing will be used as the primary finishing method and hand-sanding will be implemented where necessary.


Figure 13: Honing of the canoe

Final aesthetics will be added to the canoe after sanding is complete. Staining details were simplified to better utilize the team's resources and time. A new high volume, low pressure airbrush will be used to apply an even coat of stain and reduce hand application. Lastly, the canoe will be sealed with two layers of ChemMaster® Crystal Clear-A to protect the final product from water penetration and enhance the finished aesthetics.

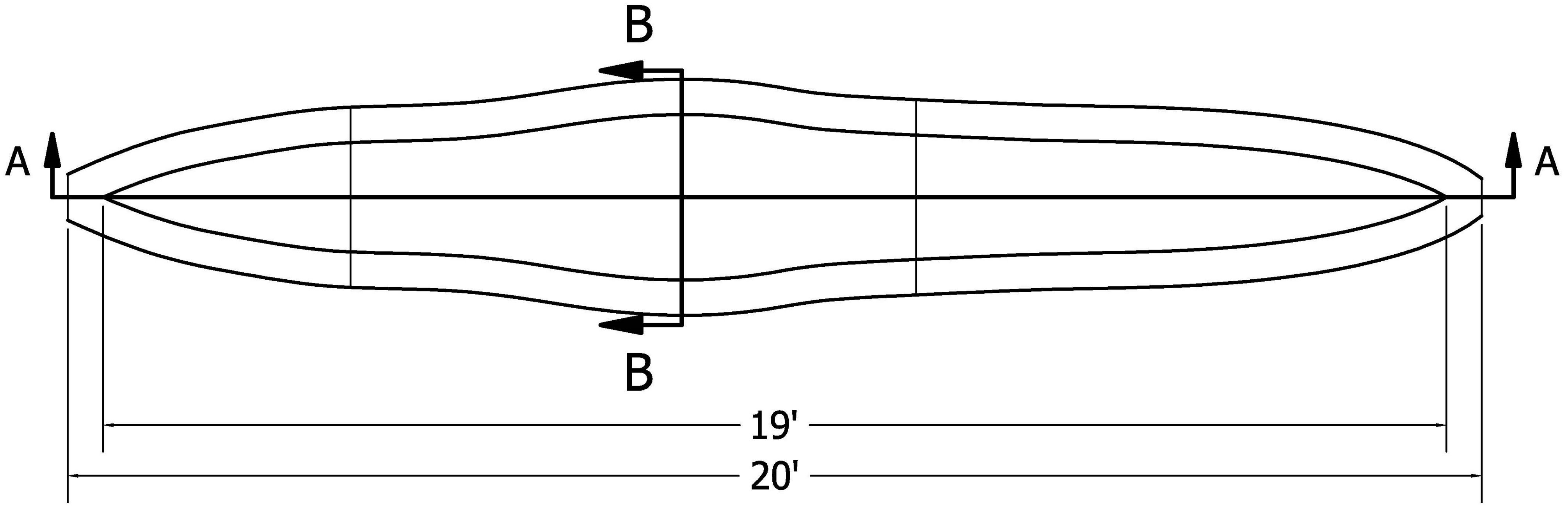
Despite the obstacles of the construction process, Michigan Tech is proud to present *Talvi Sielu*, a true representation of the tenacious heart of the university and soul of the surrounding community throughout its winter season.

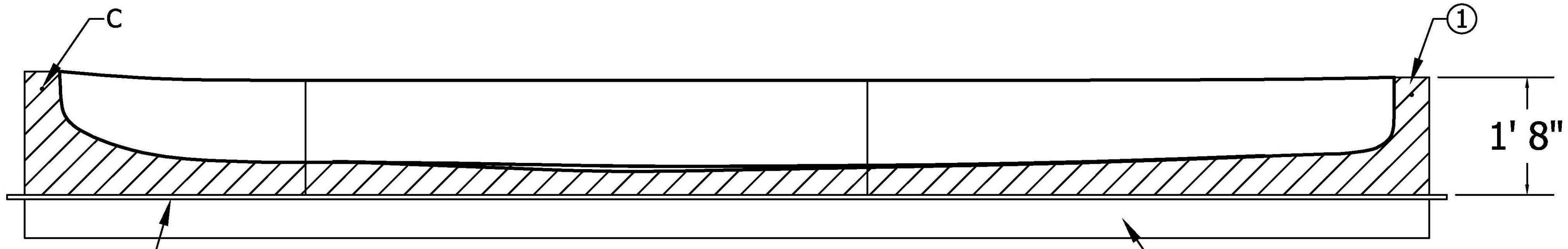
ID	Task Name	Baseline Start	Baseline Finish	Actual Start	Actual Finish
1	**Project Management**	**Tue 9/2/14**	**Sat 4/4/15**	**Tue 9/2/14**	**Sat 4/4/15**
2	Notice to Proceed	Tue 9/2/14	Tue 9/2/14	Tue 9/2/14	Tue 9/2/14
3	Rules Released	Wed 9/10/14	Wed 9/10/14	Wed 9/10/14	Wed 9/10/14
4	Theme Decision	Wed 9/24/14	Wed 9/24/14	Wed 10/1/14	Wed 10/1/14
5	Fundraising	Tue 9/2/14	Sat 4/4/15	Tue 9/2/14	Sat 4/4/15
6	**Canoe Development**	**Tue 9/2/14**	**Sun 3/29/15**	**Wed 9/10/14**	**Mon 4/6/15**
7	**Hull Design**	**Tue 9/2/14**	**Tue 10/28/14**	**Wed 9/10/14**	**Tue 10/28/14**
8	Hull Design Research	Tue 9/2/14	Wed 9/10/14	Wed 9/10/14	Mon 9/22/14
9	Draft Hull Design	Wed 9/10/14	Wed 9/24/14	Wed 9/10/14	Wed 9/24/14
10	Prototype Construction	Fri 9/26/14	Sat 10/11/14	Fri 9/26/14	Sat 10/11/14
11	Prototype Testing	Sat 10/11/14	Sat 10/18/14	Sat 10/11/14	Sun 10/26/14
12	Final Hull Design Selection	Tue 10/28/14	Tue 10/28/14	Tue 10/28/14	Tue 10/28/14
13	**Structural Analysis**	**Wed 9/10/14**	**Sat 10/18/14**	**Wed 9/10/14**	**Sat 10/18/14**
14	Analysis	Wed 9/10/14	Sat 10/18/14	Wed 9/10/14	Sat 10/18/14
15	Analysis Results	Sat 10/18/14	Sat 10/18/14	Sat 10/18/14	Sat 10/18/14
16	**Mold Fabrication**	**Mon 11/3/14**	**Sun 11/30/14**	**Mon 11/3/14**	**Sat 12/13/14**
17	Release Hull Dimensions	Mon 11/3/14	Mon 11/3/14	Mon 11/3/14	Mon 11/3/14
18	Foam Sized and CNC Milled	Mon 11/3/14	Tue 11/25/14	Mon 11/3/14	Tue 12/9/14
19	Mold Pick-up and Delivery	Tue 11/25/14	Sun 11/30/14	Fri 12/12/14	Sat 12/13/14
20	**Mix Design**	**Mon 9/8/14**	**Fri 10/31/14**	**Wed 9/10/14**	**Sun 2/1/15**
21	Material Procurement	Mon 9/8/14	Fri 10/31/14	Wed 9/10/14	Fri 11/21/14
22	**Structural Concrete Mix Design**	**Mon 9/8/14**	**Fri 10/31/14**	**Wed 9/10/14**	**Fri 12/26/14**
23	Binder, Aggregate, and Fiber Testing	Mon 9/8/14	Wed 10/1/14	Wed 9/10/14	Wed 11/5/14
24	Proposed Final Mix Design	Wed 10/1/14	Fri 10/31/14	Wed 11/5/14	Fri 12/26/14
25	Final Structural Mix Design Selection	Fri 10/31/14	Fri 10/31/14	Fri 12/26/14	Fri 12/26/14
26	**Finishing Concrete Mix Design**	**Mon 9/29/14**	**Wed 10/15/14**	**Mon 9/29/14**	**Sun 2/1/15**
27	Finishing Concrete Testing	Mon 9/29/14	Wed 12/10/14	Mon 9/29/14	Sun 2/1/15
28	Final Finishing Concrete Selection	Wed 12/10/14	Wed 12/10/14	Sun 2/1/15	Sun 2/1/15
29	**Reinforcement**	**Tue 9/2/14**	**Fri 10/31/14**	**Tue 9/16/14**	**Fri 12/19/14**
30	Material Procurement and Testing	Tue 9/2/14	Fri 10/31/14	Tue 9/16/14	Fri 12/19/14
31	Final Reinforcement Selection	Fri 10/31/14	Fri 10/31/14	Fri 10/31/14	Fri 10/31/14
32	Procurement of Final Reinforcement Quantities	Fri 10/31/14	Fri 11/21/14	Fri 10/31/14	Fri 11/21/14
33	**Initial Casting**	**Mon 10/6/14**	**Mon 1/12/15**	**Mon 10/6/14**	**Sun 2/15/15**
34	Casting Practices	Mon 10/6/14	Sat 12/6/14	Mon 10/6/14	Sat 1/17/15
35	Pre-Batching Final Structural Mix	Mon 12/1/14	Fri 12/5/14	Mon 1/12/15	Fri 1/16/15
36	Mold Assembly and Release Application	Fri 12/5/14	Fri 12/5/14	Mon 1/12/15	Sat 1/17/15
37	Pre-cutting Reinforcement	Fri 12/5/14	Fri 12/5/14	Sat 1/17/15	Sat 1/17/15
38	Concrete Placement	Sat 12/6/14	Sat 12/6/14	Sun 1/18/15	Sun 1/18/15
39	Initial Cure with Mold	Sat 12/6/14	Sat 12/20/14	Sun 1/18/15	Sun 2/1/15
40	Mold Removal	Sat 12/20/14	Sat 12/20/14	Sun 2/1/15	Sun 2/1/15
41	Final Curing	Sat 12/20/14	Mon 1/12/15	Sun 2/1/15	Sun 2/15/15
42	**Second Casting**	**Mon 2/2/15**	**Tue 3/24/15**	**Mon 2/2/15**	**Fri 3/20/15**
43	Material Procurement	Mon 2/2/15	Fri 2/20/15	Mon 2/2/15	Fri 2/13/15
44	Casting Practices	Mon 2/16/15	Mon 2/23/15	Mon 2/16/15	Thu 2/19/15
45	Pre-Batching Final Structural Mix	Mon 2/16/15	Mon 2/23/15	Tue 2/17/15	Thu 2/19/15
46	Mold Reconstruction and Release Application	Mon 2/2/15	Mon 2/23/15	Mon 2/2/15	Thu 2/19/15
47	Pre-Cutting Reinforcement	Mon 2/23/15	Mon 2/23/15	Thu 2/19/15	Thu 2/19/15
48	Concrete Placement	Tue 2/24/15	Tue 2/24/15	Fri 2/20/15	Fri 2/20/15
49	Initial Cure with Mold	Tue 2/24/15	Tue 3/10/15	Fri 2/20/15	Fri 3/6/15
50	Mold Removal	Tue 3/10/15	Tue 3/10/15	Fri 3/6/15	Fri 3/6/15
51	Final Curing	Tue 3/10/15	Tue 3/24/15	Fri 3/6/15	Fri 3/20/15
52	**Finishing & Aesthetics**	**Mon 1/12/15**	**Sun 3/29/15**	**Fri 2/27/15**	**Mon 4/6/15**
53	Sanding and Honing	Mon 1/12/15	Fri 2/13/15	Fri 2/27/15	Sun 3/8/15
54	Staining	Fri 2/13/15	Thu 3/19/15	Mon 3/9/15	Sat 3/28/15
55	Sealing	Thu 3/19/15	Sun 3/22/15	Sun 3/29/15	Mon 3/30/15
56	Sealing Cure	Sun 3/22/15	Sun 3/29/15	Mon 3/30/15	Mon 4/6/15
57	Finishing Complete	Sun 3/29/15	Sun 3/29/15	Mon 4/6/15	Mon 4/6/15
58	**Communications**	**Mon 11/17/14**	**Wed 4/8/15**	**Mon 12/22/14**	**Wed 4/8/15**
59	**Oral Presentation**	**Mon 11/17/14**	**Wed 4/8/15**	**Mon 1/12/15**	**Wed 4/8/15**
60	Design Presentation	Mon 11/17/14	Tue 2/3/15	Mon 1/12/15	Fri 2/13/15
61	Select Presenters	Sun 2/1/15	Sun 2/1/15	Tue 1/27/15	Tue 1/27/15
62	Practice and Review for Potential Questions	Mon 2/16/15	Wed 4/8/15	Fri 2/13/15	Wed 4/8/15
63	**Design Paper**	**Mon 1/12/15**	**Fri 2/27/15**	**Mon 12/22/14**	**Fri 2/27/15**
64	Paper Outline and Draft	Mon 1/12/15	Sun 2/1/15	Mon 12/22/14	Wed 2/4/15
65	Professional Reviews	Mon 2/2/15	Fri 2/20/15	Wed 2/4/15	Wed 2/18/15
66	Final Revision and Refinements	Sat 2/21/15	Thu 2/26/15	Wed 2/18/15	Wed 2/25/15
67	Design Paper Submittal	Fri 2/27/15	Fri 2/27/15	Fri 2/27/15	Fri 2/27/15
68	**Engineer's Notebook**	**Mon 12/8/14**	**Fri 2/27/15**	**Mon 1/19/15**	**Fri 2/27/15**
69	Engineer's Notebook Collection & Formatting	Mon 12/8/14	Wed 2/18/15	Mon 1/19/15	Wed 2/18/15
70	Engineer's Notebook Final Revision	Wed 2/18/15	Fri 2/27/15	Wed 2/18/15	Fri 2/27/15
71	Engineer's Notebook Submittal	Fri 2/27/15	Fri 2/27/15	Fri 2/27/15	Fri 2/27/15
72	**Product Display**	**Mon 12/8/14**	**Sun 3/29/15**	**Mon 12/8/14**	**Sun 3/29/15**
73	Cross Section Construction	Mon 12/8/14	Sun 3/29/15	Sat 1/10/15	Sun 3/29/15
74	Table Top Display Construction	Mon 12/8/14	Sun 3/29/15	Mon 1/19/15	Sun 3/29/15
75	Stands Construction	Mon 12/8/14	Sun 3/29/15	Mon 12/8/14	Sun 3/29/15
76	Display Components Complete	Sun 3/29/15	Sun 3/29/15	Sun 3/29/15	Sun 3/29/15
77	**Physical Conditioning**	**Tue 9/2/14**	**Sun 4/5/15**	**Tue 9/2/14**	**Sun 3/29/15**
78	Outdoor Paddling Practice	Tue 9/2/14	Sat 11/22/14	Tue 9/2/14	Sat 11/22/14
79	Indoor Paddling Practice	Sat 12/6/14	Sat 3/28/15	Sat 12/6/14	Sat 3/28/15
80	Determination of Paddlers	Sun 2/1/15	Sun 2/1/15	Tue 1/27/15	Tue 1/27/15
81	Pre-Regional Competition Paddling Trip	Fri 4/3/15	Sun 4/5/15	Fri 3/27/15	Sun 3/29/15
82	**North Central Conference**	Thu 4/9/15	Sun 4/12/15	Thu 4/9/15	Sun 4/12/15



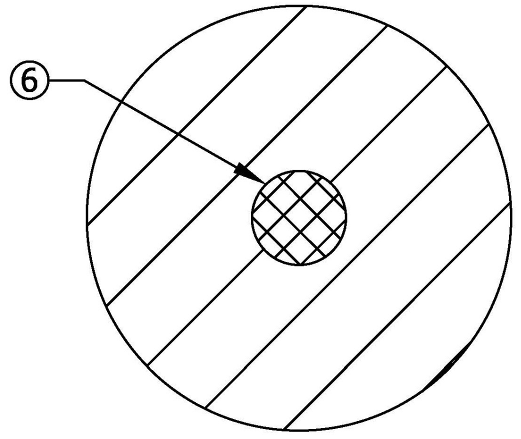
Actual Start 🟦 Baseline ▨ Summary ▬ Critial Path 🟥 Baseline Milestone ◇ Milestone ◆

Michigan Tech Concrete Canoe Project Schedule 2014-2015

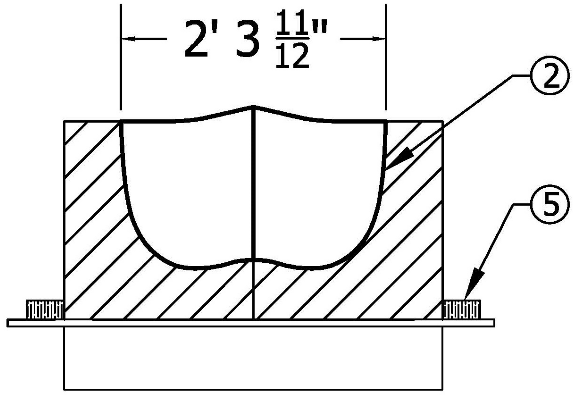




SECTION A-A
SCALE 1 / 25



Detail C
Scale 1:1



SECTION B-B
SCALE 1 / 20

MichiganTech

Michigan Technological University

1400 Townsend Dr.
Concrete Canoe
Houghton MI, 49931

Bill of Materials

No.	Qty.	Description
1	6	Polystyrene Foam
2	1 gal.	Epoxy
3	48 ft²	3/4" OSB
4	56 LFT	2x6 Lumber
5	56 LFT	2x4 Lumber
6	2	1/4"x8" Bolt Assembl

Drawing Name: Mold Design
Boat Name: Talvi Sielu
Drawn By: Robert Herrick
Checked By: Phillip Doederlein
Date: 21 February 2015
Scale: 1/25 Sheet: 11

APPENDIX A: References

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Appendix B: Mixture Proportions

Mixture ID: Loska					Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3):		0.200							
Cementitious Materials				SG	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Federal White Type I Portland Cement			3.15	316.6	1.611	2.3	0.012	330.9	1.684
CM2	Lafarge NewCem®GGBFS			2.99	126.6	0.679	0.9	0.005	132.4	0.709
CM3	VCAS™ 140			2.60	63.3	0.390	0.5	0.003	66.2	0.408
CM4	VCAS™ 160			2.60	126.6	0.781	0.9	0.006	132.4	0.816
	Total Cementitious Materials:				633.2	3.461	4.7	0.026	661.8	3.617
Fibers										
F1	Nycon-PVA RF4000			1.30	5.1	0.063	0.0	0.000	5.4	0.066
F2	Nycon-PVA RECS15			1.30	5.1	0.063	0.0	0.000	5.4	0.066
	Total Fibers:				10.3	0.127	0.1	0.001	10.8	0.133
Aggregates										
A1	Poraver ® 1-2 mm	Abs:	20	0.41	206.8	8.083	1.5	0.060	216.1	8.448
A2	Poraver® 0.5-1.0 mm	Abs:	25	0.45	75.2	2.678	0.6	0.020	78.6	2.799
A3	Poraver® 0.25-0.5 mm	Abs:	30	0.68	94.0	2.215	0.7	0.016	98.2	2.315
A4	3M™ K-1	Abs:	22	0.13	41.8	5.150	0.3	0.038	43.7	5.383
	Total Aggregates:				417.8	18.127	3.1	0.134	436.6	18.945
Water										
W1	Water for CM Hydration (W1a + W1b)			1.00	221.6	3.552	1.6	0.026	231.6	3.712
	W1a. Water from Admixtures				5.2		0.0		5.5	
	W1b. Additional Water				216.4		1.6		226.2	
W2	Water for Aggregates, SSD			1.00	97.6		0.7		102.0	
	Total Water *(W1 + W2)*:				319.2	3.552	2.4	0.026	333.6	3.712
Solids Content of Latex, Dyes and Admixtures in Powder Form										
S1	Xypex® Xycrylic			1.05	11.9	0.182	0.1	0.001	12.5	0.190
	Total Solids of Admixtures:				11.9	0.182	0.1	0.00	12.5	0.19
Admixtures (including Pigments in Liquid Form)				% Solids	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)	Amount (fl oz)	Water in Admixture (lb)	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)
Ad1	Xypex® Xycrilic	*8.8*	*lb/gal*	28.02	38.05	4.6	0.28	0.0	39.77	4.9
Ad2	BASF Glenium® 3030NS	*9.2*	*lb/gal*	20.27	6.34	0.6	0.05	0.0	6.63	0.6
	Water from Admixtures *(W1a)*:					5.2		0.0		5.5
	Cement-Cementitious Materials Ratio				0.50		0.50		0.50	
	Water-Cementitious Materials Ratio				0.35		0.35		0.35	
	Slump, Slump Flow, *in*.				1 in ± 0.5 in		0.5 in		0.5 in	
M	Mass of Concrete. *lbs*				1392.4		10.3		1455.3	
V	Absolute Volume of Concrete, ft^3				25.448		0.189		26.597	
T	Theorectical Density, lb/ft^3 = (M / V)				54.7		54.7		54.7	
D	Design Density, lb/ft^3 = (M / 27)				51.6					
D	Measured Density, lb/ft^3						53.9		53.9	
A	Air Content, % = [(T - D) / T x 100%]				5.7		1.5		1.5	
Y	Yield, ft^3 = (M / D)				**27.0**		0.2		27.0	
Ry	Relative Yield = (Y / Y_D)						0.96			

Mixture ID: Finishing					Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3):		0.200							
Cementitious Materials				SG	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Federal White Type I Portland Cement			3.15	636.4	3.238	4.7	0.024	647.1	3.292
CM2	Lafarge NewCem®GGBFS			2.99	254.6	1.364	1.9	0.010	258.9	1.387
CM3	VCAS™ 140			2.60	127.3	0.785	0.9	0.006	129.4	0.798
CM4	VCAS™ 160			2.60	254.6	1.569	1.9	0.012	258.9	1.596
Total Cementitious Materials:					1272.9	6.956	9.4	0.052	1294.3	7.073
Aggregates										
A3	Poraver ® 0.1-0.3 mm	Abs:	35	0.90	9.4	0.168	0.1	0.001	9.6	0.171
A4	3M™ K-1	Abs:	22	0.13	85.0	10.474	0.6	0.078	86.4	10.650
Total Aggregates:					94.4	10.642	0.7	0.079	96.0	10.821
Water										
W1	Water for CM Hydration (W1a + W1b)			1.00	445.5	7.140	3.3	0.053	453.0	7.260
	W1a. Water from Admixtures				10.5		0.0		10.7	
	W1b. Additional Water				435.0		3.3		442.3	
W2	Water for Aggregates, SSD			1.00	22.0		0.2		22.4	
Total Water *(W1 + W2)*:					467.5	7.140	3.5	0.053	475.4	7.260
Solids Content of Latex, Dyes and Admixtures in Powder Form										
S1	Xypex ® Xycrylic			1.05	24.0	0.366	0.2	0.003	24.4	0.372
Total Solids of Admixtures:					24.0	0.366	0.2	0.00	24.4	0.37
Admixtures (including Pigments in Liquid Form)				% Solids	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)	Amount (fl oz)	Water in Admixture (lb)	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)
Ad1	Xypex ® Xycrilic	*8.8*	*lb/gal*	28.02	38.05	9.3	0.28	0.0	38.69	9.5
Ad2	BASF Glenium® 3030NS	*9.2*	*lb/gal*	20.27	6.34	1.2	0.05	0.0	6.45	1.2
Water from Admixtures *(W1a)*:						10.5		0.0		10.7

		Design Proportions (Non SSD)	Actual Batched Proportions	Yielded Proportions
	Cement-Cementitious Materials Ratio	0.50	0.50	0.50
	Water-Cementitious Materials Ratio	0.35	0.35	0.35
	Slump, Slump Flow, *in*.	1 in ± 0.5 in	0.5 in	0.5 in
M	Mass of Concrete. *lbs*	1858.8	13.8	1890.0
V	Absolute Volume of Concrete, *ft^3*	25.104	0.186	25.526
T	Theorectical Density, *lb/ft^3 = (M / V)*	74.0	74.0	74.0
D	Design Density, *lb/ft^3 = (M / 27)*	68.8		
D	Measured Density, *lb/ft^3*		70.0	70.0
A	Air Content, *% = [(T - D) / T x 100%]*	7.0	5.5	5.5
Y	Yield, *ft^3 = (M / D)*	**27.0**	0.2	27.0
Ry	Relative Yield *= (Y / Y_D)*		0.98	

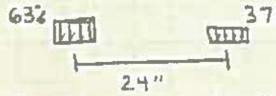
Appendix C: Bill of Materials

Material	Units	Quantity	Unit Price	Total
Federal White Type I White Portland Cement	lb	41.00	$0.27	$11.07
Lafarge NewCem® GGBFS	lb	16.40	$0.05	$0.82
VCAS™ 140	lb	8.20	$0.35	$2.87
VCAS™ 160	lb	16.40	$0.35	$5.74
Poraver® 1.0-2.0mm	lb	26.50	$0.85	$22.53
Poraver® 0.5-1.0mm	lb	9.65	$0.85	$8.20
Poraver® 0.25-0.5mm	lb	12.00	$0.85	$10.20
3M™ K-1	lb	6.00	$11.03	$66.18
Nycon® RECS15 (8mm) PVA	lb	0.65	$6.60	$4.29
Nycon® RF4000 (30mm) PVA	lb	0.65	$6.90	$4.49
Xypex® Xycrylic-Admix	gal	0.50	$5.10	$2.55
BASF Glenium® 3030 NS	gal	0.10	$15.00	$1.50
Textile Products Kevlar® 4009-1	sq ft	80.00	$7.69	$615.20
10% Post-Consumer Recycled Foam Mold	LS	1.00	$1,702.02	$1,702.02
DOW® Extruded Polystrene Foam	sq ft	20.00	$1.25	$25.00
West Systems® Epoxy	gal	0.40	$145.00	$58.00
Huron Technologies Release Coating 7572	gal	0.20	$22.50	$4.50
Butterfield Color Elements™ Transparent Concrete Stain – Assorted Colors	oz	36.00	$1.85	$66.60
Canoe Finishing	LS	1.00	$220.00	$220.00
ChemMasters Crystal Clear - A	gal	1.00	$22.00	$22.00
Total Production Cost				$2,853.75

Assumptions:

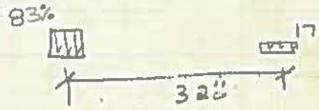
- Paddler Load: 200 lb with 20% increase due to dynamic loading $\Rightarrow P_B = P_S = 240$ lb

Kneeling Paddler (each line load 6" long)



Superimposed load applied @
$D_{PB} = 30$ in (bow) $D_{PS} = 195$ in (stern)

Sitting Paddler (each line load 6" long)



Superimposed load applied @
$D_{PB} = 48$ in (bow) $D_{PS} = 205$ in (stern)

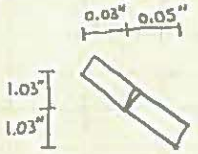
- Nominal thickness = 3/8", unit weight concrete = 58 pcf
- Canoe is free to pitch in water
- x and y coordinates reference same axis set used by PROLINES

Cross-sectional Properties (needed to find canoe self-weight and buoyant forces)

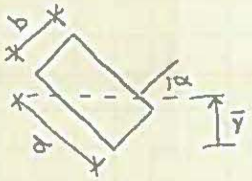
- The process used to obtain cross-section properties involves breaking each cross-section into pieces, based on the number of control points for the profile curve. The sample calculations below is for the cross-section 112 in from the bow, which is the location of max moment in the men races. Cross section 112 has 62 control points. Properties were calculated for one side, and doubled if necessary.

Control Points

Point	x(in)	y(in)
1	-13	6
2	-12.97	4.97
3	-11.92	3.94



Chine y = 6 in
Keel y = -8.73 in



$$I = \frac{bd}{12}\left(d^2\cos^2\alpha + b^2\sin^2\alpha\right)$$

$$A = bd$$

$$\bar{y} = \frac{1}{2}\left(d\cos\alpha + b\sin\alpha\right)$$

$$\alpha = \pi - \left|\tan^{-1}\left(\Delta y/\Delta x\right)\right|$$

From Engineer's Edge www.engineersedge.com/calculators/section_square_case_9.htm

$$d = \sqrt{(\Delta x)^2 + (\Delta y)^2}$$

$b = 0.375$ in

Piece	Δx(in)	Δy(in)	α(rad)	d(in)	A(in^2)	I_c(about piece centroid)(in^4)	$\bar{y}$ from bottom point (in)	$\bar{y}$ from coor. axis (in)
1	0.3	-1.03	0.04	1.03	0.39	0.03	0.52	5.49
2	0.5	-1.03	0.05	1.03	0.39	0.03	0.52	5.46

- After all properties are calculated for each piece, section properties can be found:

Area, A: sum all areas, multiply by two $\Rightarrow A = 18.51$ in^2

Location of neutral axis, $\bar{y}$: Using A and centroids, location of neutral axis can be found:

$$\bar{y} = \frac{\Sigma(A \cdot c)}{\Sigma A} = -2.14 \text{ in}$$

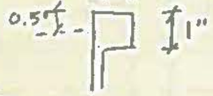
I_x: Given I_c, A, $\bar{y}$, and location of neutral axis, I_x about the x axis can be found using parallel axis theorem:

$$I_x = \Sigma I + \Sigma(a \cdot d^2) = 779.79 \text{ in}^4$$

- Gaps and Overlaps (
  - Using angles between pieces, area, centroids, and moment of inertia for gaps and overlaps were calculated. In depth examples of this procedure, which relies on breaking each gap/overlap into 2 pieces, would exceed the page limit of this appendix.
  - For cross-section 112,

$A_{gap} = -0.96$ in^2, $\bar{y}$ from coor axis = -3.56 in, I_x about x axis = -6.09 in^4

- Gunwale Caps



$A_{cap} = 1.25$ in^2
$\bar{y}$ from coor. axis = 5.5"
I_x about x axis = 87.88 in^4

Total cross-section properties (adding together appropriately)

$A = 18.79$ in^2
$\bar{y} = -1.55$ in
$I_x = 808.39$ in^4 $\Rightarrow$ I about neutral axis = 853.79 in^4

Loading

- Paddler Loads (Kneeler in bow, sitter in stern ⇒ produces largest moment)

Kneeler front line load: $(200\text{ lb}\cdot 1.2)\cdot 0.63/6\text{ in} = 25.2\text{ lb/in}$ starts @ 18 in
Kneeler rear line load: $(200\text{ lb}\cdot 1.2)\cdot 0.37/6\text{ in} = 14.8\text{ lb/in}$ starts @ 42 in
Sitter front line load: $(200\text{ lb}\cdot 1.2)\cdot 0.17/6\text{ in} = 6.8\text{ lb/in}$ starts @ 175 in
Sitter rear line load: $(200\text{ lb}\cdot 1.2)\cdot 0.83/6\text{ in} = 33.2\text{ lb/in}$ starts @ 207 in

- Canoe self-weight

Self weight was determined using an assumed concrete unit weight of 58 pcf and the volume of each cross-section (area · 1 in). Center of gravity of the canoe was determined based on these cross-sectional areas and distance from bow.

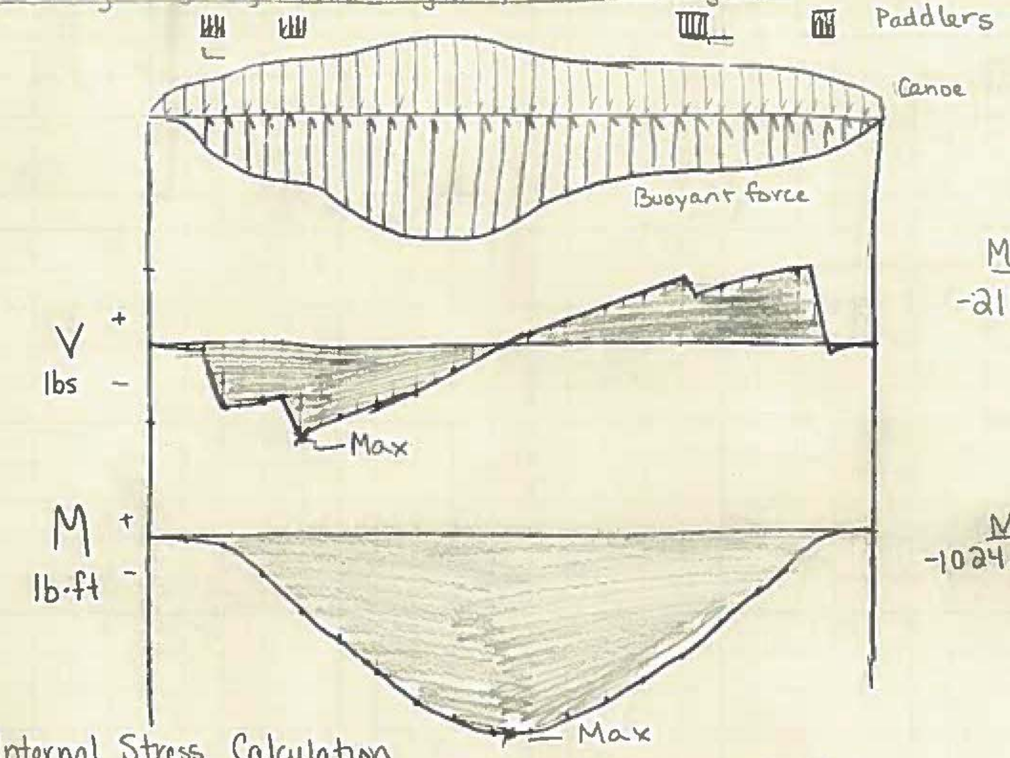
$C.G. = 113.97\text{ in}$, $C_W = 117.6\text{ lb}$

- Buoyant Force

Buoyant Force is force needed to counteract paddler load and canoe weight and acts through the center of buoyancy. By raising either the bow or stern, the center of buoyancy shifts. During the calculation of cross-section properties, the volume of the cross-section submerged as the waterlevel increased in 0.01 in increments were recorded in a 1001 x 227 matrix. Using these values, a baseline waterline was set at the C.G. based on the water depth that created a buoyant force that would counteract the paddler and canoe load. The canoe was then rotated to raise or lower the bow. The new volume and C.B. were recorded. This process was iterated until the following static equilibrium equation was met.

$$\circlearrowleft + \sum M_{Bow} = 0 = -P_B \cdot D_{PB} - P_S \cdot D_{PS} - C_W \cdot CG + CB \cdot \text{Buoyant}$$

Loading Diagram, Shear Diagram, Moment Diagram



Max Shear
-215.25 lb @ 49"

Max Moment
-1024.14 lb·ft @ 112"

Internal Stress Calculation

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

$$y_{chine} = 6\text{ in} - (-1.55\text{ in}) = 7.55\text{ in}$$
$$y_{keel} = -8.73\text{ in} - (-1.55\text{ in}) = -7.18\text{ in}$$

$$\boxed{\begin{aligned}\sigma_{chine} &= -1024.14\text{ lb}\cdot\text{ft}\,\frac{12\text{ in}}{1\text{ ft}}(7.55\text{ in})/853.79\text{ in}^4 = -108.7\text{ psi}\\ \sigma_{keel} &= -1024.14\text{ lb}\cdot\text{ft}\,\frac{12\text{ in}}{1\text{ ft}}(-7.18\text{ in})/853.79\text{ in}^4 = +103.4\text{ psi}\end{aligned}}$$