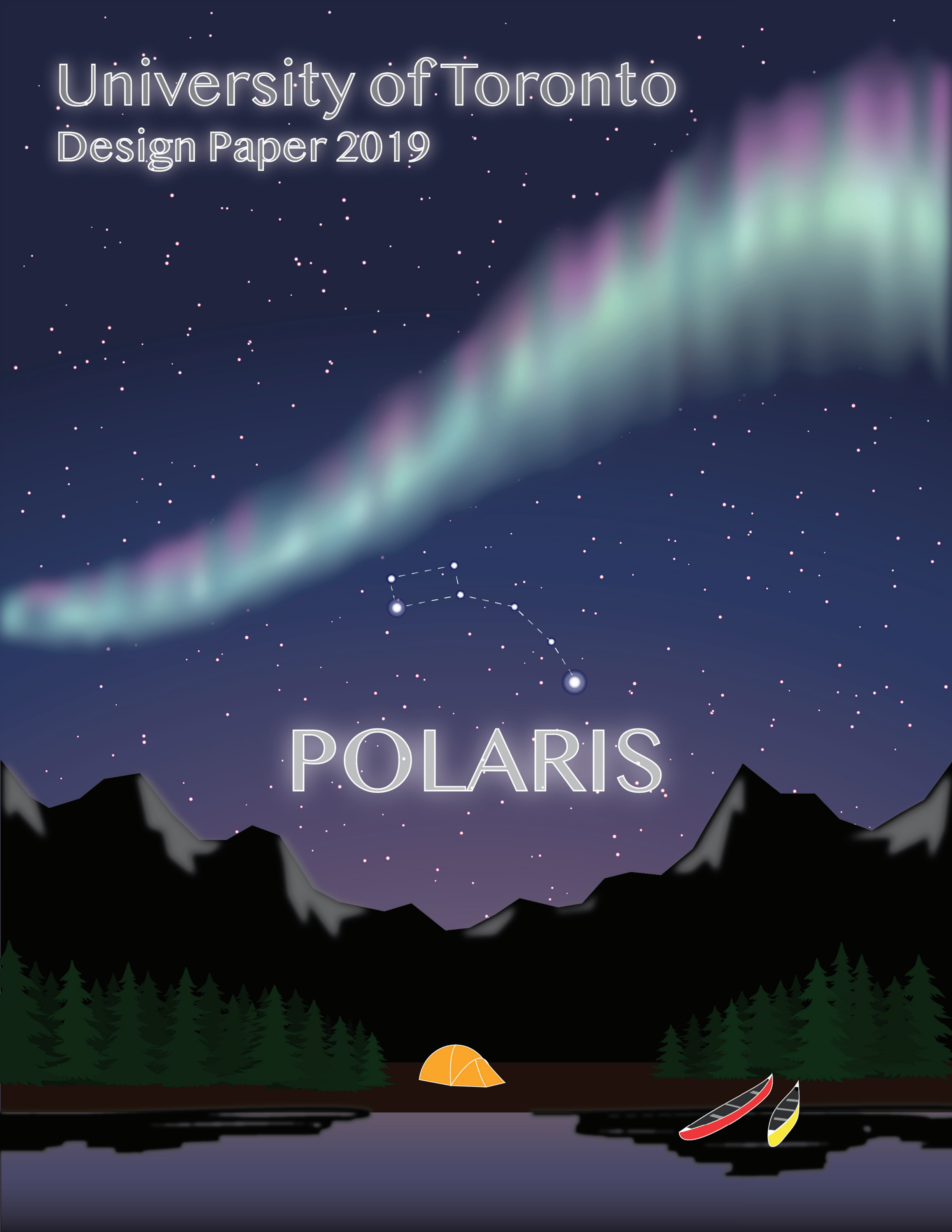
University of Toronto

Design Paper 2019



POLARIS

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Executive Summary

Towards the North Star, *Polaris*, lies fascinating lights unscathed by the development of society. Accompanied by the ambiance of lush forests, voices of the wind, and freedom in wilderness, the lights instill an intangible connection to the environment and its inherent sustainability. The University of Toronto Concrete Canoe Team (UTCCT) aims to recreate the same connection to sustainability and be the guiding star for people everywhere with its own Polaris.

The UTCCT has proudly represented the University of Toronto, located in downtown Toronto, Ontario, in the Canadian National Concrete Canoe Competition (CNCCC) since the competition's inception. The team ranked 5th with Orion in 2016, 6th with *Kamaji* in 2017, and, most recently, 5th with *TrackOne* at the 2018 competition. This year, the team took on new initiatives in all aspects of work, as listed in Table 1, to increase its performance and overall sustainability.

Table 1. Key achievements in project area

Project Area	Key Achievements
Project Management	• Implemented Agile management strategies • Completed key milestones earlier than previous years • Continued public involvement to maintain healthy presence with students and industry
Construction	• Integrated reusable modular core into mould • Improved canoe casting efficiency and quality control
Mix Design	• Maintained sustainability-related rationale in choosing materials to create lighter mixes relative to the baseline mix
Hull Design and Structural Analysis	• Developed in-house Python script to improve efficiency of hull design process • Utilized failure criterion approach to model concrete resistance

The team used Agile management strategies to ensure that all tasks were accounted for, and there were no gaps in the project's work breakdown structure. With Agile strategies, week-to-week focus on work was heightened, and milestones could be accomplished earlier. The canoe's hull design was selected in early September 2018 as a result. The final specifications can be found in Table 2.

Executives were able to focus on innovating analysis methods for hull design and structural analysis to improve the team's knowledge base and enhance knowledge transfer for future years. A Python script was created to automate the optimization process of the hull selection which greatly improved the speed of hull selection.

Table 2. Canoe specifications

Name	Polaris
Maximum Length (m)	5.50
Maximum Width (m)	0.75
Maximum Depth (m)	0.35
Average Thickness (m)	0.016
Weight (kg)	82
Primary Colours	Black, Green, Yellow
Primary Reinforcement	Reduced Carbon Fibre Mesh
Secondary Reinforcement	8 mm PVA Fibres

The team improved sustainability and quality control in canoe construction by innovating mould design and simplifying casting procedures. A modular core composed of milk crates was used to reduce the volume of foam required for construction. Also, the usage of foam inlays as thickness gauges along the length of the mould allowed cleaner separation between coloured concrete sections while creating better thickness control.

The team simplified construction by using a single mix design, shown in Table 3. The mix design incorporated metakaolin and a strength-enhancing admixture while eliminating materials from distant suppliers. Compared to last year's mix, these changes improved sustainability while lowering density and maintaining strengths.

Table 3. Concrete mix properties

Property	Value
ASTM C138 (2017d) Wet Unit Weight (kg/m^3)	890
ASTM C138 (2017d) Oven-Dried Unit Weight (kg/m^3)	886
28-Day ASTM C39 (2018c) Compressive Strength (MPa)	5.20
28-Day ASTM C496 (2017e) Tensile Strength (MPa)	1.35
28-Day ASTM C947 (2016b) Composite Flexural Strength (MPa)	5.80
Air Content (%)	1.2

The team's push for innovation in all aspects of the project work has been driven by a culture of sustainable decision-making. Like the awe-inspiring feeling when viewing the northern lights and stars at night, the team hopes to inspire awe with its 2019 canoe, *Polaris*.

Hull Design and Structural Analysis

Hull Design Development

Last year's canoe, *TrackOne* (UTCCT 2018), lacked stability during the races at the 2018 CNCCC and capsized during the co-ed sprints. *TrackOne* used a new process that utilized DELFTship® (DELFTship 2019). For *Polaris*, the team returned to using its internally developed hull design program, PANDA (Program for Automated Naval Design Analysis) (UTCCT 2008), which was used to design canoes from 2008 to 2017. PANDA can create thousands of canoe designs in minutes by taking geometric parameters such as length, width and curvature to create a canoe design. For each design, PANDA will evaluate properties such as waterplane centroid, block coefficient, and drag using internally coded equations. The team can iteratively determine new designs based off of previous PANDA analysis. While some abilities of PANDA are similar to DELFTship, the team has full control over the code and has a wealth of detailed documentation on PANDA.

This year, the team introduced a new Python (Python Software Foundation 2015) script, POSSUM (PANDA Optimization Supplemental Script Using Machine-learning) (UTCCT 2019), to automate and more efficiently optimize the PANDA hull design process. POSSUM implements basic machine learning principles (Guo 2017) by training PANDA to recognize and optimize towards a suitable design using a root-finding optimization algorithm. The process places more emphasis on design objectives, such as stability, instead of physical properties such as length. Keeping the two softwares allows the team to easily change the code, without affecting PANDA's core functionality.

Canoe Characteristics

Table 4 provides the general design characteristics of *Polaris*. For the design of *Polaris*, POSSUM and PANDA created a final design after 49,152 preliminary designs and reduced a typically semester-long process to one month. *Polaris* features a very flat-bottomed "U-shape" hull instead of a tumblehome like *TrackOne*. Along with an almost vertical flare angle, a reduced stern rocker, and a higher maximum width, these changes aim to increase stability at the expense of maneuverability. To compensate for the loss of maneuverability, and to work around space constraints at the club's work space, the team kept the canoe relatively short at 5.50 m. Lastly, the maximum depth was reduced by 10.0 cm to ensure that shorter paddlers can reach the water without compromising their posture.

Table 4: General design characteristics of Polaris and TrackOne (UTCCT 2018)

Parameter	TrackOne (2018)	Polaris (2019)
Length (m)	5.38	5.50
Bow Rocker (cm)	13.2	13.0
Stern Rocker (cm)	8.20	0
Maximum Width (cm)	70	75
Maximum Depth (cm)	45	35
Flare Angle (Degrees)	-10	10

Structural Analysis Theory

The team continued to rely on an internally developed MATLAB® (MathWorks 2018) software, CAP (Canoe Analysis Program) (UTCCT 2015), to perform its structural analysis by analyzing around 300 cross-sections of the canoe. CAP is able to analyze longitudinal and transverse bending caused by water pressure, gravity load from the canoe, and the paddlers. The team theorized that transverse bending is significant because the plane-section hypothesis necessary for pure longitudinal bending may not be true due to water pressure on the sides of the canoe and paddler loading which causes transverse bending (Beer 2015). *Polaris* displays this theory as it does not use ribs to reinforce its cross-section. CAP analyzes the longitudinal and transverse bending in a biaxial approach that makes use of the Mohr circle. CAP also applies paddler loading factors from 0.75 to 1.25 to account for asymmetric loading, and variation in paddler weight.

The team also utilized the Mohr-Coulomb failure criterion approach to model concrete resistance once principal stresses from CAP were known. Designing the canoe to resist the ultimate tensile strength (UTS) may not adequately prevent cases where the concrete cracks but does not fail (Beer 2015), especially since the UTS is only an uniaxial stress (Lin and Wood 2003). While the concrete can still resist additional tensile loading, cracking will still be harmful and allow water to enter the canoe. A failure criterion provides the benefit of attempting to model and predicting the region where concrete has not cracked under any combination of strengths and loads. Mohr-Coulomb accurately describes brittle materials with far greater compression strengths than tensile strengths, and is widely used for concrete strengths (Labuz and Zhang 2012), unlike the more common Tresca's yield criterion (Juvinall and Marshek 1991).

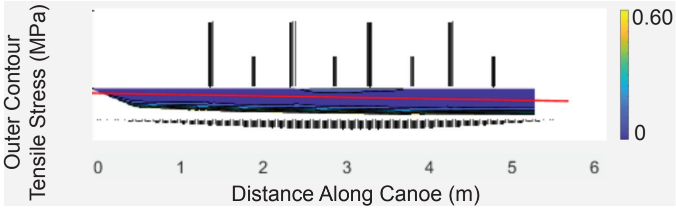


Figure 1: Contour map of maximum tensile strength in the most critical load case

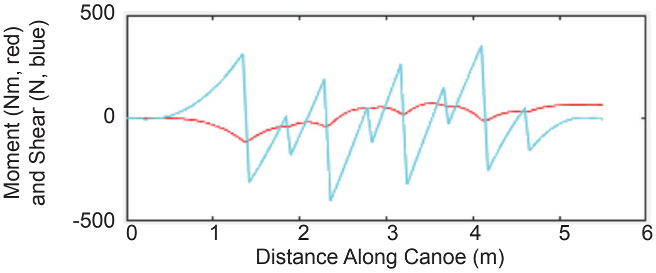


Figure 2: Shear and moment diagrams of the most critical 4 paddler loading case at the most critical paddling placements along the canoe

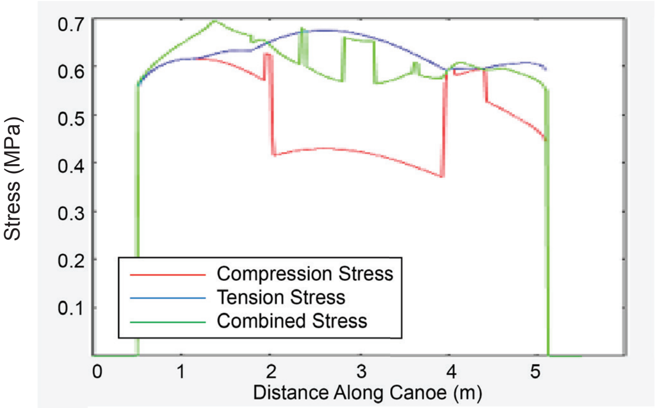


Figure 3: Stress envelopes of all loading cases run by CAP

Structural Analysis Results

After evaluating 351 loading cases, CAP predicted a maximum compression and maximum tensile principal stresses of 0.627 MPa and 0.674 MPa respectively, with the most critical load case being the 4 paddler co-ed race as seen in Figure 2 and Figure 1, with a stress envelope of all loading cases results in Figure 3. Using the Mohr-Coulomb failure criterion, the team predicted that a compression strength and tensile strength of 1.41 MPa and 0.77 MPa respectively would be needed to resist all loading demands. While the team's compression and tensile strength of 5.21 MPa and 1.36 MPa would nominally mean that the canoe is sufficient, the team decided to use a confidence based statistical analysis (Devore 2012), because concrete strengths are normally distributed (Song et al. 2005). The team determined a 99% probability any batch will have at least 5.03 MPa and 1.25 MPa compression and tensile strengths respectively, again proving that the team's strengths are sufficient to resist loads.

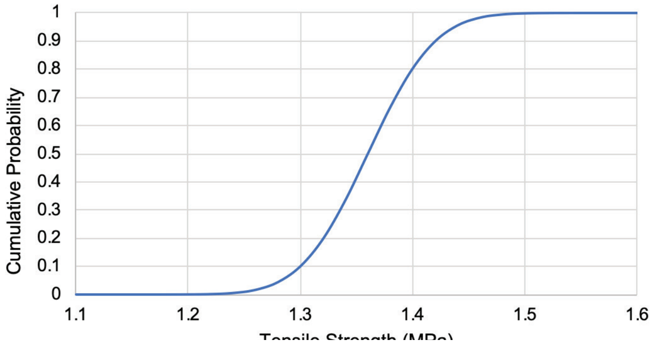


Figure 4: Predicted probability the mix will be below a specific tensile strength

Toe-blocks and Bulkheads

The team decided to keep incorporating toe-blocks in the canoe instead of ribs. Toe-blocks allow paddlers to have a push-off point while undergoing their paddling stroke. Paddlers can also slot their seats between toe-blocks to avoid sliding around in the canoe. Based on previous paddler feedback, paddlers significantly prefer paddling canoes with toe-blocks, such as *TrackOne* (UTCCT 2018), compared to UTCCT practice canoes with ribs, such as *Ecto-2* (UTCCT 2007). It was decided that incorporating toe-blocks was well worth the additional weight and structural demands.

With the concrete density being lighter than water, the team had the option to not have additional flotation in the form of bulkheads. However, during paddling practice, the team noticed large volumes of water entering *Unladen Swallow* (UTCCT 2011), which did not have bulkheads. Additionally, the space at the front and back of the canoe is normally too narrow for paddling, creating little downside for incorporating bulkheads. Therefore the team decided to create 0.1 m^3 in bulkheads, split roughly evenly between the front and back of the canoe, primarily to stop water from entering the canoe.

Development and Testing

In designing the concrete mix for *Polaris*, the team considered impacts on environmental sustainability in addition to objectives of reducing density and acceptable concrete strengths. Last year, two mixes were designed and used for *TrackOne* (UTCCT 2018). The inner structural mix focused on providing the bulk of hull strength and the outer finishing mix focused on aesthetic casting capabilities. However, many challenges were present when using the multiple mixes. Since the two mixes differed in workability, aggregate content, and fibre content, layers of concrete bonded poorly against each other and the mould, causing considerably longer casting periods and cold joint cracks in the exterior layer once cured. The additional mix also led to increased amounts of wasted concrete, which increased costs and greenhouse gas emissions (GHGs) for the team.

This year, to avert these challenges faced with mixing, workability, and casting, the team decided to switch from using two mixes to using a single structural mix. The structural mix of *TrackOne* (UTCCT 2018) provided an acceptable initial baseline due to its excellent flexural strength and sustainability standards. However, modifications were required to achieve objectives of reduced density, and make the mix suitable for creating aesthetic designs. In addition, the team succeeded in reducing total concrete waste, reducing total concrete production from 300 L to 180 L, cutting the concrete-related GHGs by 44%.

Material Selection

This year, white cement and white silica fume were chosen to replace their grey-coloured counterparts in order to maximize the effectiveness of pigments. In addition, the team continued to focus on sustainability during the development of the mix. Local suppliers from the Greater Toronto Area (GTA), such as Poraver®, MasterBuilder® products, and SBR latex, were primarily chosen to reduce GHGs by transportation and also reduce shipping costs. This also allowed the team to personally network with the respective companies and build connections in anticipation for future partnerships. Moreover, usage of fly ash and VCAS-150® was replaced with metakaolin, another pozzolan, as one of the Supplementary Cementitious Materials (SCM) in the binder. Both materials had low carbon footprints in their production, however a holistic "cradle to grave" analysis deemed its use unsustainable due to its excessive amount of embodied carbon associated with transportation. Moreover, only new quantities of white silica fume and Norlite® were procured from locations outside of the GTA. White cement, metakaolin, K37®, and SBR latex were all procured from locations within the GTA at right-sized quantities to reduce waste, while the team used existing quantities of K1®, slag, pigments, Poraver®, and MasterBuilder® admixtures.

Mix Testing

The team utilized a two week testing cycle with alternating objectives. The first week in the cycle iterated on the baseline mix by testing cementitious materials proportions and controlling all other variables, while the second week tested either aggregate proportions, reinforcement, or workability. After two-weeks, the team selected the baseline mix for the next two-week interval. This iterative 10-week flexure testing allowed the team to determine the best performing mix.

ASTM C947 (2016b) flexural testing was conducted weekly for four mixes, each comprised of four beams. Flexural testing was used as the primary testing method to minimize the amount of concrete used and maintain a sustainability focus while satisfying strength testing requirements. Flexural testing was also more representative of actual canoe loading as opposed to compressive tests. Since concrete can reach 75% of their 28-day strength (Lange 1994) in seven days, the team tested each mix after seven days of curing. This allowed the team to mimic rapid prototyping in software development settings, and allowed to team to rapidly assess the results of each mix. 28-day ASTM C39 (2018c) compressive, ASTM C947 (2016b) flexural and ASTM C496 (2017e) tensile tests were conducted after the final mix was selected to ensure rule compliance and to develop the failure criterion needed for the structural analysis process. At the end of the three-month testing period from September to November, 29 unique mixes were designed using 80 L of concrete.

Cementitious Materials Composition

In general, the team aimed to use as much SCMs, such as slag, silica fume, and metakaolin, as possible since they have less than a quarter of the unit carbon emissions of portland cement. Therefore, attempts were made to further decrease the amount of portland cement in the mix from the existing 0.25 c/cm used in *TrackOne*. Flexural testing results, displayed in Table 5, showed a 47.6% strength decrease from 0.25 c/cm and 0.2 c/cm. As a result, the team decided to maintain the cement content because the significant strength loss was deemed unacceptable and could not be compensated by only a marginal improvement in sustainability.

Table 5: Strength results of mixes with variations in c/cm ratios

c/cm ratio	0.25	0.2	0.15	0.1
Average 7 Day ASTM C947 (2016b) Flexural Strength (MPa)	3.30	2.05	1.73	0.98

Metakaolin was introduced because it has much faster reaction times than VCAS and fly ash, and has a supplier within the GTA to reduce transportation-related GHGs. Metakaolin also produced a more cohesive concrete with less bleeding (Kosmatka et al. 2002), better mould adhesion (Ženíšek et al. 2016), and decreased porosity of the cement binder (Ambroise et al. 1994). The largest volume of cementitious material was occupied by slag. A literature review suggests that large amounts of slag in concrete mixes will not have effects on the strength (Aldea et al. 2000) or workability of the mix (Qasrawi et al. 2009), making it well suited for use as the primary replacement for portland cement. The team continues to use silica fume despite its high water demand because it increases both early and long-term compressive and tensile strength (Kosmatka et al. 2002). The team tested silica fume volumes extensively during *TrackOne* (UTCCT 2019), and focused more attention on testing the other cementitious materials.

Aggregate & Mineral Filler Composition

In response to the rule change surrounding mineral filler, and the lack of particle size data for K1® and K37®, the team conducted sieve tests, with data shown in Table 6, for use in the mix design and batching process. Norlite® 4x0, the ASTM C330 (2017b) aggregate, was also tested to confirm the manufacturer provided value. As the team did not have consistent access to a mechanical sieving machine, the team opted to not adjust the gradation of K1® and K37®, and use both materials as aggregate and mineral filler, since manually sieving the material was very labour-intensive. In contrast, the team sieved out all Norlite® particles that passed the No. 200 sieve as the heavier density made it much easier to sieve manually. This was done to decrease the density of mineral filler as much as possible.

Table 6: Results of ASTM C136 (2014) sieve test done on aggregates

Material	Norlite® 4x0	K1	K37
Percent Passing No. 200 Sieve	7.8	86.7	96.9

To achieve the team's objectives of reducing density, larger aggregate sizes were used. In contrast to the 1 mm maximum aggregate size in *TrackOne*, larger 2 mm Poraver® and Norlite® were used. The 2 mm Poraver® size was noticeably lighter than the 1 mm size. For Norlite®, the team chose the larger Norlite® 4x0 over Norlite® 8x0 for *TrackOne*, which has a reduced oven dried density of 1550 kg/m^3 compared to the 1700 kg/m^3 for Norlite® 8x0. These substitutions showed no noticeable reduction in strength during flexure tests while decreasing the density.

Table 7: Strength results of K37® and K1® volumes at 0.420 m^3 total mineral filler volume. 0.006 m^3 of mineral filler volume was occupied by Norlite fines throughout all tests

Volume of K37® (m^3)	Volume of K1® (m^3)	Average 7 Day ASTM C947 (2016b) Flexural Strength (MPa)	Density of Mix (kg/m^3)
0.290	0.124	2.88	795
0.269	0.245	2.75	790
0.249	0.166	3.12	785
0.228	0.186	3.37	780

Last year, testing results using very steep gradients demonstrated that using significantly more volumes of K1® than K37® provided a decrease in the concrete's strength. K1®'s low crush strength may have been the cause. Despite K1®'s low density, the team decided to focus on finding the combination of mineral filler with the highest strengths. A reduction in density could be found by other means such as through the use of latex, larger aggregate sizes and more use of total mineral filler compared to last year. Therefore, testing for this year's mineral filler focused on gradually increasing the volume of K1®, seen in Table 7, to find the ratio of K37® to K1®

with the highest strength. This was determined to be 55% K37 to 45% K1® for a flexural strength of 3.37 MPa.

Admixture Selection

During the construction of *TrackOne*, the team observed large variations in the workability of the concrete, ranging from soup-like consistency to gravel-like consistency. The team deduced that this was primarily caused by dosages of MasterGlenium® 7700, a high-range water reducer, and MasterSure® Z 60, a workability-retaining admixture, being more than double the recommended dosage to compensate for the loss of SBR Latex. At high dosages, the team observed that the workability of the mix would be inconsistent. The absence of latex resulted in a reduction in flexural strengths and significant losses of workability, for which the team attempted to compensate by manipulating the dosages.

The team also noticed many instances of shrinkage cracking on the hull of *TrackOne*, and also attributed the cause to large dosages of MasterGlenium® and MasterSure®. With competition rules reauthorizing SBR Latex, the team was able to reduce dosages of MasterGlenium® and MasterSure® to around the recommended levels. In addition to improving workability, the team observed that SBR Latex led to a 47% improvement in flexural strengths. The team also introduced one new admixture for *Polaris* - Master X-Seed® 55. Master X-Seed® is a hardening accelerator admixture that increases the development of concrete strength by nucleating increased growth of CSH crystals within the cement binder (Pizoń et al. 2016). The team found that the addition of X-Seed® at recommended dosages increased flexural strengths 25% compared to the baseline mix.

Reinforcement

Similar to *TrackOne*, two layers of carbon fibre mesh were again used this year to increase flexural strength, transverse stresses, and reduce the risk of potential punching shear damage. The carbon fibre mesh was reduced to around 60-70% of its manufactured density by removing excess strands to provide better bonding between concrete layers on opposite sides of the mesh and to comply with rules surrounding the percent open area of reinforcement. Carbon fibre was selected over alternative reinforcing materials such as fibreglass to make use of existing supply from past sponsorships, reducing waste and increasing sustainability.

In addition to a carbon fibre mesh, PVA fibres were used as a secondary reinforcement. The team chose to use 8 mm PVA fibres, which are shorter, are easier to sand off, and provide more tensile and flexural strength than the previous 18 mm PVA fibre. In previous years, declumping fibres was labour-intensive due to the two-stage process of hand-declumping fibres and drill mixing the declumped fibres into the mix. This year, the team used a drill to both mix the concrete materials and declump the fibres. This led to a reduction of 12 person-minutes in the mixing process for a 5 L batch of concrete, compared to the previous method. This also contributed to slightly higher strengths since the drills did a better job of declumping and incorporating the fibres into the concrete than manually by hand. The new fibres also contributed to an approximately 10% increase in flexural strengths compared to the 18 mm fibres.

Final Mix Design

In accordance with the team's main objectives, the final mix displays a significant decrease in density with a slight decrease in strength compared to the structural mix from 2018, as shown in Table 8. The density loss is mainly a result of using SBR Latex, which permits a higher w/cm ratio, increased use of glass microspheres as well as using larger aggregate gradations. This was all done while maintaining the team's sustainability standards in the mix.

Table 8: Concrete properties of the mix

Property	TrackOne	Polaris
ASTM C138 (2017d) Wet Unit Weight (kg/m^3)	1220	886
ASTM C138 (2017d) Dry Unit Weight (kg/m^3)	1190	810
28 Day ASTM C39 (2018c) Compressive Strength (MPa)	14.90	5.20
28 Day ASTM C947 (2016b) Flexural Strength (MPa)	4.40	4.65
28 Day ASTM C496 (2017e) Tensile Strength (MPa)	2.50	1.35
28 Day ASTM C947 (2016b) Composite Flexural Strength (MPa)	6.85	5.80
28 Day ASTM C469 (2014) Elastic Modulus (MPa)	N/A	5.60

Construction

Mould Design and Construction

This year, the team implemented a new mould design, which increased the efficiency of the demoulding process and reduced the amount of extruded polystyrene (XPS) used. During the construction of *TrackOne* (UTCCT 2019), the team used a homogeneous mould consisting of only computer numerically controlled (CNC) machined foam pieces, which had a volume of approximately 1.80 m^3. The demoulding of a homogeneous mould required all foam to be removed and significantly damaged the foam in the process, making it harder for the team to reuse the foam for the cross-section. This new mould design reduced the foam usage by approximately 0.60 m^3, to 1.2 m^3, and was accomplished by having a modular core that can be reused in future years. The mould for *Polaris* has a reusable modular core surrounded by CNC-machined XPS pieces, on which concrete can be casted upon. The core consisted of 6 milk-crates that the team normally uses as reusable boxes during competition, which ensured that standard dimensions could be used for future years, while also eliminating material and electricity to build the core. Foam then surrounded the core, as seen in Figure 5, and any gaps were filled with a combination of scrap fibreboard and art clay.

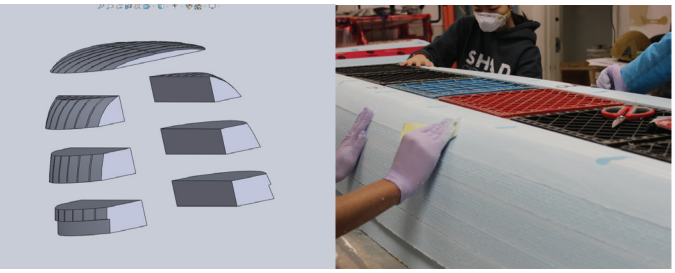


Figure 5: CAD design of foam surrounding the modular core (left), and the mould being assembled and sanded (right). The modular core is the black, blue, red milk crates between the foam pieces

The constructed mould was then wrapped with shrink wrap and taped at the seams. The shrink wrap acted as a release agent that can easily be applied to surfaces. Once heated, it conforms to the shape of the mould, and leaves minimal marks on cured concrete surfaces. Compared to chemical release agents, shrink wrap requires no personal protection equipment (PPE), providing a safer environment for team members and other tenants sharing the building. With the new mould design, the team was able to demould the canoe in approximately 20 minutes, as oppose to the several hours it took to demould previous years' canoes. Compared to previous years, the team significantly reduced the damage to foam pieces needed for the cross section, and was able to shorten the time to construct the cross section by 6 person-hours. The mould also significantly reduced carbon emissions and cost, seen in Table 9. The modular core is part of a larger long-term effort by the team to reduce foam use by reusing foam for the cross-section, and optimizing pieces to eliminate waste.

Table 9: Volume of foam, cost of mould construction and carbon emissions in constructing the mould

Canoe	Cost ($)	Carbon Emissions (kg CO_2)	Volume of Foam (m^3)
Orion (UTCCT 2016)	3400	281	4.5
Kamaji (UTCCT 2017)	3150	169	2.7
TrackOne (UTCCT 2018)	3000	113	1.8
Polaris (2019)	2500	75	1.2

Concrete Mixing Procedure

Prior to casting day, all dry materials that constitute the concrete were mixed and pre-bagged. This was done in order to reduce the time for mixing and to focus more time on casting and quality control during canoe construction. By pre-weighing the dry materials, the team was also able to verify no wrongly measured batches were produced before canoe construction. For *Polaris*, only one concrete mix was used to reduce batching, mixing, and casting complexity, and the team purchased a corded drill to mix concrete instead of the cordless drill and hand-mixing combination used for *TrackOne*. The corded electric drill had several advantages such as increased torque, increased speed, and most importantly, a non-battery source of power. This led to an improvement in concrete production from 0.27 L/min to 0.97 L/min.

Casting Procedure

Casting instructions were revamped in order to ensure that the casting of *Polaris* was done as efficiently as possible. Each member was shown how to cast and given tips to improve their casting technique to have smoother surfaces, better thickness control, and proper placement of the concrete. Furthermore, all members were acquainted with safety procedures (i.e. use of gloves, coveralls, and N95 masks/P100 respirators). The team also designated four quality control personnel, made up of veteran members, whose sole job was to enforce quality control.

To increase the casting speed, the team utilized a new layering configuration depicted in Figure 6, with the carbon fibre mesh between each layer.. Through past experiences and testing, the team noticed that thin layers of concrete were slower to cast and harder to control in thickness, compared to thicker layers. With equal 4 mm thick layers, the casters developed a metaconscious knowledge (Vanderburg 2016) of concrete thicknesses, and avoided time wasted to relearn proper thicknesses for each layer. Along with 4 mm thick aesthetic inlays, multiple 4 mm thick foam rails were placed at 30 cm clear separation from each other across the mould, to ensure that concrete layers had a uniform thickness throughout the canoe. Quality control personnel also checked for proper thicknesses using the rails.

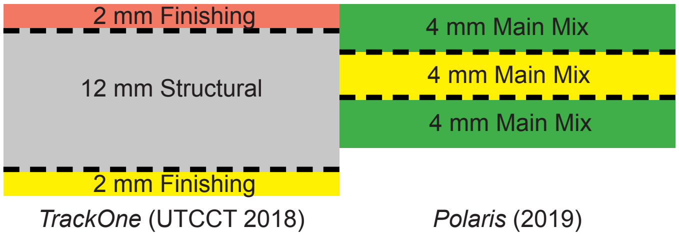


Figure 6: Layering for TrackOne (UTCCT 2018) (left) and Polaris (Right)

The carbon fibre meshes were modified before canoe construction so the two meshes were ready to apply during construction. The team trimmed the mesh to properly fit the canoe, and concrete was gradually placed over the mesh. In cases where the mesh was distorted, quality control personnel readjusted the strands to have perpendicular mesh openings.

Aesthetic Design Elements

To depict mountains and northern lights on the canoe, the team used foam inlays similar to the ones used on *TrackOne*. Inlays were suspended from the mould to cast the first colour around the inlay. After removing the inlays, the second colour was filled in the areas outlined by the first colour. Similar to the thickness rails, inlays for *Polaris* were 4 mm thick and provided additional guidance for proper canoe thickness. An image of the inlays used to cast the aesthetic elements of *Polaris* can be seen in Figure 7.

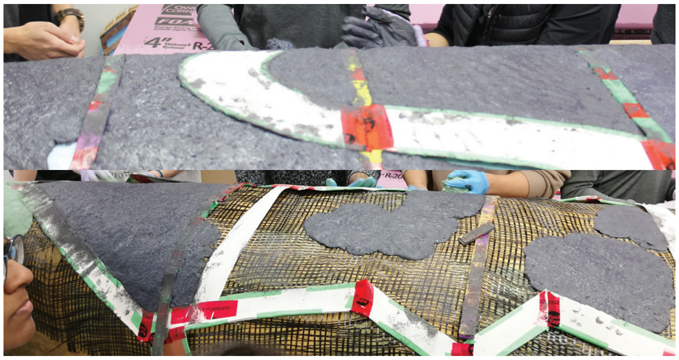


Figure 7: Thickness rails, and two types of foam inlays used for designing the northern lights (top) and mountains (bottom)

Curing Procedure

Similar to previous years, a humidity tent was used to cure *Polaris* at a 100% relative humidity environment for the 28 day curing period. Vapour barrier supported by posts surrounded the canoe and was sealed with tape. Four evaporative humidifiers were placed in the tent to maintain humidity. The team used a custom-made humidity monitor (derived from an Arduino Kit) to measure humidity in the tent and used an “(s,S) inventory policy” (Arrow et al. 1951) to monitor humidity and correct any leaks on a regular basis.

Sanding and Sealing

With the team reaching many critical milestones early, the team devoted more time to sanding and finishing the canoe. The team manually wet sanded the dry side of the canoe indoors at 120, 320, 600, and 800 grits to prevent harmful dust exposure to members and nearby offices. With the water side of the canoe being a convex surface, the team was able to use its power sanders to also sand the canoe at 120, 320, 600, and 800 grits. Before applying the sealer, the team made spot checks on the canoe and manually sanded any region that did not get properly sanded by the power sanders.

The team continued to apply two coats of MasterKure® CC300 XS. Having a VOC content of 347 g/L, the team ensured that proper respirators blocking organic vapours were worn by the team. Despite the increased safety concerns a solvent-based sealer would have, the team prefers the glossy finish it creates. After both coats of sealer, the team sanded all surfaces of the canoe with 2000 grit sandpaper to remove any bubbles in the sealer that may create bumps.

Project Planning and Management

Project Management

During the design and development of *Polaris*, the team committed to using Agile project management strategies to encourage efficiency, teamwork, and accountability. Agile focuses on breaking down overarching project tasks into smaller subtasks, completing these subtasks, and inspecting and reflecting on progress (Schwaber 2004). An overview of the Agile process can be seen in Figure 8. The team facilitated this by employing a digital task tracking board, Trello (Atlassian 2019), to track progress. The Trello board was replicated on a physical kanban board accessible by every team member. The team then held weekly 15-minute "stand-up" meetings involving team leads before full team meetings to share progress, identify problems, and update the boards.

With Agile strategies (Schwaber 2004), the person-hours of members were managed more efficiently. Weekly progress updates ensured accountability while allowing other team leads and project managers to identify issues or improvements. This improved productivity and quality because leads were motivated to refine their work regularly and cohesively. Broadly speaking, Agile strategies have helped shift person-hour allocation towards productivity in technical work and refining construction, while taking advantage of larger member turnouts in meetings. This can be seen in the project's person-hour breakdown in Figure 9.

Figure 8. Overview of the Agile process

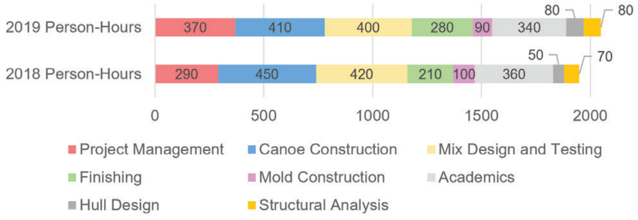


Figure 9. Distribution of person-hours in 2018 and 2019 seasons

As with last year, a flat organization structure with divisions for the different aspects of core project tasks (outlined on Page 10) was used because it was successful in involving general members in multiple project divisions. A key difference this year, however, is the sharing of sub-team responsibility with multiple team leads. For novice team leads, this approach allowed more time to be spent on learning and reduced the stress of executing tasks. While more time is spent in building consensus-based decisions, Agile management and a larger roster mitigated this with productivity improvements.

Project Budgeting

In developing the project budget shown in Figure 10, the team employed zero-based budgeting strategies where a budget started from zero and every purchase had to be justified (Pyhrr 1977). The team was able to avoid unneeded expenditures, saving $1,100 in construction costs compared to *TrackOne* (UTCCT 2018). These savings helped the team plan for higher competition-related expenses due to longer travel, a larger roster, and higher accommodation costs in Montreal. To further mitigate these costs, the team committed to only using coach buses and public transit during competition while continuing to share canoe transportation with the Ryerson Concrete Canoe and Ryerson Steel Bridge teams. This will also reduce all three teams' carbon footprints and foster better inter-university relationships. Other mitigation efforts focused on raising over $6,000 in financial or in-kind donations. Remaining funding was achieved through faculty sponsorship and student society funding to balance a budget of $20,500.

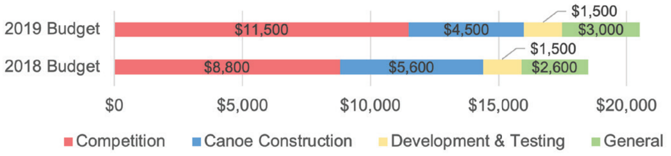


Figure 10. Comparison of budgets in 2018 and 2019 seasons

Project Planning

The scope of the project schedule varied slightly compared to previous years. The core tasks for competition deliverables were essentially the same. However, to mitigate risks associated with mould construction, hull selection was completed in early September. The early completion created float time to mitigate schedule and quality risks in planned subcontracting of mould construction, which has created issues for the team in the past. The critical path for the project, primarily including concrete design, hull design, and canoe design and construction tasks, was determined using the critical path method while accounting for scheduled float times. In general, the major milestones falling on the critical path of the project, outlined in Table 10, were completed relatively earlier than in previous years to create additional float time for risk mitigation. Float time would then be used in the event of unexpected problems or to remedy poor quality work. For instance, the team's mould milling subcontractor completed delivery two weeks later than expected, but float time allowed mould construction to be completed without delaying critical tasks. Barring any major delays, completion of the canoe is expected to be on schedule.

Table 10: Comparison of planned project milestones

Milestone	2017-2018 Scheduled Date	2018-2019 Scheduled Date	Relative 2018-2019 Timing During Academic Year
Hull Selection	10/17/2017	09/01/2018	7 weeks earlier
Mix Design Selection	12/09/2017	12/08/2018	-
Canoe Casting	02/03/2018	01/26/2019	1 week earlier
Canoe Completion	04/28/2018	04/13/2019	2 weeks earlier

Quality Control and Assurance

To ensure compliance with competition rules, project managers created checklists outlining key rules for team leads. Team leads were asked for any uncertainty in the rules, which would then be submitted as a request for information (RFI). The competition website was checked on a weekly basis by project managers, and any new RFI responses were communicated to relevant team leads. In the event that a material technical data sheet was unclear in terms of rule compliance, team leads consulted with suppliers for additional documentation.

The team's use of Agile strategies ensured that all tasks were accounted for by someone so there were no gaps in the project's work breakdown structure. The execution of important tasks was accompanied by a peer review process with project managers and team leads, ensuring sufficient work quality. The team established multiple stages of team review after a very rough initial draft of technical documents or funding applications. This process created an iterative way to draft technical deliverables that also regularly checks for the quality of the work.

Safety Measures

Measures were taken to ensure safety in all material testing and construction. Concrete team leads conducted an inventory of all materials, and all Safety Data Sheets (SDS) were compiled and stored openly in the team's workspace. Old admixtures and other chemicals that were no longer of use were labeled and disposed of through environmental health and safety services. All other materials were stored as prescribed by their SDSs. Construction training sessions were also held earlier in the year to teach members how to use power tools and PPE. This training was mandatory for all members, and all construction was supervised by a trained team lead.

Sustainability in Planning

The team continued its involvement in its school's orientation week by sharing team media, organizing mini-games, speaking at department lunches, and expanding its club fair presence. The team also continued its involvement with several alumni events, student newspaper articles, university open houses, and a showcase of an old concrete canoe at a concrete industry conference. Events engaged twice as many new students than in previous years, and the team has seen increased emails and social media activity as tracked by MailChimp® (The Rocket Science Group, 2019) and Instagram© (Facebook, 2019). Many industry companies have also recognized the team through these events and have led to sponsorship partnerships and additional networking opportunities.

The team also held several introductory workshops outside of weekly meetings for general members and the general student community. These workshops provided a high level overview of technical portfolios such as hull design, mix design, and structural analysis. Along with new comprehensive transition documents shared using Google Drive™ (Google, 2019), this ensured that knowledge transfer to future leaders of the team progressed smoothly.

Organization Chart

Rick Liu (Jr)
Matthew Garcia (Sr)
Project Managers &
Team Captains

AESTHETICS AND CONSTRUCTION

Muhammad Ali (Jr)
Maria Wu (Grad)
Team Leads

Aidan Ashton (Fr)
Sydney Ng (Fr)
Jeffrey Wang (Jr)
Nicola Liu (Fr)
Caitlin Lee (Sr)

STRUCTURAL AND HULL DESIGN

Reynold Chan (Jr)
Ahnaf Ferdous (Jr)
Brian Ra (Jr)
Team Leads

Andy Liao (Jr)
Tony Tao (So)
Natasha Valenton (Jr)
Benjamin Leung (Grad)
Paul Go (Jr)

PADDLING

Gordon Wong (Sr)
Gabrielle Lau (So)
Team Leads

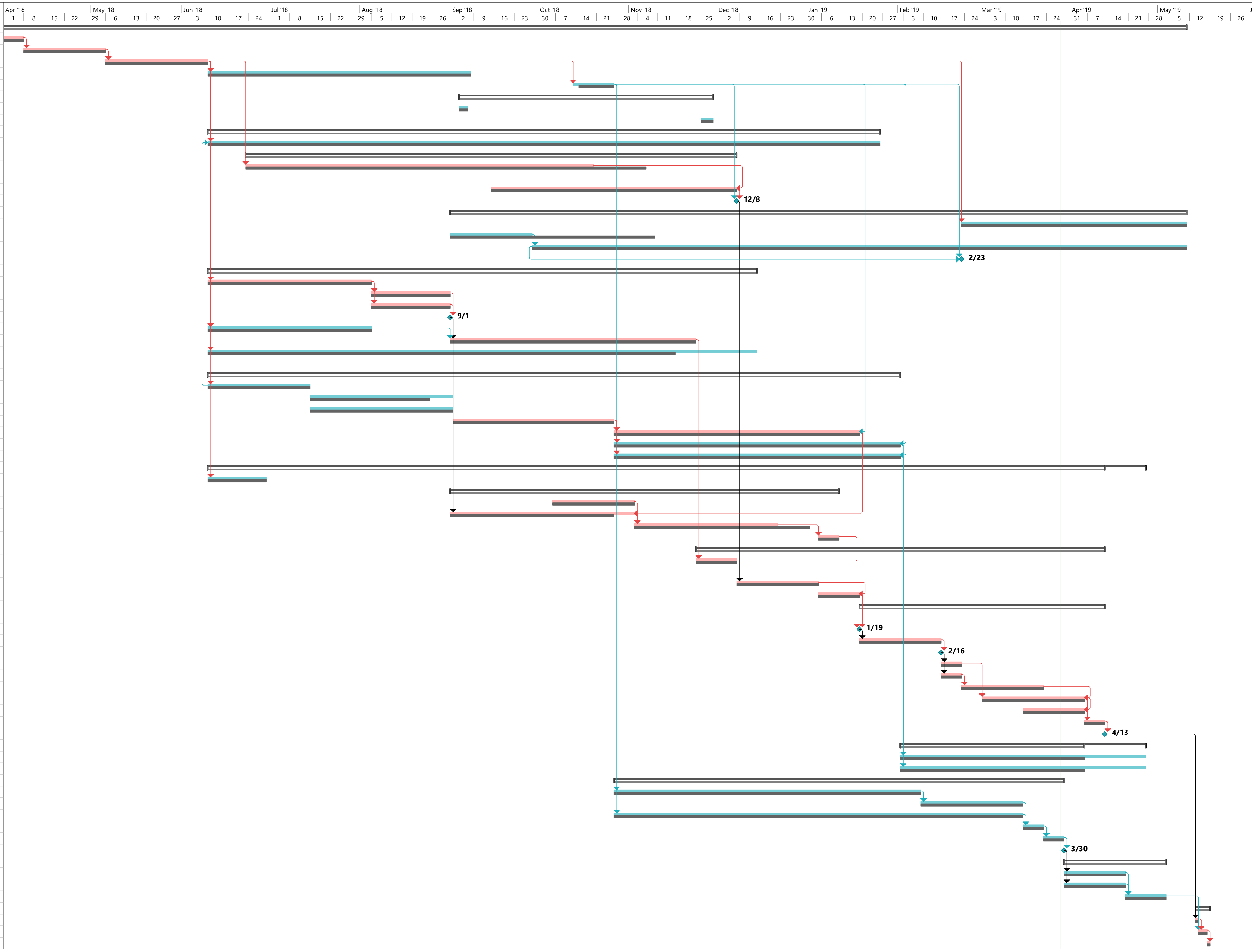
Eileen Lau (Jr)
Michael Zolis (So)
Andrew Wuebbolt (So)
Baotian Fu (So)
Yca Theresa (Sr)

CONCRETE MIX DESIGN

Shirley Zhang (So)
Ashley An (So)
Team Leads

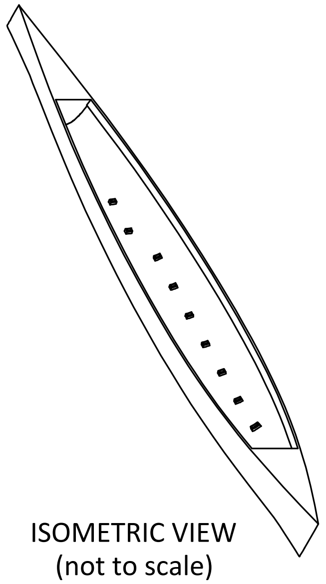
Moranne Parsons (So)
Robin Ahmed (So)
Ernie Lee (Fr)
Kira Philips (Fr)
Stella Gregorski (Fr)
Sarah Birch (Fr)

ID	Task Name	Duration	Baseline Start	Baseline Finish	Start	Finish
1	**Preparations for 2019 CNCCC**	**405 days**	**Sun 4/1/18**	**Sat 5/11/19**	**Sun 4/1/18**	**Sat 5/11/19**
2	Establish Yearly Goals	7 days	Sun 4/1/18	Sun 4/8/18	Sun 4/1/18	Sun 4/8/18
3	Exec Recruitment	28 days	Sun 4/8/18	Sun 5/6/18	Sun 4/8/18	Sun 5/6/18
4	Leader Turnover	35 days	Sun 5/6/18	Sun 6/10/18	Sun 5/6/18	Sun 6/10/18
5	Draft Timeline	90 days	Sun 6/10/18	Sat 9/8/18	Sun 6/10/18	Sat 9/8/18
6	Review CNCCC Regulations	14 days	Mon 10/15/18	Sat 10/27/18	Sat 10/13/18	Sat 10/27/18
7	**Recruitment and Event Participation**	**87 days**	**Tue 9/4/18**	**Fri 11/30/18**	**Tue 9/4/18**	**Fri 11/30/18**
8	Frosh Events and Clubs Fair	3 days	Tue 9/4/18	Fri 9/7/18	Tue 9/4/18	Fri 9/7/18
9	World of Concrete Pavilion	4 days	Mon 11/26/18	Fri 11/30/18	Mon 11/26/18	Fri 11/30/18
10	**Sponsorship**	**230 days**	**Sun 6/10/18**	**Sat 1/26/19**	**Sun 6/10/18**	**Sat 1/26/19**
11	Fundraising	230 days	Sun 6/10/18	Sat 1/26/19	Sun 6/10/18	Sat 1/26/19
12	**Concrete**	**168 days**	**Sat 6/23/18**	**Sat 12/8/18**	**Sat 6/23/18**	**Sat 12/8/18**
13	Material Inventory and Procurement	119 days	Sat 6/23/18	Wed 11/7/18	Sat 6/23/18	Sat 10/20/18
14	Testing and Design	84 days	Sat 9/15/18	Sat 12/8/18	Sat 9/15/18	Sat 12/8/18
15	Final Mix Design Decision	0 days	Sat 12/8/18	Sat 12/8/18	Sat 12/8/18	Sat 12/8/18
16	**Paddling**	**252 days**	**Sat 9/1/18**	**Sat 5/11/19**	**Sat 9/1/18**	**Sat 5/11/19**
17	On-Water Paddling	77 days	Sat 2/23/19	Sat 5/11/19	Sat 2/23/19	Sat 5/11/19
18	Paddler Recruitment	28 days	Sat 9/1/18	Sat 11/10/18	Sat 9/1/18	Sat 9/29/18
19	Gym Training	224 days	Sat 9/29/18	Sat 5/11/19	Sat 9/29/18	Sat 5/11/19
20	Paddling Team Finalization	0 days	Sat 2/23/19	Sat 2/23/19	Sat 2/23/19	Sat 2/23/19
21	**Hull Design and Structural Analysis**	**188 days**	**Sun 6/10/18**	**Sat 12/15/18**	**Sun 6/10/18**	**Sat 12/15/18**
22	Preliminary Hull Design	56 days	Sun 6/10/18	Sun 8/5/18	Sun 6/10/18	Sun 8/5/18
23	Hull Design Analysis	27 days	Sun 8/5/18	Sat 9/1/18	Sun 8/5/18	Sat 9/1/18
24	Preliminary Structural Analysis	27 days	Sun 8/5/18	Sat 9/1/18	Sun 8/5/18	Sat 9/1/18
25	Hull Selection	0 days	Sat 9/1/18	Sat 9/1/18	Sat 9/1/18	Sat 9/1/18
26	Failure Criterion Investigation	56 days	Sun 6/10/18	Sun 8/5/18	Sun 6/10/18	Sun 8/5/18
27	Advanced Structural Analysis	84 days	Sat 9/1/18	Sat 11/24/18	Sat 9/1/18	Sat 11/24/18
28	In-House Analysis Program Development	188 days	Sun 6/10/18	Sat 11/17/18	Sun 6/10/18	Sat 12/15/18
29	**Aesthetics**	**237 days**	**Sun 6/10/18**	**Sat 2/2/19**	**Sun 6/10/18**	**Sat 2/2/19**
30	Sponsorship Package Redesign	35 days	Sun 6/10/18	Sun 7/15/18	Sun 6/10/18	Sun 7/15/18
31	Banner Design	49 days	Sun 7/15/18	Sat 8/25/18	Sun 7/15/18	Sun 9/2/18
32	Poster Creation	49 days	Sun 7/15/18	Sun 9/2/18	Sun 7/15/18	Sun 9/2/18
33	Theme Decision	55 days	Sun 9/2/18	Sat 10/27/18	Sun 9/2/18	Sat 10/27/18
34	Canoe Finish Design	84 days	Sat 10/27/18	Sat 1/19/19	Sat 10/27/18	Sat 1/19/19
35	Stand Design	98 days	Sat 10/27/18	Sat 2/2/19	Sat 10/27/18	Sat 2/2/19
36	Table Display Design	98 days	Sat 10/27/18	Sat 2/2/19	Sat 10/27/18	Sat 2/2/19
37	**Construction**	**321 days**	**Sun 6/10/18**	**Sat 4/13/19**	**Sun 6/10/18**	**Sat 4/27/19**
38	Mixing Apparatus Construction	20 days	Sun 6/10/18	Sat 6/30/18	Sun 6/10/18	Sat 6/30/18
39	**Mold Construction**	**133 days**	**Sat 9/1/18**	**Sat 1/12/19**	**Sat 9/1/18**	**Sat 1/12/19**
40	Material Procurement	28 days	Sat 10/6/18	Sat 11/3/18	Sat 10/6/18	Sat 11/3/18
41	Mould Modelling	63 days	Sat 9/1/18	Sat 10/27/18	Sat 9/1/18	Sat 11/3/18
42	CNC Milling	49 days	Sat 11/3/18	Wed 1/2/19	Sat 11/3/18	Sat 12/22/18
43	Mould Assembly	7 days	Sat 1/5/19	Sat 1/12/19	Sat 1/5/19	Sat 1/12/19
44	**Concrete Construction**	**140 days**	**Sat 11/24/18**	**Sat 4/13/19**	**Sat 11/24/18**	**Sat 4/13/19**
45	Primary Reinforcement Preparation	14 days	Sat 11/24/18	Sat 12/8/18	Sat 11/24/18	Sat 12/8/18
46	Concrete Material Procurement	28 days	Sat 12/8/18	Sat 1/5/19	Sat 12/8/18	Sat 1/5/19
47	Concrete Prebatching	14 days	Sat 1/5/19	Sat 1/19/19	Sat 1/5/19	Sat 1/19/19
48	**Canoe and Cutaway Section Construction**	**84 days**	**Sat 1/19/19**	**Sat 4/13/19**	**Sat 1/19/19**	**Sat 4/13/19**
49	Canoe Casting	0 days	Sat 1/19/19	Sat 1/19/19	Sat 1/19/19	Sat 1/19/19
50	Canoe Curing	28 days	Sat 1/19/19	Sat 2/16/19	Sat 1/19/19	Sat 2/16/19
51	Canoe Demolding	0 days	Sat 2/16/19	Sat 2/16/19	Sat 2/16/19	Sat 2/16/19
52	Bulkhead Casting	7 days	Sat 2/16/19	Sat 2/23/19	Sat 2/16/19	Sat 2/23/19
53	Cutaway Section Casting	7 days	Sat 2/16/19	Sat 2/23/19	Sat 2/16/19	Sat 2/23/19
54	Cutaway Section Curing	28 days	Sat 2/23/19	Sat 3/23/19	Sat 2/23/19	Sat 3/23/19
55	Sanding	35 days	Sat 3/2/19	Sat 4/6/19	Sat 3/2/19	Sat 4/6/19
56	Sealing	21 days	Sat 3/16/19	Sat 4/6/19	Sat 3/16/19	Sat 4/6/19
57	Decal Application	7 days	Sat 4/6/19	Sat 4/13/19	Sat 4/6/19	Sat 4/13/19
58	Canoe Completion	0 days	Sat 4/13/19	Sat 4/13/19	Sat 4/13/19	Sat 4/13/19
59	**Display Construction**	**84 days**	**Sat 2/2/19**	**Sat 4/6/19**	**Sat 2/2/19**	**Sat 4/27/19**
60	Stand Construction	84 days	Sat 2/2/19	Sat 4/6/19	Sat 2/2/19	Sat 4/27/19
61	Table Display Construction	84 days	Sat 2/2/19	Sat 4/6/19	Sat 2/2/19	Sat 4/27/19
62	**Design Report**	**154 days**	**Sat 10/27/18**	**Sat 3/30/19**	**Sat 10/27/18**	**Sat 3/30/19**
63	Draft	105 days	Sat 10/27/18	Sat 2/9/19	Sat 10/27/18	Sat 2/9/19
64	Revision	35 days	Sat 2/9/19	Sat 3/16/19	Sat 2/9/19	Sat 3/16/19
65	Graphic Design	140 days	Sat 10/27/18	Sat 3/16/19	Sat 10/27/18	Sat 3/16/19
66	Final Formatting	7 days	Sat 3/16/19	Sat 3/23/19	Sat 3/16/19	Sat 3/23/19
67	Printing	7 days	Sat 3/23/19	Sat 3/30/19	Sat 3/23/19	Sat 3/30/19
68	Submission/Shipping	0 days	Sat 3/30/19	Sat 3/30/19	Sat 3/30/19	Sat 3/30/19
69	**Oral Presentation**	**35 days**	**Sat 3/30/19**	**Sat 5/4/19**	**Sat 3/30/19**	**Sat 5/4/19**
70	Draft Outline	21 days	Sat 3/30/19	Sat 4/20/19	Sat 3/30/19	Sat 4/20/19
71	Development of Visuals	21 days	Sat 3/30/19	Sat 4/20/19	Sat 3/30/19	Sat 4/20/19
72	Presentation Practice	14 days	Sat 4/20/19	Sat 5/4/19	Sat 4/20/19	Sat 5/4/19
73	**Canadian National Competition**	**5 days**	**Tue 5/14/19**	**Sun 5/19/19**	**Tue 5/14/19**	**Sun 5/19/19**
74	Transportation to Montreal	1 day	Tue 5/14/19	Wed 5/15/19	Tue 5/14/19	Wed 5/15/19
75	Competition Events	3 days	Wed 5/15/19	Sat 5/18/19	Wed 5/15/19	Sat 5/18/19
76	Transportation to Toronto	1 day	Sat 5/18/19	Sun 5/19/19	Sat 5/18/19	Sun 5/19/19



UTCCT 2018-2019 Schedule
Status Date: March 29, 2019

Summary Task	⊢⊣	Baseline Summary	⊢⊣	Critical Task	▬	Task	▬	Baseline	▬	Milestone	◆
										Baseline Milestone	◇



ISOMETRIC VIEW
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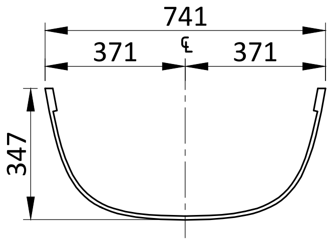

CROSS-SECTION A-A
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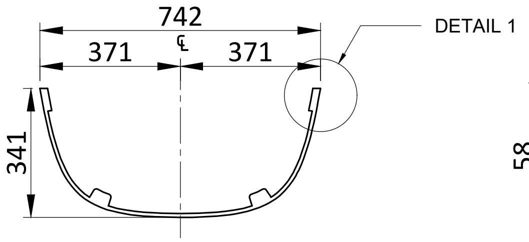

CROSS-SECTION B-B
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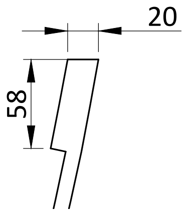

DETAIL 1
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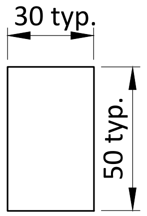

DETAIL 2
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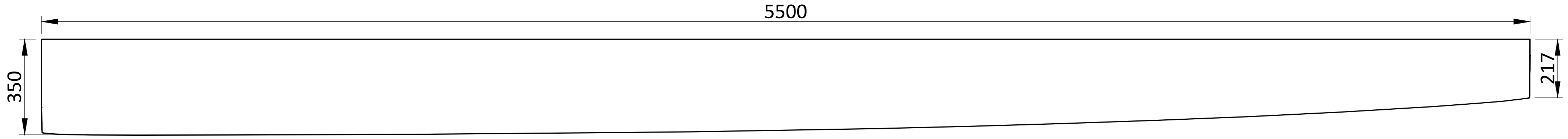
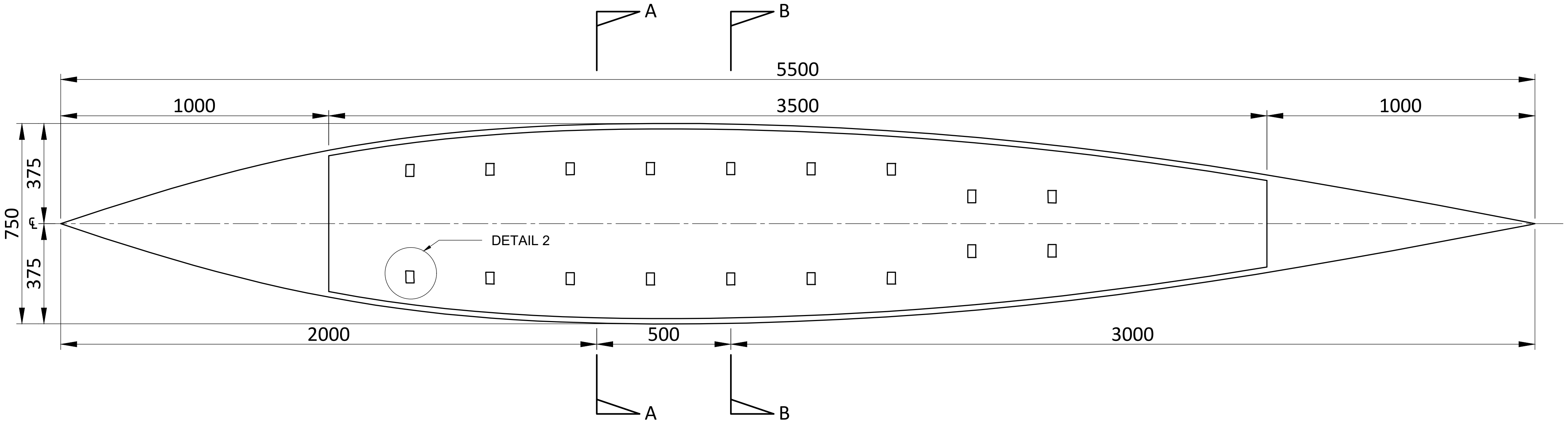


ELEVATION 1:20



PLAN 1:20

UNIVERSITY OF TORONTO CONCRETE CANOE TEAM

BILL OF MATERIALS

No.	Item	Quantity
1	White Portland Cement	7.884 kg
2	White Silica Fume	6.264 kg
3	Slag, Grade 100	9.396 kg
4	Metakaolin	7.884 kg
5	PVA Fibres	2.268 kg
6	Poraver® 0.5-1 mm	2.808 kg
7	Poraver® 1-2 mm	3.996 kg
8	Norlite®	10.476 kg
9	K37® Glass Microshperes	8.100 kg
10	K1® Glass Microshperes	2.484 kg
11	Euclid SBR Latex	22.248 kg
12	Workability Retaining Admixture	0.432 L
13	High Range Water Reducing Admixture	0.432 L
14	Strength Enhancing Admixture	0.324 L
15	Pigment	2.484 kg
16	Carbon Fibre Mesh	11.000 m^2
17	Sealer	3 L
18	XPS Mould	1.20 m^3
19	Lettering	1 LS

Polaris

REVISIONS

DATE	DETAILS OF REVISION
11/02/2018	MODELLED BY: R. LIU
01/27/2019	DRAWN BY: M. ALI
03/10/2019	CHECKED BY: M. GARCIA, R. LIU
1:20	Sheet 1 of 1

Appendix A - References

All graphics and photos in this design paper are original and were made and/or taken by the team. No external graphics or photos were used.

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MIXTURE DESIGNATION: Main Mix

CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (m^3)*	*Amount (mass/volume) (kg/m^3)*	
Type I White Cement, ASTM C150	3.2	0.023	*73.00*	*Mass of all cementitious materials, cm* **306.00** *kg/m^3* *c/cm ratio* **0.25**
Type S Slag Cement, Grade 100, ASTM C989	3.2	0.027	87.00	
Silica Fume, ASTM C1240	2.3	0.025	58.00	
Class N Metakaolin, ASTM C618	0.47	0.033	73.00	

FIBERS

Component	*Specific Gravity*	*Volume (m^3)*	*Amount (mass/volume) (kg/m^3)*	
NYCON® PVA RECS15	1.30	0.016	*21.00*	*Total Amount of Fibers* **21** *kg/m^3*

AGGREGATES

Aggregates (Indicate ASTM compliance if applicable)	*A (%)*	*SG (OD)*	*SG (SSD)*	*Base Quantity (kg/m^3)*		*Volume, SSD (m^3)*
				OD	*SSD*	
Norlite® expanded shale 4x0, ASTM C330	15	1.55	1.78	96.88	111.41	0.063
Poraver® microspheres 1-2mm	26	0.36	0.45	26.27	33.10	0.073
Poraver® microspheres 0.5-1mm	27	0.44	0.56	36.70	46.60	0.083
K1® Glass Microspheres	0	0.13	0.13	3.10	3.10	0.025
K37® Glass Microspheres	0	0.37	0.37	2.35	2.35	0.006

ADMIXTURES

Admixture	*SG*	*Dosage* (ml/100 kg of CM*)*	*% Solids*	*Water in Admixture (kg/m^3)*	
Master X-Seed® 55, strength-enhancing admixture	*1.20*	817	31	*2.07*	*Total Water from Admixtures, $\sum W_{admx}$* **120.35** *kg/m^3*
MasterSure® Z 60, workability-retaining admixture	*1.06*	1233	25	*3.00*	
MasterGlenium® 7700, high-range water-reducing admixture	*1.06*	921	34	*1.98*	
SBR Latex	*1.20*	61200	45	*113.3*	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)

Component	*Specific Gravity*	*Volume (m^3)*	*Amount (mass/volume) (kg/m^3)*	
SBR Latex	1.53	0.061	92.7	*Total Solids from Admixtures, $\sum S_{admx}$* **208.2** *kg/m^3*
Interstar® concrete colours, ASTM C979	0.750	0.030	22.5	
K1® Glass Microspheres	0.125	0.161	20.14	
K37® Glass Microspheres	0.370	0.197	72.85	

WATER

	Amount (mass/volume) (kg/m^3)		*Volume (m^3)*
Water, kg/m^3		W_{total}: 131.11	*0.131*
Total Free Water from All Aggregates, kg/m^3		$\sum W_{free}$: -31.26	
Total Water from All Admixtures, kg/m^3		$\sum W_{admx}$: 120.35	
Batch Water, kg/m^3		W_{batch}: 41.53	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (kg)	306.00	21.00	196.55	208.20	131.11	*$\sum M$: 862.85*
Absolute Volume, V, (m^3) (< 1 m3)	0.116	*0.016*	*0.250*	*0.449*	*0.131*	*$\sum V$: 0.962*
Theoretical Density, T, (=$\sum M$ / $\sum V$)	897	*kg/m^3*	***Air Content [= (T – D)/T x 100%]***			*1.2 %*
Measured Density, D	886	*kg/m^3*	***Slump, Slump flow***			*10 mm*
water/cement ratio, w/c:	1.73		***water/cementitious material ratio, w/cm:***			0.43

Cementitious Material Calculation and Proportioning

Table B-1: Given Masses and Densities of Cementitious Materials

Material	Mass, m_i (kg)	Density, ρ_i (kg/m^3)
White Cement	76.00	3200
Slag	92.00	3200
White Silica Fume	61.00	2300
Metakaolin	76.00	2200

Volume of material $i = v_i = \frac{m_i}{p}$

Table B-2: Calculation of Volume of Cementitious Material

Material	Volume, V_i (m^3)
White Cement	$V_{cem} = \frac{76.00kg}{3200kg/m^3} = 0.024$
Slag	$V_{slag} = \frac{92.00kg}{3200kg/m^3} = 0.029$
White Silica Fume	$V_{SF} = \frac{61.00kg}{2300kg/m^3} = 0.027$
Metakaolin	$V_M = \frac{76.00kg}{2200kg/m^3} = 0.036$

Total = White Cement + Slag + White Silica Fume + Metakaolin

Total volume of cementitious materials = V_{CM}

$$V_{CM} = \sum V_i = 0.024m^3 + 0.029m^3 + 0.027m^3 + 0.036m^3 = 0.116m^3$$

Total mass of cementitious materials = m_{CM}

$$m_{CM} = \sum m_i = 76.00kg + 93.00kg + 61.00\ kg + 76.00kg = \ 306.00kg$$

Cement-to-cementitious-material mass ratio = $\frac{m_{Cement}}{m_{CM}} = \frac{76.00kg}{306kg}$ = 0.25

Aggregate Calculation and Proportioning

Material Passing No. 200 Sieve

Table B-3: Masses of Materials Passing No. 200 Sieve

Material	Percent Passing No. 200 Sieve	Combined Filler and Aggregate Mass, m_i (kg)
K1®	86.67	23.25
K37®	96.88	75.20

Only Norlite masses above the No. 200 Sieve were used for aggregate calculations.

K1 and K37 masses above the No. 200 Sieve were considered in the calculations of Aggregates Mineral Filler ($K1®_{Agg}$ and $K37®_{Agg}$). K1 and K37 masses below the No. 200 Sieve were considered in the calculations of Mineral Filler ($K1®_{Filler}$ and $K37®_{Filler}$).

No additional modification of the existing particle size distribution for K1 and K37 was done.

Table B-4: Given Masses and Densities of Aggregate

Aggregate	SSD Density, ρ_i $\left(\frac{kg}{m^3}\right)$	W_{OD} (kg)	W_{SSD} (kg)	W_{STK} (kg)	Abs (%)	MC_{STK} (kg)
Norlite® (ASTM C330)	1783	96.88	111.41	96.88	15	0
Poraver® 1-2 mm	454	26.27	33.10	26.27	26	0
Poraver® 0.5-1 mm	559	36.70	46.60	36.70	27	0
$K1®_{Agg}$	125	3.10	3.10	3.10	0	0
$K37®_{Agg}$	370	2.35	2.35	2.35	0	0

Volume of aggregate i = $V_i = \frac{mi}{\rho i}$

Table B-5: Calculation of Volume of Aggregates

Aggregate	Volume, V_i (m^3)
Norlite® (ASTM C330)	$V_{Norlite} = \frac{111.41kg}{1783kg/m^3} = 0.063$
Poraver® 1-2 mm	$V_{Poraver1} = \frac{33.10kg}{454kg/m^3} = 0.073$
Poraver® 0.5-1 mm	$V_{Poraver0.5} = \frac{46.6kg}{559kg/m^3} = 0.083$
$K1®_{Agg}$	$V_{K1_{Agg}} = \frac{3.10kg}{125kg/m^3} = 0.025$
$K37®_{Agg}$	$V_{K37_{Agg}} = \frac{2.35kg}{370kg/m^3} = 0.006$

Total volume of aggregates = V_{Agg}

$$V_{Agg} = \sum V_i = 0.063m^3 + 0.073m^3 + 0.083m^3 + 0.025m^3 + 0.006m^3 = 0.25m^3$$

Total mass of aggregates = m_{Agg}

$$m_{Agg} = \sum m_i = 111.41kg + 33.10kg + 46.60\ kg + 3.097kg + 2.346kg = \ 196.55kg$$

Proportioning of Norlite® (ASTM C330 Aggregate)

$\%Norlite = \frac{0.063m^3}{0.25m^3} \times\ 100\% = 25\%\ \geq 25\%$

Meets ASTM C330 Non-Glass Microsphere Volumetric Minimum Requirement of 25%

Water in Aggregates

<u>Norlite®</u>

$$A = \frac{W_{SSD} - W_{OD}}{W_{OD}} = \frac{111.41kg/m^3 - 96.88kg/m^3}{96.88kg/m^3} \times 100\% = 15\%$$

$$MC_{total} = \frac{W_{STK} - W_{OD}}{W_{OD}} = \frac{96.88kg/m^3 - 96.88kg/m^3}{96.88kg/m^3} \times 100\% = 0\%$$

$$MC_{free} = MC_{total} - A = 0\% - 15\% = -15\%$$

$$w_{free} = 96.88kg/m^3 \ \times \frac{-15\%}{100\%} = -14.53kg/m^3$$

<u>Poraver® 1-2 mm</u>

$$A = \frac{W_{SSD} - W_{OD}}{W_{OD}} = \frac{33.10kg/m^3 - 26.27kg/m^3}{26.27kg/m^3} \times 100\% = 26\%$$

$$MC_{total} = \frac{W_{STK} - W_{OD}}{W_{OD}} = \frac{26.27kg/m^3 - 26.27kg/m^3}{26.27kg/m^3} \times 100\% = 0\%$$

$$MC_{free} = MC_{total} - A = 0\% - 26\% = -26\%$$

$$w_{free} = 26.27kg/m^3 \ \times \frac{-26\%}{100\%} = -6.83kg/m^3$$

Poraver® 0.5-1 mm

$$A = \frac{W_{SSD} - W_{OD}}{W_{OD}} = \frac{46.60kg/m^3 - 36.70kg/m^3}{36.70kg/m^3} \times 100\% = 27\%$$

$$MC_{total} = \frac{W_{STK} - W_{OD}}{W_{OD}} = \frac{36.70kg/m^3 - 36.70kg/m^3}{36.70kg/m^3} \times 100\% = 0\%$$

$$MC_{free} = MC_{total} - A = 0\% - 27\% = -27\%$$

$$w_{free} = 36.70kg/m^3 \times \frac{-27\%}{100\%} = -9.9kg/m^3$$

K1®

$$A = \frac{W_{SSD} - W_{OD}}{W_{OD}} = \frac{3.10kg/m^3 - 3.10kg/m^3}{3.10kg/m^3} \times 100\% = 0\%$$

$$MC_{total} = \frac{W_{STK} - W_{OD}}{W_{OD}} = \frac{3.10kg/m^3 - 3.10kg/m^3}{3.10kg/m^3} \times 100\% = 0\%$$

$$MC_{free} = MC_{total} - A = 0\% - 0\% = 0\%$$

$$w_{free} = 3.10kg/m^3 \times \frac{0\%}{100\%} = 0kg/m^3$$

K37®

$$A = \frac{W_{SSD} - W_{OD}}{W_{OD}} = \frac{2.35kg/m^3 - 2.35kg/m^3}{2.346kg/m^3} \times 100\% = 0\%$$

$$MC_{total} = \frac{W_{STK} - W_{OD}}{W_{OD}} = \frac{2.35kg/m^3 - 2.35kg/m^3}{2.35kg/m^3} \times 100\% = 0\%$$

$$MC_{free} = MC_{total} - A = 0\% - 0\% = 0\%$$

$$w_{free} = 2.35kg/m^3 \times \frac{0\%}{100\%} = 0kg/m^3$$

Mineral Filler Calculation and Proportioning

Table B-6: Given Masses and Densities of Mineral Fillers

Mineral Filler	Mass, $m_i\ (kg)$	Density, $\rho_i\ \left(\frac{kg}{m^3}\right)$
$K1®\ _{Filler}$	20.14	125
$K37®\ _{Filler}$	72.85	370

Volume of Mineral Filler i = V_i = $\frac{mi}{\rho i}$

Table B-7: Calculation of Volume of Mineral Fillers

Mineral Filler	Volume, $V_i\ (m^3)$
$K1®\ _{Filler}$	$V_{K1_{Filler}} = \frac{20.14kg}{125kg/m^3} = 0.161$
$K37®\ _{Filler}$	$V_{K37_{Filler}} = \frac{72.85kg}{370kg/m^3} = 0.197$

Total = K1® + K37®

Total volume of Mineral Filler = V_{MF}

$$V_{MF} = \sum V_i = 0.161m^3 + 0.197m^3 = 0.358m^3$$

Total mass of aggregates = m_{MF}

$$m_{MF} = \sum m_i = 20.14kg + 72.85kg = 92.99\ kg$$

Fibres Calculation and Proportioning

Fibres Used: Nycon® RECS15

Given Mass: m_{RECS15} = 21.00 kg

Given Density: ρ_{RECS15} = $1300\,\frac{kg}{m3}$

Volume: : $V_{RECS15} = \frac{21kg}{1300kg/m3} = 0.016\ m^3$

Pigment Calculation and Proportioning

Table B-8: Given Mass, Density and Volume Calculation of Pigments

Material	Mass, m_i (kg)	Density, ρ_i (kg/m^3)	Volume, V_i (m^3)
Interstar Ready Mix Colors	22.50	750	$V_{pigment} = \frac{22.50kg}{750kg/m3} = 0.030\ m^3$

Admixture Dosage and Water Content

Table B-9: Given Parameters of Admixtures

Admixture	Mass, m_i (kg)	Density, ρ_i (kg/m^3)	% Solids
Master X-Seed®	3.00	1200	31
MasterSure®	4.00	1060	25
MasterGlenium®	4.00	1064	34
SBR Latex®	206.00	1100	45

Density of Latex

For 1100 kg of Latex or 1 m^3 of Latex

m solids $_{Latex}$= 1100kg/m^3 x 45% = 495 kg/m^3

m water $_{Latex}$= 1100 kg/m^3 x 55% = 605 kg/m^3

V solids $_{Latex}$= 1000kg/m^3 - 605kg/m^3 = 395kg/m^3

SG solids $_{Latex}$= $\frac{495kg}{395m^3}$= 1.25

Density solids $_{Latex}$= 1.25 x 1000kg/m^3 = 1250 kg/m^3

Latex Solids Mass

m solids $_{Latex}$ = $206kg\ x\ 45\%$ =92.7 kg

V solids $_{Latex}$ = $\frac{206kg\ x\ 45\%}{1530\ kg/m^3}$= 0.061 m^3

Dosage of admixture

Dosage of admixture *i* = $\text{Dosage}_i = \frac{mi \times 1000L/m^3 \ \times 1000mL/L \times 100kg_{CM}}{\rho_{i \times} m_{CM}}$

$\text{Dosage}_{\text{X-Seed}} = \frac{3.00kg \times 1000L/m^3 \ \times 1000mL/L \times 100kg_{CM}}{1200kg/m^3 \ \times 306kg}$ = 817 *mL*/100*kg* of CM

$\text{Dosage}_{\text{MasterSure}} = \frac{4.00kg/m3 \times 1000L/m^3 \ \times 1000mL/L \times 100kg_{CM}}{1060\ kg/m^3 \ \times 306\ kg}$ = 1233 *mL*/100*kg* of CM

$Dosage_{\text{MasterGlenium}} = \frac{3.00kg \times 1000L/m^3 \times 1000mL/L \times 100kg_{CM}}{1064kg \ \times 306\ kg}$ = 921*mL*/100*kg* of CM

$Dosage_{\text{Latex}} = \frac{206.00kg \times 1000L/m^3 \ \times 1000mL/L \times 100kg_{CM}}{1100kg/m^3 \ \times 306\ kg}$ = 61200 *mL*/100*kg* of CM

Water content of admixture

Water content of admixture *i* = $w_i = m_i \times (1 - \%solids)$

$w_{\text{X-Seed}} = 3.00kg \times (1 - \frac{31\%}{100\%})$ = 2.07 kg

$w_{\text{MasterSure}} = 4.00kg \ \times (1 - \frac{25\%}{100\%})$ = 3.00 kg

$w_{\text{MasterGlenium}} = 3.00kg \times (1 - \frac{34\%}{100\%})$ = 1.98 kg

$w_{\text{Latex}} = 206.00kg \times (1 - \frac{45\%}{100\%}) =$ 113.3 kg

Total water content in admixtures = $\sum m_{admix}$ = 2.07 kg + 3.00 kg + 1.98 kg + 113.30 kg = 120.35 kg

Total Solids Masses and Volumes (Excluding Mineral Filler)

Total = Pigment + SBR Latex Solids

Total mass = $\sum m_i$ = 22.50 kg + 92.70 *kg* = 115.20 *kg*

Total volume = $\sum m_i$ = + 0.030 m^3 = + 0.061 m^3 = 0.091 m^3

Total Free and Batch Water for All Aggregates

Total Free Water = K1® + K37® + Norlite® + Poraver® 1-2 mm + Poraver® 0.5-1 mm

$$w_{free} = 0kg/m^3 \ + 0kg/m^3 \ + -14.53kg/m^3 \ + -6.83kg/m^3 \ + -9.90kg/m^3 \ = \ -31.26kg/m^3$$

$$w_{batch} = 131.11kg/m^3 - (-31.26kg/m^3 + \ 120.35kg/m^3) \ = \ 42.02kg/m^3$$

$$V_{water} = \frac{131.11kg}{1000kg/m^3} = 0.131m^3$$

Densities, Air Content, Slump and Ratios

Total Mass = Cementitious Materials + Mineral Filler + Aggregate + Water + Solids + Fibers

Mass = 306.00 kg + 92.99 kg + 196.55 kg + 131.11 kg + 115.20 kg + 21.00 kg = 862.85 kg

Volume = 0.116 m^3 + 0.358 m^3 + 0.250m^3 + 0.131m^3 + 0.091 m^3 + 0.016 m^3= 0.962 m^3

Theoretical Density, T = $\frac{Mass}{Volume} = \frac{862.85\ kg}{0.962\ m^3} = 897\ kg/m^3$

Measured Density, D = $886\ kg/m^3$

Air Content = $\frac{T-D}{D} = \frac{\left(897\frac{kg}{m^3} - 886\frac{kg}{m^3}\right)}{897\frac{kg}{m^3}} = 1.2\ \%$

Water to Cement Ratio, w/c = $\frac{131.11\ kg}{76.00\ kg} = 1.73$

Water to Cementitious Material Ratio, w/cm = $\frac{131.11\ kg}{306\ kg} = 0.43$

Slump = 10 mm

Shear Stress in Chine and Deflection in Gunwale

Assumptions:

- Water pressure along the canoe is being submerged to the point of the gunwale
- Cross Section is approximated as a C Channel
- No net pressure acts along the bottom of the canoe as it is in vertical equilibrium with the dead load
- Loading for the canoe is modelled as a cantilever since moment is resisted across the bottom
- Uniform thickness throughout the cross section

Given:

- Maximum Height of Canoe h = *36.6 cm*
- Maximum Width of Canoe w = *75 cm*
- Thickness of Canoe walls t = *12 mm*
- Length of Canoe b = 5.5 *m*
- Specific weight of Water $\gamma = 9.8\ KN/m^3$
- Dynamic Load factor $\phi = 1.3$
- Stiffness of Concrete E = 5.6 GPa

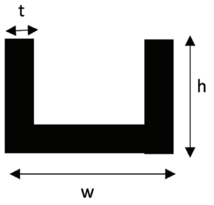
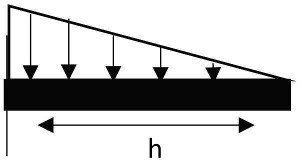
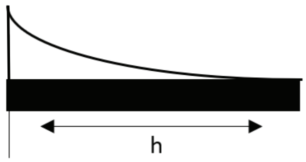


Figure C1- Cross Section of Canoe approximated as a C Channel



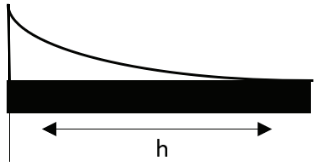
Loading of the Canoe is given by a linear function with $\phi\gamma hb$ at the base and 0 at the gunwale where b is a unit length of width

Figure C2- Loading of the Canoe



Shear force diagram of the Canoe is given by a Parabolic function with $\phi\gamma h^2 b/2$ at the base and 0 at the gunwale

Figure C3- Shear Force Diagram



Bending Moment diagram of the Canoe is given by a Cubic function with $\phi\gamma h^3 b/6$ at the base and 0 at the gunwale

Figure C4- Bending Moment Diagram

From second moment area theorem, the deflection can be determined by finding the area of the curvature diagram, and the centroid of the area measured from the gunwale.

$$Area\ of\ Curvature\ diagram = \frac{\phi\gamma h^3 b}{EI24},\ Centroid = \frac{4\text{h}}{5}$$

$$Deflection = Centroid * Area = \frac{\phi\gamma h^4 b}{30EI} = \frac{2\phi\gamma h^4}{5Et^3} = \frac{2(1.3)(5500\ mm)\left(0.0000098\frac{N}{mm^2}\right)(362mm)^4}{5(5600MPa)(12mm)^3}$$

$$= \mathbf{21.95\ mm}$$

The loading of the canoe by the water pressure can be written as the following equation, $w(x) = \phi\gamma b(h - x)$, where x is defined from the base of the canoe toward the gunwale, which can be integrated to find the shear force equation below.

$$v(x) = \phi\gamma b\left[\left(hx - \frac{x^2}{2}\right) - \frac{h^2}{2}\right] = \phi\gamma b\left[\left(ht - \frac{t^2}{2}\right) - \frac{h^2}{2}\right]$$

$$= 2(1.3)(5500\,mm)\left(0.0000098\frac{N}{mm^2}\right)\left[\left((366mm)(16mm) - \frac{(16\,mm)^2}{2}\right) - \frac{(366\,mm)^2}{2}\right] = \mathbf{8586\ N}$$

$$\sigma_{\max shear} = \frac{VQ}{IT} = \frac{3V}{2A} = \frac{3(8586\,N)}{2(16\,mm)(5500\,mm)} = \mathbf{0.146\ MPa}$$

Evaluation of Punching Shear Stress as per ACI 318 (ACI Committee 318, 2014)

Given

- Knee area is 25.4 mm x 25.4 mm
- Load = 75% of 91 kg male onto one knee
- Flexural reinforcement to be considered
- Punching stress shall be unfactored

Design Parameters

- Thickness of concrete in canoe is 16 mm
- Assumed effective depth of canoe section is 11 mm or 0.43 in
- Compressive strength, f'_c = 5.20 MPa
- Tensile strength, f_{ct} = 1.35 MPa

Assumptions:

- Canoe section under the effect of the applied load will behave as a two-way slab
- Knee will resemble a case similar to the case of an interior column
- Flexural reinforcement will resist all flexural moment and no moment will be transferred elsewhere (i.e. no unbalanced moment will be considered)
- Knee load that is directly transferred to the support (water) will not be discounted from the direct shear force, thus our punching stress estimation will be more conservative
- Concrete is the only component resisting the shear stress (i.e. no stirrup reinforcement is provided)

Calculation:

Direct shear force = V_a = 0.75 x 91 kg = 68.25 kg = 0.67 kN
Critical section for the canoe was defined as per 22.6.4, as shown in the diagram below. Effective depth of the canoe section was determined to be 11 mm.

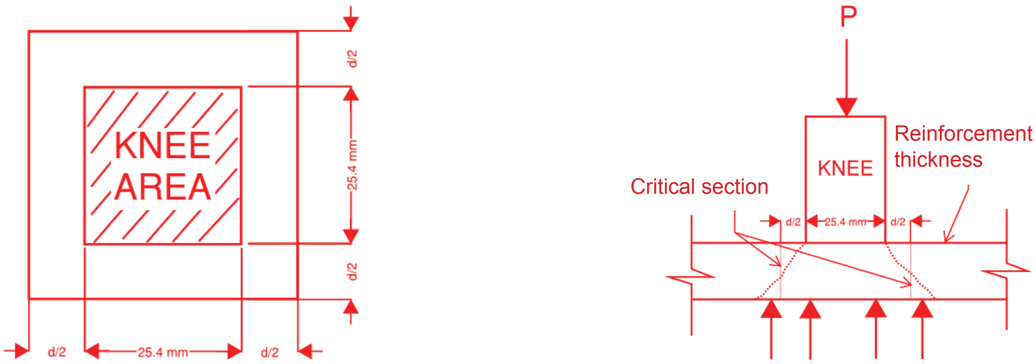


Figure C-5: Schematic of critical section and perimeter

Then we can proceed to determine the area and perimeter of the critical section, which is:

$b_o = 4 \text{ x } (25.4 \text{ mm} + \frac{d}{2} + \frac{d}{2}) = 145.6 \text{ mm} = 5.73 \text{ in}$

$A_c = b_o \text{ x } d = 145.6 \text{ mm x } 11 \text{ mm} = 1601.6 \text{ mm}^2 = 2.46 \text{ in}^2$

Following the equation give in R8.4.4.2.3 (ACI Committee 318, 2014), the punching shear stress is expressed as:

$$Vu = Vug + \frac{\gamma\text{v} * \text{Msc} * \text{c}}{\text{Jc}}$$

Where we can omit the second term as we do not have any unbalanced moment to consider. Hence, our punching shear stress **in both direction at a knee area of 25.4 mm by 25.4 mm** is:

$$Vu = \frac{Va}{Ac} = \frac{0.67\ kN}{1601.6\ mm2} = \mathbf{0.42\ MPa = 60.67\ psi}\ \textbf{(unfactored)}$$

Two-way shear resistance provided by concrete without consideration of stirrup can be evaluated using Table 22.6.5.2 in ACI 318-14 (ACI Committee 318, 2014) where:

$\beta = 1$

$\alpha_s = 40$

$f'_c = 5.2 \text{ MPa} = 754.2 \text{ psi}$

$f_{ct} = 1.35 \text{ MPa} = 195.8 \text{ psi}$

$b_o = 145.6 \text{ mm} = 5.73 \text{ in}$

$\lambda = 0.75$ assuming all-light weight concrete

Table C-1: Shear resistance as a result of Table 22.6.5.2

Cases	Result
$V_c = 4\lambda\sqrt{f_c'}$	82.38 psi or 0.57 MPa
$V_c = \left(2 + \frac{4}{\beta}\right)\lambda\sqrt{f_c'}$	123.58 psi or 0.85 MPa
$V_c = \left(2 + \frac{\alpha_s d}{b_o}\right)\lambda\sqrt{f_c'}$	103.02 psi or 0.71 MPa

Since V_c = **0.57 MPa**> V_u = **0.42 MPa**, canoe will not fail under punching shear with a 25.4 mm by 25.4 mm knee area.

Percent Open Area Calculations

The team used ImageJ (National Institutes of Health 2019), an image processing software, to calculate the percent open area of the team's primary reinforcement, the reduced carbon fibre mesh. The team took a picture of the mesh, and used ImageJ to render the image in only black and white.

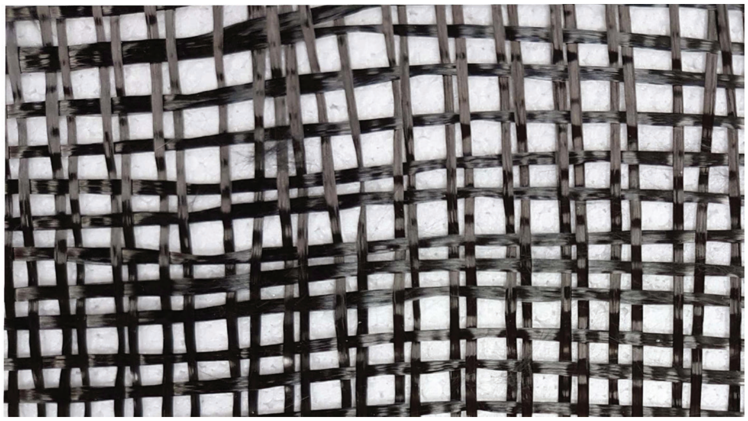


Figure D-1: Picture of the carbon fibre mesh sample against a white background

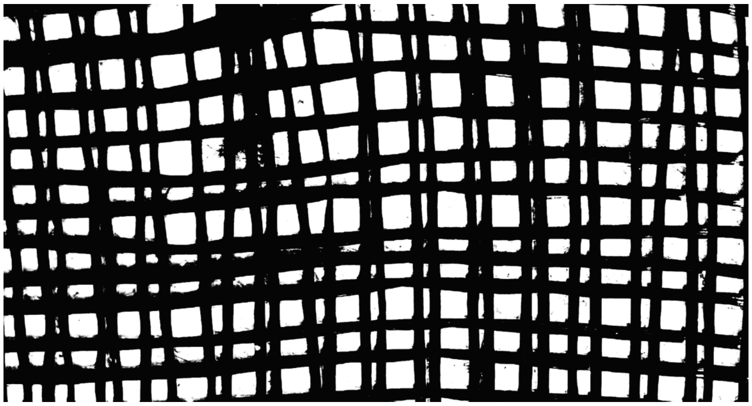


Figure D-2: Picture of the sample after ImageJ processed the image to 2 colours

The team used ImageJ to count the black and white pixels in the processed image. The black pixels represent the mesh, while the white pixels represent the openings in the mesh. ImageJ counted 3,010,381 white pixels, and 1,641,971 black pixels.

$$Percent\ Open\ Area = \frac{Open\ Area}{Total\ Area} = \frac{White\ Pixels}{White\ Pixels + Black\ Pixels}$$

$$Percent\ Open\ Area = \frac{3010381}{3010381 + 1641971} = 64.7\%$$

Since 64.7% > 40%, the team's reinforcement meets the minimum percent open area.

Hull Thickness/Reinforcement Check

Once the canoe was built, the team measured a sample of the carbon fibre mesh and the canoe itslef with calipers.

The carbon fibre mesh was placed between two glass plates, and the team compared the thickness of the two glass plates with the mesh, and the glass plates themselves. After this process, the team determined that the mesh was 0.25 mm thick.

The team measured the canoe 30 times. Each measurements was spaced 30 cm apart to ensure all areas of the canoe was measured. Table D-1 lists the minimum thicknesses for various canoe elements.

Table D-1: Minimum thicknesses for each canoe element

Canoe Element	Minimum Thickness (mm)
Walls	15
Gunwales	20
Toe-blocks	44
Bulkhead Cover	6

Since the team used 2 carbon fibre mesh layers as primary reinforcement, the total thickness of the 2 layers must not exceed 50% of the canoe thickness. Since reinforcement was not placed in between the bulkhead cover, and the walls being thinest section containing reinforcement, all areas of the canoe will comply with the thickness requirements if the walls do.

$$Percent\ Reinforcement = \frac{Thickness\ of\ 2\ Reinforcement\ Layers}{Minimum\ Canoe\ Thickness} = \frac{2\ \times\ 0.25\ mm}{15\ mm}$$
$$= 3.33\%\ \leq 50\%$$

Therefore, the canoe meets the thickness requirements.

Appendix E - Sustainability Overview

With reliable information when evaluating *TrackOne*'s sustainability impact, the team aimed to reduce negative sustainability impacts during the 2018-2019 school year for all activities and avoid using end of pipe solutions meant to mitigate sustainability impacts after all activities have been completed (Vanderburg 2016). The team evaluated its impact during the construction of *Polaris*, after all mitigation efforts have been completed.

Evaluation

The team shares its workspace with two other design teams. Unchanged from last year, 99 m2 is allocated directly to the team, while the space for all three teams is 350 m2. Additionally, the building is shared with various university administration offices. The team often uses more than the allocated space, so coordination occurs with the other two teams to ensure that no space conflicts, and delays as a result of space conflicts, can occur.

The team has increased its roster by 11 regular members and 3 team leads, to 35 regular members, with 11 of them being team leads. A successful outreach effort over the past year and during orientation week led to the increase in the team's size. While increasing overall person-hours, the person-hours for an individual member is reduced from last year with the greater efficiencies that come from a larger roster. With only 5 members graduating this year, the team is poised to have a very smooth transition process.

Electricity use, in Table E-2, was found by identifying the power rating of lights, tools, and appliances used and recording the duration they were used, while water use, also in Table E-2, was recorded at each meeting. Since the team shares its workspace with university offices and other clubs, including HVAC systems was not appropriate. Despite being a high energy user, these systems are in use whether the team is in the building or not. Humidifiers for curing concrete made up the largest portion of the team's 482 kWh electricity consumption and a significant part of the team's water consumption. While using a misting system for curing would reduce electricity consumption, the team determined that the excess water use was not worth the savings in electricity.

Table E-1: Electricity and water consumption by use

Activity	Electricity Consumption (kWh)	Water Consumption (L)
Lighting	26	
Curing	319	129
Cleaning	36	152
Construction Tools	33	
Concrete Production	3	22
Computer	25	
Milling	32	
Misc	7	5

The university does not charge for water consumption or disposal, but the team is mindful of the impact the team's dirty water has on the city's stormwater sewers. Likewise, the team is always mindful of the GHG emissions produced during electricity generation, given that about a quarter of Ontario's electricity (Ministry of Energy 2017) is produced through natural gas plants.

Fuel was calculated by recording/estimating mileage of all trips and using fuel economy and emission factors from Natural Resources Canada using the exact vehicle make and model for passenger vehicles (Natural Resources Canada 2019) and box trucks (Penske Truck Rental 2019), while using average fuel mileage and emission factors for a coach bus (Union of Concerned Scientists 2008). The team estimated that 540 L of fuel was consumed in travelling to competition and material delivery inside the GTA. In addition, the team also estimated the fuel consumption of long distance material delivery using commercial freight trucks. Mileage was estimated from the delivery address of each shipment, and in conjunction with fuel economy sources (USNHTSA 2018) and emission factors (Plumptre et al. 2017), the team estimated that 1690 L of fuel was used in delivery of materials from locations outside the GTA.

A similar method was used to calculate carbon dioxide emissions. The team recorded the mass or volume of all materials used, then consulted relevant sources to find the unit carbon emissions for each material and activity. While commercial life-cycle analysis software exists, the assumptions made by those software may not apply to team practices and materials. Table E-2 breaks down the 1283 kg of carbon dioxide emissions emitted by the team.

Table E-2: Carbon emission breakdown by team activity

Activity	Carbon Dioxide Emission (kg CO_2)	Sources
Concrete Production	79	(Hammond et al. 2008), (Delogu et al. 2016), (Yang et al. 2015), (Papa et al. 2014), (European Environmental Agency 2016)
Transportation	1102	(Natural Resources Canada 2018), (Union of Concerned Scientists 2008)
Shipping of Materials	68	(Natural Resources Canada 2018), (Plumptre et al. 2017), (USNHTSA 2018)
Building Materials	77	(Das 2011), (Hammond et al. 2008)
Electricity	37	(Ministry of Energy 2017)

On an absolute basis, the team estimated that transportation to the CNCCC will make up the largest portion of carbon dioxide emissions, and will sharply increase from 346 kg of CO_2 in 2018 to 1102 kg in 2019. Fuel use will also sharply increase from 110 L to 540 L. These changes are heavily dependent on the location of the competition as Montreal is much further from Toronto than Waterloo. The team also estimated a normalized usage by km of transportation GHG emissions and fuel consumption. This provided a fairer comparison to compare data across different competition locations. The team found transportation related unit fuel usage and unit carbon emissions will be 0.38L/km and 0.98 kg CO_2/km respectively.

Mitigation

To mitigate transportation related unit fuel use and unit carbon emissions, the team committed to using a combination of commercial coach bus and the shared UofT Engineering Society Van to transport members to and from competition. Within Montreal, the team will solely use public transport or active modes of transportation such as biking and walking. The team also continued its truck sharing agreement with Ryerson Concrete Canoe, while also including Ryerson Steel Bridge in the agreement. Aggregating the unit reductions in Table E-3, these measures reduced unit carbon emissions from 1.46kg CO_2/km and 0.50L/km in 2018 to 1.01 kg CO_2/km and 0.55L/km in 2019.

In further mitigating GHG emissions from *TrackOne*, the team focused its efforts on reducing resource consumption, and reusing old material, rather than recycling. Limiting the production of new material produced through the reduction of resource consumption provides much better improvements to environmental sustainability (Vanderburg 2016) since there would be zero associated GHG emissions to produce, transport, and recycle materials. This also has a positive impact on team financial sustainability by eliminating procurement or recycling cost. The team employed many actions related to this strategy. Foam consumption was cut by 33% compared to *TrackOne*. A reduction in waste concrete led to a 40% reduction in concrete production. The team focused procurement in the GTA to reduce transportation related GHG emissions, leading to a carbon emission decrease of 5.4 kg. Wood and foam were salvaged, including the entire display board from previous year's activities and from other clubs to avoid buying new building materials. Along with increasing team's financial sustainability, the team used zero-based budgeting to reduce or eliminate any unneeded purchases, which would lead to further increases in the team's carbon emissions. Figure E-1 shows the effect of these mitigation measures.

Table E-3: Reductions in carbon emissions, fuel, and cost by transportation mitigation measures

Activity	Change from 2018 to 2019		
	Change in Unit Carbon Emissions (kg CO_2/km)	Change in Unit Fuel Consumption (L/km)	Change in Cost (Dollars)
Canoe Transportation	-0.42	-0.18	-130
Member Transportation to Montreal	-0.06	-0.01	-350

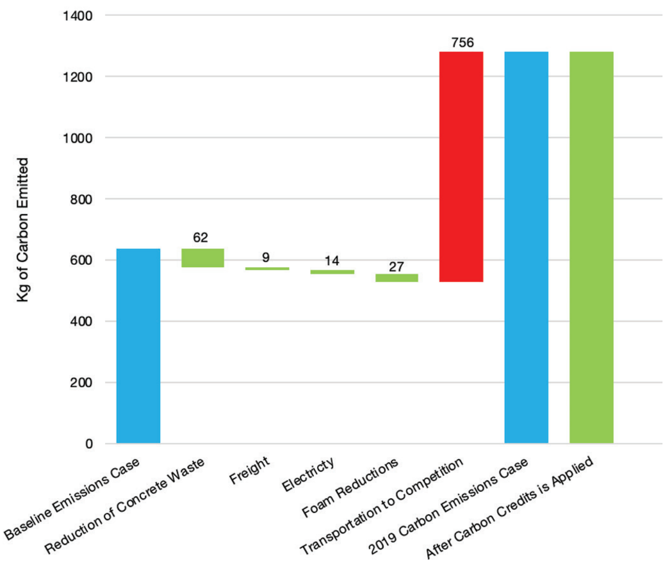


Figure E-1: Breakdown of decreases and increases in carbon emissions as a result of competition and mitigation measures from the baseline case of 2018.

One major complaint from members of the club in previous years was the length of general meetings, with many meetings lasting up to 4 hours. Beyond increasing workload for members, this also increased the lighting demand for the club's space and led to more space conflicts with other clubs. Partly through Agile management and partly through increased member recruitment, the team was able to shorten meetings by an average of 2 hours. Due to this, the team was able to reduce lighting electricity demand by 54%, reduce and associated GHG emissions, and reduce space conflicts with other clubs. This also reduced the chance of delays as a result of conflicts, and led to increased team morale by reducing the time commitment of the team's members.

The team was wary of the volume of dirty water it produced in cleaning buckets. Members of the team brought practices taught at UofT's water treatment courses and co-op placements, and applied it to treat the team's dirty water. The strategy detailed in Figure E-2 aims to settle out as much solid waste as possible, so the team can dispose it separately, while reusing the treated water. In addition to reducing cleaning related water use by 73% in 2018 to 76 L, this also allows team members to use skills in the water treatment engineering, providing another way for members to apply civil engineering skills.

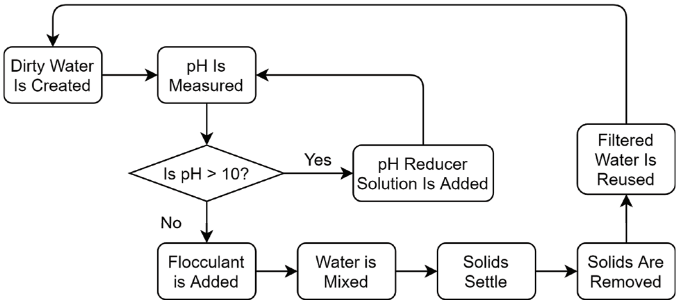


Figure E-2: Flowchart of the team's process to treat and reuse dirty water

The team continued all of the outreach events hosted in 2017-2018 and focused on improving member retention. One strategy was to organize more social activities to improve team bonding. The team organized socials once every two months and made sure activities were low-cost, centrally located, and inclusive to all members and cultures. The other strategy was to involve members in as many technical activities as possible, which includes activities not related to concrete or structural engineering, such as programming, industrial engineering, and water treatment. Both of these strategies allow members feel more passionate and engaged, helping to secure the long term sustainability of the club.

Implementation

Building a concrete canoe is not an environmentally sustainable activity because of the amount of GHG emissions produced in most activities of the club. While the team continued to purchase carbon offset credits, this conflicted strongly against the team's belief against end of pipe mitigation efforts (Vanderburg 2016). In light of that, the team has a social responsibility to create a culture of sustainability, embedded in all aspects, to offset the negative environmental aspects of the club.

This cultural change towards valuing sustainability started when project managers of the team chose new team leads. In the interview process, each team lead had to prove to the project managers their commitment to sustainability and discuss the actions they would take to make the team a leader in sustainability within their own sub-team. This ensured that sustainability was a core value in all decisions of the club, and valued equally, or more importantly, than traditional metrics such as concrete strength, concrete density, cost/ease of material, and visual aesthetics. One example of this is the team's continued choice to have a c/cm ratio of 0.25, despite knowing and seeing in test results that up to 50% higher strengths can be realized with a more unsustainable mix.

The team hopes to create benefits cascaded to the other two pillars of sustainability by targeting unnecessary resource consumption in the form of materials, services, or person-hours, in either environmental, financial, or social sustainability. Therefore, ensuring that the team values sustainability and traditional metrics equally will create tangential benefits in all aspects of the club. This result, and the culture that enables it, will not only allow the team to entrench sustainability in decisions made well after the current leadership is gone, but also educate team members in applying sustainability concepts in practice. This is with the hope that sustainability will be a core value in the member's own engineering and personal decisions, years after they leave the team.

Appendix F - Competition Eligibility

Name	Degree	Number of Years on the Team	Number of Years on the Official Team (incl. 2019)	CSCE Membership Number
Aidan Ashton	Civil Engineering	1	0	92923
Andrew Wuebbolt	Materials Engineering	2	2	91112
Ashley An	Civil Engineering	2	0	91176
Baotian Fu	Electrical Engineering	2	1	91180
Eileen Lau	Electrical Engineering	1	1	92932
Gabrielle Lau	Mechanical Engineering	1	1	92889
Gordon Wong	Civil Engineering	5	2	87827
Jeffrey Wang	Materials Engineering	4	0	87829
Maria Wu	Mechanical Engineering	2	0	91185
Matthew Garcia	Civil Engineering	5	2	87848
Michael Zolis	Chemical Engineering	2	2	91178
Moranne Parsons	Civil Engineering	1	0	93001
Muhammad Ali	Civil Engineering	3	1	89048
Natasha Valenton	Mechanical Engineering	4	3	87814
Nicola (Yuexin) Liu	Mathematics	1	0	92903
Rick Liu	Civil Engineering	3	2	89047
Sarah Birch	Chemical Engineering	1	0	92921
Shirley (Shuocheng) Zhang	Civil Engineering	2	1	91110
Stella Gregorski	Chemical Engineering	1	0	92899
Yca Theresa	Materials Engineering	1	1	93027