SUGAR RUSH

UNIVERSITY OF CALIFORNIA LOS ANGELES

2018-2019

DESIGN PAPER

TABLE OF CONTENTS

EXECUTIVE SUMMARY ii
HULL DESIGN AND STRUCTURAL ANALYSIS....................1
DEVELOPMENT AND TESTING....................3
CONSTRUCTION....................6
PROJECT AND QUALITY MANAGEMENT 8
ORGANIZATION CHART....................10
PROJECT SCHEDULE....................11
CONSTRUCTION DRAWING 12

LIST OF FIGURES

FIGURE 1: Stress in gunwales before pre-tensioning....................2
FIGURE 2: 2-man racing stress profile at gunwales 2
FIGURE 3: Stress conditions at hull wall mid-section after PT 2
FIGURE 4: Comparison between density and compressive strength of Sugar Rush and La Sirena....................4
FIGURE 5: Sugar Rush & La Sirena - cm/agg ratio and compressive strength comparison 4
FIGURE 6: Sugar Rush & La Sirena - aggregate size to cumulative volume comparison 5
FIGURE 7: Compressive strength of structural mix over time 5
FIGURE 8: Casting aesthetic elements in the first layer of concrete 7
FIGURE 9: Acrylic letter block-outs in final concrete layer....................7
FIGURE 10: Breakdown of total project person-hours, excluding paddling 8
FIGURE 11: Breakdown of 2019 actual budget....................8
FIGURE 12: Comparison of 2018 budget, 2019 projected budget, and 2019 actual budget 8

LIST OF TABLES

TABLE 1: Canoe innovations and improvements....................ii
TABLE 2: Structural dimensions....................ii
TABLE 3: Mix properties....................ii
TABLE 4: *The Jabberwock*, *La Sirena*, and *Sugar Rush* hull performance indicators 1
TABLE 5: Maximum stress values....................2
TABLE 6: Comparison between design strength and actual strength 5

LIST OF APPENDICES

APPENDIX A: References....................A1
APPENDIX B: Mixture Proportions B1
APPENDIX C: Example Structural Calculations....................C1
APPENDIX D: Hull Thickness/Reinforcement and Percent Open Area Calculations D1

EXECUTIVE SUMMARY

Baked goods, candies and other confections are as much an exact science in their creation as they are a joy in their consumption. Their construction involves precise measurement of ingredients, careful design of structural integrity, and attention to aesthetic beauty. The UCLA concrete canoe team built *Sugar Rush* with these same ideals in mind to create a sweet final product.

The University of California, Los Angeles built their first Canoe *P.D.S* (Please Don't Sink) in 1990. Thankfully it lived up to its name, and UCLA has built and expanded upon this success since then. In the past three years, UCLA has consistently placed in the top 3 at Pacific Southwest Regional Conference (PSWC), where *El Fey* placed 1st in 2016, *The Jabberwock* placed in 2nd in 2017, and *La Sirena* placed in 3rd in 2018. *El Fey* also went on to place 2nd at the National Concrete Canoe Competition. With *Sugar Rush*, the 2019 team has worked hard to lay the groundwork for UCLA's continued success through thoughtful design and innovative methods.

Table 1: *Canoe innovations and improvements*

Hull Design	-Reduced maximum length and keel fin length -Modeled drag coefficients of multiple candidates
Construction	-Created new CNC milled reusable mold
Mix Design & Testing	-Optimized accurate gradation with increased lightweight smaller-sized aggregates -Optimized strength vs. density with Ashby diagram
Materials	-Incorporated higher polymer content admixture for improved workability and ASTM compliance -Introduced more effective water-reducing admixture
Aesthetics	-Implemented 3D concrete effects -Casted multi-colored artwork in letters
Sustainability	-Donated unused sizes of structural fines -Reused EPS foam from previous mold in canoe tips

Sugar Rush's maneuverability was improved by adjusting the maximum length and the keel length. The optimal width profile was verified through computational fluid dynamics (CFD) analysis using ANSYS Fluent and modelled using Fusion 360. The male form was constructed through Computer Numerical Controlled (CNC) Milling of Expanded Polystyrene Foam (EPS). This expenditure assured numerical accuracy in critical calculations, and was constructed to be reused in future years in order to reduce foam waste.

The concrete mix design team focused on reducing concrete density without sacrificing strength or workability. Aggregate proportioning was adjusted to favor lighter materials, effectively altering the fuller curve. The associated increase in aggregate surface area was accounted for by increasing cm/agg ratio, and using a higher solids content latex. Risk management of erroneous results was accounted for by testing duplicates of all unique mixes.

Table 2: *Structural dimensions*

Maximum Length	19'
Maximum Width	2'-6"
Maximum Depth	1'-1.3"
Avg. Thickness	0.38"
Weight	180 lbs

New varieties of eye-catching art were employed in *Sugar Rush's* construction process. Three-dimensional aesthetic elements were casted on the bow and stern tips. In addition, partially cured concrete was inlaid within pink letters to resemble technicolor sprinkles. The canoe's tan exterior, reminiscent of a graham cracker, allowed these pink letters to pop. While the development process added time to canoe construction, the result created an aesthetically pleasing look and unified the theme.

UCLA Concrete Canoe is proud to present *Sugar Rush*, an exhilarating combination of exacting precision and aesthetic design.

Table 3: *Mix properties*

		Structural	Finishing
Densities (lb/ft^3)	Wet (Plastic)	70.1	68.7
	Oven-Dried	64	63
Air Content		2.8%	3.1%
Strengths (psi)	Compressive	1830	1470
	Tensile	460	280
	Composite Flexural	2460	
Primary Reinforcements		Bidirectional Carbon Grid, Galvanized Aircraft Cable	
Secondary Reinforcements		Short Stuff ESS5F, PVA Fiber	

HULL DESIGN

To better adapt to the alterations made to the 200m slalom course, the hull design team focused on increasing maneuverability without compromising the straight-line tracking ability necessary for the sprint course. This was accomplished by reducing the length of *La Sirena*'s 19.5 feet mold to 19 feet. Additional changes were kept at a minimum to improve upon *La Sirena* while still retaining familiarity among returning paddlers. The keel fin was omitted from the design due to *La Sirena*'s keel fin showing a negligible effect on the canoe's straight-line tracking ability. The height was unaltered to retain a similar volume to that of *La Sirena*, and effectively have an identical buoyancy. Since the length and height were constrained, the cross-sectional width was left to be determined and was validated using CFD analysis. These desired changes necessitated a new mold to cast *Sugar Rush*.

Three different hull iterations were considered: proportionally scaling the width to match the 0.5 foot length reduction, keeping the width and shape of the stern the same as from *La Sirena*'s, or interpolating the width change from the previous two options. The latter option was selected based on results from CFD performed using ANSYS Fluent modelling. Drag coefficient in straight and angled orientations were the primary parameters considered. This hull was found to increase maneuverability without radically affecting the straight-line top speed of the canoe. The max width of *Sugar Rush*'s mold is 28", which is 0.25" less than that of *La Sirena*. The maximum width is located 12 feet from the tip of the bow to retain the same approximate ⅔ ratio of *La Sirena* to reduce wavemaking and essentially descrease resistance (McGuffin 1999).

Many of the properties from *La Sirena* were included in *Sugar Rush*. The 5" chine radius of *La Sirena* was reused for the provided secondary stability which aids paddlers when executing tight cornering and to prevent capsizing (McGuffin 1999). This sacrifices the greater primary stability of a smaller chine radius, but was deemed acceptable due to paddler familiarity with the 5" chine. The same flared walls were translated from *La Sirena* onto *Sugar Rush*. The outward-flaring gunwales were also kept the same to provide concrete cover for the PT cables and mitigate water entry. Additionally, they provide stability and durability for the walls and canoe as a whole. *Sugar Rush* also has the same moderate rocker as *La Sirena* which features a short waterline length, optimized wetted surface area, which results in less drag and greater maneuverability (Jackson 1995).

The prismatic coefficient (PC) is the ratio of the volume of a canoe to that of a prism created by projecting its largest cross-section across its length, and it quantifies how evenly the volume is distributed along the hull. A high PC indicates a uniform and buoyant canoe that generates minimal wavemaking resistance, while a low PC characterizes a canoe that encounters less wetted surface area resistance and provides limited paddler space (Slade 1998). The most efficient PC for a canoe correlates with its speed to length ratio (SLR), and the ideal PC for *Sugar Rush's* expected SLR of 1.2 is 0.580. *Sugar Rush's* actual PC of 0.545 deviates 6.0 percent from this ideal, as compared to *La Sirena's* PC of 0.587, which exhibited a 1.2 percent deviation. The increased deviation in PC of *Sugar Rush* reflects the decision to prioritize turning ability over top speed by decreasing the length without proportionally decreasing the width. *Sugar Rush*'s increased PC is better optimized to handle the redesigned slalom course, which enables it to balance resistance forces and increased turning ability (Kasten 1997).

Table 4: *The Jabberwock, La Sirena, and Sugar Rush hull performance indicators*

	El Fey (2016)	The Jabberwock (2017)	Sugar Rush (2019)	Reason(s) for change/ retention
Overall Length	19.5'	19.5'	19.0'	Decreased to increase turning ability and reduce frictional forces
Max. Width	2'-6.38"	2'-6.38"	2'-6"	Decreased to maintain general canoe shape due to length decrease
Chine Radius	4"	5"	5"	Maintained for optimal secondary stability
Keel fin at bow	Included	Not included	Not included	Decrease wetted surface area and reduce drag force during turns

STRUCTURAL ANALYSIS

The structural analysis team analyzed the stresses on the gunwale and the keel of the canoe using moment diagrams, taking into account the new dimensions of the Sugar Rush mold.

Since the canoe will experience the most tension in the gunwale and keel, identifying variables such as moment and stress under different loading conditions at these points is a critical aspect of the structural design of the canoe. An average estimate was calculated for the weight of the paddlers, which was used as a point load with a safety factor of 1.26 times their actual weight. The weight of the canoe and the buoyant force were treated as distributed dead loads. The moment and stress diagrams were developed to reflect the following three conditions: 4-men race, 2-men race, and display. Transportation was considered to be negligible, because the stress on the canoe will be uniformly distributed as the canoe is being carried.

Bending moment diagrams were used to calculate the stress profile for each of these conditions using the distance between each paddler and distance between each of the stands. As seen in the Figure 1, the distance vs. stress diagrams visualize how the canoe behaves under different stress conditions.

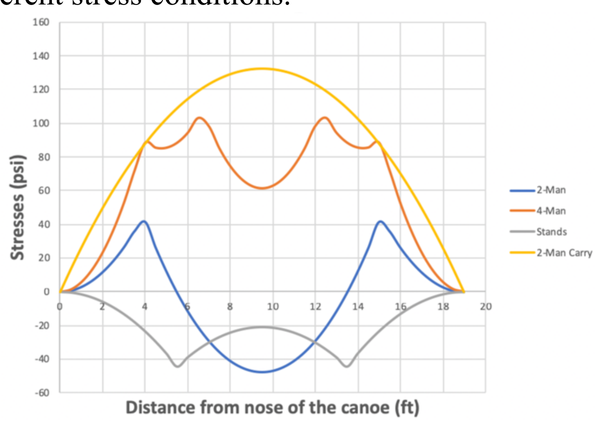


Figure 1: *Stress in gunwales before pre-tensioning*

The pre-tensioning system (PT system) was incorporated in the canoe design to reduce tensile stresses and increase the compression strength at the critical points by introducing tension in the canoe. Two locations were targeted for pre-tensioning: the gunwale and midpoint section located 3” above the gunwale. According to the peak values calculated, the gunwale will experience more tensile stress than the keel. The team used the critical stresses found in the stress profiles to serve as a guideline for the placement of each wire and the weight being added. The gunwale wire was loaded with 53 pounds and the midsection with 51 pounds. The addition of the PT system resulted in a 64% reduction in the maximum tensile stress.

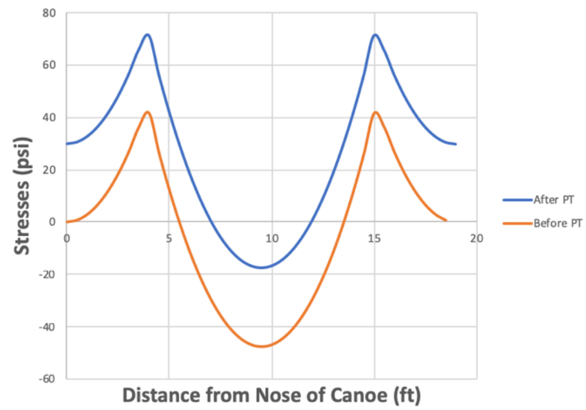


Figure 2: *2-man racing stress profile at gunwales*

Table 5: *Maximum stress values*

	Compressive	Tensile
Gunwale Before PT	132.7 psi	47.5 psi
Gunwale After PT	163.0 psi	17.5 psi

Using the pre-stressed concrete analysis implemented last year, the effect of PT on the stress conditions of the tendons and concrete was calculated. The eccentricity of each tendon was determined as the distance to the neutral axis. The resulting stress profile was found by superimposing the effects of paddler weight and eccentric loading forces and dividing by section moduli. The post PT stress condition at the mid-section of the canoe has a 43.83psi compressive stress at the gunwale and 20.8psi tensile stress at the keel (Figure 3).

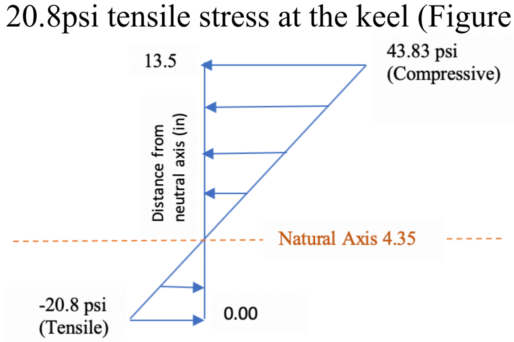


Figure 3: *Stress conditions at hull wall mid-section after PT*

DEVELOPMENT & TESTING

With ambitions to "take the cake," this year's mix design team set out with the objective of decreasing the density of the structural concrete mix while still retaining a high compressive strength. Last year, *La Sirena*'s structural mix had a compressive strength of 1447 psi. This was attributed to its high proportion of ASTM C330 lightweight aggregate which comprised 37% of the total aggregate volume, compared to the 25% minimum requirement. The team aimed to decrease the amount of ASTM C330 aggregate in the mix while still adhering to the mix design specifications and maintaining an acceptable compressive strength. This was deemed feasible with the high factor of safety associated with *La Sirena*'s strength and observation of the new "mineral filler" specification listed in the 2019 National Concrete Canoe Competition (NCCC) Rules and Regulations. Another goal was to establish optimal admixture proportions with Styrofan 1186, a latex with a 17% increase in solids content from the previous year.

La Sirena's structural mix was chosen as the baseline for its high compressive strength and aggregate proportioning, the latter of which was identified as a potential area to reduce density. Since there are only 14 weeks between the start of the academic year and Casting Day, pivotal decisions regarding the testing process were established to guarantee sufficient characterization of material properties within the mix. Fast curing Type III portland cement was substituted for Type I, allowing for more frequent testing without drastically changing chemical properties of the mix (Kosmatka et al. 2011). Cylinder compression tests (ASTM C39) were prioritized over flexural plate tests (ASTM C78) due to positive correlation between these two strengths (Lane 1998) (UCLA Concrete Canoe 2018). Two cylinders were created of each mix variation to improve the reliability of compression test results.

New specifications regarding aggregate proportioning state that any aggregate passing through the No. 200 (75 µm) sieve will be regarded as mineral filler and excluded from the calculation of total aggregate volume. K15 glass microspheres, the lightest aggregate component, have a D_{50} of 60 µm. Therefore, only 50% of the K15 volume is included in the calculation of *Sugar Rush's* aggregate volume since 50% of K15 glass bubbles range in size from 30 to 60 µm. With an overall smaller aggregate volume, less ASTM C330 aggregate, the densest aggregate component, is needed to meet the 25% minimum requirement. Since testing with K15 would be increased substantially, project engineers were instructed on proper safety protocol and potential safety hazards of the material. Safety measures enforced when interacting with K15 included N95 masks, latex gloves, and wind-blocked environments.

Initial density reduction tests involved keeping total aggregate volume constant and testing 0%, 5% and 10% increases in K15 while proportionally decreasing amounts of other aggregate components. Additionally, varying amounts of smaller, denser Poravers sized 0.1 – 0.3 mm and 0.25 – 0.5 mm were replaced with larger, lighter Poravers sized 0.5 – 1 mm and 1 – 2 mm. To compensate for potential strength losses while still maintaining an aggregate size distribution similar to the baseline, the gradation of Trinity Lightweight Structural Fines was accordingly weighted towards grain sizes equivalent to the smaller, replaced Poravers. These adjustments varied over 8 different mixes, each with theoretical densities lower than that of the baseline. Generally, test results indicated that mixes lost strength with increases in K15. Additionally, the percentage of smaller Poravers swapped for sieved Trinity showed a slight positive correlation with strength. Manually adjusting Trinity gradation was rejected, as any potential strength gains would not justify the time required to sift. An Ashby diagram logarithmically comparing compressive strength to density was utilized to identify the greatest performance index (Figure 4). A 5% increase in K15 was identified to yield sufficient decreases in density and minimal strength losses.

Having increased the volume of K15, the team predicted that more cementitious material would be required to compensate for increased surface area from larger proportions of small aggregates. Referencing the aggregate rework test results, mixes with increases in K15 exhibited slightly lower strengths due to increased aggregate surface area and therefore volume of matrix-aggregate interface voids (Kozul and Darwin 1997).

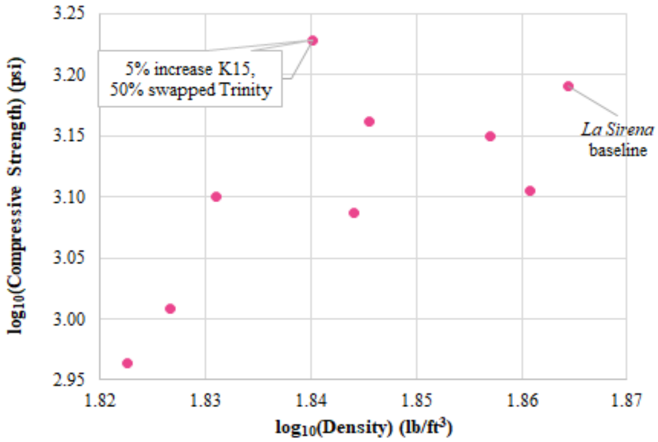


Figure 4: *Comparison between density and compressive strength of Sugar Rush and La Sirena*

Thus, the second iteration of tests focused on optimizing the cm/agg ratio to accommodate the updated aggregate gradation. Using *La Sirena*'s water to cementitious materials (w/cm) ratio and keeping it constant, various cementitious materials to aggregate (cm/agg) ratios centering around the baseline ratio 0.272 were tested. Concurrently, these ratios were tested with the 0%, 5% and 10% increases in K15 for a total of 11 different mixes. Confirming the results of the aggregate rework tests, increasing K15 resulted in weaker mixes, with 5% being a suitable segue between strength loss and decrease in density (Figure 5). A higher, optimal cm/agg of 0.295 was identified, aligning with the previously stated predictions.

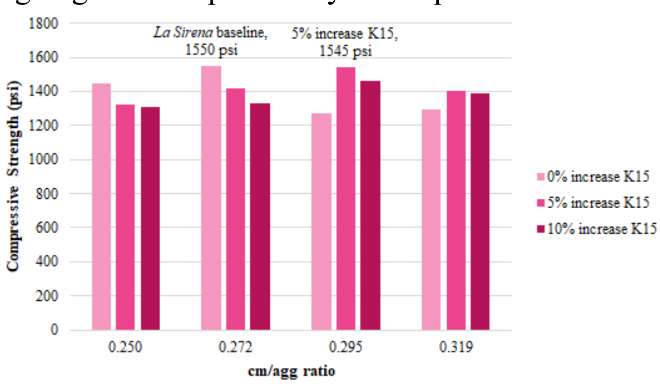


Figure 5: *Sugar Rush and La Sirena - cm/agg ratio and compressive strength comparison*

The next two iterations of tests focused on optimizing admixture proportions for improved workability. MasterEmaco A660 was replaced with Styrofan 1186 due to its increased solids content and regulation compliance (ASTM C1438). In designing the admixture baseline using the new latex, the solids content was kept constant between the old and new latex measurements, with the remaining water difference added to the water measurement in order to maintain a constant w/cm. However, mixes cast using these measurements were consistently dryer than expected. In an effort to obtain a satisfying workability, the ratio of water from water to water from latex (w/w_L) in *La Sirena's* baseline was identified to be 0.33 and kept constant. This was concurrently tested with 5%-10% incremental increases of K15 to further optimize the balance between density reduction and strength gain. The team selected a final mix having an 8.3% increase in K15.

The final component of testing investigated the effect of water-reducing admixture proportions on workability. The penultimate mix was relatively watery because in satisfying *La Sirena*'s w/w_L ratio, latex was increased by 33%. Increased use of latex resulted in increased slump to the point of diminished workability (ASTM C143). Therefore, water reducer proportions were adjusted in decreasing increments, with qualitative descriptions of workability noted on a results analysis spreadsheet before cylinders were cast for compression tests. Water reducer was decreased from 11.6% of water content to 9.6% of water content with no appreciable effect on compressive strength. The dosage of air entrainer from the baseline was retained.

In addition to cylinder compression tests, split-tensile tests were performed on the finalized structural mix (ASTM C496). Furthermore, flexural strength tests were conducted on 6" x 22" concrete plates. The layering scheme of Sugar Rush, which consists of two layers of bidirectional carbon fiber grid (BCFG) reinforcement embedded within three layers of structural concrete mix, was recreated when constructing test plates. Results from flexural strength and split-tensile strength tests allowed for clear understanding of the canoe's race performance while withstanding significant strains.

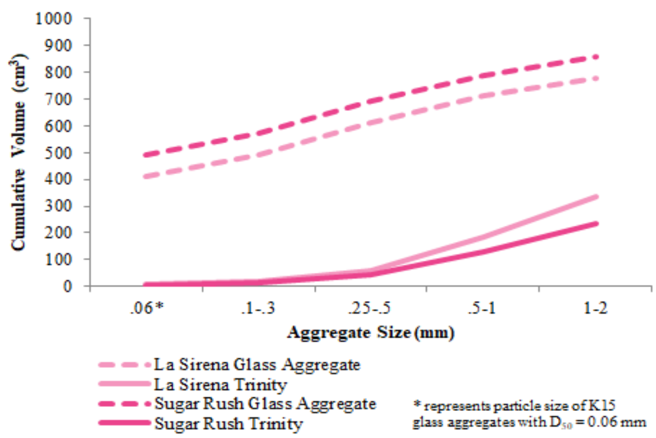


Figure 6: *Sugar Rush & La Sirena - aggregate size to cumulative volume comparison.*

The team successfully reduced the structural mix theoretical density from 79.20lb/ft^3 to 72.75 lb/ft^3 as compared to the *La Sirena* baseline. In addition, the 28 day compressive strength was increased from 1447 psi to 1830 psi. This was done by lowering the percentage of heavier lightweight aggregate within the aggregate volume to 27% while still meeting the mix design specifications regarding ASTM C330 aggregate proportioning. Modified Fuller curves comparing *La Sirena*'s and *Sugar Rush*'s glass aggregate and lightweight aggregate gradations show the replacement of dense aggregate while maintaining a relatively similar size distribution (Figure 6). Additionally, strength gain over time of the structural mix meets the required strengths identified through structural analysis with sufficient factors of safety (Figure 7 and Table 6).

La Sirena's finishing mix served as the baseline for that of *Sugar Rush*, particularly for its aggregate distribution. Because this mix would be used for very detailed work such as casting intricate candy silhouettes, high workability was prioritized while still adequately meeting structural demands. Poraver with particle sizes larger than 0.5 mm and Trinity with particle sizes larger than 0.833 mm were eliminated through sifting. Additionally, 19 mm Polyvinyl Alcohol (PVA) fibers were substituted with smaller 8 mm fibers, while the amount of 12 mm fibers used in the structural mix remained constant. Out of six test batches containing varying quantities of latex and K15, the batch with a 6.2% higher latex content than the structural mix was chosen for its enhanced workability.

Sustainable products incorporated in *Sugar Rush's* mix include the pozzolanic materials Vitreous Calcium Aluminio-Silicate (VCAS) and Newcem Slag Cement. Since cement creates carbon dioxide during production, usage of Portland Cement was mitigated by including these pozzolans (Naik and Moriconi 2005). Sifting larger particles of Trinity for the finishing mix also posed concerns for material waste. To reduce waste output, these larger particles were donated to UCLA's Soil Mechanics Laboratory.

The expenditure of a new foam mold necessitated that the budgets for other project aspects be lowered accordingly. Mix design was no exception, having been allotted \$340 compared to \$1000 from the previous year. Efficient batching protocols aided in minimizing mistakes, such as printing out mix tables to clearly communicate measurements to directors and project engineers. Additionally, most materials used were either donated or were held in surplus from previous years, with the exception of VCAS and PVA fibers.

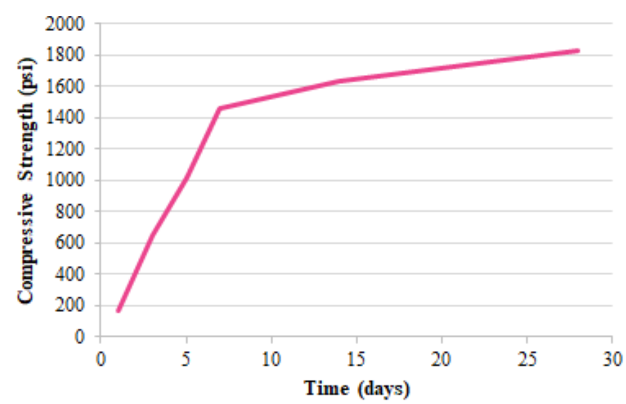


Figure 7: *Compressive strength of structural mix over time*

Table 6: *Comparison between design strength and actual strength*

	Required	Sugar Rush (2019)	Factor of Safety
Compressive Strength	163.0 psi	1830 psi	11.2
Tensile Strength	17.5 psi	460 psi	26.3

CONSTRUCTION

This year's main construction goals were to place emphasis on reusable materials and lean construction practices. Material from past years was repurposed whenever possible to minimize waste and unnecessary expenditure. Any new material ordered was designated to be reusable for future use.

The team ordered a CNC milled mold made of EPS foam, which was designed to be easy to carry, cut and reuse to reduce waste in future years. Changes in the competition rules necessitated a modification of the hull design and therefore the purchase of a new mold. Although this led to an increased budget and a tighter schedule, this change was seen as an essential improvement to create a competitive final product.

Due to transport limitations, the mold was scheduled to arrive in two separate pieces. A dogbone design was used to cut the mold in half to prevent movement in the x and y direction upon recombination, and secured in the z direction with the aid of bonding adhesive. The back tip of the mold required a higher degree of precision, so it was cut manually and sanded by hand. The front tip of the mold was cut to a fine point as per the specifications, and was then sanded down and thickened with plaster to be more durable. After the adhesive set, plaster was applied to the mold to fill any small abrasions and cracks and ensure a completely level surface. Then the mold was covered with two coats of paint and two coats of epoxy to provide a hard casting surface. Finally, contact paper was spread over the entirety of the mold as a final layer of smoothness and wooden blocks were then glued 1" from the sides of the mold to create gunwale forms.

Following last year's method, *Sugar Rush* was pre-tensioned (PT). In order to conserve resources, the same PT stands from last year were reused with slight modifications to fit the dimensions of the new mold. A six-inch wide wooden block was attached to the back of one of the stands. The increased width of the stand was successful in repositioning the point where the wires crossed paths closer to the tip of the mold. Pre-tensioning allowed for the team to cast the bow within the timeframe of casting day, saving time and enabling unity along the entire canoe by preventing cold joints.

To prepare for casting day, the team held three practice casts throughout fall quarter. Keeping in line with the goal to conserve foam and other resources, the previous year's mold was used for the practice casts, and casting was limited to a 4 ft midsection of the canoe. The first practice cast helped familiarize new members with concrete and the proper way to handle it. The second practice cast tested the various colors of the candy designs. The third practice cast focused on efficiency, covering an additional two feet of the practice mold, within a 2 hour casting window.

This year, Casting Day was scheduled on a Saturday to make use of the increased availability of students. Without any classes to disrupt work, project members were able to work for an extended period of time, providing a more seamless casting experience, and allowing Casting Day to be completed in 8 hours with 44 project members in attendance. Volunteers were divided into teams— concrete production, aesthetics, depth checking and general casting— based on experience from practice casts. The aesthetics team drew outlines of the theme designs on the contact paper and taped them off from the rest of the mold. The concrete production team prepared batches of structural concrete, thoroughly hand mixing the components of each batch with its designated color pigment to avoid splotches of color. Form oil was applied to the mold before the casting team began placing yellow concrete onto it. Simultaneously, a second casting team placed colored batches of concrete onto the sweet designs. The simultaneous placing of the different colored concrete improved the canoe's structural integrity, since the team was able to properly press the two points of contact together while both sets of concrete batches were still in a moist and workable state.

To ensure that the PT wires remained fixed in the correct position without being cast underneath the first layer, the PT wires along the gunwales were held onto the canoe mold with metal T-Nut spacers while concrete was cast around the spacers and underneath the wires. After the first ⅛" layer was placed, a layer of bidirectional carbon fiber grid (BCFG) reinforcement was placed over it. A ⅛" second layer of uncolored concrete was then cast quickly, with special care taken to make sure that the reinforcement was perfectly flush with the mold. This layer covered the PT wires around the gunwales and around the midsection, which were loaded with 53 lb and 51 lb

Figure 8: *Casting aesthetic elements in the first layer of concrete*

free-hanging weights and held the wires in place within the canoe. After the second layer, another layer of BCFG reinforcement was placed and the final layer was cast. In line with QA/QC objectives, the depth of the concrete was constantly gauged using ⅛", ¼", and ⅜" custom-built depth gauges to certify that each layer had the desired thickness. The third layer was composed of a tan colored concrete mix, and acrylic letter block-outs were used to spell out the canoe and university name.

Figure 9: *Acrylic letter block-outs in final concrete layer*

Following casting day, the canoe was misted at regular intervals in order to maintain saturation, and a curing blanket was used to help retain moisture. After 28 days, the canoe was deemed strong enough to demold, based on cylinder compression strength results. As a result of effective placement of form oil during casting day, the canoe was easily removed without any damage to the mold. Afterwards, the letter block-outs were filled in with pink finishing concrete and pre-casted concrete "sprinkles" made from semi cylindrical molds, then the sanding process began. First, high grit sandpaper was used to sand unwanted curves or bumps, then the canoe was patched with fresh concrete to form a smooth surface.

Following the casting of the letters, EPS foam blocks were hot-wire cut according to the AutoCAD cross-section design measurements to form tip inserts for the bow and stern. In an effort to increase sustainability, the foam used to create the inserts was recycled from an obsolete mold used in previous years. The bow and the stern were both designed to be 1.5 feet in length, as opposed to last year's canoe, which featured a 3' bow and 1.5' stern. This change reduced the amount of foam and concrete used in constructing the canoe, further minimizing waste. These tip inserts were covered with pink concrete and sanded down to create a smooth surface, and became the base for additional aesthetic elements. On the back tip of the canoe, tan concrete was hand cast in a basket weave formation to resemble a pie lattice, while a rubber mold was used to cast an ice cream cone on the front tip. Additional candy elements were cast on the interior walls in a similar fashion. Gunwale covers were created with pink finishing concrete to cover the PT spacers that were otherwise visible on the canoe's interior and to match the color of the letters.

The final finishing process included sanding the exterior of the canoe with 60- through 2000- grit sandpaper to achieve the desired smoothness and texture. Limited sanding on the interior of the canoe was necessary to smooth out any color irregularities. Following this, two coats of water-repellant penetrating sealant were applied to the entire canoe. The overall construction process utilized past materials and employed lean construction techniques to create *Sugar Rush* in an efficient and sustainable fashion. By recycling resources such as PT stands and old foam blocks, costs were reduced and waste was avoided. This resulted in a sustainable and more cost effective canoe compared to previous years.

PROJECT & QUALITY MANAGEMENT

Sugar Rush's development began over the summer, with the appointment of a new board of Project Directors (PDs) to identify and outline areas of innovation from *La Sirena*. Project Managers (PMs) developed a streamlined schedule adhering to the critical path, which followed the key milestones of hull design completion, mold completion, canoe construction, finishing, and the transportation of the canoe to the competition.

PMs met with PDs to communicate project goals and areas of responsibility. Due to the young nature of the director's team, the facilitation of knowledge transfer from past PD's was a primary goal of project leadership. Weekly director meetings provided platforms for sharing best practices and keeping directors cognizant of upcoming milestones. Lessons and takeaways from construction and aesthetic practice events were reviewed to define proper techniques going forward. Also, directors gave presentations at the beginning of workdays to general members about mix design, hull design, quality management, and structural analysis to build interest in and understanding of core project concepts.

During fall quarter, management focused primarily on mix design development and preparations for mold completion upon arrival of the CNC milled foam. General members stripped and refurbished a section of the previous year's mold so that they could become familiar with the mold construction process. Concurrently, aesthetics and mix design meetings were held periodically to facilitate planning and implementation of key innovation areas, and to foster communication between project managers and directors.

Following canoe casting early in Winter Quarter, the focus shifted towards completion of competition deliverables such as cutaway and display. PDs orchestrated separate workdays at their discretion to complete their assignments promptly and effectively. Approximately 2,200 person-hours were dedicated to the manufacturing of *Sugar Rush*.

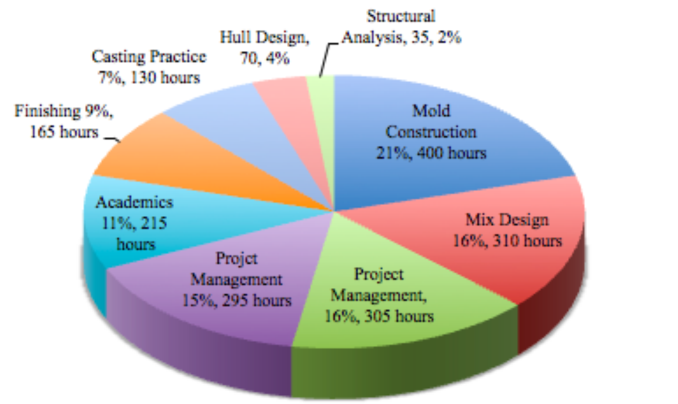


Figure 10: *Breakdown of total project person-hours, excluding padding*

To account for the high cost of a new CNC-milled mold, the budget for all other non-mold expenses was reduced by 73%. These savings were made possible due to subsidized PPE by the general ASCE fund, cost-effective recruitment methods and material investments from last year. The total annual cost to build *Sugar Rush* was $3,824, a similar budget to previous years.

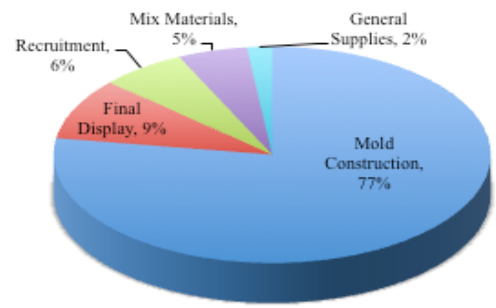


Figure 11: *Breakdown of 2019 actual budget*

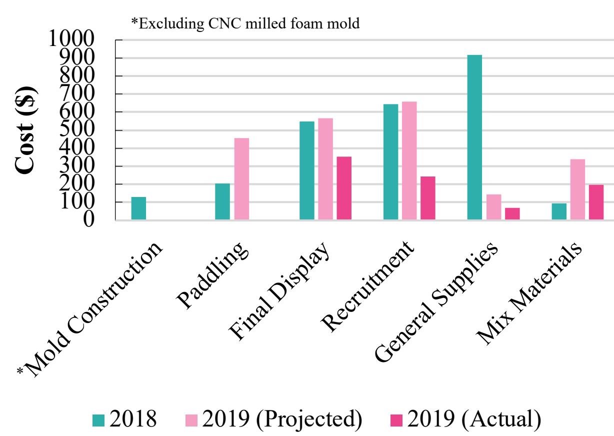


Figure 12: *Comparison of 2018 budget, 2019 projected budget, and 2019 actual budget.*

Quality Assurance (QA) and Quality Control (QC) techniques were observed throughout the construction of *Sugar Rush* to ensure not only that the canoe end product met the quality requirements and expectations highlighted in the rules and regulations, but also that it represented the highest level of quality achievable by the team.

Within the appointed board of PDs, each director tackled a responsibility based on their skills and interests for growth. A QA/QC director was selected to help foster a continuous group consciousness on the NCCC rules and to establish a safe working environment at each workday. PMs and the QA/QC Director consistently conducted reviews of the rules and debriefed project engineers to increase their awareness of regulations. Also, all members completed the “Lab Safety Fundamentals” course provided by the UCLA Environment, Health and Safety Department before participating in workdays. The course emphasized the fundamentals of proper lab procedure, chemical safety, and action under emergency in laboratory settings, followed by a comprehension test.

Furthermore, before each workday, the PDs made it a habit to consolidate objectives, utilize Material Safety Data Sheets (MSDS) for the appropriate handling of materials as needed to fulfill an object, organize the workspace to minimize potential hazards, and ensure that adequate Personal Protection Equipment (PPE) was accessible and worn by all members. Concurrently, members were required to complete a respirator training and fitting session before permitted to work in mix workdays. Following the debriefing of objectives by PMs, team members were assessed through trivia questions and broken up into teams with specific missions guided by one of the eight PDs. For the duration of the workdays, PMs observed the progress of each mini-project to ensure that the PDs and team members were equipped with the essential materials to fulfill their objects. Also, practice casting, demolding, and sanding days were facilitated to build skills in members before repeating the process on the final product. One technique observed was depth checking- a method orchestrated by an appointed team under the supervision of the QA/QC Director to gauge the proper thickness of each concrete layer.

Throughout workdays, the decluttering of workplaces, elimination of tripping and circuit hazards via the unplugging and storing of instruments when not in use, and the adequate disposal of chemicals and materials to avoid cross-contamination helped maximize safety and were delegated to all members. After each workday, members labeled their reusable PPE (N95 masks) to decrease waste production and were highly encouraged to sanitize themselves for hygienic purposes.

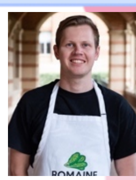
A Google Drive System (GDS) was employed to organize the project by section and to allow for a readily accessible collaborative unit between the PDs. For example, the Structural Analysis Director ’s design calculations were reviewed by PMs, alumni, and professors through the GDS. Calculations from previous years were utilized as references, thus allowing the team to minimize error and accurately evaluate canoe stresses. Furthermore, UCLA engineering faculty mentors advised on pre-tensioning (PT) configurations and stress modeling, which ultimately helped the team conduct analyses with different perspectives and approaches. PMs and PDs also handled mix material procurement that enabled them to perform checks against each other to confirm the compilation of the donated or purchased materials with the ASTM criteria.

In summary, the PMs and the QA/QC director inspected each material used and assured that the products were compliant with the standards. MSDS sheets kept in the mix room were accessible to the mix directors who ensured that the manufacturers’ safety precautions were followed during both batching and mixing. And to avoid misinterpretation of any rules, the team submitted Requests for Information (RFI) and reviewed published RFI responses on the NCCC Facebook page. Through in-depth skill training, rigorous PPE regulations, a stringent QA/QC process, and the collective cohesiveness observed in all levels of the team, the team successfully manufactured the highest quality version of *Sugar Rush*.

Alumni Advisors:
Trini Inouye (BS '18)
Sam Delwiche (BS '13)
Justin Maynard (BS '12)

Faculty Advisors:
Professor Jian Zhang, Ph.D
Professor Eric Alberg, Ph.D

PROJECT MANAGER



Colin Burrowes (Sr.)*
Responsible for logistics, scheduling, material procurement, and overseeing directors.

ASSISTANT P.M.

Lizzy Robinet (Jr.)*
Responsible for contacting sponsors and budget.

HULL DESIGN

Javier Gomez (So.)
Developed design for optimal canoe performance.

STRUCTURAL ANAYSIS

Rahaf Barrkoudi (Jr.)
Performed structural calculations and determined loading cases.

QA/QC

Anthony Garcia (So.)
Ensured a quality product and safe work environment.

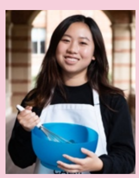
ADMINISTRATION

Ameya Patel (So.)
Managed team communication, member tracking, and outreach.

MIX DESIGN

Catherine Nguyen (So.)
Developed and tested concrete mixes and led mix design workdays.

MIX DESIGN

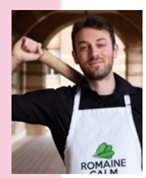


Rachel Tam (So.)
Developed and tested concrete mixes and researched mix designs and materials.

CONSTRUCTION

Kristine Ocampo (Jr.)
Led aesthetic design related to canoe construction.

CONSTRUCTION



Yousef Almalla (Jr.)
Directed overall construction and developed pre-tensioning system.

PRINCIPAL MEMBERS

PADDLING
Ada Chang (Sr.)
Andrew Wong (Fr.)
Anjali Swamy (So.)
Anne Mast (So.)
Catherine Nguyen (So.)
Colin Burrowes (Sr.)
Eliot Yang (So.)
Heather Wong (Sr.)
Johnny Schmidt (Sr.)
Joshua Widjaja (Sr.)
Mahsa Sheykhsoltan (Sr.)
Yash Kansal (Sr.)

CONSTRUCTION
Anjali Swamy (So.)
Andrew Wong (Fr.)
Anne Mast (So.)
Ayla Dvoretzky (Fr.)
Daniel Mitchener (Jr.)
Ki Ja Ourdoune (Fr.)
Mahsa Sheyksoltan (Sr.)
Matthew Saiki (Fr.)
Megan Magorka (So.)
Yash Kansal (Sr.)

FINAL PRODUCT
Ada Chang (Sr.)
Andrew Wong (Fr.)
Anjali Swamy (So.)
Anne Mast (So.)
Ayla Dvoretzky (Fr.)
Daniel Mitchener (Jr.)
Ki Ja Ourdoune (Fr.)
Mahsa Sheyksoltan (Sr.)
Matthew Saiki (Fr.)
Megan Magorka (So.)

MIX DESIGN
Abigail Edwards (Sr.)
Cheston Cheung (Jr.)
Facundo Sirri (Jr.)
Jenna Shigeta (So.)
Joshua Widjaja (Sr.)
Liz Menendez (Sr.)
Lucas Tang (Fr.)
Matthew Saiki (Fr.)
Megan Magorka (So.)
Sara Abou Karroum (Jr.)

***team captains**

ACI Committee 318. (2014). *Building code requirements for structural concrete: (ACI 318-14) ; and commentary (ACI 318R-14)*. Farmington Hills, MI: American Concrete Institute.

ANSYS. (2019, January 16). ANSYS Fluent 2019 (Version 19.2) [Computer Software].

ASTM (2004). "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens." C496/C496M-11. West Conshohocken, PA.

ASTM (2013). "Standard Specification for Latex and Powder Polymer Modifiers for use in Hydraulic Cement Concrete and Mortar." C1438-13. West Conshohocken, PA.

ASTM (2015). "Standard Test Method for Slump of Hydraulic-Cement Concrete." C143/C143M-15a. West Conshohocken, PA.

ASTM (2016). "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." C39/C39M-16b. West Conshohocken, PA.

ASTM (2016). "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)." C78/C78M16. West Conshohocken, PA.

Autodesk. (2016, March 21). AutoCAD 2017 (Version 21.0) [Computer Software].
Autodesk. (2019, January 16). Fusion 360 2019 (Version 2.0.5338) [Computer Software].

Bluebeam. (2017, October 25). Bluebeam Revu 2017 [Computer Software].

Jackson, P. S. (1995). Performance prediction for Olympic kayaks. *Journal of Sports Sciences*, 13(3), 239-245.

Kasten, M. (2016). General hull form equations. From *Kasten Marine Design*. Retrieved February 13, 2018, from http://www.kastenmarine.com/_pdf/coefficients_of_form_equations.pdf

Kosmatka, S.H., & Wilson, M.L. (2011). *Design and control of concrete mixtures* (15th ed.). Skokie, Illinois: Portland Cement Association.

Kozul, R., & Darwin, D. (1997). Effects of aggregate type, size, and content on concrete strength and fracture energy. *SM Report, 43*. Retrieved from https://kuscholarworks.ku.edu/handle/1808/20457/

Lane, D.S. (1998). *Evaluation of concrete characteristics for rigid pavements.* Charlottesville, VA: Virginia Transportation Research Council.

McGuffin, G., & McGuffin, J. (1999). *Paddle your own canoe*. Erin, Ontario: Boston Mills Press.

Microsoft. (2015, September 22). Microsoft Excel 2016 (Version 16.0) [Computer Software].

Microsoft. (2015, September 22). Microsoft Project 2016 [Computer Software].

Microsoft. (2015, September 22). Microsoft Word 2016 [Computer Software].

Naik, T. R., & Moriconi, G. (2005). Environmental-friendly durable concrete made with recycled materials for sustainable concrete construction.

Slade, S. (1998). Understanding the prismatic coefficient. Retrieved February 13, 2015 from http://www.navweaps.com/index_tech/tech-004.htm/

University of California, Los Angeles Concrete Canoe. (2018). "*La Sirena.*" Pacific Southwest Conference Concrete Canoe Design Paper, University of California, Los Angeles, CA.

MIXTURE DESIGNATION: STRUCTURAL MIX (YELLOW)

CEMENTITIOUS MATERIALS				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Cement, ASTM Type I White	*3.15*	*1.473*	*289.5*	*Total Amount of cementitious materials* ***704.99*** *lb/yd^3* *c/cm ratio:* ***0.41***
NewCem Slag	*2.5*	*0.808*	*126.1*	
VCAS	*2.6*	*1.784*	*289.5*	

FIBERS				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of Fibers (mass/volume) (lb/yd^3)*	
Short Stuff ESS5F	*0.96*	*0.178*	*10.67*	*Total Amount of Fibers* ***19.86*** *lb/yd^3*
Nycon-PVA RECS100	*1.3*	*0.038*	*3.06*	
Nycon-PVA RFS400	*1.3*	*0.075*	*6.12*	

AGGREGATES							
Aggregates	*ASTM C330**	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*Volume (ft^3)*
					OD	*SSD*	
K15	*No*	*0.0*	*0.15*	*0.15*	*29.1*	*29.1*	*3.105*
Poraver .1-.3	*No*	*22.0*	*0.95*	*1.16*	*58.2*	*70.9*	*0.980*
Poraver .25-.5	*No*	*15.0*	*0.70*	*0.81*	*64.9*	*74.7*	*1.477*
Poraver .5-.1	*No*	*9.0*	*0.50*	*0.55*	*38.6*	*42.1*	*1.226*
Poraver 1-2	*No*	*7.0*	*0.40*	*0.43*	*21.2*	*22.6*	*0.844*
Trinity Lightweight	*Yes*	*21.1*	*1.83*	*2.22*	*315.4*	*382.0*	*2.764*

ADMIXTURES					
Admixture	*lb/gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
Styrofan 1186	*9.18*	*1005.7*	*48.00*	*264.41*	*Total Water from Admixtures, $\sum w_{admx}$* ***290.78*** *lb/yd^3*
MasterAir AE 90	*8.48*	*2.8*	*6.00*	*1.22*	
Adva 195	*8.34*	*54.8*	*0.00*	*25.15*	

SOLIDS (LATEX, DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Styrofan 1186	*1.01*	*3.873*	*244.07*	*Total Solids from Admixtures* ***286.80*** *lb/yd^3*
Synthetic Iron Oxide Yellow Pigment	*4.1*	*0.028*	*7.06*	
Mineral Filler Trinity Lightweight	*1.83*	*0.058*	*6.60*	
Mineral Filler K15	*0.15*	*3.105*	*29.10*	

WATER			
	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		*w: 276.81*	*4.436*
Total Free Water from All Aggregates, lb/yd^3		*$\sum w_{free}$: -93.13*	
Total Water from All Admixtures, lb/yd^3		*$\sum w_{admx}$: 290.78*	
Batch Water, lb/yd^3		*w_{batch}: 79.16*	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	*704.99*	*19.86*	*621.40*	*286.80*	*276.81*	*$\sum M$: 1909.86*
Absolute Volume of Concrete, V, (ft^3)	*4.065*	*0.291*	*10.396*	*7.063*	*4.436*	*$\sum V$: 26.25*
Theoretical Density, T, *(=$\sum M$ / $\sum V$)*	*72.75 lb/ft^3*		***Air Content*** *[= (T – D)/T x 100%]*			*2.77%*
Measured Density, D	*70.74 lb/ft^3*		***Slump, Slump flow***			*1.25 in.*
water/cement ratio, w/c:	**0.956**		***water/cementitious material ratio, w/cm:***			**0.393**

NOTE: Mix produced in three color variations: Yellow, Tan, and Red. This mix table shows calculations for the Yellow variation, as it is the densest of the three and has the most accurately identified specific gravity.

MIXTURE DESIGNATION: FINISHING MIX (TAN)

CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Cement, ASTM Type I White	3.15	1.524	299.6	*Total Amount of cementitious materials* ***729.77*** *lb/yd^3* *c/cm ratio:* ***0.41***
NewCem Slag	2.5	0.836	130.5	
VCAS	2.6	1.847	299.6	

FIBERS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of Fibers (mass/volume) (lb/yd^3)*	
Short Stuff ESS5F	0.96	0.184	11.05	*Total Amount of Fibers* ***17.39*** *lb/yd^3*
Nycon-PVA RECS15	1.3	0.039	3.17	
Nycon-PVA RECS100	1.3	0.039	3.17	

AGGREGATES

Aggregates	*ASTM C330**	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*Volume (ft^3)*
					OD	*SSD*	
K15	*No*	0.0	0.15	0.15	30.1	30.1	3.214
Poraver .1-.3	*No*	22.0	0.95	1.16	113.6	138.6	1.914
Poraver .25-.5	*No*	15.0	0.70	0.81	75.7	87.1	1.722
Poraver .5-.1	*No*	9.0	0.50	0.55	0.0	0.0	0.000
Poraver 1-2	*No*	7.0	0.40	0.43	0.0	0.0	0.000
Trinity Lightweight	*Yes*	21.1	1.83	2.22	317.6	384.6	2.776

ADMIXTURES

Admixture	*lb/gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
Styrofan 1186	9.18	1068.8	48.00	290.89	*Total Water from Admixtures, $\sum W_{admx}$* ***314.95*** *lb/yd^3*
MasterAir AE 90	8.48	4.3	6.00	1.95	
Adva 195	8.34	46.5	0.00	22.11	

SOLIDS (LATEX, DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Styrofan 1186	1.01	4.260	268.51	*Total Solids from Admixtures* ***321.72*** *lb/yd^3*
Synthetic Iron Oxide Tan Pigment	4.5	0.026	7.31	
Mineral Filler Trinity Lightweight	1.83	0.138	15.80	
Mineral Filler K15	0.15	3.214	30.10	

WATER

	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		*w: 278.11*	4.457
Total Free Water from All Aggregates, lb/yd^3		*$\sum W_{free}$: -102.40*	
Total Water from All Admixtures, lb/yd^3		*$\sum W_{admx}$: 314.95*	
Batch Water, lb/yd^3		*W_{batch}: 65.56*	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	729.77	17.39	640.26	321.72	278.11	*$\sum M$: 1987.24*
Absolute Volume of Concrete, V, (ft^3)	4.208	0.224	9.627	7.639	4.457	*$\sum V$: 26.15*
Theoretical Density, T, *(=$\sum M / \sum V$)*	*75.98 lb/ft^3*		***Air Content*** *[= (T – D)/T x 100%]*			3.13%
Measured Density, D	*73.60 lb/ft^3*		***Slump, Slump flow***			1.5 in.
water/cement ratio, w/c:	**0.928**		***water/cementitious material ratio, w/cm:***			**0.381**

NOTE: Mix produced in five color variations: Tan, Red, Yellow, Green, and Blue. Specific gravity for Tan was given as 4.0-5.0 and was taken to be 4.5. This mix table shows calculations for the Tan variation, as it is theoretically the densest of the five and is the predominant finishing pigment.

Step-by-Step Calculation of Yielded Mixture Proportions of Structural Mix

*All measurements given per cubic yard.

Cementitious Materials

Component	***Mass$_{CM}$***, given **(lb)**	***Specific Gravity***	$\boldsymbol{Volume} = \frac{mass}{specific\ gravity \times 62.4\ lb/ft^3}$
Cement Type I White	289.5	3.15	$\boldsymbol{Volume}_{\boldsymbol{Cement\ Type\ 1\ White}} = \frac{289.5\ lb}{3.15 \times 62.4 \frac{lb}{ft^3}} = 1.473\ ft^3$
NewCem Slag	126.1	2.5	$\boldsymbol{Volume}_{\boldsymbol{NewCem\ Slag}} = \frac{126.1 lb}{2.5 \times 62.4 \frac{lb}{ft^3}} = 0.808\ ft^3$
VCAS	289.5	2.6	$\boldsymbol{Volume}_{\boldsymbol{VCAS}} = \frac{289.5\ lb}{2.6 \times 62.4 \frac{lb}{ft^3}} = 1.784\ ft^3$

Total Mass and Volume of Cementitious Materials:

$$\sum \boldsymbol{Mass}_{\boldsymbol{CM}} = 266.3\ lb + 116.0\ lb + 266.3\ lb = \boldsymbol{704.99\ lb}$$

$$\sum \boldsymbol{Volume}_{\boldsymbol{CM}} = 1.473\ ft^3 + 0.808\ ft^3 + 1.784\ ft^3 = \boldsymbol{4.065\ ft^3}$$

Fibers

Component	***Mass, given*** **(lb)**	***Specific Gravity***	$\boldsymbol{Volume} = \frac{mass}{specific\ gravity \times 62.4\ lb/ft^3}$
Short Stuff ESS5F	10.67	0.96	$\boldsymbol{Volume}_{\boldsymbol{Short\ Stuff\ ESS5F}} = \frac{10.67\ lb}{0.96 \times 62.4 \frac{lb}{ft^3}} = 0.178\ ft^3$
Nycon-PVA RECS100	3.06	1.3	$\boldsymbol{Volume}_{\boldsymbol{Nycon-PVA\ RECS100}} = \frac{3.06\ lb}{1.3 \times 62.4 \frac{lb}{ft^3}} = 0.038\ ft^3$
Nycon-PVA RFS400	6.12	1.3	$\boldsymbol{Volume}_{\boldsymbol{Nycon-PVA\ RFS400}} = \frac{6.12\ lb}{1.3 \times 62.4 \frac{lb}{ft^3}} = 0.075\ ft^3$

Total Mass and Volume of Fibers:

$$\sum \boldsymbol{Mass}_{\boldsymbol{Fibers}} = 10.67\ lb + 3.06\ lb + 6.12\ lb = \boldsymbol{19.86\ lb}$$

$$\sum \boldsymbol{Volume}_{\boldsymbol{Fibers}} = 0.178\ ft^3 + 0.038\ ft^3 + 0.075\ ft^3 = \boldsymbol{0.291\ ft^3}$$

Aggregates

Given quantities:

Component	W_{stk} *(lb)*	SG_{OD}	MC_{stk} *(%)*	*Abs (%)*
K15	29.1	0.15	0.00%	0.0%
Poraver .1-.3	58.4	0.95	0.50%	22.0%
Poraver .25-.5	65.3	0.70	0.50%	15.0%
Poraver .5-1	38.8	0.50	0.50%	9.0%
Poraver 1-2	21.3	0.40	0.50%	7.0%
Trinity	315.4	1.83	0.00%	21.1%

Mass in oven-dried condition:

$$\boldsymbol{W_{OD}} = \frac{\boldsymbol{W_{stk}}}{\boldsymbol{MC_{stk}} + \mathbf{1}}$$

Mass in saturated, surface dry condition:

$$\boldsymbol{W_{SSD}} = \left(\mathbf{1} + \frac{\boldsymbol{Abs}}{\mathbf{100\%}}\right) \times \boldsymbol{W_{OD}}$$

Component	W_{OD} *(lb)*	W_{SSD} *(lb)*
K15	$W_{OD} = \frac{29.1\ lb}{0.00\% + 1} = 29.1\ lb$	$W_{SSD} = \left(1 + \frac{0.0\%}{100\%}\right) \times 29.1\ lb = 29.1\ lb$
Poraver .1-.3	$W_{OD} = \frac{58.4\ lb}{0.50\% + 1} = 58.2\ lb$	$W_{SSD} = \left(1 + \frac{22.0\%}{100\%}\right) \times 58.2\ lb = 70.9\ lb$
Poraver .25-.5	$W_{OD} = \frac{65.3\ lb}{0.50\% + 1} = 64.9\ lb$	$W_{SSD} = \left(1 + \frac{15.0\%}{100\%}\right) \times 64.9\ lb = 74.7\ lb$
Poraver .5-1	$W_{OD} = \frac{38.8\ lb}{0.50\% + 1} = 38.6\ lb$	$W_{SSD} = \left(1 + \frac{9.0\%}{100\%}\right) \times 38.6\ lb = 42.1\ lb$
Poraver 1-2	$W_{OD} = \frac{21.3\ lb}{0.50\% + 1} = 21.2\ lb$	$W_{SSD} = \left(1 + \frac{7.0\%}{100\%}\right) \times 21.2\ lb = 22.6\ lb$
Trinity	$W_{OD} = \frac{315.4\ lb}{0.00\% + 1} = 315.4\ lb$	$W_{SSD} = \left(1 + \frac{21.1\%}{100\%}\right) \times 315.4\ lb = 382.0\ lb$

Specific gravity in saturated, surface-dry condition:

$$\boldsymbol{SG_{SSD}} = \frac{\boldsymbol{W_{SSD}} \times \boldsymbol{SG_{OD}}}{\boldsymbol{W_{OD}}}$$

Volume in saturated, surface-dry condition:

$$\boldsymbol{Volume_{SSD}} = \frac{\boldsymbol{W_{SSD}}}{\boldsymbol{W_{SSD}} \times \mathbf{62.4}\ \boldsymbol{lb/ft^3}}$$

Component	SG_{SSD}	$Volume_{SSD}\ (ft^3)$
K15	$SG_{SSD} = \frac{29.1\ lb \times 0.15}{29.1\ lb} = 0.15$	$Volume_{SSD} = \frac{29.1\ lb}{0.15 \times 62.4\ lb/ft^3} = 3.105\ ft^3$
Poraver .1-.3	$SG_{SSD} = \frac{70.9\ lb \times 0.95}{58.2\ lb} = 1.16$	$Volume_{SSD} = \frac{70.9\ lb}{1.16 \times 62.4\ lb/ft^3} = 0.980\ ft^3$
Poraver .25-.5	$SG_{SSD} = \frac{74.7\ lb \times 0.70}{64.9\ lb} = 0.81$	$Volume_{SSD} = \frac{74.7\ lb}{0.81 \times 62.4\ lb/ft^3} = 1.477\ ft^3$
Poraver .5-1	$SG_{SSD} = \frac{42.1\ lb \times 0.50}{38.6\ lb} = 0.55$	$Volume_{SSD} = \frac{42.1\ lb}{0.55 \times 62.4\ lb/ft^3} = 1.226\ ft^3$
Poraver 1-2	$SG_{SSD} = \frac{22.6\ lb \times 0.40}{21.2\ lb} = 0.43$	$Volume_{SSD} = \frac{22.6\ lb}{0.43 \times 62.4\ lb/ft^3} = 0.844\ ft^3$
Trinity	$SG_{SSD} = \frac{382.0\ lb \times 1.83}{315.4\ lb} = 2.22$	$Volume_{SSD} = \frac{382.0\ lb}{2.22 \times 62.4\ lb/ft^3} = 2.764\ ft^3$

Total moisture content:

$$MC_{total} = \frac{W_{stk} - W_{OD}}{W_{OD}} \times 100\%$$

Free moisture content:

$$MC_{free} = MC_{total} - Abs$$

Component	MC_{total} (%)	MC_{free} (%)
K15	$MC_{total} = \frac{29.1\ lb - 29.1\ lb}{29.1\ lb} \times 100 = 0.00\%$	$MC_{free} = 0.00\% - 0.00\% = 0.00\%$
Poraver .1-.3	$MC_{total} = \frac{58.4\ lb - 58.2\ lb}{58.2\ lb} \times 100 = 0.50\%$	$MC_{free} = 0.50\% - 22.00\% = -21.50\%$
Poraver .25-.5	$MC_{total} = \frac{65.3\ lb - 64.9\ lb}{64.9\ lb} \times 100 = 0.50\%$	$MC_{free} = 0.50\% - 15.00\% = -14.50\%$
Poraver .5-1	$MC_{total} = \frac{38.8\ lb - 38.6\ lb}{38.6\ lb} \times 100 = 0.50\%$	$MC_{free} = 0.50\% - 9.00\% = -8.50\%$
Poraver 1-2	$MC_{total} = \frac{21.3\ lb - 21.2\ lb}{21.2\ lb} \times 100 = 0.50\%$	$MC_{free} = 0.50\% - 7.00\% = -6.50\%$
Trinity	$MC_{total} = \frac{315.4\ lb - 315.4\ lb}{315.4\ lb} \times 100 = 0.00\%$	$MC_{free} = 0.00\% - 21.10\% = -21.10\%$

Free water carried into batch:

$$w_{free} = W_{OD} \times \left(\frac{MC_{free}}{100\%}\right)$$

Component	w_{free} (lb)
K15	$w_{free} = 29.1\ lb \times \left(\frac{0.00\%}{100\%}\right) = 0\ lb$
Poraver .1-.3	$w_{free} = 58.2\ lb \times \left(\frac{-21.50\%}{100\%}\right) = -12.50\ lb$
Poraver .25-.5	$w_{free} = 64.9\ lb \times \left(\frac{-14.50\%}{100\%}\right) = -9.42\ lb$
Poraver .5-1	$w_{free} = 38.6\ lb \times \left(\frac{-8.50\%}{100\%}\right) = -3.28\ lb$
Poraver 1-2	$w_{free} = 21.2\ lb \times \left(\frac{-6.50\%}{100\%}\right) = -1.38\ lb$
Trinity	$w_{free} = 315.4\ lb \times \left(\frac{-21.10\%}{100\%}\right) = -66.56\ lb$

Negative values indicate a dry and absorptive aggregate.

Water contributed by aggregates:

$$\sum w_{free} = 0\ lb + (-12.50)lb + (-9.42)lb + (-3.28)lb + (-1.38)lb + (-66.56)lb = \mathbf{-93.13\ lb}$$

Total Mass and Volume of Aggregate:

$$\sum Mass_{Aggregate} = \sum W_{SSD} = 29.1\ lb + 70.9\ lb + 74.7\ lb + 42.1\ lb + 22.6\ lb + 382.0\ lb = \mathbf{621.4\ lb}$$

$$\sum Volume_{Aggregate} = \sum Volume_{SSD} = 3.105\ ft^3 + 0.980\ ft^3 + 1.477\ ft^3 + 1.226\ ft^3 + 0.844\ ft^3 + 2.764\ ft^3 = \mathbf{10.396\ ft^3}$$

Admixtures

Given quantities:

Component	*Dosage(fl oz/cwt)*	*Water Content (%)*	*lb/gal of admixture*
Styrofan 1186	1005.7	52.00%	8.48
MasterAir AE 90	2.8	94.00%	8.34
Adva 195	54.8	100.00%	9.18

$\boldsymbol{cwt} = \sum Mass_{CM}/100 = 7.050\ cwt$

Water in admixtures:

$\boldsymbol{w_{admx} = dosage\ (fl\ oz/cwt) \times cwt\ of\ cm \times water\ content}\ (\%) \times \boldsymbol{1\ gal/128\ fl\ oz \times lb/gal\ of\ admixture}$

Component	$\boldsymbol{w_{admx}\ (lb)}$
Styrofan 1186	$\boldsymbol{w_{admx}} = 1005.7\ fl\ oz/cwt \times 7.050\ cwt \times 52.00\% \times 1\ gal/128\ fl\ oz \times 9.18\ lb/gal = 264.410\ lb$
MasterAir AE 90	$\boldsymbol{w_{admx}} = 2.8\ fl\ oz/cwt \times 7.050\ cwt \times 94.00\% \times 1\ gal/128\ fl\ oz \times 8.48\ lb/gal = 25.151\ lb$
Adva 195	$\boldsymbol{w_{admx}} = 54.8\ fl\ oz/cwt \times 7.050\ cwt \times 100.00\% \times 1\ gal/128\ fl\ oz \times 8.34\ lb/gal = 1.217\ lb$

$$\sum \boldsymbol{w_{admx}} = 264.410\ lb + 25.151\ lb + 1.217\ lb = \boldsymbol{290.777\ lb}$$

Solids (Latex, Dyes and Mineral Filler)

Solids in Latex:

$\boldsymbol{Solids\ in\ latex} = 1005.7\ fl\ oz/cwt \times 7.050\ cwt \times (100.00\% - 52.00\%) \times 1\ gal/128\ fl\ oz \times 9.18\ lb/gal = 244.07\ lb$

Accounting for Mineral Fillers:

K15: The average particle size of K15 is 60 μm (K15 MTDS). 6.21 ft^3 of K15 was used, so 50% of it was counted as mineral filler (2.86 ft^3).

Trinity: According to a sieve analysis performed by UCLA Concrete Canoe, 2.05% of Trinity particles are smaller than 0.75 μm. 2.82 ft^3 of Trinity was used, so 2.05% of it was counted as mineral filler (0.06 ft^3).

Component	*Mass, given* (lb)	*Specific Gravity*	$\boldsymbol{Volume} = \dfrac{mass}{specific\ gravity \times 62.4\ lb/ft^3}$
Styrofan 1186	244.07	1.01	$\boldsymbol{Volume_{Styrofan\ 1186}} = \dfrac{244.07\ lb}{1.01 \times 62.4 \frac{lb}{ft^3}} = 3.873\ ft^3$
Synthetic Iron Oxide Yellow Pigment	7.06	4.1	$\boldsymbol{Volume_{Yellow\ Pigment}} = \dfrac{7.06\ lb}{4.1 \times 62.4 \frac{lb}{ft^3}} = 0.028\ ft^3$
Mineral Filler Trinity	6.60	1.83	$\boldsymbol{Volume_{Mineral\ Filler\ Trinity}} = \dfrac{6.60\ lb}{1.83 \times 62.4 \frac{lb}{ft^3}} = 0.058\ ft^3$
Mineral Filler K15	29.1	0.15	$\boldsymbol{Volume_{Mineral\ Filler\ K15}} = \dfrac{29.1\ lb}{0.15 \times 62.4 \frac{lb}{ft^3}} = 3.105\ ft^3$

Total Mass and Volume of Solids:

$$\sum \boldsymbol{Mass_{Solids}} = 244.07\ lb + 7.06\ lb + 6.60\ lb + 29.10\ lb = \boldsymbol{286.80\ lb}$$

$$\sum \boldsymbol{Volume_{Solids}} = 3.556\ ft^3 + 0.028\ ft^3 + 0.058\ ft^3 + 3.105\ ft^3 = \boldsymbol{7.063 ft^3}$$

Water

$\boldsymbol{w_{batch}} = 79.16\ lb$

Total Mass and Volume of Water:

$$\boldsymbol{w} = \boldsymbol{w_{batch}} + \left(\sum \boldsymbol{w_{free}} + \sum \boldsymbol{w_{admx}}\right) = 79.16\ lb + (-93.13)\ lb + 290.78\ lb = \boldsymbol{276.81\ lb}$$

$$\boldsymbol{Volume_{water}} = \frac{\boldsymbol{mass}}{\boldsymbol{specific\ gravity \times 62.4\ lb/ft^3}} = \frac{276.81\ lb}{1 \times 62.4\ lb/ft^3} = \boldsymbol{4.436\ ft^3}$$

Concrete Analysis

Theoretical Density, T:

$$\boldsymbol{Mass_{Total}} = \sum Mass_{CM} + \sum Mass_{Fibers} + \sum Mass_{Aggregate} + \sum Mass_{Solids} + w = \boldsymbol{1909.86\ lb}$$

$$\boldsymbol{Volume_{Total}} = \sum Volume_{CM} + \sum Volume_{Fibers} + \sum Volume_{Aggregate} + \sum Volume_{Solids} + Volume_{water} = \boldsymbol{26.25\ ft^3}$$

$$\boldsymbol{T} = \frac{\boldsymbol{Mass_{Total}}}{\boldsymbol{Volume_{Total}}} = \boldsymbol{72.75\ lb/ft^3}$$

Measured Density, D: $\boldsymbol{D = 70.74\ lb/ft^3}$

Gravimetric Air Content:

$$\boldsymbol{Air\ Content} = (T - D)/T \times 100\% = (72.75\ lb/ft^3 - 70.74\ lb/ft^3)/72.75\ lb/ft^3 \times 100\% = \boldsymbol{2.77}\%$$

$$\boldsymbol{Air\ Content} = (27 - Volume_{Total})/27\ \times 100\% = (27 - 26.25)/27\ \times 100\% = \boldsymbol{2.77}\% \leftarrow \boldsymbol{CHECK}$$

Wet Unit Weight:

$$\boldsymbol{Volume_{cylinder}} = (diameter/2)^2 \times height \times \pi = (3\ in/2)^2 \times 6\ in \times \pi = 42.412\ in^3$$
$$= 42.412\ in^3 \times (1\ ft/12\ in)^3 = \boldsymbol{0.02454\ ft^3}$$

$$\boldsymbol{Mass_{cylinder}}\ \text{(wet, minus mass of cylinder mold)} = 772\ g = 772\ g \times (1\ lb/453.5924\ g) = \boldsymbol{1.7020\ lb}$$

$$\boldsymbol{Wet\ Unit\ Weight} = \frac{Mass_{cylinder}}{Volume_{cylinder}} = \frac{1.7020\ lb}{0.02454\ ft^3} = \boldsymbol{69.356\ lb/ft^3}$$

Ratios:

cement/cementitious ratio: $\boldsymbol{c/cm} = Mass_{Cement}/\sum Mass_{CM} = 289.5\ lb/705.0\ lb = \boldsymbol{0.411}$

water/cement ratio: $\boldsymbol{w/c} = w/Mass_{Cement} = 276.81\ lb/289.5\ lb = \boldsymbol{0.956}$

water/cementitious material ratio: $\boldsymbol{w/cm} = w/\sum Mass_{CM} = 276.81\ lb/705.0\ lb = \boldsymbol{0.393}$

Slump: Measured at **1.25 in.**

Compliance

$$\boldsymbol{Aggregate\ Ratio}\ (\%) = \frac{\sum Volume_{Aggregate}}{27} \times 100\% = \frac{10.396\ ft^3}{27.00\ ft^3} \times 100\% = \boldsymbol{38.5\% > 25\%} \rightarrow \boldsymbol{Compliant}$$

$$\boldsymbol{ASTM\ C330\ Ratio}\ (\%) = \frac{Volume_{Trinity}}{\sum Volume_{Aggregate}} \times 100\% = \frac{2.764\ ft^3}{10.396\ ft^3} \times 100\% = \boldsymbol{26.6\% > 25\%} \rightarrow \boldsymbol{Compliant}$$

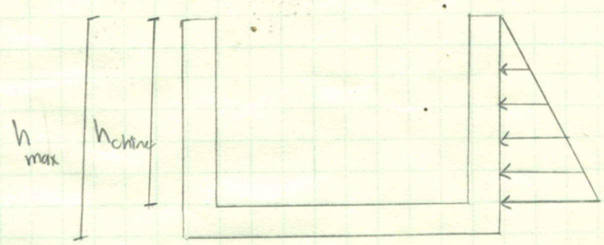
Shear Stress in Chine and Deflection in Gunwale

$h_{max} = 13.5''$

$t \to$ thickness $= 3/8''$

$h_{chine} = 13.5 - 3/8$

$= 13.125'' = 1.1'$



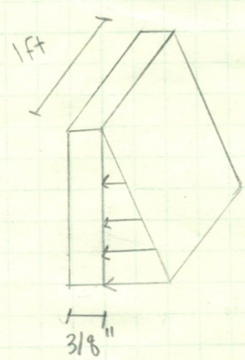
take a cross section of canoe length of 1 ft:

* Force applied on the sidewall

$$F = \int 1.3\gamma y \, dA = \int_0^{h_{chine}} 1.3\gamma y W \, dy = 1.3\gamma W \frac{y^2}{2}\Big|_0^{h_{chine}}$$

$$= 1.3\gamma W \frac{h_{chine}^2}{2} = 1.3\,(63\ \text{lbs/ft}^3)\,(1\text{ft})\,\frac{(1.1)^2}{2} = 49.5\ \text{lbs}$$

49.5 lbs applied at $\frac{1}{3}$ from the chine



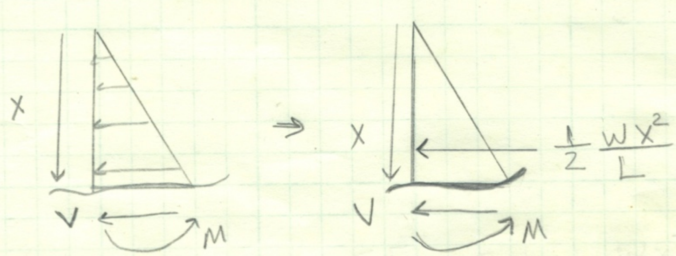
Area where force is applied:

$$A = \left(\frac{3}{8}\text{in}\right)\left(\frac{1}{12}\text{ft}\right)(1\text{ft}) = 0.031\ \text{ft}^2$$

$$F_{chine} = (49.5)\left(\frac{2}{1.1}\right) = 90\ \text{lbs}$$

$$w_o = \frac{90\text{lbs}}{1.1} = 81.8\ \text{lbs/ft}$$

Shear stress in chine: $\sigma = \frac{F_{chine}}{A} = \frac{90}{0.031} = 2903.2\ \text{lbs/ft}^2$

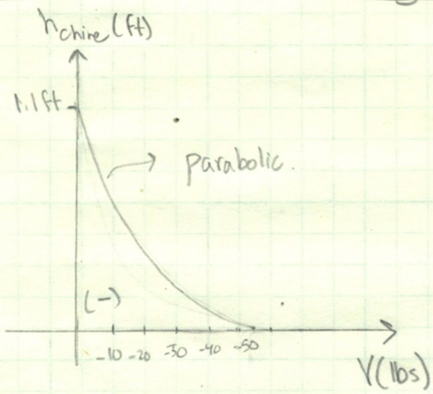


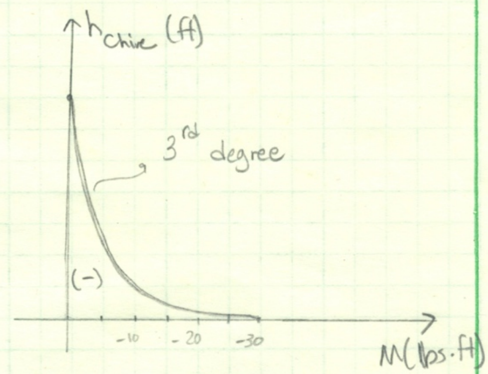
taking a cut to calculate shear and bending

$$\xrightarrow{+} \Sigma F_y = -V - \frac{1}{2} w \frac{x^2}{L} \Rightarrow V = \frac{-wx^2}{2L}$$

$$\circlearrowleft + \Sigma M_x = M + \frac{1}{2} \frac{wx^2}{L} \frac{x}{2} \Rightarrow M = -\frac{wx^3}{4L}.$$

Shear and moment diagram:

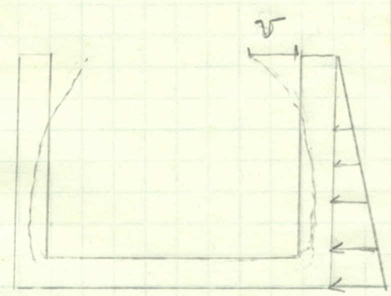




Deflection in the gunwale:

Assume side wall is cantilever beam with fixed support at the bottom of chire; the deflection in the gunwale would be given by

$$v = \frac{wL^4}{30 E_c I}$$



Provided by ACI: $E_c = 57000\sqrt{f_c'}$

$E_c = 57000\sqrt{1830} = 2.44 \times 10^6$ psi.

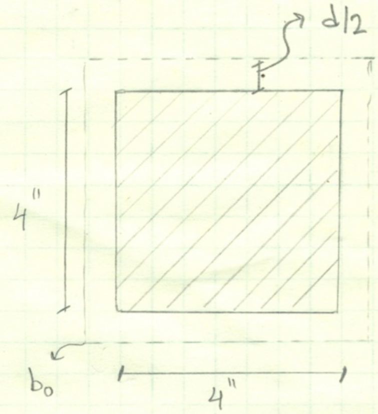
moment of inertia for cross section:

$$I = \frac{1}{12} b h^3 = \frac{1}{12} (12\text{in}) \left(\frac{3}{8} \text{in}^3\right) = 318 \text{ in}^4$$

$$v = \frac{(81.8 \text{ lbs/ft})(1/12 \text{ in})(1.1 \times 12 \text{ in})^4}{30 \, (2.44 \times 10^6 \text{ psi})(318 \text{ in}^4)} = \boxed{0.0075 \text{ in}}$$

* Note: Figures are not drawn to scale.

Punching Stress



Using equations provided in ACI for punching stress for two way slab:

$V_n = V_c + V_s$

$V_s = 0$, reinforcement doesn't provide any shear

Using table 22.6.5.2 in ACI 318-14

$$V_c = \min \begin{cases} 4\lambda\sqrt{f_c'} = (4)(0.85)\sqrt{1830} = 145.4\text{ psi} \\ \left(2 + \frac{4}{\beta}\right)\lambda\sqrt{f_c'} = \left(2 + \frac{4}{1}\right)(0.85)\sqrt{1830} = 218.2\text{ psi} \\ \left(2 + \frac{\alpha_s d}{b_o}\right)\lambda\sqrt{f_c'} = \left[2 + \frac{(40)(3/8)}{17.5}\right](0.85)\sqrt{1830} = 103.9\text{ psi} \end{cases}$$

$V_c = 103.9\text{ psi}$

$\Rightarrow V_n = V_c = 103.9\text{ psi}$

where d = thickness of canoe $= 3/8"$

β = ratio of two sides $= 1$

$\alpha_s = 40$ assume interior columns

$\lambda = 0.85$ for normal weight concrete.

b_o = length of critical perimeter $= 4(4 + 3/8) = 17.5"$

Demand shear strength $V_u = \frac{V}{b_o d} = \frac{(0.75)(200)}{(17.5)(3/8)} = 22.86\text{ psi}$

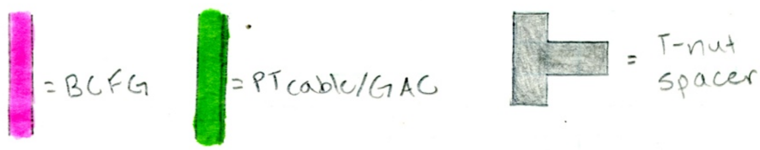
Comparing demand with design shear strength.

$\phi V_n = (0.75)(103.9) = 77.9\text{ psi} > V_u$ satisfies the code.

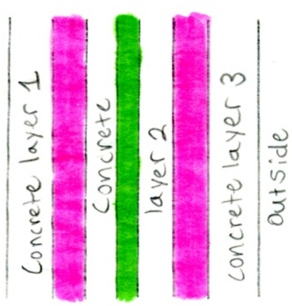
Hull Thickness/Reinforcement Calculations

Reinforcement Thickness & Hull-to-Reinforcement Calculations

BCFG = Bidirectional Carbon Fiber Grid
PT = Pre-tensioning
GAC = Galvanized Aircraft Cable



Wall Conditions



Case 1: BCFG, GAC

Reinforcement Thickness:
BCFG thickness = 0.1 cm
GAC thickness = 1/16 in
canoe thickness = 3/8 in

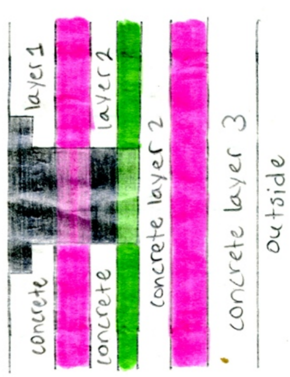
Reinforcement to Thickness Percentage:

$$= \frac{2 \cdot \text{BCFG th.} + \text{GAC th.}}{\text{canoe th.}} \times 100\%$$

$$= \frac{2(0.1\text{cm})\left(\frac{1\text{in}}{2.54\text{cm}}\right) + \frac{1}{16}\text{in}}{\frac{3}{8}\text{in}} \times 100\%$$

$\boxed{\text{case 1} = 37.66\%}$

Gunwale Conditions



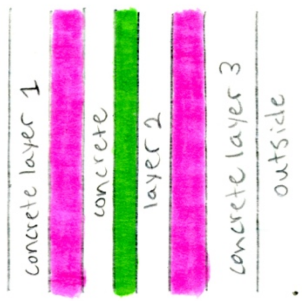
Case 2: T-nut spacer, BCFG, GAC

Reinforcement Thickness:
BCFG thickness = 0.1 cm
GAC thickness = 1/16 in
canoe thickness = 1 in

Reinforcement to Thickness Percentage:

$$= \frac{\text{T-nut spacer th.}}{\text{canoe th.}} \times 100\% = \frac{\frac{1}{4}\text{in}}{1\text{in}} \times 100\%$$

$\boxed{\text{case 2} = 25\%}$



case 3: BCFG, GAC

Reinforcement Thickness:

BCFG thickness = 0.1cm

GAC thickness = 1/16 in

canoe thickness = 1 in

Reinforcement to Thickness Percentage:

$$= \frac{2 \cdot \text{BCFG th.} + \text{GAC th.}}{\text{canoe th.}} \times 100\%$$

$$= \frac{2(0.1\,\text{cm})\left(\frac{1\,\text{in}}{2.54\,\text{cm}}\right) + \frac{1}{16}\,\text{in}}{1\,\text{in}} \times 100\%$$

$$\boxed{\text{case } 3 = 14.12\%}$$

Percent Open Area (POA) Calculations:

Bidirectional Carbon Grid:

$n_1 = 3$, $n_2 = 3$

$d_1 = 1.9cm$, $d_2 = 2.1cm$

$t_1 = 0.4cm$, $t_2 = 0.2cm$

Length = $n_1 \cdot d_1 = (3)(1.9) = 5.7cm$

Width = $n_2 \cdot d_2 = (3)(2.1) = 6.3cm$

Total Open Area = $(d_1 - t_1)(d_2 - t_2) \cdot n_1 \cdot n_2$

$= (1.9 - 0.4)(2.1 - 0.2)(3)(3)$

$= 25.65 cm^2$

Area Total = Length $\cdot$ Width

$= (5.7)(6.3) = 35.91 cm^2$

$$POA = \frac{\text{Total Open Area}}{\text{Area Total}} = \frac{(25.65cm^2)}{(35.91cm^2)} \times 100\%$$

$$\boxed{POA = 71.4\%}$$