2026 NAU Concrete Canoe

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90% DESIGN REPORT

CENE 486C

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List of Abbreviations

ASCE- American Society of Civil Engineers
ASTM- American Society for Testing and Materials
CECMEE- Civil Engineering, Construction Management, Environmental Engineering
NAU- Northern Arizona University
ISWS- Intermountain Southwest Student Symposium
C4- Committee on Concrete Canoe Competition
PM- Project Manager
QA/QC- Quality Assurance and Quality Control
RFP- Request for Proposal
MTDS- Material Technical Data Sheet
POA- Percent Open Area

SDS- Safety Data Sheet
SFD- Shear Force Diagram

Acknowledgements

We would like to begin by expressing our sincere gratitude to Robin Tuchscherer, Taylor Layland, and Adam Bringhurst for their guidance and for sharing their prior experience to greatly contribute to the success of the NAU Pluto Jacks Team. Their mentorship and continued support have played a critical role in enabling the 2026 Concrete Canoe team to work safely, efficiently, and successfully throughout the design and development process. We also extend our sincere appreciation to our sponsors, including Oxendale Auto Group and Civil Solutions and Management, for the resources and support they provided, which were essential to the advancement of this project. Additionally, we would like to thank Eileen Armendariz for offering valuable feedback and guidance drawn from her experience in the Concrete Canoe Competition. The collective support from our advisors, sponsors, and mentors has been invaluable, and we are grateful for their continued commitment to our team and its success.

Project Introduction

The purpose of this project is to design, construct, and race a canoe made of concrete. The Department of Civil Engineering, Construction Management, and Environmental Engineering (CECMEE) and the Northern Arizona University (NAU) American Society of Civil Engineers (ASCE) Student Chapter has provided students the opportunity to compete at the Intermountain Southwest Student Symposium (ISWS) 2026 hosted by University of Utah in Salt Lake City, Utah. The competition expects competitors to fully design and analyze, construct, and race a concrete canoe in accordance with the Request For Proposal (RFP) provided on September 2nd, 2025. Per the RFP, the goal of this project is to highlight the versatility and durability of concrete as a construction material while showcasing civil engineering as a vital and innovative profession to the industry and public.

In order to provide civil engineering students with hands on experience and leadership skills and project management as an objective of this competition, the Pluto Jacks have created a schedule and budget, procuring sponsorships and donations. In addition, material testing in accordance with appropriate ASTM standards were conducted unless testing apparatus were unavailable.

The NAU Pluto Jacks Concrete Canoe was designed and constructed at NAU utilizing the CECMEE field station, Lab 116, and Lab 117 for material testing, formwork, and construction. This was accomplished using cement, supplementary cementitious materials (SCM's), admixtures, and lightweight aggregates to comprise a lightweight mix under 80 pounds per cubic foot (pcf) capable of withstanding the forces associated with racing. .

There were several design constraints that influenced the design of our hull geometry, display, and concrete mix. This includes all materials being used within the mix complying with ASTM's outlined below.

Table 0-1: Material Constraints

Cementitious Materials	
Hydraulic Cement	ASTM: C150, C595, C1157, C845
Coal Ash	ASTM: C618 (Class C or F)
Metakaolin, Calcined Clay, Ground Pumice, Pumicite, or Volcanic Ash Natural Pozzolan	ASTM: C618 (Class N)
Slag Cement	ASTM: C989
Silica Fume	ASTM: C1240
Hydrated Lime	ASTM C:207
Ground-Glass Pozzolan	ASTM: C1866
Blended supplementary cementitious material	ASTM: 1697
Alternative Cementitious Materials	AST: C1709

Fibers	
Fibers	ASTM: C1116
Admixtures	
Water Reducing	ASTM: C494
Air Entraining	ASTM: C260
Coloring	ASTM: C979
Specialty Admixtures	ASTM: 494 (Type S)
Latex Emulsions	ASTM: C1438

The only constraint limiting the geometrical design of the canoe is a required freeboard of 6 inches under a 4-person loading. Traveling also limits the width of our canoe to fit within ASCE's trailer. It was determined that at a maximum, for construction of mold as a means of transport that the width could not exceed 4ft in order to allow room for other competition teams utilizing the trailer. The trailer being used to transport the canoe is also 23.5ft long, providing a maximum length for our design. The stand for displaying the canoe must be able to be hold the canoe approximately 4ft in the air. In addition, the canoe must be able to rise to the surface after being fully submerged in water.

1.0 Project Preparation

1.1 Project Research

Project research consisted of examining past concrete canoe designs/trends, technical documents related to mix design and structural analysis, and the ASCE RFP. Project research was broken into 2 categories, materials research, referring to mix design material selection, proportioning, and acquisition, and hull design referring to means and methods for completing the assigned structural analysis and selection of hull design geometries. The bulk of the project research task was contained within materials research by referencing past NAU teams and previous concrete canoe competition winners' mix design. This was supplemented by further literature review focusing on high-strength, lightweight mix design. Project research into the hull design relied on technical guidelines such as PCI Industry Handbook and ACI 316 as well as examples provided by the Committee on Concrete Canoe Competitions (C4). To ensure compliance with the RFP, aFor construction methods, the team referenced prior NAU design reports and published concrete canoe construction documentation to help us make decisions for the mold type, concrete placement sequencing, layering [1] [2] [3]. These sources provided practical knowledge for mold fabrication and construction, which helped to determine the best concrete placement sequencing and batching concrete. In addition, a QA/QC coordinator whose main purpose was to ensure that all methods and materials proposed within the project research phase were in compliance was also designated. Periodic check-ins with the QA/QC coordinator ensured that our technical team didn't waste project hours on items unable to be presented within the competition.

1.2 Sponsorships/Donations

To secure sponsors for the NAU Concrete Canoe team, we first identified connections through work experience, internships, and prior sponsorship relationships. These contacts were carefully researched to ensure alignment with the team's goals and the nature of the competition. We reached out to each potential sponsor through professional emails and follow-up communication. To make our outreach more engaging, we created personalized videos tailored to each sponsor. These videos explained the concrete canoe project, the competition, and how their support would make a direct impact. We also highlighted the benefits sponsors would receive, such as visibility and student engagement. This personalized and professional approach helped us successfully build strong relationships and gain sponsor support. The two main sponsors that we were able to get through this approach were Mike Oxendale from the Oxendale Auto Group and ASCE. Material donations include three pails of admixtures from Master Builder Solutions and a thirty-six-count box of concrete testing cylinders from Fenagh Engineering and Testing.

1.3 Lab Safety & Cleanup

A health and safety plan for this project was created based on planned work and materials used throughout construction. First, various safety trainings were had to gain lab access. This includes trainings for chemical hygiene, hazard communication, hand and power tool safety, and hearing conservation. From there, a lab safety binder was then creating, relaying the scope of work, expected materials, and plans for handling disposal of said material to the lab manager, Dr. Adam Bringhurst. This binder also contained the Safety Data Sheet (SDS) for each material and emergency contacts for Environmental

Health and Safety (EH&S) for quick access in case of emergency. A usage agreement prepared by the Dr. Bringhurst was also jointly reviewed and signed to ensure a mutual understanding of proper lab usage.

2.0 Mix Design

2.1 Material Research

The mix design material research started with the team looking through prior teams' concrete mixes and reports to determine what went right and wrong with their project as well as identify materials that have worked well in the past. Once promising materials were identified, the team went to NAU's field lab to take an inventory of materials that were left-over from prior teams. If these materials were properly labeled, could be identified, and were suitable to use, samples were taken of the materials, and testing was done to determine the material properties (absorption, specific gravity, and gradation). This was done only for the aggregates in consideration for use. Any information that could be found out about these materials from prior team reports and online resources was found and confirmed through testing. Technical material information on all materials used with the required ASTM highlighted can be found in Appendix A: MTDS Notebook/Mix Design

<u>Cementitious Materials</u>

A combination of Portland Cement (Type I/II), Nippon Slag Cement, Hydrated Lime (Type S) and Fly Ash (Class F) was used as the cementitious materials in each mix to increase the workability, durability, and long-term strength as well as reduce the environmental impacts of portland cement. The specific gravity of these materials was found and used in mix design calculations. All cementitious material MTDS's were reviewed by the teams QA/QC coordinator to ensure all materials meet ASTM standards required by ASCE. Cementitious material MTDS's with the ASTM requirement highlighted can be found in Appendix A: MTDS Notebook/Mix Design. Below is a summary table of the cementitious materials considered and the specific gravity of each material.

Table 2-1: Cementitious Material Properties

Cementitious Material	Specific Gravity
Portland Cement (Type I/II)	3.15
Nippon Slag Cement	3.00
Hydrated Lime (Type S)	2.32
Fly Ash (Class F)	2.32

Aggregates

Below is a summary table of the aggregates that were tested and the values that were found from testing.

Table 2-2: Properties of Considered Aggregates

Aggregate	Specific Gravity	Absorption (% of weight)	Particle Size (mm)
Horticulture Perlite	.125	665%	0.10 – 1.00 mm
Poraver	.296	224%	0.25 – 2.00 mm
K1 Bubbles	.125	0%	< 0.075mm
Volcanic Pumice	1.64	11%	0.20 - 2.00 mm
Utelite Expanded Shale	1.40	60%	0.20 – 2.00 mm
Lightweight Aggregate	1.66	30%	1.00 – 2.00 mm
Aero Aggregate	1.65	88%	0.05 – 2.00 mm
Recycled Aggregate	1.47	9%	0.05 – 2.00 mm

Particle Size Distributions were determined in accordance with *ASTM C136*. This information was then used to inform the Specific Gravity testing. ASTM C127 and ASTM C128 were followed to determine the specific gravity of our coarse and fine materials.

Chemical Admixtures

To decrease density and increase air content, an air entrainer (MasterAir AE 200) was used in each mix. Air entrainer introduces tiny stable air bubbles into the concrete as it cures which results in a less dense concrete. To keep workability high (high slump), a superplasticizer (Master Glenium 7500) was used. Superplasticizer reduces the amount of water that is needed to hydrate cementitious materials. The low w/cm ratio range we used in each of the mixes (between 0.30 and 0.36) results in a stiffer concrete and while a low slump would be preferred for placement of our concrete a slump of 2 inches was difficult to handle when testing and would result in a labor-intensive placement process. A retarder (MasterSet Delvo) was considered in precursor trial mixes but ultimately not used as it resulted in a self-consolidating concrete not suitable for placement.

Table 2-3: Admixture Summary

Admixture	Type of Admixture	Purpose
MasterAir AE 200	Air Entrainer	Retains air and decreases density.
Master Glenium 7500	Superplasticizer	Reduces the amount of water needed to hydrate cement.
Master Set Delvo	Retarder	Slows down hydration process and keeps concrete at batch slump for longer.

Reinforcement

The reinforcement used in the composite mix design was Simpson Strong Tie Carbon Grid. For the primary reinforcement a material that is light, durable, and high in tensile strength that also met the RFP percent open area requirement of at least 40% was required. Simpson Strong Tie Carbon Grid met these requirements and was readily available. Calculations for hull reinforcement thickness and POA were conducted to ensure the chosen reinforcement provides sufficient open space for proper concrete flow. The equations used for this calculation are described below, and calculations can be found in Appendix B: Reinforcement Thickness and POA Excel Calculations.

Table 2-4: Secondary Reinforcement Properties

Reinforcement	Tensile Strength (ksi)	Hull Thickness to Reinforcement Ratio (%)	Percent Open Area (%)
Simpson Strong Tie Carbon Grid	130	34.00	92.60

Concrete Sealer

Rainguard WS concrete sealer is applied to concrete after it cures to make it impermeable, reduce staining, and reduce cracking. As per ASCE, the sealer does not need to meet a certain standard, but it must be a “silane or siloxane-based penetrating sealer with a VOC of less than or equal to 350 g/L” [1]. Rainguard WS complies with a VOC of 0 g/L, as can be seen in Appendix A: MTDS Notebook/Mix Design.

Flotation

Owens Corning Foamular NGX250 foam was used as flotation in the bulkheads of the canoe. It is a light durable foam that is easily cut so it can be formed to the dimensions of our hull design. The foam floatation used was not required to meet a certain standard by ASCE, but it is specifically buoyant and water-resistant foam as identified in its MTDS which can be found in Appendix A: MTDS Notebook/Mix Design.

2.2 Material Testing

The tests done on the aggregates and composite mixes are shown below.

Table 2-5: Test Done and Purpose of Test

Material/ Concrete Test	ASTM	Purpose
Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens	ASTM C39 [2]	Compressive Strength
Standard Test Method for Slump of Hydraulic-Cement Concrete	ASTM C143 [3]	Workability
Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete	ASTM C138 [4]	Density/Air Content
Standard Test Methods for Sieve Analysis of Fine and Coarse Aggregates	ASTM C136 [5]	Gradation
Standard Test Methods for Splitting Tensile Strength of Cylindrical Concrete Specimens	ASTM C496 [6]	Tensile Strength
Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing	ASTM C685 [7]	Batching of Concrete

<u>Sieve Analysis</u>

A sieve analysis was performed to determine the gradation of the aggregates both considered to be used in mixes and a composite gradation of the aggregates used in trial mixes. ASTM C136 was followed to determine the gradation. The sieve analysis results were used to determine the different aggregates that needed to be used in a mix to have an evenly distributed particle size. An example excel spreadsheet used for gradation calculations can be found in Appendix D: Sieve Analysis Example Excel Calculation, while the resulting particle size distribution tables and graphs for all individual aggregates and composite aggregates for all 3 mix designs can be found in Appendix C: Gradation of All Aggregates. A summary gradation graph with the particle size distribution of each aggregate can be found below as well as a picture of the sieves used during testing.

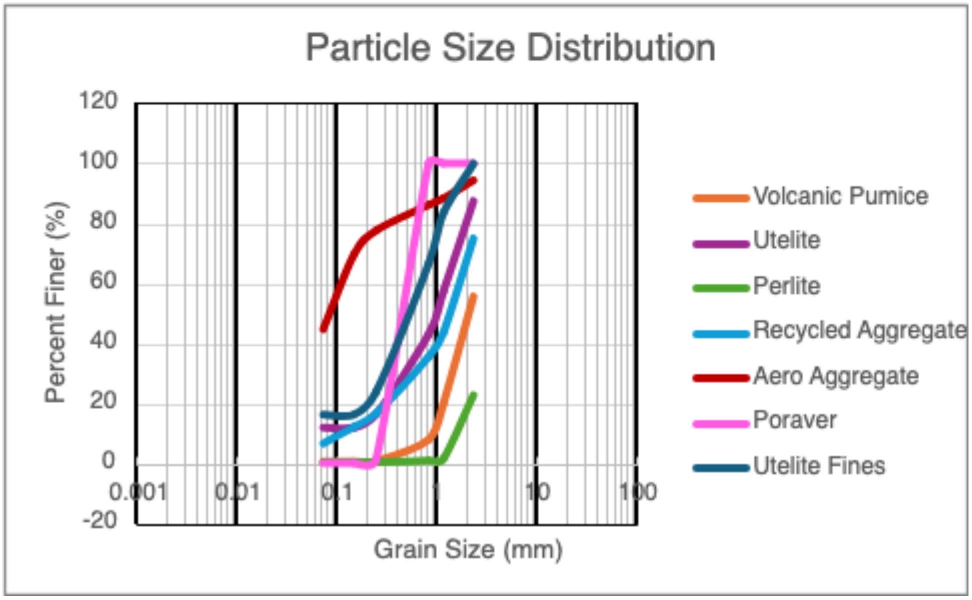

Figure 2-1: Particle Size Distribution of All Aggregates

Figure 2-2: Sieve Stack

Concrete Batching

ASTM C685 was followed to batch the mix designs created. Each component of the mix was proportioned out by mass in buckets. To get the correct material proportions to produce one cubic foot of concrete each material weight in our mix design sheets was divided by 27 because the material values in our sheets result in one cubic yard of concrete. The materials were added to the concrete mixer in the order of cementitious materials, aggregates, water, and admixtures, then fibers. Aggregates were pre-soaked one day prior to batching to ensure the proper w/cm ratio and reduce inaccuracies in the absorption and batch water calculations. The concrete batched for the trail mixes was used to complete the slump, unit weight, tensile, and compressive strength tests outlined below. Batching of both the trail mixes and final mix design that was used in the placement of the canoe was conducted at the NAU Field Station. Below is a table showing the final mix design proportions used for one cubic foot and a picture of the batching process.

Table 2-6: Final Mix Design Proportions

Final Mix Proportions (per 1 ft^3)	
Fly ash (lbs)	19.78
Slag (lbs)	17.93
Portland Cement (lbs)	21.54
Fibers (lbs)	0.37
Lime (lbs)	2.47
Perlite (lbs)	1.85
Poraver (lbs)	11.03
K1 (lbs)	3.70
Air Entrainer (lbs)	0.03
Water (lbs)	23.05

Figure 2-3: Concrete Batching

Slump Testing

One slump test was completed for each mix design. ASTM C143 was followed to test the slump of the batched mixes. This test measures the stiffness or fluidity of concrete and was important to know for the placement process of the canoe. If the slump is too high, it is impossible to place it into a mold and cannot be used. A value of lower than 4 inches was desired for our slump. A summary of the results from our three trail mixes can be found below as well as a picture of concrete after it has been removed from the slump cone.

Table 2-7: Slump Test Results

Mix Design	Slump (in.)
Mix Design 1	10
Mix Design 2	2
Mix Design 3	6
Mix Design 4	2

Figure 2-4: Slump Testing

Unit Weight

One unit weight test was completed for each mix. The unit weight of our concrete was determined by measuring the weight of concrete poured into a container with a known value and dividing the mass of the concrete minus the weight of the container by the volume of that container. The unit weight values of our concrete are critical to determine whether the concrete will float and to have a lighter, easier to handle canoe. The unit weight limit for the canoe was 80.0 pcf with a desired value of less than 62.4 pcf (unit weight of water). The air content value was used to help adjust our trial mixes. If the air content is high, the strength of the concrete can be increased by removing air entraining admixtures and if the air content is low, the density of the concrete can be lowered by increasing air entraining admixtures. A value of less than 6.00% was desired for air content to ensure proper strength of the concrete. A summary of the unit weight and air content results can be found below as well as a picture of the air content and unit weight tests.

Table 2-8: Unit Weight Test Results

Mix Design	Unit Weight/Density (pcf)	Air Content
Mix Design 1	78.4	4.50%
Mix Design 2	83.6	2.00%
Mix Design 3	58.6	5.00%
Mix Design 4	67.2	2.75%

Figure 2-5: Volumetric Air Content Test

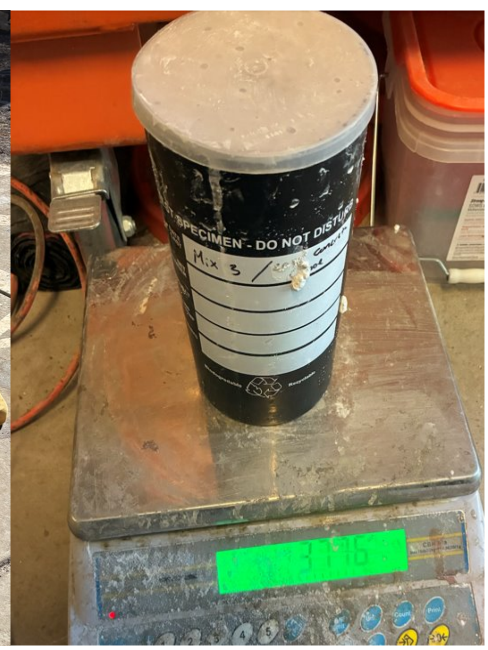

Figure 2-6: Unit Weight of Concrete Test

Compressive Strength Testing

ASTM C39 was followed to obtain the compressive strength data for trial mixes. This test involves the compression of concrete cylinders using a compression apparatus. Cylinders were tested at 7, 14, and 28 days to observe the strength progression of our concrete with 7-day breaks used as an indicator of if our concrete would meet the required strength of our hull design. If cylinders met or exceeded 1000 psi at 7-days, it was an early indicator that the mix was viable in terms of compressive strength to move forward with. The required compressive strength determined by our hull design is 1500 psi without a factor of safety and 1800 psi with a factor of safety. If cylinders met or exceeded 1500 psi at any point during testing, they passed and could be considered for the final mix design. Pictured below is the Humboldt Compression Device set-up for the compressive strength test completed, and a summary table of the compressive strength test results for each mix.

Table 2-9: Compressive Strength Test Results

Mix Design	**7-Day Results (psi) 2 Tests**	**14-Day Results (psi) 1 Test**	**28-Day Results (psi) 2 Tests**
Mix Design 1	3,115	3,515	3,350
Mix Design 2	2,630	3,207	3,180
Mix Design 3	310	425	520
Mix Design 4	1,610	1,910	2,260

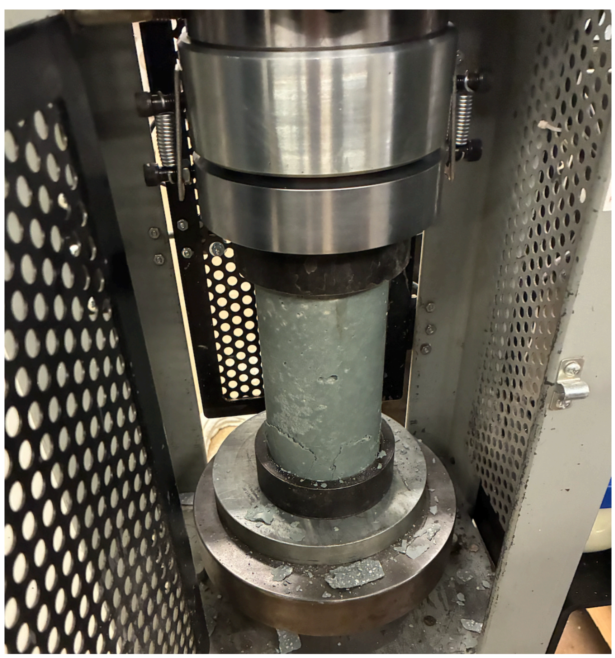

Figure 2-7: Compressive Strength Test Using Humboldt

Tensile Strength Testing

ASTM C496 was followed to determine the tensile strength data for our trial mixes. This test uses a compression machine (Humboldt) equipped with a splitter attachment to break concrete cylinders in compression with the cylinder laying length side of town. The results of this test were used to determine if a mix will meet the tensile strength requirements of the hull design. Tensile tests for Mix Design 4 were estimated using compressive strength values.

Table 2-10: Tensile Strength Test Results

Mix Design	**7-Day Results (psi) 1 Test**	**28-Day Results (psi) 1 Test**
Mix Design 1	385	500
Mix Design 2	338	440
Mix Design 3	55	72
Mix Design 4 (Estimated)	280	360

Figure 2-8: Tensile Strength Test Using Humboldt Splitting Device

2.3 Mix Design Selection

The first step in our mix design selection process was to create three mixes with the same cementitious materials but different aggregate makeup to determine the best aggregate makeup with the materials on hand. The concrete from these three mixes were batched, and cylinders were made from them while density, air content, and workability were measured. Looking mainly at the density and workability of these mixes, the least dense and most workable mix was chosen to move forward with being optimized in our three trial mixes. Calculations and specifications for all three mix designs are provided in Appendix A: MTDS Notebook/Mix Design.

While creating our trial mixes, the team wanted a high strength lightweight mix so that the canoe made would be dense enough that it would float and strong enough to support the load cases discussed in the hull design section. To make sure we had a mix suitable for these parameters, the team went through an iterative process using our three trial mixes. The weaknesses of mix 2 were determined and assessed in mixes 1, 3, and 4. Below is a summary table of the materials used in each mix and their tested properties Table 2-5: Test Done and Purpose of Test contains the ASTM standard used for each test done.

Table 2-11: Mix Design Summary

Mix Design Summary				
	Mix 1	**Mix 2**	**Mix 3**	**Mix 4**
Portland Cement (Type I/II)	290.79 lbs	208.65 lbs	97.21 lbs	290.79 lbs
Hydraulic Lime (Type S)	33.37 lbs	34.00 lbs	9.72 lbs	33.37 lbs
Fly Ash (Type F)	267.02 lbs	325.42 lbs	59.78 lbs	267.02 lbs
Nippon Slag Cement	241.99 lbs	287.13 lbs	149.21 lbs	241.99 lbs
Horticullture Perlite	56.19 lbs	57.43 lbs	88.22 lbs	24.92 lbs
Poraver	148. 90 lbs	146.40 lbs	131.23 lbs	148.90 lbs
K1 Bubbles	18.73 lbs	19.14 lbs	38.89 lbs	50.00 lbs
Master Fiber 150	5.05 lbs	4.79 lbs	4.86 lbs	5.05 lbs
Master Glenium 7500	6.00 (fl oz/cwt)	4.00 (fl oz/cwt)	6.00 (fl oz/cwt)	0.00 (fl oz/cwt)
Master Air AE 200	1.50 (fl oz/cwt)	0.80 (fl oz/cwt)	1.50 (fl oz/cwt)	1.50 (fl oz/cwt)
w/cm	0.33	0.30	0.36	0.33
Compressive Strength (psi) [2]	3116	2630	307	2260
Tensile Strength (psi) [6]	500	440	72	360
Density (pcf) [4]	78.4	83.6	58.6	67.2
Slump (in) [3]	10	2	6	2
Cost	$800	$800	$1200	$1000

Mix 1 was changed from mix 2 by increasing the c/cm ratio from 25% in mix 2 to 36% to get an increase in strength, increasing the amount of superplasticizer used to 6.00 fl oz/cwt to increase the workability of the concrete, and increasing the w/cm ratio from 30% to 33% also to increase the workability of the concrete. Mix 2 was extremely hard to handle because of these properties. The aggregates in mix 1 include perlite, poraver, and k1 bubbles and were kept at around the same proportions as in mix 2. The material properties for mix 1 are found below, and a particle size distribution chart can be found in Appendix C: Gradation of All Aggregates

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Mix 3 was changed from mix 1 by decreasing the c/cm ratio from .36 in mix 2 to .31 to get an increase in workability, increasing the amount of lime to 5% to increase the durability, increasing the w/cm ratio from 33% to 36% also to increase the workability of the concrete, and changing the percentage of aggregates to 48% horticulture perlite, 30% poraver, and 22% K1 bubbles. This change increases the amount of low-density material in the mix, decreases the mix density, and increases the amount of coarse aggregate which helps to have a more distributed gradation in the mix. The material properties for mix 3 are found below, and a particle size distribution chart can be found in Appendix C: Gradation of All Aggregates.

Because of a failure in a category for each mix in our decision matrix mix 4 was created based on Mix 1. The superplasticizer was removed from the mix to decrease the slump, and a majority of the perlite in mix 1 was replaced with K1 bubbles to decrease the density because of the lower specific gravity value, perlite being 0.96, and K1 bubbles being 0.13. The mix 4 design properties can be found in the table below. Because of issues with NAU's Humboldt machine, preliminary tensile test results could not be completed but will be completed on March 29, 2026, and reported.

2.4 Decision Matrix

For the composite mix design selection, a decision matrix was built with scores given to each of the criteria important to the team and crucial for success.

Table 2-12: Mix Design Decision Matrix

Mix Design Decision Matrix							
	Density 30%	**Compressive Strength 20%**	**Tensile Strength 10%**	**Workability 20%**	**Cost 10%**	**Durability 10%**	
Mix 1	78.4 pcf	3,350 psi	500 psi	10 in	$800	3	
Mix 2	83.6 pcf	3,180 psi	440 psi	2 in	$800	3	
Mix 3	58.6 pcf	520 psi	72 psi	6 in	$1,200	2	
Mix 4	67.2 pcf	2260 psi	360 psi	2 in	$1,000	3	
Weighted Scores							**Total Weighted Score**
Mix 1	19.9	20.0	10.0	0.0	10.0	10.0	69.9
Mix 2	0.0	19.0	8.8	20.0	10.0	10.0	67.8
Mix 3	30.0	0.00	0.00	10.00	6.7	6.7	53.4
Mix 4	25.6	13.5	7.2	20.0	8.0	10.0	84.3

*Red highlight is a value that does not meet the limits specified in the rules and results in a 0.0 Score
*Green Highlight is the chosen or winning mix design

Density was weighted at 30% of the total score; it was given the highest weighting because if the canoe does not float than the project is a failure, and density directly correlates to the canoe floating. Compressive strength was weighted at 30% of the total score; it was given this weighting because if the canoe punctures due to the loads it endures the project is a failure. Tensile strength was weighted at 10% of the total score; it was given this weighting because it is much more likely that the canoe fails due to punching shear which is a function of compressive strength rather than in tension, and the tensile demand of the canoe is not very high. Workability was given a 20% weighting of the total score; it was given this weighting because if we cannot properly place the concrete into our mold there is no way for our canoe to be built which would result in a project failure, the value that was used to measure workability was slump with a two-to-six-inch desired range. Cost was given a 10% weighting of the total score; it was given this weighting because the materials in our mixes are largely the same with only proportions being different, and cost difference between the three mixes is minimal. Durability was given a 10% weighting of the total score; it was given this weighting because a canoe with low durability is still raceable, and a low durability value would not result in a project failure. The durability of each mix was determined by the number of cracks or air bubbles in cylinders after setting as well as the type of break a cylinder endures during compressive testing. A scale of 1-3 was used for durability with 1 being a failure, 2 being suitable, and 3 being a pass. The final mix design was chosen based on the highest score.

3.0 Hull Design

3.1 Design Criteria and Decision Matrix

When determining the design of the canoe, consideration into strategy for race preparedness was considered to determine the weighting of our design criteria. This design criteria were used to determine the geometry of the canoe's hull for race optimization. The following design criteria were considered: Stability, Straight Line Speed, Maneuverability, and constructability were considered.

Recognizing a difficulty in obtaining dedicated rowers and mentees from efforts in the fall, stability was weighed heavily at 40%. This in conjunction with straight line speed were identified by the team as the most necessary criterion based on the anticipated 3 Sprint Races compared to the 2 Slalom Races at Symposium. This resulted in a weight of 25% Straight Line Speed and 20% Maneuverability. Construability, based on cross section shape, and rocker was also considered at 15%. See Table 3-1 for the design geometries considered. "L", in ft, represents length of the span, measured from bow to stern, "w", in inches, represents the center cross section's inner width, and "d", in inches represents the center cross sections height, from centerline to bottom. Since these equations result in a unitless value, Length, measured in ft, compared to h an width of the cross section, in inches, were evaluated on the same scale as their values were within similar magnitudes, and felt as though having a value of 216 for length compared to cross section information would have introduced a skewing into results. All calculations can be found in

Appendix E: Decision Matrix Design Criteria Calculations.

Table 3-1: Decision Matrix

Design	**Stability**		**Straight Line Speed**		**Maneuverability**		**Constructability**		**Score**	
	Raw	Weighted	Raw	Weighted	Raw	Weighted	Raw	Weighted	Raw	Weighted
(L, w, h, Cross Section, Rocker)	---	(40%)	---	(25%)	---	(20%)	---	(15%)	---	---
Design 1: 18,30,18, Notched, Rocker	1.25	.50	.80	.20	1.11	.22	.5	.08	3.66	1.00
Design 2: 18, 30,18, Arch, No Rocker	1.25	.50	.68	.17	.89	.17	2.25	.34	5.07	1.18
Design 3: 16,30,16, Arch, Rocker	1.66	.67	.68	.17	1.25	.25	.5	.08	4.09	1.17

The calculations for determining Stability, Straight Line Speed, Maneuverability, can be found within Appendix E: Decision Matrix Design Criteria Calculations. Stability was likened to a ratio of w/d, straight line speed–considering length, depth, and width, and maneuverability–inversely length and rocker. Length and Rocker were standardized with the longer canoes being a ratio of their length to the shortest, and Rocker having a default value of .8 and No Rocker having a value of 1 used in the equations used to calculate. Due to an anticipated difficulty in acquiring skilled based on previous outreach a larger disparity was placed among constructability, considering placement of concrete on a precise curve, and measuring accuracy of placement during construction.

3.2 Structural Analysis

Under C4 constraint, the canoe was determined to be analyzed for a 4-person load. For analysis, the canoe was simplified into a beam assuming that weight force of the canoe was a triangularly distributed load acting in tandem with the 4-person load and peaking at the center cross section, and buoyancy force was the same, acting in the opposing direction. With no identified horizontal loads along the span, the beam was statically determinate. The point loads were also identified as being evenly distributed across the span of the canoe. See Figure 3-1 for visual representation of assumptions made.

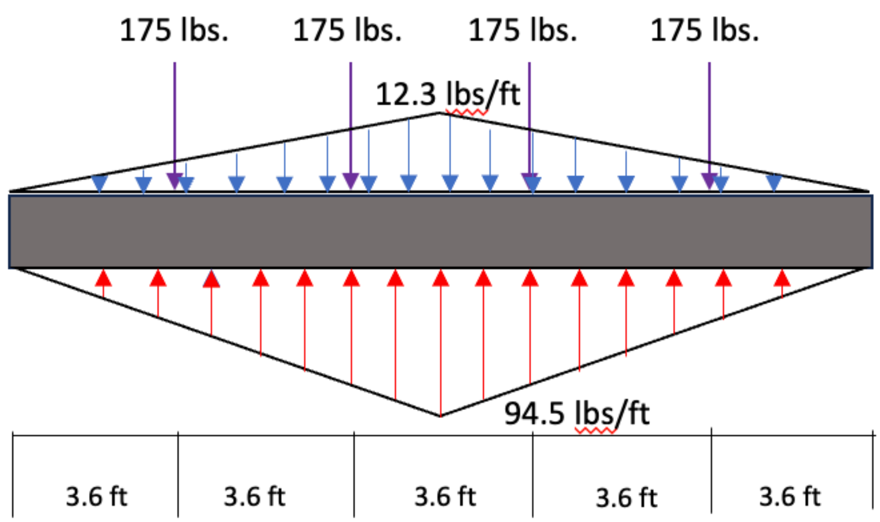

Figure 3-1: Load Force Diagram

Based on the use of the canoe, undergoing the most extreme stresses from just competition and transportation, it was determined that the canoe would be designed to undergo service stresses.

For analysis, the 4-person point load were distributed evenly across the beam. The magnitude of this load was based on the average male and female weight reported by CDC 200lb and 170lb respectively [4].

The Load Force Diagram above was used to calculate the Shear along the span of the canoe as seen below

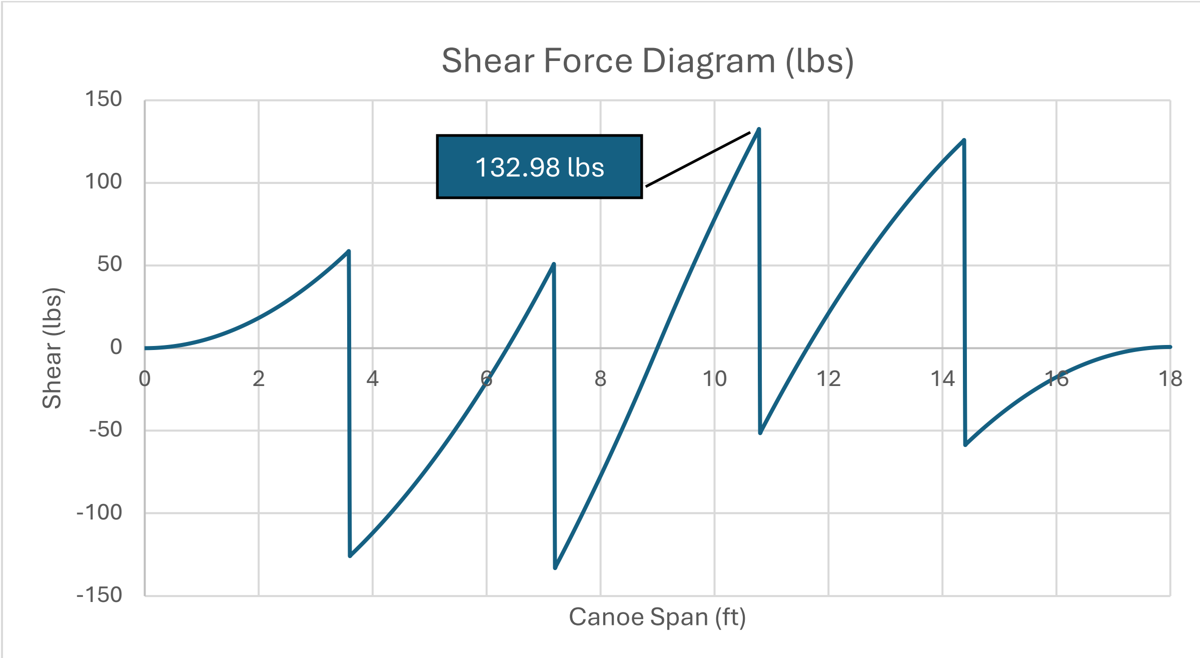

Figure 3-2: Shear Force Diagram

The Shear Force Diagram was integrated to calculate the Bending Moment Diagram seen below.

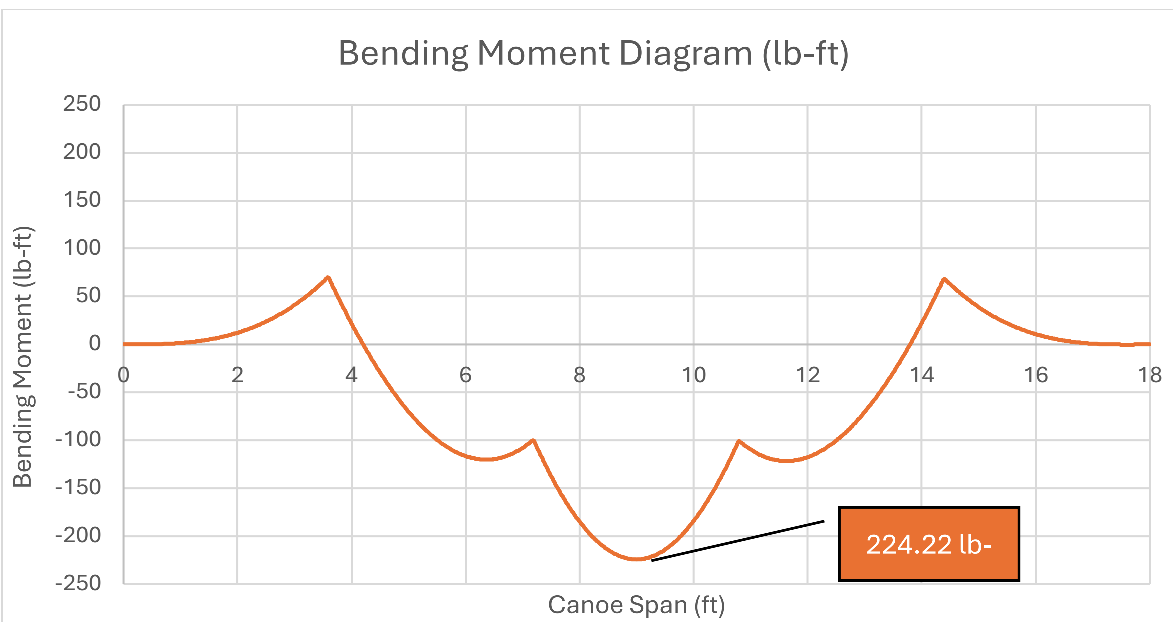

Figure 3-3: Bending Moment Diagram

Based on the Decision Matrix Criterion, a canoe with radial width of 15in and depth of 18 in was pursued for analysis. A cross-section width of .5in was determined based on previous NAU designs. See Appendix F for calculations.

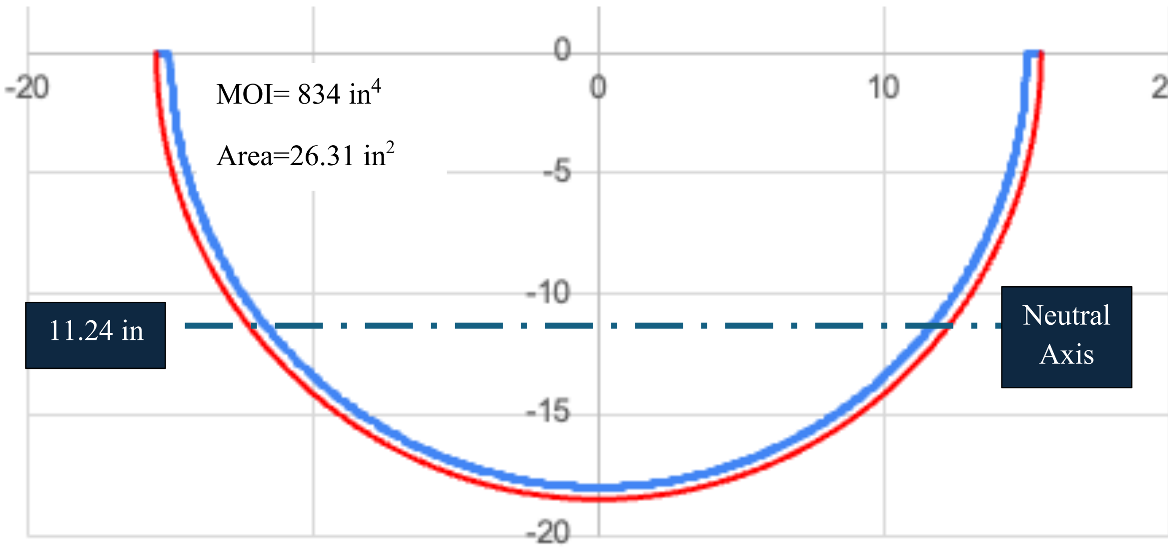

Figure 3-4:Center Cross Section

In order to calculate the max bending stresses on the canoe and their location, the parallel axis theorem was used. This calculated the centroid of the area above the neutral axis, the compression zone where a resultant compression bending stress could be calculated, and the centroid of the area below the neutral axis, the tension zone where a resultant tensile stress could be calculated using Equation 14: Flexural Stress Formula found within Appendix E: Decision Matrix Design Criteria Calculations. Punching shear, which is a materials tendency to 'punch through' a plane due to forces following a plane parallel the applied force was calculated in accordance with ACI 318, considering the material properties of the final mix design concrete.

A summary of the calculated demand stresses, with an applied Factor of Safety of 3 compared to the tested capacity of the concrete can be found below. Punching shear was calculated based on the maximum shear loading demand on the canoe taken over its effective area.

Table 3-2: Stress Demand to Capacity Comparison

	Simplified Canoe Demand Stress (psi) (F.S=3)	**Simplified Canoe Capacity (psi)**
Compressive	53.88	1900
Tensile	34.62	500+
Shear	132.39	68.61

Buoyancy, the upward force acting on the canoe was calculated based on the cross-sectional area of the canoe. The downward weight force of the canoe, alongside the 4-person load was supported by the area of the canoe underwater. The height of the area not underwater was the freeboard: 7.72in.

3.3 Finite Element Analysis

A comparison of the 2D analysis conducted by hand was done with Finite Element Analysis. These stresses were and cross-sectional information were then compared to each other. From the 2D analysis, the center cross section was determined to be the critical cross section for bending, but 3.6 ft from the center in either direction was considered the critical cross section for Shear loading. This is represented within the model.

In order to conduct a Finite Element Analysis (FEA) a 3D rendition of the hull was constructed being constructed within Solid Works before conducting a survey. This can be seen in Figure 3-5 below.

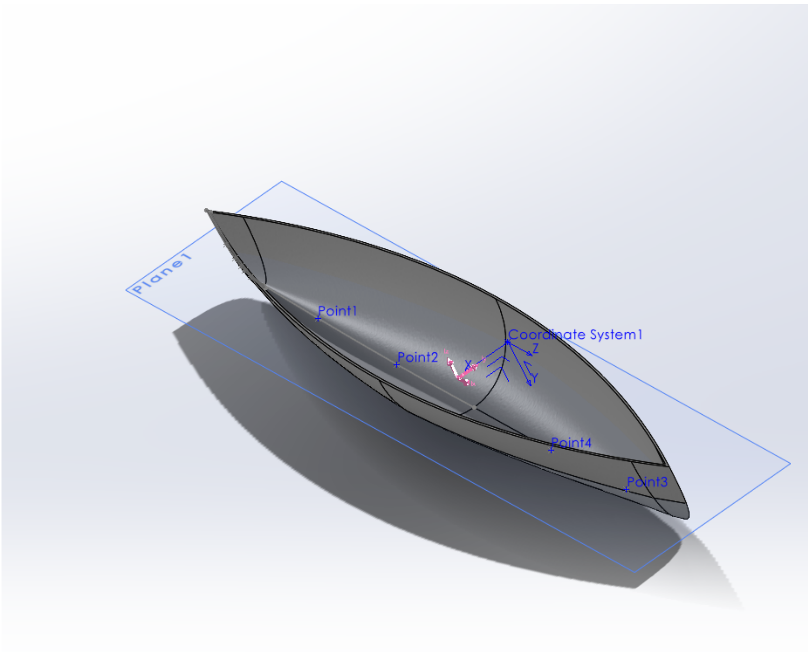

Figure 3-5: 3D Canoe Model

This model was constructed under the following material assumptions:

Table 3-3: FEA Material Assumptions

Density (lb/in^3)	.041
Modulus of Elasticity ksi	842,437.71
Poisson's Ratio	.11
Shear Modulus	379 ksi

A pressure load was applied to the canoe alongside a gravity load. The four-person point loads were not considered as a single instance created immense stress due to their miniscule surface area. The study resulted in the following von Mises stress on the surface of the canoe.

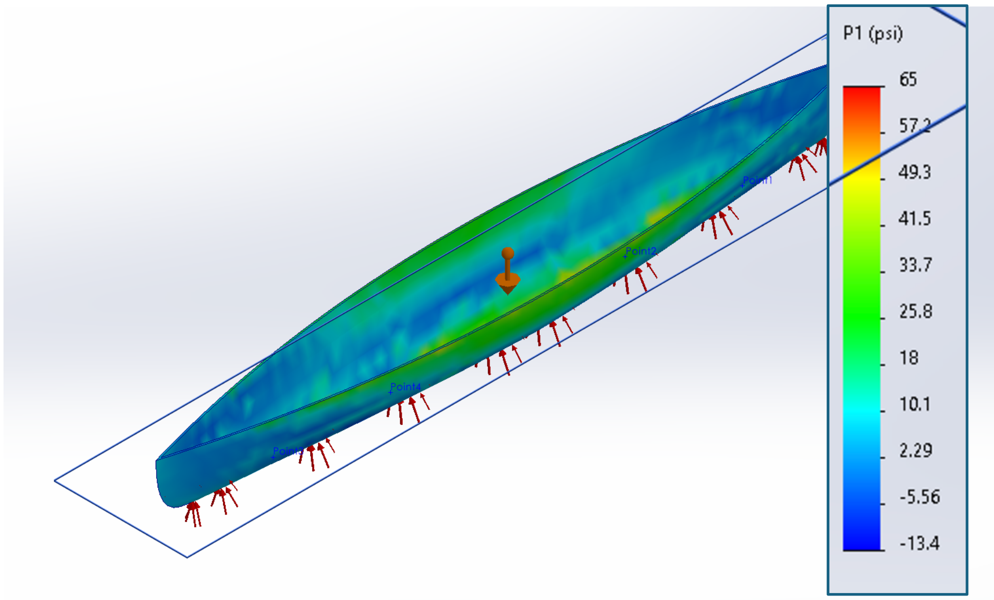

Figure 3-6: Orthogonal FEA Study

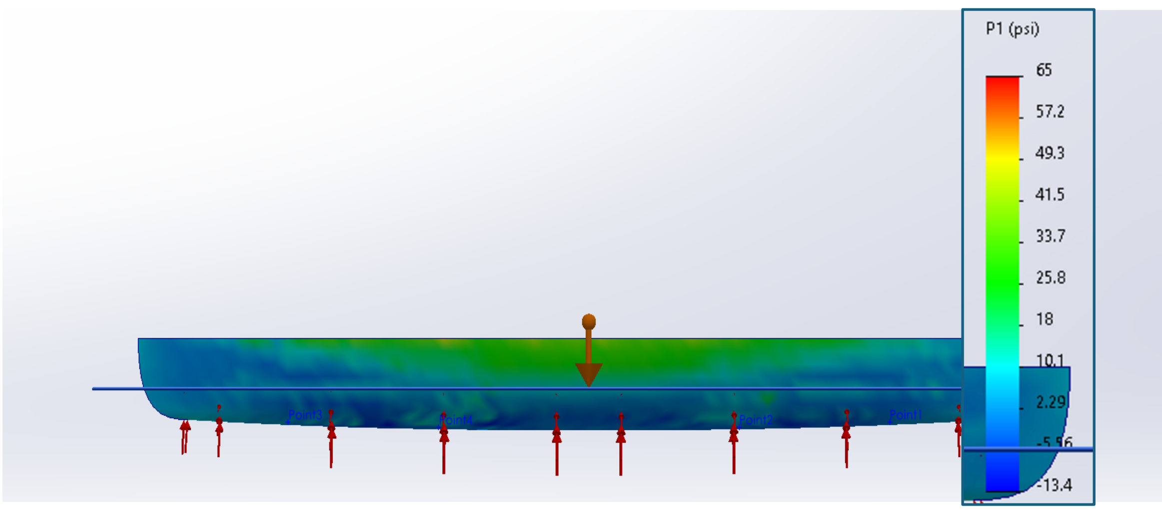

Figure 3-7: Profile FEA Study

A comparison of the FEA demand results to the hand calculation demand and capacity can be found below.

Table 3-4: FEA to Hand Calc Max Stress Comparison

	FEA Demand	**Hand Calc Demand**	**Capacity**
Tension (psi)	65	54	1900
Compression (psi)	13	35	280

4.0 Construction/Fabrication

4.1 Mold

A female mold was chosen so we could place the entire canoe in one day. If a male mold was chosen, foam flotation would have had to been added to the bulkheads on a separate day after the outside of the canoe had cured. The female mold also ensured that the concrete would slump toward the bottom of the canoe rather than the gunwales. The canoe mold construction proceeded as follows. The first step was to cut the 4ft x 8ft foam insulation boards into fourths using a hot knife tool to produce 4ft x 2ft sections of 1.5 in. thickness. After boards were cut, cross sections were drawn using construction drawing specifications. Construction Drawings can be found in Appendix G: Construction Drawings. To keep track of construction, cross-sections were labeled with an alpha-numeric system. For example, the four boards immediately to the left and right of the center of the mold were labeled A1-A4 and the next four from center labeled B1-B4 and so on. Next, the major cross section changes (A1, B1, C1…) were cut and fit into the mold. After that, each major cross section was fit with the other panels of the same letter labeling, traced, and cut using a hot knife. Below are images of the cross-section drawing and cutting process.

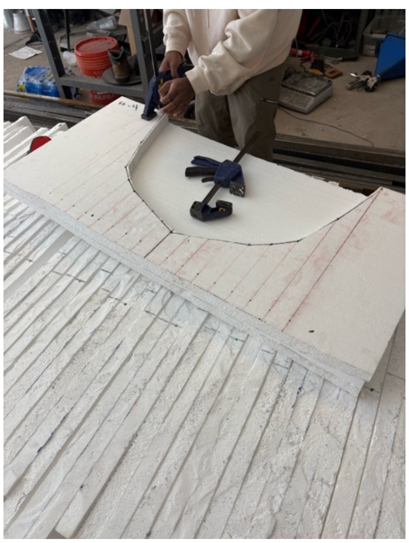

Figure 4-1: Cross Section Cutting

Figure 4-2: Cross Section Alignment

Figure 4-3: Canoe Mold

Once all the cross sections were cut, they were fit together in order and glued together. A wooden frame was also constructed using scrap lumber from the CECMEE Field Station to further compress the length of the canoe and ensure the mold would not separate during concrete placement and curing. Finally, the inside of the canoe mold was sanded to be smooth with a handheld electric surface conditioning tool, and black flex seal was applied with paintbrushes to prevent the concrete curing to the porous foam surface. This sanding and sealing of the mold also ensured a smoother finish to the canoe, which lessened the concrete sanding process later during finishing. After the flex seal cured for 48 hours, a thin layer of

Vaseline was applied to the inside of the mold to make the demolding process easier. Included below is the final canoe mold.

Figure 4-4: Final Canoe Mold

4.2 Stand

The stand was taken from prior canoe teams and painted black with white speckles to match the PLUTO Jacks space theme for this year. It is made from wood and features two separate wood frames with small 2x4 wood platforms above the ground around 4 feet for the canoe to sit on. Cushioning was nailed down onto the platforms to prevent damage to the bottom of the canoe. A picture of the completed stand can be found below.

Figure 4-5: Final Canoe Stand being Transported

4.3 Canoe

4.3.1 Concrete Batching

Once the concrete mix was finalized, the team gathered the materials needed for the batch. One key detail that we noticed during mix design testing was that the weighing of materials was taking a decent amount of time. So before pour day the team pre-weighed the materials so that on pour day, we had a quick and efficient mixing process. A total of five cubic feet was needed for the canoe based on our hull design calculations. The mixing process was broken up into three batches, the first batch was one cubic foot, second was two cubic feet, and third was two cubic feet. This insured that we would have a steady amount of concrete in supply for our placement team to use and helped minimize cold joints by having a consistent placement process. Materials were weighed out in the first two batches of one cubic foot and two cubic feet one day prior to pour day, and the third batch was weighed on pour day. After mixing, the concrete was transferred from the mixer into both a wheelbarrow and plastic buckets and distributed to our placement team.

Figure 4-6: Concrete Mixing Process

4.3.2 Concrete Placement

For the concrete placement, the concrete was applied onto the mold in two layers, with the primary reinforcement placed in between, and each layer being roughly 0.25 in thick for a total thickness of 0.5 in.

Figure 4-9: Reinforcement Placement

Figure 4-7: Final Concrete Placement

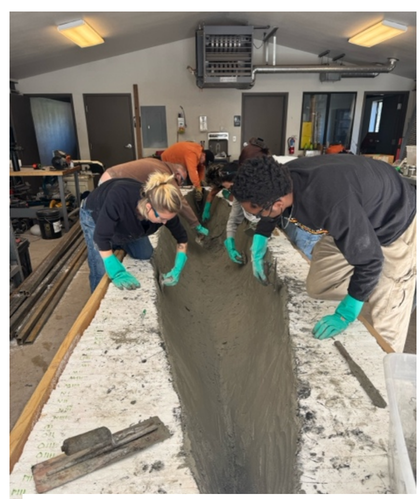

Figure 4-8:Concrete Placement

The thickness throughout the canoe was frequently measured using toothpicks with 0.25 in and 0.5 in markings to ensure consistency during placement. The first layer of concrete was applied to the mold using finishing trowels and upward placement motion to resist the concretes natural slump down toward the canoe centerline. Then, the fiber mesh was trimmed to fit the canoe measurements and was applied to the top of the first concrete layer to provide additional strength and structural integrity. Then, the second layer of concrete was applied on top of the fiber mesh which brought the canoe to its intended thickness of 0.5 in. After the first two layers were placed, pieces of the pink panther foam flotation were set into place in the bulkheads of the canoe and reinforcement was placed over the top of the flotation.

Once flotation and reinforcement were in place, a layer of concrete 0.5 in thick was placed over the top to enclose the bulkheads. The placement process is pictured above. A team of 6 was working to ensure the concrete was placed in a timely manner so the concrete could not set before all layers were applied. Final smoothing and thickness checks were also done to minimize the finishing required.

A curing chamber was created prior to placement to be placed over the canoe while it cures. The curing chamber was made of recycled pvc pipe fit together to the dimensions of the mold, and plastic sheets to fully enclose the canoe. After placement of the concrete, the pvc frame was put over the canoe mold and plastic sheets were placed over the top and taped together to prevent moisture from escaping the chamber. Humidifiers were put inside the greenhouse and refilled every couple of days to prevent moisture from leaving the concrete during curing. This was done so the concrete would meet its full strength. The canoe was pulled from the mold at 28-days. Pictured below is the final canoe curing process used.

Figure 4-10: Concrete Canoe Curing

4.3.3 Concrete Finishing

After the canoe was pulled from the mold, the canoe was sanded with both a diamond edge sander for more substantial bumps and a 120-grit rolling sander for a smooth finish. The entire canoe was sanded, including the edges, to achieve a smooth finish throughout and remove any secondary reinforcement protruding from the canoe. After sanding, a liquid black stain was applied to the canoe. The outside of the canoe was prewet to promote absorption of the stain, and the stain was sprayed on using a pump sprayer. This same process was used for the inside of the canoe with the top of the bulkheads stained yellow and the inside stained purple. After the stain had dried, graphics were painted onto the outside of the canoe all following the Pluto Jacks space theme. This included "NAU PLUTO" painted on the top 6 inches of the canoe per the RFP rules and different space themed objects such as "Alien Louie", "Jacks Rocket", and "Pluto." After all paint and stain was applied to maximize aesthetics, two coats of liquid concrete sealer was applied to the entire outside of the canoe using a pump sprayer.

Figure 4-11: Final Canoe Prototype (left side)

Figure 4-12: Final Canoe Prototype (right side)

5.0 Competition

5.1 Competition Preparation

Competition preparation included gathering samples, preparing an example cross section, and printing an infographic for the display as well as putting together a presentation that showed the technical aspects of our process. Samples included one 4x8 inch cylinder split in two halves for each mix, labeled aggregates placed into clear containers that were used in each mix, composite blend of aggregates used in each mix, reinforcement used in the canoe, life jackets to be used on race day, paddles to be used on race day, and any flotation used on race day. The example cross section was a part of our display and included the mold, first layer of concrete, reinforcement layer, second layer of concrete, and finishing layer clearly labeled to show the construction process. The infographic was also part of our display and included relevant technical information shown through pictures and data essential for someone to understand our design process.

5.2 Transportation

The canoe was transported to the ISWS Student Symposium in Salt Lake City, Utah on April 15, 2026. It was transported in a box trailer towed by a suburban. The mold we built for our canoe was put into the back of the trailer to ensure it was secure and did not break or crack during transit. The canoe was moved onto the stand built using two person straps so the foam mold pieces could be moved from the NAU Farm into the back of the trailer. Then, the canoe was transferred from the stand back into the mold at the back of the trailer. No extra securing was needed during transit. The process of moving the canoe from the mold to the stand then back to the mold was used for all loading and unloading procedures.

Figure 5-1: Canoe Transportation Method

5.3 Presentation/Display

The competition score was broken into 4 sections, report (Technical Execution Package), final canoe prototype, presentation, and race. The display was factored into the final canoe prototype score. The display included the samples, example cross section, and infographic previously prepared by the team as well as the canoe propped up by the stand we built. Grading of the display included scores for finishing, aesthetics, properly showing design process, consistent hull thickness, floatation, etc. Five judges checked our canoe for these requirements and asked us for an elevator pitch of why they should choose our canoe and to explain our design process to them using the display. A 5-minute technical presentation was given to the 5 judges and any attendees to show the design processes we used. Grading for the presentation included preparation, confidence, quality of visuals, content, and professionalism. After the presentation questions were asked to the team by the five judges about aspects of the design process.

Figure 5-2: Pluto Jacks Display

5.4 Buoyancy/Swamp Test

The buoyancy test was done at the Jordanelle Reservoir in Utah. In this test, the team filled our canoe with water using buckets and pushed down on the bulkheads, so the canoe became fully submerged under water. The test states that the canoe must float back to the surface within two minutes of being submerged. The teams' canoe came back to the surface almost immediately after being submerged, so full points were awarded.

Figure 5-3: Buoyancy/Swamp Test

5.5 Race

The race portion of the competition was not completed because it was too cold for a safety officer to approve. The rules state that a combined air/water temperature of 85 degrees Fahrenheit is needed to move forward with racing and because this threshold was not met, races were canceled. However, the Pluto Jack Team was still able to test and paddle the canoe under a four-person loading to assess freeboard at the competition. An image of our canoe prototype under a four-person loading is included below.

Figure 5-4: Four-person Canoe Loading

5.6 Results

Final results detailing scores for different sections of the Technical Execution Package have yet to be posted at the time of submittal, however NAU's Pluto obtained 3rd Place on the display.

6.0 Design Recommendation

6.1 Summary of Deliverables

The NAU Pluto Jacks Team compiled a comprehensive set of deliverables to successfully complete the proposed 2026 ASCE concrete canoe project. First, as preparation for the project a Lab Safety Binder and Material Technical Data Sheet (MTDS) Notebook were completed. The Lab Safety Binder included all possible hazards and emergency procedures associated with concrete canoe construction, as well as all safety data sheets (SDS's) for all materials used, while the MTDS Notebook compiled all MTDS's for all materials used to ensure ASTM and VOC compliance with ASCE rules. A proposal and qualification package was also composed and sent to ASCE to introduce the project.

As far as technical design deliverables and documentation, the NAU Pluto Jacks Team provided results for mix design, hull design, and structural analysis to support the chosen design and fabrication method. For the mix design analysis, Pluto Jacks provided mix design sheets detailing the proportioning and calculations (w/cm ratio, air content, etc.) for all trial and final mixes, results for all material testing organized in a table (compressive and tensile strength, density, slump, etc.), a sieve analysis document with all particle size distribution curves, and a mix design decision matrix to decide on a final mix. For the hull design and structural analysis, deliverables included all calculations and results for hull freeboard, shear and moment 2D analysis, moment of inertia, maximum stresses, and hull punching shear, Finite Element Analysis (FEA) documentation using Solidworks software, detailed construction drawings for each hull cross section, and a hull decision matrix to decide on final hull geometry. All these technical deliverables were compiled into one document entitled "Technical Execution Package," which was sent to ASCE to showcase all technical results.

The final deliverable before the showcase at ISWS was the construction of the concrete canoe prototype, "PLUTO," along with a final presentation and display. Deliverables for the final presentation and display included an infographic showcasing technical project details, a physical cross-section of the canoe and mold to display all stages of construction, samples of all materials, split cylinders for each mix tested, and a comprehensive presentation of the final results. Aside from completing the physical concrete canoe prototype, a photo log was also created to document a visual record of the construction process including mold preparation, concrete batching and placement, and finishing. Alongside the deliverables provided above, the Pluto Jacks team also created documentation for schedule and budget tracking. These additional deliverables included a Gannt Chart to monitor critical path, tables for proposed and actual cost to implement design, and a task hour log to provide a summary of engineering work.

6.2 Cost of Implementing Design

Included below is the cost to implement this design and fabrication method.

Permanent Material Costs					
Material	QTY	Unit	Cost/Unit	Cost	Source
White Portland Cement, Type I/II	92.60	lb	$0.43	$39.82	Lehigh
Slag Cement	28.00	lb	$0.12	$3.36	CalPortland
Fly Ash, Type F	11.11	lb	$1.50	$16.67	InCide
Secondary Reinforcement Fibers	1.00	lb	$30.00	$30.00	Master Builder Solutions
Perlite	17.00	lb	$2.60	$44.20	Viagrow
Poraver	24.30	lb	$2.42	$58.81	Poraver
K1 Bubbles	7.00	lb	$100.00	$700.00	3M
Master Glenium 7500	1.00	gal	$59.00	$59.00	Master Builder Solutions
Master AE 200	1.00	gal	$30.00	$30.00	Master Builder Solutions
Carbon Fiber Mesh	5.00	ft^3	$10.00	$50.00	Simpson Strong-Tie
Water	25.00	gal	$0.03	$0.75	Flagstaff Municipal
Sealer	2.00	gal	$20.00	$40.00	Raingaurd
Floatation Foam	5.00	ft^3	$60.00	$300.00	NGX
			Material Costs (MC)	**$1,372.60**	

Canoe Fabrication Labor Costs				
Role	RLR	DEC	HRS	Extended
SENG	$217.00	1.5	4	$1,302.00
PM	$170.00	1.5	6	$1,530.00
EIT	$133.00	1.5	16	$3,192.00
TECH	$133.00	1.5	12	$2,394.00
QM	$130.00	1.5	25	$4,875.00
		Labor Subtotal	63	$13,293.00
		Profit Multiplier (P)	18%	$2,392.74
			Canoe Fabrication Direct Labor Total (DL)	**$15,685.74**

Canoe Fabrication Expenses		
Description		Cost
Material Costs Per Canoe (MC) - Above		$1,372.60
Mixing Supplies		$250.00
PPE		$100.00
Other Consumables		$100.00
Mold Sanding/Tape		$100.00
Display Materials		$250.00
Expenses Subtotal		$2,172.60
Markup (M)	10%	$217.26
Canoe Fabrication Expenses		**$2,389.86**

Mold Fabrication Labor Costs				
Role	RLR	DEC	HRS	Extended
SENG	$217.00	1.5	7	$2,278.50
PM	$170.00	1.5	20	$5,100.00
EIT	$133.00	1.5	35	$6,982.50
TECH	$133.00	1.5	45	$8,977.50
QM	$130.00	1.5	23	$4,485.00
Labor Subtotal			130	$27,823.50
Profit Multiplier (P)			18%	$5,008.23
Mold Fabrication Direct Labor Total (DL)				**$32,831.73**

Mold Fabrication Expenses		Extended
Materials Cost		
Foam		$1,200.00
Cutting Tools		$120.00
Glue		$35.00
Tape		$20.00
Curing System		$80.00
Wood		$60.00
Hardware/Screws		$50.00
Expenses Subtotal		$1,565.00
Markup (M)	10%	$156.50
Mold Fabrication Expenses (E)		**$1,721.50**

Cost of Implementing Design	
Canoe Fabrication Labor	$15,685
Mold Fabrication Labor	$32,832
Labor Subtotal	**$48,517**
Canoe Fabrication Expenses	$2,389
Mold Fabrication Expenses	$1,721
Expenses Subtotal	**$4,111**
Total Implementation Cost	**$52,628**

7.0 Project Impacts

The alternatives that will be assessed in terms of their impact to people, planet, and price will be the impacts of 1) completing this project on paper and not constructing a final prototype or competing in the ISWS competition compared to 2) constructing the canoe and competing in the ISWS competition. The two alternatives will be referred to as "ISWS" for competing in the competition and "Theory" for not competing in the competition in the following comparison.

ISWS	People (Social)	Planet (Environment)	Price (Economic)
Negative Impacts	-Must transport people/canoe to Salt Lake City -Exposed to material & equipment hazards during construction	$-CO_2$ emissions from cement/concrete production	-Cost of travel -Cost of shipping canoe -Cost of building canoe
Positive Impacts	-Practical construction experience -More effective teamwork development -Confirmation on if design work was correct	-More effective research & development (innovations in sustainable practices)	-Can generate sponsorships & donations - Comparison of proposed and actual cost

Theory	People (Social)	Planet (Environment)	Price (Economic)
Negative Impacts	-No development of relationships with industry professionals -No confirmation of if the design was successful	-Ineffective research & development since results won't be confirmed	-Cannot accept sponsorships & donations
Positive Impacts	-Not exposed to any construction hazards -No travel arrangements need to be made	-No CO_2 emissions from cement	-No construction costs

Triple Bottom Line Scores				
	People	Planet	Price	Sustainability Index
ISWS	85	40	20	80
Theory	15	60	80	90

The sustainability index of going to the ISWS conference was 80 compared to a 90 index not going to the conference. The impact on people going to the conference was far higher since the team gained hands-on construction experience, professional exposure and networking that a paper only project could not provide. Theory scored better on planet and price because it avoided cement emissions, travel miles and roughly $149,000 in implementation cost, but those savings do not replace the educational purpose of the competition. The Pluto Jacks chose ISWS because the small gap in index is outweighed by the experience gained, and the team stands by that decision.

8.0 Summary of Engineering Work

Below is a summary of the proposed hours for the project before work was started.

Task Name	SENG	PM	EIT	TECH	QM	Subtotal
Task 1: Project Preparation	5	15	20	10	5	55
Task 2: Concrete Mix Design	15	25	50	60	35	185
Task 3: Hull Design/Structural Analysis	15	10	45	15	15	100
Task 4: Construction/Fabrication	10	30	50	55	40	185
Task 5: Competition	2	10	15	5	5	37
Task 6: Project Impacts	3	10	10	0	10	33
Task 7: Project Deliverables	15	35	40	15	5	110
Task 8: Project Management	5	20	10	5	5	45
Total Hours	**70**	**155**	**240**	**165**	**120**	**750**

Below is a summary of the actual hours worked by the team after completion of the project.

Task Name	SENG	PM	EIT	TECH	QM	Subtotal
Task 1: Project Preparation	0	22	25	0	47	94
Task 2: Concrete Mix Design	18	4	62	111	14	209
Task 3: Hull Design/Structural Analysis	5	21	92	20	8	146
Task 4: Construction/Fabrication	11	26	57	59	49	202
Task 5: Competition	6	32	10	30.5	26	104.5
Task 6: Project Impacts	1	1	1	1	1	5
Task 7: Project Deliverables	3	45	67	34	43	192
Task 8: Project Management	2	23	5	4	6	40
Total Hours	**45**	**173**	**318**	**258.5**	**193**	**992.5**

Major discrepancies in the proposed hours worked compared to the actual hours worked include hours worked in Task 1: Project Preparation, Task 3: Hull Design/Structural Analysis, Task 5: Competition, and Task 7: Project Deliverables. Major discrepancies in specific role hours worked include EIT, TECH, and QM.

The discrepancies in project preparation can be attributed to the teams' struggle to obtain materials. More hours were spent reaching out to different suppliers of aggregates, cementitious materials, and admixtures because of a lack of prior connections and an inability of certain suppliers to sell direct to consumers.

Increased hours in hull design/structural analysis are because of an underestimation of Finite Element Analysis. Increased hours for the competition task are because travel hours were not added into proposed calculations. Increased hours for project deliverables are because the deliverables for the ISWS conference were not familiar to the team and took longer than expected to complete. The increased hours for the EIT, TECH, and QM positions can be attributed to the amount of labor that the project called for. The construction and concrete mix design tasks took up most of our project and are both labor-intensive tasks. The EIT and TECH positions were given most of these labor hours. To get a more accurate hour count for positions, a Laborer position could be added to our estimate.

The discrepancy in project preparation, which was our first task, led to major delays in our schedules. The delay in material acquisition because of the reasons previously stated as well as delays in acquiring donations/sponsorship for the project impacted the start date of material testing. Before we could start testing trial mixes, we needed the proper materials to batch a mix. To stay on schedule, the team took another inventory of the materials on hand at the NAU farm and created mix designs using those materials. This allowed the team to start the testing process so we would have the proper test results to analyze our mixes before important deadlines such as mix design decision matrix, hull design, mold construction, and canoe construction.

9.0 Summary of Engineering Costs

Below is a table of the proposed cost of the project.

Personnel	Rate, $/Unit	Quantity	Unit	Subtotal
SENG	$217	70	HR	$15,190
PM	$170	155	HR	$26,350
EIT	$133	240	HR	$31,920
TECH	$133	165	HR	$21,945
QM	$130	120	HR	$15,600
Total Personnel				**$ 111,005**
Travel				
Mileage	$0.7/mile	1000	MILE	$700
Van Rental	$62/day	4	DAY	$248
Lodging	$120/night	6	Room-Night	$720
Supplies				
Equipment	$2,000	1	LS	$2,000
Lab Rental	$100/day	56	DAY	$5,600
Materials	$5,000	1	LS	$5,000
Total				**$125,273**

Below is a table of the actual cost of the project.

Personnel	Rate, $/Unit	Quantity	Unit	Subtotal
SENG	$217	45	HR	$9,765
PM	$170	173	HR	$29,410
EIT	$133	318	HR	$42,294
TECH	$133	258.5	HR	$34,381
QM	$130	193	HR	$25,090
Total Personnel				**$140,940**
Travel				
Mileage	$0.7/mile	1400	MILE	$980
Van Rental	$62/day	4	DAY	$248
Lodging	$120/night	3	Room-Night	$720
Supplies				
Equipment	$2,000	1	LS	$1,539
Lab Rental	$100/day	30	DAY	$3,000
Materials	$5,000	1	LS	$2,572
Total				**$149,031**

Major discrepancies in cost positionally include the SENG, EIT, TECH, and QM positions. The difference in the SENG position relates to the difference in the QM position; the increased workload from the quality manager allowed for the quick approval of technical work and minimal technical work having to be done by the SENG. The quality manager would look over work done and send it back to either the EIT or TECH to be reworked or redone. This process in turn adds to the workload of both the EIT and TECH. Overall, the increased workload by the EIT, TECH, and EIT positions as well as the decreased workload of the SENG position was caused by trial-and-error processes used by the team in both the mix and hull design tasks as well as greater than expected labor time during the construction process that was done by both the EIT and TECH.

There were minimal cost differences in the travel category of this project. The supplies cost of this project was overestimated. This overestimation is a result of an inaccurate estimate in the number of days that the lab would be needed. The material testing task was predicted to take the most amount of lab time and ended up needing less lab time than mold construction. The difference is also a result of inaccurate material cost estimations. The team estimated double the cost of the actual material cost. This difference is most likely due to the teams change in strategy once it was apparent that we would not get the sponsorship/donations to get everything we wanted such as a laser cut mold. The team pivoted to finding cheaper ways to construct the mold and canoe to remedy this budget problem.

10.0 Conclusion

The NAU Pluto Jacks designed, built and brought a concrete canoe to the 2026 ISWS competition in Salt Lake City. Mix 4 was selected as the final mix with the unit weight of 67.2 pcf, a 28 days compressive strength of 2,260 psi, an estimated tensile strength of 360 psi and a 2 inch slump, all of which met the RFP density limit of 80 pcf and the compressive strength of 1,800 psi design strength required by hull analysis. The 18-foot arched hull was selected through the decision matrix for its balance of stability, speed and constructability and both the 2D hand calculations and the SolidWorks FEA confirmed a factor of safety of roughly 2 against the punching shear, which governed the hull design. Construction followed with a female mold method allied the full came to be placed in a single day with reinforcement layered between two 0.25-inch concrete lifts. After the canoe was placed, it was cured for 28 days inside the PVC and plastic sheet greenhouse with humidifiers to train moisture and reach full strength. Then we sanded with diamond and 120 girt sanders, stained black on the outside with purple and yellow on the interior and finished with painted Pluto Jacks space themed graphics. For transportation to Salt Lake City, the canoe was placed in the trailer with the full foam mold, and the team checked it at every stop along the route to confirm it had not shifted or cracked in transit.

At ISWS, the canoe passed the buoyancy and swamp test and measured 9 inches of freeboard under a four-person load, well above the 6-inch minimum, though the races were cancelled because the combined air and water temperature fell short of 85°F safety threshold. Outside of the race results, the project delivered on its core purpose of giving the team real construction, project management and ASCE compliance experience. Future canoe teams should start sponsorship outreach in the fall to avoid the material delays documented in Section 8.0, continue using female mold approach and keep detailed QA/QC coordinators to catch ASTM issues before they become deliverable problems.

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Appendices

Appendix A: MTDS Notebook/Mix Design

PHOENIX FLY ASH

CLASS F POZZOLAN

Salt River Materials Group

100% AMERICAN™

Salt River Materials Group (SRMG) Class F Fly Ash meets all chemical and physical requirements of the current ASTM Specification C 618 Coal Fly Ash for use in Concrete. Collected and processed at several power plants in Northern Arizona and New Mexico, Phoenix Class F fly ash is a pre-approved pozzolan source for Arizona Department of Transportation (ADOT), Caltrans, New Mexico Department of Transportation (NMDOT), Colorado Department of Transportation (CDOT), Texas Department of Transportation (TxDOT), Utah Department of Transportation (UDOT), Idaho Transportation Department (IDT), Nevada Department of Transportation (NDOT), the Bureau of Reclamation and the Army Corps of Engineers.

Proportioning

Under normal conditions, Phoenix Class F fly ash is used to replace 15-35% of portland cement by weight. Replacement rates outside of this normal range have been used successfully for more specialized applications. Phoenix Class F fly ash can also be added without cement reduction to achieve desired mix characteristics. Throughout the range of fly ash percentages, proper testing can provide proportions and material combinations yielding competitive strengths at various age requirements.

Strength, Set Time and Pumping Ability

Strengths of concrete properly proportioned with Phoenix Class F fly ash can be designed to closely match those of equivalent cement-only mixes. In fact, due to the secondary pozzolanic reaction, fly ash mixes with similar 28-day compressive strengths generally achieve 10-20% higher strengths at ages beyond 28 days.

Concrete set times utilizing 15-35% Phoenix Class F fly ash can be extended if adjustments are not made to the mix. Proper testing can provide the materials combinations and proportions to yield comparable set times. Due to the spherical particle shape of fly ash, the ball bearing effect, whereby the use of fly ash in concrete lubricates the mix, results in superior pumping ability in mixes using very angular materials or high in coarse aggregate content.

Durability

Tests made in accordance with ASTM C 441 and ASTM C 1012 have shown that the use of Phoenix Class F fly ash significantly reduces the potential for damage due to alkali-aggregate reactivity and sulfate attack. ACI 232.2, Use of Fly Ash in Concrete recommends Type II cement and Class F fly ash as superior to Type V cement alone for high resistance to sulfate attack.

Water Demand

Depending on the quantity of ash used, the use of Phoenix Class F fly ash consistently provides a 10% or greater reduction in the amount of water required for a given workability. This translates directly into increased strength and durability, reduced potential for shrinkage, reduced segregation, and most importantly, lower permeability.

Uniformity

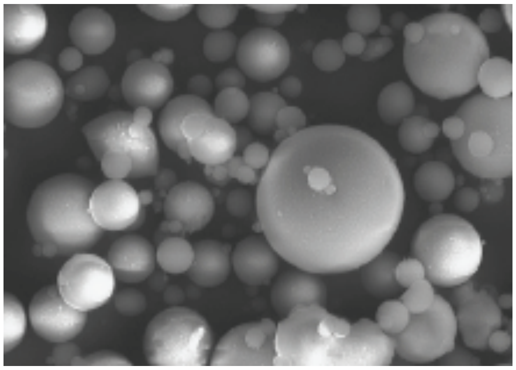
Phoenix Class F fly ash is selected by particle size to ensure the best and most consistent performance possible. In-line sampling can detect inferior fly ash and allow operators to reject it before the fly ash reaches the customer. This is why the carbon content in Phoenix Class F fly ash is consistently some of the lowest found in the region.

The understanding of end product performance enhances our ability to provide predictable and consistent product meeting customer requirements.

SRMG has processed and supplied fly ash to the Southwest since 1986. This experience enables SRMG to continue to provide some of the highest quality fly ash available.

Sources of Salt River Materials Group Fly Ash:

- Cholla
- Four Corners
- San Juan
- Escalante



Micrograph of Cholla Fly Ash particles

Four Corners Fly Ash Facility

Mission Statement

Creating Opportunities and Solutions with Quality Products and Exceptional People

Values

Profitability The Right Way... Integrity, Accountability, Excellence

	ASTM C618 Average Results				Class F
Chemical Analysis	Cholla	Four Corners	San Juan	Escalante	Specification
Calcium Oxide, CaO_2	3.86%	2.10%	4.66%	3.91%	NA
Silicon Dioxide, SiO_2	59.33%	61.70%	56.31%	62.31%	NA
Aluminum Oxide, Al_2O_3	23.78%	24.60%	27.24%	23.01%	NA
Ferric Oxide, Fe_2O_3	6.22%	4.38%	3.61%	4.82%	NA
$SiO_2+Al_2O_3+Fe_2O_3$	89.33%	90.68%	87.16%	90.13%	70.0% Min
Magnesium Oxide, MgO	1.39%	1.22%	1.15%	1.24%	NA
Sulfur Trioxide, SO_3	0.33%	0.18%	0.38%	0.23%	5.0% Max
Moisture content	0.06%	0.06%	0.06%	0.05%	3.0% Max
Loss on Ignition	0.36%	0.29%	0.45%	0.20%	6.0% Max
Available alkalies as Na_2O	0.35%	0.35%	0.42%	0.28%	1.5% Max*
Total alkalies as Na_2O	1.35%	2.01%	2.04%	1.21%	5.0% Max*
Physical Analysis					
Fineness, +325 Sieve	20.0%	22.0%	16.0%	25.0%	34.0% Max
Variation from average	0.30%	0.31%	0.58%	0.14%	5.0% Max
Density, g/cm^3	2.25	1.95	2.05	2.10	NA
Variation from average	0.00%	0.00%	0.00%	0.02%	5.0% Max
Strength Activity Index w/ Cement					
7 Day, % of control	80%	79%	78%	78%	NA
28 Day, % of control	87%	85%	82%	85%	75% Min
Water Requirement, % of control	95%	96%	97%	96%	105% Max
Soundness	-0.03%	-0.03%	0.00%	-0.02%	0.8% Max

* not an ASTM specification requirement

SRMG Salt River Materials Group

PHOENIX CEMENT 100% AMERICAN

8800 E. Chaparral Rd., Ste 155 | Scottsdale, AZ 85250
(480) 850-5757 | Fax: (480) 850-5758 | www.srmaterials.com

ENERGY STAR PARTNER

Product Data Sheet

Division 3 — Concrete
Division 4 — Masonry

PRODUCT NAME

- Lehigh White Portland Cement Types I, II, III and V
- Lehigh White Portland Cement - Type I Water Repellent Added
- Lehigh White PLC - Portland Limestone Cement, GUL or GU
- Lehigh White Masonry Cement, Types N and S

MANUFACTURER

Lehigh White Cement Company
1601 Forum Place
Suite 1110
West Palm Beach, FL 33401
info@lehighwhitecement.com
www.lehighwhitecement.com

PRODUCT DESCRIPTION

Lehigh White Cement Company is the leading supplier of white cements in North America. We have been producing quality portland cements since 1897. For more than 100 years Lehigh has built a reputation for serving the construction industry with high performance products that encourage creativity and ensure longevity. This Product Data Sheet gives a brief overview of the types, specifications and some common uses of our cement. Depending on application, Lehigh White Cement products may be specified in Division 3 - Concrete or Division 4 - Masonry. For more info on our products visit us online @ www.lehighwhitecement.com.

SPECIFICATIONS

Portland Cements

Portland Cements are manufactured to meet ASTM C150 / AASHTO M85 and CSA A3001 specifications

PLC - Portland Limestone Cement

Portland Limestone Cements are manufactured to meet either the ASTM C595 and CSA A3001 or ASTM C1157 specifications.

Masonry Cements

Masonry Cements are manufactured to meet ASTM C91 and CSA A3002 specifications

APPLICATIONS

Lehigh White Portland Type I - Lehigh White Cements are regularly used to produce architectural concrete. General applications include cast-in-place or precast wall panels, floors, slabs, terrazzo, thin-set and tile grouts, cast stone, masonry units and mortars, stucco, swimming pools & spas, glass fiber reinforced concrete, ornamental statuary, floor tiles, concrete roof tiles, perimeter security, pavers and traffic safety items such as concrete median barriers, bridge parapets, pedestrian crosswalks, curbs and other delineators. White cement is often used to produce bright finishes, vibrant colors or ultra high performance concretes that look great and provide structural performance that make them ideal for resilient building applications.

Portland Type II and Type V - In addition to general use, Type II and Type V cements have moderate heat of hydration. Combined in mixes with low water-to-cement ratios and low permeability, Type II and Type V cements are less susceptible to the negative effects of higher than normal sulfate concentrations.

APPLICATIONS - Continued

Portland Type III - Type III portland cement is intended for use where high early strength or a finer grind is required. Type III portland cement is frequently used in precast and cold weather applications.

Portland Limestone Cement CSA A3001 GUL - To make our GUL cement for the Canadian market we intergrind additional limestone and special additives into this blended cement to yield similar strength & setting characteristics to our Type I Portland Cement. It is used in applications typical for Type I cement.

PLC - Portland Limestone Cements ASTM 1157 Type GU - This cement conforms to the Standard Performance Specification for Hydraulic Cement for general construction. It is used where longer set times and workability are preferred characteristics. This specialty cement is most often used in cement rich mixtures such as pool plasters.

Lehigh White Masonry Cements Types N and S - Lehigh White Masonry Cements are combined with sand to produce either Type N or Type S Masonry Mortars per the ASTM C270 specification. They can also be used to produce interior plasters & exterior stucco. These cements are specially formulated for enhanced workability and water retention.

QUALITY

Lehigh White Portland, PLC and Masonry Cements are produced using carefully selected raw materials and rigid manufacturing standards to assure uniform whiteness and high performance. Count on our quality to stretch architectural boundaries through design, color and texture.

SUSTAINABILITY

Minerals used to produce white cement rank among the most abundant elements on earth. Besides having very low embodied energy and CO_2 emissions, portland cement concrete is resilient, durable & long lasting. Specify white cement for dynamic architectural & structural applications.

STORAGE

Portland cement must be kept dry in order to retain its quality. Protect packaged cement from moisture; store bulk cement weather-tight silos.

AVAILABILITY

Not every cement type is available in all markets. Lehigh White Cements are distributed throughout the United States and Canada.

SAFETY

Prior to using or handling cement products first read and understand Safety Data Sheets available at www.lehighwhitecement.com.

WARRANTY

Information and statements given are believed reliable, but are not to be construed as a warranty or representation for which the manufacturer assumes legal responsibility. No warranty, representation, or condition of any kind, expressed or implied (including no warranty of merchantability or fitness for a particular purpose) shall apply. Having no control over the use of cement, Lehigh will not guarantee finished work, nor shall Lehigh White Cement Company be liable for consequential damages.

Chemstar Type S Lime

It's the Choice of Architects, Specifiers, Engineers, Contractors and Masons, for a High Performance, Cost Effective Mortar.

CHEMSTAR

TYPE S LIME

Chemical Lime
A Lhoist Group Company

Superiority of Cement-Lime Mortar

In independent university and Brick Industry of America studies, cement-lime mortars consistently outperformed ASTM C270 mortar cement and masonry cement types by a significant margin. Compared to the other mortar types and mortars made with clay and air entraining agents, cement-lime mortar with Chemstar Type S lime delivered:

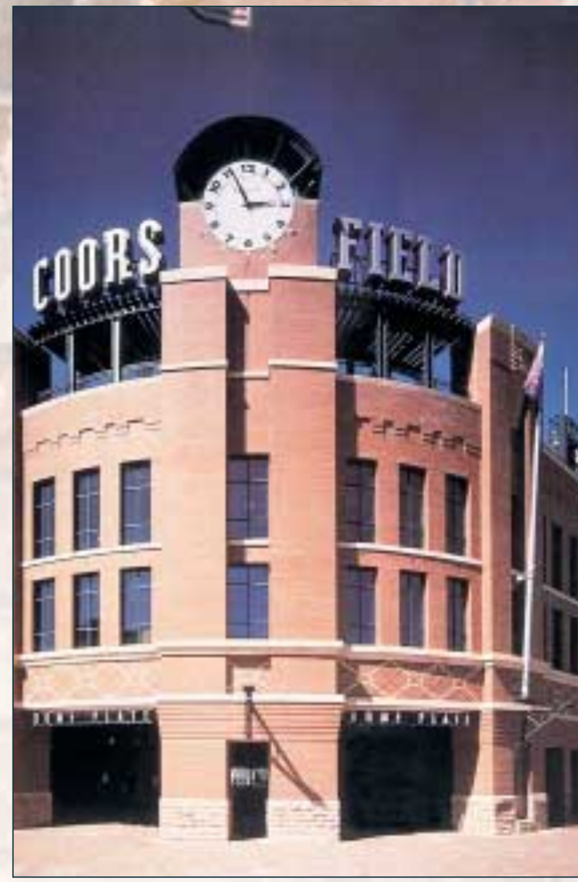
- Two to four times the flexural bond strength
- 20-40 times better resistance to water penetration
- 2-3 times the boardlife
- Excellent compatibility with all types of clay bricks and concrete masonry units
- Superior compatibility with white cement reducing flash setting

CHEMSTAR

TYPE S
LIME

Chemstar Type S Lime . . . it belongs in your mortar

When it comes to workability, boardlife, and sand carrying capacity, nothing is better than a cement-lime mortar with Chemstar Type S lime. And nothing enhances the quality and productivity of your masonry project like Chemstar Type S lime. By specifying Chemstar Type S lime, you are providing your customers with the best flexural bond strength and resistance to water penetration available. No wonder it is the market leader.



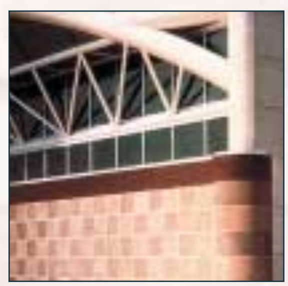
Chemstar sets the standard

While cement-lime mortar is superior to other compositions, mortar made with Chemstar Type S lime is clearly a cut above the rest. Produced from the calcination of high quality dolomite and subsequent pressure hydration of the resulting quicklime, Chemstar Type S lime meets or exceeds all applicable standards, including:

- ASTM C 207
- ASTM C 206 (Henderson and New Braunfels production)
- Uniform Building Code (UBC) standard 21-13
- International Building Code (IBC) 2000, 2103.7

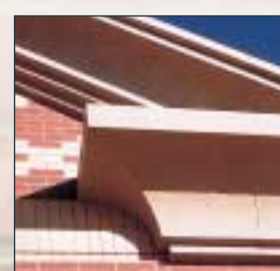
As a result of their very small size (1/100th of a micron) the Chemstar Type S lime particles have very special properties which yield the following, significant benefits:

- Prolonged cement hydration for increased boardlife
- Excellent water retention
- Use of marginal mortar sand, as every grain is fully coated
- Maximum sand yield
- Superior workability
- Improved mortar consistency due to high dispersing properties.



Chemstar meets the code

Building codes, including IBC and UBC standards, recognize the flexural bond strength of cement-lime mortars. Unreinforced masonry walls built using cement-lime mortars are allowed by code to accommodate a lateral load (i.e., seismic or wind driven) 67% greater than either masonry cement or mortar cement. In fact, masonry cement is not even allowed in seismic zones because of its deficiencies in bond strength. Chemstar Type S lime goes a step further by helping to knit the mortar to the masonry unit surface. This enhances the bond and promotes the early hydration of the cement, assuring full development of mortar strength during the first few critical days.



When Results Count

Chemical Lime Company, North America's leading producer and supplier of lime for building construction, supports your business with an expert team of technical and application specialists. Their function is to work with you, ensuring you achieve the best possible results from product development to mortar testing and analysis. Our production facilities in Nevada, Texas, and Utah supply Chemstar Type S lime to knowledgeable building material dealers across the country. Chemstar Type SA hydrated lime is manufactured at our facility in Texas and is available throughout that market.

Headquartered in Fort Worth, Texas, Chemical Lime Company serves a variety of industrial markets from 55 locations in North America. Chemical Lime Company is a member of the Lhoist Group headquartered in Brussels, Belgium.

Safety information is contained in Material Safety Data Sheets (MSDS) available from your supplier or directly from Chemical Lime Company by fax or our website.

CHEMSTAR

TYPE S LIME

Chemical Lime

A Lhoist Group Company

Call 800.365.6724

Fax 817.732.8564

Visit www.chemicallime.com

Write PO Box 985004
Fort Worth, Texas 76185.5004

Manufacturer's Certification

Report Date: 1/29/2024

We hereby certify that CalPortland Slag Cement meets the standard requirements of ASTM C989 and AASHTO M302 Grades 100 and 120 specifications for Ground Granulated Blast Furnace Slag (GGBFS). Reported are the average chemical and physical data for the lot indicated below.

Lot #: 24-006

Source: Muroran Hokkaido, Japan **Slag Cement**

Chemical Properties	Grade 100 Requirements	Grade 120 Requirements	Analysis Results
Sulfide Sulfur (S), max, %	2.5	2.5	**0.0**
Sulfur Trioxide (SO_3), %	---	---	**4.0**
Aluminum Oxide (Al_2O_3), %	---	---	**11.8**
Chloride (Cl), %	---	---	**0.00**
Alkalies (Na_2O+0.658*K_2O), %			
Reference Cement, %	0.60 - 0.90	0.60 - 0.90	**0.83**
Slag Cement, %	---	---	**0.38**

Physical Properties	Grade 100 Requirements	Grade 120 Requirements	Analysis Results
Air Content of Slag Mortar, max, volume %	12	12	**2.7**
Density, g/cm³	---	---	**3.03**
Retained 45um (#325) sieve, max %	20	20	**1**
Blaine Fineness, m²/kg	---	---	**409**
Compressive Strength			
Reference Cement 7 Day, psi	---	---	**4340**
Reference Cement 28 Day (from previous lot), min, psi	5000	5000	**5140**
Slag + Reference Cement 7 Day, psi	---	---	**5410**
Slag + Reference Cement 28 Day (from previous lot), psi	---	---	**6820**
Slag Activity Index			
7 Day, %	---	---	**125**
28 Day (from previous lot), min, %	90	110	**133**

Apparatus and methods used in this laboratory have been checked by the Cement and Concrete Reference Laboratory of the National Institute of Standards and Technology. A copy of the report detailing their findings is available upon request. Major oxides are analyzed in accordance with ASTM C114.

Randy Romeo - Cement Technical Services

P.V.P. INDUSTRIES INC.

Technical Data Sheet (TDS)

Coarse Perlite

CONTACT US AT:

440-685-4701

800-255-4801

INFO@PVPIND.COM

WWW.PVPIND.COM

LOCATION:

MAILING: P.O. BOX 129

PHYSICAL: 9819 PENNIMAN ROAD

NORTH BLOOMFIELD, OH 44450

ABOUT US:

PERLITE, VERMICULITE, SOIL BLENDER AND CUSTOM/PRIVATE LABEL PACKAGING MANUFACTURER SINCE 1984.

COMMON USES:

COARSE PERLITE IS MOST COMMONLY USED IN PROFESSIONAL SOIL MIXES AND HYDROPONICS. IT'S ALSO BEEN USED AS INSULATION, SPILL CLEANUP, AGGREGATE IN CEMENT, TEXTURED COATINGS, ECT.

TYPICAL PARTICLE ANALSYIS

US Mesh	Coarse Perlite			Average	Average
screen	cc	%	%CUM.	WT./60cf	lbs./cu.ft.
8	680	57.63%	57.63%	330	5
16	230	19.49%	77.12%	Avgs	Retained
30	140	11.86%	88.98%	+8	50-70%
50	95	8.05%	97.03%	-8 +16	30-50%
100	10	0.85%	97.88%	-16 + 30	5-20%
pan	25	2.12%	100.00%	-30	0-10%

TYPICAL CHEMICAL ANALSYIS

Analyte	SiO2	AI203	Fe203	MgO	CaO	Na2O	K2O
Unit/kg	%	%	%	%	%	%	%
MDL	0.01	0.01	0.04	0.01	0.01	0.01	0.01
PVP30	73.63	13.33	0.75	0.05	0.78	3.83	4.72

TYPICAL PROPERTIES

Moisture Content: < 0.5%
PH Range: 6.5-7.5
Bulk Density: 4-6 Lbs/ Cu.Ft.
Bulk Packaged in 4 Cu.Ft. 30-36 bags per pallet, 24-28 pallets per truckload.60 Cu.ft. and 70Cu.ft. Bags, 2 bags per pallet, 24-30 pallets per truckload
Also available in retail packaging

PORAVER

Sustainable Material Innovation

TECHNICAL DATA SHEET

LIGHTWEIGHT AGGREGATE ACCORDING TO DIN EN 13055-1 AND ASTM C330, C331, C332, C29, C29M, C128 [3)]

		GRAIN SIZES					
Product name		**PORAVER® 0.04-0.125**	**PORAVER® 0.1-0.4**	**PORAVER® 0.25-0.5**	**PORAVER® 0.5-1**	**PORAVER® 1-2**	**PORAVER® 2-4**
Granular size	[mm]	0.04-0.125	0.1-0.4	0.25-0.5	0.5-1	1-2	2-4
Bulk density	[kg/m^3]	530 ± 70	370 ± 60	340 ± 30	270 ± 30	230 ± 30	190 ± 20
	[lb/ft^3]	33.1 ± 4.4	23.1 ± 3.8	21.2 ± 1.9	16.9 ± 1.9	14.4 ± 1.9	11.9 ± 1.3
Particle density	[kg/m^3]	1,150 ± 150	800 ± 150	700 ± 80	500 ± 80	400 ± 60	320 ± 60
	[lb/ft^3]	71.8 ± 9.4	49.9 ± 9.4	43.7 ± 5.0	31.2 ± 5.0	25.0 ± 3.7	20.0 ± 3.7
Crushing resistance	[N/mm^2]	≥ 9.0	≥ 3.0	≥ 2.6	≥ 2.0	≥ 1.6	≥ 1.4
	[lbf/ft^2]	≥ 1,305	≥ 435	≥ 377	≥ 290	≥ 232	≥ 203
Oversize	[wt.-%]	≤ 10					
Undersize	[wt.-%]	≤ 15					
pH value		8 - 12					
Moisture content	[wt.-%]	≤ 0.5					
Water absorption 5 min. [1)]	[vol.-%]	30	25	15	9	7	4.5
Water absorption 5 min. [1)]	[wt.-%]	50	35	21	18	19	14
Softening point	[°C]	approx. 700					
Colour		creamy white					
Thermal conductivity [2)]	[W/(m·K)]	0.106	0.091	0.080	0.076	0.072	0.072
R-value [2)]	[°F-ft^2-h/BTU]	1.367	1.584	1.802	1.897	2.007	2.007
RSI-value [2)]	[K·m^2/W]	0.24	0.27	0.31	0.33	0.35	0.35
CE according DIN EN 13055-1		-	-	•	•	•	•
Approval Z-3.42-1894		-	-	•	•	•	•

1) Approximate values due to possible measurement tolerances
2) Values according to ASTM C 518-17 Thermal Transmission Properties
3) Unless otherwise noted DIN EN 13055-1 is primary standard followed, ASTM is available on request.

The strength grades may vary within the tolerance range of bulk densities. The availability and delivery conditions for special grain sizes will be agreed on an individual basis.

CHEMICAL ANALYSIS

Constituent	Applied to the sample dried at 105°C	Analysis method
SiO_2	70 - 75 %	DIN EN ISO 12677 measured with XRF
Na_2O	10 - 15 %	
CaO	7 - 11 %	
Al_2O_3	0.5 - 5 %	
MgO	0 - 5 %	
K_2O	0 - 4 %	

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3M™ Glass Bubbles K Series, S Series and iM Series

Introduction

3M™ Glass Bubbles are engineered hollow glass microspheres that are alternatives to conventional fillers and additives such as silicas, calcium carbonate, talc, clay, etc., for many demanding applications. These low-density particles are used in a wide range of industries to reduce part weight, lower costs and enhance product properties.

The unique spherical shape of 3M glass bubbles offers a number of important benefits, including: higher filler loading, lower viscosity/improved flow and reduced shrinkage and warpage. It also helps the 3M glass bubbles blend readily into compounds and makes them adaptable to a variety of production processes including spraying, casting and molding.

The chemically stable soda-lime-borosilicate glass composition of 3M glass bubbles provides excellent water resistance to create more stable emulsions. They are also non-combustible and non-porous, so they do not absorb resin. And, their low alkalinity gives 3M glass bubbles compatibility with most resins, stable viscosity and long shelf life.

3M Glass Bubbles K Series, S Series and iM Series are specially formulated for a high strength-to-weight ratio. This allows greater survivability under many demanding processing conditions, such as injection molding. They also produce stable voids, which results in low thermal conductivity and a low dielectric constant. 3M glass bubbles are available in a variety of sizes and grades to help you meet your product and processing requirements.

Typical Properties

Not for specification purposes

Isostatic Crush Strength

	Product	Test Pressure (psi)	Target Fractional Survival	Minimum Fractional Survival
K Series	K1	250	90%	80%
	K15	300	90%	80%
	K20	500	90%	80%
	K25	750	90%	80%
	K37	3,000	90%	80%
	K46	6,000	90%	80%
S Series	S15	300	90%	80%
	S22	400	90%	80%
	S32	2,000	90%	80%
	S35	3,000	90%	80%
	S38	4,000	90%	80%
	S38HS	5,500	90%	80%
	S60	10,000	90%	80%
	S60HS	18,000	90%	90%
iM Series	iM16K	16,000	90%	90%
	iM30K	28,000	90%	90%

True Density

			True Density (g/cc)	
	Product	Typical	Minimum	Maximum
K Series	K1	0.125	0.10	0.14
	K15	0.15	0.13	0.17
	K20	0.20	0.18	0.22
	K25	0.25	0.23	0.27
	K37	0.37	0.34	0.40
	K46	0.46	0.43	0.49
S Series	S15	0.15	0.13	0.17
	S22	0.22	0.19	0.25
	S32	0.32	0.29	0.35
	S35	0.35	0.32	0.38
	S38	0.38	0.35	0.41
	S38HS	0.38	0.35	0.41
	S60	0.60	0.57	0.63
	S60HS	0.60	0.57	0.63
iM Series	iM16K	0.46	0.43	0.49
	iM30K	0.60	0.57	0.63

Typical Properties

Chemical Resistance

In general, the chemical properties of 3M™ Glass Bubbles resemble those of a soda-lime-borosilicate glass.

Thermal Conductivity

Series	Product	Calculated Thermal Conductivity (W·m-1·K-1) at 70°F (21°C)
K Series	K1	0.047
	K15	0.055
	K20	0.070
	K25	0.085
	K37	0.124
	K46	0.153
S Series	S15	0.055
	S22	0.076
	S32	0.108
	S35	0.117
	S38	0.127
	S38HS	0.127
	S60	0.200
	S60HS	0.200
iM Series	iM16K	0.153
	iM30K	0.200

Conductivity increases with temperature and product density. The thermal conductivity of a composite will depend on the matrix material and volume loading of 3M glass bubbles.

Thermal Stability

Appreciable changes in bubble properties may occur above 1112°F (600°C) depending on temperature and duration of exposure.

Flotation

Series	Product	Floaters (% by bulk volume) Typical	Minimum
K Series	K1	96%	90%
	K15	96%	90%
	K20	96%	90%
	K25	96%	90%
	K37	94%	90%
	K46	92%	90%
S Series	S15	96%	90%
	S22	96%	90%
	S32	94%	90%
	S35	96%	90%
	S38	94%	90%
	S38HS	96%	90%
	S60	92%	90%
	S60HS	92%	90%
iM Series	iM16K	96%	90%
	iM30K	92%	90%

Packing Factor (Ratio of bulk density to true particle density)

Averages about 60%.

Oil Absorption

0.2–0.6 g oil/cc of 3M glass bubbles, per ASTM D281-84.

Volatile Content

Maximum of 0.5 percent by weight.

Alkalinity

Maximum of 0.5 milliequivalents per gram

pH

Because 3M glass bubbles are a dry powder, pH is not defined. The pH effect will be determined by the alkalinity as indicated above. When 3M glass bubbles are mixed with deionized water at 5% volume loading, the resulting pH of the slurry is typically 9.1 to 9.9, as measured by a pH meter.

Dielectric Constant

K Series: 1.2 to 1.7 @ 100 MHz, based on theoretical calculations.

S Series: 1.2 to 2.0 @ 100 MHz, based on theoretical calculations.

iM Series: 1.2 to 1.7 @ 100 MHz, based on theoretical calculations

The dielectric constant of a composite will depend on the matrix material and volume loading of 3M glass bubbles.

Particle Size

Series	Product	Particle Size (microns, by volume) 3M QCM 193.0 — Distribution 10th%	50th%	90th%	Effective Top Size
K Series	K1	30	65	115	120
	K15	30	60	105	115
	K20	30	60	90	105
	K25	25	55	90	105
	K37	20	45	80	85
	K46	15	40	70	80
S Series	S15	25	55	90	95
	S22	20	35	65	75
	S32	20	40	70	80
	S35	20	40	65	80
	S38	15	40	75	85
	S38HS	19	44	70	85
	S60	15	30	55	65
	S60HS	12	29	48	60
iM Series	iM16K	12	20	30	40
	iM30K	8.6	15.3	23.6	26.7

Particle Size (continued)

Hard Particles (3M QCM 93.4.3)
No hard particles (e.g. glass slag, flow agent, etc.) greater than U.S. number 40 (420 microns) standard sieve will exist.

Oversize Particles (3M QCM 93.4.4)
For *K1, K15, K20* and *K25* glass bubbles:
Using a 10 gram sample on a U.S. number 80 standard sieve (177 microns), a maximum of five (5) percent by weight glass bubbles will be retained on the sieve.

For *K37* and *K46* glass bubbles:
Using a 10 gram sample on U.S. number 100 standard sieve (149 microns), a maximum of one (1) percent by weight glass bubbles will be retained on the sieve.

For *S15, S32, S35, S38, S38HS, S60, S60HS, iM16K* and *iM30K* glass bubbles:
Using a 10 gram sample on a U.S. number 140 standard sieve (105 microns), a maximum of three (3) percent by weight glass bubbles will be retained on the sieve.

For *S22* glass bubbles:
Using a 10 gram sample on a U.S. number 200 standard sieve (74 microns), a maximum of five (5) percent by weight glass bubbles will be retained on the sieve.

Appearance (3M QCM 22.85)

White to the unaided eye.

Flow (3M QCM 22.83)

3M™ Glass Bubbles remain free flowing for at least one year from the date of shipment if stored in the original, unopened container in the minimum storage conditions of an unheated warehouse.

Labeling

3M glass bubbles will be packaged in suitable containers to help prevent damage during normal handling and shipping. Each container will be labeled with:

1. Name of manufacturer
2. Type of 3M glass bubbles
3. Lot number
4. Quantity in pounds

Storage and Handling

To help ensure ease of storage and handling while maintaining free flowing properties, 3M™ Glass Bubbles have been made from a chemically stable glass and are packaged in a heavy-duty polyethylene bag within a cardboard container.

Minimum storage conditions should be unopened cartons in an unheated warehouse.

Under high humidity conditions with an ambient temperature cycling over a wide range, moisture can be drawn into the bag as the temperature drops and the air contracts. The result may be moisture condensation within the bag. Extended exposure to these conditions may result in “caking” of the 3M glass bubbles to various degrees. To minimize the potential for “caking” and prolong the storage life, the following suggestions are made:

1. Carefully re-tie open bags after use.
2. If the polyethylene bag is punctured during shipping or handling, use this bag as soon as possible, patch the hole, or insert the contents into an undamaged bag.
3. During humid summer months, store in the driest, coolest space available.
4. If good storage conditions are unavailable, carry a minimum inventory, and process on a first in/first out basis.

Dusting problems that may occur while handling and processing can be minimized by the following procedures:

1. For eye protection wear chemical safety goggles. For respiratory system protection wear an appropriate NIOSH/MSHA approved respirator. (For additional information about personal protective equipment, refer to Material Safety Data Sheet.)
2. Use appropriate ventilation in the work area.
3. Pneumatic conveyor systems have been used successfully to transport 3M glass bubbles without dusting from shipping containers to batch mixing equipment. Static eliminators should be used to help prevent static charges.

   Diaphragm pumps have been used to successfully convey 3M glass bubbles. Vendors should be consulted for specific recommendations.

3M glass bubble breakage may occur if the product is improperly processed. To minimize breakage, avoid high shear processes such as high speed Cowles Dissolvers, point contact shear such as gear pumps or 3-roll mills, and processing pressures above the strength test pressure for each product.

Health and Safety Information

For product Health and Safety Information, refer to product label and Material Safety Data Sheet (MSDS) before using product.

Packaging Information

Small Box (10 Cubic ft.)

A single corrugated box with a plastic liner. All boxes are banded together and to the wooden pallet. 4 boxes per pallet.

Each box inside diameter is 22 in. × 19 in. × 39 in.
Pallet size is 42 in. × 48 in.

Large Box (50 Cubic ft.)*

A single corrugated box with a plastic liner. Top enclosed with interlocking double cover banded. Bottom is normal box closure, entire box banded to wooden pallet.

Each box inside diameter is 48 in. × 42 in. × 44 in. Overall load size is 48 3/4 in. × 42 3/4 in. × 50 in. including pallet.
Pallet size is 42 in. × 48 in.

*S60 and S60HS large boxes are 38 cubic ft.

Box Weights

Series	Product	Small Box	Large Box*	Truckload Large Box* 44 Pallets
K Series	K1	40 lb.	210 lb.	9,240 lb.
	K15	50 lb.	265 lb.	11,660 lb.
	K20	60 lb.	350 lb.	15,400 lb.
	K25	80 lb.	430 lb.	18,920 lb.
	K37	100 lb.	660 lb.	29,040 lb.
	K46	125 lb.	815 lb.	35,860 lb.
S Series	S15	50 lb.	265 lb.	11,660 lb.
	S22	60 lb.	385 lb.	16,940 lb.
	S32	100 lb.	525 lb.	23,100 lb.
	S35	100 lb.	630 lb.	27,720 lb.
	S38	100 lb.	680 lb.	29,920 lb.
	S38HS	100 lb.	680 lb.	29,920 lb.
	S60	125 lb.	850 lb.	37,400 lb.
	S60HS	125 lb.	850 lb.	37,400 lb.
iM Series	iM16K	99 lb.	800 lb.	–
	iM30K	125 lb.	850 lb.	37,400 lb.

*Box weights may vary due to manufacturing tolerances on each product.

Resources

3M™ Glass Bubbles are supported by global sales, technical and customer service resources, with fully-staffed technical service laboratories in the U.S., Europe, Japan, Latin America and Southeast Asia. Users benefit from 3M's broad technology base and continuing attention to product development, performance, safety and environmental issues.

For additional technical information on 3M glass bubbles in the United States, call 3M Advanced Materials Division, **800-367-8905**. For other 3M global offices, and information on additional 3M products, visit our website at: **www.3M.com/engineeredadditives**.

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MASTER® BUILDERS SOLUTIONS

MasterGlenium® 7500

Full-Range Water-Reducing Admixture

Description

MasterGlenium 7500 full-range water-reducing admixture is very effective in producing concrete mixtures with different levels of workability including applications that require self-consolidating concrete (SCC). MasterGlenium 7500 admixture meets ASTM C 494/C 494M compliance requirements for Type A, water-reducing, and Type F, high-range water-reducing, admixtures.

Applications

Recommended for use in:

- Concrete with varying water reduction requirements (5-40%)
- Concrete where control of workability and setting time is critical
- Concrete where high flowability, increased stability, high-early and ultimate strengths, and improved durability are needed
- Producing self-consolidating concrete (SCC)
- Strength-on-demand concrete, such as 4x4™ Concrete
- Pervious concrete
- Geotechnical grouting and ground improvement

Features

MasterGlenium 7500 full-range water-reducing admixture is based on the next generation of polycarboxylate technology found in all of the MasterGlenium 7000 series products. This technology combines state-of-the-art molecular engineering with a precise understanding of regional cements to provide specific and exceptional value to all phases of the concrete construction process.

- Dosage flexibility for normal, mid-range and high-range applications
- Excellent early strength development
- Controls setting characteristics
- Optimizes slump retention/setting relationship
- Consistent air entrainment

Benefits

- Faster turnover of forms due to accelerated early strength development
- Reduces finishing labor costs due to optimized set times
- Use in fast track construction
- Minimizes the need for slump adjustments at the jobsite
- Less jobsite QC support required
- Fewer rejected loads
- Optimizes concrete mixture costs

Performance Characteristics

Concrete produced with MasterGlenium 7500 admixture achieves significantly higher early age strength than first generation polycarboxylate high-range water-reducing admixtures. MasterGlenium 7500 admixture also strikes the perfect balance between workability retention and setting characteristics in order to provide efficiency in placing and finishing concrete. The dosage flexibility of MasterGlenium 7500 allows it to be used as a normal, mid-range, and high-range water reducer.

Guidelines for Use

Dosage: MasterGlenium 7500 admixture has a recommended dosage range of 2-15 fl oz/cwt (130-975 mL/100 kg) of cementitious materials. For most mid- to high-range applications, dosages in the range of 5-8 fl oz/cwt (325-520 mL/100 kg) will provide excellent performance. For high performance and producing self-consolidating concrete mixtures, dosages of up to 12 fl oz/cwt (780 mL/100 kg) of cementitious materials can be utilized. Because of variations in concrete materials, jobsite conditions and/or applications, dosages outside of the recommended range may be required. In such cases, contact your local sales representative.

Mixing: MasterGlenium 7500 admixture can be added with the initial batch water or as a delayed addition. However, optimum water reduction is generally obtained with a delayed addition.

Product Notes

Corrosivity – Non-Chloride, Non-Corrosive: MasterGlenium 7500 admixture will neither initiate nor promote corrosion of reinforcing steel embedded in concrete, prestressing steel or of galvanized steel floor and roof systems. Neither calcium chloride nor other chloride-based ingredients are used in the manufacture of MasterGlenium 7500 admixture.

Compatibility: MasterGlenium 7500 admixture is compatible with most admixtures used in the production of quality concrete, including normal, mid-range and high-range water-reducing admixtures, air-entrainers, accelerators, retarders, extended set control admixtures, corrosion inhibitors, and shrinkage reducers.

Do not use MasterGlenium 7500 admixture with admixtures containing beta-naphthalene sulfonate. Erratic behaviors in slump, workability retention and pumpability may be experienced.

Storage and Handling

Storage Temperature: MasterGlenium 7500 admixture must be stored at temperatures above 40 °F (5 °C). If MasterGlenium 7500 admixture freezes, thaw and reconstitute by mechanical agitation.

Shelf Life: MasterGlenium 7500 admixture has a minimum shelf life of 9 months. Depending on storage conditions, the shelf life may be greater than stated. Please contact your local sales representative regarding suitability for use and dosage recommendations if the shelf life of MasterGlenium 7500 admixture has been exceeded.

Packaging

MasterGlenium 7500 admixture is supplied in 55 gal (208 L) drums, 275 gal (1040 L) totes and by bulk delivery.

Related Documents

Safety Data Sheets: MasterGlenium 7500 admixture

Additional Information

For additional information on MasterGlenium 7500 admixture or on its use in developing concrete mixtures with special performance characteristics, contact your local sales representative.

Master Builders Solutions creates technologies for the construction industry inspiring people to build better. We are active in ~40 countries and operate 35 production sites with over 1,600 employees. We develop, produce, and market high-quality chemical admixtures, as well as adjacent core technologies, to master the challenges of today and support a decarbonized future. Our people are pivotal and pair leading technologies and a strong brand heritage to surpass our customers' expectations and drive continuous value creation.

Limited Warranty Notice

Master Builders Solutions Admixtures US, LLC ("Master Builders Solutions") warrants this product to be free from manufacturing defects and to meet the technical properties on the current Technical Data Guide, if used as directed within shelf life. Satisfactory results depend not only on quality products but also upon many factors beyond our control. MASTER BUILDERS SOLUTIONS MAKES NO OTHER WARRANTY OR GUARANTEE, EXPRESS OR IMPLIED, INCLUDING WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE WITH RESPECT TO ITS PRODUCTS. The sole and exclusive remedy of Purchaser for any claim concerning this product, including but not limited to, claims alleging breach of warranty, negligence, strict liability or otherwise, is shipment to purchaser of product equal to the amount of product that fails to meet this warranty or refund of the original purchase price of product that fails to meet this warranty, at the sole option of Master Builders Solutions. Any claims concerning this product must be received in writing within one (1) year from the date of shipment and any claims not presented within that period are waived by Purchaser. MASTER BUILDERS SOLUTIONS WILL NOT BE RESPONSIBLE FOR ANY SPECIAL, INCIDENTAL, CONSEQUENTIAL (INCLUDING LOST PROFITS) OR PUNITIVE DAMAGES OF ANY KIND.

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Certified to NSF/ANSI 61

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MASTER® BUILDERS SOLUTIONS

MasterAir® AE 200

Air-Entraining Admixture

Description

MasterAir AE 200 air-entraining admixture provides concrete with extra protection by creating air bubbles that are ultrastable, small and closely spaced – a characteristic especially useful in the types of concrete known for their difficulty to entrain and maintain the air content desired.

Even when used at a lower dosage than standard air-entraining admixtures, MasterAir AE 200 admixture meets the requirements of ASTM C 260, AASHTO M 154, and CRD-C 13.

Applications

Recommended for use in:

- Concrete exposed to cyclic freezing and thawing
- Production of high-quality normal or lightweight concrete (heavyweight concrete normally does not contain entrained air)

Features

- Ready-to-use in the proper concentration for rapid, accurate dispensing
- Greatly improved stability of air-entrainment
- Ultra stable air bubbles

Benefits

- Increased resistance to damage from cyclic freezing and thawing
- Increased resistance to scaling from deicing salts
- Improved plasticity and workability
- Improved air-void system in hardened concrete
- Improved ability to entrain and retain air in low-slump concrete, concrete containing high-carbon content fly ash, concrete using large amounts of fine materials, concrete using high-alkali cements, high-temperature concrete, and concrete with extended mixing times
- Reduced permeability – increased watertightness
- Reduced segregation and bleeding

Performance Characteristics

Concrete durability research has established that the best protection for concrete from the adverse effects of freezing and thawing cycles and deicing salts results from: proper air content in the hardened concrete, a suitable air-void system in terms of bubble size and spacing and adequate concrete strength, assuming the use of sound aggregates and proper mixing, transporting, placing, consolidation, finishing and curing techniques. MasterAir AE 200 admixture can be used to obtain adequate freezing and thawing durability in a properly proportioned concrete mixture, if standard industry practices are followed.

Air Content Determination: The total air content of normal weight concrete should be measured in strict accordance with ASTM C 231, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method" or ASTM C 173/C 173M, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method."

The air content of lightweight concrete should only be determined using the Volumetric Method. The air content should be verified by calculating the gravimetric air content in accordance with ASTM C 138/C 138M, "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete." If the total air content, as measured by the Pressure Method or Volumetric Method and as verified by the Gravimetric Method, deviates by more than 1.5%, the cause should be determined and corrected through equipment calibration or by whatever process is deemed necessary.

Guidelines for Use

Dosage: There is no standard dosage for MasterAir AE 200 admixture. The exact quantity of air-entraining admixture needed for a given air content of concrete varies because of differences in concrete making materials and ambient conditions. Typical factors that might influence the amount of air entrained include: temperature, cementitious materials, sand gradation, sand-aggregate ratio, mixture proportions, slump, means of conveying and placement, consolidation and finishing technique.

The amount of MasterAir AE 200 admixture used will depend upon the amount of entrained air required under actual job conditions. In a trial mixture, use 0.125 to 1.5 fl oz/cwt (8-98 mL/100 kg) of cement. In mixtures containing water-reducing or set-control admixtures, the amount of MasterAir AE 200 admixture needed is somewhat less than the amount required in plain concrete. Due to possible changes in the factors that can affect the dosage of MasterAir AE 200 admixture, frequent air content checks should be made during the course of the work. Adjustments to the dosage should be based on the amount of entrained air required in the mixture at the point of placement. If an unusually high or low dosage of MasterAir AE 200 admixture is required to obtain the desired air content, consult your Local sales representative. In such cases, it may be necessary to determine that, in addition to a proper air content in the fresh concrete, a suitable air-void system is achieved in the hardened concrete.

Dispensing and Mixing: Add MasterAir AE 200 admixture to the concrete mixture using a dispenser designed for air-entraining admixtures; or add manually using a suitable measuring device that ensures accuracy within plus or minus 3% of the required amount. For optimum, consistent performance, the air-entraining admixture should be dispensed on damp, fine aggregate or with the initial batch water. If the concrete mixture contains lightweight aggregate, field evaluations should be conducted to determine the best method to dispense the air-entraining admixture.

Precaution

In a 2005 publication from the Portland Cement Association (PCA R&D Serial No. 2789), it was reported that problematic air-void clustering that can potentially lead to above normal decreases in strength was found to coincide with late additions of water to air-entrained concretes. Late additions of water include the conventional practice of holding back water during batching for addition at the jobsite. Therefore, caution should be exercised with delayed additions to air-entrained concrete. Furthermore, an air content check should be performed after post-batching addition of any other materials to an air-entrained concrete mixture.

Product Notes

Corrosivity – Non-Chloride, Non-Corrosive: MasterAir AE 200 admixture will neither initiate nor promote corrosion of reinforcing and prestressing steel embedded in concrete, or of galvanized steel floor and roof systems. No calcium chloride or other chloride-based ingredients are used in the manufacture of this admixture.

Compatibility: MasterAir AE 200 admixture may be used in combination with any Master Builders Solutions admixture, unless stated otherwise on the data sheet for the other product. When used in conjunction with other admixtures, each admixture must be dispensed separately into the mixture.

Storage and Handling

Storage Temperature: MasterAir AE 200 admixture should be stored and dispensed at 35 °F (2 °C) or higher. Although freezing does not harm this product, precautions should be taken to protect it from freezing. If it freezes, thaw and reconstitute by mild mechanical agitation. Do not use pressurized air for agitation.

Shelf Life: MasterAir AE 200 admixture has a minimum shelf life of 18 months. Depending on storage conditions, the shelf life may be greater than stated. Please contact your Local sales representative regarding suitability for use and dosage recommendations if the shelf life of MasterAir AE 200 admixture has been exceeded.

Safety: MasterAir AE 200 admixture is a caustic solution. Chemical goggles and gloves are recommended when transferring or handling this material. (See SDS and/or product label for complete information.)

Packaging

MasterAir AE 200 admixture is supplied in 55 gal (208 L) drums, 275 gal (1040 L) totes and by bulk delivery.

Related Documents

Safety Data Sheets: MasterAir AE 200 admixture

Additional Information

For suggested specification information or for additional product data on MasterAir AE 200 admixture, contact your local sales representative.

Master Builders Solutions creates technologies for the construction industry inspiring people to build better. We are active in ~40 countries and operate 35 production sites with over 1,600 employees. We develop, produce, and market high-quality chemical admixtures, as well as adjacent core technologies, to master the challenges of today and support a decarbonized future. Our people are pivotal and pair leading technologies and a strong brand heritage to surpass our customers' expectations and drive continuous value creation

Limited Warranty Notice

Master Builders Solutions warrants this product to be free from manufacturing defects and to meet the technical properties on the current Technical Data Guide, if used as directed within shelf life. Satisfactory results depend not only on quality products but also upon many factors beyond our control. MASTER BUILDERS SOLUTIONS MAKES NO OTHER WARRANTY OR GUARANTEE, EXPRESS OR IMPLIED, INCLUDING WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE WITH RESPECT TO ITS PRODUCTS. The sole and exclusive remedy of Purchaser for any claim concerning this product, including but not limited to, claims alleging breach of warranty, negligence, strict liability or otherwise, is shipment to purchaser of product equal to the amount of product that fails to meet this warranty or refund of the original purchase price of product that fails to meet this warranty, at the sole option of Master Builders Solutions. Any claims concerning this product must be received in writing within one (1) year from the date of shipment and any claims not presented within that period are waived by Purchaser. MASTER BUILDERS SOLUTIONS WILL NOT BE RESPONSIBLE FOR ANY SPECIAL, INCIDENTAL, CONSEQUENTIAL (INCLUDING LOST PROFITS) OR PUNITIVE DAMAGES OF ANY KIND.

Purchaser must determine the suitability of the products for the intended use and assumes all risks and liabilities in connection therewith. This information and all further technical advice are based on Master Builders Solutions' present knowledge and experience. However, Master Builders Solutions assumes no liability for providing such information and advice including the extent to which such information and advice may relate to existing third party intellectual property rights, especially patent rights, nor shall any legal relationship be created by or arise from the provision of such information and advice. Master Builders Solutions reserves the right to make any changes according to technological progress or further developments. The Purchaser of the Product(s) must test the product(s) for suitability for the intended application and purpose before proceeding with a full application of the product(s). Performance of the product described herein should be verified by testing and carried out by qualified experts.

Certified to NSF/ANSI 61

www.master-builders-solutions.com/en-us

Master Builders Solutions Admixtures US, LLC
23700 Chagrin Boulevard
Beachwood, Ohio, 44122-5544
USA ■ 800-628-9990

Master Builders Solutions Canada, Inc.
1800 Clark Boulevard
Brampton, Ontario L6T 4M7
CANADA ■ 289-360-1300

CSS-BCG

Bidirectional Carbon Grid

SIMPSON Strong-Tie®

DESCRIPTION

CSS-BCG is a bidirectional, high-strength, non-corrosive carbon grid designed to be field installed with CSS-CM cementitious matrix to create a fabric-reinforced cementitious matrix (FRCM) composite for structural reinforcement applications. This product has been evaluated per ICC-ES AC434 for concrete and unreinforced masonry strengthening and is part of the tested assembly in UL Design No. N859, which achieved a four-hour fire rating when subjected to ASTM E119 / UL 263 full-scale fire testing. Please refer to UL Online Certifications Directory for the UL listing.

CODES

ICC-ES ESR-3506

ICC ES

MATERIAL PROPERTIES

Grid Properties (in each direction)

Weight	3.9 oz./yd.^{2} (130 g/m^2)
Weight of fibers	2.4 oz./yd.^{2} (80 g/m^2)
Equivalent Dry Fabric Thickness	0.0017 in. (0.044 mm)
Ultimate Tensile Strength	9.5 kip/ft. (138 kN/m)
Ultimate Tensile Strain	1.5%
Axial Stiffness by width unit	633 kip/ft. (9,200 kN/m)
Area by width unit	0.0017 in.^{2}/in. (44 mm^2/m)
Color	Gray

Cured Composite Properties[1]

Property	Design Value[2]
Cracked Tensile Modulus	7.0×10^6 psi (48,300 MPa)
Ultimate Tensile Strain	1.1%
Ultimate Tensile Strength	143,000 psi (986 MPa)
Lap Tensile Strength	114,000 psi, 12" lap (786 MPa, 30 cm)
Thickness per Layer	0.5 in. (13 mm)

1. When installed with CSS-CM cementitious matrix and 2 layers of CSS-BCG.
2. Average tensile strength and strain minus one standard deviation per ACI 549. Modulus values are average.

PERFORMANCE FEATURES

- High strength
- Ambient Cure
- Non-corrosive
- Molds to fit various shapes
- Low aesthetic impact
- Compatible with many finish coatings
- UL listed (www.ul.com/database)

APPLICATIONS

Seismic Retrofit
- Shear strengthening
- Displacement/ductility
- Life safety

Load Rating Upgrade
- Increased live loads
- New equipment
- Change of use

Damage Repair
- Deterioration/corrosion
- Blast/vehicle impact

Defect Remediation
- Size/layout errors
- Low concrete strengths

Blast Mitigation
- Progressive collapse

STRUCTURES

- Buildings
- Bridges
- Parking garages
- Chimneys
- Piers/wharfs
- Tunnels
- Pipes

ELEMENTS

- Columns
- Beams
- Slabs
- Walls
- Piles
- Pier caps

SUBSTRATES

- Concrete
- Masonry

PACKAGING

Roll Size (Width x Length)	Model No.
77 in. (1.95 m) x 164 ft. (50 m)	CSS-BCG19550

CLASSIFIED C UL US

FIRE RESISTANCE
CLASSIFICATION FOR USE IN
BEAM/SLAB REINFORCING SYSTEM
<R37897>

Design

The number of layers, dimensions, and detailing of CSS-BCG shall be designed in accordance with ACI 549 or another recognized design guideline/code in order to meet the design performance specified for the application. Contact Simpson Strong-Tie for design and technical support.

Surface Preparation

Prepare surface and any exposed reinforcement per ICRI Guideline No. 310.1R. Concrete shall be prepared to achieve a minimum ¼" (6 mm) amplitude (CSP-6-9 in accordance with ICRI Guideline No. 310.2R) by means of sand blasting, shot blasting, or water blasting. Application surfaces shall be clean, sound, and free of standing water at time of application. All dust, laitance, grease, curing compounds, and other foreign materials that may hinder the bond must be removed before installation. All corners to be covered with grid and matrix shall be rounded to a ¾" (19 mm) minimum radius using a grinder. Wet the substrate for at least 24 hours to a saturated surface dry condition prior to FRCM application.

Application

CSS installation shall only be performed by contractors and personnel that have been properly trained by Simpson Strong-Tie. CSS-CM cementitious matrix is pumped and projected with traditional shotcrete equipment. If required, CSS-CM may be used to patch voids and defects no deeper than 2" (51 mm). Place ¼"–½" (6–13 mm) layer of CSS-CM cementitious matrix, then immediately set CSS-BCG grid into wet CSS-CM layer. Follow with additional layers of CSS-BCG, if required, set into ¼"–½" (6–13 mm) layers of CSS-CM. Finish with a final layer of CSS-CM at ¼"–½" (6–13 mm) thick and screed/trowel to desired finish. If a layer of matrix is allowed to cure with more layers to follow, the first layer must be cleaned with water pressure before the next matrix layer can be applied. See CSS-CM product data sheet for more detailed application and curing recommendations.

Matrix Working and Set Time

See product data sheet for the working time and set times of CSS-CM cementitious matrix.

Limitations

CSS installation shall take place only when the ambient and substrate temperatures are between 41°F (5°C) and 86°F (30°C). Installation shall be kept humid and protected against heat and wind for three to five days after application.

SAFETY PRECAUTIONS

Proper personal protection equipment (PPE) shall be worn at all times. Avoid contact with skin and eyes. Particulate masks, rubber gloves, safety glasses, and coverall suits are recommended. Refer to Safety Data Sheets (SDS) available at **strongtie.com/sds** for detailed information.

FIRST AID

Skin: Wash fibers off skin with water and soap. If fibers are embedded in the skin, remove with tweezers. Discard clothing that may contain embedded fibers. Seek medical advice if exposure results in adverse effects.

Eyes: Immediately flush with a continuous water stream for at least 20 minutes. Washing immediately after exposure is expected to be effective in preventing damage to the eyes. Seek medical advice.

Inhalation: If there is inhalation exposure to the fibers of this product, remove source of exposure and move affected person to fresh air. If the affected person is not breathing, give artificial respiration. If there is breathing difficulty, give oxygen. Seek medical advice for any respiratory problems.

Ingestion: Not expected to occur since ingestion is not a likely route of exposure for this product. If ingestion does occur, DO NOT INDUCE VOMITING. Give nothing by mouth if affected person is unconscious.
Seek medical advice.

CLEAN-UP

Dispose of material in accordance with local regulations.

SHELF LIFE

10 years from date of manufacture

STORAGE

Store material in a dry area with no exposure to moisture.

LIMITED WARRANTY

This product is covered by the Simpson Strong-Tie RPS Product Five-Year Limited Warranty, which is available at **strongtie.com/limited-warranties** or by calling Simpson Strong-Tie at (800) 999-5099.

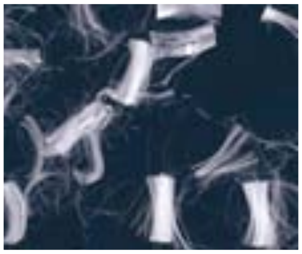
IMPORTANT INFORMATION

It is the responsibility of each purchaser and user of each Product to determine the suitability of the Product for its intended use. Prior to using any Product, consult a qualified design professional for advice regarding the suitability and use of the Product, including whether the capacity of any structural building element may be impacted by a repair. As jobsite conditions vary greatly, a small-scale test patch is required to verify product suitability prior to full-scale application. The installer must read, understand, and follow all written instructions and warnings contained on the product label(s), Product Data Sheet(s), Safety Data Sheet(s) and the **strongtie.com** website prior to use. For industrial use only by qualified applicators. KEEP OUT OF REACH OF CHILDREN!

⚠ **WARNING!** Cancer and reproductive harm — www.P65Warnings.ca.gov.

FIBERMESH® 150

PRODUCT DATA SHEET



SPECIFY FIBERMESH® 150 FIBERS:

- REDUCED PLASTIC SHRINKAGE CRACKING
- IMPROVED IMPACT, SHATTER AND ABRASION RESISTANCE
- REDUCED WATER MIGRATION AND DAMAGE FROM FREEZE/THAW
- IMPROVED DURABILITY
- AREAS REQUIRING NON-METALLIC MATERIALS
- CONCRETE THAT NEEDS AN ARCHITECTURAL FINISH

FIBERMESH® 150 SYNTHETIC FIBER

Fibermesh 150, formerly Stealth® e3®, micro-reinforcement system for concrete—100 percent virgin homopolymer polypropylene multifilament fibers containing no reprocessed olefin materials. Specifically engineered and manufactured in an ISO 9001:2000 certified facility for use as concrete reinforcement at an application rate of 1.0 to 1.5 lbs per cubic yard (.60 to .90 kg per cubic meter). UL Classified. Complies with National Building Codes and ASTM C 1116/C 1116M,Type III fiber reinforced concrete.

ADVANTAGES

Non-magnetic • Rustproof • Alkali proof • Requires no minimum amount of concrete cover • Is always positioned in compliance with codes • Safe and easy to use • Saves time and hassle.

FEATURES & BENEFITS

- Inhibits and controls the formation of intrinsic cracking in concrete
- Reinforces against impact forces
- Reinforces against abrasion
- Reinforces against the effect of shattering forces
- Reinforces against water migration
- Provides improved durability
- Reduces plastic shrinkage and settlement cracking
- Alternate system to traditional reinforcement when used for secondary (crack control) reinforcing in concrete.

PRIMARY APPLICATIONS

Applicable to all types of concrete which demonstrate a need for resistance to intrinsic cracking and improved water tightness and an aesthetic finish.

- Slabs-on-ground
- Stucco
- Slope paving
- Sidewalks
- Curbs
- Exposed aggregate
- Driveways
- Overlays & toppings

CHEMICAL AND PHYSICAL PROPERTIES

Absorption	Nil	Melt Point	324°F (162°C)
Specific Gravity	0.91	Ignition Point	1100°F (593°C)
Fiber Length*	Graded	Thermal Conductivity	Low
Electrical Conductivity	Low	Alkali Resistance	Alkali Proof
Acid & Salt Resistance	High		

*Also available in single cut lengths

FIBERMESH® 150

PRODUCT DATA SHEET

PRODUCT USE

MIXING DESIGNS AND PROCEDURES: Fibermesh® 150 micro reinforcing is a mechanical, not chemical, process.The addition of Fibermesh 150 multifilament fibers do not require any additional water or other mix design changes at normal rates. Fibermesh 150 fibers are added to the mixer before, during or after batching the other concrete materials. Mixing time and speed are specified in ASTM C 94.

FINISHING: Fibermesh 150 micro-reinforced concrete can be finished by any finishing technique. Exposed aggregate, broomed and tined surfaces are no problem.

APPLICATION RATE: The application rate for Fibermesh 150 fibers is 1.0 to 1.5 lbs per cubic yard (.60 to .90 kg per cubic meter). Note: .75 lbs per cubic yard (.44 kg per cubic meter) may be acceptable based on local building codes.

GUIDELINES

Fibermesh 150 fibers should not be used to replace structural, load-bearing reinforcement. Fibermesh 150 fibers should not be used as a means of using thinner concrete sections than original design. Fibermesh 150 fibers should not be used to increase joint spacing past those dimensions suggested by PCA and ACI industry standard guidelines.

COMPATIBILITY

Fibermesh 150 fibers are compatible with all concrete admixtures and performance enhancing chemicals, but require no admixtures to work.

PACKAGING

Fibermesh 150 fibers are available in a variety of packaging options. Special packaging is available for full truckload addition. Fibermesh 150 fibers are packaged, packed into cartons, shrinkwrapped and palletized for protection during shipping.

TECHNICAL SERVICES

Trained Propex Concrete Systems specialists are available worldwide to assist and advise in specifications and field service. Propex Concrete Systems representatives do not engage in the practice of engineering or supervision of projects and are available solely for service and support of our customers.

REFERENCE DOCUMENTS

- ASTM C 94/C 94M Standard Specification for Ready-Mixed Concrete.
- ASTM C 1116/C 1116M Standard Specification for Fiber-Reinforced Concrete.
- ASTM C 1399 Standard Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete.
- ASTM C 1436 Standard Specification for Materials for Shotcrete.
- ASTM C 1609/C 1609M Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading). Replaces ASTM C 1018.
- ACI 304 Guide for Measuring, Mixing,Transporting and Placing Concrete.
- ACI 506 Guide for Shotcrete. • International Code Council (ICC) NER-414 Evaluation Report.

CLASSIFIED UL®

UL® Classified: Type Fibermesh 150. For use as an alternate or in addition to the welded wire fabric used in Floor-Ceiling D700, D800, D900 Series Designs. Fibers may also be used in Floor-Ceiling Design Nos. G229, G243, G256, G514. Fiber added to concrete mix at a rate of 1.0 lb of fiber for each cubic yard of concrete.

SPECIFICATION CLAUSE

Use Fibermesh 150 only 100 percent virgin polypropylene multifilament fibers containing no reprocessed olefin materials and specifically engineered and manufactured in an ISO 9001:2000 certified facility for use as concrete secondary reinforcement. Application per cubic yard shall equal a minimum of 1.0 lb/yd3 (.60 kg/m3). Fibers are for the control of cracking due to plastic shrinkage, plastic settlement and thermal expansion/contraction, lowered permeability, increased impact, abrasion and shatter resistance. Fiber manufacturer shall document evidence of ten year satisfactory performance history, ISO 9001:2000 certification of manufacturing facility, compliance with applicable building codes and ASTM C 1116/C 1116M, Type III fiber reinforced concrete. Fibrous concrete reinforcement shall be manufactured Propex Operating Company, LLC, 6025 Lee Highway, Suite 425, PO Box 22788, Chattanooga,TN 37422, USA, tel: 423 892 8080, fax: 423 892 0157, web site: fibermesh.com.

Propex™ Fibermesh®

NORTH AMERICA
Propex Operating Company, LLC
6025 Lee Highway, Suite 425
Chattanooga, TN 37421
Tel: 800 621 1273
Tel: 423 892 8080
Fax: 423 892 0157

INTERNATIONAL
Propex Concrete Systems Ltd.
Propex House
9 Royal Court, Basil Close
Chesterfield, Derbyshire, S41 7SL
United Kingdom
Tel: +44 (0) 1246 564200
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Concrete Sealer

Vertical & Horizontal Concrete Surfaces

TECHNICAL DATA SHEET

Silane / Siloxane water repellent provides protection from mold, mildew, and efflorescence. Clear long lasting formula designed to seal concrete surfaces.

Rainguard® Concrete Sealer

Product Codes

LC	1Q → 2 Gal	SP-4002
LC	1Q → 5 Gal	SP-4003
Ready to Use	1 Gal	SP-4004
Ready to Use	5 Gal	SP-4005

Description

Concrete Sealer is a solvent-free, 100% active solid, silane/ siloxane repellent. Concrete Sealer forms a high-performance, deep-penetrating, alkali-resistant, and water-repellent emulsion. When applied, Concrete Sealer forms a deep water-repellent barrier within the concrete and masonry surface. This hydrophobic barrier repels water, yet remains highly vapor-permeable and allows moisture to escape. Concrete Sealer performance is not affected by weathering, UV light, or wind-driven rain. Concrete Sealer uses MICRO-LOK™ to create a micro-molecular chemical and mechanical bond between the water-repellent chemicals and the substrate. Concrete Sealer penetrates deep into porous brick and masonry surfaces for long-lasting and virtually indestructible water-repellent protection that is unaffected by weather or sunlight. It helps prevent spalling, cracking caused by freeze/thaw cycles, chloride ion intrusion, and efflorescence.

Features

- Mold and mildew inhibitor
- Protects against weathering and UV light
- Can be used on “green” concrete
- Resists damage from tires and road salts
- Contains no known carcinogens
- Breathable – does not trap moisture
- Can be used in cold temperature applications
- Will NOT yellow or turn cloudy

Benefits

- Penetrates deep – Perfect for use on sidewalks, driveways and garages
- Prevents growth of mold and mildew
- Stain resistant to oil, gas and anti-freeze
- Great winterizing agent – Protects concrete from icing and salt infiltration
- Easy to use – Same day, one coat application
- Apply in cold weather down to 40°F
- Easy clean up – Simple rinse w/ soap & water
- 0 VOC and low odor won’t harm pets or plants

Test Panel

Always apply material to a mock wall or test panel. Test wall or actual surface area to determine acceptable color, surface porosity, application rates and methods before starting application.

Coverage Rates* (Theoretical)

Substrate	Sq Ft / Gallon
Concrete Patio	150-200
Concrete Wall	150-200
Concrete Block Wall	100-150

**Extremely porous concrete may require multiple coats*

Satisfaction Guarantee

We guarantee that you will be satisfied with our products. If you are unsatisfied, we will be happy to replace the product or issue a refund. See Rainguard.com for details.

Dilution

Add clean water to concentrate ONLY
If product is Ready To Use - DO NOT DILUTE

How to Apply

1. Concrete Sealer should be applied using a hand pumped garden sprayer (do not atomize) or low-pressure airless spray equipment.
2. If using airless spray equipment we recommend a spray tip size of .035 to .051. Spray head should be held 8 to 12 inches from the surface so that the flood coat runs down the wall approximately 6-12 inches below the point of application.
3. Avoid application in windy weather.
4. Trigger gun off at the end of each pass to avoid using excessive materials. Only stop applying at corners, joints, seams, or edges
5. Multiple coats may be applied. Whiting or yellowing will not occur.

Precautions & Limitations

All concrete to be coated should be clean of any dirt and grime, efflorescence, lime run, form oils and release agents, grease, mud, excess mortar, and mold and mildew, etc. All cracks should be pointed or caulked. All voids, beeholes, concrete surface defects and openings such as conduits, pipes, drains, door frames, vents, air conditioner openings, electrical openings, control joints, or any dissimilar materials should be repaired using urethane or other approved patching.

Do not apply to concrete if moisture content is greater than 15% as measured with an electronic moisture meter. Do not apply materials in climates where freezing temperatures have existed prior to application. Allow adequate time for surfaces to thaw. Establish that air, surface, and material temperatures are above 40°F (4.4°C) and at least 5°F above the dew point prior to painting. Do not apply at temperatures below 40°F when temperatures are expected to drop below 40°F within 48 hours of application. Do not apply if rain, snow, or lower temperatures are expected within 48 hours. Do not apply if relative humidity is greater than 90%.

Store materials in a well-protected area at 45°-90°F. Avoid freezing temperatures, direct sunlight, & moisture. Keep away from heat sources.

Test Data

Wind Driven Rain	ASTM E-514-86., 98.7% Leak Red
Water Pen Fed Spec	SS-W-110C, 75% Min Req, 96.8 Leak Red Chloride Ion Intr
Salt Pounding NCHRP	No. 244 Series IV - 95% Red No. 244 Series II - 83% Red
Water Abs CMU ASTM C140-75	98.6% Effective
Water Vapor Trans ASTM D-1653-71	100% Vapor Perm
Water Repellency ASTM C67-87	98.6% Effective
Weathering ASTM G-53	3,500 Hours - No Change
Surface Burning ASTM E84	Flame Spread 0, Smoke Development 0

Technical Data

Material Type	Silane/Siloxane
Active Content	100%
Volume Solids	40 or 80%(Depends on Dilution)
Color of Material	Milky White
Odor	Slight Odor
V.O.C.	0 g/L V.O.C. Compliant
Flash Point	Non-Flammable
pH Value	6
Viscosity	9.6 Seconds No. 4 Ford Cup
Weight	Approximately 8.7 lbs./Gal.
Surface Dry/Recoat	Approx 1 Hour
Full Chemical Cure	5 to 7 days

Rainguard® Concrete Sealer

Disclaimer

Rainguard Brands, LLC guarantees that this product is free from manufacturing defects and complies with our published specifications. In the event that the buyer proves that the goods received do not conform to these specifications or were defectively manufactured, the buyer's remedies shall be limited to either the return of the goods and repayment of the purchase price or replacement of the defective material at the option of the seller. Rainguard Brands, LLC makes no other warranty, expressed or implied, and all warranties of merchantability and fitness for a particular purpose are hereby disclaimed. Manufacturer or seller shall not be liable for prospective profits or consequential damages resulting from the use of this product. Manufacturer shall not be liable for material used outside of its shelf life. For product dating, please refer to the batch number on the product or contact Rainguard Brands, LLC.

Surface conditions and application variables are out of the control of Rainguard Brands, LLC. As such, the applicator agrees to: Follow recommended application instructions, acknowledge limitations outlined in this technical data sheet, contact the manufacturer in the event there any uncertainties, perform a test panel to confirm fit and finish before any general application. The data on this sheet represents typical values. Since application variables are a major factor in product performance, this information should serve only as a general guide. Rainguard Brands assumes no obligation or liability for use of this information.

<<END>>

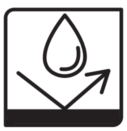
FOAMULAR® NGX® 250

EXTRUDED POLYSTYRENE (XPS) RIGID FOAM INSULATION

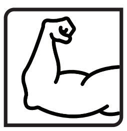
Owens Corning® FOAMULAR® NGX® 250 Extruded Polystyrene (XPS) insulation is a closed-cell, moisture-resistant rigid foam board well suited to meet the needs of a wide variety of building applications[1]. This includes both above-and below-grade residential and commercial applications, such as cavity wall, precast concrete, foundation wall, under slab, and other insulation uses.

1 Not for use in flat or low-slope roofing. For low-slope roofing applications, use FOAMULAR® NGX® THERMAPINK® 25 or FOAMULAR® NGX® 400/600/1000 Extruded Polystyrene (XPS) Rigid Foam insulation.

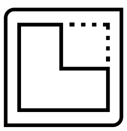
Features



SUPERIOR MOISTURE RESISTANCE



DURABLE



EASY TO CUT, FORM & FIT

Standards, Codes Compliance

- Meets ASTM C578 Type IV
- Tested to ASTM E330 per ANSI/ABTG FS100 for sheathing applications
- UL Classification Certificate U-197, Certification is available at www.owenscorning.com/U197
- Code Evaluation Report UL ER8811-01, Report is available at www.owenscorning.com/UER8811-01
- ASTM E119 Fire Resistance Rated Wall Assemblies
- Meets California Quality Standards; HUD UM #71a

Applications

- Under slabs
- Perimeter/foundation walls
- Cavity walls
- Precast walls
- Weather-resistant barrier (when joints are sealed)
- Wall Sheathing[2]

2 See technical bulletin.

Physical Properties[3]

PROPERTY	TEST METHOD[4]	VALUE
Thermal Resistance,[5] R-Value, hr•ft²•°F/Btu (RSI, °C•m²/W) @ 75°F (24°C) mean temperature	ASTM C518	5.0 (0.88)
@ 40°F (4.4°C) mean temperature		5.4 (0.95)
@ 25°F (-3.9°C) mean temperature		5.6 (0.99)
Long-Term Thermal Resistance, LTTR-Value,[6] minimum hr•ft²•°F/Btu (RSI, °C•m²/W) @ 75°F (24°C) mean temperature	CAN/ULC S770-03	5.0 (0.88)
Compressive Strength,[6] minimum psi (kPa)	ASTM D1621	25 (172)
Flexural Strength,[7] minimum psi (kPa)	ASTM C203	50 (345)
Water Absorption,[8] maximum % by volume	ASTM C272	0.3
Water Vapor Permeance,[9] maximum perm (ng/Pa•s•m²)	ASTM E96	1.5 (86)
Dimensional Stability, maximum % linear change	ASTM D2126	2.0
Flame Spread[10, 11]	ASTM E84	10
Smoke Developed[10, 11]	ASTM E84	175
Oxygen Index,[10] minimum % by volume	ASTM D2863	24
Service Temperature, maximum °F (°C)	-	165 (74)
Linear Coefficient of Thermal Expansion, in/in/°F (m/m/°C)	ASTM E228	3.5×10^{-5} (6.3×10^{-5})

3 Properties shown are representative values for 1-inch-thick material, unless otherwise specified. Extruded Polystyrene Insulation may exhibit different physical properties based upon thickness. Certain physical properties are listed by minimum and maximum values per ASTM C578. For details on specific Test Methods, please contact Owens Corning at 1-800-GET-PINK.
4 Modified as required to meet ASTM C578.
5 R means the resistance to heat flow; the higher the value, the greater the insulation power. This insulation must be installed properly to get the marked R-value. Follow the manufacturer's instructions carefully. If a manufacturer's fact sheet is not provided with the material shipment, request this and review it carefully. R-values vary, depending on many factors, including the mean temperature at which the test is conducted and the age of the sample at the time of testing. The U.S. FTC requires the R-value of home insulation to be measured at 75°F mean temperature. R-value claims should always be compared at the same mean temperature. Because rigid foam plastic insulation products are not all aged in accordance with the same standards, it is useful to publish comparison R-value data. The R-value for FOAMULAR® NGX® XPS insulation is provided from testing at mean temperatures of: -4°C (25°F), 4.4°C (40°F), and 24°C (75°F), and aging techniques of 180-day real-time aged (as mandated by ASTM C578) and accelerated aging "Long-Term Thermal Resistance" (LTTR) per CAN/ULC S770-03.
6 Value at yield or 10% deflection, whichever occurs first.
7 Value at yield or 5%, whichever occurs first.
8 Data ranges from 0.00 to value shown due to the level of precision of the test method.
9 Water vapor permeance decreases as thickness increases.
10 These laboratory tests are not intended to describe the hazards presented by this material under actual fire conditions.
11 Data from Underwriters Laboratories Inc.® classified. See Classification Certificate U-197.

Product and Packaging Data

MATERIAL Extruded polystyrene closed-cell foam, ASTM C578 Type IV, 25 psi minimum			**PACKAGING** Shipped in poly-wrapped units with individually wrapped or banded bundles					
THICKNESS (IN)	**PRODUCT DIMENSIONS THICKNESS X WIDTH X LENGTH (IN)**	**PALLET (UNIT) DIMENSIONS (TYPICAL) WIDTH X LENGTH X HEIGHT (FT)**	**SQUARE FT PER PALLET**	**BOARD FT PER PALLET**	**BUNDLES PER PALLET**	**PIECES PER BUNDLE**	**PIECES PER PALLET**	**EDGES**
¾ (R-4)	¾ x 24 x 96 (half unit)	4 x 8 x 4	1,920	1,536	4	30	120	Square Edge
	¾ x 48 x 96 (half unit)	4 x 8 x 4	1,920	1,536	2	30	60	Scored Square Edge
1	1 x 24 x 96	4 x 8 x 4	1,536	1,536	8	24	96	Tongue & Groove
	1 x 48 x 96	4 x 8 x 8	3,072	3,072	8	12	96	
	1 x 48 x 96 (half unit)	4 x 8 x 8	1,536	1,536	4	12	48	
	1 x 48 x 108	4 x 9 x 8	3,456	3,456	8	12	96	
1½	1.5 x 24 x 96	4 x 8 x 8	2,048	3,072	8	16	128	
	1.5 x 48 x 96	4 x 8 x 8	2,048	3,072	8	8	64	
2	2 x 24 x 96 (half unit)	4 x 8 x 4	768	1,536	4	12	48	
	2 x 24 x 108	4 x 9 x 8	1,728	3,456	8	12	96	
	2 x 48 x 96	4 x 8 x 8	1,536	3,072	8	6	48	
2½	2.5 x 24 x 96	4 x 8 x 8	1,152	2,880	8	9	72	
	2.5 x 48 x 96	4 x 8 x 8	1,152	2,880	4	9	36	
3	3 x 24 x 96	4 x 8 x 8	1,024	3,072	8	8	64	
	3 x 48 x 96	4 x 8 x 8	1,024	3,072	8	4	32	
4	4 x 24 x 96	4 x 8 x 8	768	3,072	8	6	48	
	4 x 48 x 96	4 x 8 x 8	768	3,072	8	3	24	

Available lengths and edge configurations vary by thickness. Other sizes may be available upon request. Consult your local Owens Corning representative for availability.

Technical Information

- FOAMULAR® NGX® XPS insulations are non-structural materials and must be installed on framing that is independently braced and structurally adequate to meet required construction and service-loading conditions.
- FOAMULAR® NGX® XPS insulations can be exposed to the exterior during normal construction cycles. During that time, some fading of color may begin due to UV exposure, and if exposed for extended periods of time, some degradation or "dusting" of the polystyrene surface may begin. It is best if the product is covered within 60 days to minimize degradation. Once covered, the deterioration stops, and damage is limited to the thin top surface layers of cells. Cells below are generally unharmed and still useful insulation.
- FOAMULAR® NGX® XPS insulations have a maximum service temperature of 165°F. Install only as much FOAMULAR® NGX® XPS insulation as can be covered in the same day. For horizontal applications, always turn the print side down so the black print does not show to the sun, which may at times act as a solar collector, raising the temperature of the foam under the print to an unacceptable level.
- Do not cover FOAMULAR® NGX® XPS insulation, either stored (factory-wrapped or unwrapped) or partially installed, with dark-colored (non-white) or clear (non-opaque) coverings and leave it exposed to the sun. Examples of such coverings include but are not limited to filter fabrics, membranes, temporary tarps, clear polyethylene, etc. If improperly covered and exposed to the right combination of sun, time, and temperature, FOAMULAR® NGX® XPS insulation deformation damage may occur rapidly. See "FOAMULAR® NGX® Extruded Polystyrene (XPS) Insulation Heat Buildup Due to Solar Exposure Technical Bulletin" for more information.
- This product is combustible. A protective barrier or thermal barrier is required to separate this product from interior living or conditioned spaces as specified in the appropriate building code.
- All construction should be evaluated for the necessity to provide vapor retarders. See current ASHRAE Handbook of Fundamentals.

Limited Warranty

FOAMULAR® NGX® XPS insulation limited lifetime warranty maintains 90% of its R-value for the lifetime of the building and covers all ASTM C578 properties. See "FOAMULAR® NGX® Extruded Polystyrene Insulation Lifetime Limited Warranty" for complete details, limitations, and requirements.

RECYCLED CONTENT MATTERS

Scan to learn more

Certifications

- Certified by SCS Global Services to contain pre-consumer recycled content.
- GREENGUARD Certified products are certified to GREENGUARD standards for low chemical emissions into indoor air during product usage. For more information, visit ul.com/gg.
- Environmental Product Declaration (EPD) has been certified by SCS Global Services. EPD #SCS-EPD-09753.
- Utilizing FOAMULAR® NGX® XPS insulation can help builders achieve green building certifications, including the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) certification.
- UL CERTIFIED — See Bulk Shipment Certificate U-197 available at www.owenscorning.com/U197.
- FOAMULAR® NGX® 250 XPS Insulation has earned the EPA's ENERGY STAR certification.

Environmental and Sustainability

Owens Corning is a worldwide leader in building material systems, insulation, and composite solutions, delivering a broad range of high-quality products and services. Owens Corning is committed to driving sustainability by delivering solutions, transforming markets, and enhancing lives. More information can be found at www.owenscorning.com.

FOAMULAR® NGX® XPS insulation use blowing agents with zero ozone depletion potential.

Detailed environmental information on the lifecycle of this product can be found in product's Environmental Product Declaration:

- "FOAMULAR® NGX® XPS Insulation Environmental Product Declaration"

Disclaimer of Liability

Technical information contained herein is furnished without charge or obligation and is given and accepted at recipient's sole risk. Because conditions of use may vary and are beyond our control, Owens Corning makes no representation about, and is not responsible or liable for, the accuracy or reliability of data associated with particular uses of any product described herein.

SCS Global Services provides independent verification of recycled content in building materials and verifies recycled content claims made by manufacturers. For more information, visit www.SCSglobalservices.com.

LEED® is a registered trademark of the U.S. Green Building Council.

Notes

Not for use in roofing. For roofing applications, use FOAMULAR® NGX® THERMAPINK® XPS insulation.

For additional information, refer to the Safe Use Instruction Sheet (SUIS) found in the SDS Database via http://sds.owenscorning.com.

OWENS CORNING FOAM INSULATION, LLC
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TOLEDO, OH 43659 USA

1-800-GET-PINK®
www.owenscorning.com

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Appendix B: Reinforcement Thickness and POA Excel Calculations

School Name:	Northern Arizona University
Canoe Name:	Pluto
Section Identifier:	CANOE WALLS/ ALL RIENFORCED SECTIONS
Hull Thickness to Reinforcement Ratio	
Reinforcement Identifier	**Thickness (in)**
CSS-BCG Bidirectional Carbon Grid	*0.0017*
Reinforcement #2	-
Reinforcement #3	-
Reinforcement #4	-
Reinforcement #5	-
Reinforcement #6	-
Reinforcement #7	-
Total Reinforcement Thickness	
Reinforcement Total Thickness (in)	*0.0017*
Section Thickness	
Total Composite Thickness (in)	*0.50*

FROM MTDS:	
Equivalent Dry Fabric Thickness (in)=	**0.0017**

Composite Percent= (Total Rienf. Thickness/ Section Thickness)*100

Verification	
Composite Ratio	*0.0034*
Composite Percent	*0.34*
	0.34% < 50%, Compliant

School Name:	Northern Arizona University
Canoe Name:	Pluto
Section Identifier:	CANOE WALLS/ ALL RIENFORCED SECTIONS
Percent Open Area	
Reinforcement Identifier	**(in)**
CSS-BCG Bidirectional Carbon Grid Length (Total)	*216.00*
CSS-BCG Bidirectional Carbon Grid Width (Total)	*18.00*
CSS-BCG Bidirectional Carbon Grid Length (Open)	*207.36*
CSS-BCG Bidirectional Carbon Grid Width (Open)	*17.28*
Reinforcement #2 Length (Total)	-
Reinforcement #2 Width (Total)	-
Reinforcement #2 Length (Open)	-
Reinforcement #2 Width (Open)	-
Reinforcement #3 Length (Total)	-
Reinforcement #3 Width (Total)	-
Reinforcement #3 Length (Open)	-
Reinforcement #3 Width (Open)	-
Total Open Area	
Cumulative Open Area	*3583.18*
Total Specimen Area	
Cumulative Speciman Area	*3888.00*

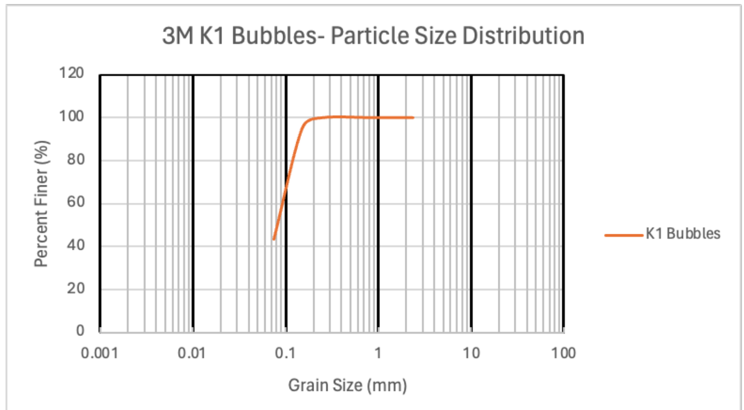
FROM MTDS:	
Area by Width of Rienforcement (in^2/in)=	**0.0017**
Length/Width Rienforcement (in/in)=	**0.04**
Length/Width Open Area (in/in)=	**0.96**
POA= (Total Open Area/ Total Specimen Area)*100	

Verification	
Speciman Percent	*92.16*
	92% > 40%, Compliant

Appendix C: Gradation of All Aggregates

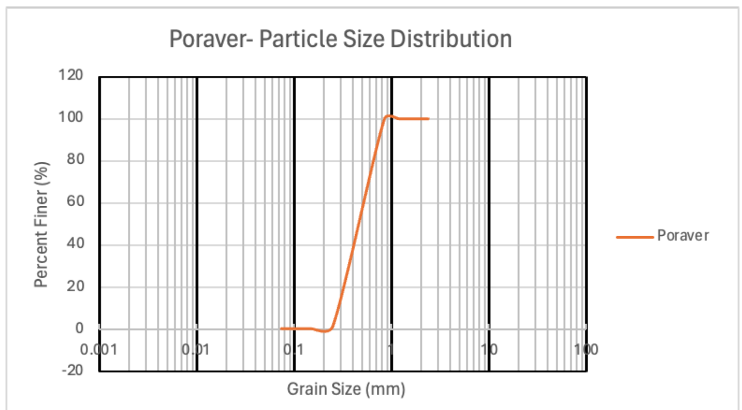
1) **3M- K1 Bubbles (Fine Aggregates)**

Sieve NO.	Sieve Size (mm)	K1 (% passing)
No. 4	4.75	100
No. 8	2.36	100
No. 16	1.18	100
No. 20	0.841	100
No. 60	0.25	100
No. 100	0.15	95.15
No. 200	0.074	43.68



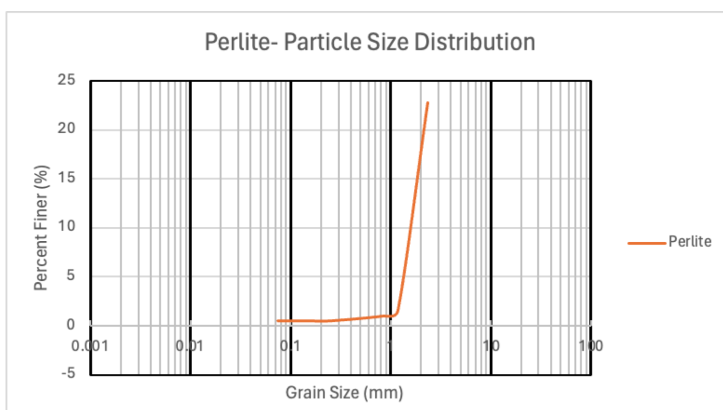
2) **Poraver (Fine Aggregate)**

Sieve NO.	Sieve Size (mm)	Poraver (% passing)
No. 4	4.75	100
No. 8	2.36	100
No. 16	1.18	100
No. 20	0.841	100
No. 60	0.25	1.34
No. 100	0.15	0.167
No. 200	0.074	0.167



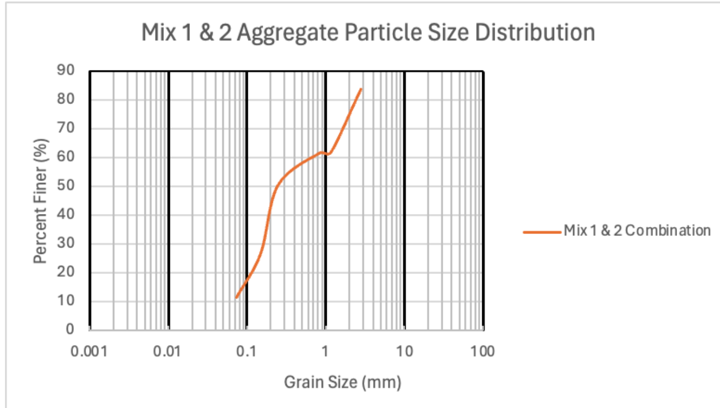
3) **Perlite (Coarse/Fine Aggregate)**

Sieve NO.	Sieve Size (mm)	Perlite (% passing)
No. 4	4.75	98.51
No. 8	2.36	22.77
No. 16	1.18	1.48
No. 20	0.841	0.99
No. 60	0.25	0.495
No. 100	0.15	0.495
No. 200	0.074	0.495



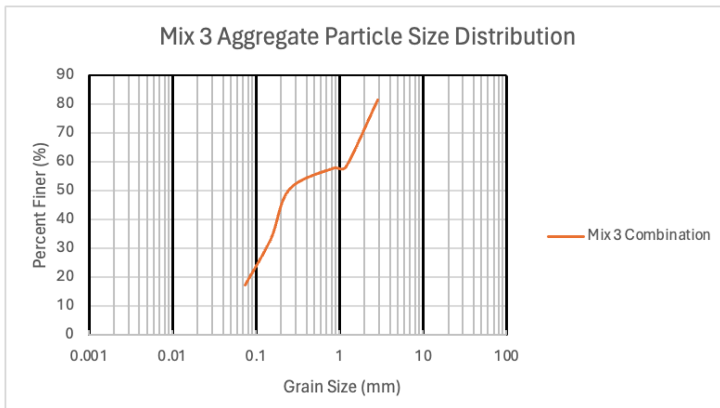
4) **Mix #1 & #2 Aggregate Combination**

Sieve NO.	Sieve Size (mm)	Mix 1 & 2 Aggregate (% passing)
No. 4	4.75	100
No. 7	2.83	83.61
No. 16	1.18	61.87
No. 20	0.841	61.53
No. 60	0.25	50.5
No. 100	0.15	26.75
No. 200	0.074	11.71



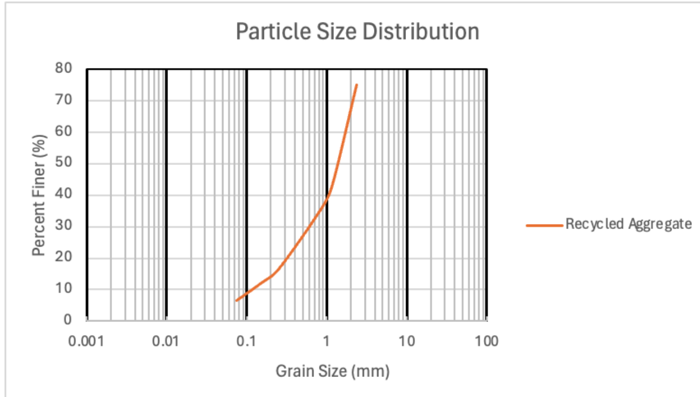
5) **Mix #3 Aggregate Combination**

Sieve NO.	Sieve Size (mm)	Mix 3 Aggregate (% passing)
No. 4	4.75	100
No. 7	2.83	81.36
No. 16	1.18	58.18
No. 20	0.841	57.72
No. 60	0.25	50.45
No. 100	0.15	33.18
No. 200	0.074	17.27



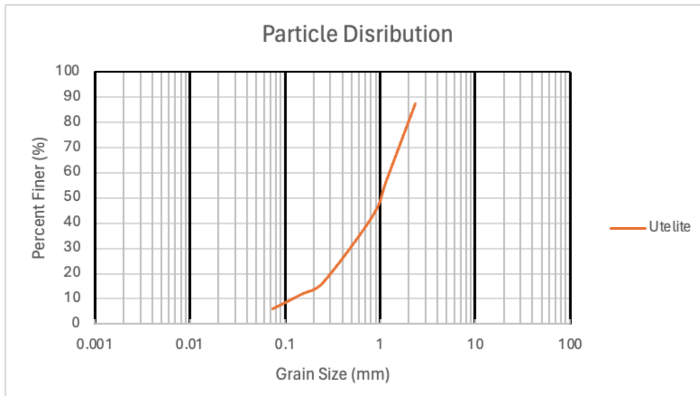
6) Recycled Aggregate* NOT USED IN FINAL MIX DESIGN

Sieve NO.	Sieve Size (mm)	% passing
No. 4	4.75	99.66
No. 8	2.36	74.96
No. 16	1.18	43.57
No. 20	0.841	35.5
No. 60	0.25	16.69
No. 100	0.15	12.19
No. 200	0.074	6.67



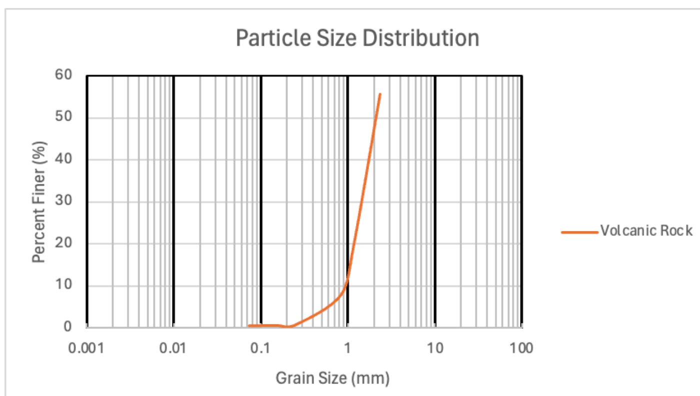
7) Utelite* NOT USED IN FINAL MIX DESIGN

Sieve NO.	Sieve Size (mm)	% passing
No. 4	4.75	99.25
No. 8	2.36	87.43
No. 16	1.18	57.29
No. 20	0.841	43.02
No. 60	0.25	16.4
No. 100	0.15	11.93
No. 200	0.074	6.075



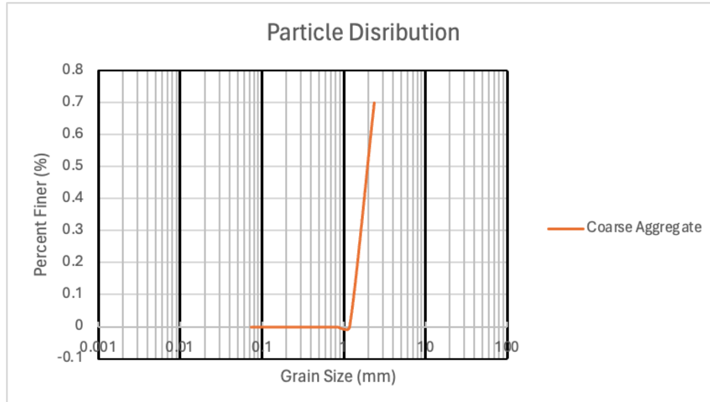
- 8) Volcanic Rock* NOT USED IN FINAL MIX DESIGN

Sieve NO.	Sieve Size (mm)	% passing
No. 4	4.75	99.72
No. 8	2.36	55.64
No. 16	1.18	19.91
No. 20	0.841	7.91
No. 60	0.25	0.73
No. 100	0.15	0.63
No. 200	0.074	0.54



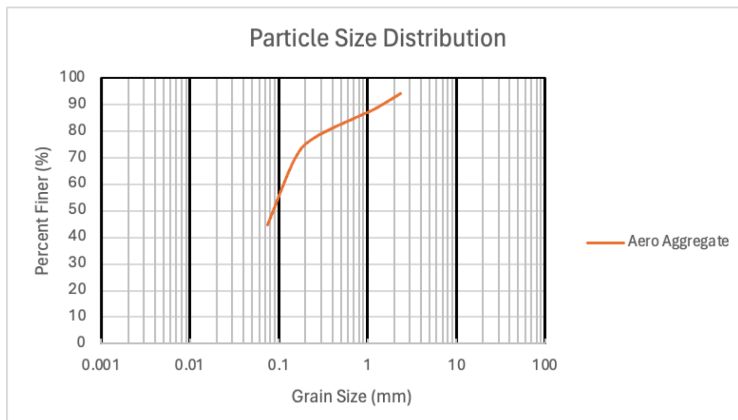
- **9) Coarse Recycled Aggregate/ Crushed Rock* NOT USED IN FINAL MIX DESIGN**

Sieve NO.	Sieve Size (mm)	% passing
No. 4	4.75	20.14
No. 8	2.36	0.69
No. 16	1.18	0
No. 20	0.841	0
No. 60	0.25	0
No. 100	0.15	0
No. 200	0.074	0



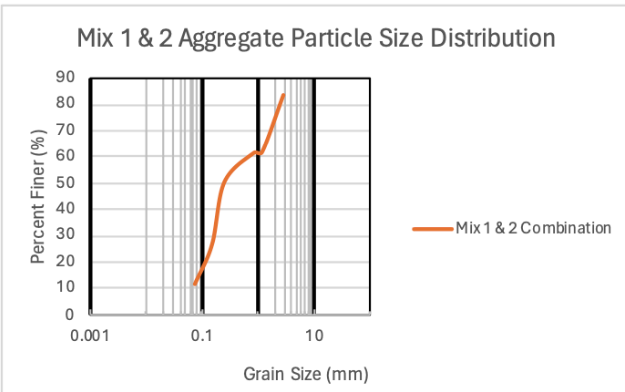
- **10) Aero Aggregate* NOT USED IN FINAL MIX DESIGN**

Sieve NO.	Sieve Size (mm)	% passing
No. 4	4.75	99.5
No. 8	2.36	94.32
No. 16	1.18	88.31
No. 20	0.841	86.14
No. 60	0.25	77.63
No. 100	0.15	69.62
No. 200	0.074	44.74



Appendix D: Sieve Analysis Example Excel Calculation

	Weight of sample (g)	Bottom Pan	#200	#100	#60	#20	#16	#7	#4	W_{ts}	Mass Lost after Testing
Weight of Pan (g)	149.5	426	298	492.5	546.5	618.5	651.5	720	520		
Weight of Pan and Sample (g)	149.5	442.5	320.5	528	563	619	684	744.5	520		
DELTA	-	16.5	22.5	35.5	16.5	0.5	32.5	24.5	0	145.9	2.40802676
Rn	-	0.11036789	15.0501672	23.745819	11.0367893	0.33444816	21.7391304	16.3879599	0		
Sum Rn	-	100	88.2943144	73.244147	49.4983278	38.4615385	38.1270903	16.3879599	0		
% finer	-	0	11.7056856	26.755853	50.5016722	61.5384615	61.8729097	83.6120401	100		
Grain Size (mm)	-	-	0.075	0.16	0.26	0.85	1.19	2.84	4.76		
Sieve Size (mm)			0.074	0.15	0.25	0.841	1.18	2.83	4.75		



Appendix E: Decision Matrix Design Criteria Calculations

Equation 1: Stability Design Matrix Criterion

$$Stability = \frac{w}{h} * N$$

Equation 2: Straight line Speed Design Matrix Criterion

$$Straightline\ Speed = L * (\frac{h}{w})$$

Equation 3: Maneuverability Design Matrix Criterion

$$Maneuverability = \frac{1}{L} * \frac{1}{R}$$

Where;

d= depth (in)

h=height (in)

L=Length (Longer=1.125, Shorter=1.0)

R=Rocker (No Rocker=1.0, Rocker=.80)

N=Notch (Notch=.75, Arch=1.0)

Appendix F: Structural Design Equations

Equation 4: Area of Half Ellipse

$$Area\ of\ Half\ Ellipse = \frac{ab\pi}{2}$$

Equation 5: Area of Center Cross Section

$$Area\ of\ Cross\ Center\ Section = \frac{AB\pi}{2} - \frac{ab\pi}{2} = \frac{18.5 * 15.5\pi}{2} - \frac{18 * 15\pi}{2} = 26.31\ in^2$$

Equation 6: Centroid of Half Ellipse

$$Centroid\ (\bar{y}) = \frac{4a}{3\pi} = \frac{4 * 18.5}{3\pi} = 7.85in; \frac{4 * 18}{3\pi} = 7.64$$

Equation 7: Centroid of Cross Section

$$Centroid\ (\bar{Y}) = \frac{\sum Ay}{\sum A} = \frac{\frac{4 * 18.5}{3\pi} * \frac{18.5 * 15.5\pi}{2} - \frac{4 * 18}{3\pi} * \frac{18 * 15\pi}{2}}{26.31} = 11.27\ in^2$$

Equation 8: MOI of Half Ellipse

$$Moment\ of\ Inertia\ of\ Half\ Ellipse = a^3 b(\frac{\pi}{8} - \frac{8}{9\pi})$$

Equation 9: Parallel Axis Theorem

$$Parallel\ Axis\ Theorem\ MOI = I + Ad^2$$

Equation 10: Bigger MOI about Centroid of Cross Section

$$Bigger\ MOI\ about\ Centroid\ (\bar{Y}) = (18.5^3 * 15.5)\left(\frac{\pi}{8} - \frac{8}{9\pi}\right) + \frac{18.5 * 15.5\pi}{2} * (11.27 - 7.85)^2 = 16041.9\ in^4$$

Equation 11: Smaller MOI about Centroid of Cross Section

$$Smaller\ MOI\ about\ Centroid\ (\bar{Y}) = (18^3 * 15)\left(\frac{\pi}{8} - \frac{8}{9\pi}\right) + \frac{18 * 15\pi}{2} * (11.27 - 7.64)^2 = 15198.84\ in^4$$

Equation 12: MOI of Cross Section

$$MOI\ (Cross\ Section) = \text{Bigger MOI-Smaller MOI} = 16041.9\ in^4 - 15198.84\ in^4 = 843.07 in^4$$

Equation 13: Area of Elliptical Segment

$$A = ab\cos^{-1}(1 - \frac{h}{a}) - ab\left(1 - \frac{h}{a}\right) * \sqrt{\frac{2h}{a} - \frac{h^2}{a^2}}$$

Where;

a=longer axis of ellipse

b= shorter axis of the ellipse

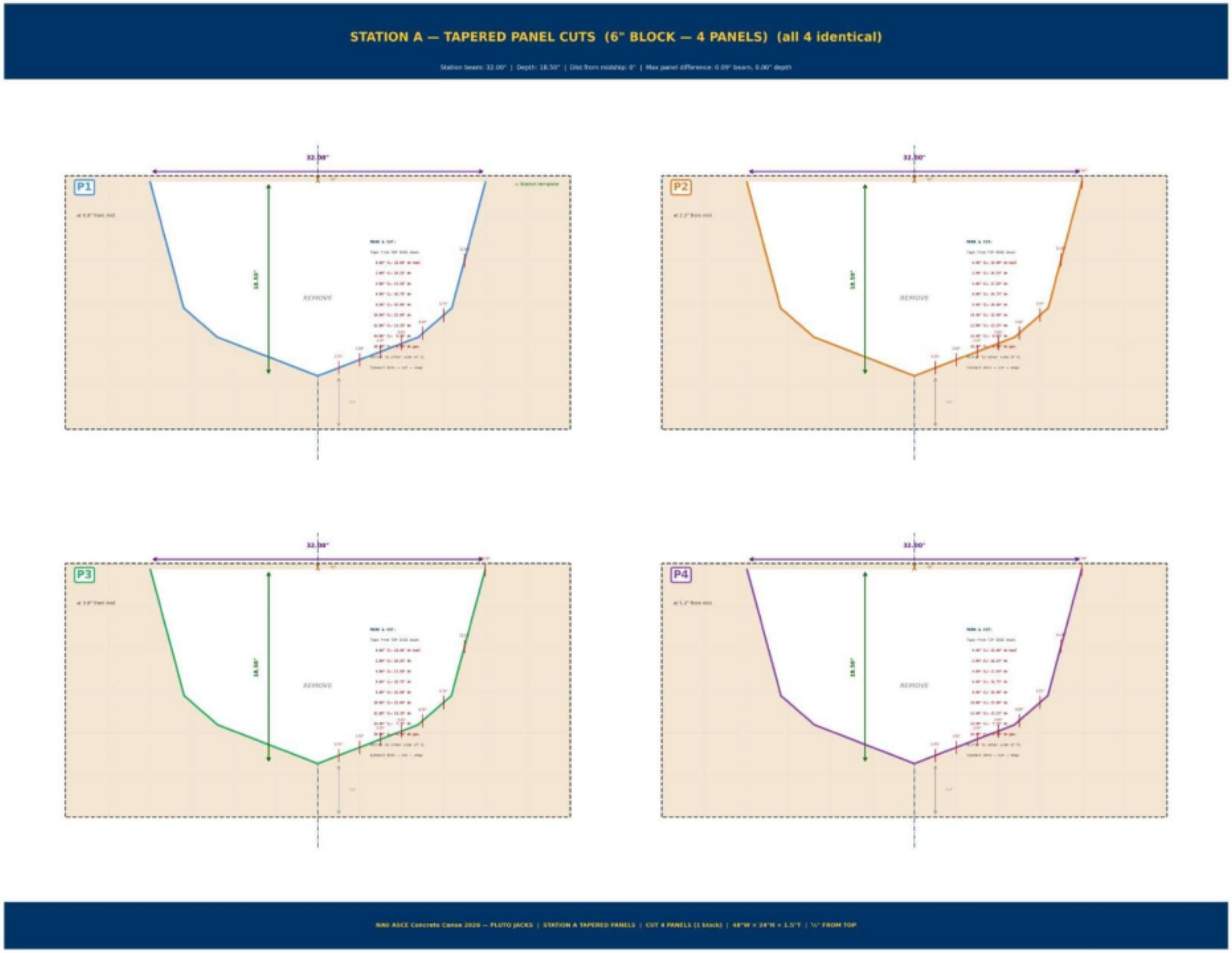
h=height of the segment

Equation 14: Flexural Stress Formula

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

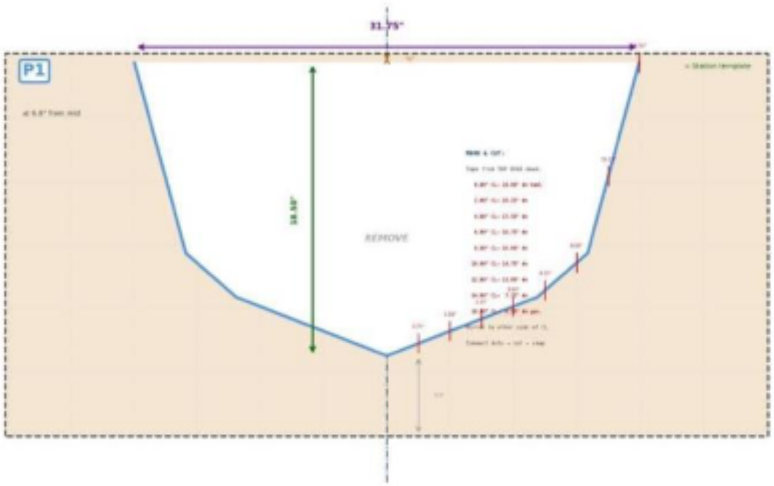
Equation 15: ACI-318 Two-Way Punching Shear Strength of Concrete without Shear Reinforcement

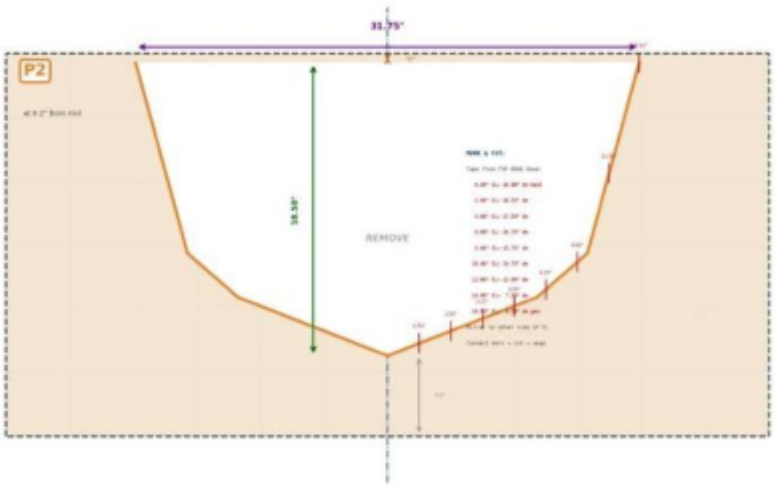
v_c		
Least of (a), (b), and (c):	$4\lambda_s\lambda\sqrt{f'_c}$	(a)
	$\left(2 + \frac{4}{\beta}\right)\lambda_s\lambda\sqrt{f'_c}$	(b)
	$\left(2 + \frac{\alpha_s d}{b_o}\right)\lambda_s\lambda\sqrt{f'_c}$	(c)

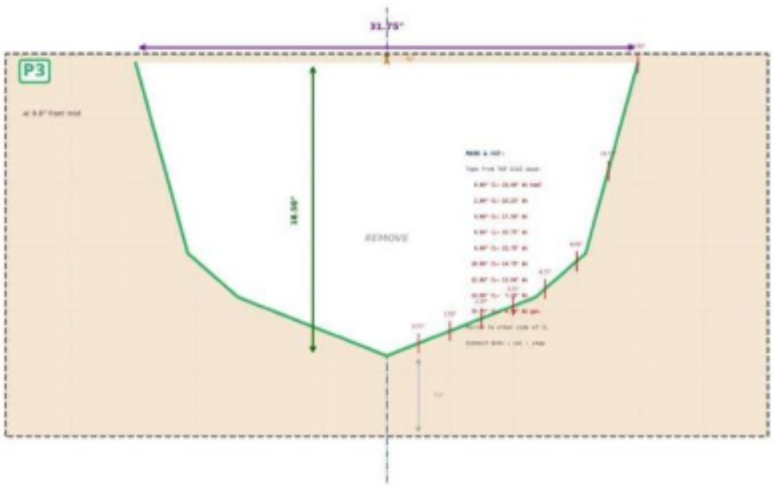

STATION A — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) (all 4 identical)
Station beam: 32.00" | Depth: 18.50" | Dist from midship: 0" | Max panel difference: 0.09" beam, 0.00" depth
P1
P2
P3
P4
32.00"
18.50"
REMOVE
NAU ASCE Concrete Canoe 2026 — PLUTO JACKS | STATION A TAPERED PANELS | CUT 4 PANELS (1 block) | 48"W × 24"H × 1.5"T | ½" FROM TOP

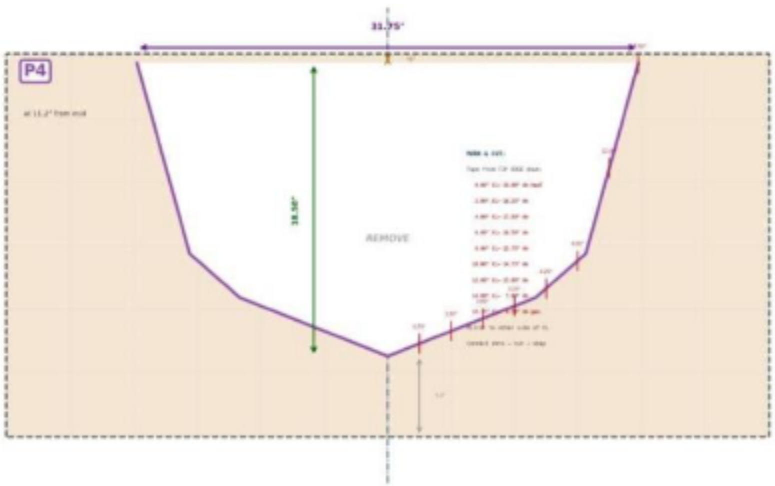
STATION B — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) (all 4 identical)

Station beam: 32.00" | Depth: 18.50" | Dist from midship: 6" | Max panel difference: 0.24" beam, 0.00" depth



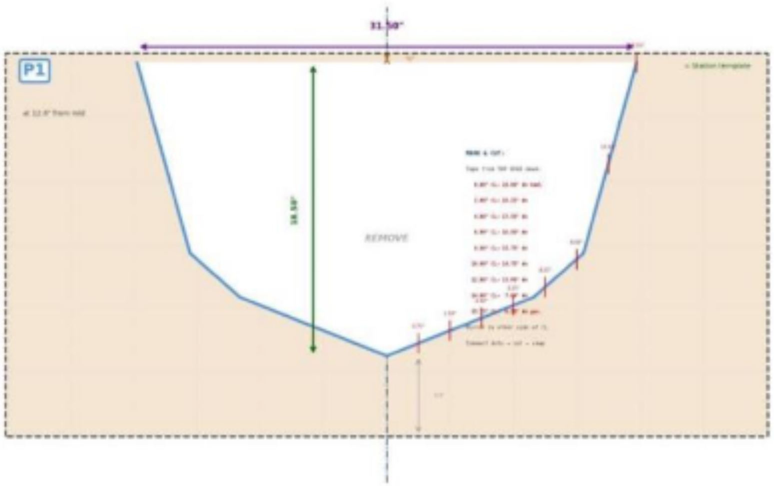


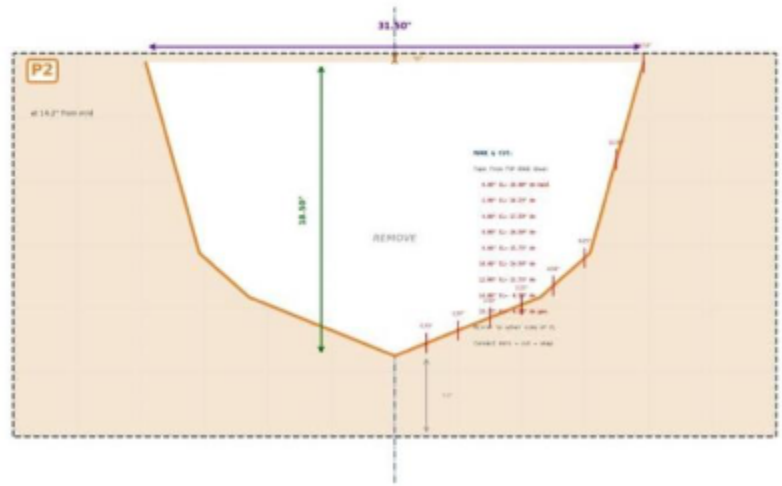


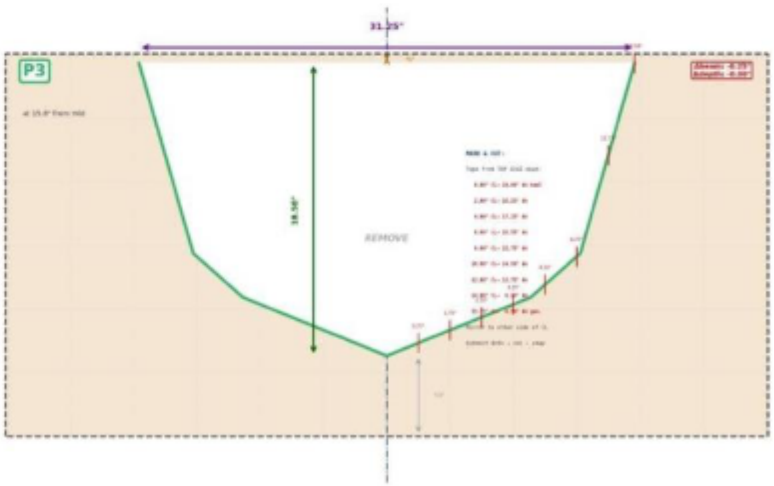


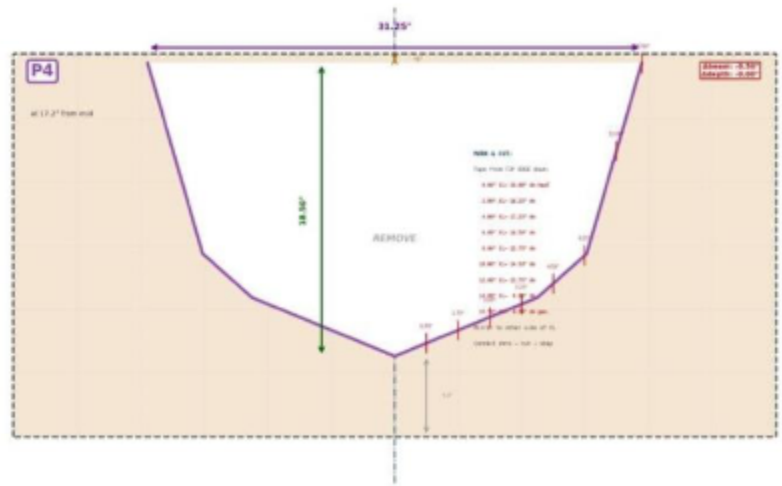
STATION C — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 31.50" | Depth: 18.50" | Dist from midship: 12" | Max panel difference: 0.42" beam, 0.00" depth





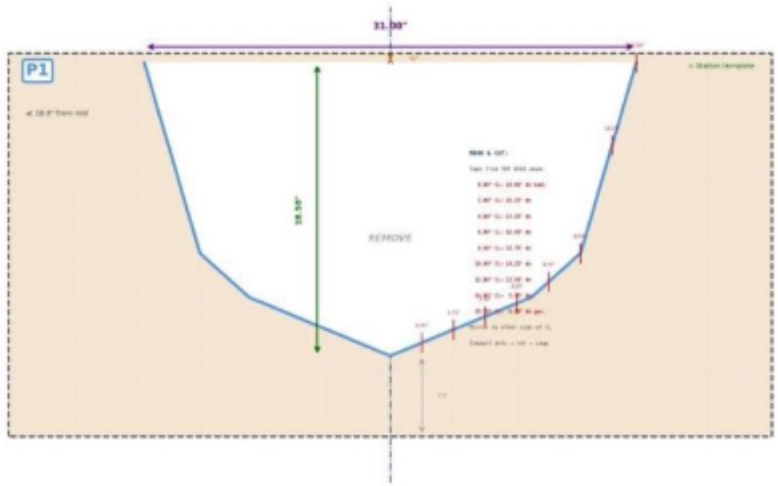


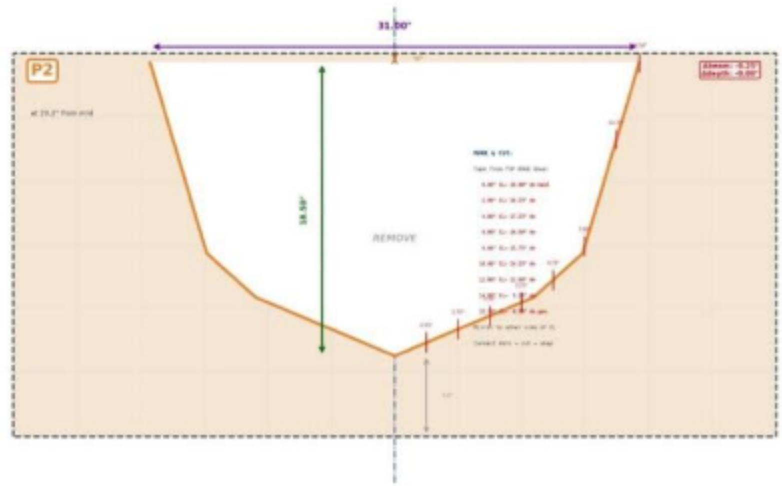


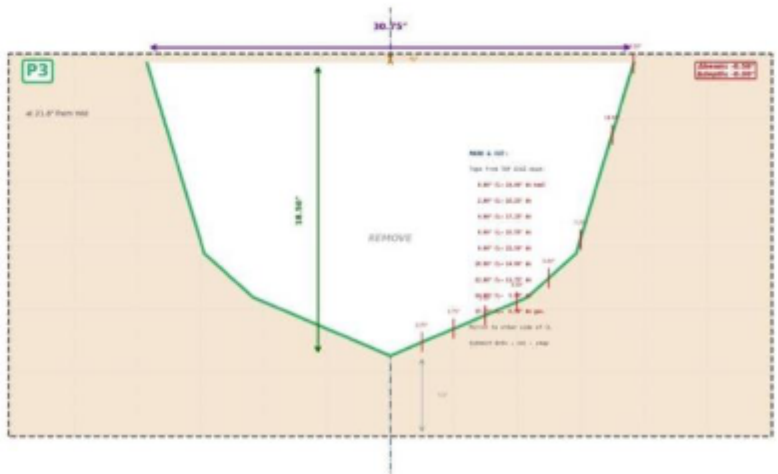
M

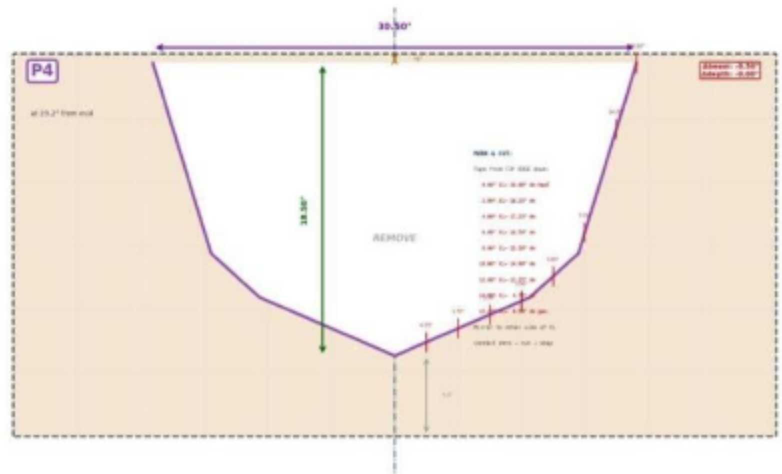
STATION D — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 31.25" | Depth: 18.50" | Dist from midship: 18" | Max panel difference: 0.59" beam, 0.00" depth





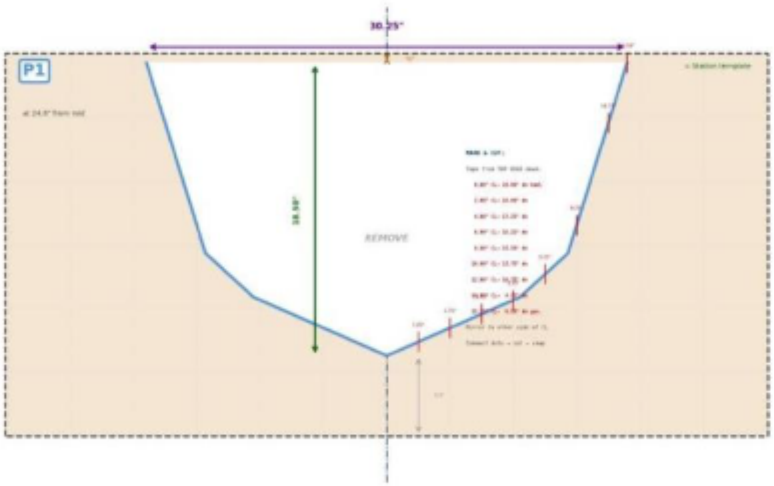


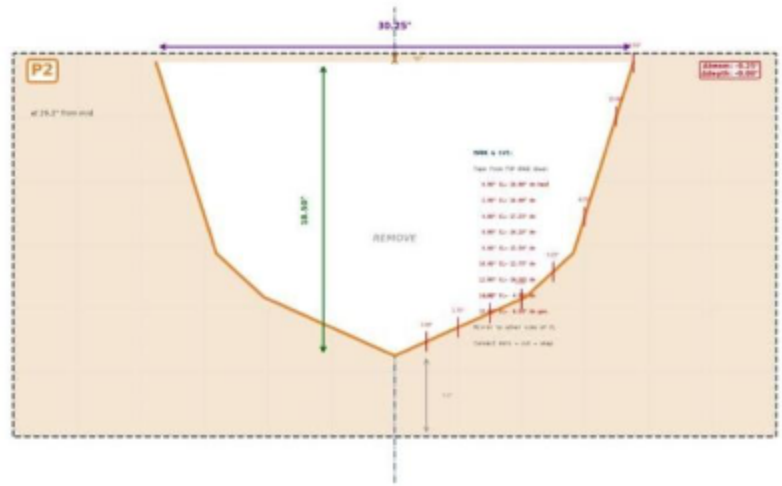


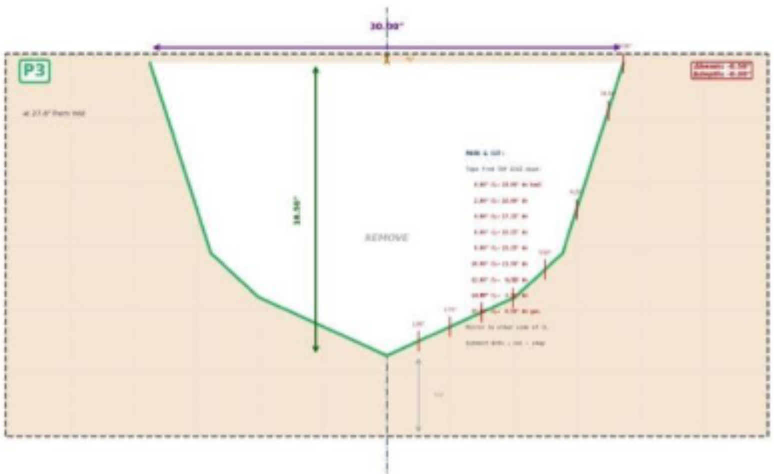
N

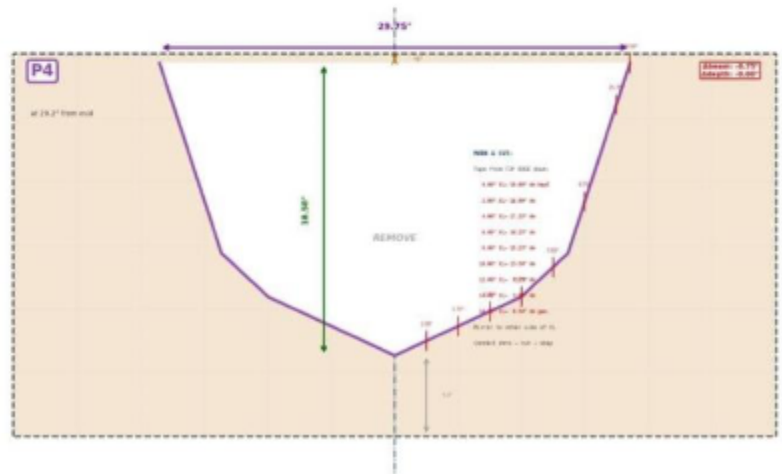
STATION E — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 30.50" | Depth: 18.50" | Dist from midship: 24" | Max panel difference: 0.75" beam, 0.02" depth





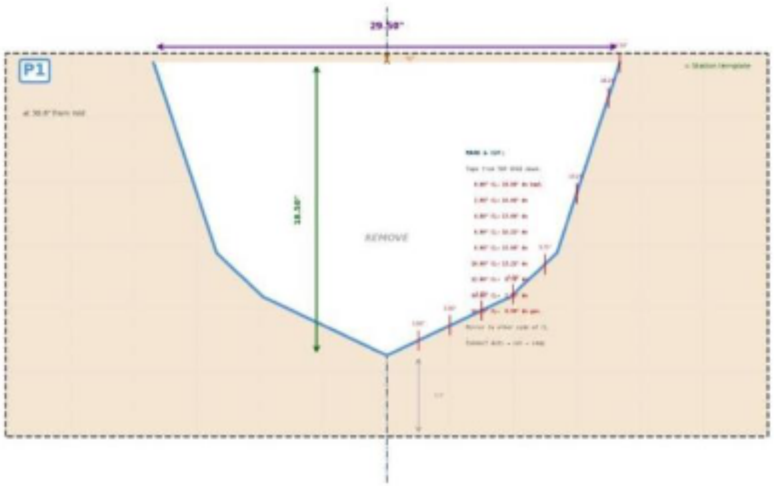


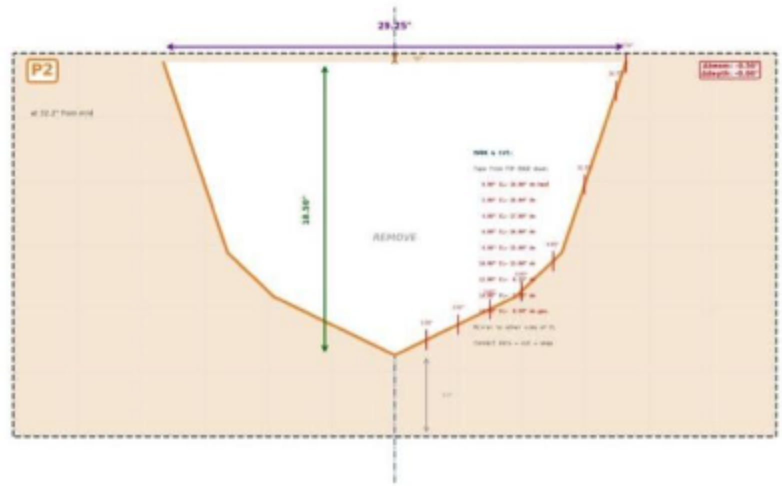


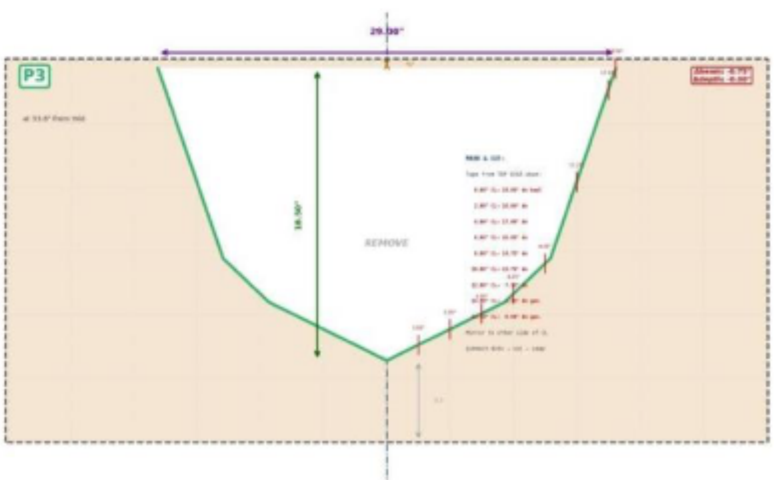
O

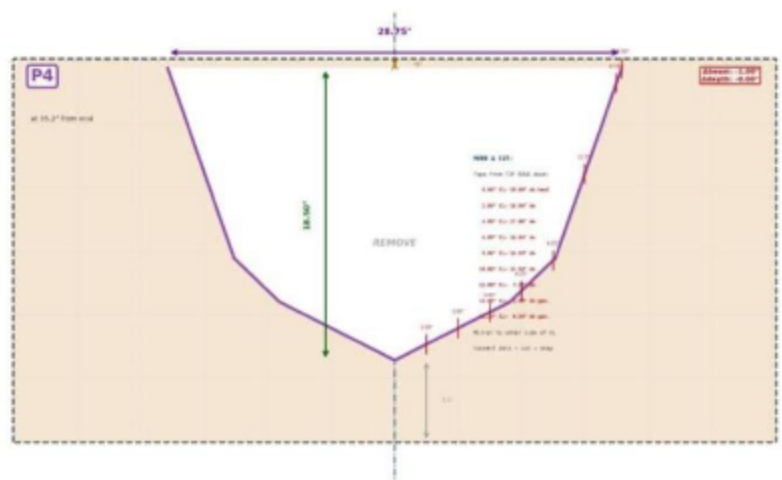
STATION F — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 29.50" | Depth: 18.50" | Dist from midship: 30" | Max panel difference: 0.95" beam, 0.06" depth





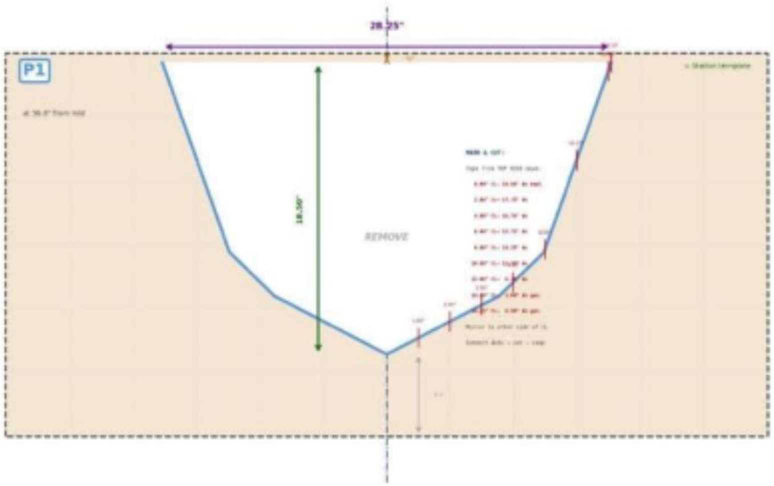


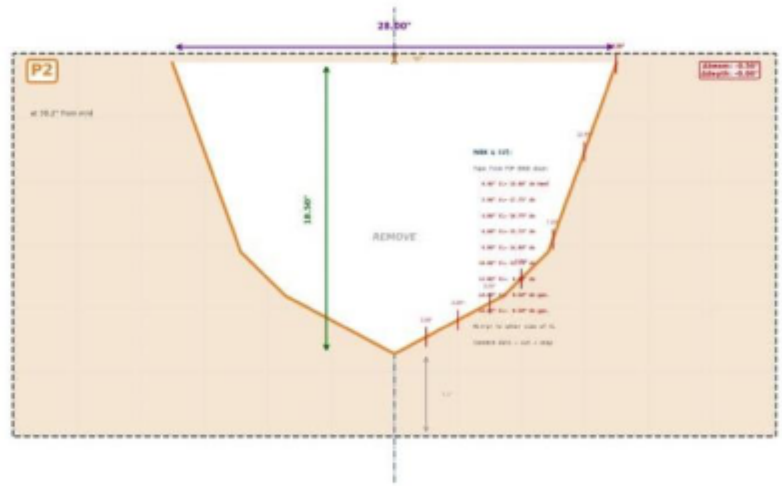


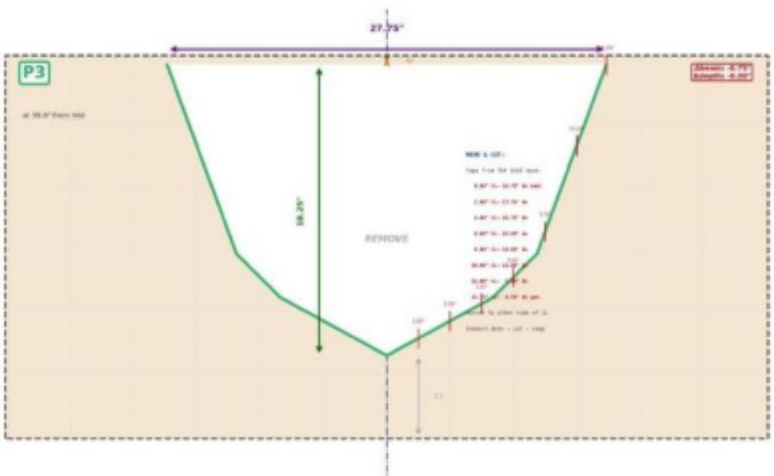
P

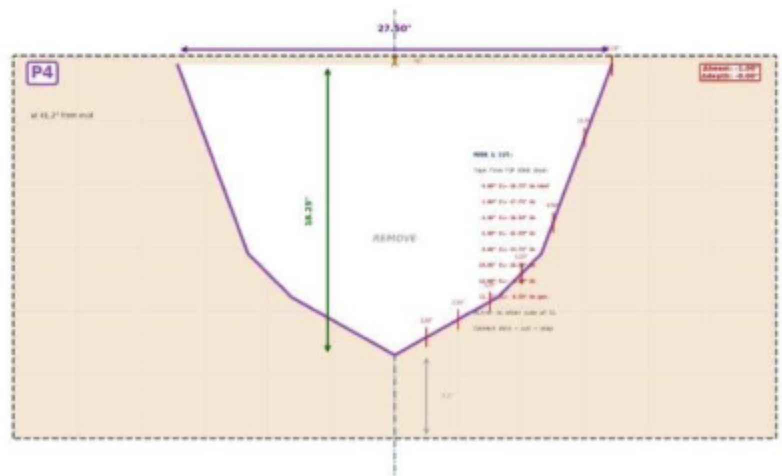
STATION G — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 28.50" | Depth: 18.50" | Dist from midship: 36" | Max panel difference: 1.10" beam, 0.08" depth







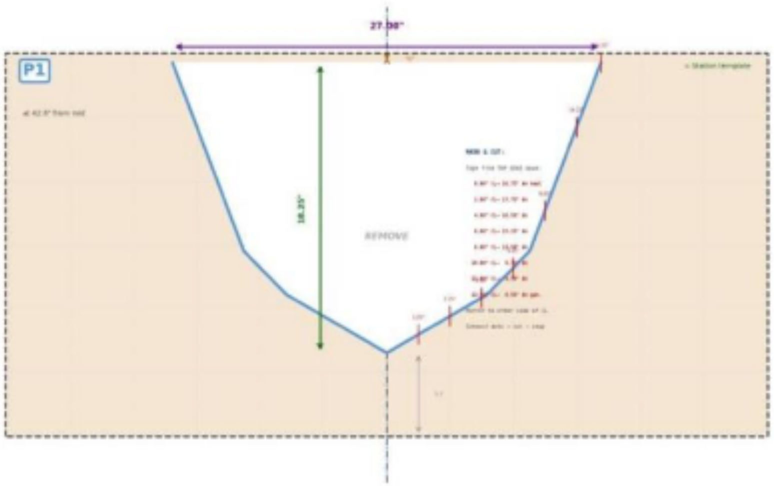


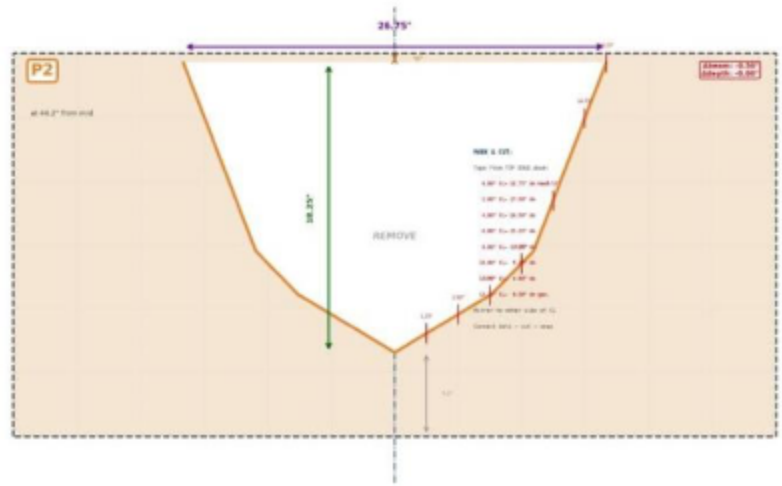
NAU ASCE Concrete Canoe 2026 — PLUTO JACKS | STATION G TAPERED PANELS | CUT 8 PANELS (2 blocks, bow + stern) | 48"W × 24"H × 1.5"T | ½" FROM TOP ⚠ EACH PANEL HAS DIFFERENT DIMENSIONS — CUT INDIVIDUALLY

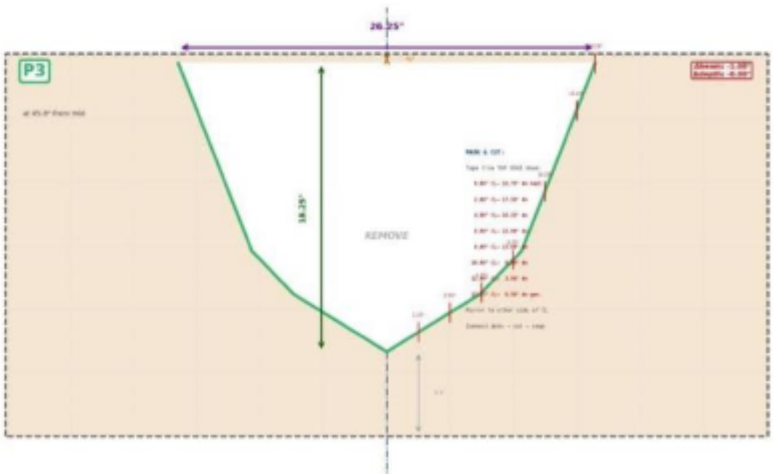
Q

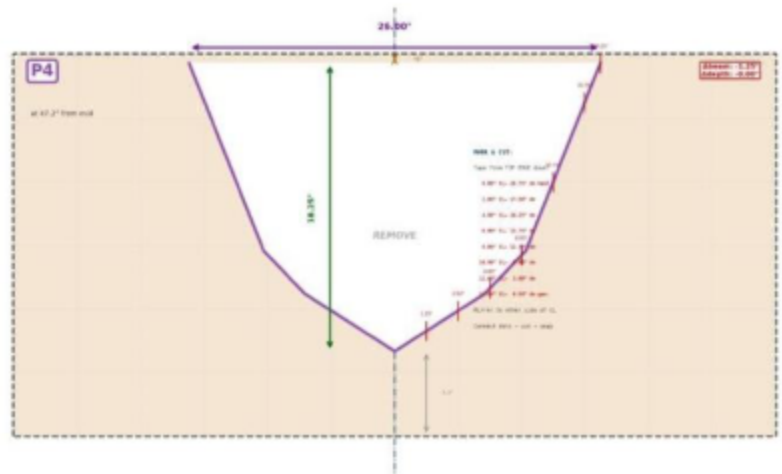
STATION H — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 27.25" | Depth: 18.25" | Dist from midship: 42" | Max panel difference: 1.30" beam, 0.11" depth





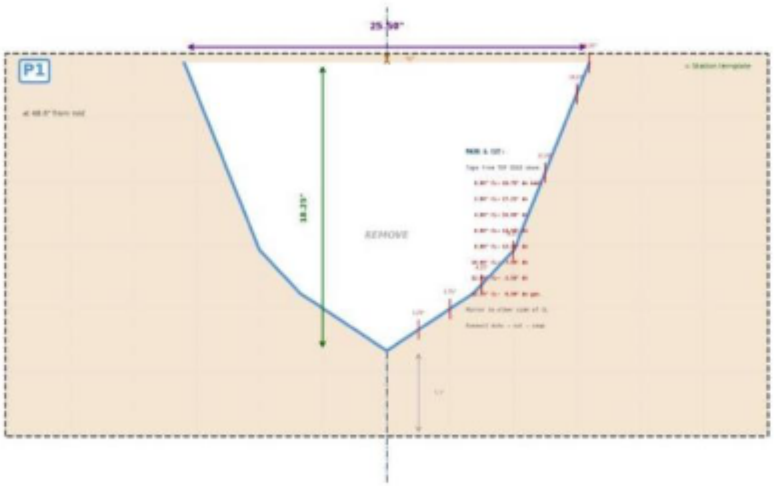


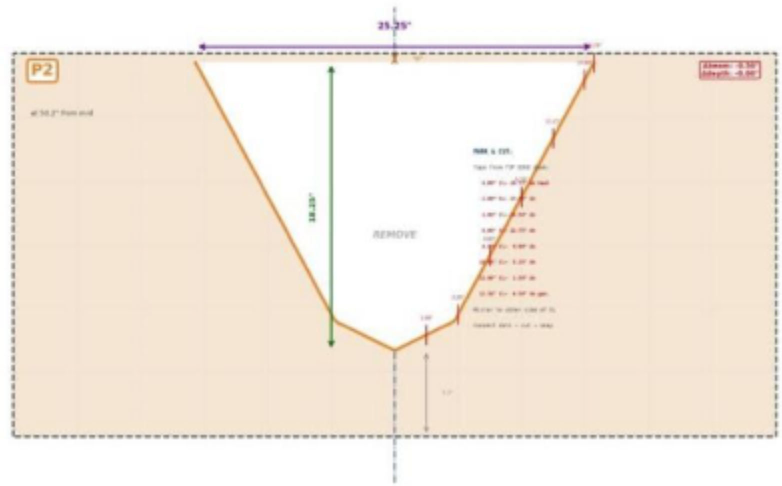


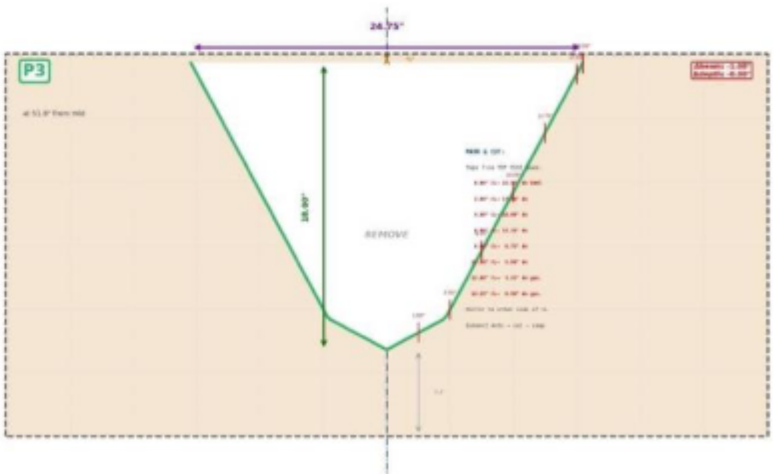
R

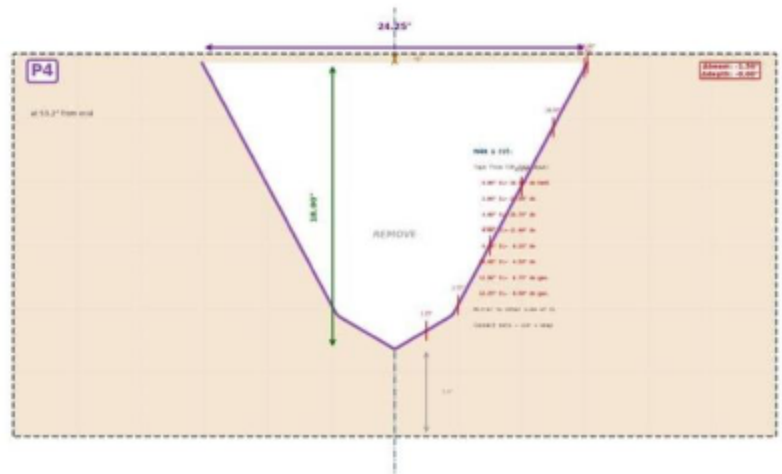
STATION I — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 25.75" | Depth: 18.25" | Dist from midship: 48" | Max panel difference: 1.45" beam, 0.11" depth



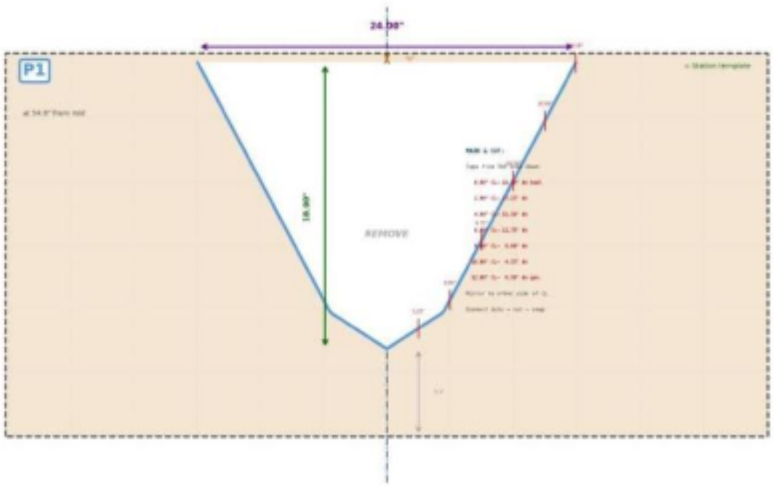


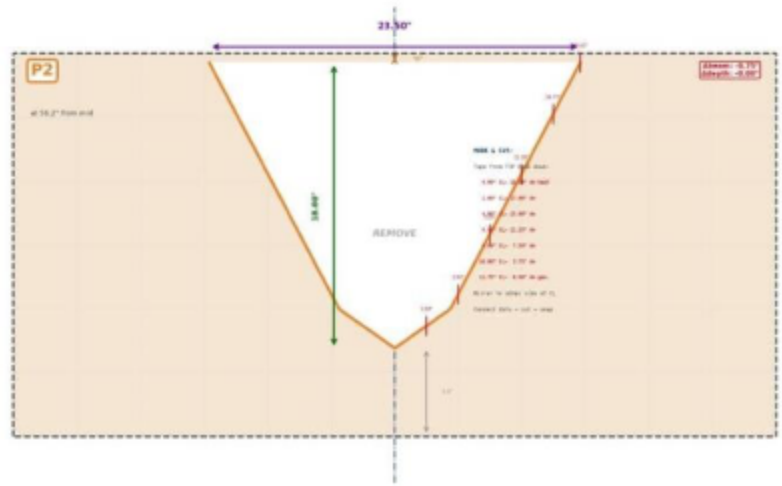


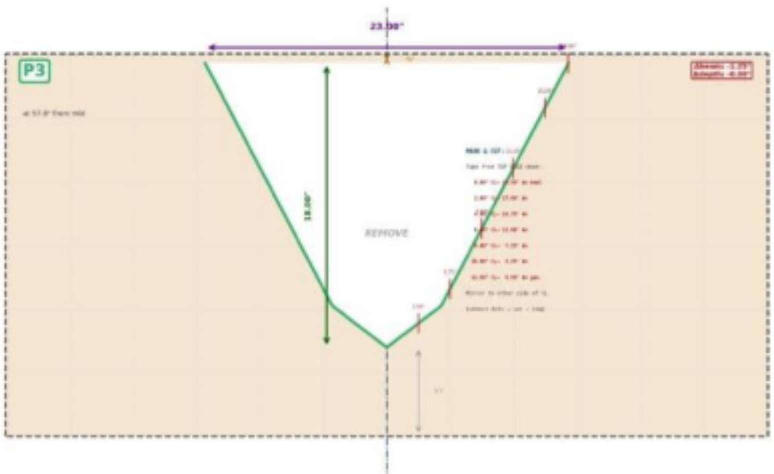


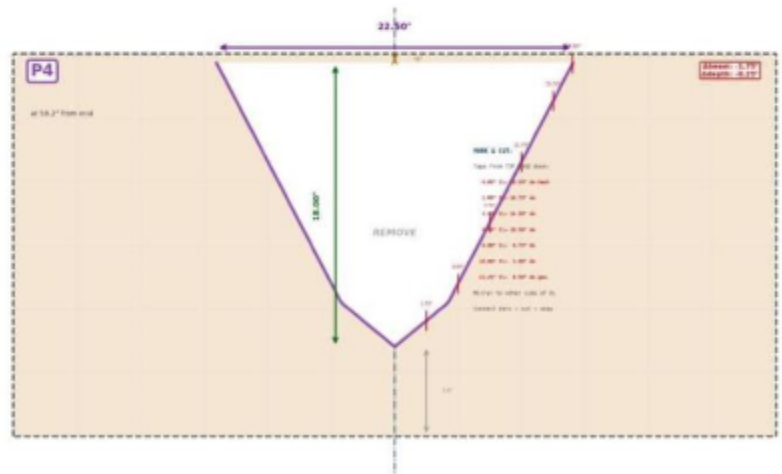
STATION J — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 24.00" | Depth: 18.00" | Dist from midship: 54" | Max panel difference: 1.63" beam, 0.14" depth







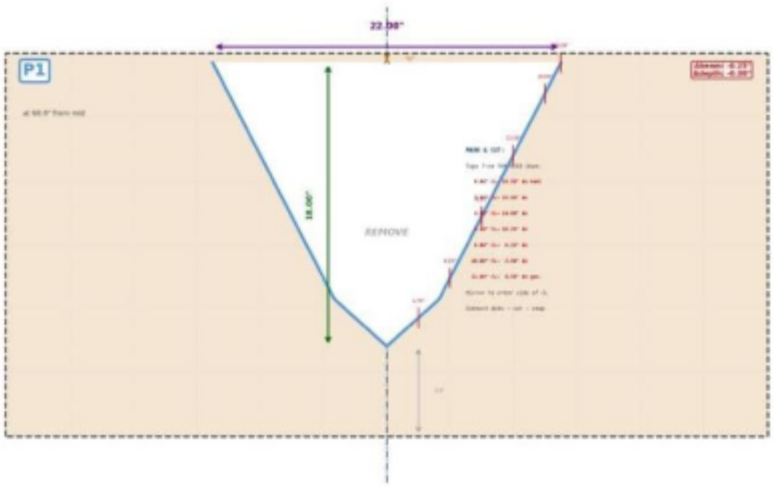


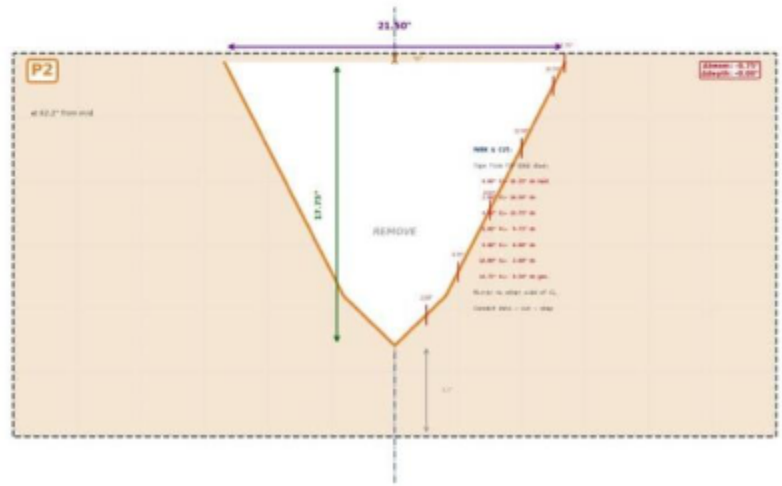
NAU ASCE Concrete Canoe 2026 — PLUTO JACKS | STATION J TAPERED PANELS | CUT 8 PANELS (2 blocks, bow + stern) | 48"W × 24"H × 1.5"T | ½" FROM TOP ⚠ EACH PANEL HAS DIFFERENT DIMENSIONS — CUT INDIVIDUALLY

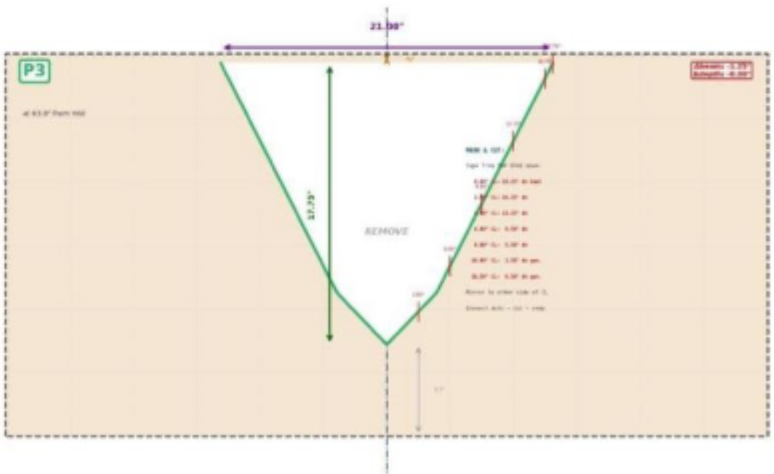
T

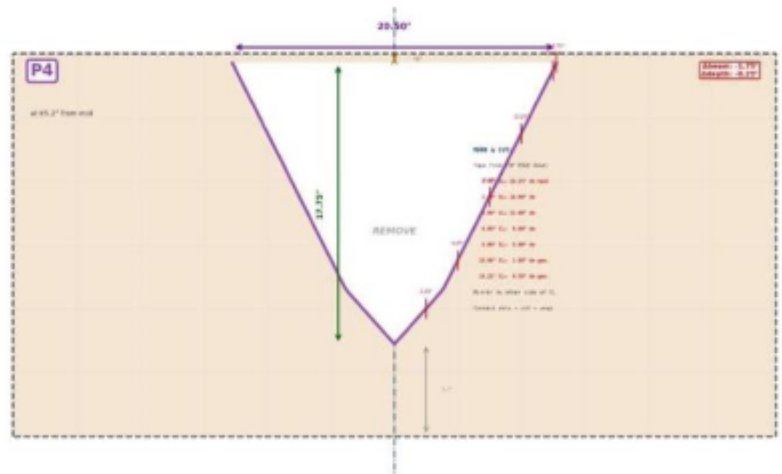
STATION K — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 22.25" | Depth: 18.00" | Dist from midship: 60" | Max panel difference: 1.79" beam, 0.16" depth





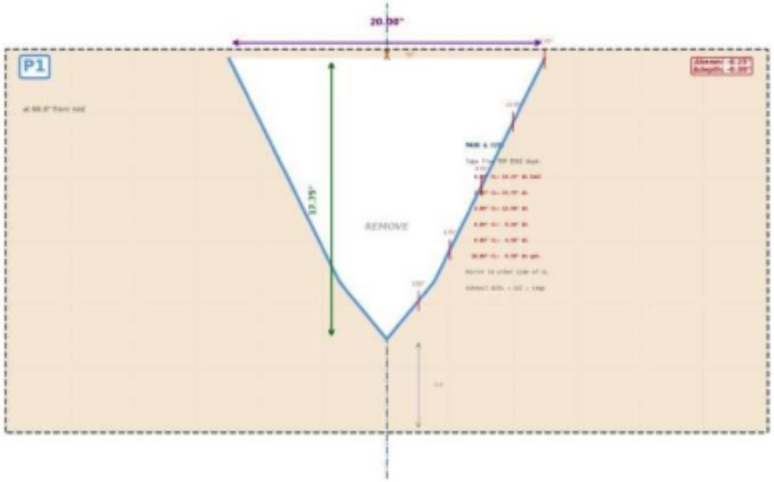


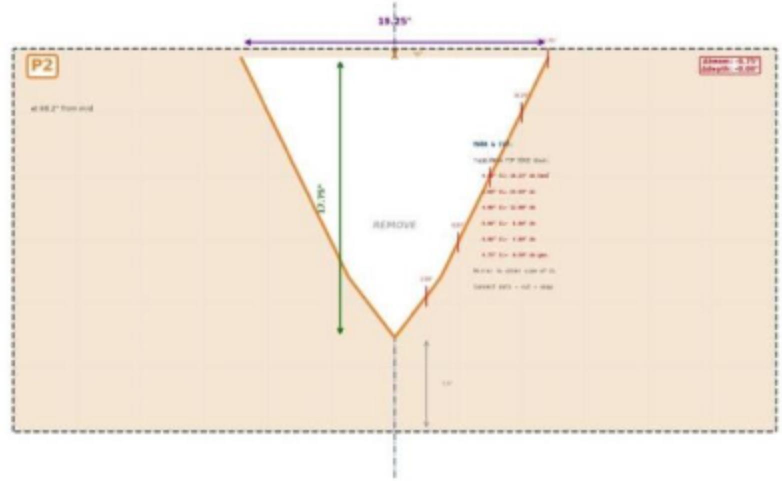


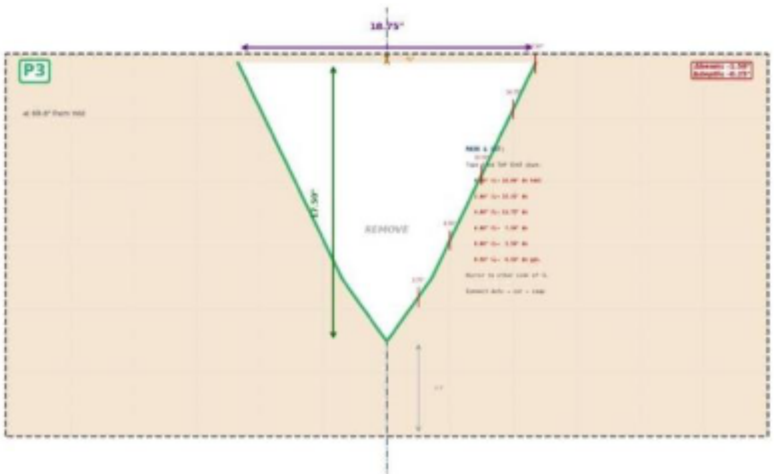
U

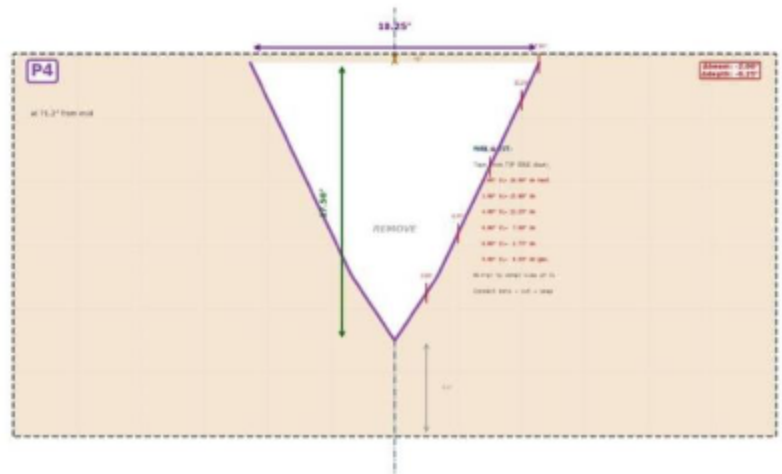
STATION L — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 20.25" | Depth: 17.75" | Dist from midship: 66" | Max panel difference: 1.99" beam, 0.18" depth







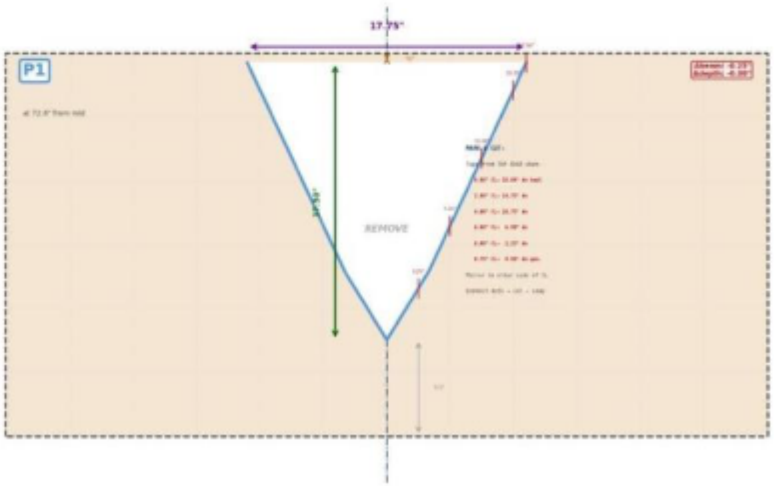


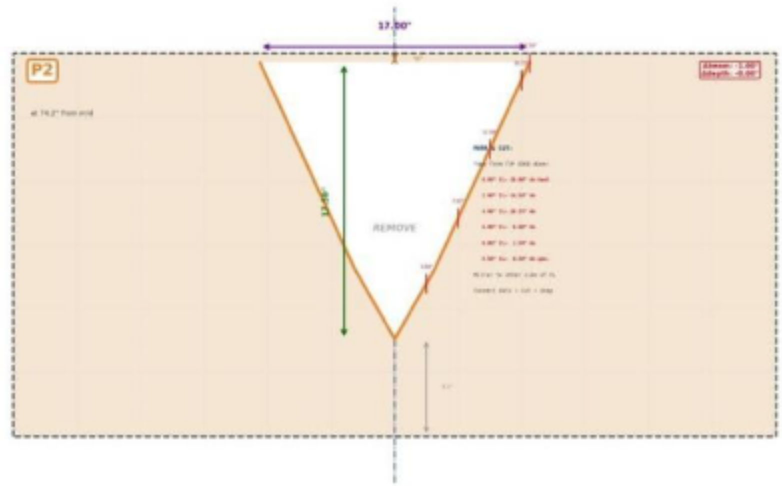
NAU ASCE Concrete Canoe 2026 — PLUTO JACKS | STATION L TAPERED PANELS | CUT 8 PANELS (2 blocks, bow + stern) | 48"W × 24"H × 1.5"T | ½" FROM TOP ⚠ EACH PANEL HAS DIFFERENT DIMENSIONS — CUT INDIVIDUALLY

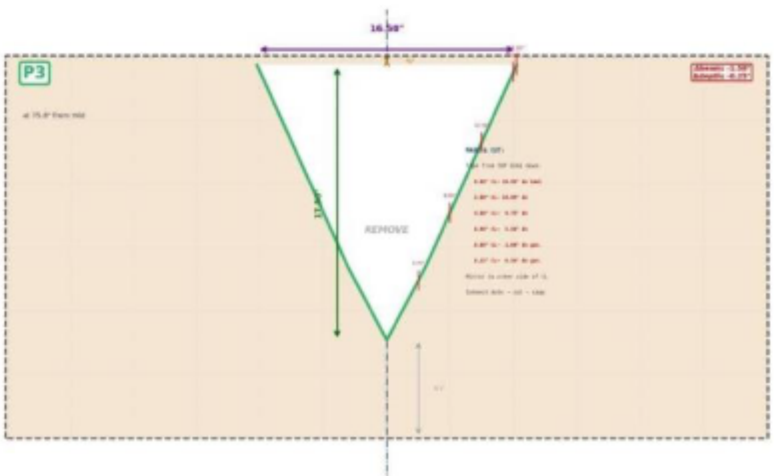
V

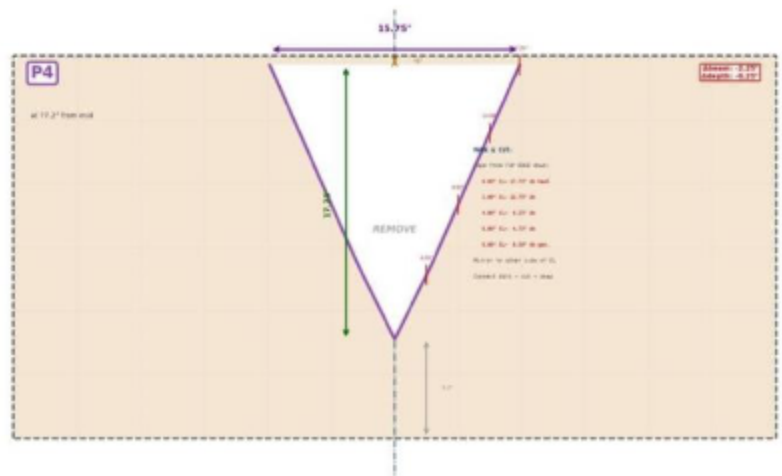
STATION M — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 18.00" | Depth: 17.50" | Dist from midship: 72" | Max panel difference: 2.17" beam, 0.19" depth





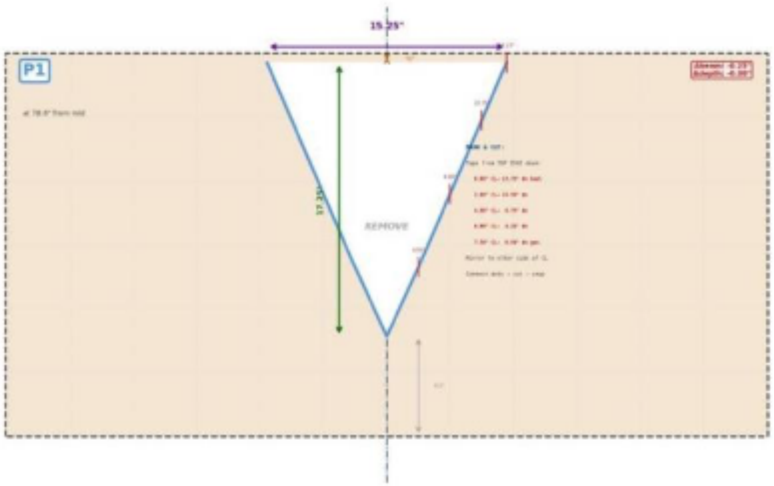


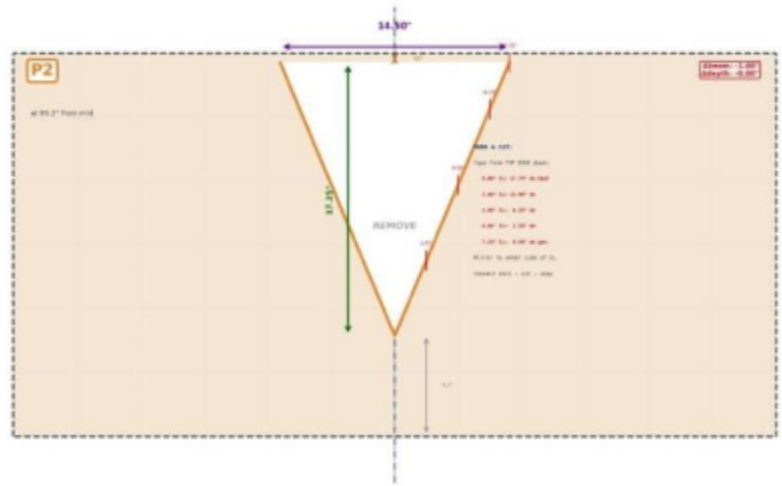


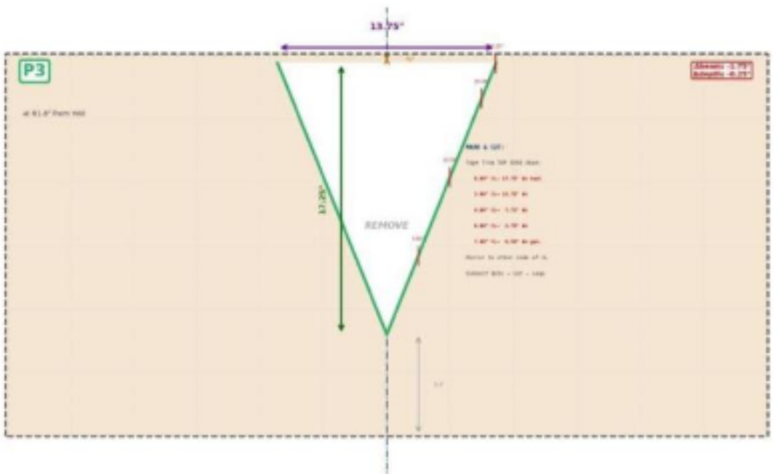
W

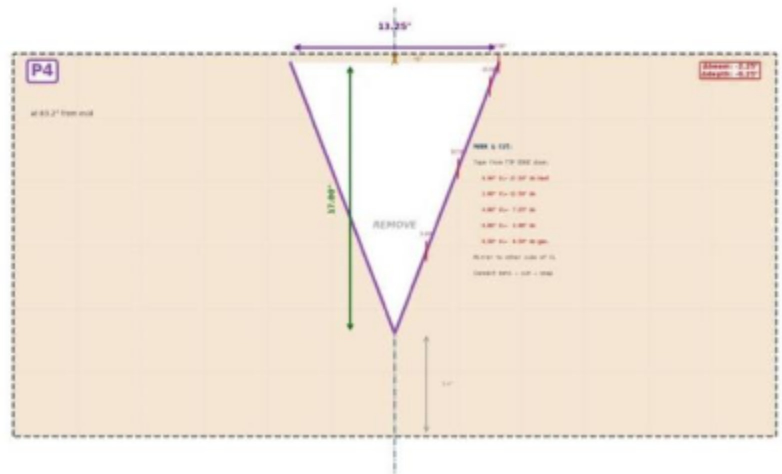
STATION N — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 15.50" | Depth: 17.25" | Dist from midship: 78" | Max panel difference: 2.33" beam, 0.22" depth





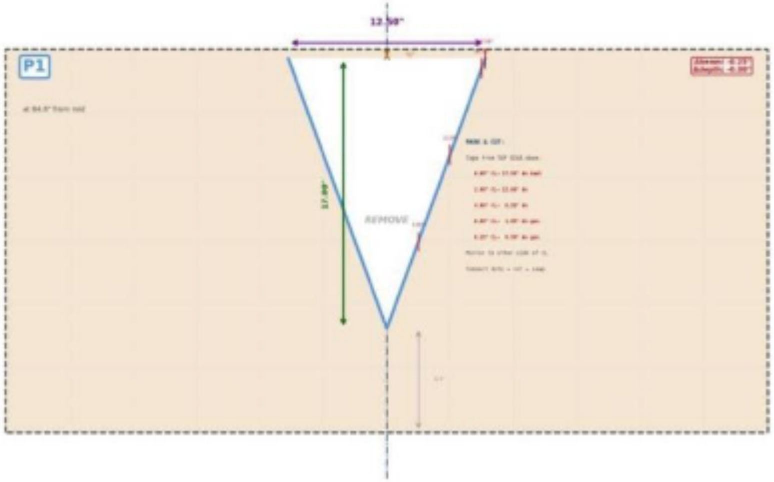


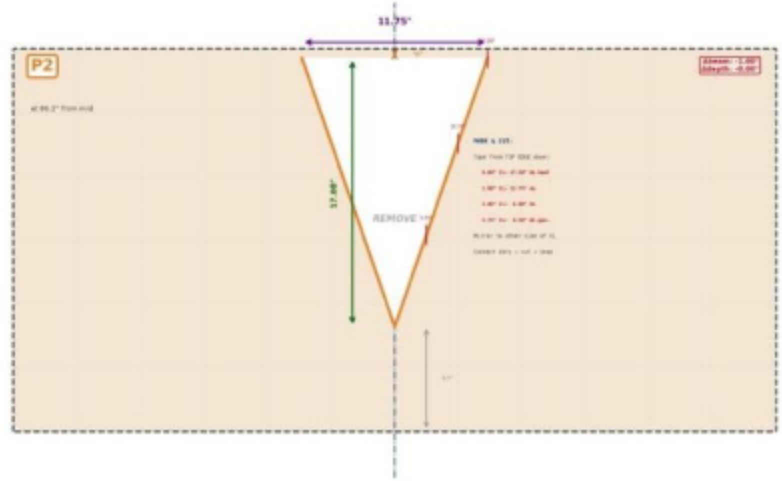


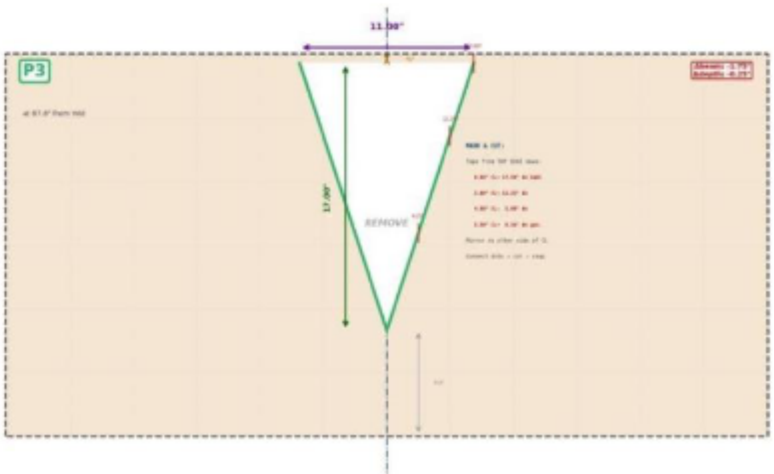
X

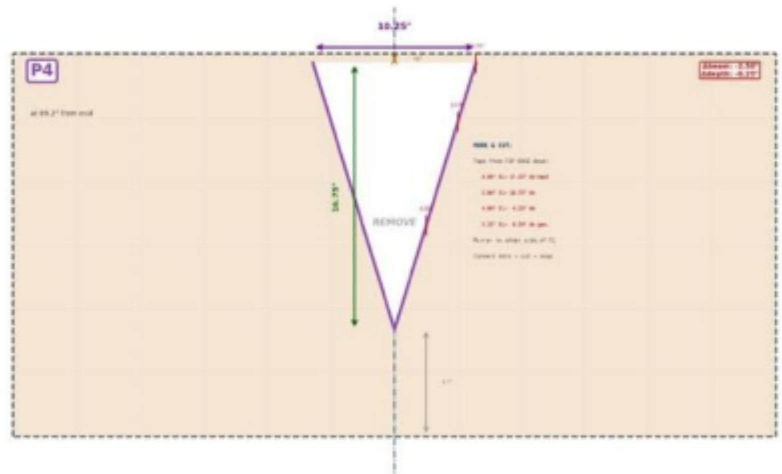
STATION O — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 12.75" | Depth: 17.00" | Dist from midship: 84" | Max panel difference: 2.52" beam, 0.23" depth





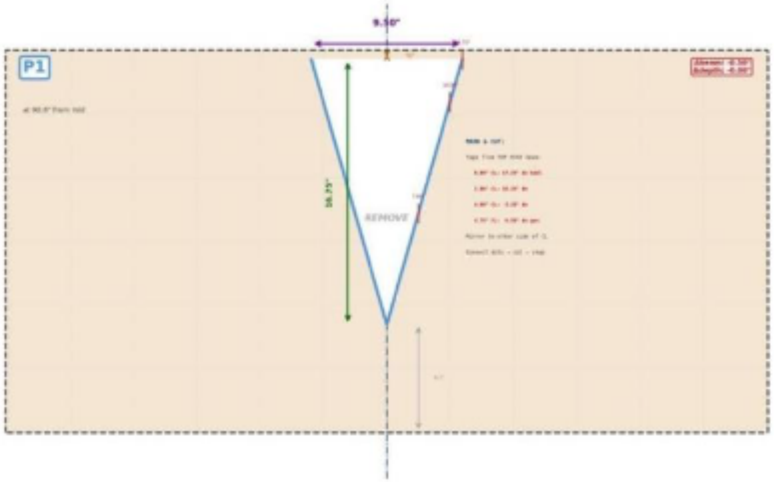


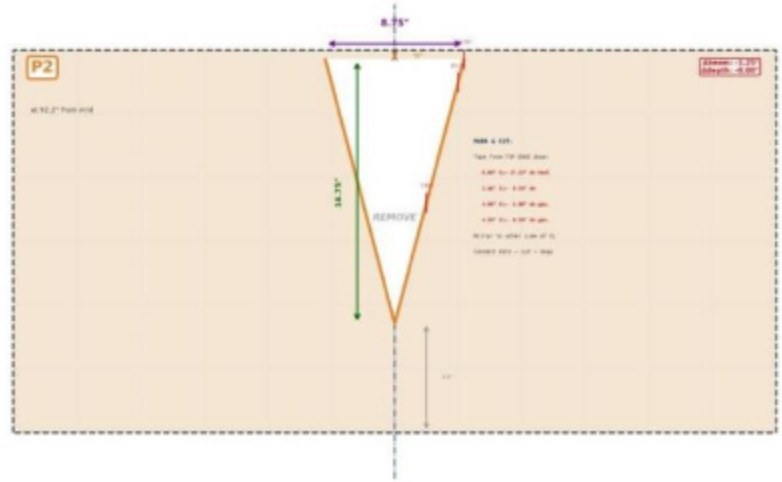


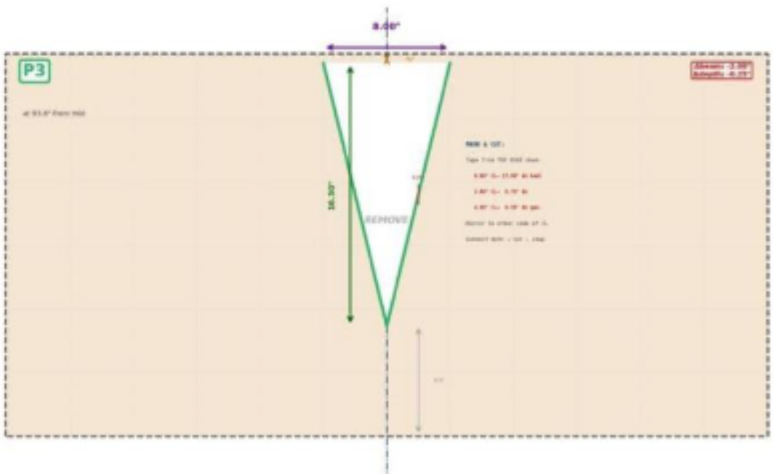
Y

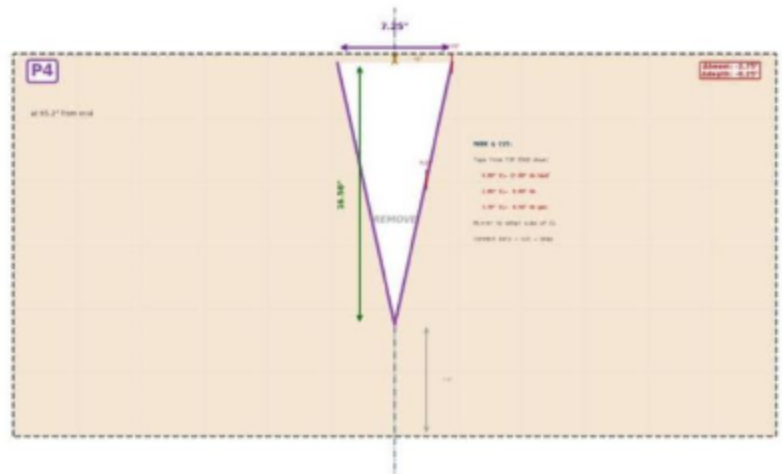
STATION P — TAPERED PANEL CUTS (6" BLOCK — 4 PANELS) ⚠ PANELS DIFFER

Station beam: 10.00" | Depth: 16.75" | Dist from midship: 90" | Max panel difference: 2.70" beam, 0.26" depth





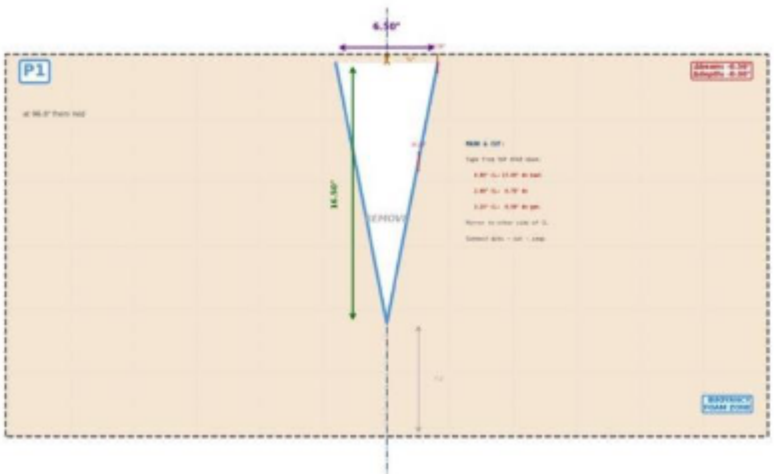


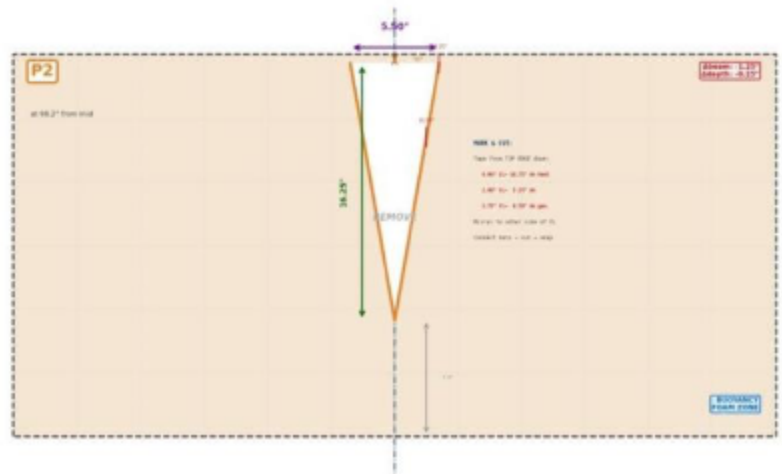


Z

STATION Q — TAPERED PANEL CUTS (3" BLOCK — 2 PANELS) ⚠ PANELS DIFFER

Station beam: 6.75" | Depth: 16.50" | Dist from midship: 96" | Max panel difference: 1.23" beam, 0.25" depth

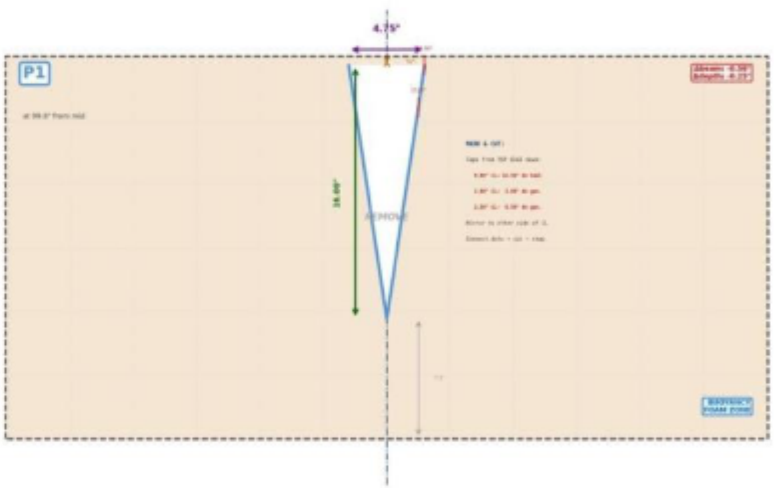


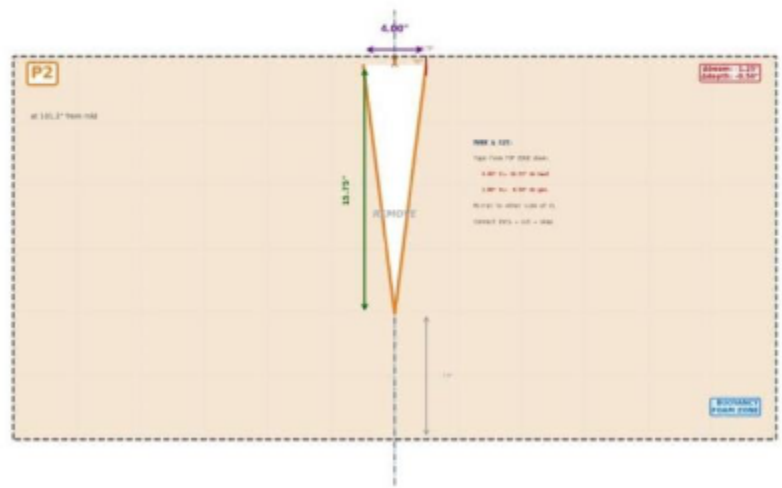


.A

STATION Q+ — TAPERED PANEL CUTS (3" BLOCK — 2 PANELS) ⚠ PANELS DIFFER

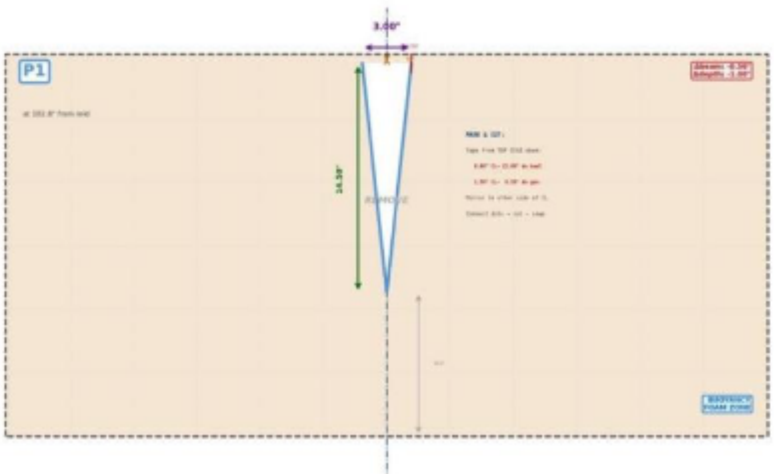
Station beam: 5.25" | Depth: 16.25" | Dist from midship: 99" | Max panel difference: 1.25" beam, 0.50" depth

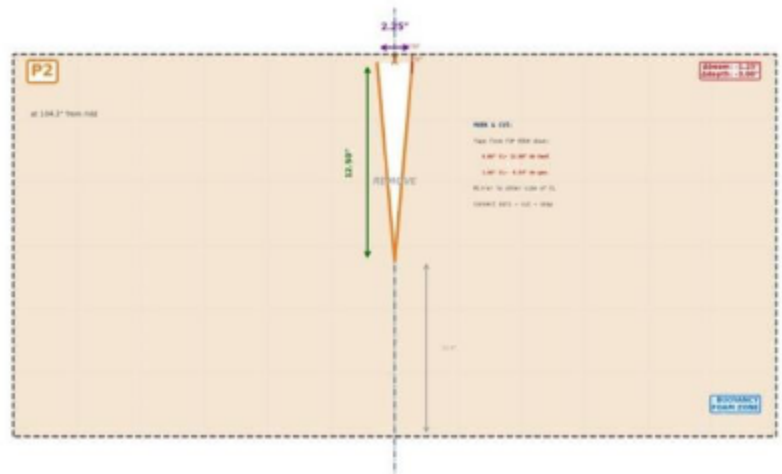




STATION R — TAPERED PANEL CUTS (3" BLOCK — 2 PANELS) ⚠ PANELS DIFFER

Station beam: 3.50" | Depth: 15.50" | Dist from midship: 102" | Max panel difference: 1.32" beam, 2.99" depth





NAU ASCE Concrete Canoe 2026 — PLUTO JACKS | STATION R TAPERED PANELS | CUT 4 PANELS (2 × 3" blocks, bow + stern) | 48"W × 24"H × 1.5"T | ½" FROM TOP | BUOYANCY FOAM ZONE ⚠ EACH PANEL HAS DIFFERENT DIMENSIONS — CUT INDIVIDUALLY

STATION R+ — TAPERED PANEL CUTS (3" BLOCK — 2 PANELS) ⚠ PANELS DIFFER

Station beam: 1.75" | Depth: 11.50" | Dist from midship: 105" | Max panel difference: 1.34" beam, 2.99" depth