NORTHERN ARIZONA UNIVERSITY

Civil and Environmental Engineering

2019 Concrete Canoe

VolCanoe

By: Virgilio Bareng, Jennifer Chavez, Trevor Mahoney, Allyson Marnocha, and Ernesto Mauricio

Project Introduction

- Design, build, and race a concrete canoe
- Follow ASCE National Concrete Canoe Competition (NCCC 2019) Rules [1]
- Compete at Pacific Southwest Conference (PSWC) at Cal Poly, San Luis Obispo from April 3-6, 2019
- *2017 Paddlegonia* placed 8th [2]
- *2018 Canoopa* placed 11th [3]

Figure 1: Concrete canoe races at PSWC 2019 at Lake Nacimiento in California.

Figure 2: VolCanoe Concrete Canoe 2019.

VolCanoe Team Goals

- Increase Maneuverability
- Maintain Stability
- Decrease Canoe Weight
- Decrease Canoe Length
- Incorporate Sustainable Building Practices

Virgilio Bareng (Sr)
Structural Lead

Ernesto Mauricio (Sr)
Mix Design Lead

Allyson Marnocha (Sr)
Project Manager

Trevor Mahoney (Sr)
Reinforcement Lead

Jennifer Chavez (Sr)
Quality Assurance and Quality Control

Milestones

- Material Development and Testing
- Hull Design and Structural Analysis
- Mold and Canoe Construction
- Project Schedule
- Final Design Report for PSWC 2019
- Project Overview and Technical Addendum for PSWC 2019
- Finish *VolCanoe*
- PSWC Table Top Display
- PSWC Oral Presentation
- Transportation to PSWC Conference

Figure 3: Report Cover for VolCanoe 2019.

Development and Testing

- **Material Procurement**
  - Crush Material
  - Clean Material

Figure 4: Crushing pumice agg.

Figure 5: Sieving pumice agg.

Figure 6: Washing crushed material.

Development and Testing

- **Concrete Testing**
  - Slump Test
  - Compressive Strength Test
  - Split Tensile Strength Test
  - Dry Unit Weight
- **Choose Final Mix**
  - Inventory Balance
  - Final Pour Volumes
  - Select Final Mix
  - Testing Results

Figure 7: Tensile break showing clear failure of aggregates.

Figure 8: Slump test on practice pour day.

Development and Testing

- **Mix Trials**
  - Combined *Canoopa* and *Paddlegonia* as baseline mix
  - Introduced new aggregates
  - Refined mix for strength and unit weight
    - High Strength
    - Low Unit Weight

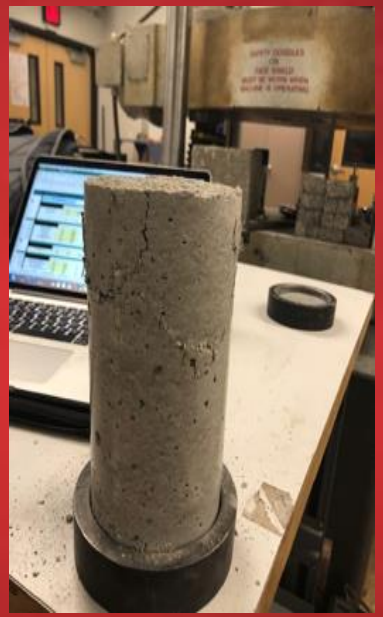


Figure 9: VolCanoe Structural Mix #5

Figure 10: VolCanoe Structural Mix #7

Figure 11: VolCanoe Structural Mix #8

Development and Testing

- **Results of Testing**
  - 15 Structural Mixes
  - 18 Finishing Mixes
    - 9 Red and 9 Black Mixes

Figure 12: VolCanoe Finishing Mix #1 Black

Figure 13: VolCanoe Finishing Mix #2 Red

Table 1: VolCanoe Concrete Mix Trials

Concrete Property	Concrete Mix Trial Number				
	Mix #5	Mix #7	Mix #8	Black Mix #1	Red Mix #1
Dry Unit Weight	63 pcf	56 pcf	53 pcf	47 pcf	47 pcf
28-Day Compressive Strength	705 psi	1,198 psi	2,080 psi	1,950 psi	1,950 psi
28-Day Tensile Strength	167 psi	168 psi	300 psi	270 psi	270 psi

Development and Testing

Figure 14: MasterFiber MAC Matrix Fibers

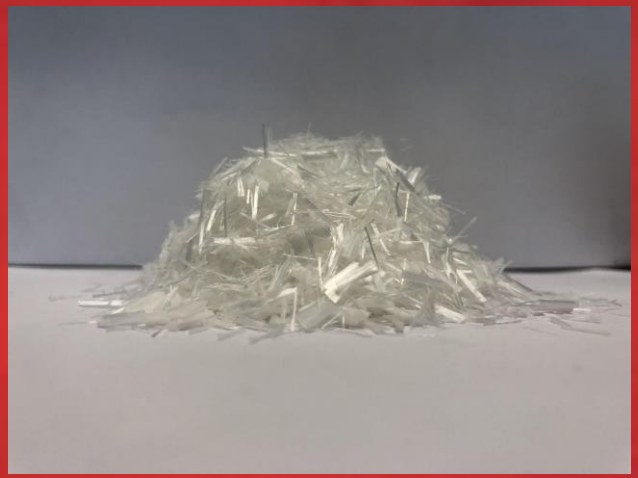


Figure 15: 8mm PVA Fibers

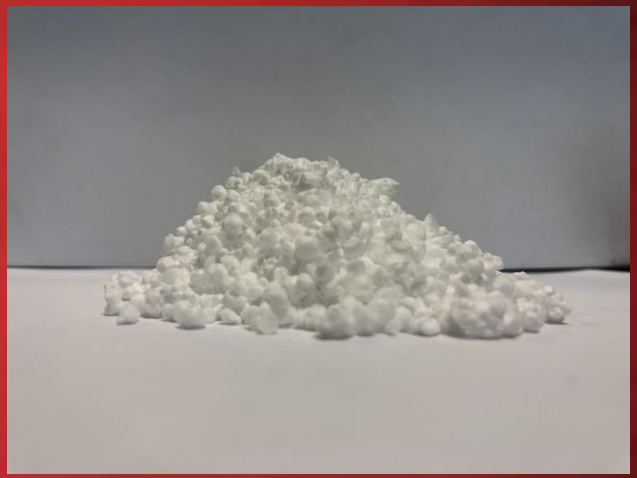


Figure 16: Shredded EPS Foam

Development and Testing

Figure 17: 0.84-4.76mm Utelite Fines Expanded Shale

Figure 18: 0.07-0.30mm Utelite #10 Mesh Expanded Shale

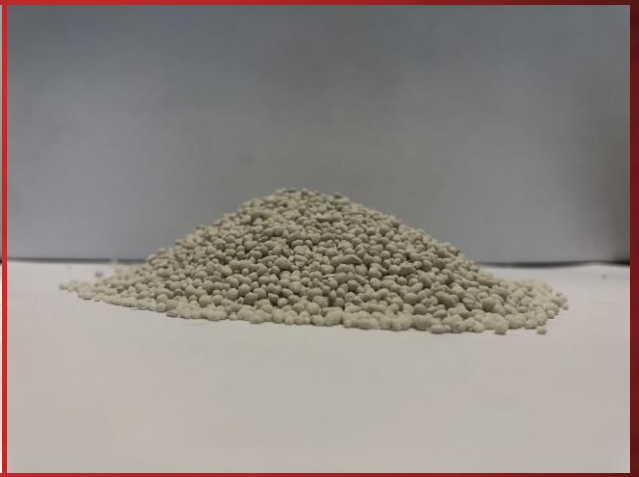


Figure 19: 1.0-2.0 mm Poraver (Expanded Glass)

Development and Testing

Figure 20: 4.76-6.35mm Pumice Aggregate

Figure 21: 2.89-3.36mm Pumice Aggregate

Figure 22: 0.07-0.84mm Pumice Sand

Development and Testing

Figure 23: 4.76-6.35mm Aeroaggregate Ultra Lightweight Foamed Glass Aggregate (UL-FGA)

Figure 24: 2.89-3.36mm Aeroaggregate Ultra Lightweight Foamed Glass Aggregate (UL-FGA)

Figure 25: Aeroaggregate Ultra Lightweight Foamed Glass Aggregate (UL-FGA) Sand

Development and Testing

Table 2: VolCanoe Concrete Properties		
Mixes	**Finishing**	**Structural**
Wet Unit Weight	59.4 pcf	63.7 pcf
Oven-Dry Unit Weight	47 pcf	53 pcf
28-Day Compressive Strength	1,950 psi	2,080 psi
28-Day Tensile Strength	270 psi	300 psi
28-Day Flexural Strength	1,330 psi	1,500 psi
Concrete Air Content	10.0%	9.1%

Structural Analysis

- Performed 2-Dimensional analysis
  - 2-Person (180 lbs typ.)
  - 4-Person (180 lbs typ.)
  - Transportation Buggie/Canoe Stand
- Modeled *VolCanoe* as a simply-supported beam
  - Shear Diagram
  - Moment Diagram

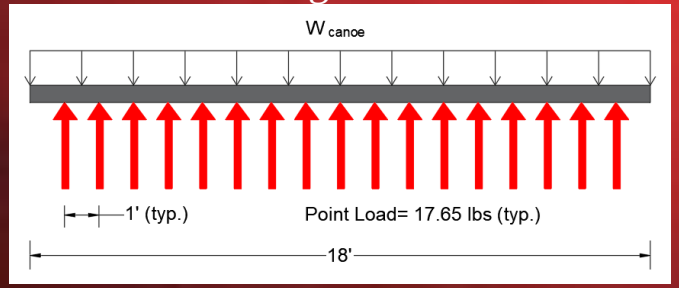


Figure 26: Simplified traansportation model.

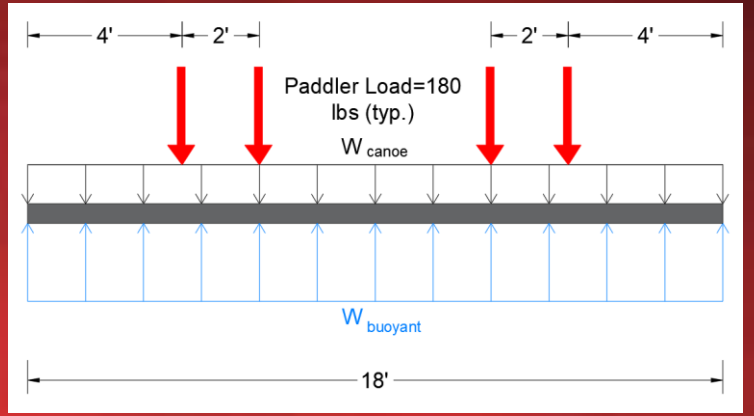


Figure 27: Simplified 4-person model.

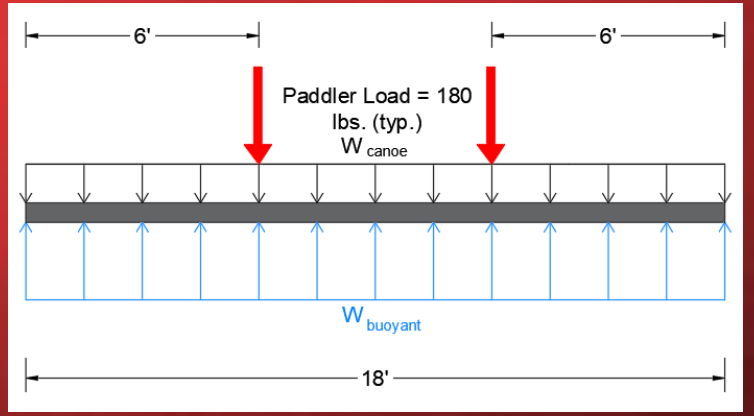
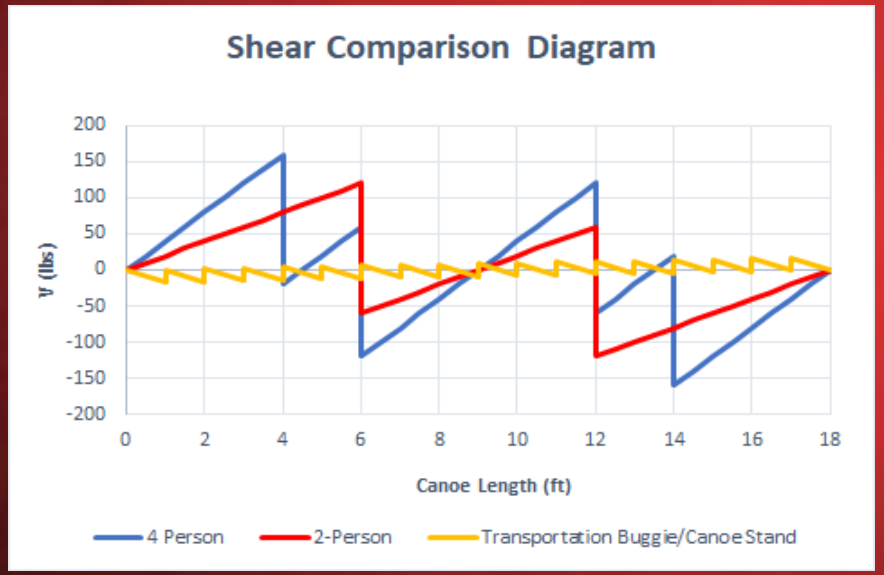


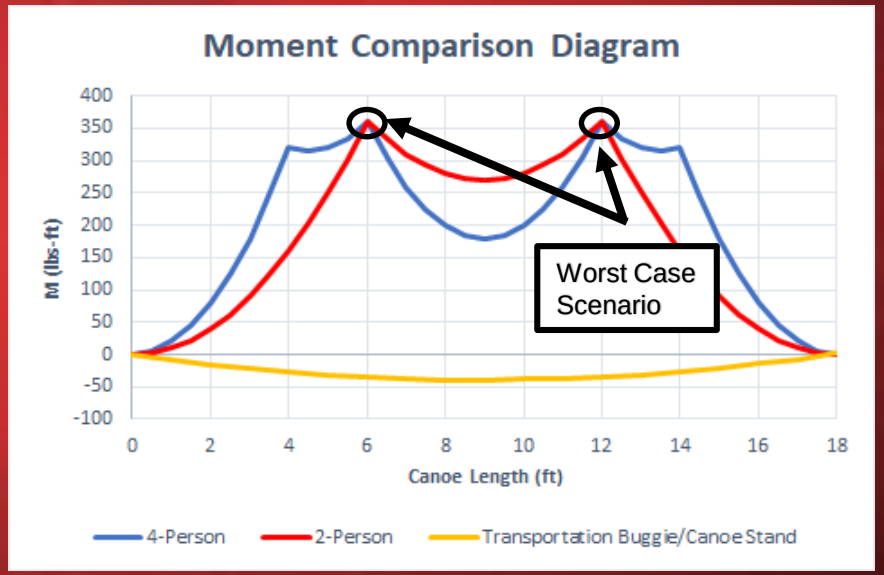
Figure 28: Simplified 2-person model.

Structural Analysis

Graph 1: Shear Load Case Comparison.



Graph 2: Moment Load Case Comparison



Structural Analysis

- Modeled *Volcano's* cross-section as 3 rectangles to represent a "U-shape"
  - Location of Centroid
  - Moment of Inertia
  - Compressive Strength
  - Tensile Strength

Table 3: Structural Analysis Results

Loading Case	2-Person Race	4-Person Race	Transportation/ Canoe Stand
Maximum Moment	4,320 lb-in	4,320 lb-in	472 lb-in
Compressive Stress	38.5 psi	38.5 psi	4.2 psi
Tensile Stress	20.2 psi	20.2 psi	2.2 psi

Reinforcement Analysis

- Nominal shear strength (V_n)
  - ACI 318-14 Code 14.5.5.1
    - Two-way slab
  - 4inch x 4inch area was used to simulate the knee of a paddler
  - V_n = 1,095.5 lbs (concrete)
- Maximum Load (warp) = 5,536 lb/ft
- Maximum Load (weft) = 5,407 lb/ft
- **<u>Final Reinforcement Design:</u>**
  - 2 layers of basalt reinforcement
    - 1st Layer: Spine
    - 2nd Layer: Full encompassing layer

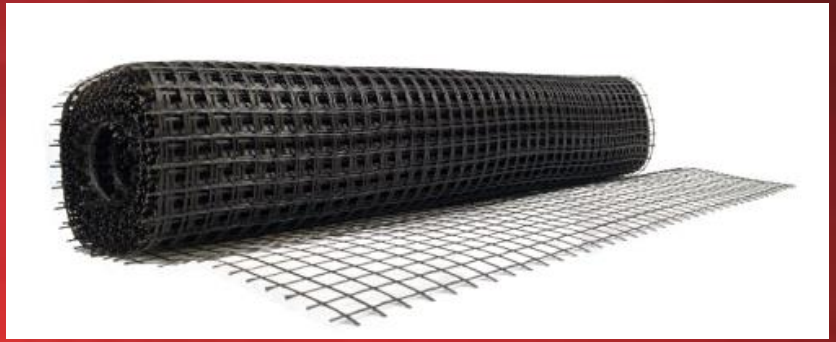


Figure 29: Basalt mesh reinforcement.

Figure 30: Basalt 1''x 1" mesh.

Hull Design

- Hull design choose on balance between stability and maneuverability
- Canoe and mold designed in SolidWorks 2018 and mold was contracted to be fabricated by XY corp
- **Final Hull Design:**
  - Shallow “V” Hull with Flared Walls

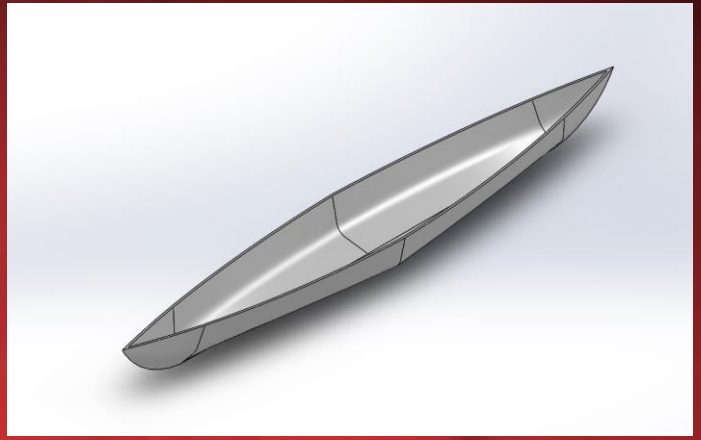


Figure 31: SolidWorks 2018 VolCanoe hull design drawing.

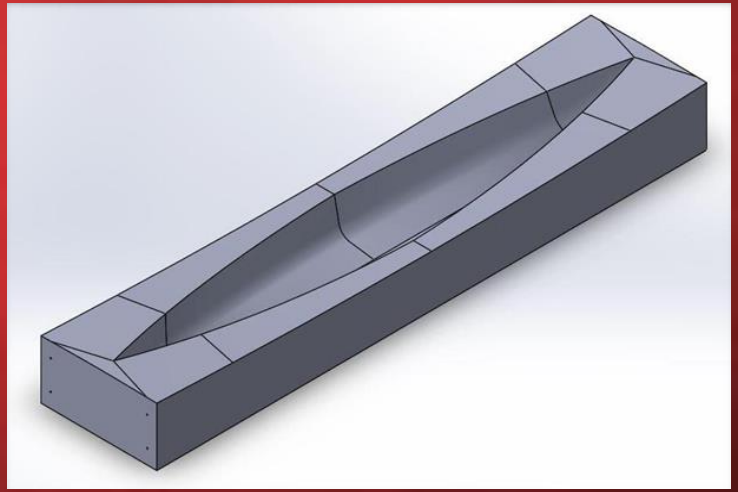


Figure 32: SolidWorks 2018 VolCanoe Mold design drawing

Cross Section Design

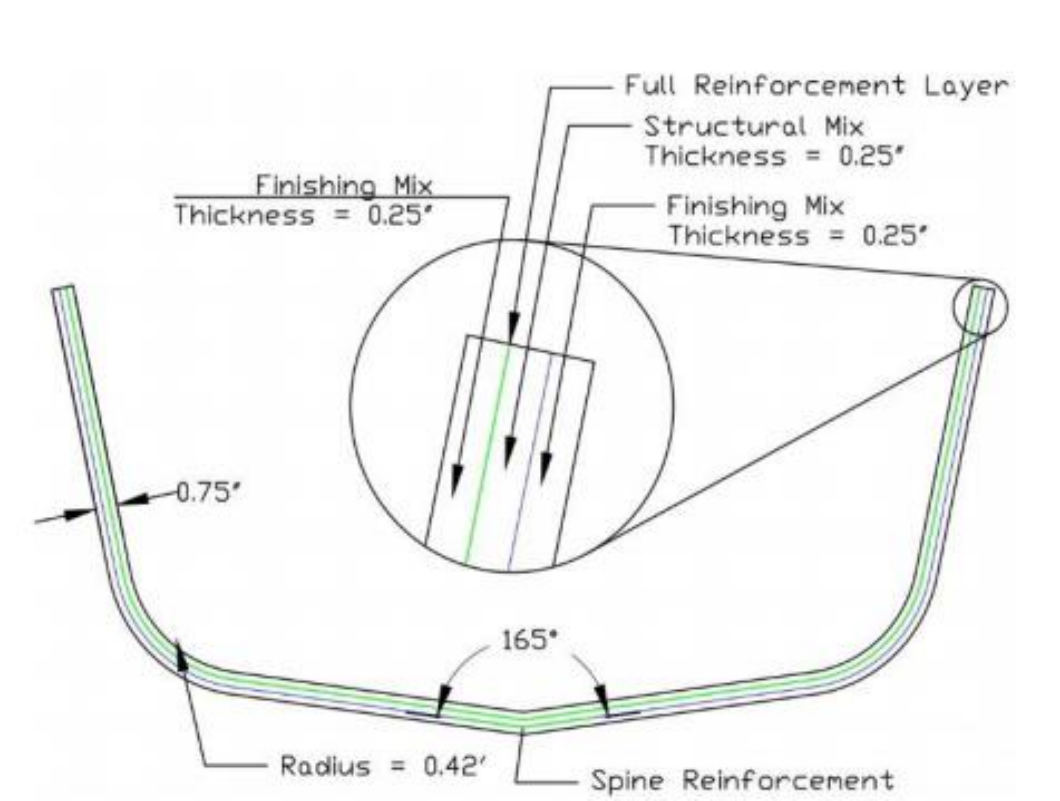


Figure 33: Section A-A from construction drawings submitted to NCCC competition

Final Hull Design

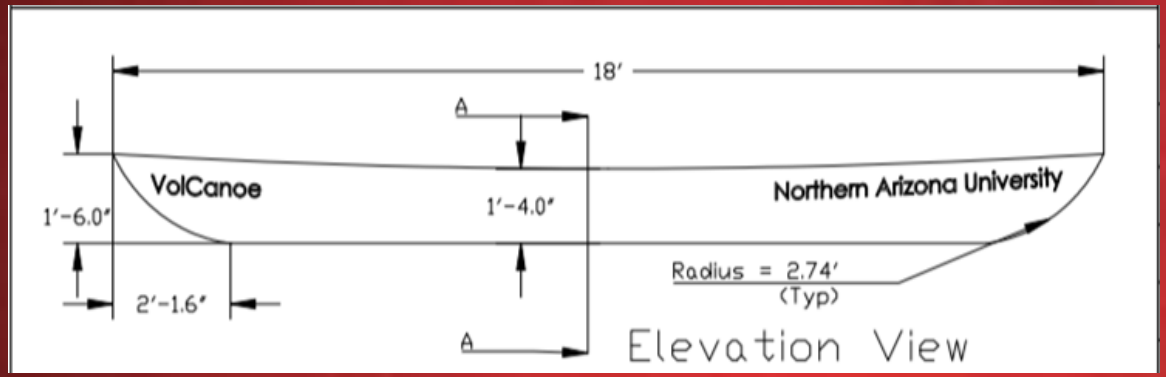


Figure 34: Elevation View from construction drawings submitted to NCCC competition

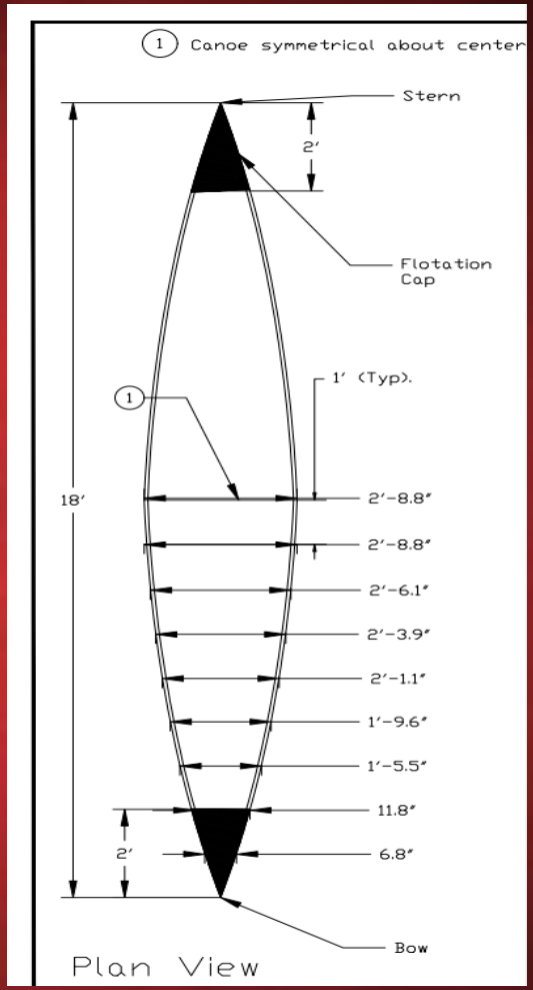


Figure 35: Plan View from construction drawings submitted to NCCC competition

Construction

- **Practice Canoe Pour Day**
  - Volume inconsistencies
  - Lacking quality control (QC) on thickness of concrete
  - Difficulty placing concrete
  - Curing chamber was successful
- **Final Canoe Pour Day**
  - Final mix design refined
  - Desired thickness achieved w/ QC precautions enforced
  - Mold re-designed for ease of constructibility

Figure 36: Practice Canoe.

Figure 37: VolCanoe Final Pour Day.

Mold Construction

Figure 38: Assembly of mold.

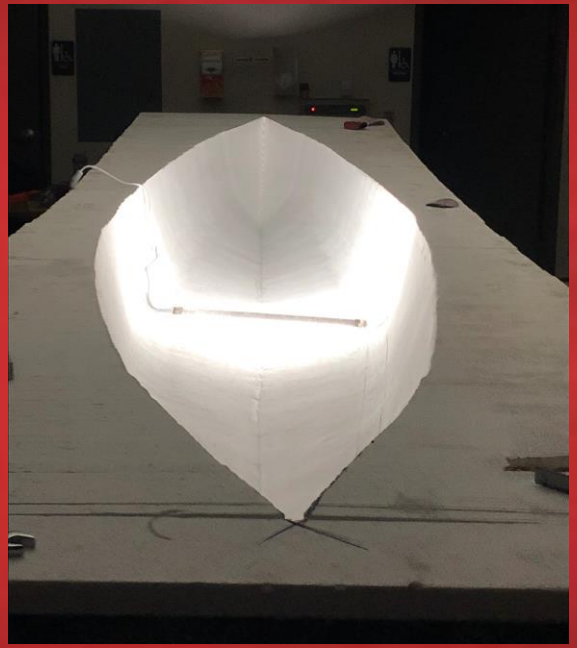


Figure 39: Shadow sanding of mold.

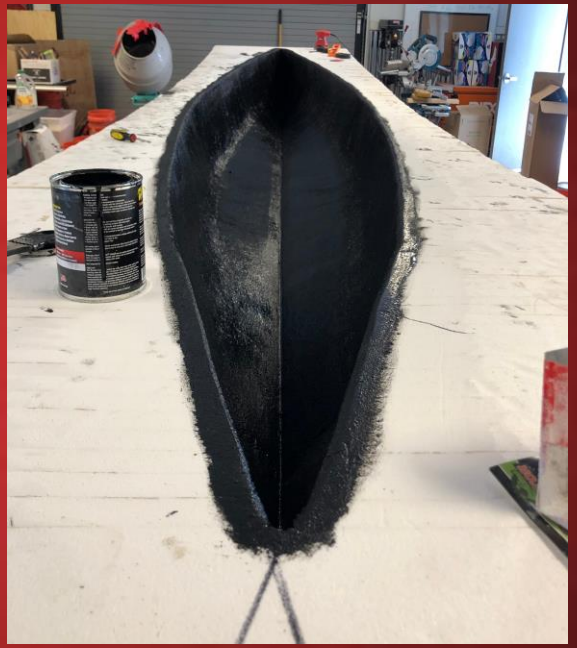


Figure 40: Applying flex seal to the final mold.

VolCanoe Pour Day

Figure 41: 1st finishing layer.

Figure 42: Reinforcement spine & structural layer.

Figure 43: Final reinforcement & 2nd finishing layer.

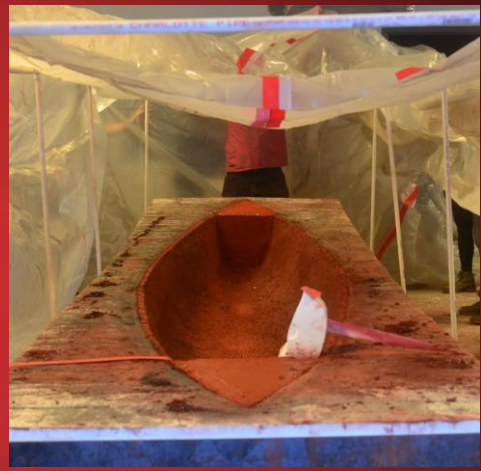


Figure 44: Final VolCanoe & curing chamber.

VolCanoe Finishing and Aesthetics

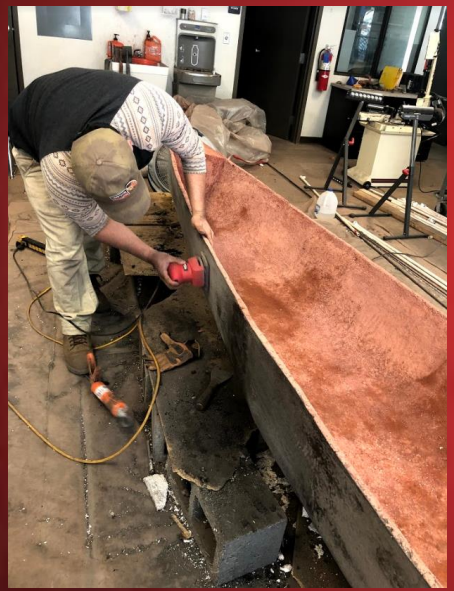


Figure 45: Sanding VolCanoe with various grit sandpaper.

Figure 46: Wet polishing VolCanoe.

Figure 47: Applying 1st layer of sealant to VolCanoe.

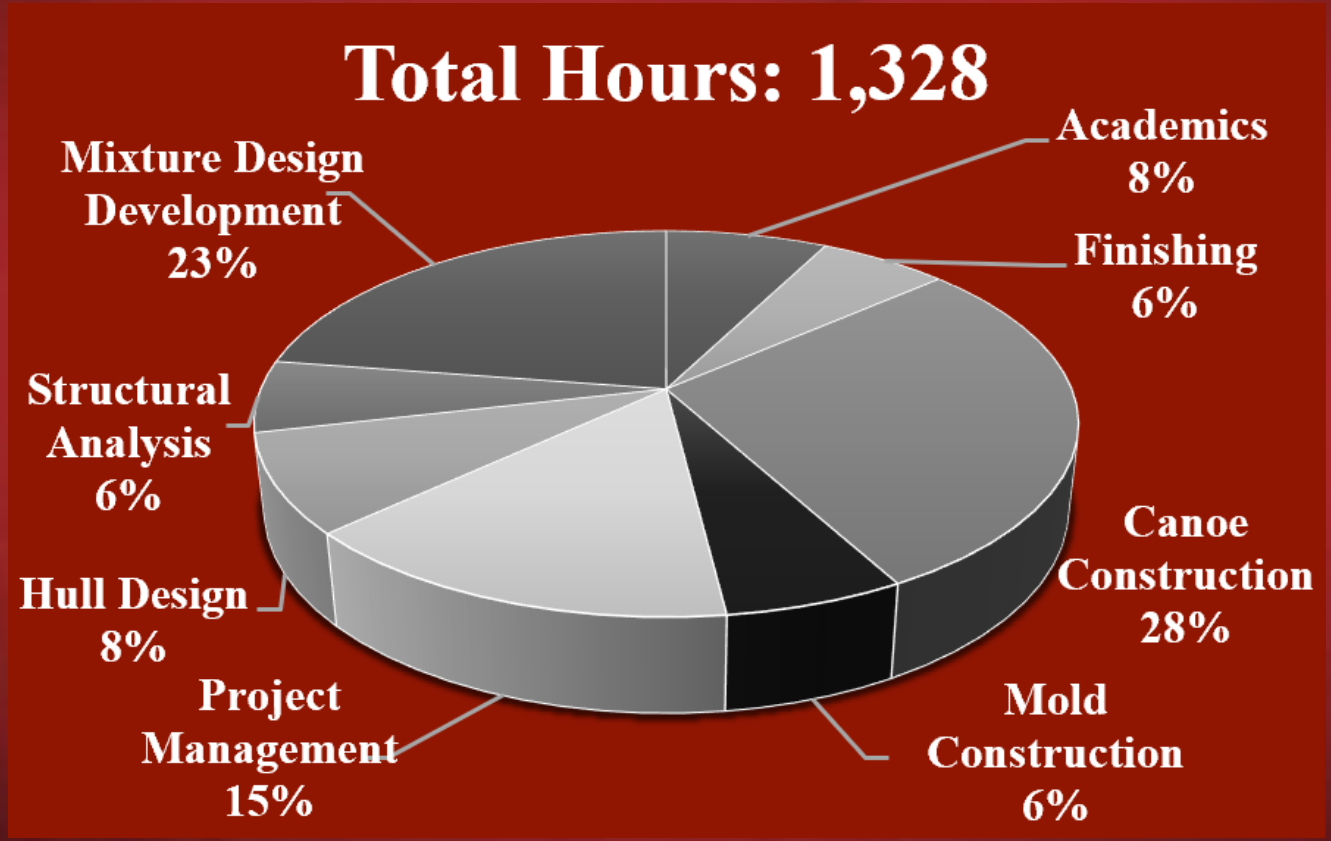
Figure 48: Applying letters to VolCanoe.

Project Management

Table 4: Staff Titles	
Classification	**Code**
Senior Engineer	SENG
Lab Technician	LT
Structural Engineer	SE
Engineer in Training	EIT
Quality Assurance and Control Supervisor	QA/QC

Table 5: Time Distribution						
Task	**SENG (Hrs)**	**LT (Hrs)**	**SE (Hrs)**	**EIT (Hrs)**	**QA/QC (Hrs)**	**Task Total (Hrs)**
1.0 Mix Design	16	89	47	0	35	187
2.0 Reinforcement Design	14	19	46	20	10	109
3.0 Hull Design	16	5	71	5	6	103
4.0 Construction	42	42	42	42	32	200
5.0 Competition	56	39	39	39	24	197
6.0 Capstone Deliverables	30	30	30	30	9	129
7.0 Project Management	84	59	49	49	32	273
Total Hours						**1198**

Project Management



Graph 3: Breakdown of time distribution.

Table 6: Monetary Value of Donated Material

Material	Quantity	Unit Cost	Total Cost
Gray Portland Cement Type I	188.00 lbs	$0.27/lbs	$50
1/2" Pumice Aggregate	21.00 ft^3	$12/$ft^3$	$252
MasterGlenium 7500	1.00 gal	$25/gal	$25
MasterColor Black	1.00 gal	$20/gal	$20
MasterColor Red	1.00 gal	$20/gal	$20
MasterFiber MAC Matrix	9.00 lbs	$12/lbs	$108
Sealant	5.00 gal	$12/gal	$60
MasterLife D300	25.00 lbs	$5/lbs	$125
Modified A/NA Latex	1.00 gal	$15/gal	$15
Tylac 4193	1.00 gal	$15/gal	$15
Rovene 4040	1.00 gal	$15/gal	$15
Ultra-Lightweight Foamed Recycled Glass Aggregate	21.00 ft^3	$15/$ft^3$	$315
Material Crushing	42.00 ft^3	$5/$ft^3$	$210
Total Value for Materials			**$1,230**

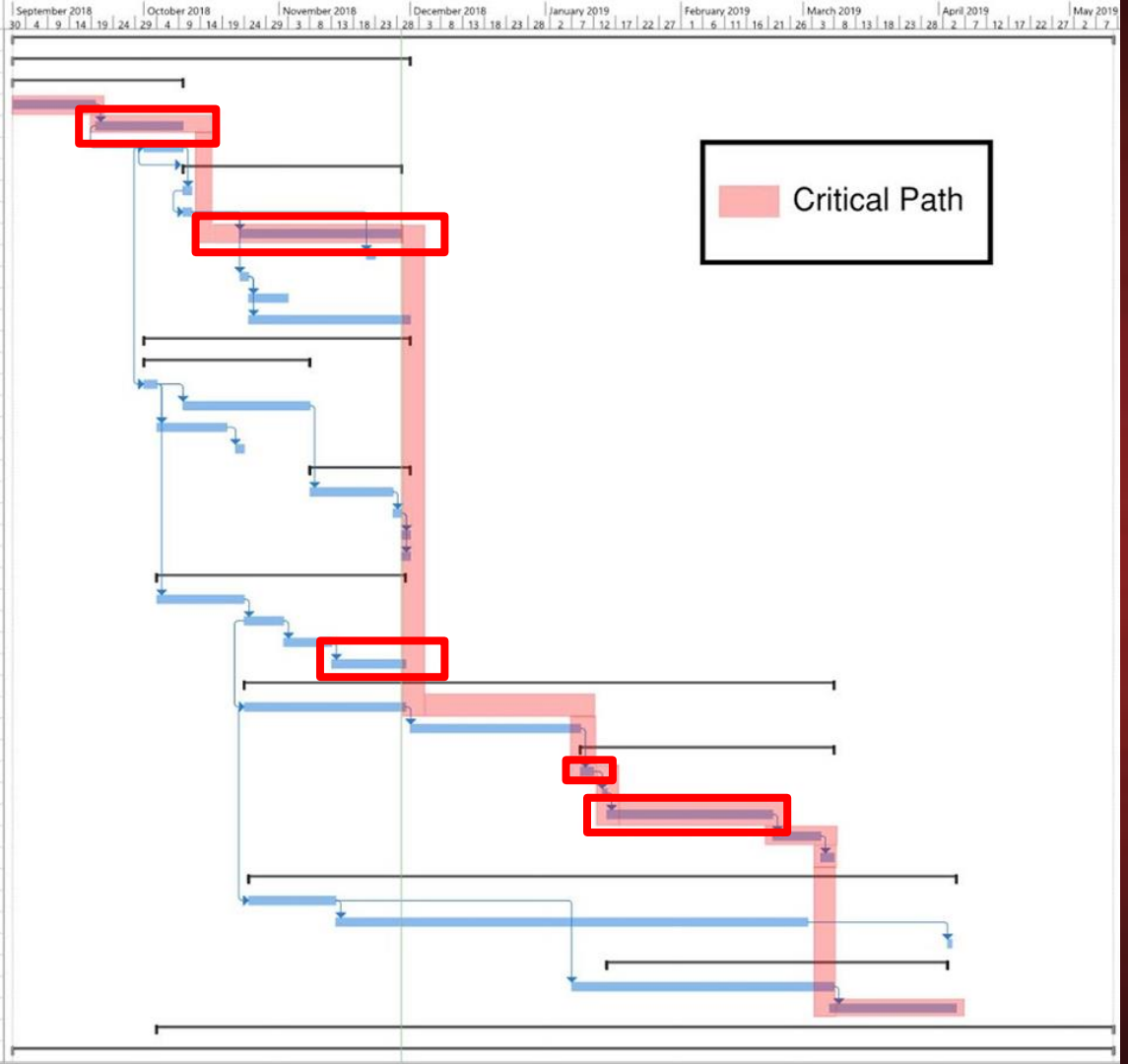
Table 7: Monetary Value of Purchased Materials

Material	Quantity	Unit Cost	Total Cost
Threaded Rod , Washers, Nuts	Varies	Varies	$100
Screws, Wood, Flex Seal, PVC Pipe	Varies	Varies	$250
Poraver 1.0-2.0 mm	38 lbs	$0.70/lbs	$27
Mold Fabrication	2 molds	Varies	$1,800
Basalt Reinforcing Mesh	225 m^2	$2/$m^2$	$450
Poraver 1-2 mm	58 lbs	$1/lbs	$58
Pumice Samples	8 lbs	Varies	$65
Total Value for Purchased Materials			**$2,750**

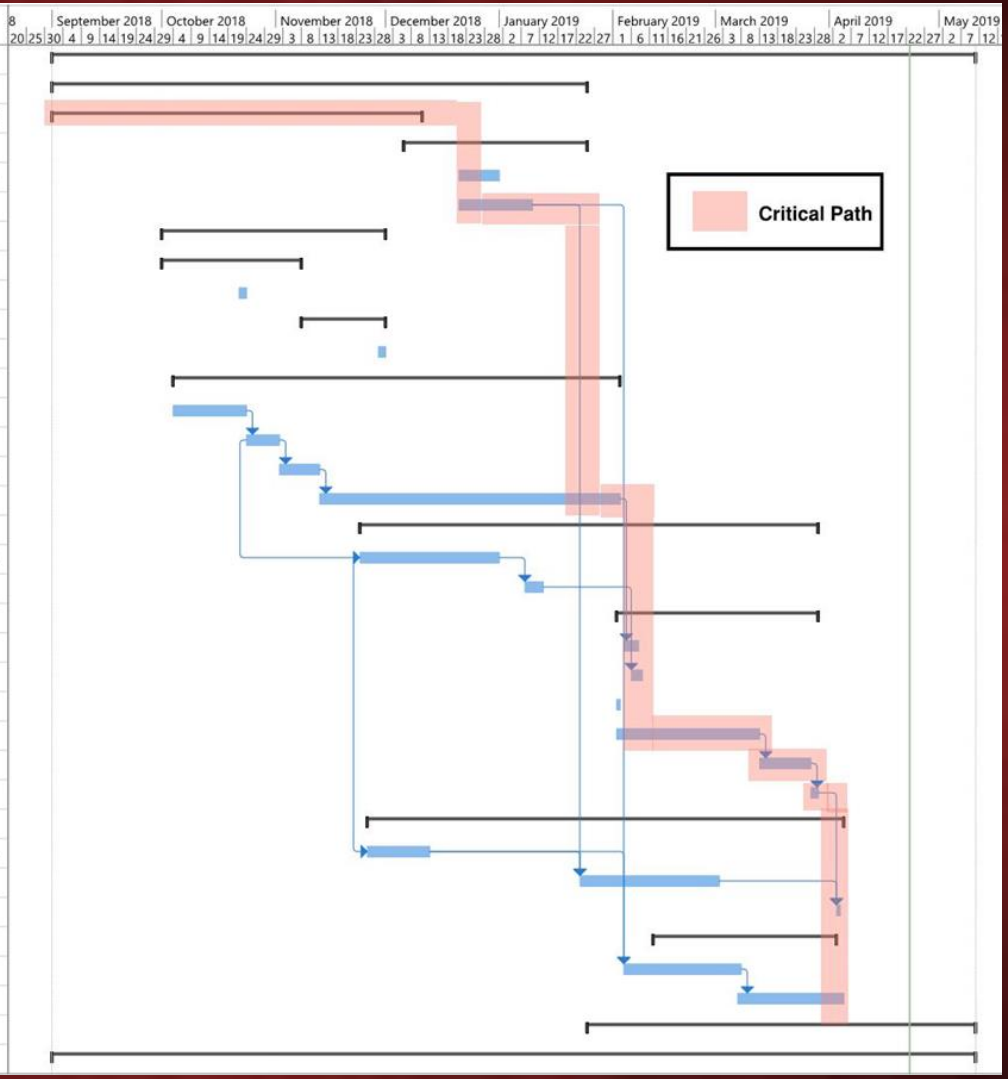
Project Management

Graph 4: Breakdown of cost distribution.

Task Name	Duration	Start	Finish
2.0 Scope	**184 days?**	**Sat 9/1/18**	**Fri 5/10/19**
2.1 Task 1.0: Mix Design	**67 days**	**Sat 9/1/18**	**Fri 11/30/18**
1.1 Material Research	**28 days**	**Sat 9/1/18**	**Tue 10/9/18**
1.1.1 Aggregates	14 days	Sat 9/1/18	Wed 9/19/18
1.1.2 Material Procurement	14 days	Thu 9/20/18	Tue 10/9/18
1.1.3 Develop Initial Mix Design	7 days	Mon 10/1/18	Tue 10/9/18
1.2 Concrete Testing	**37 days**	**Wed 10/10/18**	**Wed 11/28/18**
1.2.1 Slump Test	2 days	Wed 10/10/18	Thu 10/11/18
1.2.2 Cylinder Test	2 days	Wed 10/10/18	Thu 10/11/18
1.2.3 Compressive Strength Test	28 days	Tue 10/23/18	Wed 11/28/18
1.2.4 Split Tensile Strength Test	2 days	Wed 11/21/18	Thu 11/22/18
1.2.5 Dry Unit Weight	2 days	Tue 10/23/18	Wed 10/24/18
1.3 Creating Decision Matrix for Mix Design	7 days	Thu 10/25/18	Fri 11/2/18
1.4 Finalizing Competition Mix Deliverables	28 days	Thu 10/25/18	Fri 11/30/18
2.2 Task 2.0: Reinforcement Design	**46 days**	**Mon 10/1/18**	**Fri 11/30/18**
2.1 Testing of Reinforcement Materials	**28 days**	**Mon 10/1/18**	**Wed 11/7/18**
2.1.1 Thickness	3 days	Mon 10/1/18	Wed 10/3/18
2.1.2 Mechanical Bonding Test	21 days	Wed 10/10/18	Wed 11/7/18
2.1.3 Determine Percent Open Area	12 days	Thu 10/4/18	Fri 10/19/18
2.2 Reinforcement Selection	2 days	Mon 10/22/18	Tue 10/23/18
2.3 Concrete Pre-Stressing Assessment	**18 days**	**Thu 11/8/18**	**Fri 11/30/18**
2.3.1 Reinforcement Strength	14 days	Thu 11/8/18	Mon 11/26/18
2.3.2 Risk/Benefit Analysis	2 days	Tue 11/27/18	Wed 11/28/18
2.3.3 Determining Pre-Stressing Arrangement and Forces	2 days	Thu 11/29/18	Fri 11/30/18
2.4 Reinforcing Mix Materials	2 days	Thu 11/29/18	Fri 11/30/18
2.3 Task 3.0: Hull Design	**42 days**	**Thu 10/4/18**	**Thu 11/29/18**
3.1 Draft Hull in SolidWorks	14 days	Thu 10/4/18	Tue 10/23/18
3.2 Structural Analysis	7 days	Wed 10/24/18	Thu 11/1/18
3.3 Mold Design	7 days	Fri 11/2/18	Mon 11/12/18
3.4 Mold Procurement	14 days	Tue 11/13/18	Thu 11/29/18
2.4 Task 4.0: Construction	**99 days**	**Wed 10/24/18**	**Thu 3/7/19**
4.1 Construction Table	28 days	Wed 10/24/18	Thu 11/29/18
4.2 Practice Canoe	28 days	Sat 12/1/18	Tue 1/8/19
4.3 Final Canoe	**42 days**	**Wed 1/9/19**	**Thu 3/7/19**
4.3.1 Material Set Up	3 days	Wed 1/9/19	Fri 1/11/19
4.3.2 Placement	1 day	Mon 1/14/19	Mon 1/14/19
4.3.3 Curing	28 days	Tue 1/15/19	Thu 2/21/19
4.3.4 Finishing	7 days	Fri 2/22/19	Mon 3/4/19
4.3.5 Lettering	3 days	Tue 3/5/19	Thu 3/7/19
2.5 Task 5.0: Competition	**118 days**	**Thu 10/25/18**	**Thu 4/4/19**
5.1 Acknowledgment Form and Preliminary Schedule	14 days	Thu 10/25/18	Tue 11/13/18
5.2 Project Overview and Technical Addendum	80 days	Wed 11/14/18	Fri 3/1/19
5.3 Transportation	1 day	Wed 4/3/19	Wed 4/3/19
5.4 Aesthetics	**56 days**	**Tue 1/15/19**	**Tue 4/2/19**
5.5 Design Paper	44 days	Mon 1/7/19	Thu 3/7/19
5.6 Oral Presentation	21 days	Thu 3/7/19	Thu 4/4/19
2.6 Task 6.0: Capstone Deliverables	**160 days?**	**Thu 10/4/18**	**Fri 5/10/19**
2.7 Task 7.0: Project Management	**184 days**	**Sat 9/1/18**	**Fri 5/10/19**



Task Name	Duration	Start	Finish
2.0 Scope	**187 days**	**Sat 9/1/18**	**Fri 5/10/19**
2.1 Task 1.0: Mix Design	**108 days**	**Sat 9/1/18**	**Thu 1/24/19**
1.1 Material Research	**74 days**	**Sat 9/1/18**	**Mon 12/10/18**
1.2 Concrete Testing	**37 days**	**Thu 12/6/18**	**Thu 1/24/19**
1.3 Creating Decision Matrix for Mix Design	7 days	Fri 12/21/18	Mon 12/31/18
1.4 Finalizing Competition Mix Deliverables	14 days	Fri 12/21/18	Wed 1/9/19
2.2 Task 2.0: Reinforcement Design	**46 days**	**Mon 10/1/18**	**Fri 11/30/18**
2.1 Testing of Reinforcement Materials	**28 days**	**Mon 10/1/18**	**Wed 11/7/18**
2.2 Reinforcement Selection	2 days	Mon 10/22/18	Tue 10/23/18
2.3 Concrete Pre-Stressing Assessment	**18 days**	**Thu 11/8/18**	**Fri 11/30/18**
2.4 Reinforcing Mix Materials	2 days	Thu 11/29/18	Fri 11/30/18
2.3 Task 3.0: Hull Design	**92 days**	**Thu 10/4/18**	**Sat 2/2/19**
3.1 Draft Hull in SolidWorks	14 days	Thu 10/4/18	Tue 10/23/18
3.2 Structural Analysis	7 days	Wed 10/24/18	Thu 11/1/18
3.3 Mold Design	7 days	Fri 11/2/18	Mon 11/12/18
3.4 Mold Procurement	64 days	Tue 11/13/18	Sat 2/2/19
2.4 Task 4.0: Construction	**94 days**	**Sat 11/24/18**	**Thu 3/28/19**
4.1 Construction Table	28 days	Sat 11/24/18	Mon 12/31/18
4.2 Practice Canoe	5 days	Tue 1/8/19	Sat 1/12/19
4.3 Final Canoe	**40 days**	**Sat 2/2/19**	**Thu 3/28/19**
4.3.1 Mold Preparation	4 days	Mon 2/4/19	Thu 2/7/19
4.3.1 Material Set Up	3 days	Wed 2/6/19	Fri 2/8/19
4.3.2 Placement	1 day	Sat 2/2/19	Sat 2/2/19
4.3.3 Curing	28 days	Sat 2/2/19	Tue 3/12/19
4.3.4 Finishing	10 days	Wed 3/13/19	Tue 3/26/19
4.3.5 Lettering	2 days	Wed 3/27/19	Thu 3/28/19
2.5 Task 5.0: Competition	**98 days**	**Mon 11/26/18**	**Thu 4/4/19**
5.1 Acknowledgment Form and Preliminary Schedule	14 days	Mon 11/26/18	Wed 12/12/18
5.2 Project Overview and Technical Addendum	30 days	Wed 1/23/19	Fri 3/1/19
5.3 Transportation	1 day	Wed 4/3/19	Wed 4/3/19
5.4 Aesthetics	**36 days**	**Tue 2/12/19**	**Tue 4/2/19**
5.5 Design Paper	24 days	Mon 2/4/19	Thu 3/7/19
5.6 Oral Presentation	21 days	Thu 3/7/19	Thu 4/4/19
2.6 Task 6.0: Capstone Deliverables	**79 days**	**Fri 1/25/19**	**Fri 5/10/19**
2.7 Task 7.0: Project Management	**187 days**	**Sat 9/1/18**	**Fri 5/10/19**



Conference Results

Table 8: Pacific Southwest Conference 2019 Final Results	
Category	**Placement***
Design Paper	13th
Final Product	12th
Oral Presentation	7th
Races	14th
Concrete Canoe Overall	**11th**
* Ranking out of 18 universities	

Environmental, Social, and Economic Impacts

- Sustainable admixtures incorporated into mix design
  - Recycled foam glass aggregate and EPS foam
  - Basalt reinforcement mesh
  - Natural pumice and shale
- Canoe Team participated in kindergarteners' field trip to NAU
- 60% increase in inclusion of mentees
- Concrete Impacts
  - Lightweight concrete becomes cheaper than current prices by utilizing recycled materials
  - Donated materials minimizes price to construct

Figure 49: Teaching kindergarteners about concrete

THANK YOU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VolCanoe
Northern Arizona University
Presenters: Virgilio Bareng and Ernesto Mauricio
April 4th, 2019


NORTHERN ARIZONA UNIVERSITY
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