BYU ENGINEERING
Civil & Construction Engineering

CAPSTONE

ALGAE INCUBATOR DESIGN
PROJECT ID: CEEN_CPST_008

by

TRS Engineering
Trey Acker
Shafiq Figueroa
Rachel Valek

A Capstone Project Final Report

Submitted to

Dr. Gustavious P. Williams
Brigham Young University

Department of Civil and Construction Engineering
Ira A. Fulton College of Engineering
Brigham Young University

April 19, 2023

Executive Summary

PROJECT TITLE: ALGAE INCUBATOR DESIGN
PROJECT ID: CEEn_CPST_008
PROJECT SPONSOR: Dr. Gustavious P. Williams
TEAM NAME: TRS Engineering

This report presents the results of TRS Engineering in completing the Algae Incubator Design Project. The goals for this project were to:

- Develop three algae incubator designs.
- Run structural and cost analyses on the designs.
- Build a prototype of the design which best fit the following criteria:
    - Phytoplankton protection and sampling accessibility
    - Light penetration algae incubators
    - Reasonable certainty of incubator depth from water surface
    - Stability of algae incubator structure
    - Cost effective

The algae incubator design that was prototyped was option B in figure 3. This is a rope-ladder like structure with cylindrical containers as the "rungs" on the ladder. These cylindrical containers act as algae incubators that will be suspended at depths 6.6 inches (16.9 cm) apart (measured from center to center of consecutive algae incubators). Each incubator has a diameter of 4 inches (10 cm) and will systematically measure algae growth 2 inches above and 2 inches below the depth of the center depth of the incubator.

As mentioned above the five criteria used to determine which design was prototyped were 1) phytoplankton protection and sampling capabilities, 2) light penetration of algae incubators, 3) reasonable certainty of incubator depth from water surface, 4) stability of algae incubator structure, and 5) cost effectiveness. Option B, as with the other designs, was designed to have the algae incubator be a clear cylindrical tube with No. 200 mesh on either end. This allows for continuous flow of nutrients and water throughout the incubator tube while protecting phytoplankton from zooplankton predators. The mesh is held in place by a female coupler and Charlotte pipe so that the mesh can be easily replaced if needed. Also, if desired different size mesh could be tested in the experiment. Because of the way the mesh is secured, it is possible that a bigger predator of phytoplankton, such as carp, could potentially break the mesh barriers. Each incubator has a nozzle and tubing attached to ensure that each of the incubators can be sampled while deployed in Utah Lake. The ability to sample incubators was a major criterion of the algae incubator tool because it allows the growth of algae to be monitored while the tool is deployed.

Another criterion was to ensure that each incubator was only restricted to light based on its depth in the lake. This rope-ladder like algae incubator will be installed in Utah Lake at a 45-degree angle to decrease the amount of shade cast by incubators closer to the surface of the water on incubators closer to the lakebed. This angle reduces the potential of shade from incubators at depths closer to the water surface onto incubator tubes at depths farther from the water surface and closer to the lakebed. The amount of shading on lower incubator tubes is dependent on the time of day and the angle of the sun.

Reasonable certainty of incubator tube depths from the water surface is vital to the integrity of experiments that will be run using the algae incubator tube. Option B ensures a reasonable certainty of incubator tube depths with the use of a stabilizing pvc pipe along the edge of the incubator tubes. This pvc pipe suspends the incubators tubes in a more rigid manner than option A which used zip ties as a cost-effective incubator suspension method. Option B employs a floatation device designed from pool noodles to ensure the incubator depth is relative to the water surface.

An additional criterion for the algae incubator tool was to ensure the structural stability of the tool. We wanted to make sure that when the algae incubator was deployed in Utah Lake that it would be secure. This is vital to the experimental design; if the algae incubator tool collapses during deployment, then the depths of algae growth are compromised. Stability of the algae incubator structure in option B is reliant on the four stabilizing posts surrounding the incubators. These posts were run through a RISA structural analysis with 10-foot waves modeled as triangular loads. These 10-foot waves correlate to about 40 mph winds (‘Pounded by wave’, 2021). The RISA model indicated that so long as the posts are imbedded at least 2 feet into the lakebed the structure would hold in up to 40 mph winds on Utah Lake.

The final criterion in deciding which design to prototype was the cost. The total cost of option B came out to $676.89. This cost is comprised of all the components necessary to build the option B prototype. Option B was more expensive than option A by $93.98 and less expensive than option C by $1,308.11. It is important to note that the $676.89 price of option B is the actual cost to build the algae incubator tube whereas the costs of options A and C were projected costs. More detail of the costs of each option can be found in the “Design, Analysis, and Results” section of this report.

Option B, in figure 3, was chosen to be prototyped because it best balanced the five major criteria namely 1) phytoplankton protection and sampling capabilities, 2) light penetration of the incubator tubes, 3) reasonable certainty of incubator depth, 4) structural stability of algae incubator structure, and 5) cost effectiveness of the system.

Table of Contents

List of Figures

List of Tables

Introduction

This report presents the results of TRS Engineering in completing the Algae Incubator Design Project. The goals for this project were to:

- Develop three algae incubator designs.
- Run structural and cost analyses on the designs.
- Build a prototype of the design which best fit the following criteria:
    - Phytoplankton protection and sampling capabilities
    - Light penetration algae incubators
    - Reasonable certainty of incubator depth
    - Stability of algae incubator structure
    - Cost effectiveness

Utah Lake is a major physical feature in Utah Valley and a valuable natural resource. It is the third largest freshwater lake in the western U.S. with a surface area of about 148 mi^2 and a watershed of approximately 2,950 mi^2. It has five major inflows the American Fork River, Provo River, Hobble Creek, Spanish Fork Creek, and Currant Creek, and only one outlet, the Jordan River. It is a shallow lake with an average depth of 9 feet and an uncompacted clay sediment. It provides critical habitat to about 10 million fish, 10 million migratory birds, and has 30,000 acres of wetlands. In addition to ecological habitat, Utah Lake provides many other benefits including water storage, secondary irrigation, and recreation such as sailing, fishing, bird watching (Abbott et al., 2021).

Over the past several years health concerns have been raised over harmful algal blooms (HABs) in the lake with Utah Lake beach closures due to HABs every summer since 2016 (Tanner et al., 2022). The relative importance of light and nutrient limitation on algal growth in Utah Lake is not sufficiently understood to support management decisions. Some researchers hypothesize that algal growth is mostly nutrient-limited (Lawson, 2021), while others maintain that Utah Lake is mostly light-limited (Merritt, 2004). If algal growth in Utah Lake is nutrient-limited, then measures designed to reduce nutrient inflows to the lake could potentially reduce algal growth; however, if algal growth is light-limited, then reducing inflows would have limited impacts on algal blooms.

This Capstone project will be used to develop a tool to determine if Utah Lake is light-limited. This tool is referred to as an algae incubator in this report. It will be used to determine the rate of algal growth with depth in the hopes of determining whether Utah Lake is light limited by systematically measuring the growth of algae at varying depths.

This algae incubator tool had five main criteria: 1) phytoplankton protection and sampling capabilities, 2) light penetration of the incubator tubes, 3) reasonable certainty of incubator depth, 4) structural stability of algae incubator structure, and 5) cost effectiveness of the system. More details of the criteria and how TRS Engineering met them are in the “Design Analysis and Results” section of this report.

To better create the algae incubator tool, we split the project into two phases: the design phase and the prototyping phase. In the design phase three separate designs were drafted, documented, and analyzed. The designs were drafted in AutoCAD and are documented in this final report. These designs were then run through a structural analysis and cost analysis. This first phase was conducted from October through January. We wanted to ensure that we fully understood each criterion of the algae incubator so that we could meet them. In this initial phase we also began sourcing parts to better understand how we could design the algae incubator in detail.

After analyzing the three algae incubator designs, TRS Engineering ran a design comparison analysis to decide which design would best fit the five main criteria of the project. Once the best design was chosen, the team worked with Dave Anderson and Rodney Mayo in the structural lab to help source and determine the most effective way to build the prototype.

Schedule

We have included below the schedule that was followed throughout the course of this Capstone Project.

Completed

September 19th, 2022 – Met with Dr. Williams to discuss the algae incubator criteria and general outline of the project.

October 10th, 2022 – Looked at the current algae incubator prototype to better understand the scope of the project. We also repaired some broken parts on the algae incubator so that we could test it in Utah Lake.

October 17th, 2022 – Met with project sponsor, Dr. Williams, to discuss progress on the algae incubator.

October 23rd, 2022 – Met as a team and took the current algae incubator prototype out to Utah Lake to determine which aspects need to be improved. We discovered that one of the aspects that requires a substantial amount of work is the stabilizing system of the algae incubator.

November 7th, 2022 – Sketched out and discussed our three algae incubator designs for further analysis and modeling.

November 14th, 2022 – Met with Rodney Mayo to discuss how best to build these three algae designs.

November 28th, 2022 – Discussed anchoring system for the algae incubator. The stabilizing fence posts need to be at least 10ft to go into the stiffer part of the soil in Utah Lake (the first 2-3ft is loose sediment).

January 2023 – All three algae incubator designs were drafted in AutoCAD to better illustrate each design.

February 2023 – Structural analysis of the three algae incubator designs were run to help inform which design should be moved into the prototyping phase.

March 2023– Based on the analysis outcomes option B was chosen and the prototype was built with the help of Rodney Mayo, Dave Anderson, and Dr. Gustavious P. Williams.

April 2023 – The final report was completed and presented to Dr. Gustavious P. Williams.

Assumptions & Limitations

To create a tool in which algae growth vs. depth is determined, we had to assume that floating algae assemblage of Utah Lake grows in different layers of the water columns. We are not ecologists, so we just had to assume that phytoplankton grows at different depths within the water column as far as it has all the nutrients and light necessary for growth. We met with Utah Lake ecologist Dave Richards, and he confirmed that this assumption was correct from an ecological perspective.

With the algae incubator tool being deployed in Utah lake for a week to two weeks, we had to ensure that it was structurally stable enough and that algae could continue growing within this period. To ensure that the tool was structurally sound we created a four-pole anchoring system around the algae incubator that would go into the lakebed at least 2 ft. Ensuring that the tool was structurally sound was essential so that while the experiment was running, the various incubator tubes would stay within their designated depths.

In addition to ensuring the structural stability of the algae incubator, we had to make certain that the algae within each incubator tube could growth throughout the duration of deployment. So that the algae would not go anerobic, we made each of the incubator tools open on both ends of the tube. This would allow the algae to have access to nutrients from the water column while the tool is deployed. We also had to make sure that algae could make it into the incubator tubes but keep the zooplankton predators out. We were able to accomplish this by carefully choosing the No. 200 mesh to place on the open ends of the incubator tube. Plenty of research went into deciphering the size of floating algal assemblages and zooplankton within Utah Lake. To further guarantee the mesh size of the incubator tube was appropriate, we reached out to Dr. Dave Richards, a Utah Lake ecologist, for his input.

Another limiting factor in the algae incubator design was reducing any shadows present on lower cylindrical incubators. We did this by deploying the algae incubator tool at a 45-degree angle.

We also had to ensure that throughout the deployment period there would be access to sample each of the incubators. This was accomplished by installing a nozzle that attaches to the cylindrical incubator and tubing that would allow for extraction of samples.

The experiment using this algae incubator tool is measuring algal growth vs. depth. For the integrity of the experiment, it is important that the depth of each incubator relative to the water surface stays the same throughout the deployment period. For the depth relative to the surface to stay within the designated range we added a flotation device to the top of the algae incubator tool. This would ensure that when the water level rose or fell the incubators would stay within their designated depths. A pvc stabilizing unit was also added to the sides of the incubator tools to further ensure that they stayed where intended.

Another limitation that we worked with was the $400 budget for the additional cost of the suspension of the algae incubator tubes. A clear PVC pipe was provided at the beginning of this project. With this budget in mind, we purchase durable and cost-effective materials to build the algae incubator. For example, the floating device at the top of the algae incubator is made from a pool noodle and foam insulation wrapped in a plastic casing. This is not the most professional method, but it is cost effective and accomplishes the needed goals.

Design, Analysis & Results

The designs of the three separate algae incubators had to follow all the five main criteria and limitations described in the assumptions and limitation section. These limitations ensured that the purpose of the algae incubator was met. More specifically, the algae incubator provided a space for phytoplankton to grow undisturbed by zooplankton predators. The only limitation on the phytoplankton growth should be the light penetration at the depth the incubator is deployed. This will help determine the light limitation of the lake being tested.

The first step in building the algae incubator was developing a space for the phytoplankton to grow at an indicated depth. After deliberation it was decided that clear pvc pipe would provide a cost-effective area for the phytoplankton to grow. The clear pvc ensures that light can penetrate the incubator providing the necessary elements for phytoplankton to grow.

Once a container was designed then Dave Richards, a Utah Lake ecologist, was consulted in deliberation on mesh size necessary to keep phytoplankton in the incubator tubes and the zooplankton out. After deliberation with Dave Richards, it was decided that the No. 200 (75-micron) sieve would work best for this situation. This is the size sieve that is used by ecologists in the field to collect zooplankton samples. We discussed that a 64-micron mesh would further keep out the smaller zooplankton. With this smaller mesh we had concerns of more frequent clogging of the mesh openings so in the end it was decided to use the No. 200 (75-micron) mesh.

Mesh sizing is an aspect of the algae incubator that could be further analyzed or tested once the algae incubator is deployed. Figure 1 depicts the incubator tube design that will be suspended at various depths in the lake. It is made of a 4-inch clear PVC pipe with modified couplers. The mesh was placed on the edge of the PVC pipe and was held in place by a tightened coupler. We chose to make the mesh removeable for maintenance purposes. Also, if need be, the mesh size could easily be changed.

With the couplers attached to the clear PVC pipe, the volume of the incubator in the light was reduced. The volume of the incubator is 0.65 gallons (2.47 liters) with the couplers the attached the volume of the incubator accessible to the light is portion of the incubator visible to the light was reduced 0.57 gallons (2.16 liters).

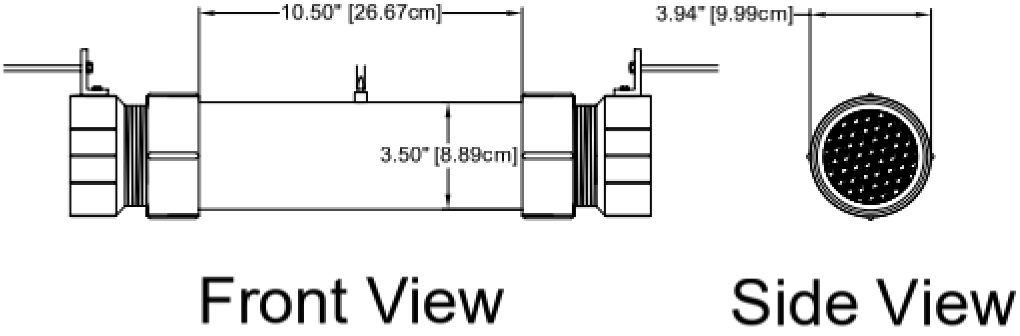


Figure 1 Incubator Tube Design

Once the incubator tubes were designed, we had to ensure that the algae incubator measured the growth of phytoplankton from the water surface to 3 ft under the surface in a systematic manner. To ensure that incubator tube depths were relative to the water surface and the top incubator tube is always as close to the surface as possible, we designed a floatation device that would continuously hold the top incubator at the water surface.

This flotation device consisted of pool noodles attached to the inside of a plastic tube with insulation foam. This was a cost-effective way to create a floatation device based on what was available in the BYU Structures Lab. In addition to keeping the same incubator tube design each of the three design options also has this same floatation device to ensure that the top incubator is placed as close to the water surface as possible.

With the incubator tubes and flotation device designed, the next step was to look at how each of the incubator tubes would be suspended throughout the water column. The suspension of the algae incubators is where the three designs differed from each other. The stabilizing pole length for each of the designs was kept the same. These lengths were informed by our experience pounding the initial pole into the lakebed. When we conducted a field visit in October of 2022, we found that there was about 3 ft of loose sediment on top of the more compacted sediment. Due to this weak loose sediment, we increased the length of the stabilizing poles to 11 feet. One foot is above the water level to ensure the structure is visible, 5 feet was modeled in the water column, 3 ft was estimated for the loose sediment, and 2 ft was modeled in the more compacted lakebed sediment. We erred on the side of the poles being too long rather than too small. The poles can always be adjusted later if need be.

Design option A is depicted in figure 2 and featured the incubators being suspended from the surface of the water to 3 ft below the water surface in a rope ladder-like structure. Each incubator would be attached to one another using zip-ties. These zip-ties would be a cost-effective way to ensure that each of the incubators would be flexible with the waves and not too rigid. This was done so that the algae incubator would be able to last in the lake longer than a rigid structure.

In addition to the zip-ties fastening each consecutive incubator tube to the previous incubator tube, the entire structure would be secured with an 11-foot fence post on either end of the structure. The algae incubator would be attached to the fence posts at the top (floatation device) and the bottom incubator tube with a pipe clamp.

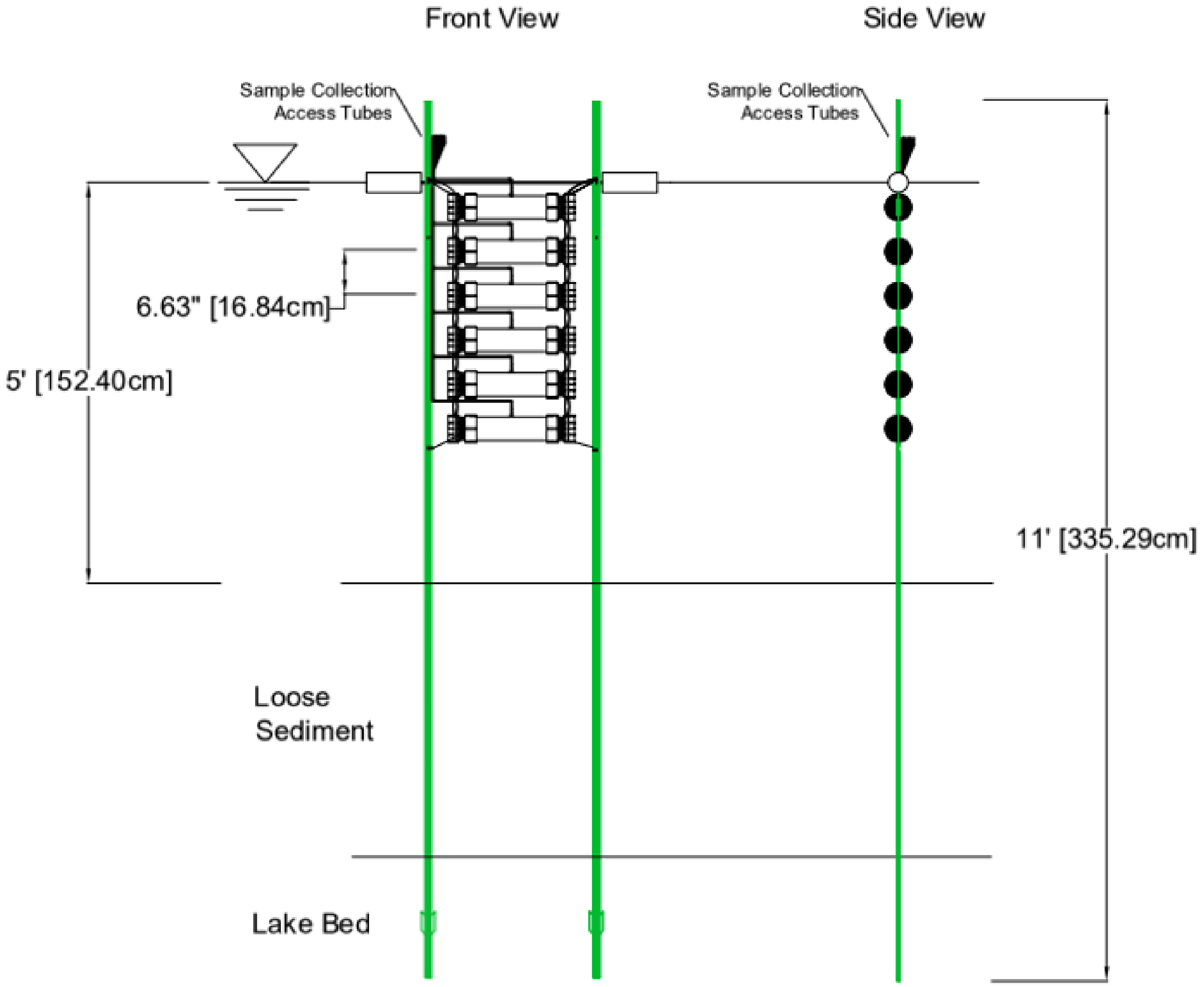


Figure 2 Option A Design

Design option B is depicted in figure 3 and suspended the algae incubators in a 45-degree angle to reduce the amount shadow on the consecutive incubators produced by the incubator above them. With the structure at a 45-degree angle we had to include a stabilizing pvc-pole along the side of the consecutive incubators to ensure that the incubator tube stayed at their respective depths throughout the duration of the experiment. This orientation also has the use of four poles to hold the incubator tubes in a 45-degree-angle.

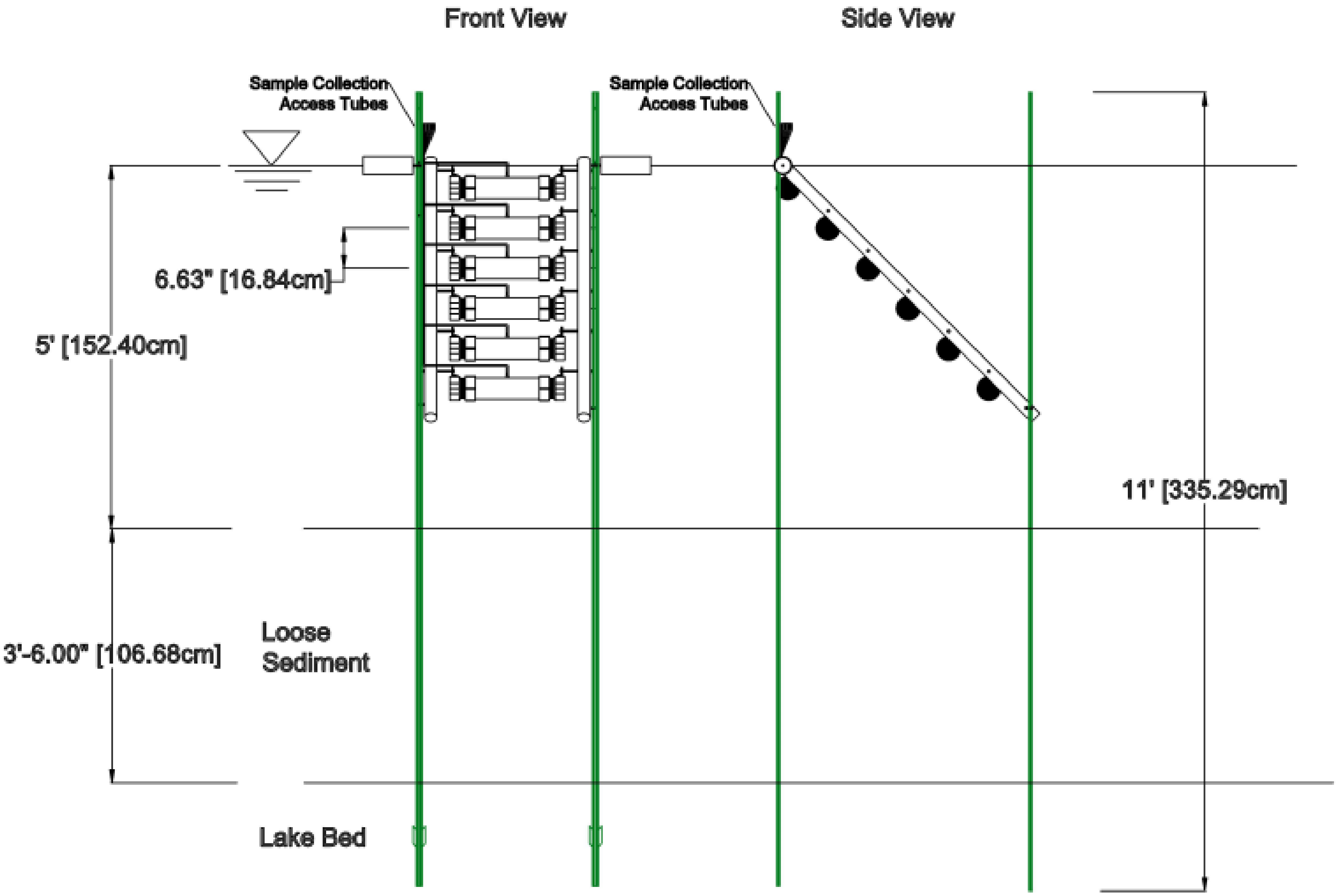


Figure 3 Option B Design

The front view of the option C design is depicted in figures 4, 5, and 6 was the third and final suspension method that we designed for the algae incubator system. With more concern for the upper incubators impeding the light available to the lower consecutive incubators, we designed this option C in six separate parts. This suspension method has four stabilizing poles holding three incubators at their respective depths. This greatly increased the cost of the design but increased the statistical significance of the experiment by including three incubator tubes at each depth.

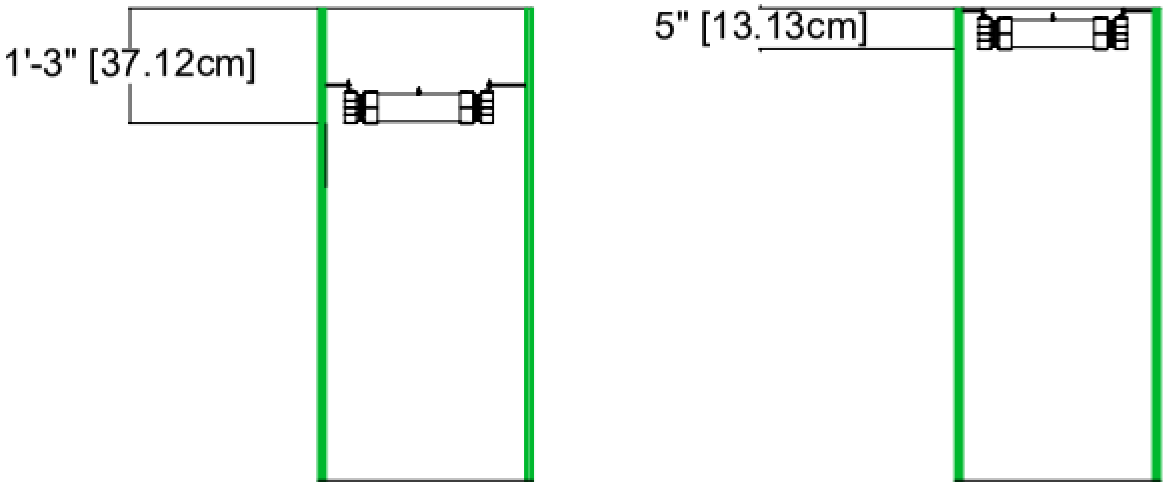


Figure 4 Option C Design Part (1)

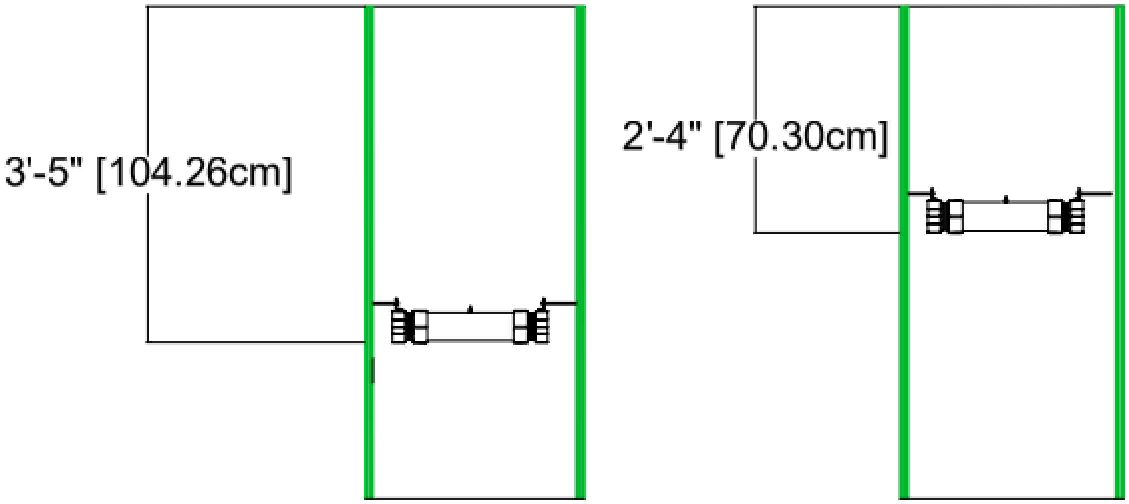


Figure 5 Option C Design Part (2)

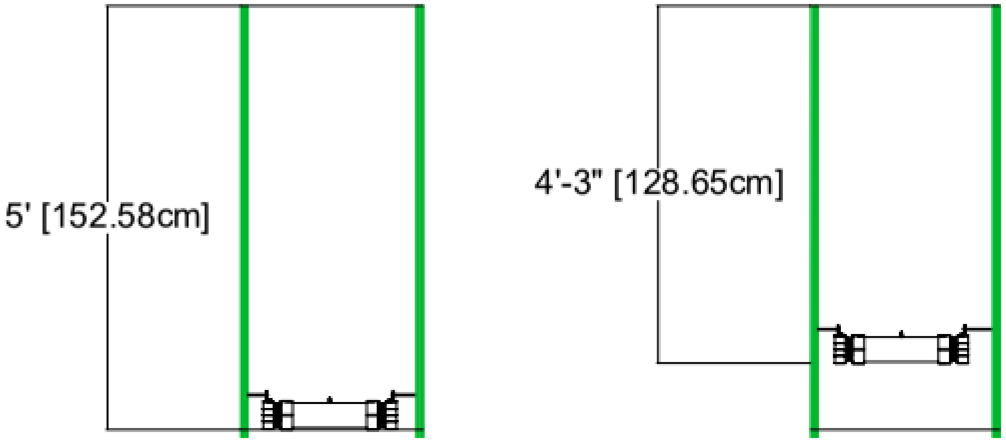


Figure 6 Option C Design Part (3)

Structural Analysis

RISA 2D, a structural engineering software was used to complete the analysis on the pole mount. RISA 2D analysis and design features allowed us to create a frame showing how our incubator would stay in place underneath Utah Lake. We assumed that the manufactured fence post that we are using to mount the incubator would meet specifications for pullout capacity in saturated soil. Because we welded two together to increase the length, we want to analyze the bending capacity of the longer poles. Because the forces acting on any of the poles of the 3 prototypes would be similar, one model was made and analyzed for one pole mount assuming worst-case loading conditions. Loads were factored using the Load and Resistance Factor Design (LRFD) method. In our model, we accounted for two different loads: the dead load and live load. The dead load included the weight of the poles and the permanent attachments of the incubator itself. The live load only included the force of waves.

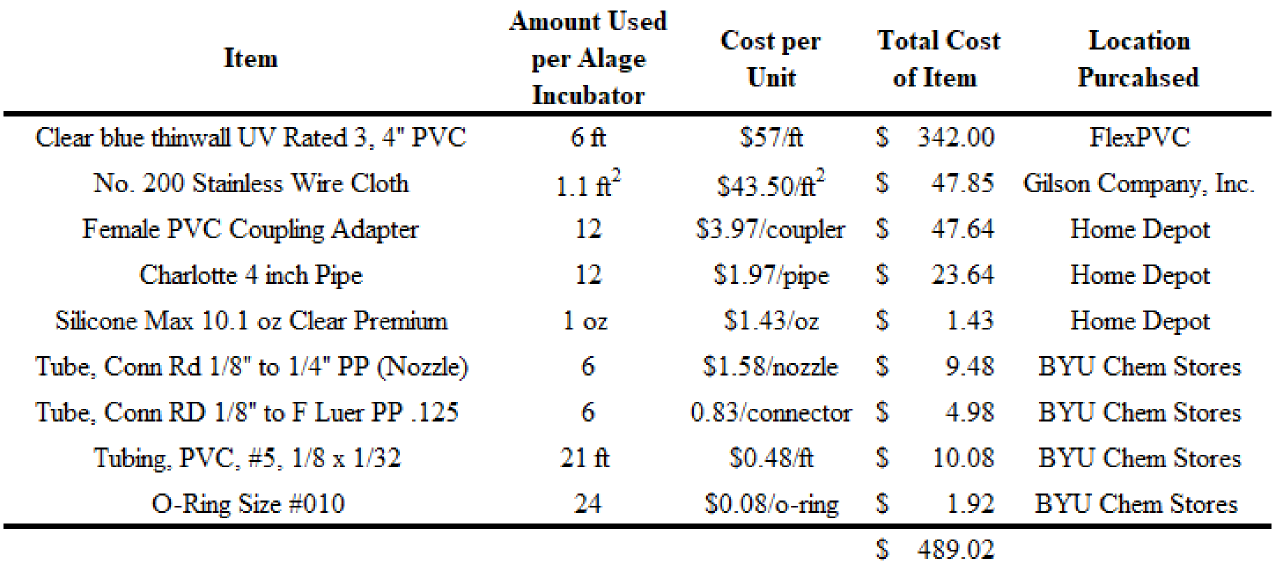
Being able to figure out how strong these waves would hit our incubator involved researching wind-driven waves near the shore of Utah Lake. We learned that waves could reach heights of 10 feet due to high winds resulting from about 40 miles per hour winds ('Pounded by wave', 2021). The live load due to the forces of the waves were estimated based on the unit weight of water multiplied by the area of a wave 10-foot wave. This load was applied in the analysis model as a triangular distributed load, assuming the force of the wave impacts the top more than the bottom of the structure. Wind loads were not included because the surface area of the structure that sticks out of the water is insignificant.

Our RISA model found in the appendix shows how all the forces are being applied. The report also shows what type of materials we used. In that specific model, we decided that our best option would be to use a steel frame. Since our fence pole was made of steel, we assumed that it would have similar properties and strengths. In the process of doing our calculations, we did come across a few challenges, one being the length of the pole. Our model continued to fail due to the long span and heavy forces of the waves. For us to get our model to pass, we had to add a reaction force down on the lower end of the pole. We collaborated as a group and agreed that the soil could act as a reaction force cutting up the full length for it to only receive that load on part of the frame. This allowed our model to be more precise on the load count and pass. Overall, the structural analysis part of this project allows us to calculate how strong our model could be once out in the water.

Cost Analysis

Each algae incubator design used the same incubator tube design depicted in figure 1 with differences in design relating to how the incubator tubes were suspended in the water column. A base cost was calculated for six incubator tubes including the clear PVC pipe, female couplers, Charlotte pipes, No. 200 mesh, nozzles, silicon, sampling tubing, lure lock connections, and O-rings. The cost breakdown of the base algae incubator cost is found in Table 1. The most expensive of the algae incubator design is the clear blue thin wall UV rated 3, 4 in PVC used and the No. 200 stainless steel mesh. The base cost of each algae incubator design is $489.02. This is the actual base cost of the materials purchased used to build the prototype.

Table 1 Base Algae Incubator Cost



Item	Amount Used per Alage Incubator	Cost per Unit	Total Cost of Item	Location Purcahsed
Clear blue thinwall UV Rated 3, 4" PVC	6 ft	$57/ft	$ 342.00	FlexPVC
No. 200 Stainless Wire Cloth	1.1 ft^2	$43.50/ft^2	$ 47.85	Gilson Company, Inc.
Female PVC Coupling Adapter	12	$3.97/coupler	$ 47.64	Home Depot
Charlotte 4 inch Pipe	12	$1.97/pipe	$ 23.64	Home Depot
Silicone Max 10.1 oz Clear Premium	1 oz	$1.43/oz	$ 1.43	Home Depot
Tube, Conn Rd 1/8" to 1/4" PP (Nozzle)	6	$1.58/nozzle	$ 9.48	BYU Chem Stores
Tube, Conn RD 1/8" to F Luer PP .125	6	0.83/connector	$ 4.98	BYU Chem Stores
Tubing, PVC, #5, 1/8 x 1/32	21 ft	$0.48/ft	$ 10.08	BYU Chem Stores
O-Ring Size #010	24	$0.08/o-ring	$ 1.92	BYU Chem Stores
			$ 489.02	

Throughout this cost analysis this cost will be referred to as the “base cost” and any cost related to the differing designs will be referred to as “additional costs”. Total costs will include the base and additional costs.

Option A additional cost breakdown can be viewed in Table 2. The additional cost of option A is the cost to suspend the algae incubator tubes as designed in figure 2. Four 6.5 ft steel T posts would need to be welded together with 6 in overlap to create the two 11 ft stabilizing posts as designed. For cost effectiveness, the incubator tubes were designed to be suspended with a series of pipe clamps and zip ties. The flotation device was designed with the use of a pool noodle and insulating foam sealant. The incubator tube’s structure was then designed to be secured to the fence posts with the use of D-rings. The additional cost of option A came out to $93.89. The total cost of option A came out to $582.91. The estimated prices listed in Table 2 came from websites of the respective location purchased column.

Table 2 Option A Additional Cost Breakdown

Item	Amount Used per Alage Incubator	Cost per Unit	Total Cost of Item	Location Purcahsed
6-1/2' Steel T Post	4	$7.84/post	$ 31.36	Home Depot
Zip ties	1 package	$4.48/20-pack	$ 4.48	Home Depot
Insulating Foam Selant	1 can	$4.38/can	$ 4.38	Home Depot
Stainless Steel Hose Clamp	16	$2.18/clamp	$ 34.88	Home Depot
D-rings	4	$2.75/ring	$ 11.00	Home Depot
Pool Noodle	1	$7.79/noodle	$ 7.79	Walmart
		Additional Cost	$ 93.89	
		Total Design Cost	$ 582.91	

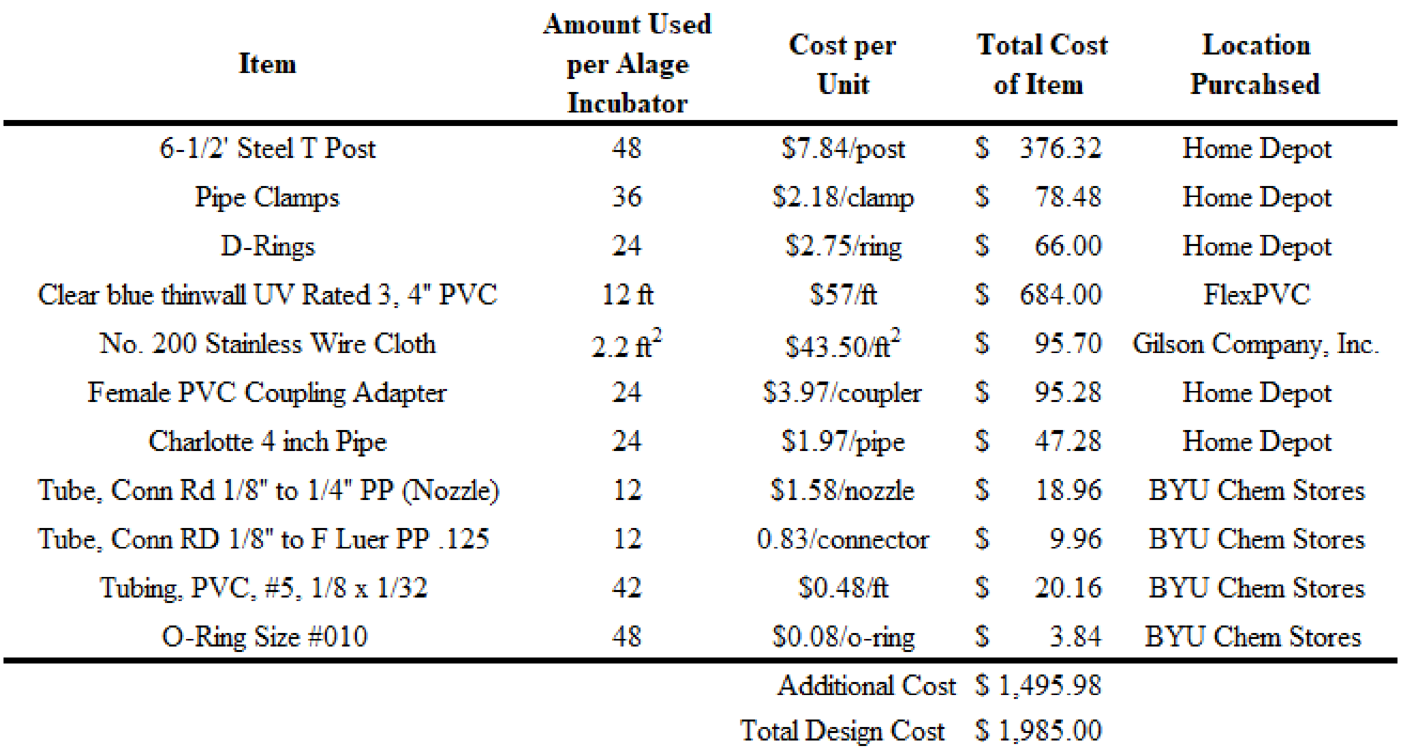
Option B's additional cost breakdown can be viewed in Table 3. As with option A, the additional cost of option B is the cost to suspend the algae incubator tubes in the option B design configuration. To account for the four needed 11 ft posts, eight 6.5 ft posts were welded together with a 6-inch overlap. This design included a stabilizing PVC pole attached to either end of the algae incubator tubes. This design added stability to the depths of the incubator tubes but increased the cost from option A by $93.98. This is due to the additional cost of 10 ft worth of stabilizing PVC, twelve corner brackets, twelve 1.5 in bolts, 96 brackets, and Loctite. The floatation design in option B was the same floatation design as option A. It consists of a pool noodle and insulating foam sealant. The total additional cost of option B came out to $187.87. The total cost for option B came out to $676.89 including the base cost. This was the actual cost to build the prototype.

Table 3 Option B Additional Cost Breakdown

Item	Amount Used per Alage Incubator	Cost per Unit	Total Cost of Item	Location Purcahsed
6-1/2' Steel T Post	8	$7.84/post	$ 62.72	Home Depot
1-1/2" x 10' PVC 40-DWV Pipe	10 ft	$1.28/ft	$ 12.80	Home Depot
1" Corner Brace Zinc Bracket	12	$0.65/bracket	$ 7.80	Home Depot
1/4" x 1.5" Bolt	12	$0.42/bolt	$ 5.04	Home Depot
1/4" x 9" Bolt	12	$3.97/bolt	$ 47.64	Home Depot
1/4" Hex Nut	96	$0.10/nut	$ 9.60	Home Depot
3/8" Hex Nut	12	$0.20/nut	$ 2.40	Home Depot
Loctite 242 Threadloocker Blue	0.2 oz	$7.98/0.2 oz	$ 7.98	Home Depot
Insulating Foam Selant	1 can	$4.38/can	$ 4.38	Home Depot
Pool Noodle	1	$7.79/noodle	$ 7.79	Walmart
Pipe Clamps	4	$2.18/clamp	$ 8.72	Home Depot
D-Rings	4	$2.75/ring	$ 11.00	Home Depot
		Additional Cost	$ 187.87	
		Total Design Cost	$ 676.89	

Option C additional cost breakdown can be viewed in table 4. This design increased the amount of algae incubator tubes to increase the statistical significance of the experiment by including three incubator tubes at each of the six depths. The clear thin wall PVC was the most expensive material in the base cost and as such greatly increased the cost of the option C design. The two additional incubator tube costs were included in the option C cost breakdown in table 4. With new incubator tubes more female couplers and charlotte pipes were needed as well as nozzles, and sampling tubing. This design removed the use of the floatation device and increased the number of 6.5 ft steel T posts needed to 48. The additional cost for option C came to $1,495.98. The total cost of building option C came to $1,985.00. The estimated prices listed in table 4 came from websites of the respective location purchased column.

Table 4 Option C Additional Cost Breakdown



Item	Amount Used per Alage Incubator	Cost per Unit	Total Cost of Item	Location Purcahsed
6-1/2' Steel T Post	48	\$7.84/post	\$ 376.32	Home Depot
Pipe Clamps	36	\$2.18/clamp	\$ 78.48	Home Depot
D-Rings	24	\$2.75/ring	\$ 66.00	Home Depot
Clear blue thinwall UV Rated 3, 4" PVC	12 ft	\$57/ft	\$ 684.00	FlexPVC
No. 200 Stainless Wire Cloth	2.2 ft^2	\$43.50/ft^2	\$ 95.70	Gilson Company, Inc.
Female PVC Coupling Adapter	24	\$3.97/coupler	\$ 95.28	Home Depot
Charlotte 4 inch Pipe	24	\$1.97/pipe	\$ 47.28	Home Depot
Tube, Conn Rd 1/8" to 1/4" PP (Nozzle)	12	\$1.58/nozzle	\$ 18.96	BYU Chem Stores
Tube, Conn RD 1/8" to F Luer PP .125	12	0.83/connector	\$ 9.96	BYU Chem Stores
Tubing, PVC, #5, 1/8 x 1/32	42	\$0.48/ft	\$ 20.16	BYU Chem Stores
O-Ring Size #010	48	\$0.08/o-ring	\$ 3.84	BYU Chem Stores
		Additional Cost	\$ 1,495.98	
		Total Design Cost	\$ 1,985.00	

Design Comparison Analysis

Table 5 below summarizes the five main criteria used to determine which of the three designs would be built into a prototype. These five main criteria include 1) phytoplankton protection and sampling capabilities, 2) light penetration of the incubator tubes, 3) reasonable certainty of incubator depth, 4) structural stability of algae incubator structure, and 5) cost-effectiveness of the system. Each of the three designs was given a score on a scale of 0 to 10 based on how well they met the respective criteria. A 0-score corresponded to a poor function with respect to that criterion and a 10-score corresponded to an excellent score with respect to that criterion.

Phytoplankton protection and sampling capabilities were evaluated based on the incubator tubes. Each of the three designs used the same incubator design and as such each of the designs were given the same score of 9. A 9 score was given to the tubes because the incubator tubes allow for sun penetration, protect the phytoplankton from zooplankton predators, and allow for sampling. The No. 200 mesh protects phytoplankton from zooplankton but not from larger predators such as carp. The couplers provide space between the end of the incubator tubes and the mesh, but a smaller fish could still potentially infiltrate the tube with enough force. It is for this reason that a score of 9 rather than a 10 was given to the designs for the first criterion.

Table 5 Design Comparison Analysis

Factor	Option A	Option B	Option C
Phytoplankton Protection	9	9	9
Light Penetration	2	8	9
Certainty of Incubator Depth	7	9	9
Stability of Structure	8	10	10
Cost	10	8	2
Total	36	44	39

Light penetration was the next criterion that was considered in this design comparison analysis. Each design contains the same incubator tube design and as such the light penetration criterion was evaluated by considering the suspension of incubator tubes in each design. Option A suspends the algae incubators in a rope-ladder like manner with the tubes hanging at a 90-dergree angle from the water surface. With the tubes hanging vertically down, the incubator tubes closer to the surface would shade the incubator tubes below them. This shade could mimic how algae growing on the surface would shade algae below. This, however, is not the purpose of the algae incubator tool. The tool was created to see how algal growth was affected by the light attenuation of the lake and not the light attenuation of other factors as such a 2 score was given to design A. Option B suspended the incubator tubes at a 45-degree angle to reduce shading of the upper tubes on the lower tubes with some shading potential still possible an 8 score was given to option B. Option C suspended the algae incubators at various depths in separate structures. This removed the shading problem of incubator tubes all together. Option C still had the potential of shading the posts onto the incubator tubes, but this was considered minimal shading and is why option C was given a 9 score. Option C is the best option when considering the light attenuation factor.

Reasonable certainly of incubator tube depth throughout the duration of deployment is vital to the integrity of the experiment. This criterion was mainly evaluated through evaluation of the suspension method of each design. Design A suspends incubator tubes with the use of zip ties and holds the suspension in place with tension on the first and last incubator tubes. This design was considered to have the least certain of depth because the zip tie connection allows for some movement and because of this option A was given a 7 score. Option B suspends the incubator tubes with the use of a PVC stabilizing post. This stabilizing post prevents movement of the tubes, so depth is reasonably certain. Option C has about the same amount of certainty as Option B because three incubator tubes are secured at each depth with posts surrounding them. Both options B and C were given a score of 9 for this criterion.

The algae incubator structure will be deployed for two weeks at a time and as such the structural stability of the structure is vital to the integrity of the experiment. Each design used the same 11 ft steel T posts and as such were tied to the same structural analysis. Because the same posts were used options B and C were given the same stability score. Option A was given a smaller score than options B and C because option A only has two posts securing the structure whereas options B and C contain four posts securing the structure. Option 8 received a score of 8 and option B and C received a score of 10 for this criterion.

The next factor that was considered in deciding which algae incubator structure to build was the cost. With the same base cost of the incubator tubes respective attachments, the main cost difference between each design was the suspension configuration of each design. Option A has 2 welded poles per a structure, option B has 4 welded poles per structure, and option C has 24 welded poles per structure (four welded poles for each of the six depths). Option A is the most cost effective with a total cost of $582.91, option B is the next cost effective with a total cost of $676.89, and C is by far the most expensive with a total cost of $1,985.00. For more detail on cost see the “Cost Analysis” section of this report. Based on the cost breakdown option A was given a score of 10, option B was given a score of 8, and option C was given a score of 2 for this criterion.

Related Issues

The algae incubator tool will be used to help determine whether Utah Lake is a light limited lake. Because the algae incubator is mostly underwater, we have considered possible safety factors related to the swimmers and boats. Boats pose the greatest threat to damage caused to the algae incubator or to the boat itself after striking the incubator. Boats in Utah Lake generally occupy the middle of the lake, while the algae incubator will sit closer to shore. While a boat striking the incubator is unlikely, we will still want to take precautions against this. Visibility is the best way to alert boaters to the device. We will spray-paint that top of the incubator a fluorescent orange color to make the post more visible. We also recommend placing an additional buoy by the incubator to increase visibility.

We have also discussed the impact of the incubator on wildlife in the lake. Carp are known to eat algae off the sides of other test devices that have been put into the lake. The fish should not be capable of breaking the incubator tube itself; smaller carp, however, could potentially break the mesh caps and get stuck inside the incubator tubes. We were also concerned about fish or birds getting caught in the algae incubator structure, but this is unlikely as it is mostly rigid with no nets or ropes used. The likelihood of a swimmer getting injured on the device is also unlikely. With phytoplankton in the algae incubator tubes, it is likely that zooplankton assemblages will be found in higher concentrations outside the incubator tubes. This higher concentration of zooplankton surrounding the algae incubator tubes could lead to a decrease in the phytoplankton surrounding the tube. The algae incubator tube will be deployed two weeks at a time so this possible decline in phytoplankton will only be temporarily.

We have also considered the possibility that a storm occurs and dislodges the algae incubator. Though there is a chance that the incubator could be lost in this scenario, we do not believe it will lead to environmental harm other than the littered plastic. The incubator is buoyant so if it begins drifting it will still be visible at the surface. With a structure this large we would recommend searching for the lost algae incubator tool and believe that this structure could be easily found. Once found most of the environmental impacts would be mitigated.

Politically, this device could affect government regulations of wastewater treatment requirements. It will be used to test whether Utah Lake is light limited or nutrient limited. The findings of this study may be used to persuade officials to remove additional effluent standards for Utah County's wastewater treatment plants. The design of this device is not politically motivated. This tool is being created to better understand Utah Lake and how to reduce toxic algae blooms.

Lessons Learned

As a team we learned the importance of brainstorming, gaining feedback, being flexible with materials, and prototyping. We decided to brainstorm designs separately and then come together to share our design ideas. From this brainstorming session we discussed the pros and cons of each presented design and tried to incorporate the pros into our final designs. This was a valuable experience and proved beneficial for the overall design of our prototype. As we continued to meet and draft the designs, we found ways to improve the design and they continued to change. One such change was realizing that an underlying constraint we hadn't thought much about was that the incubator tubes must stay at their specified depths in a more rigid way than we had originally planned for in our designs. We were able to further brainstorm and decided that a cost-effective way to make the structure more rigid for the integrity of the experiment this summer was to add stabilizing PVC to the sides of the incubator tubes.

With our designs drafted we went to discuss further with our faculty mentor, Dr. Williams, for some feedback before we entered the prototyping phase of the project. He brought in more detailed issues that we had not considered. One such example was how to attach algae incubator to the fence posts. We had drawn a connection but hadn't considered what we would purchase at Home Depot during the prototyping phase of the project. He suggested that we use a combination of a D-ring and pipe clamp. None of us team members had much experience building things quite like the algae incubator and valuable help like this was very much appreciated. Feedback from mentors, especially throughout the design and building processes is extremely helpful to the success of the project.

As a team, we also learned how to be flexible with the materials that we got. As we entered the prototyping stage of the project we worked with Rodney Mayo and Dave Andersen to source our parts. When we got the parts, they weren't always what we were expecting because what we wanted was not always available. One such instance was when we got brackets to attach the incubator tubes to the stabilizing pole the bracket holes were smaller than the bolts. To solve this issue, we met with the Prototyping Lab on campus and learned how to use their drilling machine and deburring equipment. We drilled bigger holes into all the brackets and deburred them ourselves to solve the issue.

Once we were in the full swing of prototyping and assembling the algae incubator structure together, we noticed some issues. The floatation device that would keep the depth of the incubators relative to the water surface could no longer fit where we originally planned to attach it because of the added PVC stabilizing units. We were quickly able to brainstorm and found that the floatation device could be attached to the top of the stabilizing pvc pipe we would just need to drill another hole in the PVC. In our experience prototyping of the algae incubator required flexibility when coming across issues such as the flotation and stabilizing pvc connections.

Conclusions

In conclusion the provided Option B algae incubator prototype can be implemented in Utah Lake this coming summer 2023. The option B design was found to best meet the five main criteria of the algae incubator design. These design criteria included 1) phytoplankton protection and sampling capabilities, 2) light penetration of the incubator tubes, 3) reasonable certainty of incubator depth, 4) structural stability of algae incubator structure, and 5) cost-effectiveness of the system.

The algae incubator tubes are a safe place for the algae to grow at various depths. The No. 200 mesh ensures that algae predators, such as zooplankton, cannot enter the tube and the 45-degree angle of suspension ensures that light penetration is only inhibited by the turbidity of the water column. The nozzles on the incubator tubes in addition to the sampling tubing also provide a convenient way to gather samples from the tubes for chlorophyll-a extractions as often as specified in the experiment. For quality assurance of the light limitation experiment the algae incubator has reasonable certainty of incubator tube depth relative to the water surface. This was accomplished through the use of a stabilizing pvc pipe along the side of the incubator tube depth and a floatation device to ensure that depths are relative to the water surface.

The structural analysis reports indicated that the algae incubator structure could withstand up to 10 ft waves on Utah Lake which corresponds to about 40 mph ('Pounded by wave', 2021). This structural stability was calculated assuming that the fence posts are embedded at least 2 feet into the lakebed past the approximately 3 ft of loose sediment. The final main criterion that option B met was cost effectiveness. The total cost of option B came to $679.89. The design comparison analysis found that option B best met all the main criteria of this project and as such was the design that was prototyped.

The objectives of this capstone project were met by TRS Engineering. Three algae incubator designs were developed within the constraints of the limitations of the project. These three designs were analyzed for structural integrity, cost effectiveness, and adherence to the outlined constraints. Once analyses were completed, the best fit design, option B, was built into a prototype. This prototype is ready for deployment this summer in relation to the light limitation study it was intended for.

Recommendations

We recommend the use of the Option B design. This option incorporates the cost-effectiveness of option A, and the light penetration of option C. Option B is a good mix between option A and C.

For the integrity of the algae incubator experiment we would recommend checking on the structure every couple of days. This would ensure that the mesh is intact and that the structure has not been vandalized by people or animals. Between each deployment of the algae incubator, we recommend checking the mesh for clogging. With periphyton growing in the water it would be easy for mesh of this size to get clogged.

When extracting samples for chlorophyll-a extractions we recommend extracting the water that had been in the tubing before extracting the sample. Extracting the water out of the tube with the 60-cc syringe ensures that the sample being tested is from the incubator and not from the tube.

We also recommend that the tops of the tubes be clasped closed when not immediately taking sample out of the algae incubator. This reduces the likelihood of zooplankton entering the incubator tube through the sampling tube.

We recommend securing the algae incubator structure by imbedding at least 2 feet of the stabilizing posts into the lakebed. Structural analysis was run assuming that two feet of the posts were imbedded in the lakebed. Estimates of the incubator withstanding 40 mph winds are dependent on the 2 feet of posts imbedded into the lakebed.

With the algae incubator being deployed in Utah Lake with boaters, we would recommend anchoring at least one buoy near the algae incubator. This would be for the safety of the boaters and the algae incubator. It is best to warn boaters of the structure under the water surface so that it does not get destroyed and ruin a boat motor.

We also recommend being careful when transporting the algae incubator structure. We have found that one point of failure is the nozzles that stick out of the incubator tubes and attach to the sampling tubes. These nozzles are made of plastic and will break if hit against anything. They are easy to replace, but they are something that needs to be looked out for prior to deployment. With no nozzle sampling is not possible as designed.

Works Cited

Abbott, B. W., Errigo, I. M., Follett, A., Lawson, G., Meyer, M. M., Moon, H., Shurtleff, K., LeMonte, J. J., Proteau, M., & Davis, K. (2021). Getting to know the Utah Lake Ecosystem. *Provo, Utah*, 32.

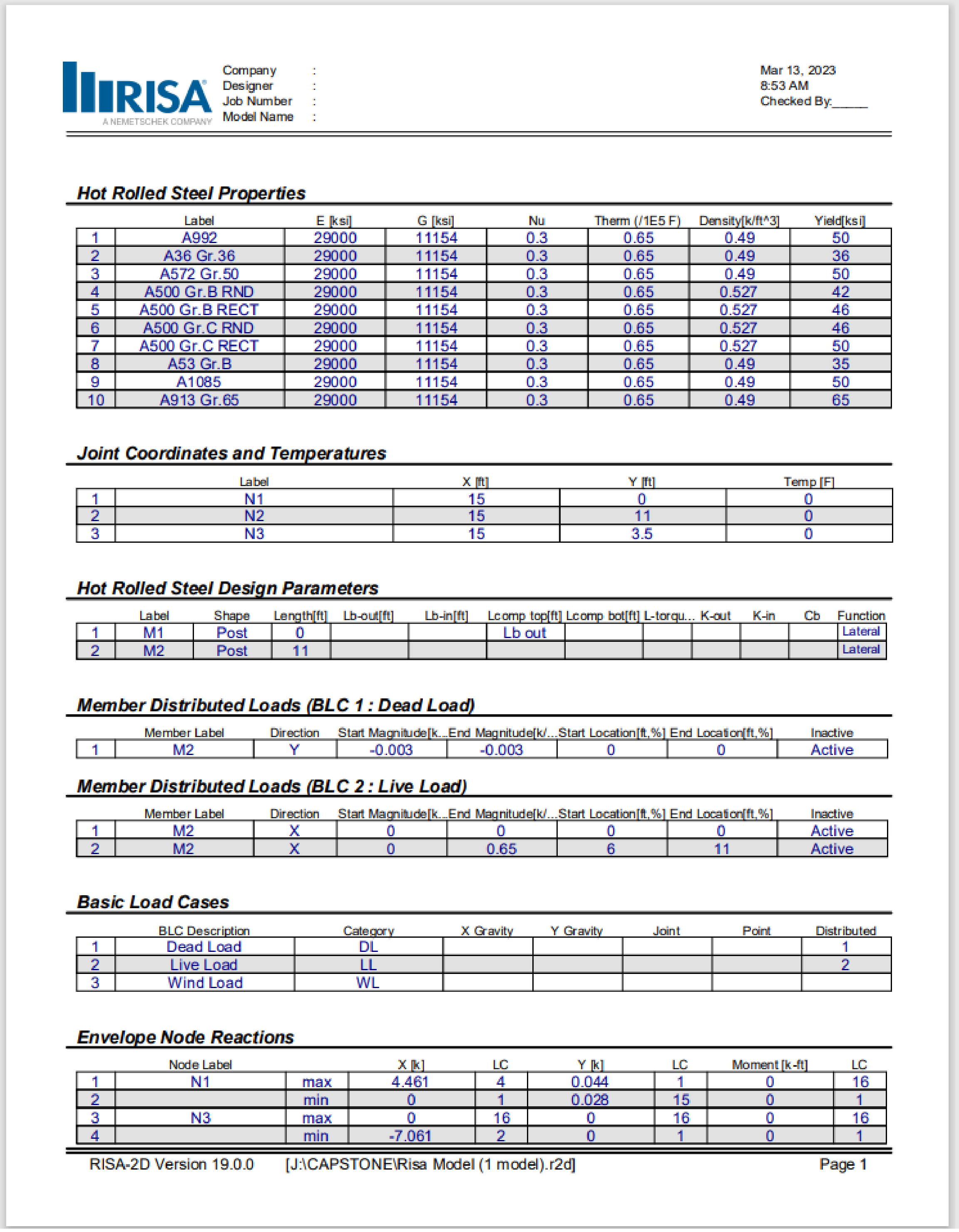
Lawson, G. M. (2021). *Seasonal Nutrient Limitations of Cyanobacteria, Phytoplankton, and Cyanotoxins in Utah Lake* Brigham Young University.

Merritt, L. (2004). Utah Lake, a Few Considerations. *Unpublished letter. 3p*.

'Pounded by wave after wave after wave': How shallow Utah lake can become dangerous. (2021, May 18). ABC4 Utah. https://www.abc4.com/news/local-news/pounded-by-wave-after-wave-after-wave-how-shallow-utah-lake-can-become-dangerous/

Tanner, K. B., Cardall, A. C., & Williams, G. P. (2022). Analysis of long-term chlorophyll trends in Utah Lake using Landsat Data and Lake Regions. 2022 Intermountain Engineering, Technology and Computing (IETC).

Appendix A



Company :
Designer :
Job Number :
Model Name :

Mar 13, 2023
8:53 AM
Checked By:_____

Hot Rolled Steel Properties

	Label	E [ksi]	G [ksi]	Nu	Therm (/1E5 F)	Density[k/ft^3]	Yield[ksi]
1	A992	29000	11154	0.3	0.65	0.49	50
2	A36 Gr.36	29000	11154	0.3	0.65	0.49	36
3	A572 Gr.50	29000	11154	0.3	0.65	0.49	50
4	A500 Gr.B RND	29000	11154	0.3	0.65	0.527	42
5	A500 Gr.B RECT	29000	11154	0.3	0.65	0.527	46
6	A500 Gr.C RND	29000	11154	0.3	0.65	0.527	46
7	A500 Gr.C RECT	29000	11154	0.3	0.65	0.527	50
8	A53 Gr.B	29000	11154	0.3	0.65	0.49	35
9	A1085	29000	11154	0.3	0.65	0.49	50
10	A913 Gr.65	29000	11154	0.3	0.65	0.49	65

Joint Coordinates and Temperatures

	Label	X [ft]	Y [ft]	Temp [F]
1	N1	15	0	0
2	N2	15	11	0
3	N3	15	3.5	0

Hot Rolled Steel Design Parameters

	Label	Shape	Length[ft]	Lb-out[ft]	Lb-in[ft]	Lcomp top[ft]	Lcomp bot[ft]	L-torqu...	K-out	K-in	Cb	Function
1	M1	Post	0			Lb out						Lateral
2	M2	Post	11									Lateral

Member Distributed Loads (BLC 1 : Dead Load)

	Member Label	Direction	Start Magnitude[k...	End Magnitude[k/...	Start Location[ft,%]	End Location[ft,%]	Inactive
1	M2	Y	-0.003	-0.003	0	0	Active

Member Distributed Loads (BLC 2 : Live Load)

	Member Label	Direction	Start Magnitude[k...	End Magnitude[k/...	Start Location[ft,%]	End Location[ft,%]	Inactive
1	M2	X	0	0	0	0	Active
2	M2	X	0	0.65	6	11	Active

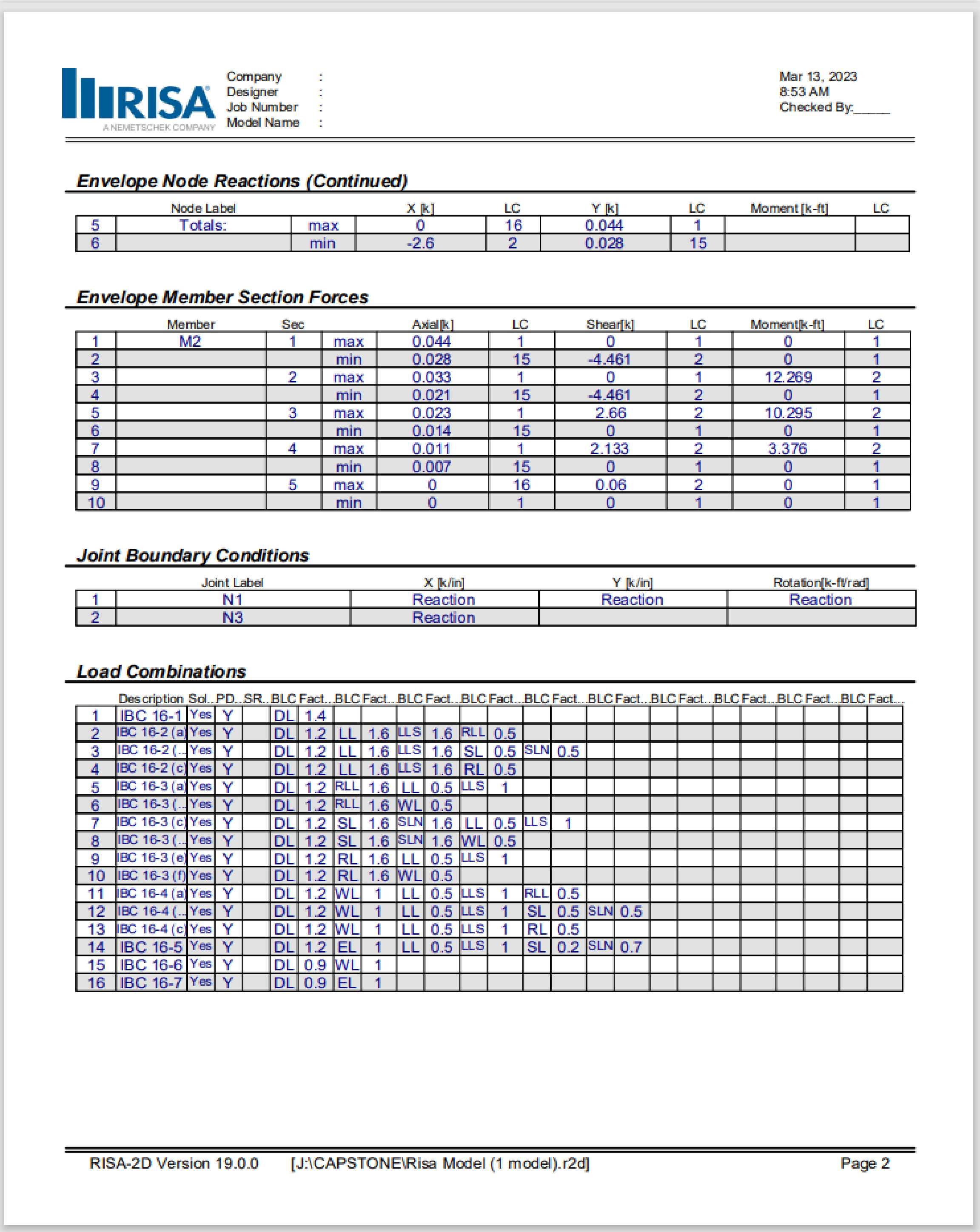
Basic Load Cases

	BLC Description	Category	X Gravity	Y Gravity	Joint	Point	Distributed
1	Dead Load	DL					1
2	Live Load	LL					2
3	Wind Load	WL					

Envelope Node Reactions

	Node Label		X [k]	LC	Y [k]	LC	Moment [k-ft]	LC
1	N1	max	4.461	4	0.044	1	0	16
2		min	0	1	0.028	15	0	1
3	N3	max	0	16	0	16	0	16
4		min	-7.061	2	0	1	0	1

RISA-2D Version 19.0.0 [J:\CAPSTONE\Risa Model (1 model).r2d] Page 1



Company :
Designer :
Job Number :
Model Name :

Mar 13, 2023
8:53 AM
Checked By:_____

Envelope Node Reactions (Continued)

	Node Label		X [k]	LC	Y [k]	LC	Moment [k-ft]	LC
5	Totals:	max	0	16	0.044	1		
6		min	-2.6	2	0.028	15		

Envelope Member Section Forces

	Member	Sec		Axial[k]	LC	Shear[k]	LC	Moment[k-ft]	LC
1	M2	1	max	0.044	1	0	1	0	1
2			min	0.028	15	-4.461	2	0	1
3		2	max	0.033	1	0	1	12.269	2
4			min	0.021	15	-4.461	2	0	1
5		3	max	0.023	1	2.66	2	10.295	2
6			min	0.014	15	0	1	0	1
7		4	max	0.011	1	2.133	2	3.376	2
8			min	0.007	15	0	1	0	1
9		5	max	0	16	0.06	2	0	1
10			min	0	1	0	1	0	1

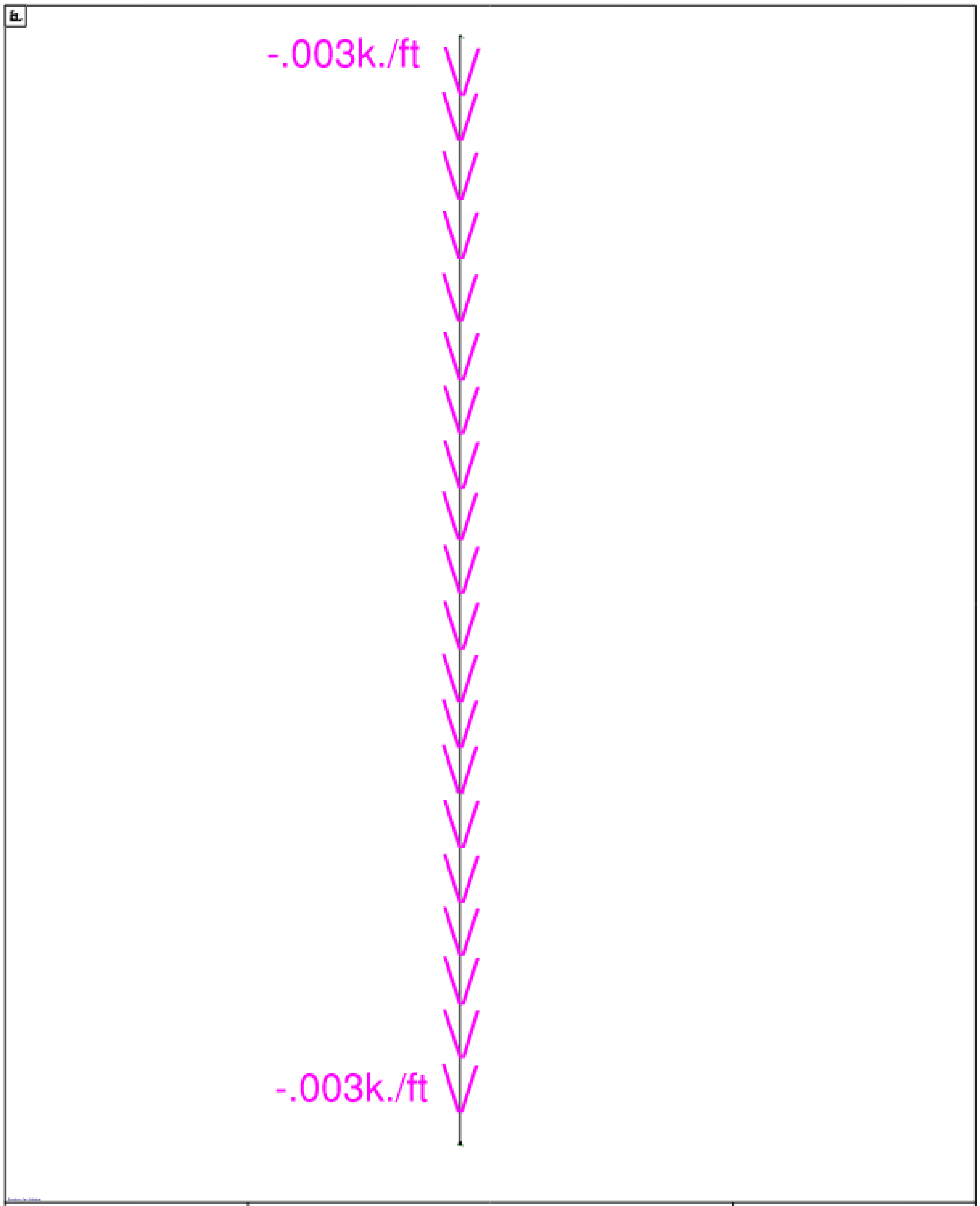
Joint Boundary Conditions

	Joint Label	X [k/in]	Y [k/in]	Rotation[k-ft/rad]
1	N1	Reaction	Reaction	Reaction
2	N3	Reaction		

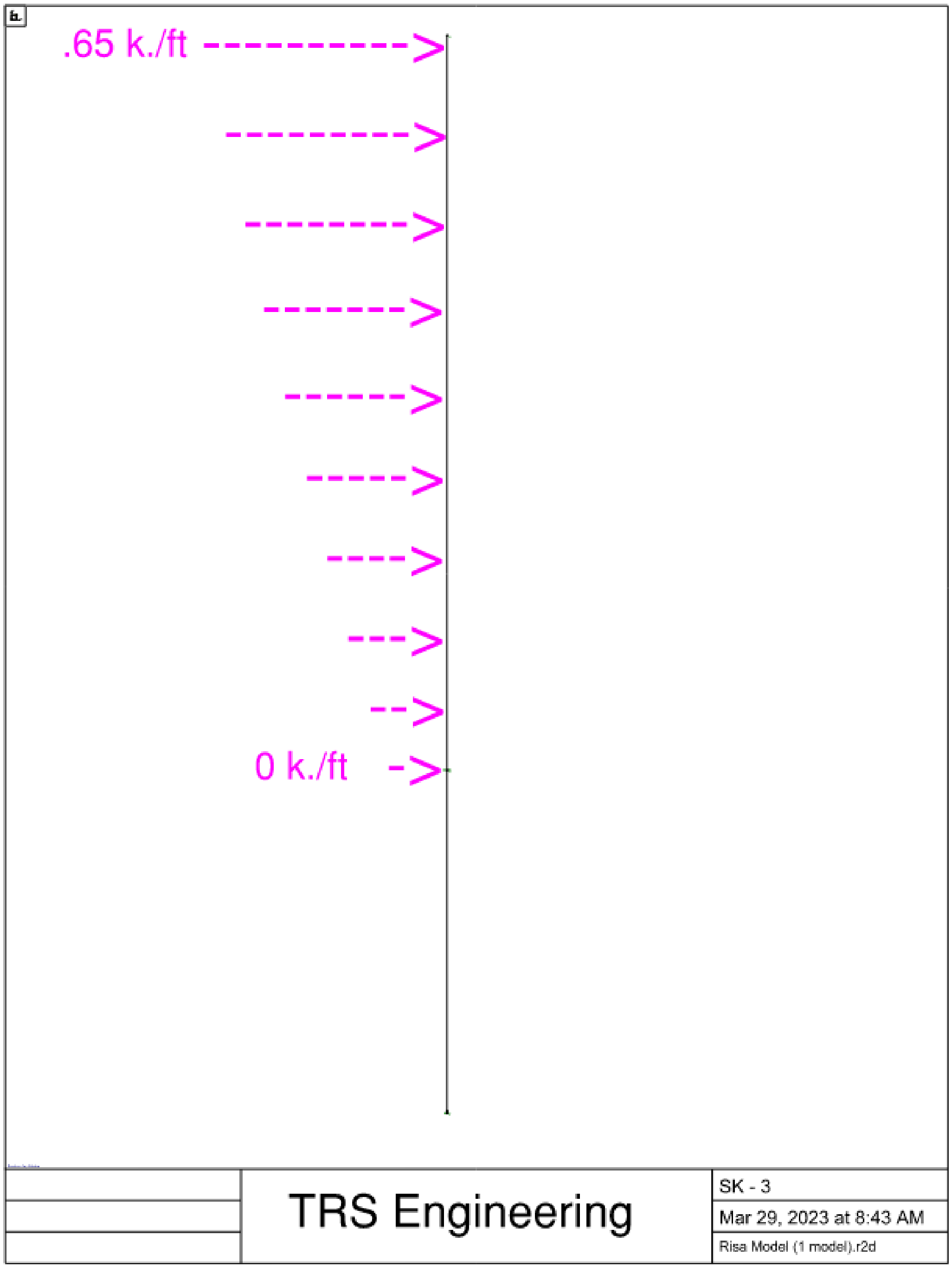
Load Combinations

	Description	Sol...	PD...	SR...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...	BLC	Fact...
1	IBC 16-1	Yes	Y		DL	1.4																		
2	IBC 16-2 (a)	Yes	Y		DL	1.2	LL	1.6	LLS	1.6	RLL	0.5												
3	IBC 16-2 (...	Yes	Y		DL	1.2	LL	1.6	LLS	1.6	SL	0.5	SLN	0.5										
4	IBC 16-2 (c)	Yes	Y		DL	1.2	LL	1.6	LLS	1.6	RL	0.5												
5	IBC 16-3 (a)	Yes	Y		DL	1.2	RLL	1.6	LL	0.5	LLS	1												
6	IBC 16-3 (...	Yes	Y		DL	1.2	RLL	1.6	WL	0.5														
7	IBC 16-3 (c)	Yes	Y		DL	1.2	SL	1.6	SLN	1.6	LL	0.5	LLS	1										
8	IBC 16-3 (...	Yes	Y		DL	1.2	SL	1.6	SLN	1.6	WL	0.5												
9	IBC 16-3 (e)	Yes	Y		DL	1.2	RL	1.6	LL	0.5	LLS	1												
10	IBC 16-3 (f)	Yes	Y		DL	1.2	RL	1.6	WL	0.5														
11	IBC 16-4 (a)	Yes	Y		DL	1.2	WL	1	LL	0.5	LLS	1	RLL	0.5										
12	IBC 16-4 (...	Yes	Y		DL	1.2	WL	1	LL	0.5	LLS	1	SL	0.5	SLN	0.5								
13	IBC 16-4 (c)	Yes	Y		DL	1.2	WL	1	LL	0.5	LLS	1	RL	0.5										
14	IBC 16-5	Yes	Y		DL	1.2	EL	1	LL	0.5	LLS	1	SL	0.2	SLN	0.7								
15	IBC 16-6	Yes	Y		DL	0.9	WL	1																
16	IBC 16-7	Yes	Y		DL	0.9	EL	1																

RISA-2D Version 19.0.0 [J:\CAPSTONE\Risa Model (1 model).r2d] Page 2



	TRS Engineering	SK - 3
		Mar 29, 2023 at 8:43 AM
		Risa Model (1 model).r2d


.65 k./ft
0 k./ft
TRS Engineering
SK - 3
Mar 29, 2023 at 8:43 AM
Risa Model (1 model).r2d