Air Bubble Curtain Anchoring

Cal Poly Mechanical Engineering Senior Project 2016-2017

Sponsor: Diablo Canyon Power Plant

Anderson Lin

axle@pge.com

Advisor: Eileen Rossman

erossman@calpoly.edu

Project Team: Donovan Lawrence

dolawren@calpoly.edu

Dakota Schwartz

dcschwar@calpoly.edu

Christian Young

cyoung24@calpoly.edu

Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

Contents

1. Introduction 10

1.1. Project Participants 10

1.2. Project Scope 10

1.3. Project Management 10

1.3.1. Milestones and Dates 10

1.3.2. Responsibilities 10

1.3.3. Gantt Chart 11

1.4. Safety Plan 12

1.4.1. Safety Hazard Identification Checklist 12

1.4.2. Special Procedures and Maintenance 14

2. Background 14

2.1. Diablo Canyon Power Plant 14

2.1.1. Intake Bay 14

2.1.2. Salp 14

2.2. Benchmarking 16

2.2.1. Current DCPP Bubble Curtain 16

2.2.2. Current Anchoring System 17

2.2.3. Bubble Curtain Operation 17

2.2.4. Ringhals Bubble Curtain and Anchoring System 17

2.2.5. Other Anchoring Systems 18

2.3. Attached Project Proposal Problem Statement and Goals 19

2.4. DCPP's Requirements 20

2.5. Engineering Specifications 20

2.6. Tests Required 21

3. Design Development 22

3.1. The Design Process 22

3.2. Ideation 23

3.2.1. Ideation Process 23

3.2.2. Quantitative 24

3.2.3. Matrices 27

3.3. Concepts 28

3.3.1. Concept 1: Mini Torpedo Anchor 28

3.3.2. Concept 2: Pulley System ... 29
3.3.3. Concept 3: Adjustable Poles from Ocean Surface ... 29
3.3.4. Concept 4: Reconfigured Current System ... 30
3.3.5. Concept 5: Buoy Leveling System ... 30
3.3.6. Concepts with Engineering Validation ... 31
3.4. Final Concept ... 33
3.4.1. Final Concept Description ... 33
3.4.2. Materials Cost Analysis ... 33
4. Final Design ... 34
4.1. Design Description ... 34
4.1.1. Design ... 34
4.1.2. Function Explanation ... 34
4.1.3. Material Selection ... 35
4.2. Tank Discussion ... 35
4.2.1. Function ... 35
4.2.2. Using the Tank ... 36
4.2.3. Air Pump ... 36
4.3. Design Justification ... 37
4.3.1. Analysis ... 37
4.3.2. Performance Prediction ... 39
4.4. Feasibility Concerns and Resolutions ... 40
4.4.1. Engineering Specification #1 ... 41
4.4.2. Pump Concerns ... 41
4.4.3. Potential Issues ... 41
4.5. Supporting Data ... 42
4.5.1. Cost ... 42
4.5.2. Budget ... 42
5. Project Realization ... 42
5.1. Manufacturing Process ... 42
5.2. Prototype Alterations from Planned Design ... 43
5.3. Recommendations for Future Manufacturing ... 43
5.3.1. Keep Pipe-Buoy Chain or Wires Adjustable ... 44
5.3.2. Keep the Pipe-Buoy Chain Long ... 44
5.3.3. Keep the Anchor-Pipe Connection Long ... 44

5.3.4. Ocean Floor Topography 44
6. Design Verification 44
6.1. Pipe Angle 44
6.1.1. Test Description and Purpose 44
6.1.2. Detailed Results 44
6.1.3. Analysis 46
6.2. Floor Shift 47
6.2.1. Description and Purpose 47
6.2.2. Analysis 48
6.3. Water Height Bubble Coverage 48
6.3.1. Test Description 48
6.3.2. Detailed Results 48
6.3.3. Analysis 49
6.4. Turbulence 49
6.4.1. Test Description 49
6.4.2. Detailed Results 49
6.5. Corrosion 50
6.5.1. Test Description w/photos 50
6.5.2. Detailed Results 50
6.6. Specification Verification Checklist 51
6.7. Incomplete Tests 51
7. Conclusion 52
7.1. Recommendations 52
7.1.1. Design Geometry 52
7.1.2. Design Components 52
7.1.3. Material 53
7.1.4. Further Testing 53
7.1.5. Recommendation Summary 53
7.2. Lessons Learned 53
Appendices: 54
References 55

List of Tables

Table 1: Pipe and Coupling parameters. 17
Table 2: Engineering Specifications Table. Each specification is assigned a risk level, High (H), Medium (M), or Low (L), noting its relative difficulty to complete. Additionally, compliance, or how we plan to verify design requirements, are listed as Analysis (A), Test(T), Similarity to Existing Designs (S) and Inspection (I). 20
Table 3: Summary of buoyancy calculations on current anchor components. 25
Table 4: Summary of statics calculations for current pipe and anchor system. 26
Table 5: The expected deflection of the bubble pipe. 27
Table 6: Summary of the decision matrix 28
Table 7: Summary of each concept using engineering analysis. 31
Table 8: Steel cable weight table, showing the effect of buoyancy and the ratio of cable weight with total buoyancy of the bubble pipe. 32
Table 9: Preliminary cost analysis. The below cost analysis is an incomplete estimate and will be updated upon scale selection 33
Table 10: Geometry relationship between full-scale and model system. Note tank dimensions below are minimum and do not reflect exact tank geometry. 38
Table 11: Loaded component factor of safety summary. See calculations in appendices. 39
Table 12: The pipe level was measured at each end using different block heights and water levels to simulate the shifting ocean floor and tides. Using the pipe ends, the angle was calculated. 47
Table 13: Data for the water height bubble test, extrapolating for the full scale model. 49
Table 14: Record of anchor and pipe inspection throughout testing. Note anchors were usually left in the water while pipe was taken out and dried after each use. 50
Table 15: Specification verification summary. Additional test information can be found in the previous sections. 51

List of Figures

Figure 1: Safety design hazard checklist provided by Cal Poly's Mechanical Engineering Department. 12
Figure 2: Descriptions of hazards and planned corrective action. 13
Figure 3: Visual of intake bay. 1 notes west breakwater, 2 notes Unit 1 intake, 3 notes Unit 2 intake, 4 notes rock with permanent chain, and 5 notes east breakwater. 14
Figure 4: Example of the concentration of salp present in an intrusion. 15
Figure 5: Concept of the Air Bubble Curtain currently used at Diablo Canyon Power Plant. Salp, depicted by the star shaped figures, are pushed toward the intake by the current. Bubbles lift them to the surface, where they are diverted away from the plant intake by the surface current and float boom (yellow block). (Diablo Canyon Power Plant, 2014) 16
Figure 6: Details of ABC layout. 16
Figure 7: A 10-year old anchor cable network used for bubble curtain anchoring applications at Ringhals Nuclear Power Plant 18
Figure 8: Torpedo anchors with and without fins 18
Figure 9: A stockless anchor preventing movement in the direction of the chain. The pictures are of one instance at different points in time. 19
Figure 10: The general format for the design processed that is going to be followed. 22
Figure 11: Examples of different ideation techniques used 24
Figure 10: Free body diagram of the bubble pipe (left) and the car stop anchor (right). 24
Figure 13: Deflection expected from distributed buoyancy load between pipe anchors. 27
Figure 14: A large torpedo anchor, used mainly to anchor oil rigs. 28
Figure 15: Pulleys are used to allow the pipe to level itself as the ocean floor changes. 29
Figure 16: Ideation of concept 3, with the orange tube as the bubble pipe, and the blue string as ocean level. 29
Figure 17: Reconfigured current system with more length between the anchors, and longer chains connecting to the pipe. 30
Figure 18: Cross section of the buoy leveling system uses the surface ocean level to maintain elevation, 30
Figure 19: Preliminary motion analysis of the buoy system. 30
Figure 20: Chosen design concept for leveling and anchoring the bubble curtain. 33
Figure 21: One junction of the full model. 34
Figure 22: The final design of the bubble curtain model consists of three assemblies that are attached to the pipes. Only one of the pipes will be producing bubbles, which simulates the conditions of the full-scale bubble curtain. On the ends of the pipes are plugs (2) and a flexible hose (3) which will attach to an air compressor. 34
Figure 23: Side view of the previously pictured weir box. 36
Figure 24: The weir box in the 192-102 fluids lab. This picture is before alterations were made; the weir plate no longer exists and tank can be filled to full height. 36
Figure 25: Protech 105W aquarium air pump. 37
Figure 26: Bubble coverage at different depths. Since salp-stopping ability is dependent upon bubble coverage, this pipe system past a certain depth will not be effective. 40
Figure 27: Predicted model motion with actual size comparison on the secondary axis. The buoy is represented by the red dot and the pipe is represented by the black circle. 40
Figure 28: Christian using a Miter saw to cut the Unistrut beams 42
Figure 29: Donavan and Dakota drilling holes in a clear PVC pipe 42
Figure 30: Christian and Dakota crimping the stainless-steel wires to the Unistruts 43
Figure 31: Donavan pouring the concrete 43
Figure 32: A picture of the model of the bubble curtain taken underwater. The lines perpendicular to the pipes are there to segment each section of the pipe for observations. Each section is labeled

with a highlighted section number. The bubbling side refers to the end of the pipe connected to the air compressor and the end cap refers to the side that is plugged by a PVC cap. The yellow arrows are used to show the direction of air flow through the pipe. The two rods extending from the surface of the water were used to orient the model for the picture. ____ 45
Figure 33: An example of the "no bubbles" rating. The area above the pipe is clear with no ripples in the water. This indicates that there are no bubbles exiting the pipe at this location. The yellow box depicts the area above the pipe that was investigated to make the observations. The picture was taken at section 4 on the pipe. ____ 46
Figure 34: An example of the "several bubbles" rating. The area above the pipe has ripples in the water and is not clear. This indicates that there are bubbles exiting the pipe at this location. The yellow box depicts the area above the pipe that was investigated to make the observations. The picture was taken at section 4 on the pipe. ____ 46
Figure 35: Anchor 3 with a 3" block below it, simulating the sinking of the adjacent anchor block.____ 47
Figure 36: A comparison of the pipe angle to the water height with blocks shown in various tests. Pipe angle correlates poorly with water height and the angle variation is due entirely to measurement uncertainty. ____ 48
Figure 37: Corrosion found on the carabiner and concrete anchor during inspection. ____ 50

Executive Summary

To prevent salp (jellyfish) from entering Diablo Canyon Power Plant's intake pipes, and ultimately having the plant shut down as a result, an air bubble curtain is anchored along the ocean floor for the duration of the salp swarm to create a barrier that prevents the salp and other debris from entering the intake. The curtain consists of four large air compressors connected to four parallel pipes with holes strategically drilled at various places along the length of the pipe. When the air compressors are turned on, a torrent of bubbles are shot out from the pipes which create a current which deters the salp from floating into the intake. As the ocean floor shifts with the current and tide, the pipes becomes unlevel and do not produce an adequate barrier of bubbles across the length of the pipe. To improve the bubble curtain, our team was tasked with creating a self-leveling anchor system to work with the existing air bubble curtain pipes.

Over the course of the last academic year, we designed, built, and tested a model sized prototype of an anchoring concept that would keep the bubble curtain pipes level. The final design suspends the bubble curtain pipes from buoys. The concept uses the surface of the water to remain level, while a long tether to a ground anchor keeps it from floating freely. Through testing, we determined this design stays level independent of change in floor elevation. However, the effectiveness is dependent on the tide, and works best at low tide and in water with a low tide greater than 20 feet. We recommend designing this system for deeper sections of the intake bay, and implementing it to allow a constant upward slope in the bubble pipe. Before building a complete system, we recommend constructing and testing a partial system to insure it behaves as expected and withstands full-scale ocean conditions.

1. Introduction

1.1. Project Participants

The Air Bubble Curtain Anchoring project is aimed at improving the anchoring system of the existing bubble curtain at Diablo Canyon Power Plant (DCPP). The air bubble curtain is a long pipe laid along the ocean floor that emits bubbles in order to create a countercurrent that deters sea life and debris from flowing into the intake of the power plant. The existing bubble curtain, which is further described in Section 2, shifts as the ocean floor moves. The pipes become unlevel, and do not emit bubbles in downward sloped sections, resulting in isolated groups of bubbles. The goal of this project was to design an anchoring system that allows the pipes to stay level without human interaction, or is otherwise resistant to elevation changes of the ocean floor. This goal was accomplished through a process of designing, building, and testing of an anchoring system, outlined in Sections 3- Section 5.

The Air Bubble Curtain Project is Cal Poly Senior Project, sponsored by DCPP. Three Cal Poly students, Donovan Lawrence, Dakota Schwartz, and Christian Young completed this project during September 2016-June 2017 with the advisory of Professor Eileen Rossman and our DCPP sponsors including Anderson Lin.

1.2. Project Scope

Due to the complexity and immensity of the ocean, we decided to use a scale physical model in our design rather than an analytical or ocean sized model. To produce acceptable and meaningful results in a test setting, we used similitude modeling (Munson, 2002). Selection of independent variables was done carefully in order to produce a useful dimensional analysis.

1.3. Project Management

1.3.1. Milestones and Dates

- Project Proposal (10/25/16)
- Preliminary Design Review Report (11/17/16)
- Preliminary Design Review with Sponsor (12/02/16)
- Critical Design Review Report (02/07/17)
- Critical Design Review with Sponsor (02/14/17)
- Project Update Report (03/16/17)
- Project Hardware/Safety Demo (05/02/17)
- Final Design Review Report (06/02/17)

1.3.2. Responsibilities

Point of Contact:

- Dakota was the point of contact for the group. She handled all e-mails and communication to and from the DCPP management team.

Initial Design:

- All team members contributed in the initial design stages, including brainstorming and choosing a design direction.
- Christian was the progress evaluator. He kept a detailed documentation of project progress. All members kept a record of progress in their logbooks.

Design:

- Dakota was the lead designer of the test tank for the analysis of the anchoring system.
- Christian was the lead designer of the anchoring system.
- Donavan was in charge of the manufacturing considerations, making sure that the designs are realistic and easy to manufacture.

Prototype Fabrications:

- Donavan was in charge of acquiring the materials for each prototype.
- Dakota was in charge of building the test tank.
- Christian was in charge of building the anchoring system.

Testing:

- Donavan was in charge of creating a testing procedure.
- Christian was in charge of testing the prototype and retrieving data.
- Dakota was in charge of analyzing the data acquired.

1.3.3. Gantt Chart

Using Microsoft Project, we were able to create a Gantt chart that shows an estimated timeline for the entire project. This chart considers which milestones are dependent on each other and schedules them accordingly. This chart can be found in Appendix E.

1.4. Safety Plan

1.4.1. Safety Hazard Identification Checklist

Safety is a priority for the duration of this project. Through this process, we payed attention to the safety of ourselves, those we are designing for, and anyone else who may come into contact with our design during testing or implementation. As a preliminary safety measure, the below Figure 1 was updated periodically to account for other potential hazards we encountered as we proceeded with our design.

DESIGN HAZARD CHECKLIST

Team: __Team Bubbles________________________________ Advisor: ____Eileen Rossman____

Y N

X ☐ 1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?

☐ X 2. Can any part of the design undergo high accelerations/decelerations?

☐ X 3. Will the system have any large moving masses or large forces?

☐ X 4. Will the system produce a projectile?

☐ X 5. Would it be possible for the system to fall under gravity creating injury?

X ☐ 6. Will a user be exposed to overhanging weights as part of the design?

☐ X 7. Will the system have any sharp edges?

☐ X 8. Will any part of the electrical systems not be grounded?

☐ X 9. Will there be any large batteries or electrical voltage in the system above 40 V?

☐ X 10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?

☐ X 11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?

☐ X 12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?

☐ X 13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?

☐ X 14. Can the system generate high levels of noise?

X ☐ 15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?

X ☐ 16. Is it possible for the system to be used in an unsafe manner?

X ☐ 17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Figure 1: Safety design hazard checklist provided by Cal Poly's Mechanical Engineering Department.

To account for these potential hazards, Figure 2 details the plan of action. Due to Cal Poly's Mechanical Engineering Department rules, we performed the majority of our building and testing on Cal Poly's campus machine shops. No building happened in our own homes or other off campus locations without department approval.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
1. The connection between the buoy and pipe is a potential pinch point in the large scale system.	Model was designed small enough to not have appendage sized pinch points.	11/01/16	1/31/17
15. The pipe system and test tank will be subject to salt water, which is corrosive and possibly dangerous in combination with electricity.	Dissimilar metals will not be paired, factors of safety over 5.0 will be used in metal components, and all components will be inspected during use for corrosion and wear. See 17. For electricity hazard.	12/01/16	1/31/17
16. The test tank could be used unsafely, if a person were to enter the tank while full of water, resulting in drowning or tank failure.	Locate tank in a secure area, implement hazard signage, cover tank with tarp, and limit the time tank is full without a project member present.	1/31/17	3/01/17 (or testing date)
17. Other: The test tank will require water and electricity in close proximity due to the air compressor.	All electrical circuits will be grounded and well insulated in case of leakage or wire-water contact.	11/01/16	3/01/17 (or build date)

Figure 2: Descriptions of hazards and planned corrective action.

Manufacturing

Safety for ourselves and others remains an important aspect beyond the design. Manufacturing took place on Cal Poly campus, per the Cal Poly ME Department requirements. Most manufacturing happened in Mustang 60, the Cal Poly machine shop located in building 128 (Bonderson). Manufacturing also happened in Cal Poly's Hanger machine shop. To maintain safety, the following points were adhered to:

1. All machine shop rules were followed
2. Work involving power tools was not done without other people present
3. Shop techs were asked for help in the case of uncertainty
4. The manufacturing plan was followed

Testing

Testing took place in the Cal Poly Mechanical Engineering Fluids lab (192-102). Professor Russ Westphal and M.E. Department safety rep, Jim Gerhardt, are the contacts for fluids lab use. We got the final approval by sharing our safety procedure protocol and information.

1.4.2. Special Procedures and Maintenance

There was at least two of the team members in the fluids lab while there was a test being performed. The model was secure in the safety of the fluids lab. None of the components needed maintenance regularly, because it is only a model and there were only a few tests performed on it before it can be discarded or put into storage.

2. Background

2.1. Diablo Canyon Power Plant

DCPP, a twin pressurized-water reactor nuclear power plant, is located in Avila Beach California and supplies about 8.6% of California's energy (Mayeda, 2013). Electricity production relies on transferring the energy from the nuclear reactor to water diverted from the ocean, creating steam that spins the turbines. The ocean water needed for the power plant comes from the intake bay. The function of the two reactors (referred to as Unit 1 and Unit 2) is dependent on receiving proper flow from the intake bay. Background information on the intake bay, problems concerning the intake bay, and current solutions are discussed in greater detail in this section.

2.1.1. Intake Bay

The intake bay is approximately 1000 ft across and 700 ft wide. The depth at the shallow end (4 in Figure 3) is about 10 ft, and about 40 ft at the end of the west breakwater. When on, units 1 and 2 draw flowrates, although the total current is determined more by the ocean than it is by the intake. The West and East breakwaters are constructed of concrete parts that fit together. Current does pass through them, but it is a diminished amount. The total current is usually directed Northwest, and approaches Unit 2 (3 in Figure 3) directly.

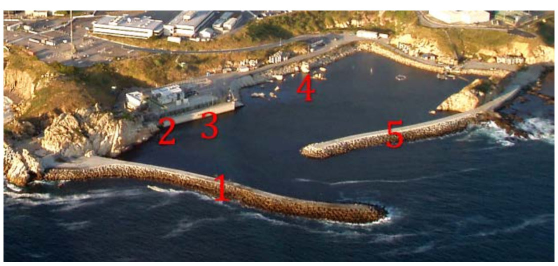


Figure 3: Visual of intake bay. 1 notes west breakwater, 2 notes Unit 1 intake, 3 notes Unit 2 intake, 4 notes rock with permanent chain, and 5 notes east breakwater.

The current Air Bubble Curtain is extended from the midpoint of the West breakwater to the permanent chain around the rock (4 in Figure 3). This was designed for convenience, as the permanent chain was the easiest place to attach the Curtain, and the angle allows the curtain to redirect the surface current. Optimization of the curtain angle is outside the scope of this project. We plan to use the existing configuration in our anchor design.

2.1.2. Salp

The main reason DCPP needed to deploy the air bubble curtain was salp. Salp are barrel-shaped tunicates that are often mistaken for jellyfish, but are actually much more biologically complex (Goodheart, 2010). They move through water by pumping water through their bodies in a type of jet propulsion. Their propulsion is considered to be one of the most efficient in the animal kingdom. Salp can range in size from a less than an inch to ten inches (CNRS, 2016). They reproduce asexually and attach to each other, forming long chains that can move in harmony with each other. They eat by filtering the water for phytoplankton. When the phytoplankton are available in vast quantities the salp explode in population.

High concentrations of salp can overload DCPP intake screens, requiring mandatory plant "curtailment or shutdown", as noted in a report submitted to the Nuclear Energy Institute (Diablo Canyon Power Plant, 2014). This report notes that salp and jellyfish swarms have occurred multiple times in recent history: once in 2008, twice in 2012, and three times in 2013. Each intrusion lasts about 3-7 days. Each day of plant shut down costs approximately $3 million dollars. A visual example of a high salp concentration can be found in Figure 2.

Diablo Canyon Unit 2 was shut down in October 2008 due to jellyfish, according to the report submitted by DCPP to the Nuclear Regulatory Commission (Diablo Canyon Power Plant, 2008). The jellyfish (not salp) caused a high differential pressure across the intake screens, resulting in bringing power to 0%. Influxes of salp, other sea-life and debris are costly hazards to the nuclear plants operation due to their ability to clog intake screens and cause plant shutdown.

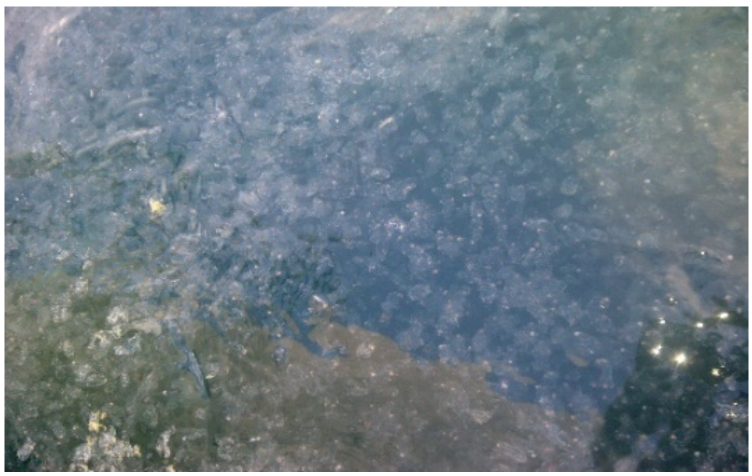


Figure 4: Example of the concentration of salp present in an intrusion.

2.2. Benchmarking

2.2.1. Current DCPP Bubble Curtain

To deter salp from clogging intake screens and causing a plant shutdown, DCPP implemented the first version of the Air Bubble Curtain (ABC) during a salp bloom in 2012 (Diablo Canyon Power Plant, 2014). The concept was developed following the observation that air bubbles easily adhere to the underside of a salp's body, causing it to rise to the surface. The ABC is designed with little holes to release small bubbles to adhere to salp, and larger holes to emit bigger bubbles which cause an upward current. As seen in Figure 3, the concept is to lift salp to the surface to divert them out of the incoming current, and into the surface current.

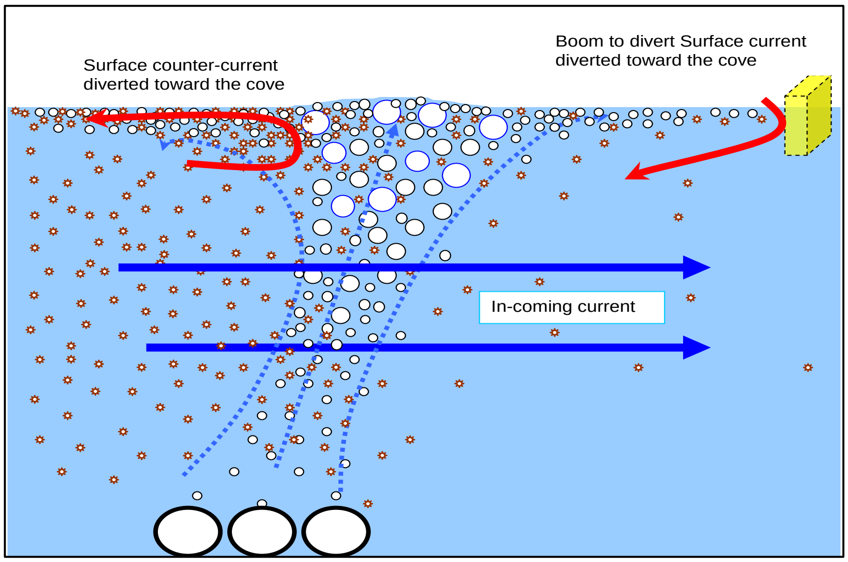


Figure 5: Concept of the Air Bubble Curtain currently used at Diablo Canyon Power Plant. Salp, depicted by the star shaped figures, are pushed toward the intake by the current. Bubbles lift them to the surface, where they are diverted away from the plant intake by the surface current and float boom (yellow block). (Diablo Canyon Power Plant, 2014)

As pictured in Figure 4, the pipes along the intake bay floor are about halfway between the east breakwater and Unit 1 and 2 intakes. The pipes are connected via firehoses to an air compressor operating at 1600 CFM. Complete drawings of the intake bay with the ABC pipes can be found in Appendix A.

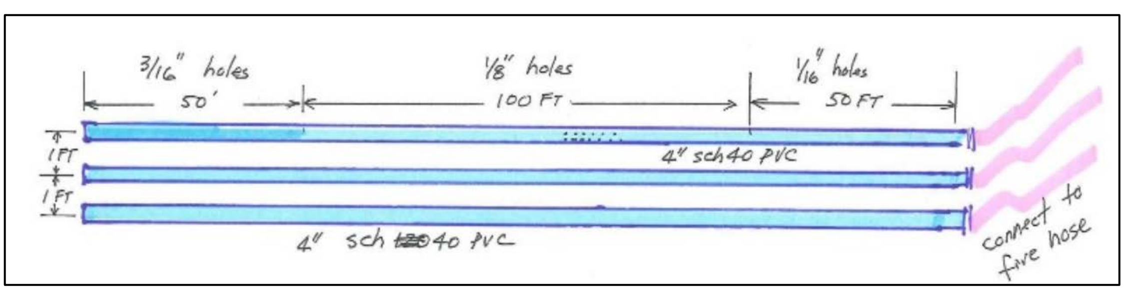


Figure 6: Details of ABC layout.

Figure 4 shows greater detail of the pipes used in the ABC design. The pipes extend 550 feet across the bay, and have 3/16 in, 1/8 in and 1/16 in holes in two parallel rows on top to release bubbles. All pipes do not release bubbles at the same positions; because of compressor capabilities, the bubble holes are offset along the distance of each pipe. One row of pipe does not release bubbles until it is 300 feet from firehouse connection point. The other rows release bubbles immediately. The ocean current naturally directs toward the Unit 2 intake and therefore has the highest bubble concentration of pipes. Pipe and connection parameters can be found in Table 1 and are labeled in greater detail in Appendix A.

Table 1: Pipe and Coupling parameters.

Pipe	
Type of Pipe	HDPE
O.D.	4.5 in
I.D.	3.3633 in
Weight	2.31 lb/ft
Length of Section	20 ft
Coupling	
Type	SS Victaulic Coupling
Weight	4 lb
Weight of Fittings	10 lb

2.2.2. Current Anchoring S…

The anchoring system that t… concrete parking bumpers used in car lots. They altere… …ps of the blocks and installing hooks. Chains atta… …ing carabiners. There are eight anchors at the beginni… along the length of the pipes. When the sand floor shifts and the anchors sink, DCPP has to hire divers to adjust the chains, except the divers are not always available. This causes the pipes to tilt, creating holes in the bubble curtain big enough for salp to penetrate.

2.2.3. Bubble Curtain Operation

The DCPP team used a ramp to deploy the ABC, sliding the pipes into the water. They connected each section of pipe separately at the start of the ramp. Then they attached the anchors to the pipes. This process takes three days. When the bubble curtain is deployed, it can only stay in the water for 30 days at a time due to regulations. The DCPP team must then reverse the process and clean the pipes of algae.

2.2.4. Ringhals Bubble Curtain and Anchoring System

Currently, the Ringhals nuclear power plant in Väröbacka, Sweden has a bubble curtain installed to prevent moon jellyfish from entering their intake, similar to DCPP. In 2004, Ringhals power plant had to shut down three separate times due to large collections of jellyfish in the cooling water strainer house (Ksu, 2004). Too prevent more jellyfish from entering they also deployed a bubble curtain system. They use a relatively small diameter hoses with holes punctured in them in order to produce the bubbles. A boom is set up in the water in order to divert floating debris back into the curtain. The intake for the Ringhals power plant is lined with concrete. The anchoring system they use involves a cable network attached along the bubble curtain. A photo of a 10-year old anchor cable network used is shown in Figure 5 below.

Figure 7: A 10-year old anchor cable network used for bubble curtain anchoring applications at Ringhals Nuclear Power Plant

This cable network is attached to the floor of the intake using metal stakes. Since the current at Ringhals is not as powerful as the one at DCPP and because of the concrete lining, the floor of the intake does not shift. The stakes work well enough in order to keep the bubble curtain anchored for long periods of time.

2.2.5. Other Anchoring Systems

Torpedo Anchor

Torpedo anchors are used for deep-water offshore mooring. The anchors are cone tipped cylinders that burrow into the sea floor after dropping them from a designated height in the water (Y.H. Kim, 2015). Rough schematics of two types of torpedo anchors are shown in Figure 6 below.

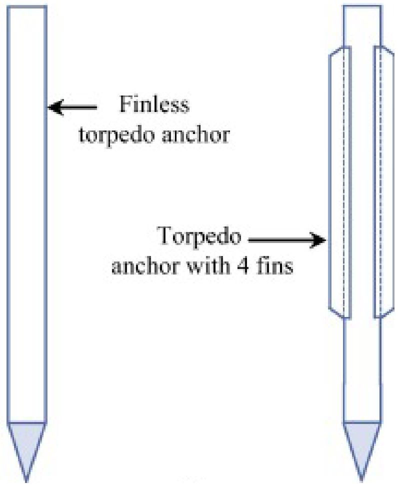


Figure 8: Torpedo anchors with and without fins

The frame of a torpedo anchor is generally made from steel pipes. The pipes are then ballasted with concrete and scrap metal in order to increase the kinetic energy gained by the anchor after they are dropped. The design of the anchors varies with drop height and the desired burrowing depth in the sea bed. These types of anchors are easy to install and can be used in ultra-deep water. However, larger water depths increase the chance of horizontal drift when dropping the anchors, causing them to go off target.

Stockless Anchors

The most common type of anchor for ships is called a stockless anchor or drag anchor. The anchors have flukes and bills in order to dig into the sea floor. This prevents boats from being taken away from the tide; However, it does not prevent the boat from moving against the current. As shown in Figure 7, the anchor prevents the motion in the direction that it is facing. These anchors are easily removed by lifting them vertically out of the sea floor.

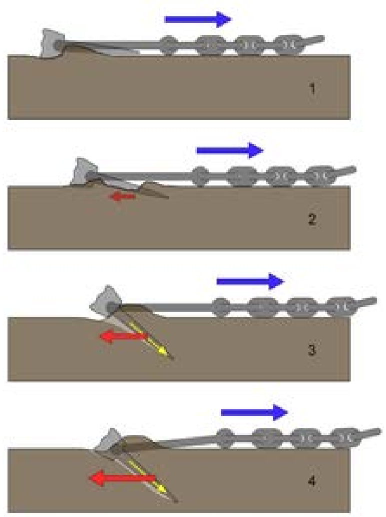


Figure 9: A stockless anchor preventing movement in the direction of the chain. The pictures are of one instance at different points in time.

2.3. Attached Project Proposal Problem Statement and Goals

Diablo Canyon Power Plant needs an anchoring system for their air bubble curtain that secures and levels the curtain as the sandy ocean bottom of the power plant's intake bay shifts. The goal of this project was to design, build and test an anchoring system that meets DCPP's requirements and our engineering specifications that were derived from those requirements. The success of our solution will be judged by how well it meets these specifications. Below is a list of our overall goals for the duration of this project.

Overall Goals:

- Design an anchoring system for the existing Air Bubble Curtain
- Design and build a test tank for the anchor system model
- Build a model of the designed anchor system with a model Air Bubble Curtain
- Test anchor system using the model
- Analyze design for effectiveness

2.4. DCPP's Requirements

This information was gathered through the initial project PowerPoint presentation, discussion with our DCPP sponsor Anderson Lin, and meeting with other advisors in our team visit to DCPP. The discussion and visit were key in our decision to focus the scope of our project to the Air Bubble Curtain's anchoring system. Our background research led us to the following requirements for the anchoring design:

- Functional as an anchor
- Self-Leveling
- Effectively deters salp
- Can withstand salt water
- Able to be uninstalled
- Non-toxic
- Withstands expected conditions

2.5. Engineering Specifications

In the interest of a functional design, the above requirements were translated to engineering specifications with the aid of the Quality Function Deployment (QFD) method. This approach defines the customers' needs and requirements, then translates them to specifics to meet those needs (Crow, 2016). A complete QFD can be found in Appendix B. Table 2 shows the results of the QFD process in the form of engineering specifications.

Table 2: Engineering Specifications Table. Each specification is assigned a risk level, High (H), Medium (M), or Low (L), noting its relative difficulty to complete. Additionally, compliance, or how we plan to verify design requirements, are listed as Analysis (A), Test(T), Similarity to Existing Designs (S) and Inspection (I).

Spec. #	Parameter Description	Requirement	Tolerance	Risk	Compliance
1	Pipe Deflection	0 ft	± 5 Feet/20 Feet	L	T, A
2	Pipe Angle (from horizontal)	0°	± 20°	H	T, A, I
3	Bubble Area Coverage of Water Column Above the Bubble Curtain	80%	Min.	H	T, A, I
4	Corrosion Resistance Time	30 days	Min.	L	S, A
5	Individual Part Weight	200 lbs.	Max	M	A, I
6	Material Toxicity	Zero	Zero	L	A
7	Able to Resist Flowrate	1.3 ft/s	Min.	M	T, I, S

The parameters relate to the DCPP anchor system requirements listed in Section 3.2. To ensure our design is a functional anchor for the Air Bubble Curtain, we decided to constrain its movement on the plane of the intake bay floor to within 3 feet of its original placement. This specification was anticipated to be low risk in the overall design. To ensure the pipe is able to stay level, we limited the pipe angle to be a maximum of 20° off center after system leveling. We anticipated 20° might have still inhibited bubbles, and we tried to limit the pipe angle as much as possible. To ensure the bubble curtain remains an effective salp deterrent, water column bubble coverage needs to be a minimum of 80%. This is an arbitrary number based on the estimated coverage of the current system. To withstand expected conditions, no materials were used that corrode heavily within the expected maximum use of the bubble curtain. So the anchoring system can be removed by two people, no part weight shall exceed 200lbs. As to not be harmful to sea life, no toxic materials were used. To maintain function and durability in maximum expected ocean conditions, our design shall account for the maximum expected flowrate. In the QFD, all of these parameters are compared to the customer requirements to see how well they correlate.

Other benchmarking ideas were included on the right side of the QFD. The benchmarked ideas were rated to see how well they incorporated the customer requirements.

2.6. Tests Required

Multiple specifications require tests to verify. Each specification in need of a test is listed below, along with how we planned to test it.

Pipe Angle: This specification was tested using a physical model of the system. The model simulated elevation changes of the intake bay floor. The pipe angle was measured to determine the self-leveling aspect of our anchoring design. Additionally, we recorded data on conditions in which the pipe did not emit bubbles.

Bubble Coverage: This was tested in conjunction with the previous test, and by altering the water height to simulate tide change. Percentage of water column covered following bay floor shifts and pipe leveling determines total bubble coverage.

Flowrate Durability: During and after each test, our model was inspected for part breakage or severe deformation to determine its durability during normal and maximum ocean conditions.

3. Design Development

3.1. The Design Process

The general design process we followed throughout this project is the one shown in Figure 8 below.

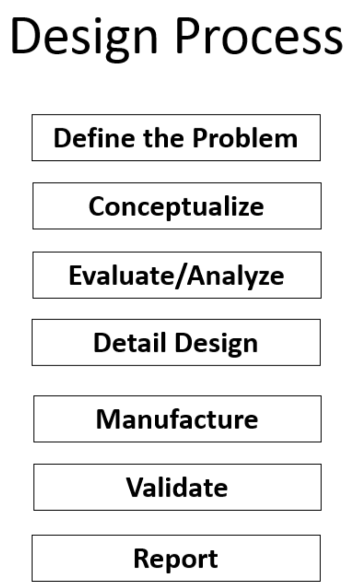


Figure 10: The general format for the design processed that is going to be followed.

Define the Problem

The main purpose of the previous project proposal was for us to define the scope, and convince you that we understood the problem, studied the background information, and will follow the processes outlined below.

Conceptualize

After this document has been sent out several ideation sessions will be held in order to come up with ideas on how to solve the problem defined above. These ideation sessions will consist of the team performing a series of set breaking activities in order to get creative ideas flowing. The idea is to do several of these sessions in order for the team to have time to incubate about the ideas made in these sessions.

Evaluate/Analyze

Once all the ideas have been generated, the team will decide on the idea that has the most realistic potential for the desired application. After that a preliminary design review will be held in order to document the chosen concept for the design and support that decision with appropriate evidence.

Detailed Design

This step is a more detailed look into the design. Several hand calculations, detailed part drawings, and schematics will be compiled into a critical design review. All of the parts and materials will be specified and ordered at this time and a well prepared presentation will be delivered to the management team at DCPP to ensure that everything is ready for the manufacturing process.

Manufacture
After the critical design presentation has been completed, the manufacturing process will follow. At this point, a test tank, as well as a scaled down version of the design, will be manufactured from the specifications made in the critical design review. A manufacturing and test review will be held at Cal Poly to report on the status of component manufacturing, the updated test plan, and a safety checklist.

Validate
Once the test rig and detailed design have been built, a series of tests will be performed in order to validate that the design performs all of the engineering specifications that were specified in this project proposal.

Report
All of the test data and analysis will be compiled into a final design review. One final presentation will be held at DCPP for the advising team in order to show the details of the results found through the testing.

3.2. Ideation

3.2.1. Ideation Process

In order to generate as many ideas as possible, we conducted a series of ideation sessions. First, we defined our functions (self-leveling or ability to remain level, and anchoring), and used a variety of brainstorming techniques, including brainstorming and brainwriting, to generate ideas. During brainstorming sessions, we wrote all ideas down on whiteboards. During brainwriting sessions, we wrote ideas down on paper, then passed them to a teammate to add to our idea list. These techniques were applied to the bubble curtain as a whole, each of the bubble curtain’s functions, and the test tank. Some of the ideation results are shown in Figure 9 on the next page.

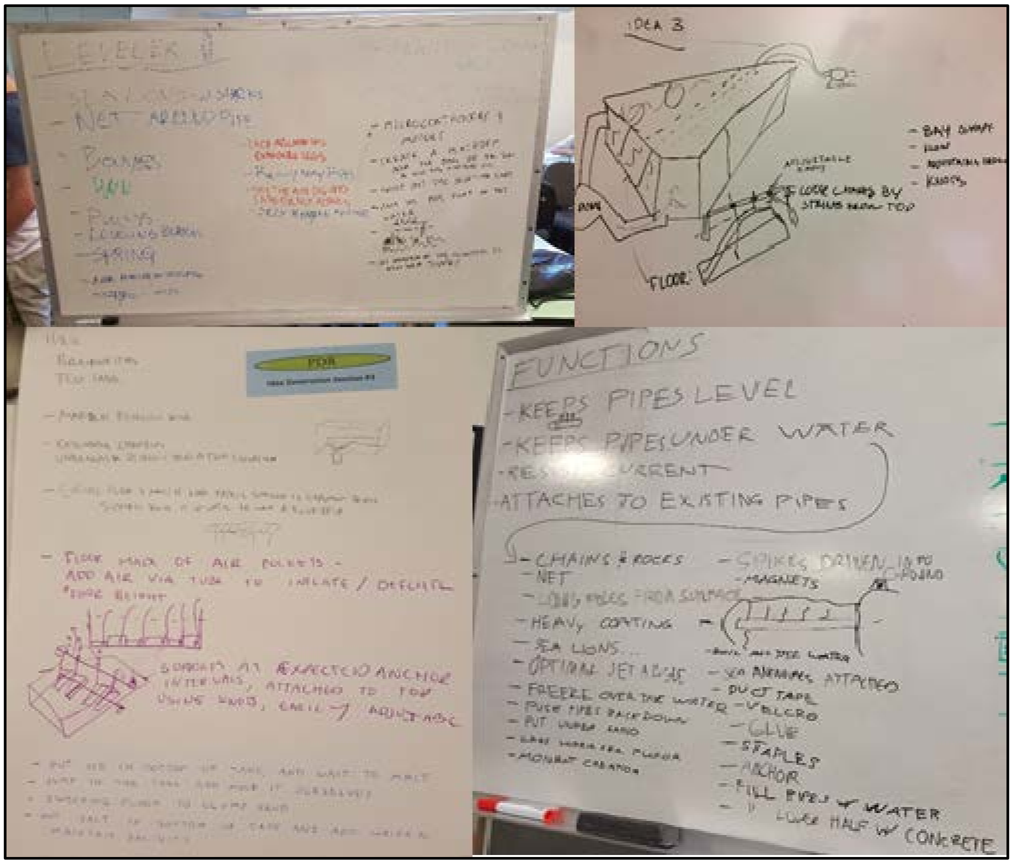


Figure 11: Examples of different ideation techniques used

3.2.2. Quantitative

To assist in the selection of a feasible concept, preliminary statics, buoyancy, drag, and deflection calculations were done in order to better understand the current system. These calculations were built from calculations done by DCPP for the current anchoring system, and altered using Excel to analyze system parameters per foot in with adjustable anchor spacing. The free body diagrams of the bubble pipe and the car stop anchor can be found in Figure 10. Descriptions and summaries of each calculation can be found below. Sample calculations of each calculation type can be found in Appendix D.

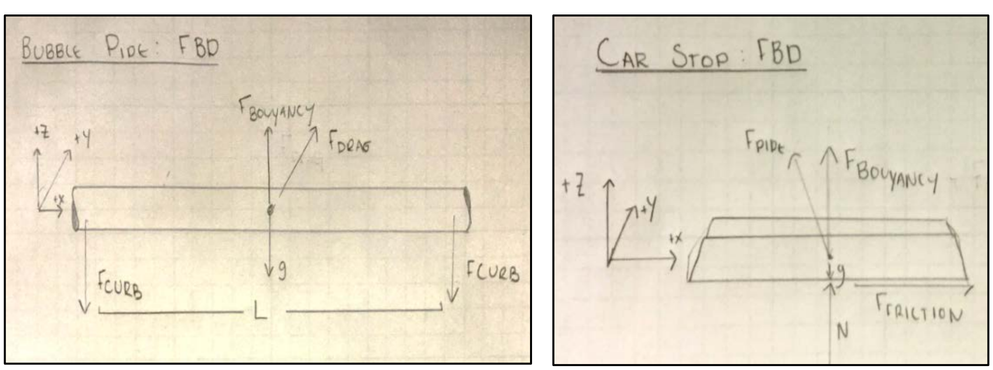


Figure 12: Free body diagram of the bubble pipe (left) and the car stop anchor

Buoyancy

This is one of the most important forces acting on the pipe and anchor system, due to the large amount of sea water displaced by the relatively less dense pipe. For these calculations, the weight of the system component (pipe or curb) was subtracted from the weight of the water displaced, as seen in Equation 1.1.

$$F_{buoyancy} = W_{Water\,Displaced} - W_{Pipe} \left[\frac{lb_f}{ft}\right]$$

Eq.1.1 $$W_{WaterDisplaced} = \frac{\pi D^2}{4} \rho_{water} g \left[\frac{lb_f}{ft}\right]$$

$$W_{pipe} = \frac{\pi(OD^2 - ID^2)}{4} \rho_{pipe} g \left[\frac{lb_f}{ft}\right]$$

For convenience, the force was calculated using units of lb_{force}/foot, so calculations can be scaled for various anchor setups. A summary of buoyancy calculations can be found in Table 3.

Table 3: Summary of buoyancy calculations on current anchor components.

	Force of Buoyancy		
Pipe	OD	4.5	**in**
	Pipe	2.3	**lb/ft**
	Coupling	4.0	**lb**
	Polycam Fitting	10.0	**lb**
Concrete Curb	Density	150.0	**lb/ft^3**
	Volume	1.0	**ft^3**
Salt Water [60°F]	Density	62.4	**lb/ft^3**
	Specific Gravity	1.025	
	Gravity	32.2	**ft/s^2**
Pipe Outputs	Force of Disp. Water	221.7	**lb/ft [+up]**
	Weight of Pipe	-164.4	**lb/ft [+up]**
	Buoyancy Force	57.3	**lb/ft [+up]**
Curb Outputs	Force of Disp. Water	2057.8	**lb [+up]**
	Weight of Pipe	4826.1	**lb [+up]**
	Buoyancy Force	-2768.3	**lb [+up]**

Please note, the discrepancy between our buoyancy force totals from DCPPs previous calculations (see Appendix D) has to do with units.

Drag and Statics

Drag was found using the drag equation (Equation 1.2.). This calculation was done per unit length so the drag force on pipe sections of varying length could be found. Current velocity was assumed to me a maximum of 1.3 feet/s, as assumed in previous DCPP calculations (see Appendix D).

$$F_{drag} = \frac{C_d\, A_{eff}/L\, \rho_{water} V^2}{2g} \left[\frac{lb}{ft}\right] \qquad \text{Eq.1.2.}$$

The drag force, in combination with buoyancy is significant in appropriate anchor design, since it is important the anchor does not move. As seen in Table 4, to ensure no movement in the y-direction (along the ocean floor), the force of friction must be greater than the force of drag from the ocean current. The force of friction opposes the drag force, and is proportional to the normal force. This is why it is important both are calculated in the same units. For anchors spaced 10 feet apart, the force of drag is very small compared to that of friction, so the concrete anchor will not move. Additionally, this table shows the statics in the z-direction (the direction of ocean height) to show the anchor will not move upwards.

Table 4: Summary of statics calculations for current pipe and anchor system.

Anchor and Pipe Statics			
Parameters	Pipes/Anchor	2	
	Static Friction	0.45*	
	Anchor Spacing	10	**ft**
	Curbs/anchor	1	
Force Y-Direction	Normal Force	1818.1	**lb**
	Ffriction	818.2	**lb**
	Fdrag	15.1	**lb**
	Ff>Fd	803.1	**YES**
	Static(Y)?	**Yes**	
Force Z-Direction	FOS	1.2	
	ΣFbuoyancy	2293.2	**lb**
	Σfcurb	-2768.3	**lb**
	ΣFz	-16.4	**lb**
	Static Z?	**Yes**	
	**wet concrete on medium, silty sand*		

Deflection

To account for deflection or breakage of the bubble pipe, deflection calculations were used to evaluate several concepts, and will be used to further determine the geometry of our final concept. See Figure 11 for a schematic of deflection across pipe length.

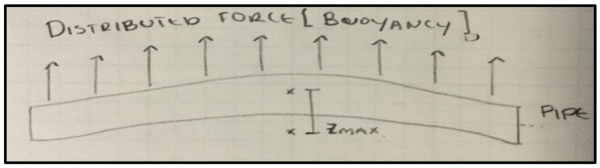


Figure 13: Deflection expected from distributed buoyancy load between pipe anchors.

Using the buoyant force as a distributed load, and the geometry of the pipe, deflection was calculated at various anchor distances. As expected, the further apart the anchors, the greater the deflection. Due to deflection that could cause damage to the pipes, or a large angle change along the length of the pipe, many concepts were decided against. A summary of the parameters the resulting deflection of a 10 foot section of pipe can be found in Table 5.

Table 5: The expected deflection of the bubble pipe.

	Bubble Pipe Deflection	
Input	**Net Buoyancy Force, *w* [lb/ft]:**	57.33
Input	**Length, *L* [ft]:**	10
Input	**Elastic Modulus, *E* [psi]:**	110,000
Input	**Inner diameter, d_i [in]:**	3.633
Input	**Outer diameter, d_o [in]:**	4.5
Output	**Maximum Deflection, z_{max} [in]:**	10.129
Output	**Approximate ϴ [°]**	4.825

3.2.3. Matrices

Once we had plenty of ideas to choose from, we narrowed it down to the top seven ideas by focusing on feasibility. From there we created a Pugh matrix; a Pugh matrix accounts for each concept's ability to satisfy the customer requirements relative to the existing product. This comparison helps determine which concept has the most potential to satisfy the customer.

We also created a decision matrix. The decision matrix differs in that each criteria is weighted by importance, and each concept is scaled with each criterion. The result is a number for each concept, allowing us to compare how each concept completes each criteria relative to each other. The summary of the decision matrix can be found in Table 6 (the top concepts listed are explained in depth in the next section). The Pugh and Decision matrices for our project can be found in Appendix F.

Table 6: Summary of the decision matrix

		Total Score	Normalized Score
Concepts	**Torpedo**	5.67	0.86
	Pulley System	5.40	0.81
	Adjustable Poles	3.70	0.56
	Reconfigured Current System	5.80	0.87
	Buoy System	6.60	1.00

The decision matrix was more helpful than the Pugh matrix, as most Pugh criteria were very similar. From these decision matrices, we were able to compare concepts for feasibility and effectiveness. As seen in the results table for the decision matrix, the buoy system, reconfigured current system, and torpedo systems scored highest, with the adjustable pole system scoring poorly.

3.3. Concepts

3.3.1. Concept 1: Mini Torpedo Anchor

Description: As pictured in Figure 12, large torpedoes are used in anchoring applications such as for oil rigs. They are dropped off the side of a ship, and bury into the ground using the kinetic energy gained from the drop. Concept 1 would be to create a miniature version of the torpedo anchor, that would have enough kinetic energy to bury deep enough into the ocean floor to not be affected by the shifting top layer. More information on existing torpedo anchors can be found in the Background Section.


Figure 14: A large torpedo anchor, used mainly to anchor oil rigs.

Components: This design would consist of torpedoes placed periodically along the ocean floor, with cables or chains to connect to the bubble pipe.

Considerations: Ultimately, we decided not to go with this option, as torpedoes would be difficult to remove from the ocean floor when the bubble curtain was removed. Additional issues with this concept are discussed in Section 4.3.6.

3.3.2. Concept 2: Pulley System

Description: Multiple configurations of this concept were worked with in ideation sessions, using the materials pictured in Figure 13. Using pulleys and attachments on the ocean bottom, the pipe is allowed to readjust with sea floor changes.

Components: Pulleys and steel cable or chain would be necessary additions to the current system for this concept.

Considerations: Since the pipe fills with water during installation, and never completely empties, there are pockets of water inside the pipe. This attributes to the complex fluid dynamics causing bubble interruptions on downhill pipe angles. Since there is water in the pipe that collects unevenly, the pipe may not be able to self-level. Additionally, appropriate tensioning of cable through the pulleys and across the length of the system would be needed to allow the pipe to self-adjust.

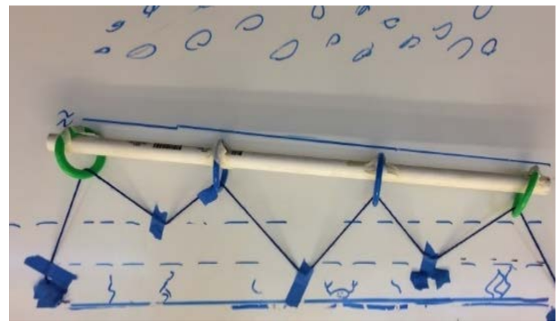


Figure 15: Pulleys are used to allow the pipe to level itself as the ocean floor changes.

3.3.3. Concept 3: Adjustable Poles from Ocean Surface

Description: The concept behind this idea was to allow the pipes to be adjusted from the ocean surface. As seen in Figure 14, the poles will attach to the anchor, with a tube around the pole connection to the pipe at one end, and is adjustable to the top of the pole at the other end. When to sand level changes, the tube can be lowered to readjust the pipe height relative to the ocean bottom.

Components: Ocean height poles, with outside piping or track connection the pipe to the pole tops, and locking or adjustable component at the top to lock the pipe in place.

Considerations: The ocean level changes with tide, which could be an issue for adjusting the pipe height.

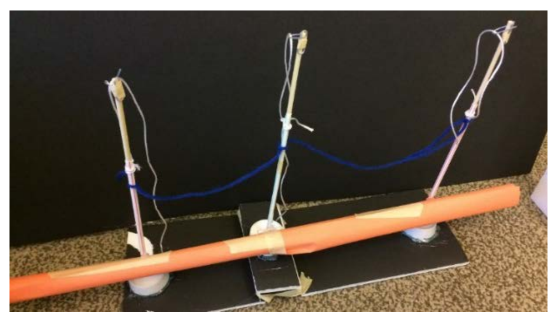


Figure 16: Ideation of concept 3, with the orange tube as the bubble pipe, and the blue string as ocean level.

3.3.4. Concept 4: Reconfigured Current System

Description: As seen in Figure 15, this system would be very similar to the current system in existence. To make the pipe more resistant to floor shifts and resulting angle changes, the length between the anchors would be increases, as with the length of the cables attaching to the anchors.

Components: Due to similarity between this and the original system, only additional chain or cable would be required.

Considerations: This system would not be self-leveling. It would only be a passive way to reduce the effect of ocean bottom elevation changes.

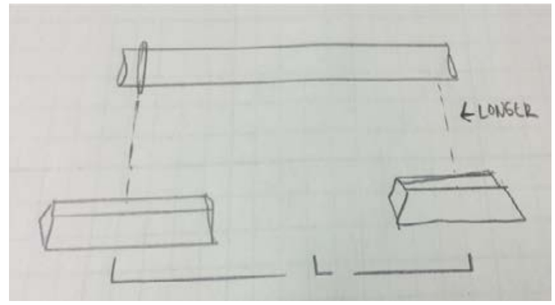


Figure 17: Reconfigured current system with more length between the anchors, and longer chains connecting to the pipe.

3.3.5. Concept 5: Buoy Leveling System

Description: This system suspends the pipes from several buoys on the surface. The rational being that the surface of the water in the breakwater will always be level. Hanging the bubble curtain from this level surface would result in the bubble curtain itself being level. As seen in Figure 16, the buoy would be attached to the pipes of the bubble curtain. Concrete curbs would then be used as secondary anchors to constrain lateral movement of the bubble curtain. Preliminary motion analysis can be seen in Figure 17.

Components: Buoys and chains or cables would be additional system components.

Considerations: Ocean tides change by up to 8 feet during tide cycles. The anchor cable length would have to allow movement without pulling the anchor further down, reducing the overall bubble curtain height during high tide. Additionally, the pipe is buoyant, and would need to be weighed down to tension the chain connecting it to the buoy.

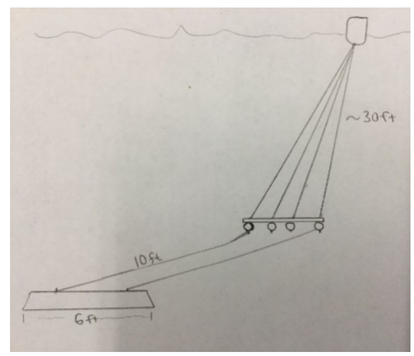


Figure 18: Cross section of the buoy leveling system uses the surface ocean level to maintain elevation,

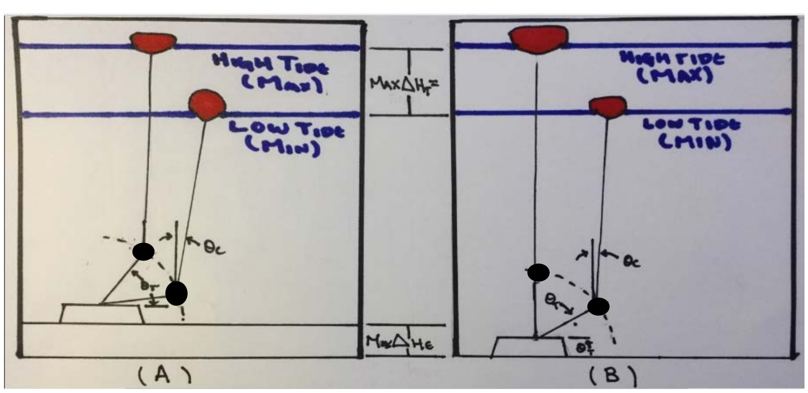


Figure 19: Preliminary motion analysis of the buoy system.

Motion: To better understand the expected motion of this system, position at four conditions are shown in a cross section of the bay. Current is assumed as moving right. Side A shows ocean bottom at its initial height, at maximum high tide, and minimum low tide. Side B shows ocean bottom at maximum change in elevation, at maximum high tide, and minimum low tide. The pipe (black dot) will move along the dotted radius, with the angle increasing with the tide. This system will be designed for extreme conditions (high tide and max. ocean bottom elevation change), so the buoys does not pull the anchor off the ground.

3.3.6. Concepts with Engineering Validation

At this point, we decided that we needed engineering validation before we made a final decision for our concept. We used the derived equations for buoyancy and deflection and tested how our top concepts held up to the equations. A simplified summary can be located in Table 7, with a short discussion of each concept below.

Table 7: Summary of each concept using engineering analysis.

	Engineering Validation		
Concept	Buoyancy	Drag	Deflection
1	Y	Y	N
2	N	Y	Y
3	Y	N	N
4	Y	Y	Y
5	Y	Y	Y

Concept 1 (mini-torpedo) proved difficult to analyze numerically, since sand submergence depth was difficult to calculate accurately. While equations for larger torpedoes do exist, they would be inaccurate for our scale since multiple feet of submergence would make a big difference in effectiveness. For instance, drag and buoyancy would be a problem if the total sand submergence of the torpedo was less than two feet, and could therefore become exposed or sink further. Due to unknowns, we focused mainly on possible problems, extrapolated from larger torpedoes. Large torpedoes often miss their ground floor target by dozens of feet. For a large oil rig, this does not often present a problem. However, for a constrained pipe area, with a definite center line, this would be problematic. If torpedoes missed their target, they would not effectively anchor the pipe and would result in larger deflections from the buoyancy and current. Due to perceived riskiness from unknowns and deflection, we decided not to pursue this concept further.

Concept 2 (pulley system) was tried in many different configurations, and ultimately decided against because of the complex fluid dynamics inside the pipe. This system would rely on equal buoyancy within the pipe to keep itself level. In reality, the pipe has, and will most likely continue to have pockets of water inside of it. This results in unevenly-distributed buoyant force along the length of the pipe, which may aggravate leveling issues instead of correcting them. While buoyancy is expected to be an issue, pipe deflection and drag from the current are not.

Concept 3 (adjustable poles) seemed like a good idea before engineering analysis. After doing calculations, we realized the poles attaching the anchor to the surface would act as a lever arm, and be very susceptible to the current, as well as being bulky and cumbersome to install. The current would create a moment about the base, which would have to result in a larger anchor structure. Additionally, the adjusting of pole height at varying water levels would be difficult to reach.

Concept 4 (reconfigured current system), while similar to what is in place now, may hold merit in simplicity. By adjusting the anchor spacing and chain attachment length, the angle of the pipe resulting from sea floor shifts would be reduced, possibly enough for the angle of the pipe to not interfere with pipe bubbling. From calculations, the pipe anchors could be spaced as much as 15 feet apart with the same concrete car curb anchors. More deflection calculations should be performed for appropriate spacing. While we will not pursue this as our main design, due to the simplicity and lack of self-leveling components, we hope to test a reconfigured current model along with our design concept for comparison.

Concept 5 (buoy leveling system) is the design we have decided to pursue. Since this concept uses the level of the bay surface to maintain pipe elevation, there are additional complications such as tides. However, this concept stood out in the decision process, and preliminary calculations show it can be effective. Specifics of this design are discussed in Section 4.3.6, but a brief summary of preliminary analysis is provided below.

- Buoyancy: Since the primary anchor will be moved from the ocean bottom for the surface, the direction of buoyancy will need to change, so the pipe puts tension on the surface buoy instead of floating up. To add density to the pipe, a steel chain or cable can be added to the length of the pipe to decrease its buoyancy and attach it to its anchors. Table 8 shows cable diameters in comparison to the effect on the total buoyant force on the pipe. A ratio of less than on shows the total downward force of the cable is greater than the pipes upward buoyancy.

Table 8: Steel cable weight table, showing the effect of buoyancy and the ratio of cable weight with total buoyancy of the bubble pipe.

Cable Diameter [in]	Weight Cable [lb/ft]	Cable Buoyancy [lb/ft]	Fcable Total [lb/ft]	Ratio Fb_pipe/F_cable
1/2	21.50	2.81	-18.69	3.07
5/8	33.59	4.38	-29.20	1.96
3/4	48.37	6.31	-42.05	1.36
7/8	65.83	8.59	-57.24	1.00
1	85.99	11.22	-74.76	0.77
1 1/8	108.83	14.21	-94.62	0.61

- Drag: The drag on the anchors will change significantly with this design. The weighting of the pipe from the buoys significantly increases the normal force expected on the concrete curbs, and the buoyant force of the pipes is no longer acting upward. This significantly increases the resistance to drag since the friction force is increased. The buoy, and chain connecting the buoy to the pipe will experience drag.
- Deflection: This is the expected limiting factor of distance between anchors, though the addition of cables will balance out the distributed buoyant force, making the point loads the main cause of deflection. More calculation needs to be done to determine the spacing of buoys and anchors.

3.4. Final Concept

3.4.1. Final Concept Description

A solid model of the final concept is shown to the right as Figure 18. The chosen design revolves around one particular idea. That idea being that the surface water will remain level regardless of the conditions of the sea floor. The design consists of attaching a hefty cable to the underside of the bubble curtain in order to have a resultant net force downwards toward the sea floor. If the net weight of the bubble curtain pipes and the attached cable are greater than the overall buoyance force, then it would be possible to suspend the bubble curtain from the surface of the water. The bubble curtain could then be suspended using several buoys distributed across the length of the bubble curtain. Chains at specified lengths along the curtain would be used to connect the buoys to the curtain.

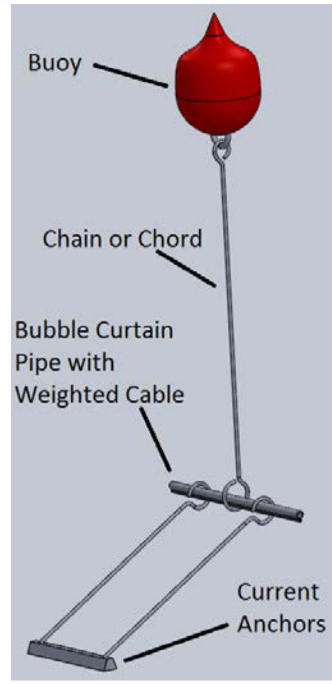


Figure 20: Chosen design concept for leveling and anchoring the bubble curtain.

However, there still would remain the problem of the bubble curtain being carried away by the drag forces of the current. To prevent this from happening, the current anchors would be chained to the pipe at a much further distance then they have previously. The chains would contain enough slack so that these anchors would only be active if the pipe moved too far from the desired lateral position. In the case that the ocean floor shifts, the anchors would be placed far enough away from the pipe that the deflection of the pipe in the vertical direction would be minimal.

3.4.2. Materials Cost Analysis

A basic table of needed materials can be found below. Since we must complete similitude analysis to choose an appropriate model scale, it would be inaccurate to specify which and how much materials will best simulate the conditions of the actual bubble curtain. We hope to make our model small enough to be transportable, which would also decrease the pump size. However, accuracy is important, and will be the biggest determining factor in model scale. After scale is determined, other materials and costs can be specified. Table 9: Preliminary cost analysis. The below cost analysis is an incomplete estimate and will be updated upon scale selection is an incomplete list of expected materials.

Table 9: Preliminary cost analysis. The below cost analysis is an incomplete estimate and will be updated upon scale selection

Basic Cost Estimate			Amount	Total
Pump	$ 500.00	unit	1	$ 500.00
Pipe	$ 2.00	foot	50	$ 100.00
Sand	$ 4.00	50lb	2	$ 8.00
Buoys (12")	$ 25.00	unit	10	$ 250.00
Chain (3/16")	$ 1.57	foot	50	$ 78.50
Total				$ 936.50

4. Final Design

4.1. Design Description

4.1.1. Design

For the bubble curtain model, our final design uses three sets of buoys and anchors. The buoys (3) and anchors (8) were attached to unistruts (4), which were purchased parts from a manufacturing company. These unistruts were connected to PVC pipes via clamps (5). Since the unistruts and clamps were both made of steel, they also had the effect of weighing down the buoyancy of the pipes without having to add any extra weights. This organization can be seen in Figure 19. The pipes would then hang from the buoys as planned using wire ropes (7). The wire rope and the buoy were connected using carabiners (6).

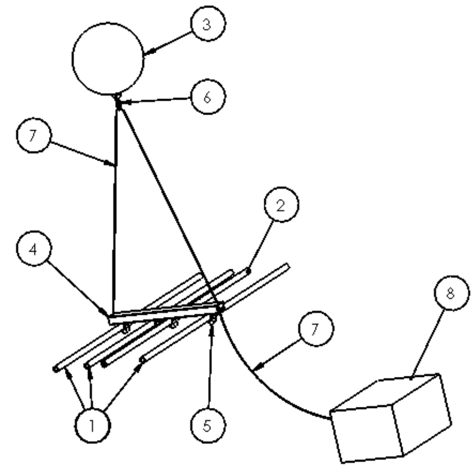


Figure 21: One junction of the full model.

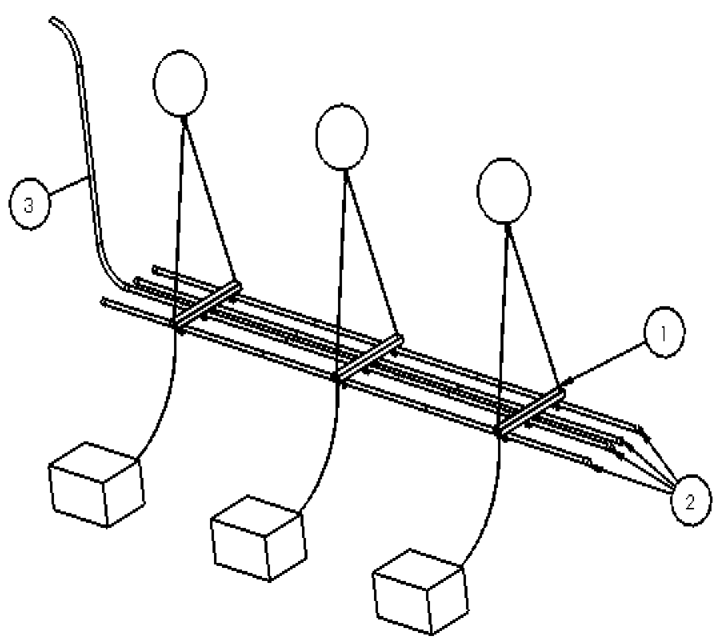


Figure 22: The final design of the bubble curtain model consists of three assemblies that are attached to the pipes. Only one of the pipes will be producing bubbles, which simulates the conditions of the full-scale bubble curtain. On the ends of the pipes are plugs (2) and a flexible hose (3) which will attach to an air compressor.

The entire structure shown in Figure 20 was inserted into a test tank. One of the PVC pipes had holes and it was attached to an air compressor to produce a bubble curtain. The other three pipes were sealed with plugs, caulk, and duct tape. A full set of drawings can be found in Appendix I.

4.1.2. Function Explanation

This design aims to provide pipe self-leveling using the ocean surface to remain level. Buoys float on the surface and are the primary anchor for the pipes. The pipe is connected to the ocean floor by a long chain attached to a concrete anchor. This prevents the pipe from floating away while translating the sea floor changes into lateral motion since the pipe is dependent on the sea level for its height.

The chain connecting the anchor to the bubble pipe was chosen using a tide of 8 feet and an expected anchor movement of 2 feet into the sea floor. The chain connecting the buoy to the pipe will be sized for specific sea floor elevations. For the purposed of the model, the chain is sized to be scaled 20 feet, due to test tank height restrictions. Because there is a greater percentage of bubble coverage in deeper water, this system is more effective in deeper water. See Section 5.3.2 for a complete performance prediction, including minimum effective height.

For the purposes of the above figures, the buoy is shown to be directly above the pipe system. However, it will experience some drag force by the current and may not be directly above the pipe. Since a surface current exists, as well as current created by the bubble curtain, the relative locations of the buoys are unknown.

4.1.3. Material Selection

The main concern for this project, as far as material selection goes, was that almost all the equipment would be submerged in the ocean. This called for choosing materials that would be resistant to corrosion and be able to withstand the current in the salt water. Since the existing bubble curtain pipes were not going to be altered, a new material did not have to be chosen; However, for the purposes of the model, the decision was made to use PVC instead of HDPE pipes. Much like HDPE, PVC is corrosion resistant, but PVC is much cheaper and easier to acquire in smaller sizes. The buoy was also decided to be made from the same material as the model pipes. For all the metal components, stainless steel 316 was chosen. This included the unistruts, pipe clamps, cables, and cable sleeves. “Because stainless steel contains at least 10.5% chromium, the oxidation of the iron is changed to produce a complex oxide that resists further oxidation and forms a passive layer on the surface” (Stainless Steel for Coastal and Salt Corrosion, 2002). After further investigation, it seems that bronze may have been the best choice, but due to the availability of stainless steel versus bronze in pre-manufactured parts no alterations in material choice was made. Some of the materials for the test rig were not made of stainless steel, but since the rig would not remain submerged in saltwater for long periods of time, the team was not worried about deleterious corrosion.

4.2. Tank Discussion

4.2.1. Function

The test tank used to test the final design had to be large enough to test the full system range of motion, and allow for sight and measurement in the tank. Originally, our team planned to build the tank. Since the tank requirements included drainage, electricity, and a relatively large area, it was decided that the Cal Poly Fluids Lab Weir Box would be used instead of constructing a new tank. The weir box inside the Fluids Lab was not in use for many years, due to issues with fluid getting stuck in the sump drain and producing fumes. Last year, the Cal Poly Robotics Club fixed and modified the box to hold water to test an aquatic robot (Lisa Dischinger, 2016). Due to their alterations, the tank meets our test requirements. Figure 24 is an older picture of the weir box; The weir plate was replaced and the tank could be filled all the way to the top if necessary. Figure 23 shows the side view of the same tank.

Figure 24: The weir box in the 192-102 fluids lab. This picture is before alterations were made; the weir plate no longer exists and tank can be filled to full height.

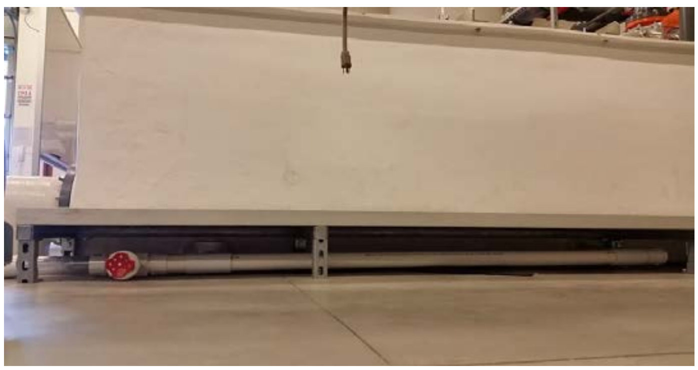


Figure 23: Side view of the previously pictured weir box.

4.2.2. Using the Tank

Despite its location in the fluids lab, the tank was somewhat difficult to fill. It was filled using a hose connected to the sink about 30 feet away. While this is not a problem, it affected the order in which we conducted tests, to avoid filling and emptying the tank regularly. To drain the tank, the robotics team diverted the drain line from the sump to the floor drain. Our contacts for receiving permission to use the Weir Box included Professor Russel Westphal and the ME Department safety representative, Jim Gerhardt.

4.2.3. Air Pump

An air pump was used with the model pipe system to replicate the bubble curtain in the actual size. This allowed for observations on the effect of the surface current on the buoy and to see possibly see changes in bubble emission due to pipe angle (from horizontal). An air pump was chosen based on the calculations in Appendix C, and an associated Excel spreadsheet. Modifications to the actual pipe design were made for manufacturability on a model scale. The original pipe has two rows of bubbles. Using the scaled holes, the approximate volume of each bubble was found. A new hole diameter was found using the same bubble volume with only one whole instead of two. This allowed for drilling one row instead of two rows. Additionally, the spacing and size of the holes were altered slightly from the actual pipe to produce the same total volume of bubbles with spacing easier to measure and manufacture. Bubble behavior is complex; we anticipated having to remake the bubble pipe to find the most accurate configuration. The final pipe had between 24 and 60 holes/foot.

The flowrate of the air pump was found using the volume of bubbles needed above the pipe and the average time it takes the bubbles to travel in the fluid they are immersed in. To keep an approximately 20% volume of air directly above the pipe, a flowrate of 3.2 CFM is needed. This is about 70 LPM. This air volume corresponded with air pumps used in large aquariums and ponds to aerate water for fish. The air pump selected is a Protech Electric-magnetic Aquarium Air Pump Oxygen Tank Aquarium, 105W, adjustable between 20-85 LPM, picture in Figure 23.

Figure 25: Protech 105W aquarium air pump.

4.3. Design Justification

4.3.1. Analysis

Analysis was done throughout the design process. Similitude analysis, discussed below and in Appendix C , was done to determine model scale and necessary tank properties. Using the model scale determination, each component of the bubble pipe system was sized and a factor of safety was determined. A discussion of each loaded component can be found below and calculations can also be found in Appendix C.

Similitude Analysis

Initially, similitude analysis was done on the system to create pi groups. The pi groups would allow for geometric and dynamic scaling of the parameters in the system. As shown in Appendix C, two dynamically similar pi groups were found: Reynold's number, and a drag coefficient per unit length. A new pipe diameter was chosen based on the smallest size pipe that the team thought they could drill holes into. Then using Reynold's number as a pi group, an appropriately scaled flowrate was given. After obtaining the new flowrate, the other dynamically similar pi group was used to get a scaled drag force per unit length. Once a new drag force was found, all the other forces could be scaled by the same factor yielding the needed weights and buoyancy forces required in the system. However, the new flowrate and drag forces were much larger than anticipated. They were so large that after the team talked to their advisor, the advisor urged them to remove the flow from the tank. She said that building a tank that could produce that much flow over a large area in a tank would be a project in itself. This is when the team talked to the sponsor to remove the flow requirement in the test tank. With the flow requirement removed, the team scaled the model by geometry alone and found a force scalar that could be applied to all the forces in the model.

Component Selection

Using the analysis discussed above, a geometrically similar model was found using the ratio of the real systems pipe outer diameter to the models pipe outer diameter. A model pipe outer diameter was selected using tank size constraints. To increase accuracy, a larger model was preferred and at least three pipe sections (with an actual section size of 10 feet) need to be tested in the model. However, the actual system cannot exceed about 6 feet due to the sizes available to place a tank. Table 10 shows geometry inputs from the full-scale system to the model system. The model geometry represents minimum tank size; actual tank size is larger and allows for larger part tolerances and easier manufacturing.

Table 10: Geometry relationship between full-scale and model system. Note tank dimensions below are minimum and do not reflect exact tank geometry.

Input: Real Size		
Pipe	OD [in]	**4.5**
	Mass [lb/ft]	**3.4**
	Sections [-]	**4.0**
	Section length [ft]	**3.0**
Geometry	Depth [ft]	**20.0**
	Δ Sea Level [ft]	**5.0**
	Δ Bay Floor [ft]	**2.0**
	Pipe Sections [ft]	**6.5**
Output: Model Size		
Pipe	OD [in]	**0.675**
	ID [in]	**0.407**
	Mass [lb/ft]	**0.138**
	Section Length [ft]	**0.75**
	Total [ft]	**3.00**
Tank Geometry	Length [ft]	**5.00**
	Width [ft]	**1.95**
	Height Max [ft]	**3.00**
	Height Min [ft]	**2.25**
	Pipe System Width [ft]	**1.20**

The parts listed in Table 11 are carry loads and were selected using common load analysis. All the analysis assumes maximum pipe weight condition, with the pipes full of water. A description of the analysis is show below, with complete calculations in Appendix C.

- The Unistrut used to support the pipe was chosen based on pipe size, and was checked with the later calculated weight from the anchor to ensure it did not exceed its maximum moment. Likewise, the pipe clamps do not exceed the load limit, as they are used as a connection point instead of to bear a load.
- The minimum spherical buoy size was determined using the maximum pipe weight, support weight, and estimated (later corrected) wire rope weight. Since bubbles decrease the buoyancy, a factor of safety of at least 2.0 was needed. After finding a minimum radius of about 3 inches, a buoy with a radius of 4 inches was chosen. While selection of small buoys was minimal, the chosen buoy has an acceptable a factor of safety of 3.3 and is marine grade.
- The anchor size was selected using the maximum buoyancy of the buoy, so if the sea level were to rise well above its predicted maximum (in the event of a storm), the buoy would not take the anchor off the sea floor. The minimum volume of concrete was then multiplied by a factor of 1.5 to determine the final anchor volume.

- The wire rope size was determined last to account for anchor weight. The mass of the entire system was summed, including the expected mass of the wire rope, and the maximum force was found at the buoy. A 1/16" wire rope has a factor of safety of 30, and was chosen. All other calculations were adjusted to account to the wire rope size, though its effect on the system mass is relatively small.

Table 11: Loaded component factor of safety summary. See calculations in appendices.

Bubble Pipe Loaded Material Summary			
Component	**Material**	**Load Limit [lb]**	**Factor of Safety**
1-1/4"X 3/4"X1.2' Unistrut	Stainless Steel	950 [in-lbs.]	42.0
3/8" Unistrut Pipe Clamp	Stainless Steel	400	116.0
1/16" Wire Rope	Stainless Steel	96	30.5
8" Buoy	PVC	4.56	3.3
Concrete Anchor	Concrete	3.45	1.5

Testing and Judgement

This design was judged by the design team per the engineering specifications listed in Table 2. Testing took place after building the model. Specifics on the testing can be found in the Design Verification Plan in Appendix H, and a detailed test plan can be found in Section 6.2.

4.3.2. Performance Prediction

Bubble Pipe Motion Performance

As discussed in Section 5.1.2, the self-leveling system pipe becomes less effective as the maximum sea level increases. This is because the anchor chain is dependent on the tide, and the tide does not vary with depth. According to Figure 24, for the bubbles to always cover at least 80% of the water depth, the maximum sea level must be at least 50 feet. However, the tide rarely is above 6 feet, improving effectiveness. Since the 70% minimum is not absolute, using the average coverage is acceptable for determining minimum effective sea level. The actual effectiveness should be slightly higher. If the anchor sinks, this also increases the effectiveness, since the pipes are held lower relative to the sea floor. Using the average bubble coverage, the recommended acceptable minimum height is 22 feet.

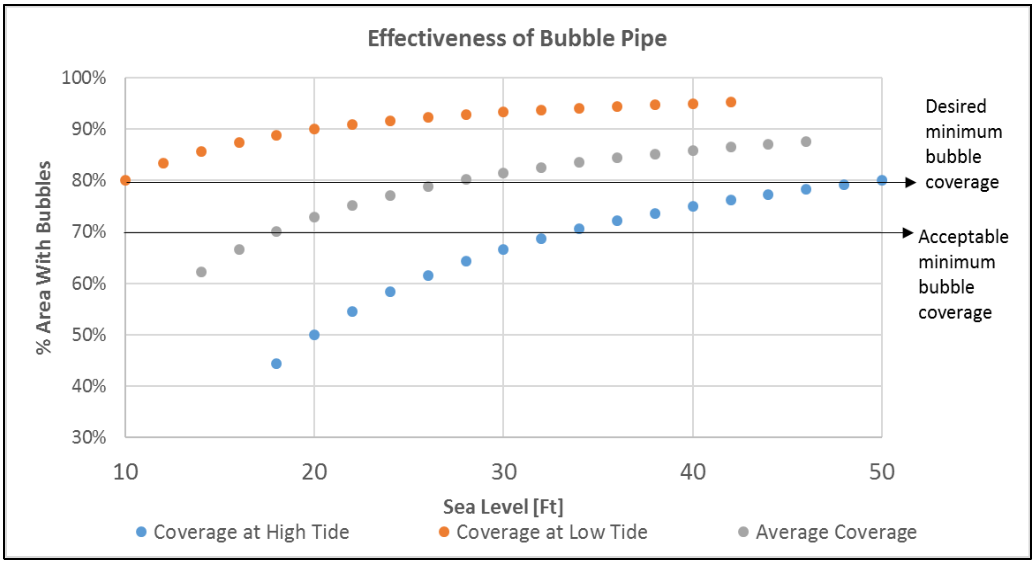


Figure 26: Bubble coverage at different depths. Since salp-stopping ability is dependent upon bubble coverage, this pipe system past a certain depth will not be effective.

The model height is defined by the tank height. The maximum water level inside the tank is 3 feet, representing the minimum acceptable height of 22 feet. Predicted motion performance is represented in Figure 25. The model will be tested using the equivalent minimum acceptable water height of 3.0 feet, but results can be extrapolated for larger depths.

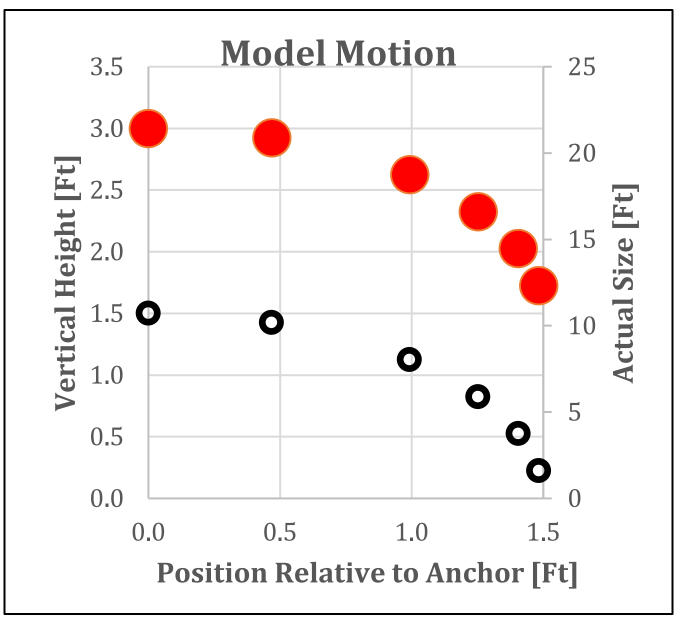


Figure 27: Predicted model motion with actual size comparison on the secondary axis. The buoy is represented by the red dot and the pipe is represented by the black circle.

4.4. Feasibility Concerns and Resolutions

4.4.1. Engineering Specification #1

Engineering Specification 1 initially stated the pipe must not move laterally with a tolerance of ±3 feet. The chosen design allowed the pipes to move freely with a radius of 10 feet. This violated the original specification. However, this movement alone was not detrimental to system functionality, and there was not a specific reason the pipe should not move more than three feet, assuming it was not floating away. Since Specification 7 ensures the ground anchor cannot move, Specification 1 was modified to specifically limit deflection instead of loosely limit lateral movement. Specification 1 now states the deflection of the pipe over a 20-foot span should not exceed a lateral deflection of 5 feet.

4.4.2. Pump Concerns

From the beginning of this project, it was assumed the pipe system would be placed in a tank with moving water to simulate current. However, due to tank size, necessary flow rate, minimal overall effect of the current, and concerns from our faculty adviser on design complexity, we decided not to incorporate a pump, or flow, into the tank design.

- *Similitude and tank flow*: from Buckingham Pi analysis, as seen in Appendix C, flow rate and pipe diameter are inversely related. For a reasonably sized pipe diameter (based on tank geometry), the flowrate would be about 6 ft./s. This would require a large pump and very large tank.
- *Minimal current effect:* While the current produces a drag force on the pipe, buoy, chain, and anchor, the effect is relatively small compared with the friction force along the concrete anchor.
- *Advisor recommendation*: Our adviser is concerned that the entire test tank is a design problem in itself, and will result in us not being able to complete our project.

Not including a pump in the design allowed for more time to test for critical design aspects, such as the self-leveling function under various tide conditions. In addition, the drag force of the current could have been approximated using a finite number of point loads, as discussed in the Section 6.2.

4.4.3. Potential Issues

Soon after getting the preliminary design approved by the project's sponsor, a failure mode effects analysis (FMEA) was performed to flesh out potential ways this design could fail. The analysis was done for three main functions: Pipe Self-leveling, acts as an anchor, and the Test Tank Holding Water. Potential failure modes were thought of for each of these functions and the potential effects and causes of these failure modes were evaluated. Severity, occurrence, and detection ratings were given to each potential failure and these ratings were multiplied together to create a risk priority number. The risk priority number made it apparent which issues were the most deleterious in the existing design. A list was created that revealed how the design attempted to prevent or alleviate these errors. The FMEA illuminated the biggest problems with the existing design. More thought was put into ways to prevent these problems and how the existing design could be tweaked. A full chart of the FMEA can be found in the attachments as Appendix G.

4.5. Supporting Data

4.5.1. Cost

The total cost for all the parts needed came out to be around $510. After talking to our sponsor, the cost increased significantly because he wanted us to use a set of trolling motors to create a current in the test tank. The most expensive items on the list include the Unistrut assembly, the air pump, utility totes, and trolling motors. We initially planned on simulating the sand floor by placing the sand into utility totes, but the friction of the tank bottom proved acceptable for the tests. A full bill of materials can be found in Appendix J.

4.5.2. Budget

For this project, the sponsor never gave a budget. After several conversations with him, it was explained that if anything could prevent the power plant from shutting down it would not matter how much money it would take. When asked for a quantitative number, the sponsor said, no more than $20,000. This seemed like a reasonable budget until it was decided that the test tank would not have flow. Without the need to purchase several pumps the overall cost the project decreased significantly. Then when the team's advisor informed us that they would be able to use a pre-made tank on campus instead of building their own, the cost came down even lower. The estimated total cost of the project was around $1500 without shipping. The costs of the project are well within the budget.

5. Project Realization

5.1. Manufacturing Process

After we had received some of the materials, we immediately began manufacturing. The first thing we did was cut the PVC pipes to the required length that would make the model geometrically like the system in Diablo Canyon. The pipes were measured using a standard tape measure and they were cut using a chop saw. While the pipes were being cut, the rest of the team cut the unistruts to length. The unistruts were measured the same way as the PVC pipes were; however, to cut the stainless steel a Miter saw was needed. The picture to the right depicts Christian cutting the unistruts while wearing a face mask. After the unistruts were cut, the cut ends were shaved down using belt sanders to eliminate sharp edges on the unistruts.

Figure 28: Christian using a Miter saw to cut the Unistrut beams

Figure 29: Donavan and Dakota drilling holes in a clear PVC pipe

One of the pipes needed holes drilled into it so that the bubble curtain could emit bubbles. To do this we went to the Cal Poly hangar and used one of their drill presses. The pipe was held in a V-clamp and vice. To prevent the drill from drilling through the entire pipe, a guard was set at a certain depth halfway through the pipes diameter. The long arduous process of drilling 50+ holes took half an hour but the results were perfect.

Before, the cables were attached to the Unistrut the pipes were clamped to the Unistruts using the Unistrut pipe clamps we order. Care was taken to make sure they were spaced per the final design. The stainless-steel cable was cut using wire cutters that were borrowed from the Cal Poly machine shop. Once the cables were cut, they were crimped to the unistruts using the sleeves and crimping tools that we ordered.

Figure 30: Christian and Dakota crimping the stainless-steel wires to the Unistruts

Figure 31: Donavan pouring the concrete

The last bit of manufacturing that was required included pouring the concrete to make the anchors in the model. Half of a five-pound bag of Quickrete was poured into a plastic bucket lined with newspaper. While pouring the Quickrete, a mask and safety glasses were worn to prevent breathing in the dust particles and splashing into eyes. Water was added to the mix until all the dry concrete was gone. Once thoroughly mixed, an eye-bolt was submerged in the mix. The buckets were set aside to cure overnight and the concrete slabs were pulled out of the buckets a day later.

All that was left was assembling the leftover parts. Carabiners were used to connect the cables to both the anchors and the buoys. A hose was attached to the air compressor and to a plastic connector that was attached to the PVC pipe with holes. End caps were sealed to the PVC pipe using caulk, PVC plugs, and duct tape.

5.2. Prototype Alterations from Planned Design

There were a few complications in our original design that we decided to alter while manufacturing and assembling it. It turns out that the wire rope we ordered was much thicker and harder to work with than we imagined. We were able to crimp the wires, but they were impossible to adjust once they were set. Instead of trying to get the precise enough measurements of the wire length between the buoy and the pipes, we instead used a synthetic rope about the same diameter as the wire. This was much easier to adjust for the proper height. Another change from the design drawing was having the bubbling pipe be on the end instead of in the middle. Also, for some reason the pipe end caps were designed to be connected using PVC connector bits instead of just attaching straight onto the pipe. To attach them, we sealed them using caulk and wrapped them in duct tape, just so we did not have to wait for another order. It let a little water in the sealed pipes, but there is some water in the pipes of the full-scale system as well.

5.3. Recommendations for Future Manufacturing

While our project scope included only a model version of a bubble-curtain anchoring concept, it was designed in a full-scale context. These recommendations are made from our own experience through building the model, and from what is expected with the full-scale design. The model concept uses the existing bubble pipe structure so the below manufacturing recommendations assume the existing structure will continue to be used.

5.3.1. Keep Pipe-Buoy Chain or Wires Adjustable
As is further discussed in the results section, the pipe does not bubble well. Assuming the same behavior in the large-scale system, the pipe will perform best if it slopes upward. Since ground topography is unpredictable, keeping the buoy-pipe attachment chain long and adjustable will allow for changes in length each time the system is deployed.

5.3.2. Keep the Pipe-Buoy Chain Long
The longer the chain is, the less of an effect the tide will be, but if this distance is too long, the pipe system will rest on the ocean floor during low tide. The bubble pipe is not designed to repeatedly hit the ocean floor, and will not be level if the floor is not level.

5.3.3. Keep the Anchor-Pipe Connection Long
The function of this connection is too keep the pipe from floating into the intake or out into the bay. This should be at least as long as the maximum tide difference plus the possible floor shift. These should be kept a similar length to the adjacent connections to prevent current from loading a single anchor point.

5.3.4. Ocean Floor Topography
Prior to full scale design, the ocean floor topography should be studied. While the floor elevation changes, general shape across the bay will be important design information. In the case of a concave or flat slope, the pipe system could be kept at a constant upward slope while covering most of the bay. If the bay is more convex, the slope cannot be constant. Since the pipe will be allowed some freedom to move forward and backward, we recommend knowing the topography of all parts of the bay floor the pipe could reasonably be located.

6. Design Verification

6.1. Pipe Angle

6.1.1. Test Description and Purpose
We took our model and removed the two buoys that were opposite where the bubbles are flowing into the pipe. Then we attached an adjustable cable to the carabiner suspending the Unistruts on the end. An underwater camera was used to read the height of the end of the pipe and the Unistrut being held by the buoy. This was done at several different end pipe heights to get a variety of test angles. At each of these angles observations were made to see how the bubbles would flow out of the pipes. The observations were split up into four sections along the pipe (starting at the end producing the air). This test allowed for us to see which angles produced the most distributed bubble flow across the pipe.

6.1.2. Detailed Results
At each angle, a measurement of the height at the end of the pipe was taken and then the entire pipe was swept across by an underwater camera to observe the bubbles coming out at each section. The sections are labeled in Figure 32.

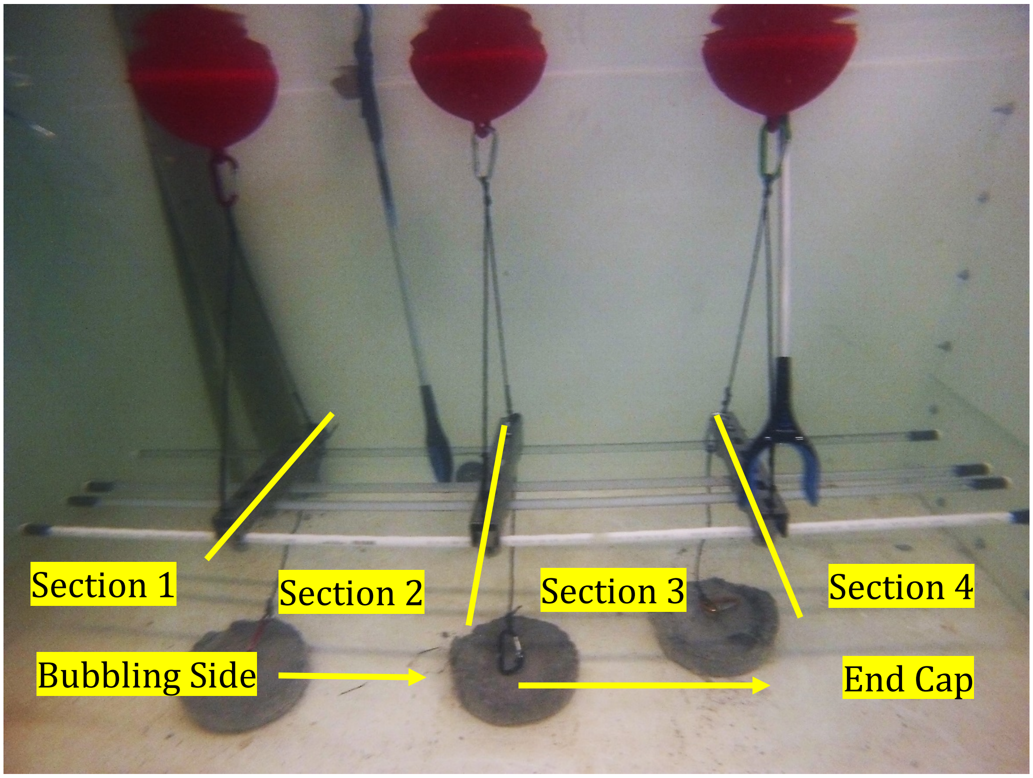


Figure 32: A picture of the model of the bubble curtain taken underwater. The lines perpendicular to the pipes are there to segment each section of the pipe for observations. Each section is labeled with a highlighted section number. The bubbling side refers to the end of the pipe connected to the air compressor and the end cap refers to the side that is plugged by a PVC cap. The yellow arrows are used to show the direction of air flow through the pipe. The two rods extending from the surface of the water were used to orient the model for the picture.

At each section a rating of the bubble coverage was given. There were only three different types of ratings: no bubbles, some bubbles, and several bubbles. A rating of "no bubbles" was given when there were absolutely no bubbles being emitted from the pipe section. The rating of "several bubbles" was given when it appeared that there was a torrent of air being shot out of the pipe section. Lastly, the rating of "some bubbles" was given when it appeared that bubbles were coming from the pipe but not a strong current or if the stream of bubbles only went halfway across the pipe. Figure 34 and Figure 35 are examples of the "no bubbles" and "several bubbles" case respectively. An example for the "some bubbles" case is not given because it was difficult to see the bubbles in the photos but they were easily depicted in the videos from the other two cases.

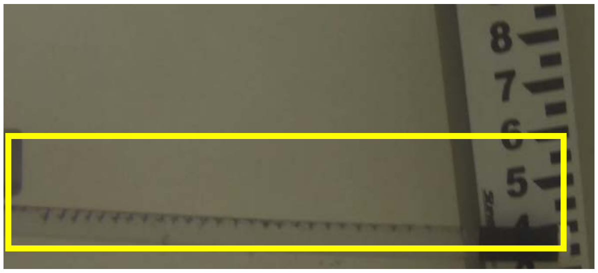


Figure 33: An example of the "no bubbles" rating. The area above the pipe is clear with no ripples in the water. This indicates that there are no bubbles exiting the pipe at this location. The yellow box depicts the area above the pipe that was investigated to make the observations. The picture was taken at section 4 on the pipe.

Figure 34: An example of the "several bubbles" rating. The area above the pipe has ripples in the water and is not clear. This indicates that there are bubbles exiting the pipe at this location. The yellow box depicts the area above the pipe that was investigated to make the observations. The picture was taken at section 4 on the pipe.

All the data values and observations for each trial can be found in a table in Appendix L.

6.1.3. Analysis

Since we were recording in different units then we were extrapolating, propagated uncertainty was performed. We recorded the heights and lengths in inches. The uncertainty for the heights was $\pm\frac{1}{4}$ inches and the uncertainty for the length of the pipe was $\pm\frac{1}{32}$ inches. For the nominal value of the pipe angle, basic trigonometric functions were used to obtain the angle in degrees. To find the uncertainty of each angle, an uncertainty propagation method was used. An example calculation of the uncertainty can be found in Appendix K. The trials with the best bubble coverage occurred between 2.8° and 9.3° from the horizontal. Angles below 2.8° resulted in air not reaching all the way to Section 4. Most of the bubbles were emitted in Section 1. Angles above 9.3° had a more even distribution of bubbles across the pipe; however, bubbles still did not emit at the fourth section of the pipe and the bubbles at section 1 were not exiting as fast as they were in Sections 2 and 3. Slight upward sloping angles give the most even distribution across the bubble curtain. These results could be used in the full-scale system if they make the lengths of the chains connected to the buoys slightly smaller as they move farther away from the air source.

6.2. Floor Shift

6.2.1. Description and Purpose

The purpose of this test was to determine if a shift in sea floor level would cause the pipe to become unlevel. In the real system, sand under anchors shifts, causing the anchors to sink. In this test, blocks were placed under the anchors to simulate the anchors without blocks sinking. The pipe was pushed away from the anchors and the height on either end was measured to determine the pipe angle. The expected result was that the pipe angle would remain constant within measurement uncertainty. An example of the test set-up can be seen in Figure 35.

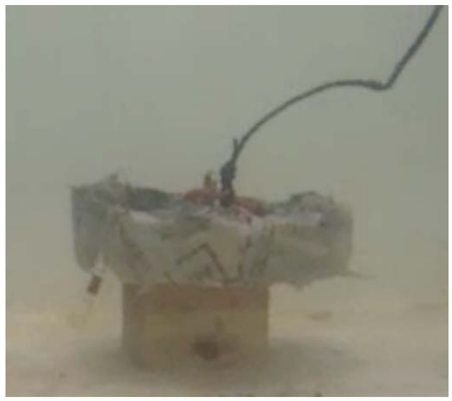


Figure 365: Anchor 3 with a 3" block below it, simulating the sinking of the adjacent anchor

Beginning with a water level of 36" and uniform anchor elevations, an initial pile angle was found to be 1.39 degrees. Blocks were placed under some anchors and the water level was changed, with the heights of pipe ends measured. The angle was calculated, and compared to the initial pipe angle with uniform anchor elevation. Data from the floor shift test can be found in Table 12.

Table 12: The pipe level was measured at each end using different block heights and water levels to simulate the shifting ocean floor and tides. Using the pipe ends, the angle was calculated.

			Anchor Height			Pipe Height*			
		Water Height [in]	1	2	3	Bubble End	Other End	Angle [Degrees]	from Initial [Deg]
1			0	0	0	11.25	12.75	1.39	0.0
2		36	1	3	1	11.25	12.5	1.16	-0.2
3			1	3	4	11	12.25	1.16	-0.2
4	**	37	1	1	1	12	13.5	1.39	0.0
5	**	35	1	1	1	10.25	11.5	1.16	-0.2
6	**	30	1	1	1	5	6.5	1.39	0.0

* Measured from top of pipe

** from water height videos

6.2.2. Analysis

To determine if the floor shift altered the pipe angle, uncertainty analysis was performed on the pipe angle. The resulting uncertainty is within 1°. This is greater than the 0.2° difference between the pipe angle measurements, leading to the conclusion the pipe angle is not affected by the shifting floor elevation. To support this conclusion, Figure 36 shows a negligible correlation between the water level and pipe angle.

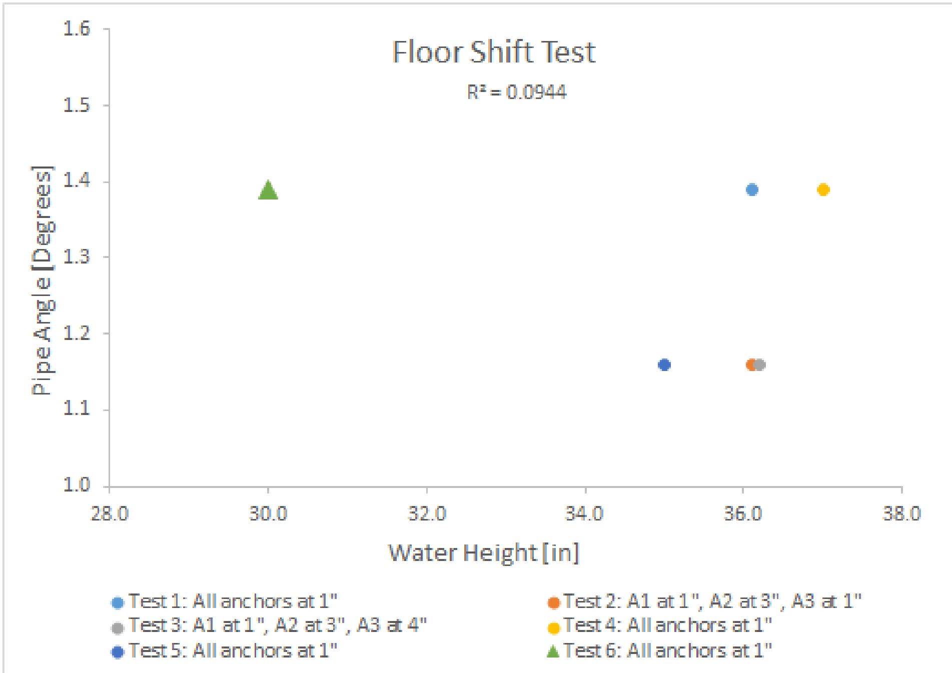


Figure 386: A comparison of the pipe angle to the water height with blocks shown in various tests. Pipe angle correlates poorly with water height and the angle variation is due entirely to measurement uncertainty.

6.3. Water Height Bubble Coverage

6.3.1. Test Description

One of the main limitations of our design is the inability to account for the daily tide that changes the height of the water. This height difference can span ten feet. In our tank, we raised the height of the water in one inch increments and measured the corresponding height of the pipe. These are compared with each other to determine the percent of bubble coverage. The design must be set for the lowest tide, then as the tide rises, the bubble coverage decreases.

6.3.2. Detailed Results

Beginning with a water height of 30 in, the bubble coverage started out at 82.1%. This is measured simply by measuring the areas of the water height and the pipe height. As the water was increased inch by inch to 37 in, the bubble coverage dropped to 65.9%. In order to see how our model will do full-scale, we extrapolated the data to include larger water heights. The data was analyzed at three expected depths: 18 ft, 30 ft, and 43 ft. The results are shown in Table 13.

Table 143: Data for the water height bubble test, extrapolating for the full scale model.

Water Height [in]	Pipe Height Bubbler End [in]	Pipe Height Pipe End [in]	Angle AB [Deg]	Bubble Coverage [%]	Large scale Equivalent Water Height [ft]	Notes
30	4.25	6.5	2.08	82.1%	16.7	The test tank size allowed for a shallow-depth test. This would be the design and resulting bubble coverage for the shallowest part of the bay, which would receive the minimum bubble coverage. Max water depth of 18'.
31	5	7	1.85	80.6%	17.2	
32	6.25	8.25	1.85	77.3%	17.8	
33	7.25	9.5	2.08	74.6%	18.3	
34	8	10.25	2.08	73.2%	18.9	
35	9.25	11	1.62	71.1%	19.4	
36	10.25	12	1.62	69.1%	20.0	
37	11.75	13.5	1.62	65.9%	20.6	
40	4.25	6.5	1.85	86.6%	22.2	Extrapolated data using expected bubble coverage for a max depth of 30'
46	5	7	1.82	76.1%	25.6	
52	6.25	8.25	1.82	66.8%	28.9	
58	7.25	9.5	1.81	59.7%	32.2	
64	8	10.25	1.78	85.7%	35.6	Extrapolated data using expected bubble coverage for a max depth of 43'
70	9.25	11	1.74	78.4%	38.9	
76	10.25	12	1.76	72.2%	42.2	
82	11.75	13.5	1.77	66.3%	45.6	

6.3.3. Analysis

The larger the initial height of the water, the less of an impact the tides will be. This is due to the fact that the relative area is much larger while the height change is the same. Notice in the table that the water height continues past each section's maximum. This accounts for the lowest values of percent bubble coverage. Even within the range of water depth the bubble coverage drops below the design requirement of 80%, thus failing the test; however, that particular engineering specification was arbitrary, and it is close to passing.

6.4. Turbulence

6.4.1. Test Description

In order to see how our design would stand against turbulence, waves needed to be generated in the tank. To do this, a plastic board was placed in the tank and rocked back and forth, creating oscillations of waves. We had the foresight to reduce the water level first to avoid splashing over the edge. This test was more of a qualitative test, seeing if bubbles still formed a barrier to block the salp. We also tried to force the model to flip over. This was a concern if the current was strong enough.

6.4.2. Detailed Results

As the waves rocked the bubble curtain, the bubbles came in waves as well. This corresponded directly with the angle of the pipe at every moment in the wave. As the waves passed, however, every portion of the bubble curtain was covered. There was no constant break in the bubbles, meaning the slow moving salp would not be able to slip past the bubble curtain. Our attempt to flip the model failed. Each unistrut was too heavy to create the torque needed to completely turn it over. This shows that even with a strong current, our design will not flip and fail.

6.5. Corrosion

6.5.1. Test Description w/photos

Rust indicates corrosion of important bubble system components. While the model system was not designed for corrosion resistance, the real scale system must be to reduce possibility of failure. Each time the model was used, it was inspected for corrosion. The inspection of the pipe system and anchors can be seen in Table 14. The concrete anchors with carabiners were left in the tank for the duration of the testing period, while the pipe system was taken out after each test, dried, and stored in a dry location.

Table 154: Record of anchor and pipe inspection throughout testing. Note anchors were usually left in the water while pipe was taken out and dried after each use.

	Date	Time in Tank	Inspection Notes
Anchors	April 27th, 2017	0.5 Hours	No rust
	May 8th,2017	1 Day	No rust
	May 9th, 2017	2 Days	No rust
	May 11th, 2017	6 Days	No rust
	May 17th, 2017	1 Day	Rust on one concrete anchor from carabiner
	May 18th, 2017	4 Days	Rust on all concrete anchor and carabiners
	May 22nd, 2017	4 Days	Rust on all concrete anchor and carabiners
Pipe	April 27th, 2017	0.5 Hours	No rust
	May 8th,2017	2.0 Hours	No rust
	May 9th, 2017	2.0 Hours	No rust
	May 11th, 2017	2.0 Hours	No rust
	May 17th, 2017	7.0 Hours	No rust
	May 18th, 2017	1.0 Hours	No rust
	May 22nd, 2017	7.0 Hours	No rust

6.5.2. Detailed Results

As seen in the table above, corrosion is a potential issue. By inspection, non-corrosion resistant carabiners showed signs of corrosion almost immediately. An example of the visible corrosion can be seen in Figure 37. This is not meant to be an indicator of exactly what will happen in a system implemented in the ocean, since different materials were used and ocean conditions are more corrosive

Figure 37: Corrosion found on the carabiner and concrete anchor during inspection.

than test conditions. The large-scale system requires corrosion resistance. From observations during project testing, we have determined it is important to use marine-grade materials in the large-scale system.

6.6. Specification Verification Checklist

A summary of the test results can be found in Table 15 below. Note the flow resistance was not tested and is discussed further in the next sub-section.

Table 175: Specification verification summary. Additional test information can be found in the previous sections.

ME428 DVP&R					
Report Date: 05/30/2017			**Sponsor**	Anderson Lin	
Component/Assembly		Bubble Curtain with Anchors	REPORTING ENGINEER: DCS, DL, CY		
TEST REPORT					
Item No	Specification or Clause Reference	Test Result	Quantity Pass	Quantity Fail	NOTES
1	Pipe Angle (from horizontal)	The pipe bubbles when the compressor connection is below the end of the pipe. It preforms best at a slightly positive slope.	20	7	100% pass for upward sloping pipe.
2	Floor Shift	Floor shift did not change pipe angle. Tests were not done at max tide limit, as the geometrically similar conditions would not account for real variables at that limit.	6	0	The full-scale design should not allow the system to reach the maximum tide limit.
3	Bubble Area Coverage of Water Column Above the Bubble Curtain	Pipe behaved as expected. As the water level decreases, the bubble coverage decreased. The Bubble coverage will be higher in deeper water.	11	5	Failure primarily is to do with test geometry.
4	Turbulence	Turbulence caused audible oscillations in pipe, but did not cause component failure or stoppage of bubbles.	3	0	Test turbulence conditions are not dynamically similar to ocean conditions.
5	Corrosion Resistance Time	Carabiners used on anchors rusted during the duration of the test.	All metal components but anchor carabiners (all three) did not visibly rust		Observational test only
6	Able to Resist Flowrate	Did Not Test	NA	NA	No trolling motors

6.7. Incomplete Tests

The trolling motors ordered on the original B.O.M. were mistakenly sent to Cal Poly, but at an address not connected to our team. They were then sent back to the manufacturers in Nebraska. This was an unfortunate learning experience for our team. While the flowrate resistance was not tested, we created a turbulence test, discussed in the design verification section. This tested half of what the trolling motors were supposed to test. Based on drag calculation, we believe the pipe system will function with the expected flowrate, though we were not able to prove or disprove so using the model system.

7. Conclusion

7.1. Recommendations

Now that this experience is almost over we have a few recommendations that we would like to throw out. We truly believe that this buoy self-leveling system concept could be implemented on a large-scale in Diablo Canyon. Based on the positive results from the model system, we can say with confidence that the overall concept works.

7.1.1. Design Geometry

As the model was geometrically similar to a large-scale system, we gained significant insight into model geometry. From the pipe angle test, we think the system could benefit from constantly upward sloping pipes. If the pipes do not at any point slope downward, there will be a constant jet of air distributed across the length of the pipe. To do this, all the wires and cable lengths need to be precise. Pipe angle, buoy-pipe attachment length, and pipe-anchor attachment length must be considered for a full-scale design.

Designing the buoy-pipe attachments to maintain a 2-3% slope across the bay can be done to keep the pipe angle at a positive upward slope. Ocean floor topography and maximizing the buoy-pipe attachment length may present a challenge in maintaining a constant slope. From the model, bubbles exited the pipe evenly with a slope between 0-10°. While the large scale system will not have identical behavior, these findings are consistent with information provided from DCPP.

The buoy-pipe attachment will be most effective when it is longer, since the bubble curtain will cover the water column more completely. It is constrained by the low tide depth and pipe-angle considerations. To prevent the pipe system from resting on the ground (and presenting the same problems as the current system), the attachment should be slightly shorter than the low tide depth. Across the bay, this attachment will also define the pipe angle. As stated previously, the buoy-pipe attachment should be longer at the beginning of the curtain and shorter at the end to maintain a slight upward slope across the bay.

The pipe-anchor attachment functions to prevent the bubble pipe from floating away. Its minimum length must equal the maximum tide difference plus possible ground floor changes. Its length is limited only by allowable location; if it can float 50 ft laterally, then this length could be 50 ft (although this seems excessive). We estimate a length of 15-20 ft. To prevent uneven loading, we recommend making adjacent anchor attachments similar lengths.

7.1.2. Design Components

Assuming the pipe remain same, three major components must be added or altered: buoys, chain/wire attachments, and a counterweight. This concept requires the pipes to sink rather than float. We recommend using ballast or similar materials distributed evenly along the bubble curtain as a counterweight. A buoy-pipe and pipe-anchor attachment (discussed in Design Geometry) must be added as well. They must be rated to the account for the maximum system weight in turbulent water. To keep the pipes level, buoys must be used. These buoys should be selected to withstand the force of the pipes full of water, plus ballast and all other components, under turbulent ocean conditions. The buoy size will depend on the total system weight, the number of pipes supported by the buoy, and the frequency of the spacing.

7.1.3. Material

To prevent corrosion, we recommend the use of marine-grade material such as stainless steel 316. The system should be periodically inspected for corrosion and repaired prior to deployment. Upon removal, the system should be dried and stored in a dry location.

7.1.4. Further Testing

Our concept worked well in our physical model. However, the full scale system presents many additional variables, such as unpredictable turbulence, current, and ocean floor topography. Prior to implementing a complete full scale version of this concept, we recommend further testing for full scale viability with a 15-25 ft section of the intake bay. Salp do not have to be present for testing. General ocean floor topography should be studied before designing a full scale system.

7.1.5. Recommendation Summary

- Study general ocean floor topography
- Keep pipes at a slight upward slope across the bay
- Keep buoy-pipe attachment as long as allowable by the low tide height
- Keep pipe-anchor attachment a minimum of the tide change
- Use a counterweight such as ballast to counteract pipe buoyancy
- Design buoys for non-buoyant pipes
- Test further before full scale system is implemented
- Use marine-grade material and inspect for corrosion

7.2. Lessons Learned

There are a variety of lessons that must be learned in the Engineering profession. Most of these lessons are learned through hands on experiences. Senior project has provided a multitude of experiences and lessons that will help cultivate us as engineers and lead us towards successful career paths.

One thing that we learned was how important prototyping is to have a successful idea/design. We spent so much time coming up with ridiculous ideas on how to solve the problem, but when we were not sure if the idea would work, we would prototype it. The prototyping was not much, but just to have something physical that you can manipulate using your hand provides more insight than staring at equations.

Another lesson we learned was how difficult it is to model something in similitude. We went into this project not very concerned about how we were going to scale the system in Diablo Canyon. After we did the calculations we found out that scaling down a parameter for one part will almost triple another parameter. In the end, we were forced to stick to geometric similitude and force scaling, but we were not able to achieve dynamic similitude due to size and equipment constraints.

Now as this senior project is coming to an end, it is astounding to look back and see how much work was put into this. Some of the logbooks of our team members clock over 200 hours of work on this project. It took three undergraduate students nine months to come up with the idea for the problem, build the model, and analyze the results. Engineering projects require a lot of time and collaboration to produce useful results.

Appendices:

Appendix A : DCPP Air Bubble Curtain Drawings
Appendix B : QFD House of Quality
Appendix C : Final and Preliminary Calculations
Appendix D : DCPP’s Calculations
Appendix E : Gantt Chart
Appendix F : Pugh Matrices
Appendix G : Failure Mode and Effects Analysis
Appendix H : Operators Manual
Appendix I : Layout Drawings
Appendix J : Bill of Materials
Appendix K : Pipe Angle Uncertainty Analysis Example
Appendix L : Pipe Angle Test Data

References

Cal Poly Department of Mechanical Engineering. (2016). *Reference Book and Success Guide.* San Luis Obispo: California Polytechnic State University.

CNRS. (2016). *Plankton Chronicles*. Retrieved from http://planktonchronicles.org/en/episode/salps-exploding-populations/

Crow, K. (2016). *Customer-Focused Development with QFD*. Retrieved from NPD Solutions: http://www.npd-solutions.com/qfd.html

Diablo Canyon Power Plant. (2008). *Current Event Notification Report.* Nuclear Regulatory Commision .

Diablo Canyon Power Plant. (2014). *Air Bubble Curtain NEI TIP Submittle.* Avila Beach: Diablo Canyon Power Plant.

Goodheart, S. (2010, January 27). *Goodheart's Extreme Science*. Retrieved from https://goodheartextremescience.wordpress.com/2010/01/27/meet-the-amazing-salp/

Ksu, A. (2004). *Operating Experience from Swedish Nuclear Power Plants.* Österbergs & Sörmlandstryck AB.

Lisa Dischinger, A. H. (2016). *Robotics UROV Team Use of the Fluids Lab Weir Box.* San Luis Obispo.

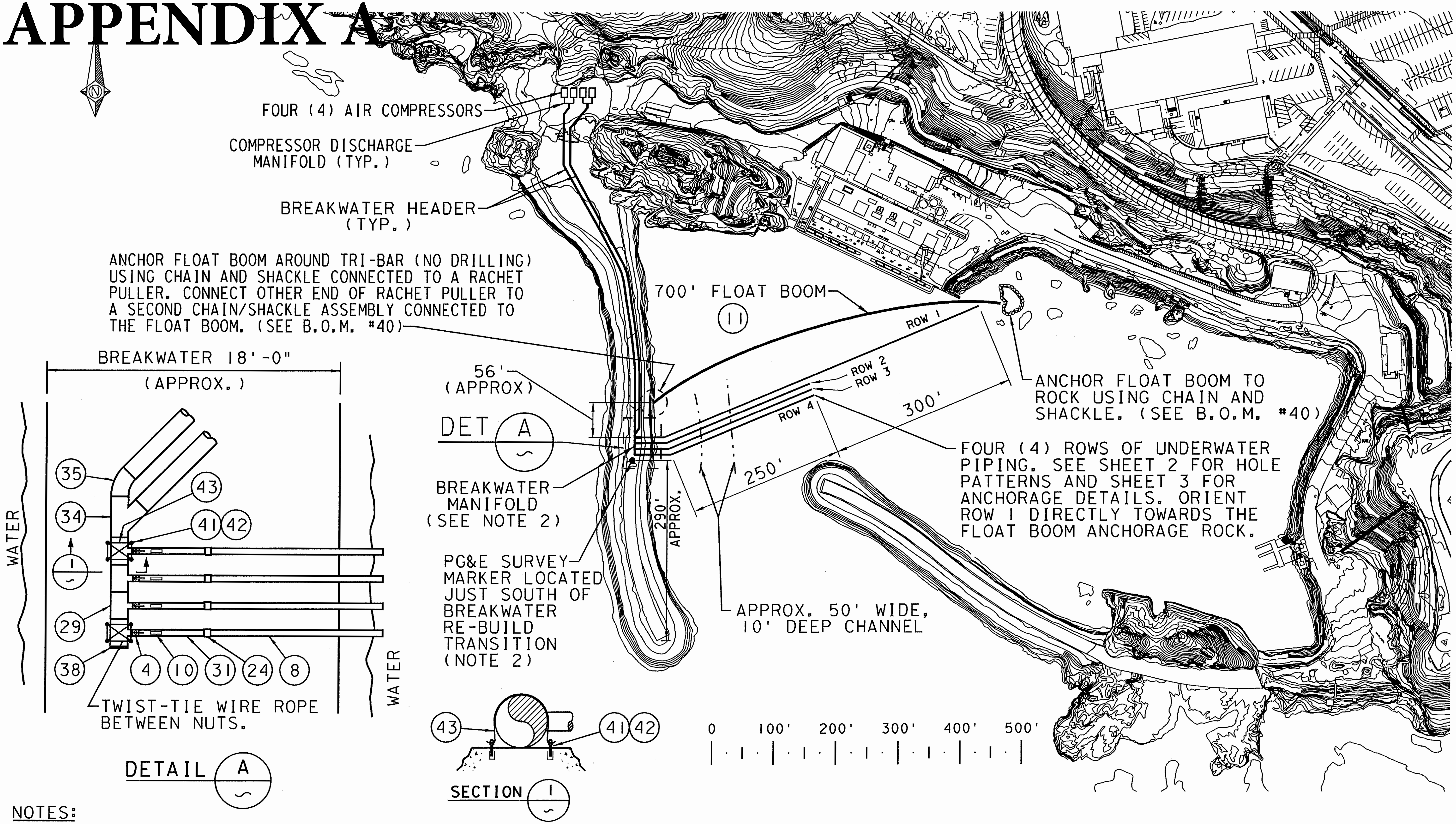
Mayeda, P. (2013). *Economic Benefits of Diablo Canyon Power Plant.* Pacific Gas & Electric Company.

Munson, B. R. (2002). *Fundamentals of Fluid Mechanics.* John Wiley & Sons, Inc.

Stainless Steel for Coastal and Salt Corrosion. (2002). *Designer Handbook*, 4.

Y.H. Kim, M. H. (2015). Numerical Investigation of Dynamic Installation of Torpedo Anchors in Clay. *Ocean Engineering*, 820-832.

APPENDIX A



NOTES:

1. SEE SHEET 4 FOR PIPING AND COMPONENT LAYOUT AND DETAILS.
2. BREAKWATER MANIFOLD SHOULD BE LOCATED ARROXIMATELY 10' INLAND FROM GREEN PG&E SURVEY MARKER.

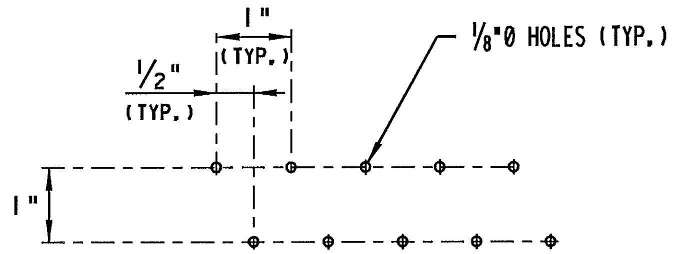
THIS IS A TYPE II SKETCH
NO DWG. CHANGE REQUIRED

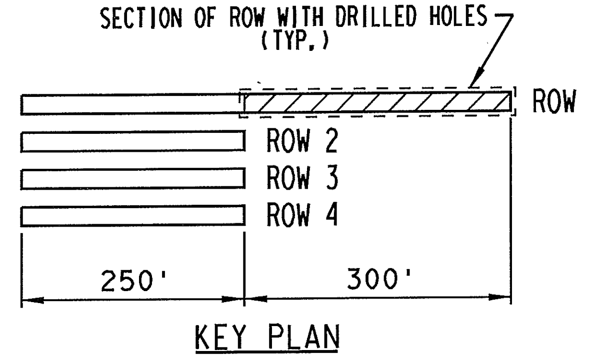
DRAWING No. N/A	SHEET No. N/A	NMOD No. 60055330	PART 000 VER 00
REV. No. N/A	UNIT No. 1&2	SHEET No. 1 of 7	
PREPARED BY: RHS1	DATE: 3/18/13	SKETCH No. DSK-SALP-LAYOUT	
REVIEWED BY: DDCP	DATE: 3/18/13	PART 000 VERSION 00	SHEET No. 1 of 1
VERIFIED BY: MZM2 LXOD	DATE: 3/18/13 3/18/13	SKETCH TYPE II	
		WALKDOWN PERFORMED: YES [X] NO [ ]	

EOC PROJECT: Intake Air Bubble Curtain N-MOD\Output
S:\...\DRAWINGS\DESIGN\RHS1\IntakeAirBubbleCurtainNMOD\SALP-Layout.dgn

ROW 1 HOLE PATTERN

ONE (1) 300 FOOT ROW OF 4" HDPE SDR-11 PIPE WITH TWO (2) ROWS OF 1/8" HOLES ON TOP





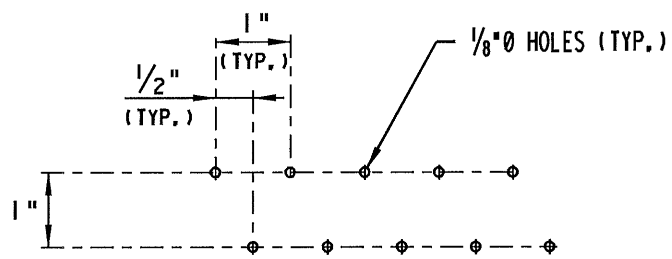
KEY PLAN

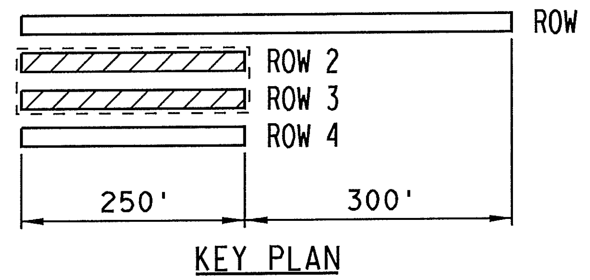
ROW 1 PIPING ORDER (FROM LEFT TO RIGHT):

(1) 10', 4" HDPE SDR-11 PIPE SEGMENT, SOLID
(12) 20', 4" HDPE SDR-11 PIPE SEGMENT, SOLID
(15) 20', 4" HDPE SDR-11 PIPE SEGMENT, W/ROW 1 HOLE PATTERN

ROW 2 AND ROW 3 HOLE PATTERN

TWO (2) 250 FOOT ROWS OF 4" HDPE SDR-11 PIPE WITH TWO (2) ROWS OF 1/8" HOLES ON TOP





KEY PLAN

ROW 2 PIPING ORDER (FROM LEFT TO RIGHT):

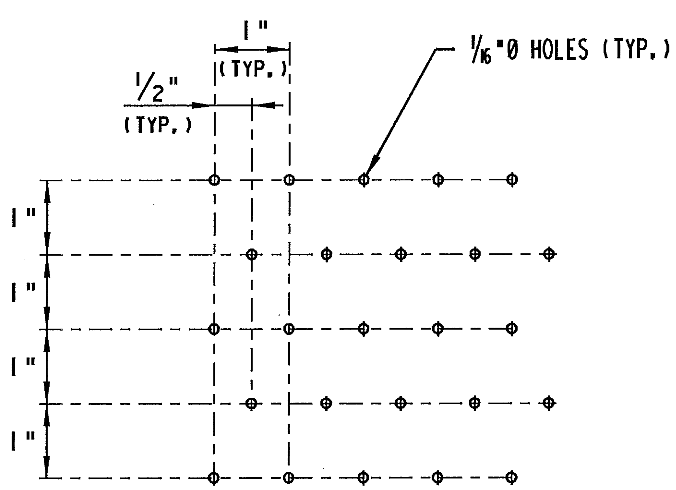
(12) 20', 4" HDPE SDR-11 PIPE SEGMENT, W/ROW 2 AND 3 HOLE PATTERN
(1) 10', 4" HDPE SDR-11 PIPE SEGMENT, W/ROW 2 AND 3 HOLE PATTERN

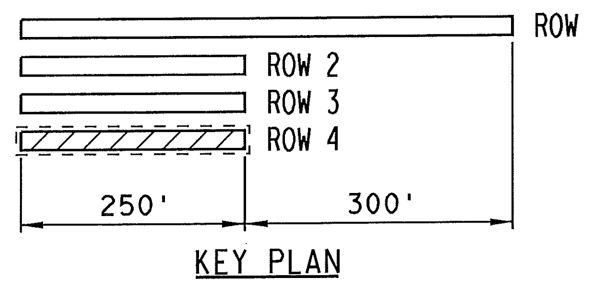
ROW 3 PIPING ORDER (FROM LEFT TO RIGHT):

(1) 10', 4" HDPE SDR-11 PIPE SEGMENT, W/ROW 2 AND 3 HOLE PATTERN
(12) 20', 4" HDPE SDR-11 PIPE SEGMENT, W/ROW 2 AND 3 HOLE PATTERN

ROW 4 HOLE PATTERN

ONE (1) 250 FOOT ROW OF 4" HDPE SDR-11 PIPE WITH FIVE (5) ROWS OF 1/16" HOLES ON TOP





KEY PLAN

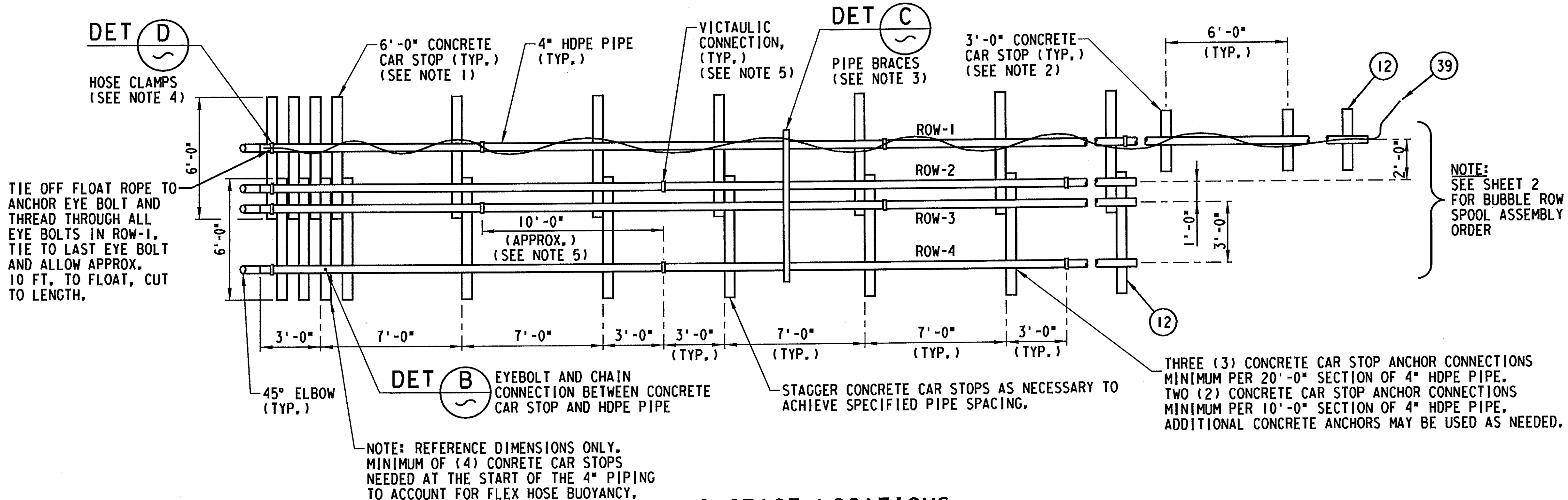
ROW 4 PIPING ORDER (FROM LEFT TO RIGHT):

(12) 20', 4" HDPE SDR-11 PIPE SEGMENT, W/ROW 4 HOLE PATTERN
(1) 10', 4" HDPE SDR-11 PIPE SEGMENT, W/ROW 4 HOLE PATTERN

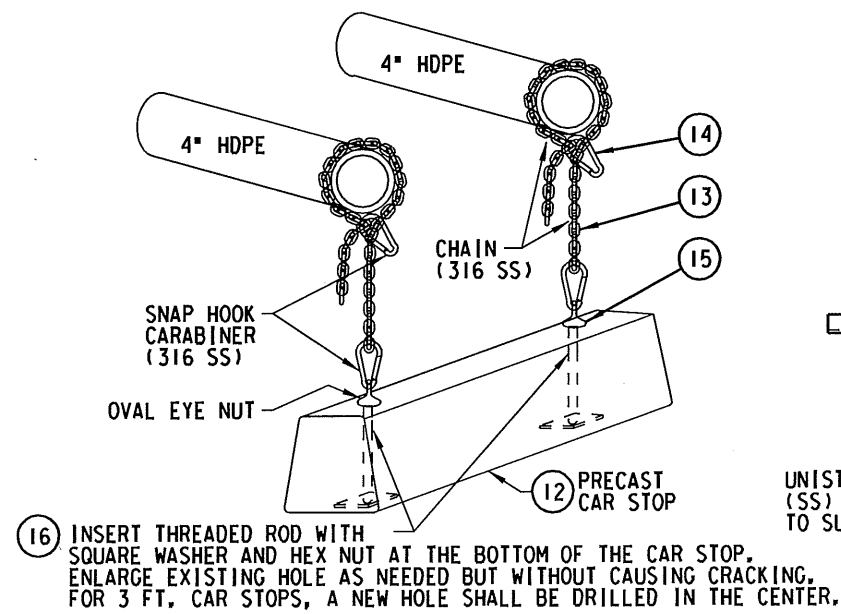
THIS IS A TYPE II SKETCH
NO DWG. CHANGE REQUIRED

DRAWING No. N/A SHEET No. N/A REV. No. N/A UNIT No. 1&2		NMOD No. 60055330 PART 000 VER 00 SHEET No. 2 of 7
PREPARED BY: RHS1	DATE: 3/18/13	SKETCH No. DSK-SALP-BUBBLE PIPE
REVIEWED BY: DOCP [signature]	DATE: 3/18/13	PART 000 VERSION 00 SHEET No. 1 of 1
VERIFIED BY: [signatures]	DATE: 3/18/13 3/18/13	SKETCH TYPE [II] WALKDOWN PERFORMED: YES [X] NO [ ]

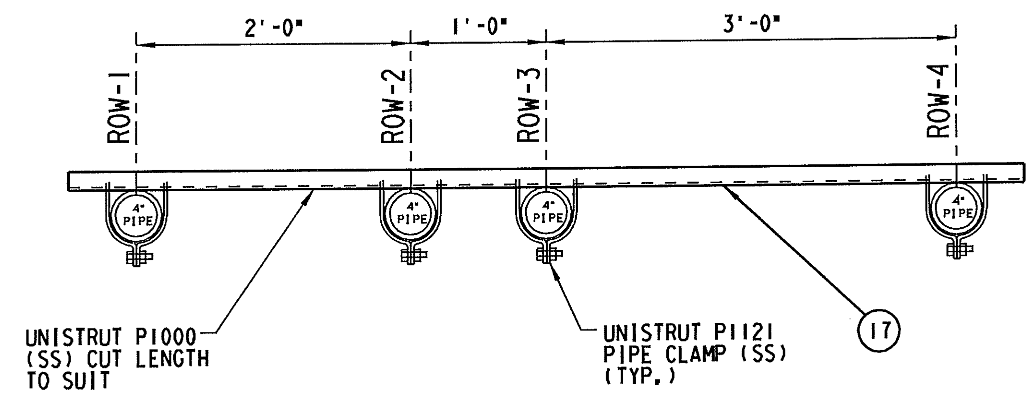
EOC PROJECT: Intake Air Bubble Curtain N-MOD
S:\...\DRAWINGS\DESIGN\RHS1\IntakeAirBubblerCurtainNMOD\SALP-BubblePipe.dgn



ANCHORAGE LOCATIONS

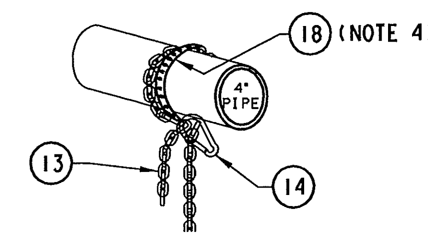


DETAIL B



PIPE LATERAL BRACE

DETAIL C



PIPE LONGITUDINAL RESTRAINT

DETAIL D

NOTES:
1. 6' CAR STOPS SHOULD BE SPACED APPROX. 6' TO 7' APART, AS SHOWN ACROSS THE (4) 250' LENGTHS OF PIPING.
2. 3' CAR STOPS SHOULD BE SPACED APPROX. 6' APART ACROSS THE 300' LENGTH OF PIPING.
3. PIPE BRACES SHOULD BE PLACED AT THE START AND END OF THE 250' UNDERWATER HDPE PIPE RUNS AND PLACED AT A RECOMMENDED DISTANCE OF 25' APART ACROSS THE LENGTH OF THE PIPING.
4. STAINLESS STEEL HOSE CLAMPS SHALL BE UTILIZED AT THE BEGINNING AND THE END OF EACH 4" UNDERWATER HDPE PIPE RUN.
5. VICTAULIC CONNECTIONS SHOULD BE STAGGERED BETWEEN ROWS BY APPROX. 10' APART.
6. PIPE RESTRAINT LOCATIONS SHOULD BE MARKED WITH NON-TOXIC LIGHT COLORED PAINT OR OTHER ENVIRONMENTALLY ACCEPTABLE METHOD TO ASSIST DIVERS IN LOCATING ANCHOR POINTS. IF PAINT IS USED IT SHALL BE 100% CURED BEFORE SUBMERSSION.

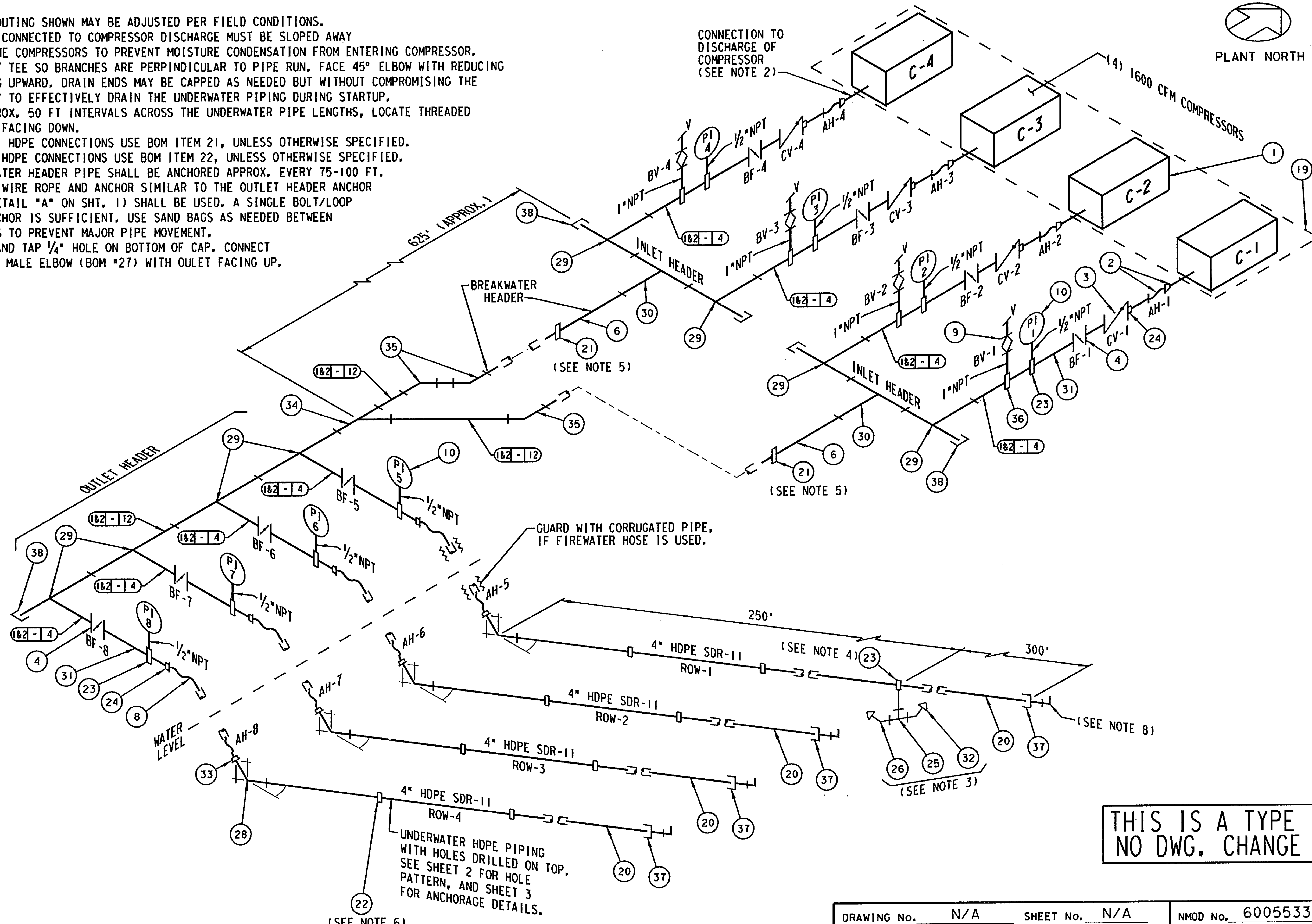
THIS IS A TYPE II SKETCH
NO DWG. CHANGE REQUIRED

DRAWING No. N/A	SHEET No. N/A	NMOD No. 60055330 PART 000 VER 00	
REV. No. N/A	UNIT No. 1&2	SHEET No. 3 of 7	
PREPARED BY: RHSI	DATE: 3/18/13	SKETCH No. DSK-SALP-ANCHORAGE	
REVIEWED BY: DDCP [signature]	DATE: 3/18/13	PART 000 VERSION 00 SHEET No. 1 of 1	
VERIFIED BY: [signatures]	DATE: 3/18/13 3/18/13 LXOD	SKETCH TYPE II	WALKDOWN PERFORMED: YES [X] NO [ ]

EOC PROJECT: Intake Air Bubble Curtain N-MOD
S:\...\DRAWINGS\DESIGN\RHSI\IntakeAirBubblerCurtainNMOD\SALP-Anchorage.dgn

NOTES:

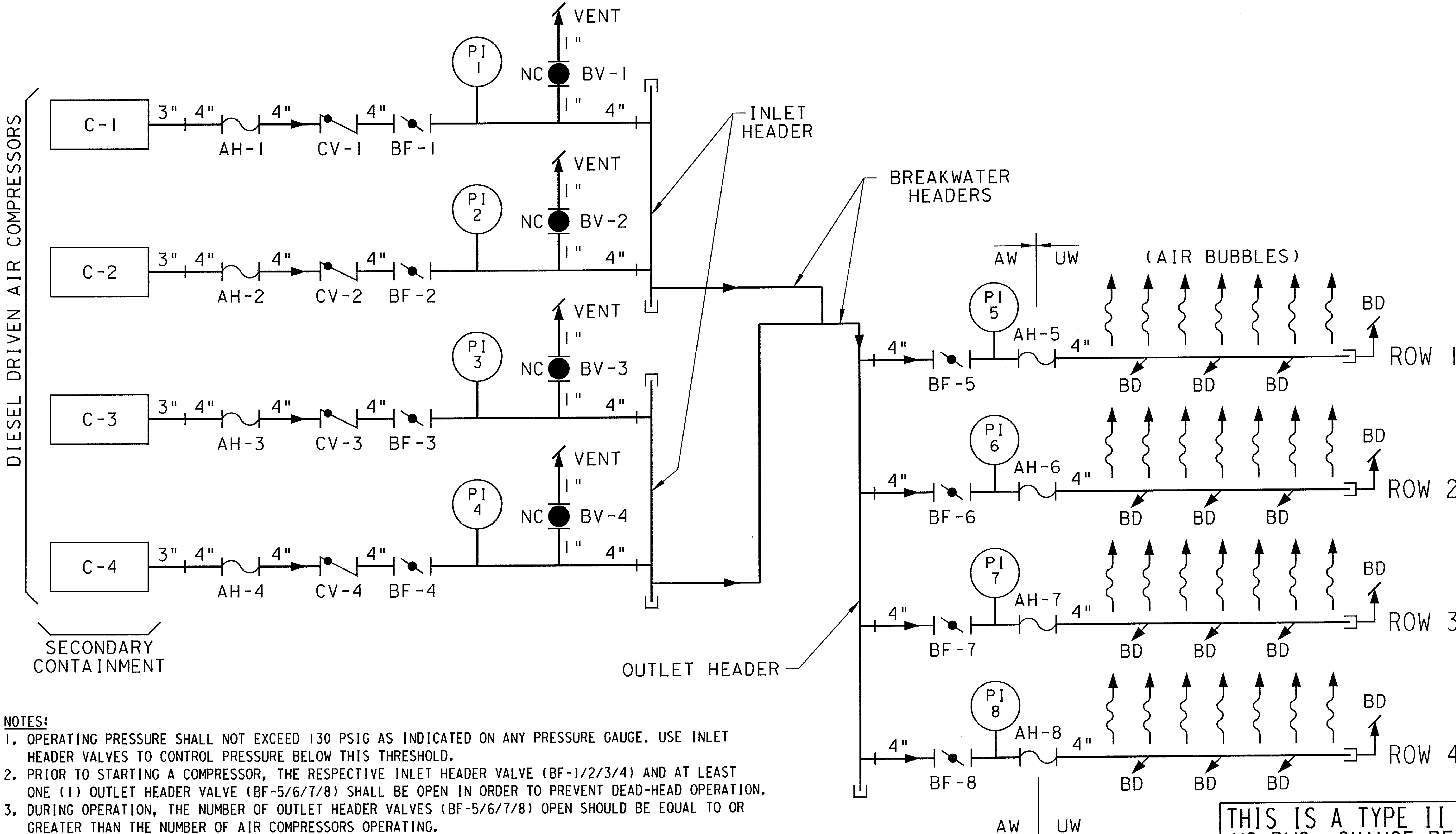
1. PIPE ROUTING SHOWN MAY BE ADJUSTED PER FIELD CONDITIONS.
2. PIPING CONNECTED TO COMPRESSOR DISCHARGE MUST BE SLOPED AWAY FROM THE COMPRESSORS TO PREVENT MOISTURE CONDENSATION FROM ENTERING COMPRESSOR.
3. CONNECT TEE SO BRANCHES ARE PERPINDICULAR TO PIPE RUN. FACE 45° ELBOW WITH REDUCING BUSHING UPWARD. DRAIN ENDS MAY BE CAPPED AS NEEDED BUT WITHOUT COMPROMISING THE ABILITY TO EFFECTIVELY DRAIN THE UNDERWATER PIPING DURING STARTUP.
4. AT APPROX. 50 FT INTERVALS ACROSS THE UNDERWATER PIPE LENGTHS, LOCATE THREADED OUTLET FACING DOWN.
5. ALL 12" HDPE CONNECTIONS USE BOM ITEM 21, UNLESS OTHERWISE SPECIFIED.
6. ALL 4" HDPE CONNECTIONS USE BOM ITEM 22, UNLESS OTHERWISE SPECIFIED.
7. BREAKWATER HEADER PIPE SHALL BE ANCHORED APPROX. EVERY 75-100 FT. USE OF WIRE ROPE AND ANCHOR SIMILAR TO THE OUTLET HEADER ANCHOR (SEE DETAIL "A" ON SHT. 1) SHALL BE USED. A SINGLE BOLT/LOOP PER ANCHOR IS SUFFICIENT. USE SAND BAGS AS NEEDED BETWEEN ANCHORS TO PREVENT MAJOR PIPE MOVEMENT.
8. DRILL AND TAP 1/4" HOLE ON BOTTOM OF CAP. CONNECT 1/4" NPT MALE ELBOW (BOM #27) WITH OULET FACING UP.



THIS IS A TYPE II SKETCH
NO DWG. CHANGE REQUIRED

DRAWING No. N/A	SHEET No. N/A	NMOD No. 60055330 PART 000 VER 00
REV. No. N/A	UNIT No. 1&2	SHEET No. 4 of 7
PREPARED BY: RHSI	DATE: 3/18/13	SKETCH No. DSK-SALP-ISO
REVIEWED BY: DDCP [signature]	DATE: 3/18/13	PART 000 VERSION 00 SHEET No. 1 of 1
VERIFIED BY: [signature]	DATE: 3/18/13 3/18/13 LX	SKETCH TYPE II
		WALKDOWN PERFORMED: YES [X] NO [ ]

EOC PROJECT: Intake Air Bubble Curtain N-MOD
S:\...\DRAWINGS\DESIGN\RHS1\IntakeAirBubblerCurtainNMOD\SALP-ISO.dgn



NOTES:

1. OPERATING PRESSURE SHALL NOT EXCEED 130 PSIG AS INDICATED ON ANY PRESSURE GAUGE. USE INLET HEADER VALVES TO CONTROL PRESSURE BELOW THIS THRESHOLD.
2. PRIOR TO STARTING A COMPRESSOR, THE RESPECTIVE INLET HEADER VALVE (BF-1/2/3/4) AND AT LEAST ONE (1) OUTLET HEADER VALVE (BF-5/6/7/8) SHALL BE OPEN IN ORDER TO PREVENT DEAD-HEAD OPERATION.
3. DURING OPERATION, THE NUMBER OF OUTLET HEADER VALVES (BF-5/6/7/8) OPEN SHOULD BE EQUAL TO OR GREATER THAN THE NUMBER OF AIR COMPRESSORS OPERATING.
4. INLET HEADER VALVES (BF-1/2/3/4) SHOULD BE CLOSED WHEN THE ASSOCIATED AIR COMPRESSOR IS OFF.
5. USE VENT VALVES (BV-1/2/3/4) TO BLEED PRESSURE FROM THE SYSTEM PRIOR TO DISCONNECTING ANY PIPING OR REMOVING THE UNDERWATER PIPING.
6. AT INITIAL STARTUP, IT IS RECOMMENDED TO START ONE (1) AIR COMPRESSOR AT A TIME UNTIL STEADY STATE IS REACHED.

THIS IS A TYPE II SKETCH
NO DWG. CHANGE REQUIRED

INTAKE AIR BUBBLE CURTAIN

DRAWING No. N/A	SHEET No. N/A	NMOD No. 60055330	PART 000 VER 00
REV. No. N/A	UNIT No. 1&2	SHEET No. 5 of 7	
PREPARED BY: RHSI	DATE: 3/18/13	SKETCH No. DSK-SALP-P&ID	
REVIEWED BY: [signature]	DATE: 3/18/13	PART 000 VERSION 00	SHEET No. 1 of 1
VERIFIED BY: [signatures]	DATE: 3/18/13 3/18/13	SKETCH TYPE II	
		WALKDOWN PERFORMED: YES [X] NO [ ]	

EOC PROJECT: Intake Air Bubble Curtain N-MOD
S:\...\DRAWINGS\DESIGN\RHSI\IntakeAirBubblerCurtainNMOD\SALP-P&ID.dgn

SALP BUBBLE CURTAIN - BILL OF MATERIAL (PG 1 OF 2)

ITEM #	TYPE	P&ID TAG	PART DESCRIPTION	RECOMMENDED PRODUCT - OR EQUAL	QUANTITY
1	COMPRESSOR	C-1, C-2, C-3, C-4	1600 CFM PORTABLE DIESEL-DRIVEN AIR COMPRESSOR, 150 PSIG MAX OUTLET OPERATING PRESSURE WITH INTEGRAL RELIEF VALVE SET NO HIGHER THAN 175 PSIG, INTEGRAL AFTER-COOLER WITH OUTLET TEMPERATURE OF APPROXIMATELY 20F DEGREES OVER AMBIENT, OIL-FREE TYPE OR PRODUCING INSTRUMENT QUALITY AIR, PERMITTED FOR AIR EMISSIONS BY THE CARB REGISTRATION PROGRAM.	DOOSAN HP1600	4
2	AIR HOSE ASSEMBLY	AH-1, AH-2, AH-3, AH-4	RECOMMENDED: 4-INCH, RUBBER HOSE WITH REINFORCED WITH STEEL WIRE, ONE END 3-INCH MNPT TO CONNECT TO AIR COMPRESSOR 3-INCH FNPT, AND ONE END 4-INCH MNPT TO CONNECT TO 4-INCH FNPT TRANSITION PIECE AT PIPING/VALVE. HOSE AND FITTINGS SHALL BE RATED FOR AT LEAST 150 PSIG AT 100F FOR COMPRESSED AIR SERVICE IN A CORROSIVE ENVIRONMENT. ** *ALTERNATE: 3-INCH AIR HOSE FROM AIR COMPRESSOR RENTAL COMPANY IS AN ACCEPTABLE ALTERNATIVE FOR THE INITIAL INSTALLATION, ONE END 3-INCH MNPT TO CONNECT TO 3-INCH FNPT AT AIR COMPRESSOR, AND ONE END 3-INCH FNPT TO CONNECT TO 3X4 MNPT X GROOVED TRANSITION REDUCER (VICTAULIC NO. 54) AT PIPING/VALVE. USE 3-INCH FEMALE COUPLING (MCMASTER #4452K136) IF RENTAL HOSE COMES WITH BOTH ENDS MALE.*	RECOMMENDED: AR61-400 HEAVY DUTY (HOSE) WITH FITTINGS, BY FLEXTRAL ********************** *ALTERNATE: AIR HOSE (RENTED W/ COMPRESSOR), FEMALE COUPLING (MCMASTER #4452K136), AND 3X4 TRANSITION REDUCER (VICTAULIC NO.54)*	RECOMMENDED: (4) X 10 FT HOSE ASSEMBLIES ***************** *ALTERNATE: (4) X 10FT HOSES (4) COUPLINGS (4) VIC. NO. 54*
3	CHECK VALVE	CV-1, CV-2, CV-3, CV-4	4-INCH SWING OR DISC TYPE CHECK VALVE, 200 PSIG AT 100F MIN RATING.	VIC CHECK VALVE 716	4
4	BUTTERFLY VALVE	BF-1, BF-2, BF-3, BF-4, BF-5, BF-6, BF-7, BF-8	4-INCH, BUTTERFLY VALVE, WITH HANDLE, THROTTLE CAPABLE, 200 PSIG AT 100F MIN RATING.	VIC-300 MASTERSEAL BUTTERFLY VALVE WITH 10-POSITION HANDLE	8
5	NOT USED				
6	PIPE	BREAKWATER HEADER	12-INCH HDPE TYPE PE4710 (PE3408), SDR 11, 200 PSI RATING. RECOMMEND USE 12-INCH STAINLESS STEEL POLYCAM SERIES 701 TRANSITIONS FOR SDR 11 HDPE. SPOOL LENGTHS ARE END-END INCLUDING THE LENGTH OF THE POLYCAM FITTING.	PER VICTAULIC HDPE SUPPLIER WITH POLYCAM 701 TRANSITION FITTINGS	(68) X 20FT SPOOLS W/ (2) FTGS/SPOOL
7	NOT USED				
8	AIR HOSE ASSEMBLY	AH-5, AH-6, AH-7, AH-8	RECOMMENDED: 4-INCH, RUBBER HOSE WITH REINFORCED WITH STEEL WIRE, ONE END 4-INCH MNPT, ONE END 4-INCH FNPT. HOSE AND FITTINGS SHALL BE RATED FOR AT LEAST 150 PSIG AT 100F FOR COMPRESSED AIR SERVICE IN A CORROSIVE ENVIRONMENT. ** *ALTERNATE: 4-INCH FEMALE-THREADED FIREWATER HOSES RATED AT LEAST 200 PSI IS AN ACCEPTABLE ALTERNATIVE FOR THE INITIAL INSTALLATION. IF FIREWATER HOSE IS USED, IT SHALL BE GUARDED WITH 6-INCH (MIN) PLASTIC OR GALVANIZED STEEL CORRUGATED PIPE TO PROTECT FROM EXTERNAL DAMAGE.*	RECOMMENDED: AR61-400 HEAVY DUTY (HOSE) WITH FITTINGS, BY FLEXTRAL ********************** *ALTERNATE: FIREWATER HOSE*	RECOMMENDED: (4) X 150 FT HOSE ASSEMBLIES ************ *ALTERNATE: (4) X 150 FT FIREWATER HOSES*
9	VENT VALVE	BV-1, BV-2, BV-3, BV-4	1-INCH BALL VALVE, THREADED, BRASS OR STAINLESS STEEL, FOR ON/OFF SERVICE.	VIC-BALL VALVE SERIES 722	4
10	PRESSURE INSTRUMENT	PI-1, PI-2, PI-3, PI-4, PI-5, PI-6, PI-7, PI-8	PRESSURE INDICATING GAUGE, 0 TO 300 PSIG RANGE WITH 10 PSIG (MAX) MARKS, 1/2" NPT MALE, WEATHER-PROOF, CORROSION RESISTANT MATERIALS	MCMASTER-CARR #4065K7	8
11	FLOAT BOOM	-	FLOATING PLASTIC BOOM	AS AVAILABLE	~700 FT
12	ANCHOR	-	REINFORCED CONCRETE CAR STOPS, MIN WEIGHT OF 150 LBS	AS AVAILABLE	(90 MIN) X 6 FT (55 MIN) X 3 FT
13	CHAIN	-	3/16-INCH STAINLESS STEEL CHAIN, MIN WORKING LOAD = 200LB AND COMPATIBLE WITH CARABINER DIMENSIONS FOR CLEARANCE FIT.	MCMASTER-CARR #3392T51	~900 FT
14	CARABINER	-	1/4-INCH DIAMETER CARABINER CONNECTOR, STAINLESS STEEL, 200 LB (MIN) WORKING LOAD	MCMASTER-CARR #33975T51	470
15	EYE-NUT	-	5/16"-18 OVAL EYE NUT, STAINLESS STEEL, 200 LB (MIN) WORKING LOAD	MCMASTER-CARR #3061T15	235
16	CAR STOP ANCHOR ASSEMBLY	-	EACH ASSEMBLY: ONE (1) 5/16"-18 X 8" LONG (MIN) THREADED ROD, STAINLESS STEEL ONE (1) 1"X1"X5/16" SQUARE WASHER, STAINLESS STEEL ONE (1) 5/16"-18 HEX NUT, STAINLESS STEEL	AS AVAILABLE	235 ASSEMBLIES
17	PIPE BRACE ASSEMBLY	-	ONE (1) ASSEMBLY CONSISTS OF: ONE (1) UNISTRUT P1000, APPROX. 10 FT LONG, STAINLESS STEEL, AND FOUR (4) UNISTRUT P1121 PIPE CLAMPS FOR 4-INCH PIPE, STAINLESS STEEL.	AS AVAILABLE	11 ASSEMBLIES
18	HOSE CLAMP	-	3-1/8"-6" WORM-DRIVE HOSE CLAMP, STAINLESS STEEL WITH STAINLESS STEEL SCREW	MCMASTER-CARR #5011T36	8
19	PLASTIC WRAP	-	SECONDARY CONTAINMENT WRAP TO PREVENT GROUND SEEPAGE AROUND COMPRESSOR STAGING AREA.	AS AVAILABLE	~ 90FT X 10FT
20	PIPE	BUBBLER ROWS 1, 2, 3, 4	4-INCH HDPE TYPE PE4710 (PE3408), SDR 11, 200 PSI RATING. USE 4-INCH STAINLESS STEEL POLYCAM SERIES 701 TRANSITIONS FOR SDR 11 HDPE. SPOOL LENGTHS ARE END-END INCLUDING THE LENGTH OF THE POLYCAM FITTING. BELOW IS A BREAKDOWN OF BUBBLE ROW SPOOLS, THE REMAINDER IN THE BOM QTY ARE SPARES (NO HOLES). ROW 1: 1X10FT (NO HOLES), 12X20FT (NO HOLES), 15X20FT (WITH HOLE PATTERN) ROW 2: 12X20FT (WITH HOLE PATTERN), 1X10FT (WITH HOLE PATTERN) ROW 3: 1X10FT (WITH HOLE PATTERN), 12X20FT (WITH HOLE PATTERN) ROW 4: 12X20FT (WITH HOLE PATTERN), 1X10FT (WITH HOLE PATTERN)	PER VICTAULIC HDPE SUPPLIER WITH POLYCAM 701 TRANSITION FITTINGS	(65) X 20FT SPOOLS (6) X 10 FT SPOOLS, EACH W/ (2) FTGS/SPOOL
21	COUPLING	-	12-INCH GROOVED FLEXIBLE COUPLING, PAINTED DUCTILE IRON HOUSING WITH STAINLESS STEEL BOLTS. IF EXCESSIVE CORROSION IS OBSERVED, VICTAULIC MAY RE-COAT THE EXISTING HOUSING WITH CORROSION-RESISTANT EPOXY, AS DETERMINED NECESSARY BY DCPP.	VICTAULIC STYLE 77	68 (HEADER) 20 (FITTINGS)
22	COUPLING	-	4-INCH GROOVED FLEXIBLE COUPLING, ALL STAINLESS STEEL INCLUDING BOLTS	VICTAULIC STYLE 489	72 (ROWS) 40 (FITTINGS)

THIS IS A TYPE II SKETCH
NO DWG. CHANGE REQUIRED

DRAWING No. N/A SHEET No. N/A
REV. No. N/A UNIT No. 1&2
PREPARED BY: RHS1 DATE: 3/18/13
REVIEWED BY: DDG [signature] DATE: 3/18/13
VERIFIED BY: MZM2 [signature] DATE: 3/18/13 3/18/13 LXOD

NMOD No. 60055330 PART 000 VER 00
SHEET No. 6 of 7
SKETCH No. DSK-SALP-BOM
PART 000 VERSION 00 SHEET No. 1 of 2
SKETCH TYPE II
WALKDOWN PERFORMED: YES [X] NO [ ]

EOC PROJECT: Intake Air Bubble Curtain N-MOD
S:\...\DRAWINGS\DESIGN\RHS1\IntakeAirBubblerCurtainNMOD\SALP-BOM.dgn

SALP BUBBLE CURTAIN - BILL OF MATERIAL (PG 2 OF 2)

ITEM #	TYPE	P&ID TAG	PART DESCRIPTION	RECOMMENDED PRODUCT - OR EQUAL	QUANTITY
23	BRANCH OUTLET	-	4"X1/2" MECHANICAL TEE-BRANCH OUTLET WITH THREADED OUTLET	VICTAULIC STYLE 920N	8 (PI'S) 24 (DRAINS)
24	THREADED ADAPTER	-	4-INCH FEMALE THREADED ADAPTER	VICTAULIC NO.80	12
25	SMALL TEE	-	1/2-INCH MALE NPT TEE, STAINLESS STEEL OR BRASS	MCMASTER-CARR #48805K129	24
26	SMALL ELBOW	-	1/2-INCH FEMALE-FEMALE NPT 45-DEG ELBOW, STAINLESS STEEL OR BRASS	MCMASTER-CARR #4452K424	48
27	SMALL ELBOW	-	1/4-INCH MALE NPT 90 DEG, STAINLESS STEEL OR BRASS	SWAGELOK # SS-4-ME	4
28	ELBOW	-	4-INCH 45 DEG GROOVED ELBOW	VICTAULIC NO.11	4
29	REDUCING TEE	-	12"X4" REDUCING TEE, GROOVED BRANCH	VICTAULIC NO.25	8
30	TEE	-	12" TEE, GROOVED	VICTAULIC NO.20	2
31	PIPE	PI/BV SPOOLS	4-INCH HDPE TYPE PE4710 (PE3408), SDR 11, 200 PSI RATING. USE 4-INCH STAINLESS STEEL POLYCAM SERIES 701 TRANSITIONS FOR SDR 11 HDPE. EACH SPOOL TO BE 4 FT LONG (END-END) INCLUDING THE LENGTH OF THE POLYCAM FITTING.	PER VICTAULIC HDPE SUPPLIER WITH POLYCAM 701 TRANSITION FITTINGS	(10) X 4FT SPOOLS
32	REDUCING BUSHING	-	1/2"X1/4" MALE-FEMALE REDUCING BUSHING	MCMASTER-CARR #4452K165	50
33	ADAPTER NIPPLE	-	4-INCH GROOVED TO THREADED ADAPTER NIPPLE	VICTAULIC NO.40	12
34	TEE	-	12-INCH TEE, 45 DEG LATERAL	VICTAULIC NO.30	1
35	ELBOW	-	12-INCH GROOVED 45 DEG ELBOW	VICTAULIC NO.11	10
36	BRANCH OUTLET	-	4"X1" MECHANICAL TEE-BRANCH OUTLET WITH THREADED OUTLET	VICTAULIC NO.920N	4
37	CAP	-	4-INCH CAP	VICTAULIC NO.60	4
38	CAP		12-INCH CAP	VICTAULIC NO.60	5
39	FLOAT ROPE	-	LIGHT-COLORED, ROT-RESISTANT, FLOATING ROPE	MCMASTER-CARR #3873T23	600 FT
40	FLOAT BOOM ANCHOR ASSEMBLY	-	7/32" CORROSION-RESISTANT STEEL CHAIN, OR ALTERNATE SIZE WITH MIN LOAD = 2000LB 3/8" SS HIGH-STRENGTH ANCHOR SHACKLE, OR ALTERNATE WITH MIN LOAD = 2000LB CABLE-TYPE RATCHET PULLER	CHAIN: MCMASTER-CARR #3410T95 SHACKLE: MCMASTER-CARR #8494T28 RATCHET: GRAINGER 3AY61	CHAIN: ~175 FT SHACKLE: 3 RATCHET: 1
41	THREADED ROD	-	1/2-INCH THREADED ROD, STAINLESS STEEL	AS AVAILABLE	(20) X 4-INCH
42	INSERT	-	1/2-INCH, STAINLESS STEEL, DROP-IN ANCHORS	HILTI # 336432	20
43	WIRE ROPE	-	3/16-INCH WIRE ROPE, STAINLESS STEEL, MIN WORKING LOAD 2600 LB	MCMASTER-CARR #8909T22	75 FT

IMPORTANT NOTES:

1) THIS BOM REPRESENTS THE PARTS NEEDED TO CONSTRUCT THE SALP BUBBLE CURTAIN SYSTEM ACCORDING TO THE SKETCHES. USE OF ALTERNATE PARTS/MATERIALS IS ACCEPTABLE IF THE ALTERNATE IS NOT IN CONFLICT WITH THE ENGINEERING EVALUATION AND ANY "SHALL" STATEMENTS IN BOM OR
2) HDPE PIPE MAY BE JOINED BY A HEAT/BUTT FUSION METHOD OR BY USE OF POLY-CAM SERIES 701 TRANSITION FITTINGS WITH VICTAULIC GROOVED-COUPLINGS .
3) ALL HPDE FITTINGS SHALL BE RATED FOR THE FULL PRESSURE RATING OF THE CONNECTING PIPE.
4) WHERE UNSPECIFIED, ALL MATERIALS SHALL BE CORROSION RESISTANT; SUCH AS STAINLESS STEEL, BRASS/BRONZE, GALVANIZED CARBON STEEL, OR PAINTED DUCTILE IRON. IT IS NOT RECOMMENDED TO JOIN GALVANIZED STEEL AND STAINLESS STEEL DUE TO GALVANIC CORROSION OF DISSIMILAR
5) VICTAULIC STANDARD GASKET MATERIAL GRADE E SHOULD BE USED.

MATERIALS REQUIRED TO ASSIST IN UNDERWATER INSTALLATION:

1) (3) X 500 FT SPOOLS OF 3/8-INCH LIGHT-COLOR POLY DACRON ROPE FOR ANCHORS
2) (1) X 500 FT SPOOL OF 3/8-INCH WHITE ROPE FOR FLOATS
3) (6) X DANFORTH STYLE ANCHORS, 20 LB EACH (MINIMUM), STAINLESS STEEL
4) 150 FT OF 5/16-INCH CHAIN, STAINLESS STEEL
5) (24) X 5/16-INCH SHACKLES, STAINLESS STEEL
6) (25) X FOAM CRAB POT TYPE FLOATS
7) (10) RELEASE HANDLE LIFT BAGS, 250 LB LIFT CAPACITY EACH
8) (40) INNER TUBES, APPROX. TIRE SIZE

THIS IS A TYPE II SKETCH
NO DWG. CHANGE REQUIRED

DRAWING No. N/A	SHEET No. N/A	NMOD No. 60055330	PART 000 VER 00
REV. No. N/A	UNIT No. 1&2	SHEET No. 7 of 7	
PREPARED BY: RHSI	DATE: 3/18/13	SKETCH No. DSK-SALP-BOM	
REVIEWED BY: [signature]	DATE: 3/18/13	PART 000 VERSION 00 SHEET No. 2 of 2	
VERIFIED BY: [signatures]	DATE: 3/18/13 3/18/13	SKETCH TYPE II	
		WALKDOWN PERFORMED: YES [X] NO [ ]	

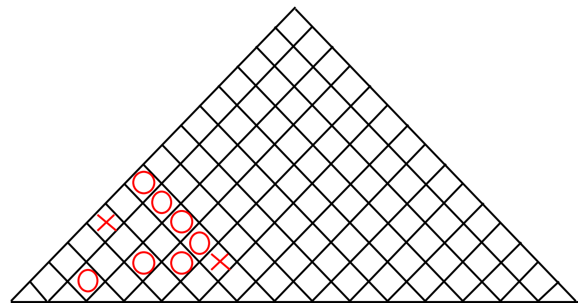
EOC PROJECT: Intake Air Bubble Curtain N-MOD
S:\...\DRAWINGS\DESIGN\RHS1\IntakeAirBubblerCurtainNMOD\SALP-BOM.dgn

APPENDIX B: QFD HOUSE OF QUAILITY

▲ Larger is Better
● Nominal is Best
▼ Smaller is Better

× ○ ○ ◎ □
⋇ ◎ △ ▽ ◇

Customer Description:
1 = DIablo Canyon Power Plant
2 = Advising Team
3 = Installers/Matintainance Team
4 = Coastal Commision



○ - Positive Correlation
× - Negative Correlation

Specifications (Hows): A = Position, B = Pipe Angle, C = Bubble Coverage, D = Corrosion Resistance Time, E = Part Weight, F = Material Toxicity, G = Flowrate Durability

Customer Description	Customer Requirements (Whats)	Importance	A Position	B Pipe Angle	C Bubble Coverage	D Corrosion Resistance Time	E Part Weight	F Material Toxicity	G Flowrate Durability	H	I	J	K	L	M	N	O	△	○	□	X
	Functional as an anchor		◎		○		△											5	5	5	2
	Self-Leveling			◎														5	1	1	1
	Effectively deters salp		○	○	◎													4	3	3	3
	Can withstand salt water					◎		○										4	4	4	4
	Able to be uninstalled		△				◎											3	3	2	2
	Non-toxic					○		◎										5	5	5	5
	Does not fall apart in expected conditions					◎		△	◎									5	5	4	1

Customer Ratings: △ Team Bubbles Vision Product; ○ DCPP Current Product; □ Cinderblocks; **X** Ringhals

Strong - ◎
Medium ○
Weak - △
Relationship Strength

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
X	3	2	5	5	5	5	1								
□	3	1	4	4	5	5	3								
○	5	2	4	4	5	5	5								
△	5	5	5	5	5	5	5								

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Targets	± 3 Feet	± 20°	Min. %80	30 days	Max 300 lbs	Zero	Ocean + Intake Flowrates								
Weighted Importance	215	166	187	271	167	154	134								
% Importance	17%	13%	14%	21%	13%	12%	10%								

Appendix C:

Contents

Final Design Analysis: Model Size

- Similitude Analysis
- Buoy Selection
- Cable Selection
- Compressor Selection

Preliminary Analysis: Actual Size

- Deflection Analysis
- Drag Analysis
- Buoyancy Analysis

X-DIRECTION:

$f_D = f(U, D, \mu, \rho, \varepsilon, l)$

f_D = force Drag per unit length of pipe
U = velocity of flow in x-direction
D = Diameter of Pipe
μ = viscosity
ρ = density
ε = surface roughness
l = length of pipe

BUCKINGHAM PI:

7 Parameters

3 repeating parameters

7 - 3 = 4

4 PI GROUPS

π_4 : $U^A D^B \rho^C \varepsilon^1$

$$\left[\frac{L}{T}\right]^A \left[L\right]^B \left[\frac{M}{L^3}\right]^C \left[L\right]^1$$

C = 0, A = 0, B = -1

$\pi_4 = \frac{\varepsilon}{D}$ GEOMETRICALLY SIMILAR

π_3 : $U^A D^B \rho^C l^1$

$$\left[\frac{L}{T}\right]^A \left[L\right]^B \left[\frac{M}{L^3}\right]^C \left[L\right]^1$$

C = 0, A = 0, B = -1

$\pi_3 = \frac{L}{D}$ GEOMETRICALLY SIMILAR

π_2 : $U^A D^B \rho^C \mu^{-1}$

$$\left[\frac{L}{T}\right]^A \left[L\right]^B \left[\frac{M}{L^3}\right]^C \left[\frac{M}{LT}\right]^{-1}$$

A = 1, B = 1, C = 1

$\pi_2 = \frac{\rho U D}{\mu}$ REYNOLD'S NUMBER DYNAMICALLY SIMILAR

X-DIRECTION (CONT'D):

$\pi_1: U^A D^B \rho^C \mathcal{F}_D^1$

$$\left[\frac{L}{T}\right]^A [L]^B \left[\frac{M}{L^3}\right]^C \left[\frac{M}{T^2}\right]^1$$

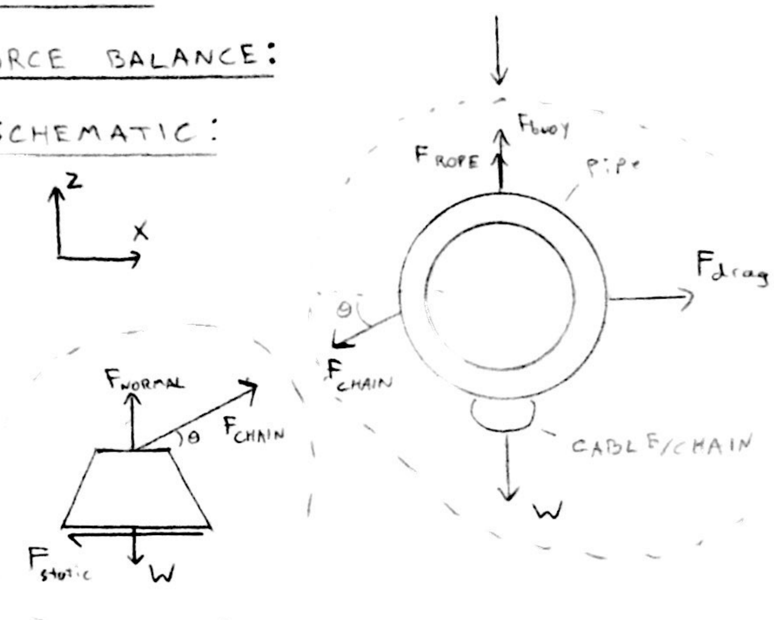
A = -2 B = -1 C = -1

$$\pi_1 = \frac{\mathcal{F}_D}{U^2 D \rho}$$ DYNAMICALLY SIMILAR

Z-DIRECTION:

FORCE BALANCE:

SCHEMATIC:



FOR PIPE:

$\sum F_x = ma$ (static)

$\sum F_x = 0$

$-F_{CHAIN} \cos\theta + F_{drag} = 0$

$$F_{drag} = F_{CHAIN} \cos\theta$$

$\sum F_z = ma$ (static)

$\sum F_x = 0$

$$F_{NET,CABLE} - F_{CHAIN} \sin\theta + F_{ROPE} - F_{NET,PIPE} = 0$$

FORCE BALANCE (CONT'D):

FOR CURB

$\Sigma F_z = ma$ (static)

$\Sigma F_z = 0$

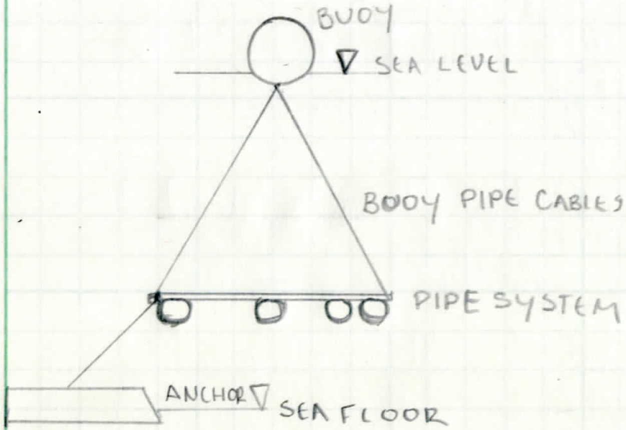
$F_{CHAIN} \sin\theta + F_{NORMAL} - F_{NET,CURB} = 0$

$\Sigma F_x = ma$ (static)

$\Sigma F_x = 0$

$$\boxed{F_{CHAIN} \cos\theta - \mu_s \left(F_{NET,CURB} - F_{CHAIN} \sin\theta \right) = 0}$$

SCHEMATIC



FIND

- BUOY SIZE TO SUPPORT PIPES AND SUPPORTS WITH A FACTOR OF SAFETY OF 2.0 MINIMUM.

KNOWNS

PIPE

OD = 0.675 [IN]
WEIGHT = 0.138 [lb/ft]
# = 4
SECTION LEGNTH = 10 [FT]

SUPPORT

STRUT = 0.78 [lb/ft]
LENGTH = 1.20 [feet]
CLAMP = 0.1 [lb]
# CLAMPS = 4
CABLE = 0.066 [lb]
CABLE LENGTH = 3.0 [ft]

PROPERTIES

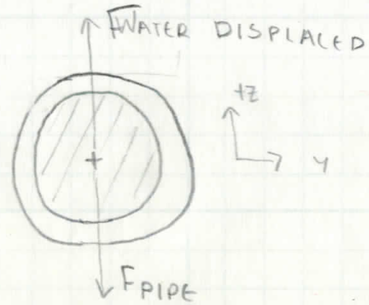
ρ_{WATER} = 63.96 [lb/ft³]
ρ_{STEEL} = 490 [lb/ft³]

ASSUMPTIONS

- T_{WATER} = 60°F, SEAWATER
- MAXIMUM BUOY FORCE OCCURS WHEN PIPES ARE FULL OF WATER

Solve

- Maximum pipe weight

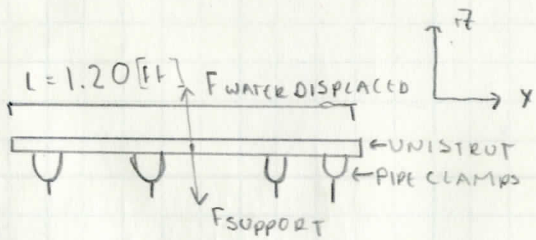


$$\Sigma F_{PIPE} = \#_{PIPE}\left(\rho_{WATER} \cdot \pi\left(\frac{OD^2}{2} - \frac{ID^2}{2}\right) \cdot L - \rho_{PIPE} L_{PIPE}\right)g$$

$$= 4\left(63.69\,[lb/ft^3] \cdot \pi\left(\frac{0.675}{24}^2 - \frac{0.407}{24}^2\right)[ft^2] \cdot 1.5\,ft - 0.138\,[lb/ft] \cdot 1.5\,[ft]\right)$$

$$= 0.221\,[lb\,[-Z]]$$

- Support weight



$$\Delta\rho = \rho_{STEEL} - \rho_{WATER} = 490 - 63.96\,[lb/ft^3]$$

$$\Delta\rho = 426.04\,lb/ft^3$$

$$\frac{\Delta\rho}{\rho_{STEEL}} = \frac{426.04}{490}\frac{[lb/ft^3]}{[lb/ft^3]} = 0.8695$$ → THIS RATIO IS USED TO DETERMINE WEIGHT OF STEEL COMPONENTS W/ UNKNOWN VOLUMES.

$$\Sigma F_{SUPPORTS} = \left(L_{STRUT} \cdot M_{STRUTT} + \#\,PIPE\,CLAMPS \cdot W_{CLAMPS}\right)\frac{\Delta\rho}{\rho_{STEEL}}$$

$$= \left(1.5[ft] \cdot 0.78\,[lb/ft] + 4 \cdot 0.1\,[lb]\right) 0.8695$$

$$= 1.16\,[lb, -Z]$$

- CABLE WEIGHT

$$F_{CABLE} = \frac{\Delta\rho}{\rho_{STEEL}} \left(M_{CABLE}\, L \right)$$

$$= 0.87 \left(0.006 \left[lb/_{ft} \right] 3 [ft] \right)$$

$$= 0.13 \left[lb, -z \right]$$

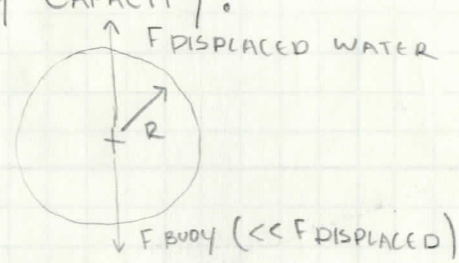
TOTAL LOAD:

$$= F_{PIPES} + F_{SUPPORTS} + F_{CABLE}$$

$$= 1.16 + 0.221 + 0.13 \; [lb]$$

$$= 1.511 \; [lb]$$

BUOY CAPACITY:



$$m = \rho_{WATER} \cdot \frac{2}{3} \pi R$$

$$m = 63.96 \cdot \frac{2}{3} \pi R$$

$$R = \sqrt[3]{\frac{1.51 \; lb}{63.96 \left[lb/_{ft^3} \right] \cdot \frac{1}{12^3} \frac{ft^3}{in^3} \cdot \frac{2}{3} \pi}} = \underline{2.693 \; [in]}$$

<u>BUOY SIZE</u> : 8 INCHES [CHOOSEN BY AVAILIBILITY]

- MAX LOAD CAPACITY $= \frac{2}{3} \pi \left(\frac{8 [in]}{2 \cdot 12 [ft/in]} \right)^3 \left(63.96 \left[lb/_{ft^3} \right] \right)$

$$= 4.96 \; [lb]$$

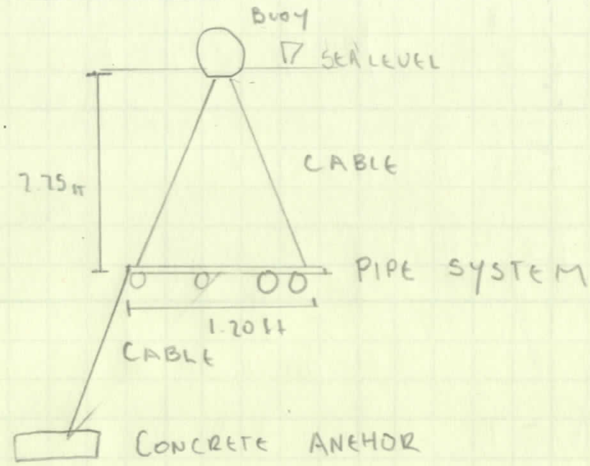
- FACTOR OF SAFETY $= \frac{1.51}{4.96}$

$$\boxed{= 3.3}$$

CABLE SELECTION CALCULATIONS

SCHWARTZ

SCHEMATIC



FIND

CABLE DIAMETER TO SUPPORT SYSTEM INCLUDING THE CONCRETE ANCHOR WITH A FACTOR OF SAFETY OF AT LEAST 2.0.

KNOWN

PIPE

$W_{PIPE\,MAX*} = 1.51\,[lb]$

*FULL OF WATER

ANCHOR

$V = 69.2\,[in^3]$

$\rho_{CONCRETE} = 150\,[lb/ft]$

FITTINGS

$W_{FITTINGS} = 1.16\,[lb]$

CABLE GUESS

MATERIAL = STEEL WIRE ROPE 1/16"

$M = 0.008\,[lb/ft]$

$L = 3.0$ FEET

OTHER

$\rho_{STEEL} = 490\,[lb/ft^3]$

$\rho_{WATER} = 63.96\,[lb/ft^3]$

$g = 32.174\,[ft/s^2]$

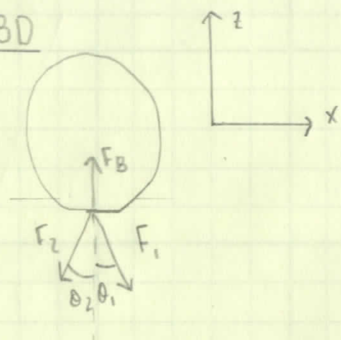
SCHWARTZ

ASSUMPTIONS

- SALT WATER @ T = 60°F
- CABLES ARE STATICALLY LOADED (CALM WATER)

SOLVE

FBD



$$F_1 = F_2 \quad (\theta_1 = \theta_2)$$

$$z: F_{Bz} = F_{1z} + F_{2z}$$

$$F_B: \quad F_B = F_{cables} + F_{supports} + F_{pipes} + F_{anchor}$$

$$F_{cables} = \left(5.49\,[ft] \cdot 0.008\,[lb/ft]\right) \frac{\rho_{steel} - \rho_{water}}{\rho_{steel}}$$

$$= 0.043$$

$$F_{anchor} = (\rho_{concrete} - \rho_{water}) \cdot V_{anchor}$$

$$= (150 - 63.96)\,[lb/ft^3] \cdot 69.2\,[in^3] \cdot \left(\tfrac{1}{12}\right)^3 [in/ft]$$

$$= 3.445\,[lb]$$

$$F_B = 0.043\,[lb] + 1.16\,[lb] + 1.51\,[lb] + 3.445\,[lb]$$

$$= 6.166\,[lb]$$

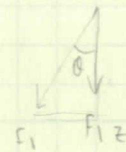
$$\theta_1: \quad \theta_1 = \tan^{-1}\left(\frac{2.25\,ft}{1.20[ft]/2}\right)$$

$$\theta_1 = 11.3°$$

$$\theta_2 = \theta_1 = 11.3°$$

F_1:

$$F_{1z} = F_1 \cos \theta_1$$



$$F_B = 2 F_1 \cos \theta_1$$

$$F_1 = \frac{F_B}{2 \cos \theta_1}$$

$$F_1 = \frac{6.166\,[lb]}{2 \cos(11.3°)}$$

$$\underline{F_1 = 3.14\,[lb]}$$

$$F_2 = F_1$$

FOS

Max Load Capacity 1/16" Wire Rope = 96 [lb]

$$FOS = \frac{\text{Max Capacity}}{\text{Max Load}} = \frac{96\,[lb]}{3.14\,[lb]}$$

$$\underline{FOS = 30.5}$$

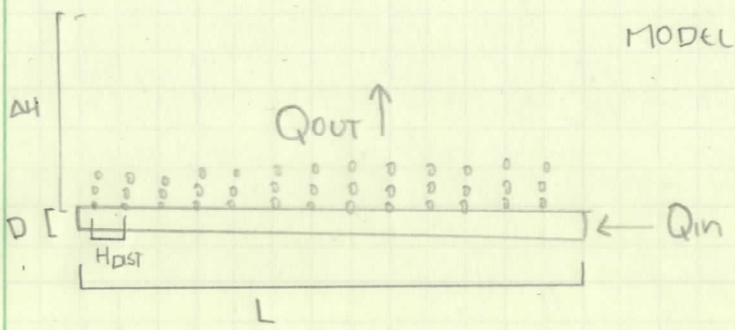
Comments: While smaller wire could be used, it is less availible at hardware stores. Additionally, a large factor of safety is okay due to possible corrosion.

COMPRESSOR SELECTION CALCULATIONS

DAKOTA SCHWARTZ

SCHEMATIC

MODEL SIZE: 0.15 : 1.00



PROPERTIES AND GEOMETRY

GEOMETRY

$L = 5$ [FT]

$D = 0.407$ [IN]

$\Delta H = 3$ [FT]

$HOLE\ D_{IA} = 0.0360$ [IN]

* SCALED TO 1/8" HOLE w/ = BUBBLE VOLUME TO X2 ROWS.

$H_{DIST} = 0.15$ [IN]

PROPERTIES

$\sigma = 74$ [DYNES/CM]

$\rho_{WATER} = 1.04$ [g/CM³] (SALT @ 20°C)

$\rho_{AIR} = 0.001225$ [g/CM³]

CONV_CM = 2.54 [CM/IN]

CONV_IN = 12 [IN/FT]

FIND

APPROXIMATE FLOWRATE NEEDED FOR A 20% BUBBLE VOLUME UNDER BUOY.*

* NOTE: BUBBLE MOVEMENT AND FORMATION ARE COMPLEX AND DIFFICULT TO MODEL ACURATLY, BELOW CALCULATIONS ARE ONLY A ROUGH ESTIMATE.

ASSUMPTIONS

- $T = 60°F$
- ρ = SALT WATER OF SEA SALINITY
- GAS FLOWRATE IS LOW OR MEDUUM ($M < 0.8$)
- IF BUBBLE RADIUS IS < 0.1 CM, ORFFICE SIZE WILL BE ALTERED TO MAINTAIN SAME VOLUME BUT INCREASE BUBBLE RADIUS > 0.1 CM. THIS IS BECAUSE ACTUAL BUBBLE SHAPE IS >> 0.1 CM AND EFFECTS BUBBUE FORMATION AND VELOCITY.

DAKOTA SCHWARTZ

SOLVE

- BUBBLE VOLUME : $\dfrac{2\pi R \sigma}{g \Delta \rho}$ [CM^3]

$$R = \frac{0.407}{2}[IN]\ \frac{2.54[CM]}{[IN]} = 0.457\ [CM]$$

$$V_B = \frac{2\pi\ 0.457\ [CM]\ 74\ [DYNES/CM]}{98.1[CM/S^2]\,(1.04 - 0.001225)\,[g/CM^3]}$$

$$V_B = 0.2086\ [CM^3]$$

- BUBBLE RADIUS = $\left(\dfrac{3}{2}\ \dfrac{R\sigma}{\Delta\rho g}\right)^{1/3}$

$$= \frac{2(0.457[CM])\ 74[DYNES/CM]}{3(1.04-0.001225)[g/CM^3]\ 98.1[CM/S^2]}$$

$$= 0.3687\ [CM]\ ✓$$

✓ · $a > 0.1$ CM, BUBBLE WILL BE ELLIPSOIDAL IN SHAPE, SO VELOCITY IS INDEPENDENT OF DIAMETER

· $0.1 < a < 0.75$ SO $U = 28 - 30$ CM/S AND WILL BE STABLE AND WILL NOT SUBDIVIDE MUCH

- AVERAGE SPEED

$$U = 29[CM/S]\ \frac{1}{12}\frac{[FT]}{[IN]} \cdot \frac{1}{2.54}\frac{[IN]}{[CM]}$$

$$= 0.951\ [FT/S]$$

- REQUIRED FLOWRATE

% BUBBLES UNDER BOUY = $0.2\left[1[FT] \times 5[FT] \times \dfrac{0.675[IN]}{12[FT]}\right]$

[1FT] (ARBITRARY FOR CALC. PURPOSES)

$$= 0.0563\ [FT^3]$$

- FLOWRATE REQUIRED TO SUPPLY 0.563 $\left[\frac{Ft^3 \text{ AIR}}{Ft \text{ DEPTH}}\right]$

$$CFS = 0.0563\left[\frac{Ft^3 \text{ AIR}}{Ft \text{ WATER}}\right] \cdot 0.951\left[\frac{Ft \text{ WATER}}{S}\right]$$

$$CFS = 0.0535\left[\frac{FT^3 \text{ AIR}}{S}\right]$$

$$CFM = 0.0535\left[\frac{Ft^3}{S}\right] \cdot 60\left[\frac{S}{MIN}\right]$$

$$\boxed{CFM = 3.211\left[Ft^3/M\right]}$$

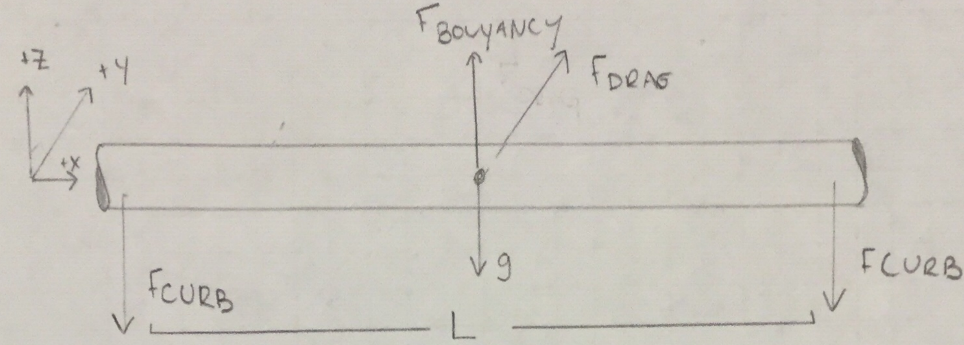
AIR COMPRESSOR

MAKE	MODEL
PROTECH	ELECTRIC-MAGNETIC AQUARIUM AIR PUMP 110V/50HZ, 20W-105W, 20-85LPM

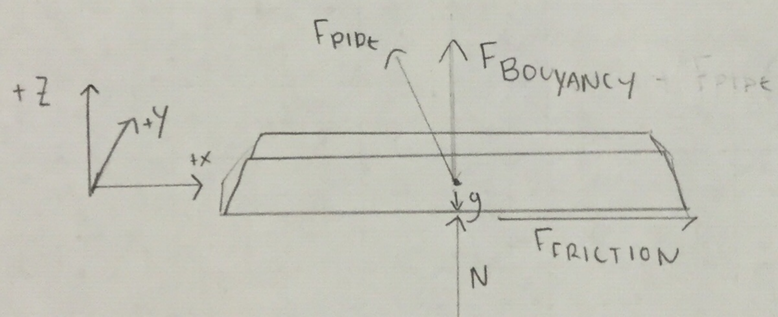
OUTLET NOZZEL 1/4"

Appendix C: Bouyancy, Drag, & Deflection

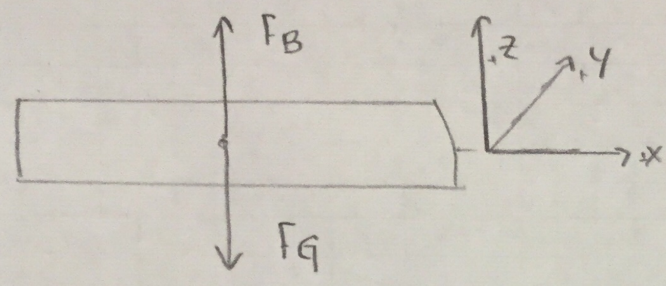
Bubble Pipe: FBD



Car Stop: FBD



SCHEMATIC / FBD



PIPE
OD = 4.5 in
ID = 3.633 in
WIEGHT = 2.31 lbm/ft

COUPLING
SS VITALIC = 4 lb
FITTING = 10 lb

WATER
$\rho = 63.96\ lbm/ft^3$

ASSUMPTIONS

- WATER TEMP = 60°F [MEAN SUMMER OCEAN TEMP IN AVILA BEACH)
- OCEAN WATER SPECIFIC GRAVITY = 1.025

ANALYSIS

$F_B\,[lbf] = W_{PIPE} + W_{WATER\ DISPLACED}$

- $W_{WATER\ DISPLACED} = \frac{\pi}{4}(OD)^2\,\rho_{WATER}\cdot g$

$$= \frac{\pi}{4}\left(\frac{4.5\,in}{12\,in/ft}\right)^2 63.96\left[\frac{lbm}{ft^3}\right] 32.174\left[\frac{ft}{s^2}\right]$$

$$= 227.28\left[\frac{lbm}{ft}\right]\left[\frac{ft}{s^2}\right] = \left[lbf/ft\right]$$

- $W_{PIPE} = \left[M_{PIPE}\left[\frac{lbm}{ft}\right] + \frac{M_{COUPLING} + M_{FITTING}\ [lbm]}{OCCURANCES/foot\ [ft]}\right] g$

$$W_{PIPE\,t} = -\left[2.31\left[\frac{lbm}{ft}\right] + \frac{10+4\,[lbm]}{10\,[ft]}\right] 32.174\left[\frac{ft}{s^2}\right]$$

$$= -164.4\left[\frac{lbm}{ft}\cdot\frac{ft}{s^2}\right] [=] \left[\frac{lbf}{ft}\right]$$

$$F_B = -164.4\left[\frac{lbf}{ft}\right] + 227.28\left[\frac{lbf}{ft}\right]$$

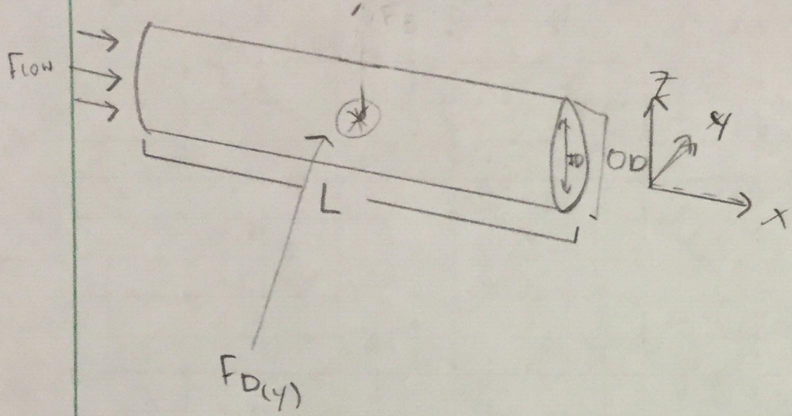
$$= -62.87\,[lbf/ft]$$

BOUYANCY FORCE ON PIPE PER UNIT LENGTH

$$F_B = -62.87\left[\frac{lbf}{ft}\right] \uparrow$$

PRELIMINARY PIPE CALCULATIONS: DRAG

GIVEN:



$\rho_{WATER} = 62.4 \frac{lbm}{ft^3}$

OD = 4.5 IN

L = 20 FT

V = 1.3 ft/s

Viscosity = 1.210 ft²/s of SEA WATER

FIND: F_D ON PIPE USING $F_D = \frac{C_D A \rho V^2}{2 g_c}$

ASSUMPTIONS:

- $T_{WATER} = 60°F$ (MEAN 1981-2005)

SOLVE:

- C_D → FOUND USING ATTACHED GRAPH (17.53 - DRAG COEFFICENT FOR A CYLINDER)

$$Re = \frac{VD}{\nu}$$

$$= \frac{1.3\,[ft/s]\; 4.5\,[in]\; 1/12\,[ft/in]}{1.210\,[ft^2/s]}$$

$$= 40289.2$$

$\Rightarrow C_D = 1.3$ (SEE GRAPH)

- $A_{EFFECTIVE} = 4.5\,in \cdot 20\,ft \left(\frac{1\,ft}{12.0\,in}\right) = 7.5\,ft^2$

$$F_D = \frac{C_D A \rho V^2}{2g} = \frac{(1.3)(7.5\,[ft^2])(62.4\,[\frac{lbm}{ft^3}])(1.3\,[ft/s])^2}{2(32.2\,[\frac{ft\,lbm}{lbf \cdot s^2}])}$$

$F_D = 15.97$ lb. [y]

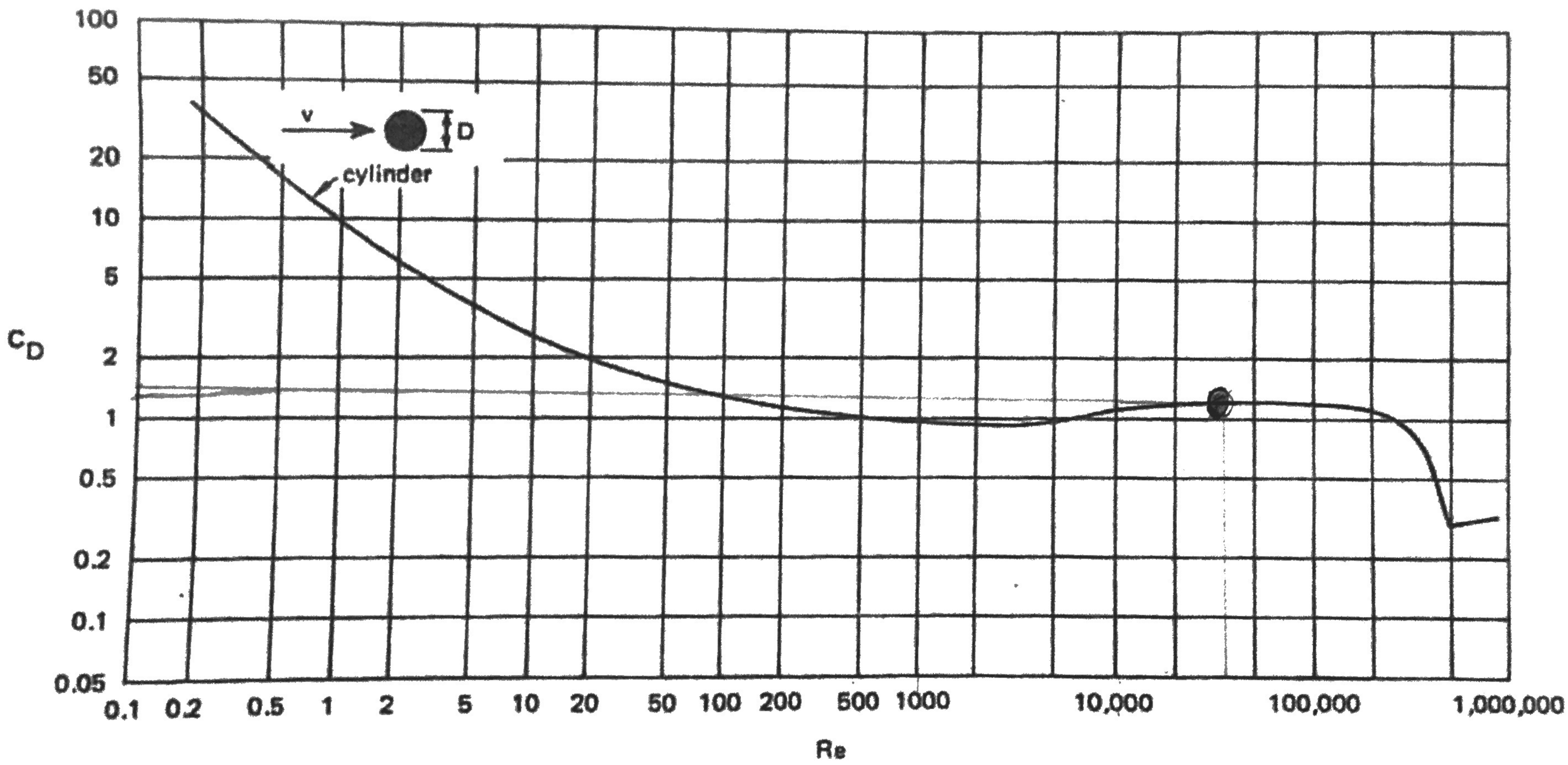
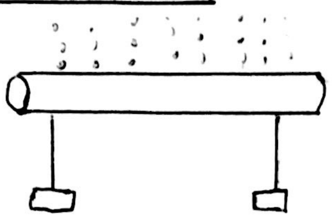
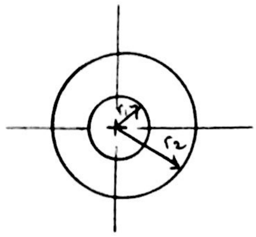


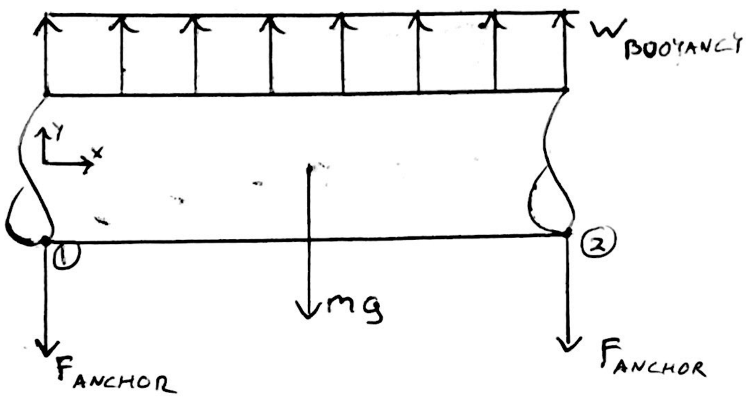
Figure 17.53 Drag Coefficient for a Cylinder

SCHEMATIC:





FREE BODY DIAGRAM



BOUNDARY CONDITIONS

$y(@ ①) = 0$

$y(@ ②) = 0$

$\frac{\partial y}{\partial x}(x = \frac{L}{2}) = 0$

ASSUMPTIONS:

1. POINTS 1 & 2 ARE LOCKED IN SPACE
2. NO HOLES ON PIPE
3. WEIGHT IS INCLUDED IN THE BUOYANCY DISTRIBUTION
4. CONSTANT CROSS-SECTIONAL AREA
5. E of 110,000 psi to ∠ 160,000 psi

ANALYSIS

EQUATION OF ELASTIC CURVE FOR DISTRIBUTED LOAD ON A BEAM:

$$y = + \frac{w}{24EI}\left(x^4 - 2Lx^3 + L^3x\right)$$

ANALYSIS (CONT'D)

MOMENT OF INERTIA OF A HOLLOW CYLINDER

$$I = \frac{\pi \left(d_o^4 - d_i^4\right)}{64}$$

$$y = \frac{8W}{3E\pi\left(d_o^4 - d_i^4\right)}\left(x^4 - 2Lx^3 + L^3x\right)$$

$$y_{max} = \frac{5wL^4}{6E\pi\left(d_o^4 - d_i^4\right)}$$

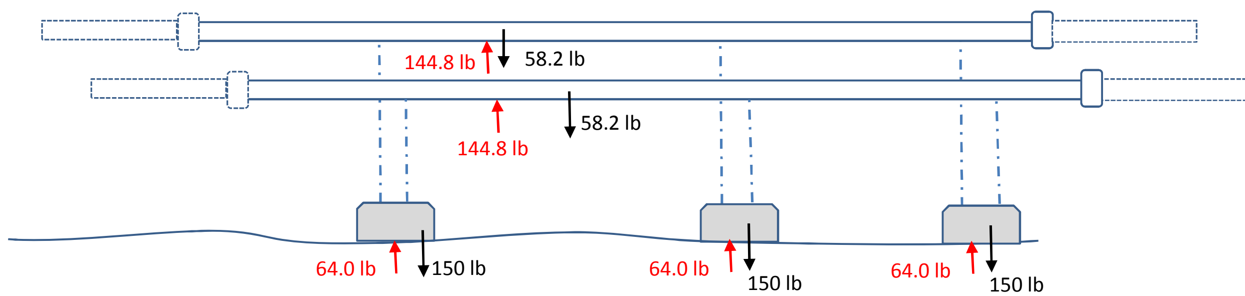
$E \approx$ 110,000 psi TAKEN FROM JMM HIGH DENSITY POLYETHYLENE PE 3408 / PE 3608 PRODUCT SPECIFICATION

Appendix D: DCPP's Original Bubble Pipe Calculations

Buoyancy Calculation

Description: The buoyancy force exerted on the submerged piping is equal to the weight of the water displaced by the volume of the piping. The anchorage needs to offset that buoyancy force on the piping, in addition to its own buoyancy.

Inputs			**Outputs**		
Piping - 20' Length of 4" HDPE SDR-11					
Type of Pipe	**HDPE**		Water Density	*63.96*	lb/ft^3
O.D. of Pipe	4.5	in	Volume of Water Displaced by Pipe	*2.21*	ft^3
I.D. of Pipe	3.633	in	Weight of Water displaced (Buoyancy Force)	*144.8*	lb
Weight of Piping	2.31	lb/ft			
Length of Pipe Section	20	ft	Weight of HDPE Piping	*46.2*	lb
Weight of SS Victaulic Coupling	4	lb	Net Weight of Victaulic Coupling	*3.5*	lb
Weight of Polycam Fittings	10	lb	Net Weight of Polycam	*8.5*	lb
			Total Weight of Piping/Coupling/Polycam	*58.2*	lb
Density of Stainless Steel	490	lb/ft^3			
SG of fluid	1.025		Req'd Support Wt. Per Pipe (Wt. Water-Wt. Pipe)	*86.7*	lb
			Req'd Support Wt. for 2 pipes	*173.3*	lb
Anchor			Required Weight with Safety Factor of 1.2	***208.0***	lb
Material	**Concrete Curb**				
Specific Weight	150	lb/ft^3	Volume of Anchor	*1*	ft^3
Anchor weight	150	lb	Weight of Anchor	*150*	lb
			Weight of Water Displaced by concrete	*64.0*	lb
			Net Anchorage Force of each Curb	***86.0***	lb
			Total Anchorage Force for 3 Concrete Curbs	***258.1***	lb



Summary

Weight of (2) 20' Lengths of Piping	-116.3	lb
Buoyancy of (2) 20' Lengths of Piping	289.6	lb
Net weight required for pipe anchorage (for (2) 20' lengths)	173.3	lb
Net anchorage requirement with safety factor of 1.2	**208.0**	lb
Weight of (1) 6' concrete curb	150.0	lb
Buoyancy of (1) 6' concrete curb	-63.96	lb
Net anchorage weight of (1) curb	86.0	lb
Number of concrete curbs	3	
Total anchorage weight of 3 curbs	**258.12**	lb

Total anchorage weight of curbs must exceed the net anchorage requirement.

69-392 (10,
Engineeri

Pacific Gas and Electric Company®

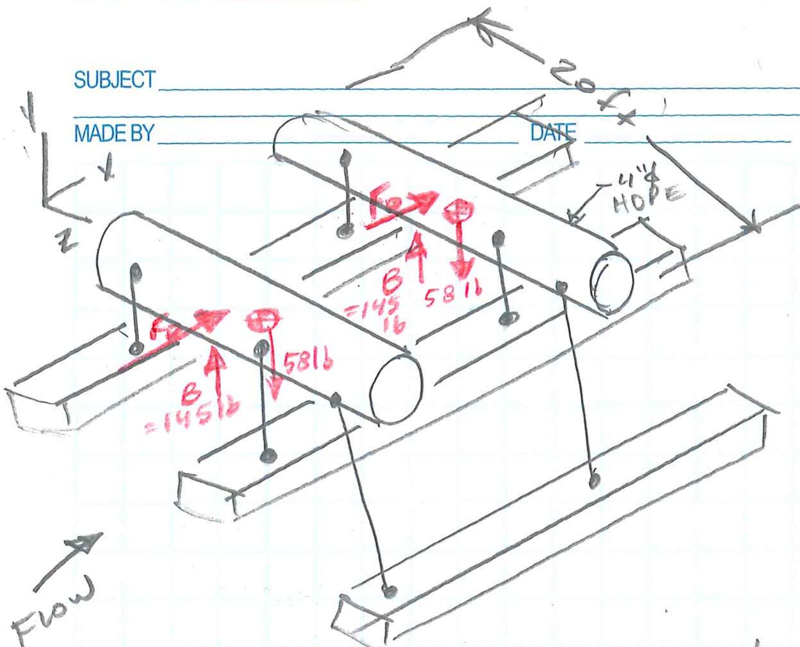
Engineering-Calculation Sheet

Project: Diablo Canyon Unit ( ) 1 ( ) 2 ( ) 1 & 2

CALC. NO. ______
REV. NO. ______
SHEET NO. 1 OF 2

SUBJECT ______

MADE BY ______ DATE ______ CHECKED BY ______ DATE ______



DRAG FORCE $V = 1.3\ ft/sec$

$$F_D = \frac{C_D A \rho V^2}{2 g_c}$$

$$\rho = (SG)(\rho_{WATER}) = (1.025)(62.4 \tfrac{lb_m}{ft^3}) = 64.0 \tfrac{lb_m}{ft^3}$$

A = PROJECTED AREA

$$= \left(\frac{4.5}{12}\right) ft\ (20\ ft) = 7.5\ ft^2$$

REYNOLD'S NUMBER $Re = \frac{VD}{\nu} = \frac{(1.3 \frac{ft}{s})(\frac{4.5}{12} ft)}{2.58 \times 10^{-3}\ ft^2/s}$

$Re = 18,870$

FIGURE 17.53 → $C_D = 1.2$

55. FLOW AROUND A CYLINDER

The characteristic drag coefficient plot for cylinders placed normal to the fluid flow is similar to the plot for spheres. The plot shown in Fig. 17.53 is for infinitely long cylinders, since there is additional wake drag at the cylinder ends. In calculating the Reynolds number, the cylinder diameter should be used as the characteristic dimension.

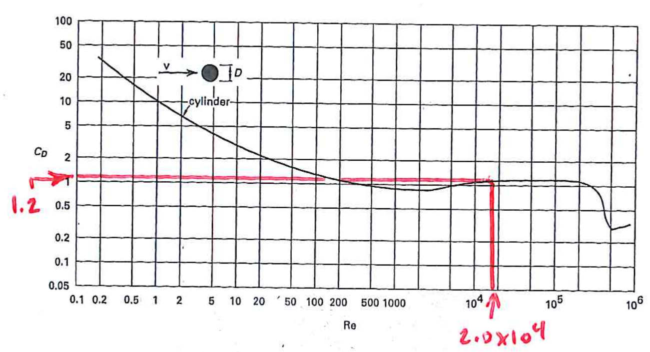


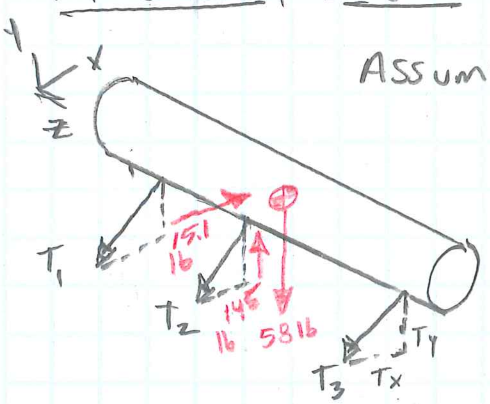
Figure 17.53 Drag Coefficient for a Cylinder

$$F_D = \frac{C_D A \rho V^2}{2 g_c}$$

$$= \frac{1.2\ (7.5 ft^2)(64.0 \frac{lb_m}{ft^3})(1.3)^2 \frac{ft^2}{s^2}}{2\ (32.2 \frac{ft \cdot lb_m}{lb_f \cdot s^2})}$$

$$\boxed{F_D = 15.1\ lb}$$

FREE-BODY DIAGRAM - SINGLE PIPE



ASSUMPTION: T_1, T_2, AND T_3 EQUALLY SUPPORT THE PIPE. THEREFORE, $T_1 = T_2 = T_3 = T$

$\Sigma F_x = 0 \rightarrow 15.1 lb - 3T_x = 0 \Rightarrow T_x = 5 lb$

$\Sigma F_y = 0 \rightarrow 145 - 58 - 3T_y = 0$

$3T_y = 87 \rightarrow T_y = 29 lb$

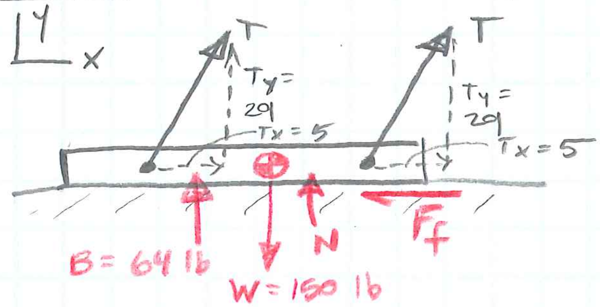
Engineering-Calculation Sheet
Project: Diablo Canyon Unit ( ) 1 ( ) 2 ( ) 1 & 2

CALC. NO. ______
REV. NO. ______
SHEET NO. 2 OF 2

SUBJECT ______

MADE BY ______ DATE ______ CHECKED BY ______ DATE ______

FBD OF CONCRETE CURB



$$\sum F_y = 64 + 29 + 29 + N - 150 = 0$$
$$N = 28\ lb$$

$$\sum F_y = 0 = 5 + 5 - F_f = 0 \rightarrow F_f = 10\ lb$$

FOR CONCRETE TO REMAIN STATIONARY ON WET SAND, THE FRICTION FORCE MUST BE MORE THAN OR EQUAL TO 10 lb.

THE COEFFICIENT OF STATIC FRICTION FOR CONCRETE AND WET SAND IS $\mu_s = 0.40$.

ACTUAL FRICTION FORCE IS

$$F_{f,ACTUAL} = \mu_s N = (0.40)(28\ lb) = 11.2\ lb$$

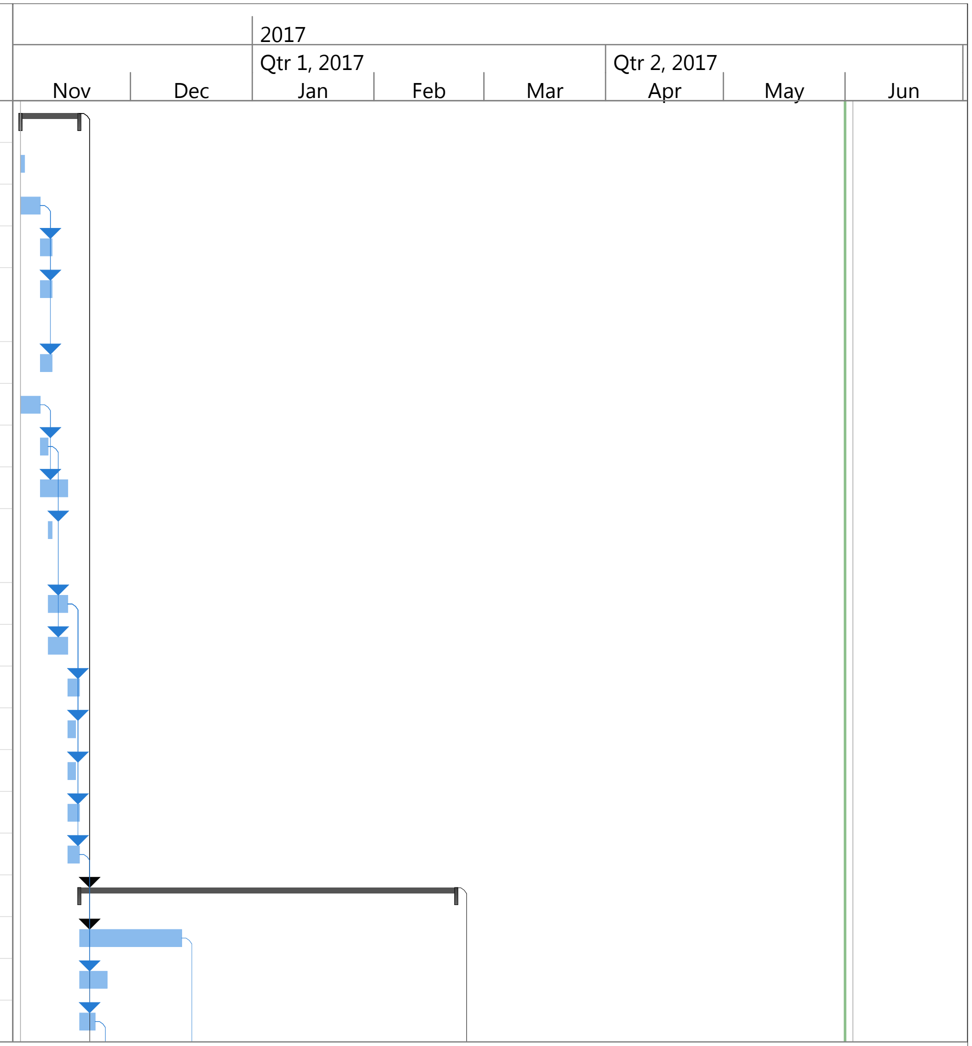
$$F_{f,ACTUAL} \geq 10\ lb$$

11.2 > 10 lb   THEREFORE, THE CONCRETE WILL NOT MOVE AT A VELOCITY OF 1.3 ft/sec OR LESS IN THE GIVEN CONFIGURATION

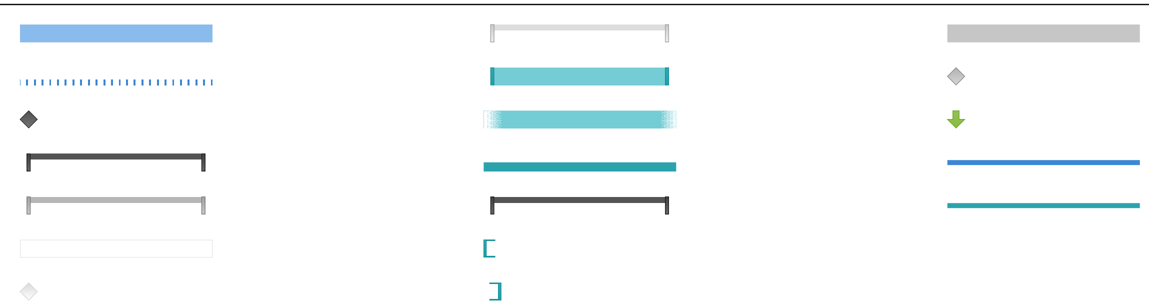
ACCORDING TO FSAR, THE MAXIMUM INTAKE FLOW IS 2 × 867,000 + 11,000 GPM = 1,745,000 GPM. THE APPROXIMATE FLOW AREA FOR THIS IS A 225 FT WIDTH AND A 40-FT DEPTH, FOR AN ESTIMATED WATER VELOCITY OF 0.43 FT/SECOND.
A MAXIMUM FLOW OF 1.3 FT/SECOND THEREFORE PROVIDES A SAFETY FACTOR OF 3.

Appendix E: Gantt Chart

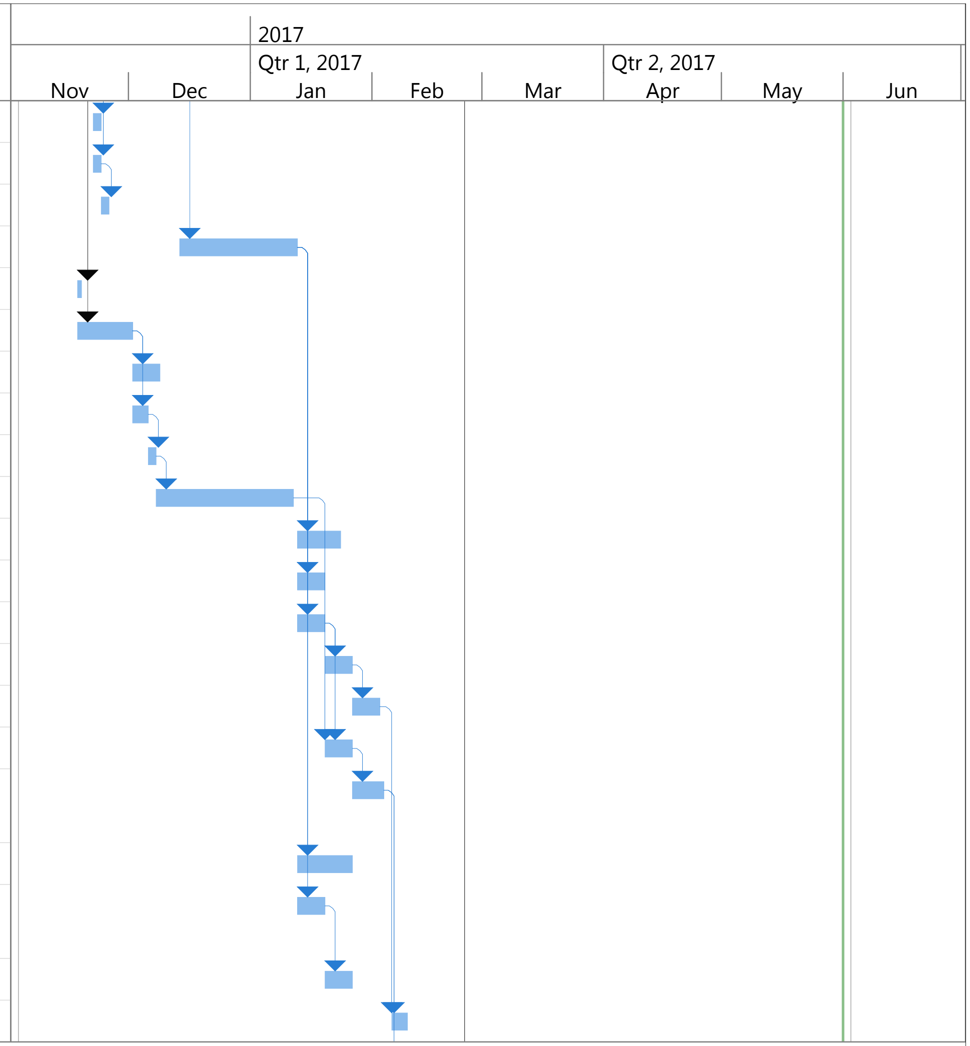
ID	Task Name	Duration	Start
1	**PDR Report**	**11 days**	**Thu 11/3/16**
2	Gantt Chart	1 day	Thu 11/3/16
3	DCPP Feedback	3 days	Thu 11/3/16
4	Improve introduction	3 days	Tue 11/8/16
5	Updated and Polished Design Requirements and Specifications	3 days	Tue 11/8/16
6	Enhance Discussion and Background	3 days	Tue 11/8/16
7	Concept Modeling	3 days	Thu 11/3/16
8	Concept Selection	2 days	Tue 11/8/16
9	Final Decision Matrix	5 days	Tue 11/8/16
10	Discuss How Concept Satisfies Specifications	1 day	Thu 11/10/16
11	Complete Concept Description	3 days	Thu 11/10/16
12	Quantitative work justifying concept	3 days	Thu 11/10/16
13	Layout Drawings	3 days	Tue 11/15/16
14	Safety Hazard Identification Checklist	2 days	Tue 11/15/16
15	Plans for Constructing and Testing	2 days	Tue 11/15/16
16	Complete PDR	3 days	Tue 11/15/16
17	Presentation	3 days	Tue 11/15/16
18	**CDR**	**53 days**	**Fri 11/18/16**
19	Supporting Analysis	18 days	Fri 11/18/16
20	Test Buoyancy with bubbles	5 days	Fri 11/18/16
21	Determine Buoy Size	2 days	Fri 11/18/16



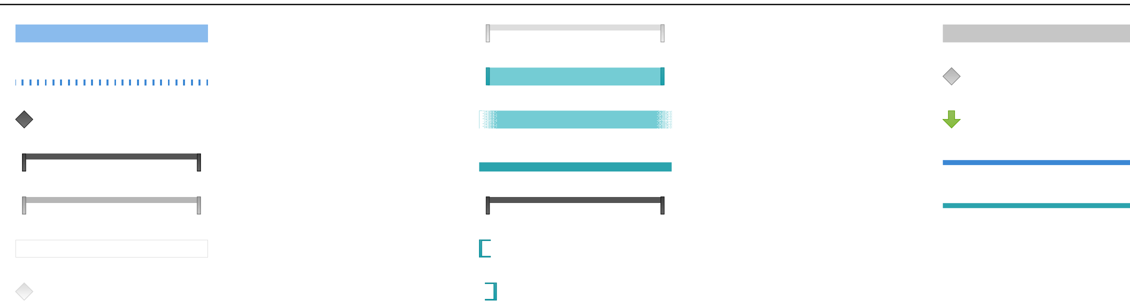
Project: Team Bubbles MP
Date: Thu 6/1/17



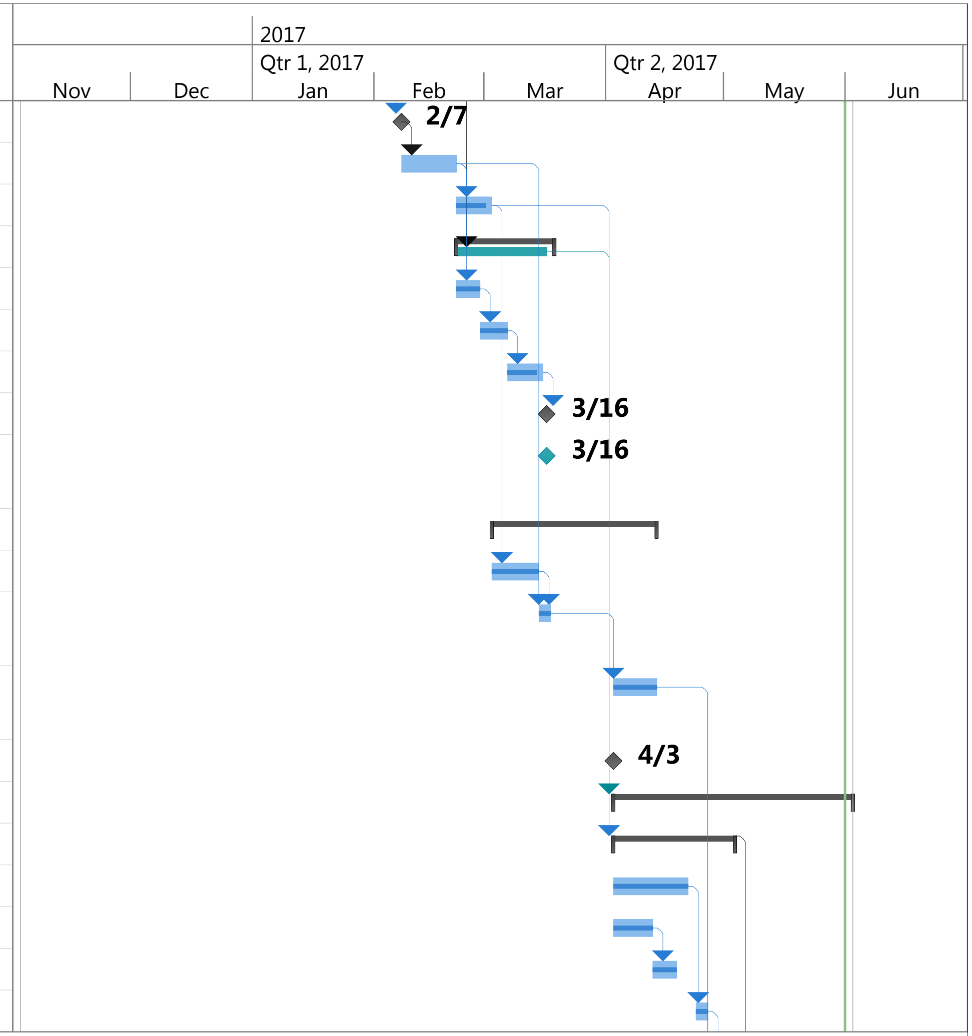
ID	Task Name	Duration	Start
22	Determine Cable Size	2 days	Tue 11/22/16
23	Determine Chain Size	2 days	Tue 11/22/16
24	Design Attachment Points	2 days	Thu 11/24/16
25	Functional Design Description	7 days	Wed 12/14/16
26	Decide on Tank Function	1 day	Fri 11/18/16
27	Similitude Analysis	10 days	Fri 11/18/16
28	Choose Pump Size	5 days	Fri 12/2/16
29	Determine Tank Size	2 days	Fri 12/2/16
30	Determine Tank Materials	2 days	Tue 12/6/16
31	Complete Tank Design	10 days	Thu 12/8/16
32	Top Level Drawing	7 days	Fri 1/13/17
33	Layout Drawings	5 days	Fri 1/13/17
34	Material Selection	5 days	Fri 1/13/17
35	Bill of Materials	5 days	Fri 1/20/17
36	Detailed Cost Analysis	5 days	Fri 1/27/17
37	Fabrication and Assembly Instructions	5 days	Fri 1/20/17
38	Maintenance and Repair Considerations	6 days	Fri 1/27/17
39	Management Plan With Gantt Chart	10 days	Fri 1/13/17
40	Critical Design Safety Hazard Identification Chart	5 days	Fri 1/13/17
41	Detailed Safety Discussion	5 days	Fri 1/20/17
42	CDR Report	4 days	Mon 2/6/17



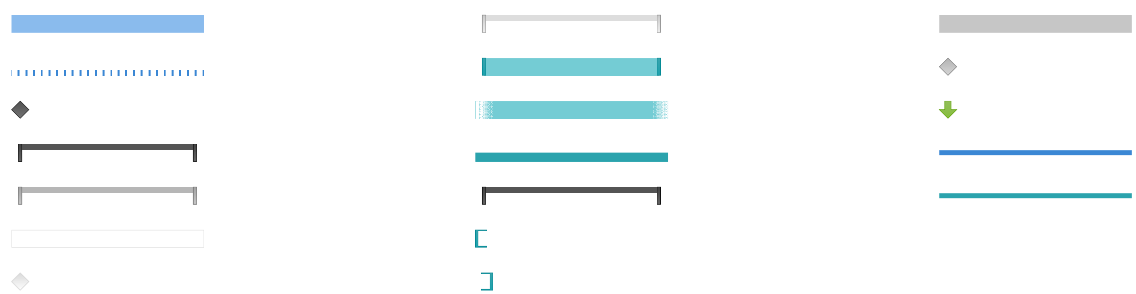
Project: Team Bubbles MP
Date: Thu 6/1/17



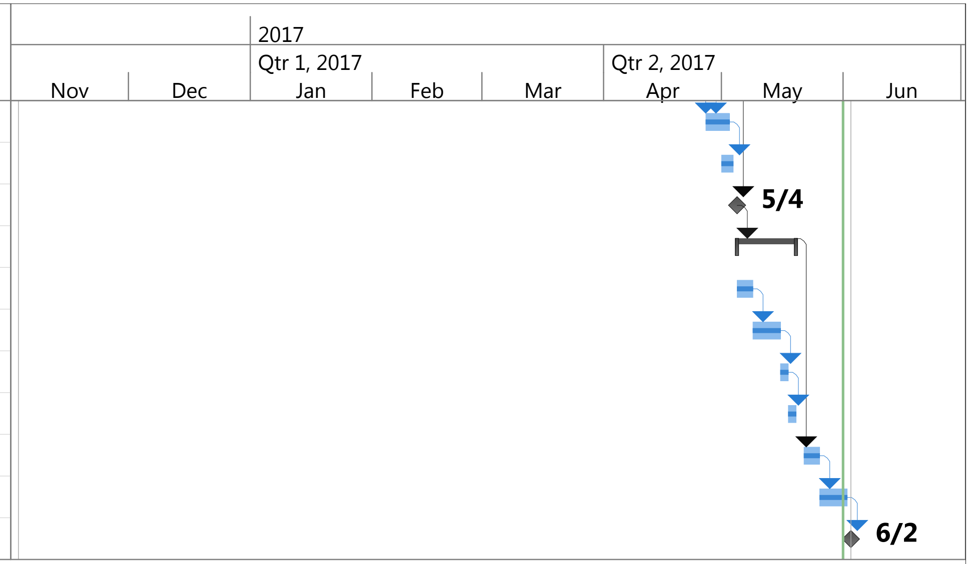
ID	Task Name	Duration	Start
43	CDR Presentation	1 day	Tue 2/7/17
44	Sponser CDR Review	10 days	Wed 2/8/17
45	Parts Ordered	7 days	Wed 2/22/17
46	**Project Update report**	**19 days**	**Wed 2/22/17**
47	Budget Alterations	4 days	Wed 2/22/17
48	Operator's Manual	5 days	Tue 2/28/17
49	Write Project Update	7 days	Tue 3/7/17
50	Project Update	1 day	Thu 3/16/17
51	Manufacturing and Test Review Presentation	1 day	Thu 3/16/17
52	**Fluids Lab Permission**	**20 days**	**Fri 3/3/17**
53	Write Manufacturing/Test Plan	8 days	Fri 3/3/17
54	Send Manufacturing/Test Plan to Westphal	3 days	Wed 3/15/17
55	Send Manufacturing/Test Plan to Jim Gerhart	9 days	Mon 4/3/17
56	All Parts Received By	0 days	Mon 4/3/17
57	**FDR**	**45 days**	**Mon 4/3/17**
58	**Build Project**	**23 days**	**Mon 4/3/17**
59	Pour Concrete	15 days	Mon 4/3/17
60	Drill Holes into PVC Pipes	8 days	Mon 4/3/17
61	Combine/Seal PVC Pipes	4 days	Thu 4/13/17
62	Combine Pieces in Tank	3 days	Mon 4/24/17



Project: Team Bubbles MP
Date: Thu 6/1/17



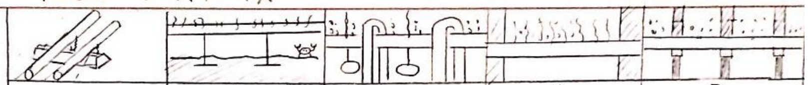
ID	Task Name	Duration	Start
63	Final Approval From Gerhart	4 days	Thu 4/27/17
64	Fill Tank with Water	2 days	Mon 5/1/17
65	**Project Safety and Hardware DEMO**	1 day	Thu 5/4/17
66	**Test Project**	**11 days**	**Fri 5/5/17**
67	Test Buoyancy with bubbles	2 days	Fri 5/5/17
68	Test Angles for Bubbles	5 days	Tue 5/9/17
69	Test Shifting Floor	2 days	Tue 5/16/17
70	Test Turbulence	2 days	Thu 5/18/17
71	Conclusions	4 days	Mon 5/22/17
72	Complete Final Design Report	5 days	Fri 5/26/17
73	FDR Project Expo	1 day	Fri 6/2/17



Project: Team Bubbles MP
Date: Thu 6/1/17

APPENDIX F: Pugh and Decision Matrices

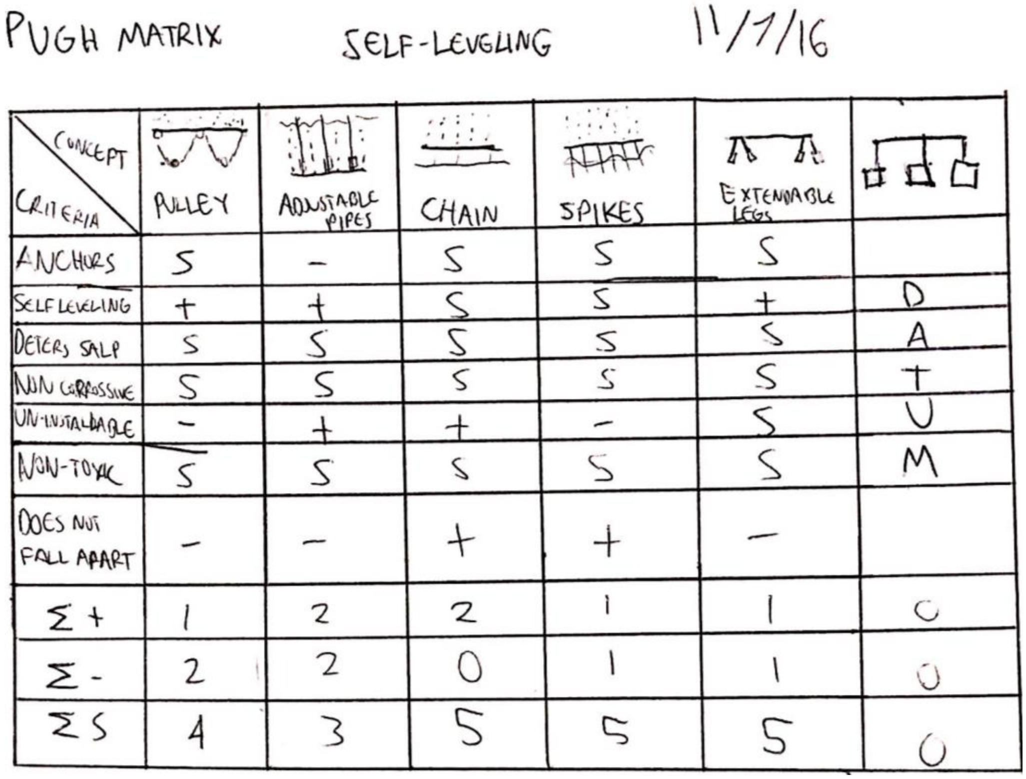
ANCHORING PUGH MATRIX



Criteria \ Concept	1	2	3	4	5
KEEPS UNDER WATER	D	S	S	S	S
DOES NOT CORRODE	A	+	—	+	—
DOES NOT MOVE LATERALLY	T	+	+	+	+
NON-TOXIC	U	S	S	S	S
EASE OF IMPLEMENTATION	M	—	—	—	—
Σ +		2	1	2	1
Σ −		1	2	1	2
Σ S		2	2	2	2

Figure 1: A Pugh matrix created from the top anchoring concepts and the customer requirements. The concepts are arranged horizontally across the top while the customer requirements are vertically on the side. Each concept is then rated for a customer requirement in comparison the existing product (the datum): same (S), better (+), or worse (-). The totals of each rating are added, giving a better idea whether the concept is worth pursuing.

APPENDIX F: Pugh and Decision Matrices



PUGH MATRIX SELF-LEVELING 11/1/16

Criteria \ Concept	PULLEY	ADJUSTABLE PIPES	CHAIN	SPIKES	EXTENDABLE LEGS	
ANCHORS	S	–	S	S	S	
SELF LEVELING	+	+	S	S	+	D
DETERS SALP	S	S	S	S	S	A
NON CORROSIVE	S	S	S	S	S	T
UN-INSTALLABLE	–	+	+	–	S	U
NON-TOXIC	S	S	S	S	S	M
DOES NOT FALL APART	–	–	+	+	–	
Σ +	1	2	2	1	1	0
Σ -	2	2	0	1	1	0
Σ S	4	3	5	5	5	0

Figure 2: A Pugh matrix created from the top leveling concepts and the customer requirements. The concepts are arranged horizontally across the top while the customer requirements are vertically on the side. Each concept is then rated for a customer requirement in comparison the existing product (the datum): same (S), better (+), or worse (-). The totals of each rating are added, giving a better idea whether the concept is worth pursuing.

APPENDIX F: Pugh and Decision Matrices

		Concept							
			Reconfigured	Chain on Top	Buoys	Adjustable Pipes	Tensioned Chain	Spikes	Anchored to Walls
		1	2	3	4	5	6	7	8
Criteria	A		S	S	S	S	-	S	-
	B		S	+	+	+	S	S	S
	C		S	S	S	S	S	S	S
	D	**D**	S	S	S	-	-	S	S
	E	**A**	S	S	S	-	S	-	-
	F	**T**	S	S	S	S	S	S	S
	G	**U**	S	S	S	-	S	S	S
	H	**M**	+	S	-	-	S	S	S
	I		S	S	-	-	S	-	-
	J		-	S	S	S	-	S	-
	Σ+	0	1	1	1	1	0	0	0
	Σ-	0	1	0	2	5	3	2	3
	ΣS	0	8	9	7	4	7	8	6

+	*Better than datum*
-	*Worse than datum*
S	*Same as datum*

Criteria Descriptions

A	Functional as an anchor	F	Non-toxic
B	Self-leveling	G	Can withstand expected current conditions
C	Efficiently deters salp	H	Cost
D	Can withstand salt water	I	Manufacture Time
E	Able to be uninstalled	J	Minimal Pipe Deflection

Figure 3: A Pugh matrix created from the top combined concepts and the customer requirements. The concepts are arranged horizontally across the top while the customer requirements are vertically on the side. Each concept is then rated for a customer requirement in comparison the existing product (the datum): same (S), better (+), or worse (-). The totals of each rating are added, giving a better idea whether the concept is worth pursuing.

APPENDIX F: Pugh and Decision Matrices

Decision Matrix

		Criteria											
		14%	24%	7%	5%	12%	2%	11%	4%	7%	14%	Total Score	Normalized Score
		A	B	C	D	E	F	G	H	I	J		
Concepts	Torpedo	10.0	4.0	7.0	9.0	3.0	8.0	4.0	8.0	7.0	4.0		0.86
		1.4	1.0	0.5	0.5	0.4	0.1	0.4	0.3	0.5	0.5	5.7	
	Pulley System	8.0	5.0	7.0	3.0	6.0	10.0	4.0	5.0	4.0	4.0		0.81
		1.1	1.2	0.5	0.2	0.7	0.2	0.4	0.2	0.3	0.5	5.4	
	Adjustable Poles	7.0	4.0	7.0	2.0	3.0	10.0	1.0	5.0	2.0	1.0		0.56
		1.0	1.0	0.5	0.1	0.4	0.2	0.1	0.2	0.1	0.1	3.7	
	Reconfigured Current System	8.0	0.0	7.0	8.0	8.0	10.0	5.0	9.0	9.0	5.0		0.87
		1.1	0.0	0.5	0.4	0.9	0.2	0.5	0.3	0.7	0.7	5.4	
	Buoy System	8.0	8.0	7.0	6.0	6.0	10.0	4.0	4.0	4.0	7.0		1.00
		1.1	1.9	0.5	0.3	0.7	0.2	0.4	0.1	0.3	0.9	6.6	

A	Functional an anchor	F	Non-toxic
B	Self-leveling	G	Can withstand expected current conditions
C	Efficiently deters salp	H	Cost
D	Can withstand salt water	I	Time to make
E	Able to be uninstalled	J	Minimal Pipe Deflection

Figure 4: The decision matrix allows for the comparison of different concepts against weighted criteria. All criteria are rated out of 100% (totaling 100%). The score under each criteria is meaningless by itself, but the totals scores on the right indicate how each concept meets each criteria, in a way that they can be compared. The normalized score shows how each concept compares to each other easily. From this comparison, The buoy system, reconfigured system, and torpedo concepts scored highest.

Appendix G: Failure Mode and Effects Analysis

FMEA NO.: 2	Prepared By :	CY	Page 1 of 1	
Machine Name : Buoy & Anchors	Product/Service Application :	Self Leveling Test Chart	FMEA Date: 5/1/17	
Design Responsibility: T.M.	Review Date :	5/4/2017	Core Team : Bubbles	

Function and Performance Requirement	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Cause of Failure	Occurren	Current Design and Machinery Controls	Detection	RPN*	Action
Pipe Self-levels	Buoy lifts concrete curb	Concrete curb moves laterally	7	Buoy chain(1) length is too short	6	Large safety factor used in design to prevent too short of chain	1	42	Completed
			7	Too much drag on buoy	3	Large safety factor used in design to prevent too short of chain	1	21	Completed
		Pipe deflection exceeds acceptable range	5	Pipe to concrete chain(2) is too short	5	Large safety factor used in design to prevent too short of chain	1	25	Completed
		Too much tension in chain (1 or 2) causes system breaks	5	Manufacturing defect in chain	1	Routine Maintenance	2	10	Ongoing
			5	Manufacturing defect in pipe-chain attachment	1	Routine Maintenance	2	10	Ongoing
			5	Carabiners detach/break	1	Routine Maintenance	2	10	Ongoing
			5	Buoy detaches	3	Routine Maintenance	2	30	Ongoing
Concrete Curbs/Chains Anchor System	Pipe Floats Away	Broken Chains	8	Chain Corrodes	2	Choose Strong Connections and Materials	2	32	Completed
			8	Animal Interaction	3	Routine Maintenance	2	48	Ongoing
			8	Concrete Attachments Erode	1	Choose Strong Connections and Materials	5	40	Completed
			8	Bad connections	1	Add Corrosion Resistant Coatings	6	48	Planned
		Concrete Moves	5	Not Heavy Enough	1	Large safety factor used in design to prevent flotation	3	15	Completed
			5	Chains Too Short	4	Large safety factor used in design to prevent too short of chain	4	80	Completed
			5	Strong Drag Force	2	Large safety factor used in design to prevent flotation	4	40	Completed
			5	Animal Interaction	3	Routine Maintenance	4	60	Ongoing
		Concrete Breaks	2	Corrosion of Concrete	3	Routine Maintenance	4	24	Ongoing
			2	Poor curb placement	1	Adjust as needed	5	10	Ongoing

APPENDIX H

Buoy Supported Air Bubble Curtain Operation and Installation Manual

Team Bubbles: May 30th, 2017

Introduction

This document is meant to supplement Diablo Canyon Power Plant's Air Bubble Curtain installation procedures. The main difference between DCPP's existing system and this is the presence of buoys. Existing protocol should be followed with the below recommended additions for use of buoys.

Caution

The Cal Poly Senior Project team's scope is limited to model design, as determined in the initial project proposal. The below recommendations do discuss the implementations of the full-scale design, but are only estimations of how we foresee the full-scale product to work. DCPP procedures and guidelines should be strictly used. **This operator's manual must be modified after a complete full-scale design to account for design alterations and additions.**

Parts

The materials listed below are the main parts referred to in the installation section. The drawings should be referred to during installation for a complete parts and assembly list.

- HDPE Pipes
- Stainless Steel Unistruts
- Pipe Clamps
- Pipe Connectors
- Buoys
- Concrete Anchors
- Connecting Chains

Installation

Full-Scale

Step 1: Place concrete curbs at 10 foot increments along the bay floor, as per DCPP protocol for the existing bubble curtain system.

Step 2: Using the existing bubble pipe system, attach buoys to drawing specs. On the first use of the system, Unistruts must be added permanently to the previous system at 10 foot intervals (see drawings). *We highly recommend connecting buoys to the pipe system prior to placing the pipes in the water. The pipes will not float, and be very difficult to connect to floating buoys after they are in the water.*

APPENDIX H

Step 3: Feed the pipe system into the water as constructing and attaching each new subsection, or as done in current set-up protocol.

Step 4: Attach the pipe system to each anchor using chains of set length as determined on drawings. Chains may be attached to anchors in the first step or separately attached to both the anchor and the pipe system in this step. Attaching the anchor chains to the pipe system is not recommended, since chains will drag along bay floor. They may get caught in kelp and/or damage kelp.

Step 5: Turn on air compressors. Make sure pipes are not floating, and are held up by buoys. Daily operation should be identical to current protocol.

Model

Model installation will be done using a similar approach. Since all parts can be reached within the tank, steps may be done in different orders if needed. Due to safety concerns, most assembly will be done prior to filling test tank.

Deconstruction

Deconstruction should occur as soon as salp dissipates, per Costal Commission requirements. Deconstruction should be accomplished as the existing DCPP protocol states, with changes only if necessary. Buoys may be stored with or separately from the pipe system. We recommend all pipes and equipment are dried prior to storage to prevent rust and microbial growth.

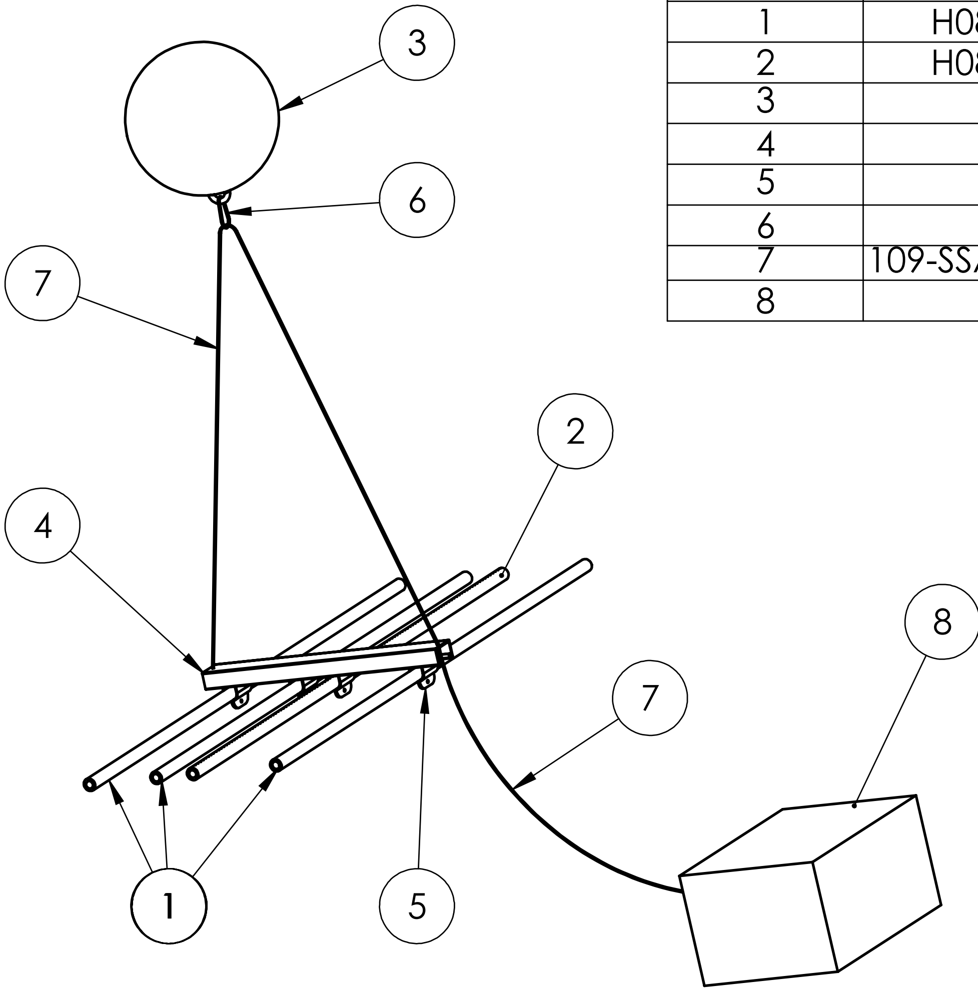
Safety Guidelines

All DCPP safety protocol should be strictly followed. If not covered by existing protocol, we recommend the following:

- The use of boats near the buoys is not recommended
- Wear hard hats and any necessary safety equipment
- Do not deploy the Bubble Curtain in rough ocean conditions
- Use appropriate number of people to lift/carry pipe pieces

Appendix I

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	H0800038PG2000	3/8 in PVC	3
2	H0800038PG2000	3/8 in PVC with Holes	1
3	3006.7318	Buoy	1
4	PS 500 10SS	Unistrut	1
5	P1109	Pipe Clamp	4
6	--	Carabiner	1
7	109-SSAC7/304/062-0000	Wire Rope	1
8	101006	Concrete Anchor	1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

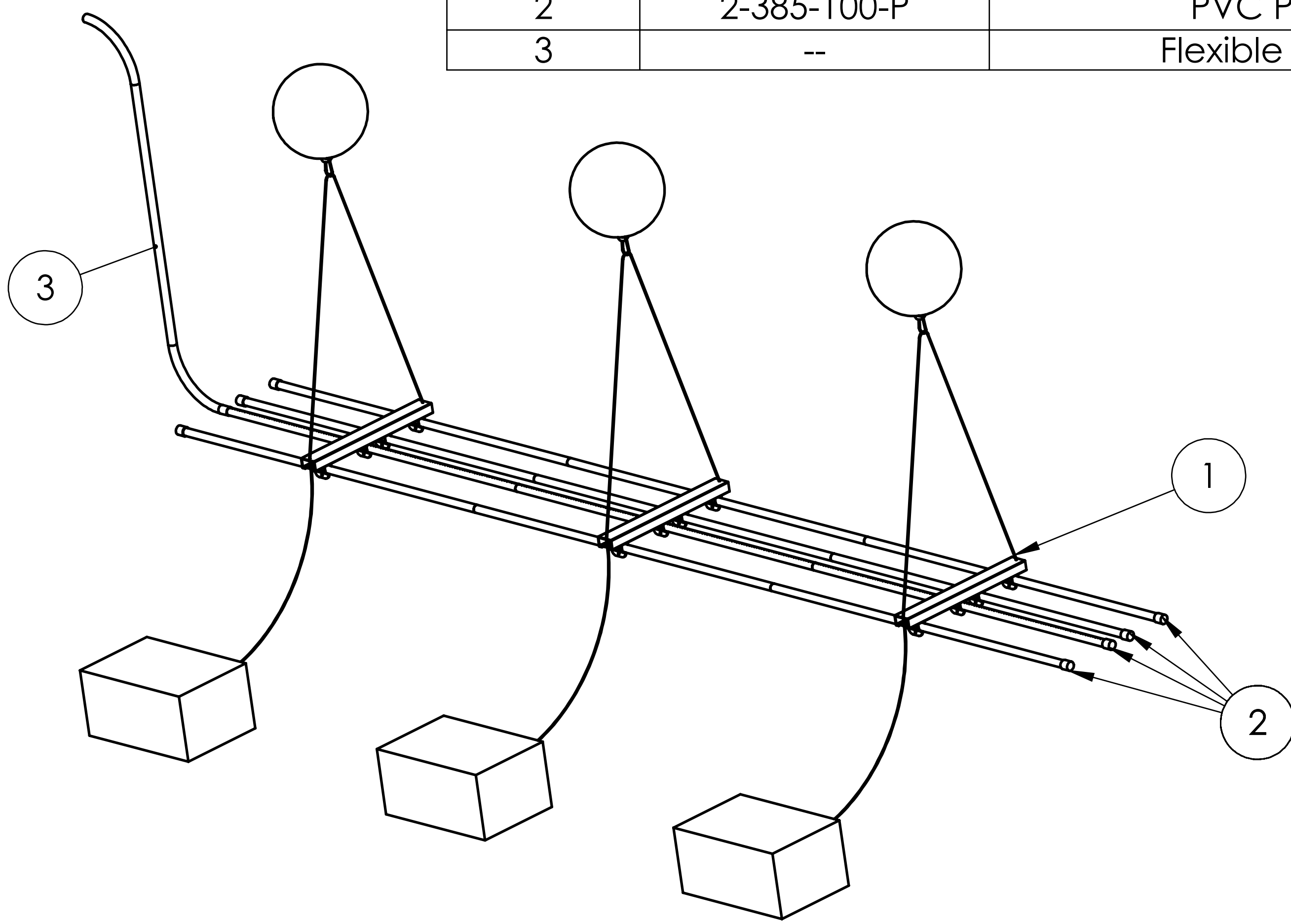
TITLE:

Model Assembly

SIZE A | DWG. NO. 1 | REV 1

SCALE: 1:10 | SHEET 1 OF 4

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1	Model Sub-Assembly	3
2	2-385-100-P	PVC Plug	7
3	--	Flexible Hose	1



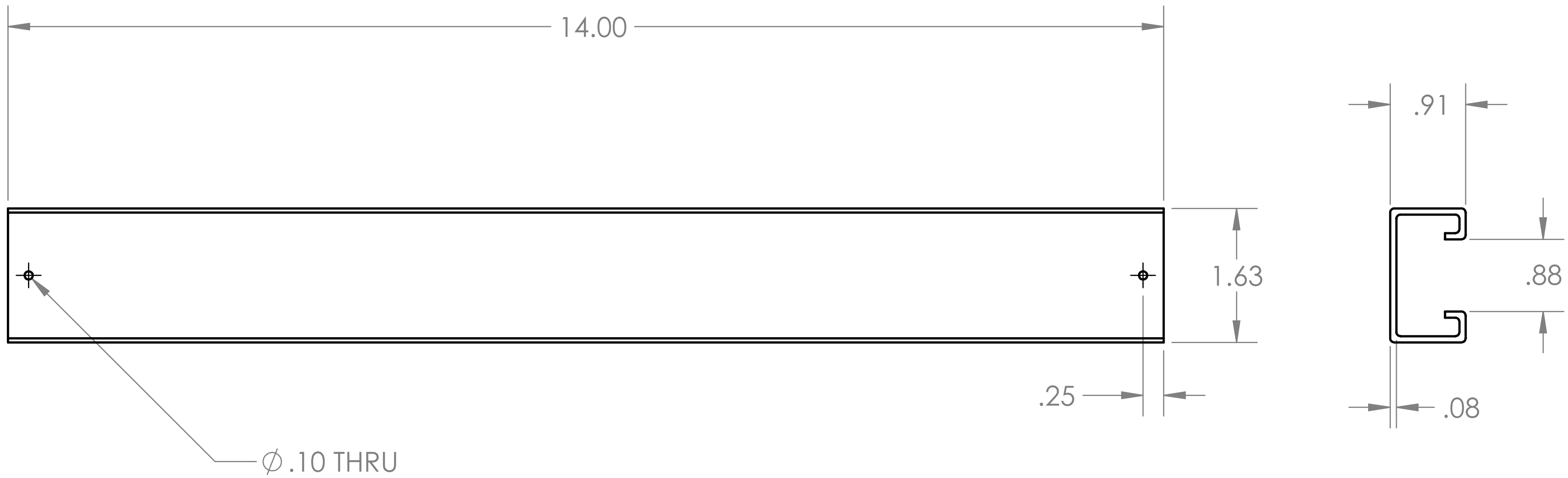
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	CY	2/9/17
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

Combined Assembly

SIZE	DWG. NO.	REV
A	2	1

SCALE: 1:16



	NAME	DATE
DRAWN	CY	2/9/17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

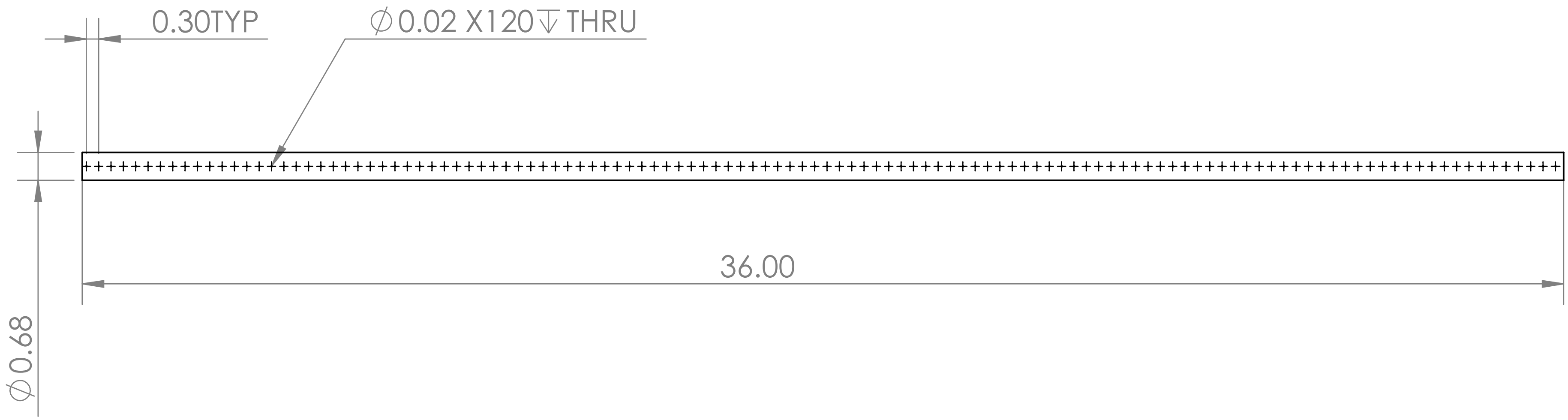
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

TITLE:

Unistrut

SIZE	DWG. NO.	REV
A	3	1

SCALE: 1:2



		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.001
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL PVC 3/8 Inch Stock
NEXT ASSY	USED ON	FINISH NA
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	DCS	02/09/17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

3_8_PVCwithHoles

SIZE A | DWG. NO. 004 | REV 1

SCALE: 1:4 | SHEET 4 OF 4

Appendix J: Bill of Materials

Indented Bill of Material (BOM)
Air Bubble Curtain Anchoring Model

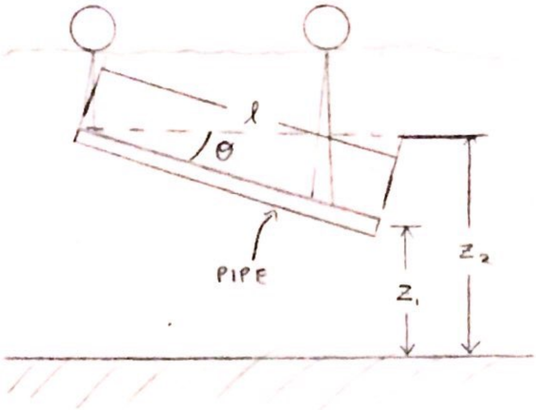
Assembly Level	Part Number	Description	Vendor	Qty	Qty (Feet)	Cost	Cost/Foot	Ttl Cost	Purchases
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4							
0		Final Assembly							
1		Pipes							
2	49035K82	3/8'' Cleaer PVC Pipe	McMaster-Car	------	24	------	$ 0.77	$ 18.48	✓
2	4880K841	3/8" PVC Plugs	McMaster-Car	6	------	$ 0.82	------	$ 4.92	✓
2	33085T79	316 Stainless Steel Strut Channel	McMaster-Car	------	10	------	$ 10.82	$ 108.20	✓
2	3115T94	3/8'' Stainless Steel Strut Pipe Clamp	McMaster-Car	18	------	$ 3.52	------	$ 63.36	✓
1		Anchors							
2	3006.7318	Buoy	Amazon	4	------	$ 8.07	------	$ 32.28	✓
2		Cement Block							
3	20256	Industrial Plastic Pail	Amazon	2	------	$ 9.61	------	$ 19.22	✓
3	------	Eye Bolts	Home Depot	6	------	$ 1.14	------	$ 6.81	✓
3	110110	10 LB Concrete Mix	Amazon	2	------	$ 14.35	------	$ 28.70	✓
2		Wires							
3	3461T26	3/16" Stainless Steel Rope	McMaster-Car	------	20	------	$ 2.98	$ 59.60	✓
3	35155T16	Compression Tool	McMaster-Car	1	------	$ 195.43	------	$ 195.43	✓
3	3883T45	Stainless Steel Sleeve	Mcmaster-Car	20	------	$ 1.34	------	$ 26.80	✓
1		Tank/Test Setup							
2	B01MTKBDK0	Air Pump, AC006 (3cfm)	Amazon	1	------	$ 79.99	------	$ 79.99	✓
2	------	Kiln-Dried Whitewood Stud	Home Depot	2	------	$ 2.83	------	$ 5.66	X
2	IK-021475	Transom-Mount Trolling Motor	Cabelas	5	------	$ 109.99	------	$ 549.95	X
2	------	Clamp Set (4-Piece)	Home Depot	1	------	$ 38.21	------	$ 38.21	X
2	49036	Ettore Grip'n Grab Reach Tool, 32"	Amazon	2	------	$ 16.49	------	$ 32.98	✓
2	EXP1270	12 Volt Lead Acid Battery	Amazon	5	------	$ 16.41	------	$ 82.05	✓
1		Miscellaneous							
2	------	Flexible Hose	Home Depot	1	------	$ 8.87	------	$ 8.87	✓
2	------	Caulk Seal	Miners Ace Hardware	1	------	$ 3.99	------	$ 3.99	✓
2	------	Carabiners	Home Depot	9	------	$ 0.98	------	$ 8.82	✓
2	------	Extra 3/8" PVC Pipe	Home Depot	1	------	$ 5.35	------	$ 5.35	✓
2	------	Hose to PVC Pipe Connector	Home Depot	1	------	$ 2.36	------	$ 2.36	✓
2	------	Extra Key For Lock	Miners Ace Hardware	1	------	$ 3.10	------	$ 3.10	✓

Key:

Purchased/Arrived	✓
Purchased/Shipping	✓
Not Purchased	X

Appendix K: Pipe Angle Uncertainty Analysis Example

PIPE ANGLE EQUATION:



$$\theta = \arcsin\left(\frac{Z_2 - Z_1}{\ell}\right)$$

$$Z = Z_2 - Z_1$$

$$U_Z = \sqrt{U_{Z_2}^2 - U_{Z_1}^2}$$

UNCERTAINTY PROPAGATION:

$$U_\theta = \pm\left[\left(\frac{\partial\theta}{\partial Z}U_Z\right)^2 + \left(\frac{\partial\theta}{\partial \ell}U_\ell\right)^2\right]^{1/2}$$

$$\frac{\partial\theta}{\partial Z_1} = \left(\frac{Z_2 - 1}{\ell}\right)\frac{1}{\sqrt{1-\left(\frac{Z_2-Z_1}{\ell}\right)^2}}$$

$$\frac{\partial\theta}{\partial Z} = \left(\frac{1}{\ell}\right)\frac{1}{\sqrt{1-\left(\frac{Z}{\ell}\right)^2}}$$

$$\frac{\partial\theta}{\partial Z_2} = \left(\frac{1-Z_1}{\ell}\right)\frac{1}{\sqrt{1-\left(\frac{Z_2-Z_1}{\ell}\right)^2}}$$

$$\frac{\partial\theta}{\partial \ell} = \left(\frac{Z}{-\ell^2}\right)\frac{1}{\sqrt{1-\left(\frac{Z}{\ell}\right)^2}}$$

$$\frac{\partial\theta}{\partial \ell} = \left(\frac{Z_2 - Z}{-\ell^2}\right)\frac{1}{\sqrt{1-\left(\frac{Z_2-Z_1}{\ell}\right)^2}}$$

FIRST DATA POINT:

$Z_1 = 3.25$
$Z_2 = 9.75$
$\ell = 46.5625$
$U_{Z_1} = 0.25$
$U_{Z_2} = 0.25$
$U_\ell = 0.03125$

$$U_Z = \sqrt{(0.25)^2 + (0.25)^2}$$

$$U_Z = 0.3536$$

$$\frac{\partial\theta}{\partial Z} = \left(\frac{1}{46.5625\,in}\right)\frac{1}{\sqrt{1-\left(\frac{9.75-3.25}{46.5625}\right)^2}}$$

$$\frac{\partial\theta}{\partial Z} = 0.02169\ in^{-1}$$

CONTINUED ON NEXT PAGE →

$$\frac{\partial \theta}{\partial z_2} = \left(\frac{1 - 3.25}{46.5625}\right) \frac{1}{\sqrt{1 - \left(\frac{9.75 - 3.25}{46.5625}\right)^2}}$$

$$\frac{\partial \theta}{\partial z_2} = -0.04880$$

$$\frac{\partial \theta}{\partial \ell} = \left(\frac{9.75 - 3.25}{-(46.5625)^2}\right) \frac{1}{\sqrt{1 - \left(\frac{9.75 - 3.25}{46.5625}\right)^2}}$$

$$\frac{\partial \theta}{\partial \ell} = -3.028 \times 10^{-3}$$

$$U_\theta = \pm\left\{\left[(0.02169\,in^{-1})(0.3536\,in)\right]^2 + \left[(-3.028 \times 10^{-3}\,in^{-1})(0.03125\,in)\right]^2\right\}^{1/2}$$

$$U_\theta = \pm 0.00767\ rad$$

$$(0.00767\ rad)\frac{360\ degrees}{(2\pi\ rad)}$$

$$U_\theta = \pm 0.53^\circ$$

Appendix L: Pipe Angle Test Data

Table 1: The data taken from the pipe angle tests that were performed using a model of the bubble curtain in Diablo Canyon. The table displays the pipe angle extrapolated from the height of the end of the pipe. The other end was held at fixed constant by a buoy and the length of the pipe remained the same. The uncertainties for all the values are listed as well. The pipe angle uncertainty had to be obtained through propagation. Observations for each section of the pipe are given. Each symbol refers to a specific bubble output rating and can be deciphered from the key.

End of Pipe Height, Z_1 [in]	Uncertainty of Z_1, U_{Z1} [in]	Change in Pipe Height ΔZ, [in]	Uncertainty of ΔZ, $U_{\Delta z}$ [in]	Pipe Angle, θ [◦]	Uncertainty of ϑ, U_{ϑ} [◦]	Observations*			
						Section 1	Section 2	Section 3	Section 4
3.25	0.25	6.50	0.35	-8.0	0.439	+	-	-	-
4.5	0.25	5.25	0.35	-6.5	0.438	+	-	-	-
8	0.25	1.75	0.35	-2.2	0.435	+	|	-	-
8.5	0.25	1.25	0.35	-1.5	0.435	+	-	-	-
9.75	0.25	0.00	0.35	0.0	0.435	+	|	-	-
10.75	0.25	-1.00	0.35	1.2	0.435	+	|	|	-
12	0.25	-2.25	0.35	2.8	0.436	|	|	+	+
13	0.25	-3.25	0.35	4.0	0.436	+	+	+	+
13.25	0.25	-3.50	0.35	4.3	0.436	+	+	+	+
17	0.25	-7.25	0.35	9.0	0.440	|	+	+	+
17	0.25	-7.25	0.35	9.0	0.440	|	|	+	+
17.25	0.25	-7.50	0.35	9.3	0.441	|	+	+	|
21	0.25	-11.25	0.35	14.0	0.448	|	+	+	-
21.5	0.25	-11.75	0.35	14.6	0.450	|	+	+	-
25.5	0.25	-15.75	0.35	19.8	0.463	|	+	+	-
26.5	0.25	-16.75	0.35	21.1	0.467	|	+	+	-
29.75	0.25	-20.00	0.35	25.4	0.482	|	+	+	-
31	0.25	-21.25	0.35	27.2	0.489	|	+	+	-
33.25	0.25	-23.50	0.35	30.3	0.504	|	+	+	-

*Key for Observations: "+" = Several Bubbles, "|" = Some Bubbles, "-" = No Bubbles