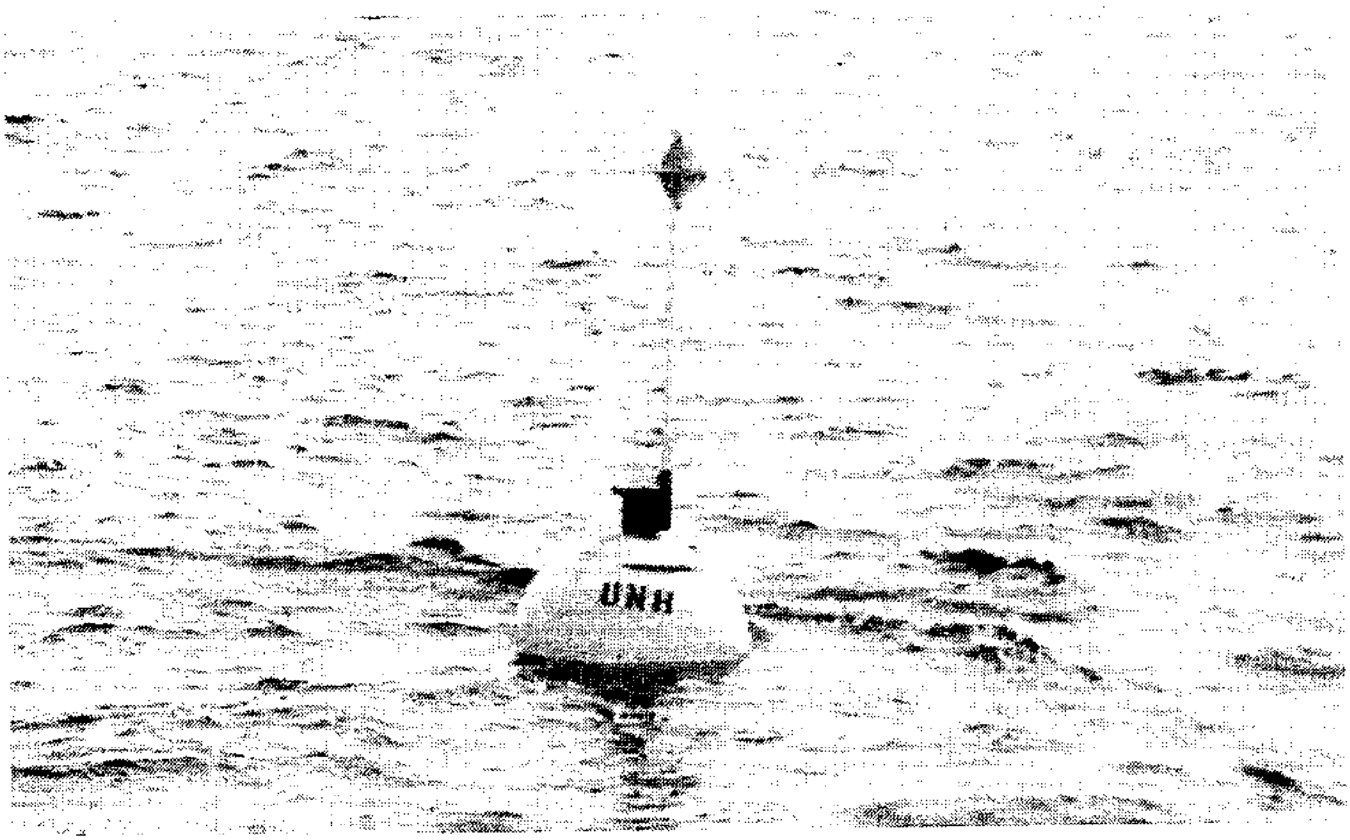
NHU-T-01-002 C2

Apparatus to Capture *Stoloteuthis luecoptera*



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Sea Grant
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Apparatus to Capture *Stoloteuthis Luecoptera*

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ABSTRACT

Stoloteuthis leucoptera is a small, bioluminescent squid that lives in water deeper than 400 ft in the Gulf of Maine. Little is known about how or why this squid creates luminescence or how it develops. Involved in the study of this squid is Gabriela Martinez, a PhD. candidate in the Zoology Department of the University of New Hampshire. The project team was commissioned to design, build, and test a trap to catch *Stoloteuthis leucoptera*. The trap was built with a stiff wire frame, clear acrylic walls and a light source as bait. Although the trap did not catch any squid during the initial test, minor modifications will enable the trap to function as intended. The deep water mooring system proved to be extremely robust, surviving a severe Nor Easter with high winds and 25 ft waves with no damage or relocation.

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INTRODUCTION

Purpose

Stoloteuthis leucoptera is a benthic squid from the family *Sepiolidae*. It is found in the North Atlantic in depths ranging from 150 M to 300M. Adults grow to be about 2 inches Dorsal Mantle Length. Interest is centered on this specie because it is a family of cephalopods whose phylogeny has not yet been well resolved. In other words, their relationships to the real squids and to the cuttlefish is not known although they appear to be exactly in between. These squid are also bioluminescent. They have a ventral light organ or photophore whose evolutionary origin is not known nor its embryology. Also, the source of light in this photophore is not known. It could be a bacterial symbiotic system, where bioluminescent bacteria of the genus Vibrio or Photo bacterium are housed. The other possibility is that they synthesize their own bioluminescence by producing their own luciferin protein and luciferase enzyme. The hypothesis is that they are bacterial luminescent based on their close relatives *Euprymna scolopes*, which is a shallow water benthic Hawaiian species. The only problem with this theory is that *Stoloteuthis* and *Euprymna* have completely different habitats.

Previous Work

Stoloteuthis leucoptera are frequently found in deep water trawls in the North Atlantic and there are also recorded encounters in the Mediterranean. Shown at right in figure 1 is a plot of recorded *Stoloteuthis leucoptera* capture. The figure

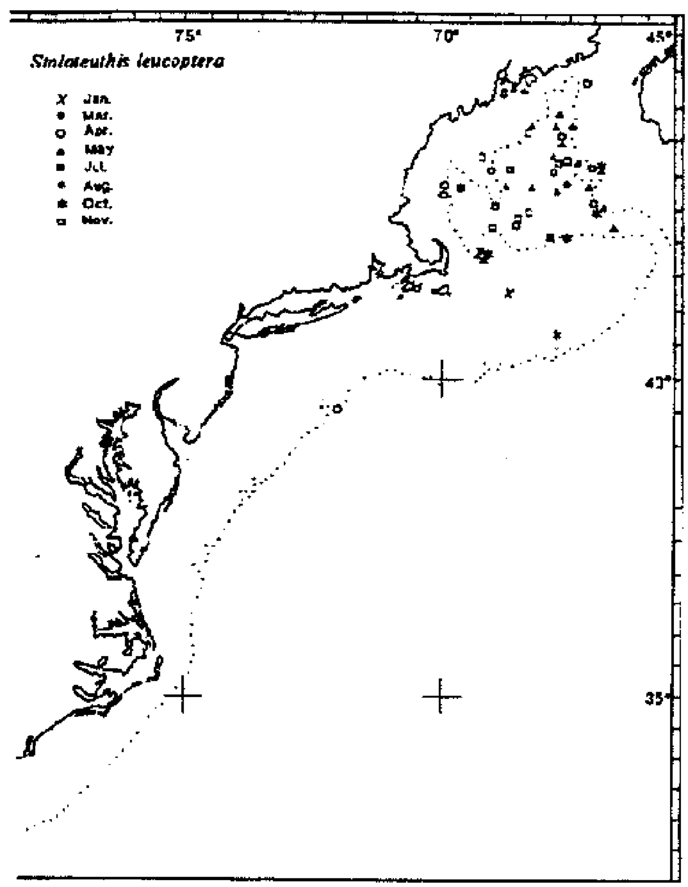

Figure 1: Locations of recorded capture

contains much of the east coast and each recorded capture is noted with a symbol on the upper left. Recorded captures are in depths between 400 and 1000 ft. Gabriela Martinez has previously been on the NOAA Albatross IV for inventory cruises in the Gulf of Maine in an attempt to obtain specimens of the squid. Live specimens were not obtained because the method of capture severely stresses the animals.

Objectives

The objectives of this project were to design, build, test a squid trap.

Approach

Stoloteuthis leucoptera has large eyes as can be seen in figure 2 although it lives at a depth where no light penetrates. It can therefore be assumed that light would draw its attention as it does many other deep-water animals. *Stoloteuthis leucoptera's* bioluminescence is presumed to be used for communication and/or attracting prey. If this is true, a light of similar color to its own will also spark interest in the squid.

Figure 2: Stoloteuthis leucoptera

CHAPTER II

TRAP DESIGN AND CONSTRUCTION

Lure System Design Criteria

- **Attraction of desired species**

  The main purpose of the lure is to attract squid into the trap. This could be by scent, taste, visual, or combinations of them.

- **Mechanical Integrity**

  The environment where this lure will be deployed is about 50miles off shore in 600feet deep water. It must withstand the pressure of up to 20 times the atmospheric pressure, and the impact from the deployment process. It might also encounter other environmental factors, such as a large fish.

- **Duration of Operation**

  The plan is to leave the trap out about a week at a time. The lure system needs to last at least a week to increase the chance of catching the squid.

- **Size Limitations**

  The lure should fit inside the trap with enough room for holding space, and other components.

- **Cost**

  The lure needs to be built within our set budget.

Lure System Design

To attract a creature, there are basically two options: by scent/taste or by sight. The *Stoloteuthis Leucoptera* is bioluminescent, and their close relative, *Euprymna*, also a bioluminescent, is attracted to light. This evidence suggests that the target squid is attracted to light. The light based system is easier to control because it's useful life depends only on the capacity of the battery. *Stoloteuthis leucoptera* emits a bluish light, the wavelength that travels the most distance in seawater, which is 500nm and can be seen in figure 5. It is for these reasons that the light lure was chosen.

The most severe environmental factor was the pressure at 600ft. There were two basic options to protect the light system at this depth. The first option was to purchase a pressure-proof battery and light. The advantage of this was that it's already designed to withstand high pressure. However, there were very limited options and most of which were not ideal for the squid trap. Most deep-sea lights require a lot of power because they are designed for cameras. Since the lure needed to last for a week a large amount of batteries would be needed. This option was not practical for our purpose because of money and the space constraints. These lights were also highly directional which would provide limited exposure. The second option was to encase ordinary lights and battery in a pressure tight vessel. This opens up a whole field of light and battery options and makes optimizing the light source much easier. These components would also be much cheaper as they are designed for a much friendlier environment. This option made the most sense for the project.

However, the second option would work only if a pressure resistant vessel could be obtained. One of the constraints was that the pressure vessel had to be transparent over some portion of its surface. The first option was to design and build a pressure vessel. This of course introduces many uncertainties into the system because no matter how well designed the vessel was, it would be basically untested. The design would also most likely be complex because light must be allowed to travel in many directions. Options for testing this vessel were also severely limited.

Fortunately, a perfect solution was found: A deepwater instrument housing. The entirely transparent instrument housing is made of low expansion borosilicate glass and is tested up to an equivalency depth of 6000m. It was purchased for $395 from Benthos Inc., which is located in Falmouth MA. Literature on sphere specifications can be seen in appendix A, Glass Instrument Housing. The sphere is made of two halves, thus components inside can be accessed very easily. Positive pressure on the outside of the sphere keeps the sphere sealed. Normally a vacuum port is added to the sphere but this attachment was $120. It is possible to seal the sphere by heating the air inside, closing it, and then cooling the sphere. This way the gas inside the sphere becomes less active as it cools and therefore creates less pressure. The watertight seal is maintained by placing a pliable butyl rubber strip around the seam and covering it with three layers of black vinyl tape. This method was more time consuming than the vacuum port but was feasible and saved money. It has enough space inside to install batteries and other components, yet

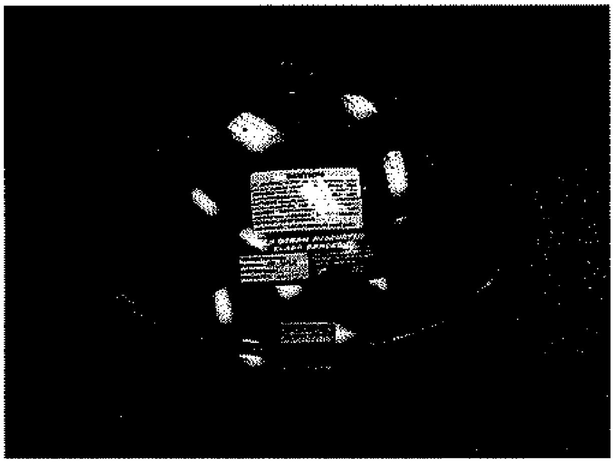

Figure 3: glass instrument housing

small enough to fit inside the trap. It was also safer to put electric circuits inside the sphere because it was made out of non-conducting glass.

The next step was to find a light source that is bright enough, and a battery to power that light source. After several different considerations, it was decided that LED's, Light Emitting Diodes, were the best option. Compared to other types of light sources, LED's consume very little power, yet it still produces a bright light, from 600mcd 28,000mcd. A light with a small viewing angle and 28cd luminous intensity is too bright to look at. LED's are also more tolerant to pressure change than traditional light bulb because they do not contain any gas.

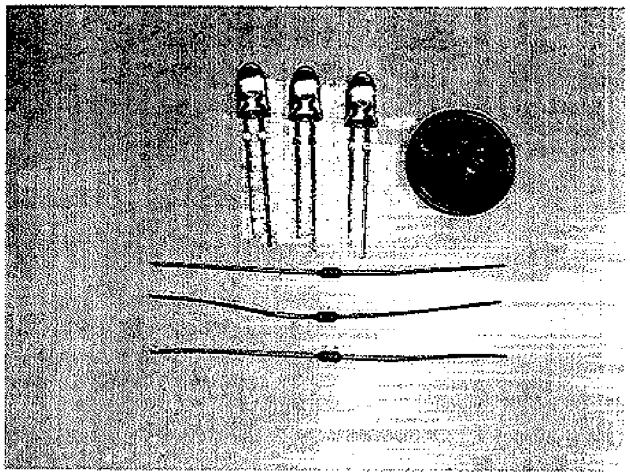

Figure 4: LED's and resisters

It also produces significantly less heat compared to the light bulb. The LED is very small, less than 1cm wide, thus it was possible to line up several LED's and fit them inside the sphere. The LED is made of a tough epoxy, which means it is more durable and shock resistant than conventional incandescent light bulbs.

Figure 5 below is a graph of energy penetration verses wavelength and shows a

Figure 5.7 Energy spectra at a depth of 10 m for: pure water (0), clear oceanic water (1), average oceanic water (2), average coastal water (3), and turbid coastal water (4).
Inset: An energy spectrum at 100 m depth in clear oceanic water (1a) compared with that for 10 m in turbid coastal water (4).
Compare this Figure with Figures 2.5 and 5.1 and note that it represents only a small part of the spectrum shown in Figure 2.5.

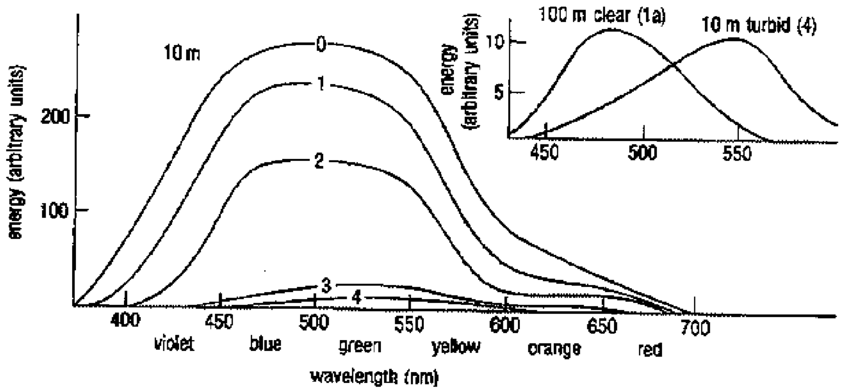

Figure 5: Energy Spectrum of light

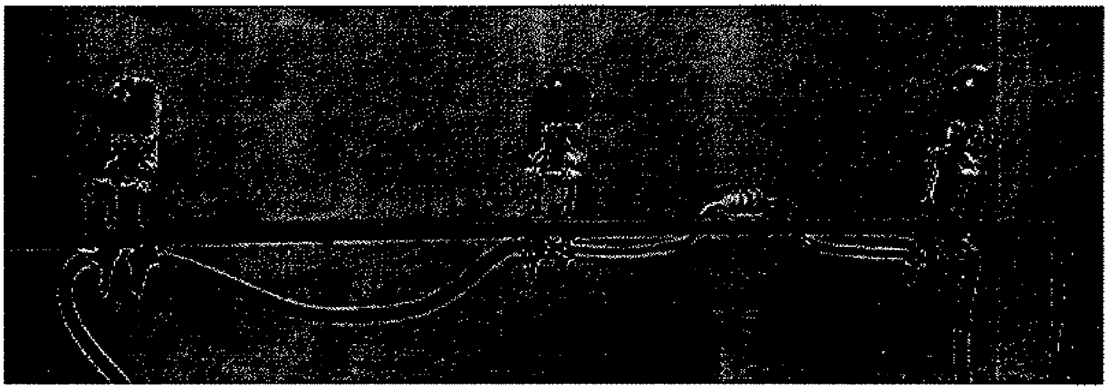

Figure 6: LED's in series

peak at 500nm, which is blue green light. This means that light of this wavelength will travel the farthest distance in ocean water. The brightest LED found fortunately produced light at 500nm with 28,000mcd luminous intensity over a 15° viewing angle. Detailed specifications for this LED can be seen in appendix A, LED Specifications. It was also presumed to be close enough to blue to be attractive to the squid. The circuit configuration was determined by comparing the specifications of the LED and the power output of the battery. It was calculated that it was possible to have 3 LED's and a resister in series with a 12volt battery. Shown at top is a diagram of the LED circuit. Three LED's and a resistor can be placed in series with a 12-volt battery. The resistance required was found to be 75Ω. Calculations for this configuration can be seen in appendix A, Resistance Calculation. The battery could not been too large due to the set dimension of the sphere. A simple program was created that took the dimensions of batteries and tested their compatibility with the sphere. Two 12 V batteries, rated for 20 Amp-hours were determined to provide the most power for the space allowed. These batteries were capable of running 30 LED's for at least 8 days. Battery duration calculations and specifications can be seen in appendix A, Battery Duration. Each battery had an independent LED loop which provided some redundancy to the system. If one of the circuits fails, the other should still function. The LED can be easily mounted on the circuit board with solder, and does not require any special equipment or skill. The LED's are also relatively inexpensive.

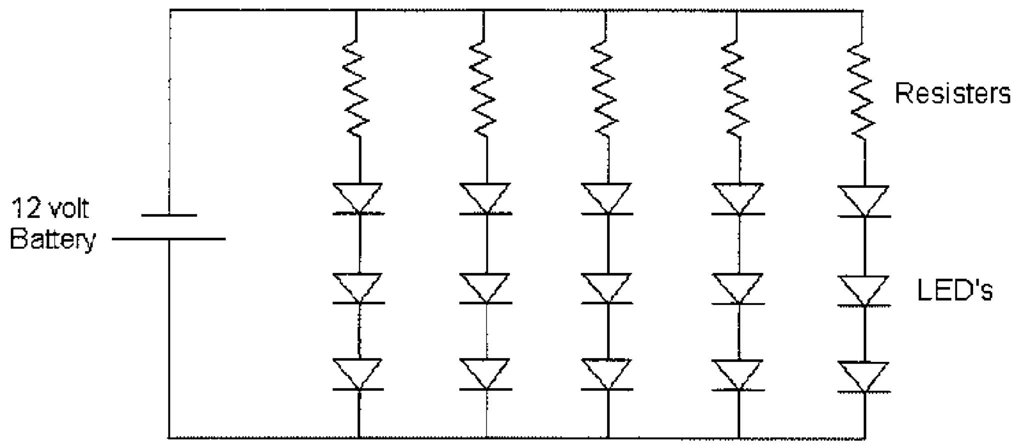

Figure 7: LED circuit configuration

The batteries and LED circuit could not be directly mounted to the inside surface of the sphere because it is very difficult to attach fasteners to the smooth surface. Instead a frame made of ½" PVC piping was built to restrain the components. PVC was chosen because of its ease of construction, accessibility and its cost. This frame was constructed so that each corner would contact the inner wall of the sphere, holding the battery in place. Black vinyl tape was placed at each corner to prevent the frame from sliding. Finally, the battery was tied down to frame with zip-ties.

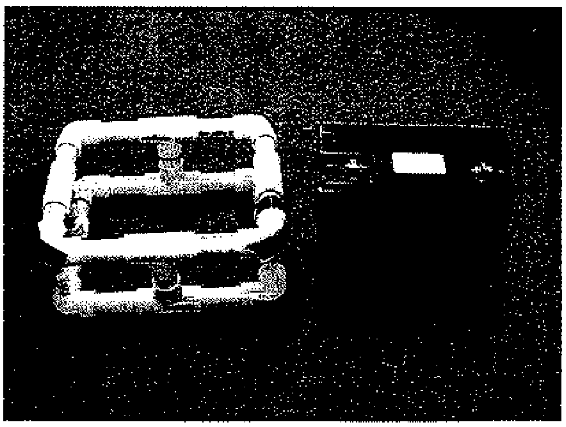

Figure 8: PCV pipe frame and battery

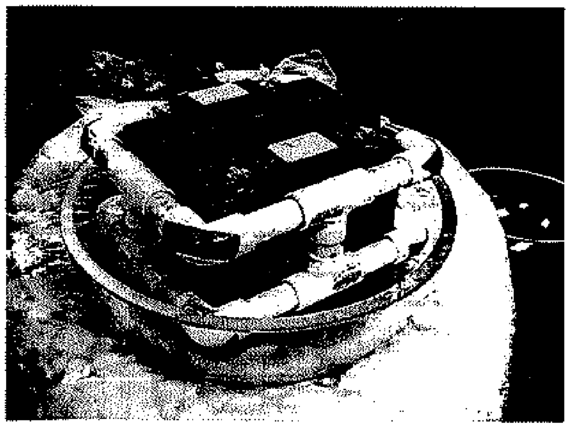

Figure 9: Frame and battery configuration

The LED's were mounted on a ½ inch wide strips of circuit board. Each strip had 3 LED's in series with a resistor, and each battery was connected to 5 of these strips in parallel. The LED strips were set up to face out in all directions. Strips of perfboard were used to mount the LED strips to the frame. Fishing line was used to tie the strips together because it is strong and does not conduct electricity.

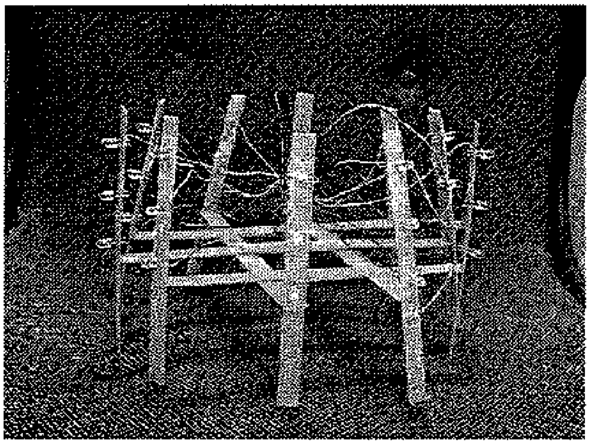

Figure 10: LED circuits set up

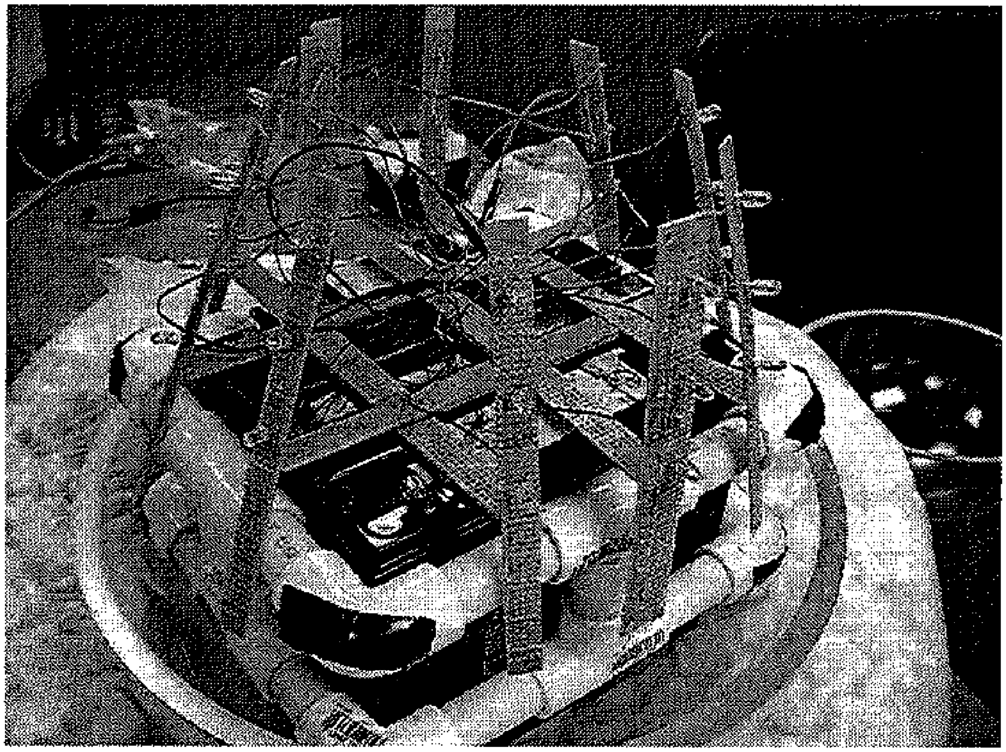

Figure 11: Complete set up of lure system

Trap Design Criteria

- **Physical size**

  The trap must have room for the lure to fit inside and still accommodate squid.

- **Mechanical Strength**

  This trap must withstand the pressure at depth of 600ft, and any impact it may experience from chains, lines, or during the deployment/retrieval process.

- **Transparency**

  The light is used to attract the target squid, which is installed inside the trap. Thus the light must be visible from the outside of the trap.

- **Restraint configuration**

  Stoloteuthis leucoptera is less than an inch wide and about 2 inches long. There cannot be any openings that are large enough for them to go through other than the entrance.

- **Cost**

  The trap must be built within budget.

Trap Design

The first step in building the trap was to find a frame that was strong enough for this purpose. It needed to be strong and still let light pass through. Thus a commercial lobster trap frame was chosen. The strength and durability of the trap was already proven by the usage that it gets by the lobster fishing. The wire mesh of the trap should provide enough protection for the inside, and should not prevent light from passing through. The trap already has a large hinged panel on the top for access. The lobster trap was relatively cheap, easy to obtain, and easily modified if required. The trap was special ordered from B & B Trap Co. in York, Maine, at cost of $23.

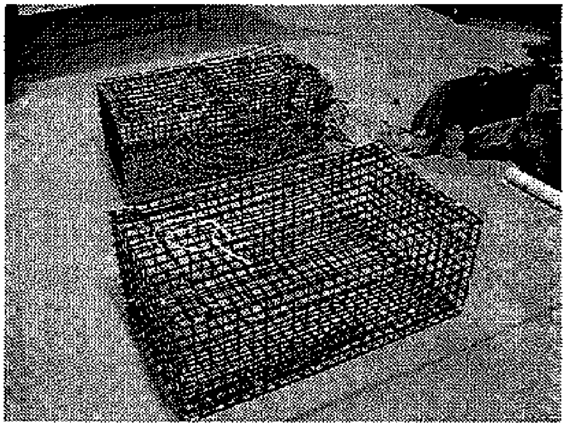

Figure 12: Lobster trap frame

The mesh of the trap was too large for the squid so the inside of the lobster trap was covered with acrylic sheets. The acrylic sheets were somewhat flexible, durable, and resistant to shattering. Lexan was considered for the inside paneling because it is more durable than acrylic. However, acrylic has 90% light transmission and Lexan has only 60%. The top panel of the trap was covered with acrylic sheeting as well to limit the amount of water flow through the trap and the stress on the squid during retrieval. Since it is completely transparent, the light should be clearly visible from outside. The acrylic sheets were also easy to work with, and were available inexpensively at hardware stores.

Instead of acrylic, thick CPVC sheeting was used for the bottom of the trap because it has less of a tendency to shatter and was free. The bottom, where the glass

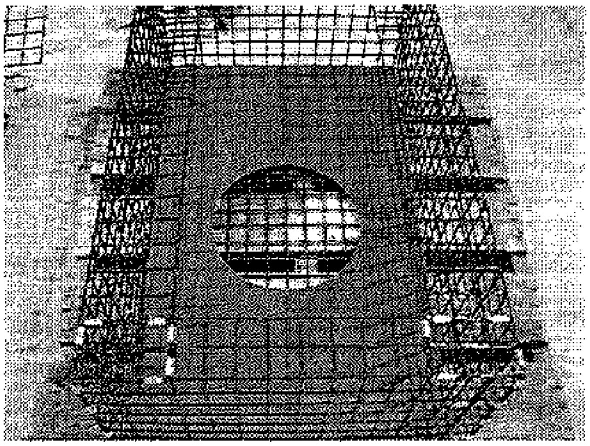

Figure 13: CPVC sheeting for bottom

sphere was to be installed, needed to be as strong as possible. The bottom of the trap did not need to be transparent, since it sits on the top of the anchor. The bottom two inches of the trap was sealed with silicon sealant. This should keep some water at the bottom of the trap so that the squids would still be submerged in the water when the trap was retrieved. All of the plastic sheets were attached to the frame by zip-ties.

The trap was divided into three chambers by acrylic sheets. The sphere was placed at the middle chamber at the center of the trap. It was set up so that the sphere sits in a hole on the floor of the trap, and the bottom 3 inches of the sphere is actually outside of the trap. This makes the light source placed at the center plane of the trap, and prevents the sphere from moving. A protective cage was attached to the bottom of the cage to protect the sphere where it was exposed. Rubber tape was placed

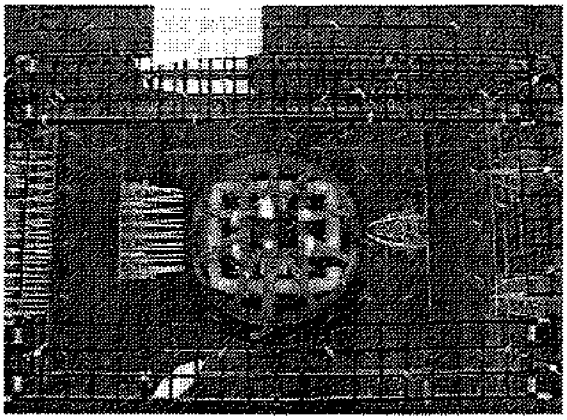

Figure 14: showing three chambers with sphere

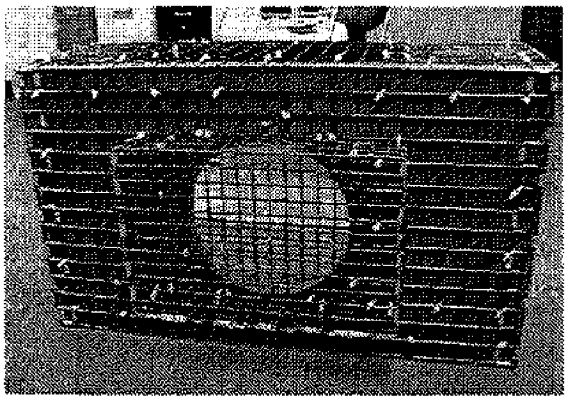

Figure 15: Protective cage underneath trap

around the rim of the hole to form a watertight seal and protect the sphere. The sphere is tied down to the trap by zip-ties through two loops of string attached directly to the bottom frame of the trap. The sphere can be removed from the trap easily, and the trap does not need to be resealed.

The most important component of the trap was the entrance in that it must allow the squid in with as little resistance as possible but also prevent them from leaving. An entrance with moving trap door was considered, but moving parts would make construction difficult and reliability a concern. It was decided to use a stationary entrance with two different shapes: rectangular and circular. The different types of entrance would increase the chance of a squid entering the trap, in case one of the entrances discourage them.

The rectangular entrance was made with pieces of acrylic sheets put together into V-shape. The outer wall entrance was made larger to increase the chances of squid entering the trap. The inner entrance was smaller to increase the chances they would stay. The openings on the wall were about 2 inches high, and 12 inches wide on the outer wall and 6 inches on the inner wall. The entrances were put together and secured on to the trap by marine sealant/adhesive and zip-ties. The circular entrance was made with the top portion of a 20 oz soda bottle because it had the right cone shape and size. Two entrances were placed on the outer wall and one was placed on the inner wall. All of the

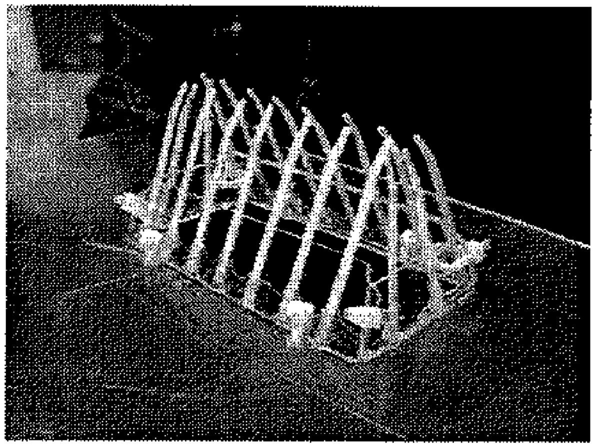

Figure 16: Rectangular entrance

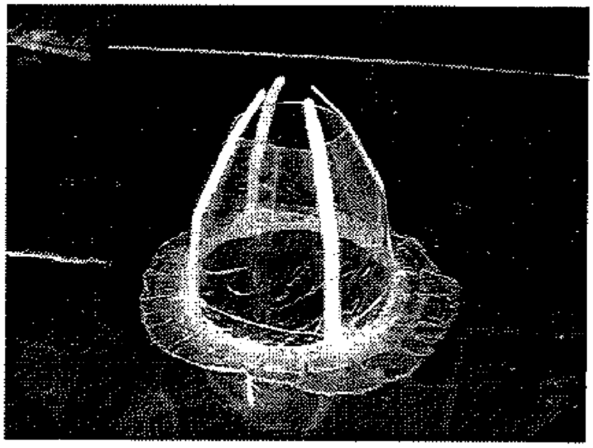

Figure 17: Circular entrance

pieces were glued to the wall, pointing inward, with extra plastic sheeting to increases the contact area of the glue. Both types of entrances had the inner edge lined with the "exit prevention device." These were made out of end pieces of the zip-ties, pointing inwards. It is very easy to push into the trap, however, it is difficult to find a way out.

CHAPTER III

MOORING SYSTEM DESIGN AND CONSTRUCTION

Major Considerations

There are two factors that can affect the mooring system and cause it to fail. One is human interference and the other is environmental interference, such as wave action, tides, etc. Human interference can deliberate or unintentional. Deliberate contact, such as cutting mooring lines, would most likely occur at the surface so the surface floats must be designed with this is mind. Unintentional interference occurs when a ship collides with the surface buoy. Fishing gear and trawl nets may also become entangled in mooring lines or bottom gear.

Ideally, the system would be tested in the warmer months when the sea is more

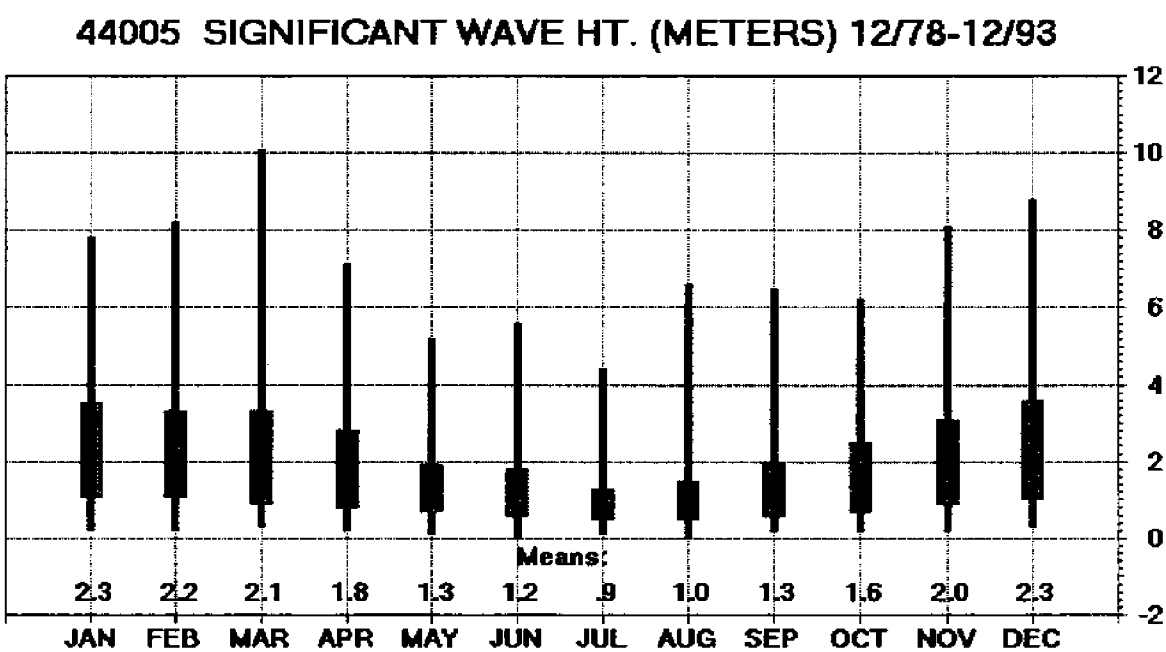

Figure 18: Significant wave height at buoy 44005

sedate. However, time constraints only allow for a March deployment test. Shown in figure 18 is data taken from buoy 44005, which is located in the Gulf of Maine. The average significant wave height between 1978 and 1993 is 2.1m for the month of March. This is the 4th highest. March also has the highest recorded significant wave height at 10m. This is the wave height that must be designed for. The "hundred year wave" must be considered as well, which was taken as 100ft.

Final Design

Initial research showed that the components of a complete mooring system, including rope, buoy and anchor would be beyond the project budget. The alternative to purchasing everything outright was to borrow as much equipment as was possible. The Ocean Engineering department, specifically Open Ocean Aquaculture donated the use of a significant amount of gear. Shown in figure 19 is the final design of the mooring

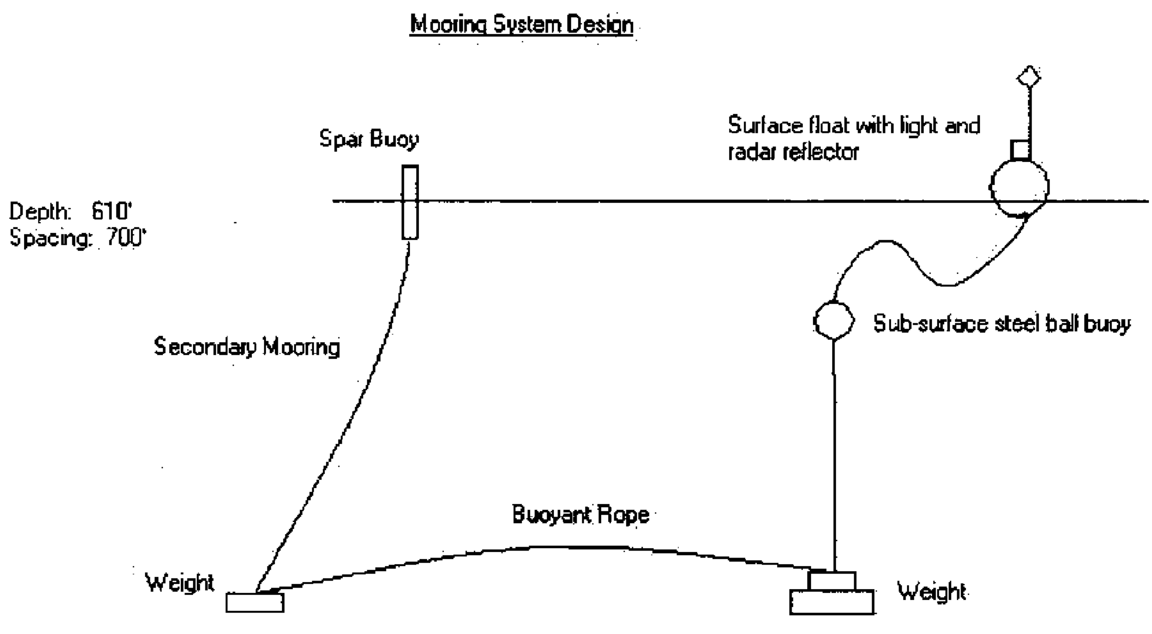

Figure 19: Mooring system design

system.

The system is composed of two mooring lines and an intermediate ground line. The mooring leg on the right was the original design but the second leg was added for insurance against failure of the primary line. Aside from this, the major features of this design are the sub-surface buoy, the s-type curve between the sub-surface and surface buoy, and the buoyant intermediate rope.

Primary Mooring

Sub-Surface Buoy

The purpose of the sub-surface buoy was to keep tension on the lower leg of the mooring line. This keeps the mooring from pounding on the trap. It also functions as a buffer between the sub-surface buoy and the anchor. Wave energy decays with depth so a surface float placed at 100ft or deeper would not feel the waves. This is advantageous for any mooring system because movement is what causes failure. If the trap and anchor can be kept static, then chances of survival increase. This also makes a more welcoming setting for squid.

The problem with having a sub-surface buoy is that the mooring line can become entangled. However, this can be avoided with an S-type configuration, which can be seen in figure 19. This "S" is created by using both negatively and positively buoyant ropes spliced together. Our system uses ¾" nylon with a specific gravity of 1.14 and ¾", buoyant polysteel with specific gravity of 0.93. The polysteel is attached to the top of the sub-surface float. Nylon is shackled to the bottom of the chain attached to the surface buoy and spliced into the polysteel. By balancing the buoyancy of each rope, an "S" is created. The mooring line therefore floats off of the top of the sub-surface buoy and sinks off of the bottom of the surface buoy. The amount of rope used allows the surface buoy to travel with waves, tides, and currents but the rope will not become entangled in either the sub or surface buoys at any time. The calculations that accompany this line of thought can be seen in appendix B, "S" Configuration Buoyancy Calculation.

There were two options for a sub-surface float. The Ocean Engineering department has trawler balls, seen at right in figure 20, which are rated to 450m and have 7lbs of buoyancy. A configuration of several balls could provide the buoyancy needed. However, this is an untested and unreliable design. The other option was to purchase a sub-surface buoy. Steel balls, syntactic foam, and glass balls are all used for sub-surface buoyancy. A 28 " steel ball with 350lbs of buoyancy and costs $800. A 28in steel ball was purchased from Peter Clay of Mooring Systems in Cautamet MA with a significant discount for $200 and can be seen at right in figure 21. Dr. Ken Baldwin, head of the Marine Program, also agreed to cover half of the cost if the ball was donated to the Ocean Engineering department at the termination of ACSL.

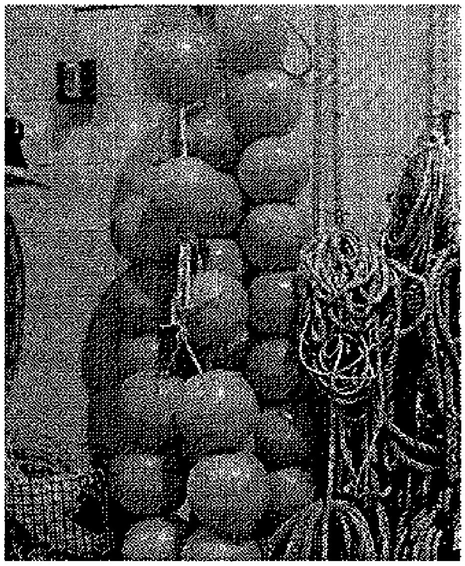

Figure 20: Trawler balls

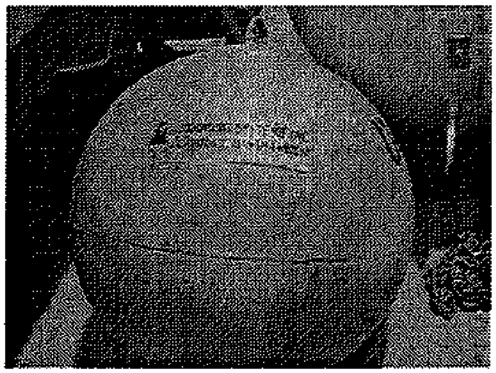

Figure 21: Steel sub-surface buoy

Primary Surface Buoy

The OE dept., specifically OOA, Open Ocean Aquaculture, owns several 37" steel balls. One of these 37" spheres, a picture of which can be seen at right in figure 22 was used as the primary surface buoy. These spheres cost $2000 and similar buoys are on the same price scale. The cheapest alternative was a cylindrical, foam buoy for $500. The steel ball is more reliable and free of charge. The only difficulty with the steel ball were that the only attachment points are two opposing rounded tabs with one inch holes. This is a problem because it does not leave much to attach a radar reflector or buoy light to. These buoys are also good wave followers and energetic surface floats, which is bad for our system. The movement of the buoy with 750lb buoyancy was damped by adding 300 lbs of 1" long link chain. This was also donated by OOA in 5ft sections. The top three shackles along with the connection to the buoy were welded to prevent shackle failure.

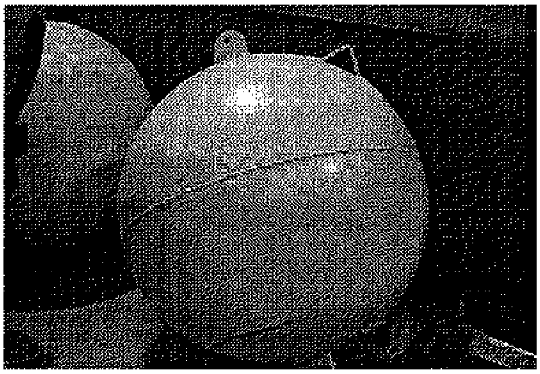

Figure 22: 37" steel ball

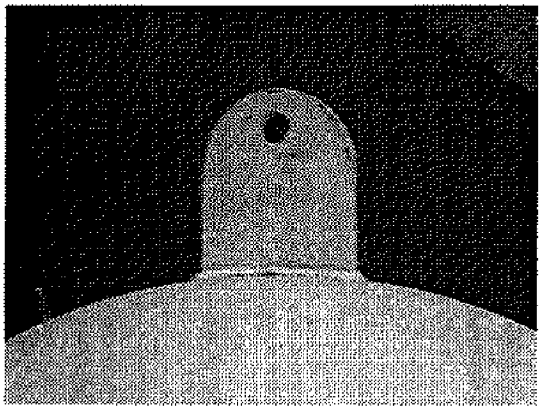

Figure 23: Rounded tab on steel ball

Chief Quartermaster Jack McLaughlin of the USCG recommended adding a light and high-flyer to make the buoy more visible and prevent accidental human interference.

However, all there was to attach such a device was the 5/8" tab with a 1" hole seen in figure 23, as mentioned earlier.

Figure 24: Steel bracket on the primary surface buoy

A bracket was designed, fitted, and built on the buoy to act as a platform for the light and to secure the high flyer to the buoy. Again the materials were donated by the OE dept. Quarter inch steel plate was used for the platform and 2" and 6" stock was used for the rest. A 1 ¼" pipe was attached to the side as a sheath for the high flyer (radar reflector). This bracket can be seen above in figures 24.

The high flyer is composed of 10"radar reflector and a 5 ½' of 1" aluminum pipe, both of which were purchased from NEW England Fishing Gear in Portsmouth NH. As you can see in the photo two slots were cut in the 1 ¼" steel pipe and two U-bolts were fitted to these grooves in order to secure the pipe. A two nautical mile light was purchased from Watermark Navigation Systems for $150. This light was originally priced at $259 but it was surplus from a company that was taken over. A Zinc anode was added to the bottom of the top plate as

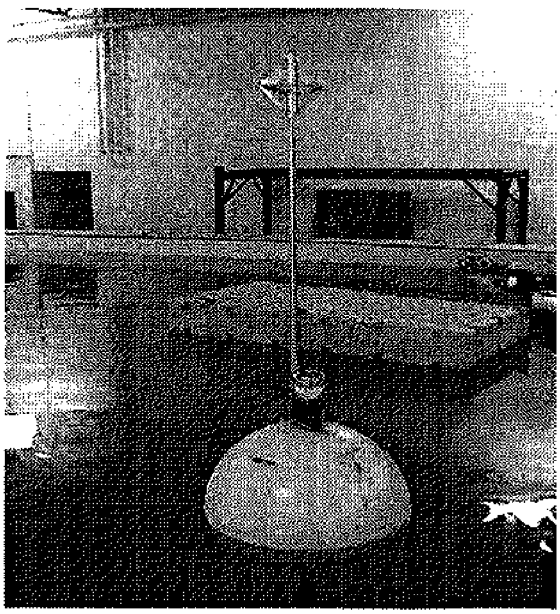

Figure 25: Complete primary surface buoy

insurance against corrosion. The bracket was also painted. The finished product for the primary buoy can be seen in figure 25.

The US Coast Guard must approve all private aids to navigation. Chief Quartermaster McLaughlin also suggested using yellow for the signal light and as the color for the buoy as it is the USCG designated color for aids classified as "other". He also suggested staying away from hazards in the Gulf of Maine such as unexploded depth charges. Fishermen were also consulted for an ideal site.

Primary Anchor

The primary anchor was made of two concrete blocks in a steel framework. The concrete blocks were made from excess concrete and forms from another project. They were made by pouring the extra concrete into two 2 X 3 ft, box shaped, black plastic floats. The two blocks can be seen at right in figure 26. Each block weighed 500lbs in air and 230lbs in water. These values were obtained using an Omega Engineering model LC101-5k 5000lb load cell. When combined with the iron frame and relevant chain, the anchor weighed 1200lbs in air and 700lbs in water. This of course made the anchor difficult to handle. Construction took place in the OE high bay, which has a ½ ton chain fall and a 2-ton stationary crane. When completed our anchor would be too heavy for the chain fall, so the crane had to be used. However, the welder needed to make the frame was also quite unwieldy and

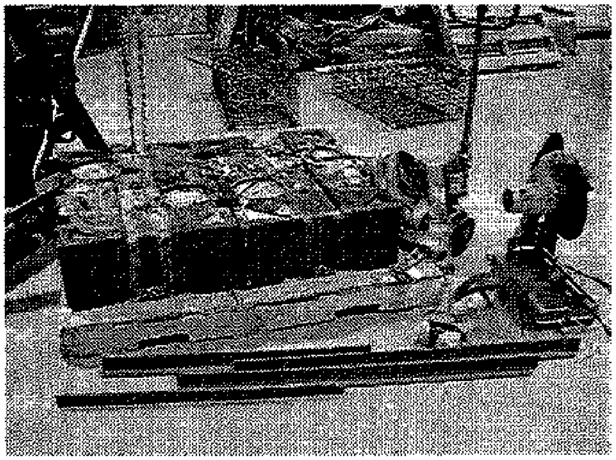

Figure 26: Concrete blocks

located on the opposite side of the building. The solution to this problem was to either make the anchor in sections or make it mobile. The sectioned anchor frame was more complex and prone to failure so the mobile idea was used. The solution was to build a platform for the anchor that could be moved with a pallet jack, which was rated for 3500lb. This way the anchor could be moved to the crane upon completion. Glen Rice performed all welding.

Angle iron was used for the frame because it cupped the edges of the block well and was available free of charge from the OE department. Flat 2" X ¼" steel was used for the intermediate lengths as you can see in the picture at right. The corner pieces were added to reinforce the joints but also to follow the contours of the bottom of

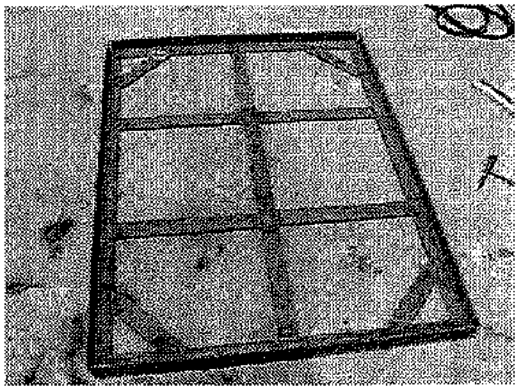

Figure 27: Angle iron frame

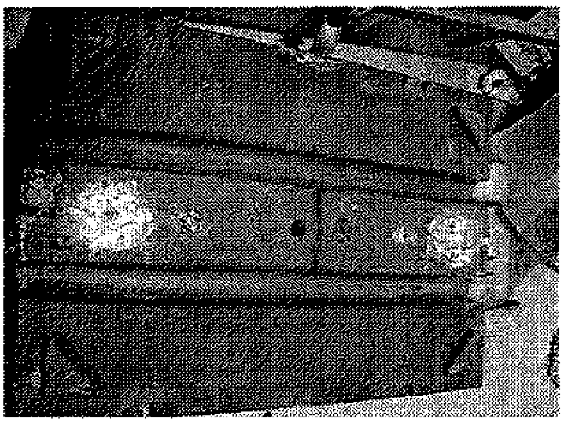

Figure 28: Bottom of float

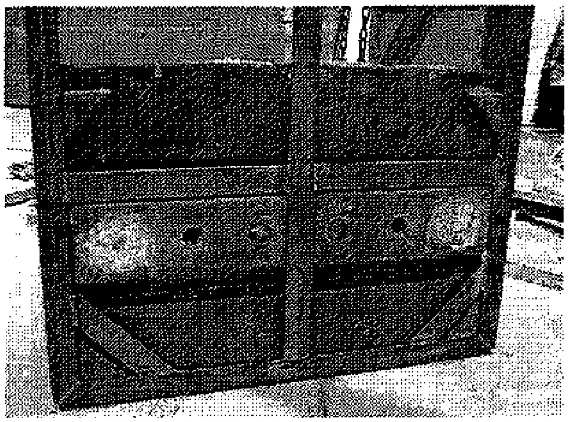

Figure 29: Bottom fit

the float and increase stability. This can be seen in figure 28. The bottom of the frame was designed and built so that it would fit in the grooves in the floats as seen in the 29.

Four posts were extended off of each corner of the anchor to raise the chain away from the trap, which sits on top of the anchor. This was done to prevent interference between the actual trap and the chain. The connection points on each post is simply a link of ½" long link chain welded into the crease of the angle iron and can be seen in figure 30. This was the least complicated and easiest solution to apply. These points were strong enough to support double the weight of the anchor taken at a very small angle from the horizontal. This was proven when the anchor was lifted onto the boat by using only two of the connections with a horizontal chain between them. The finished product can be seen at below.

Figure 30: Four posts on primary anchor

Figure 31: Complete set up for anchor and trap

Secondary Mooring

The secondary mooring was added to provide insurance should the primary line fail. A 480lb steel, hexagonal cone was used as the weight with a 5ft spar buoy. The buoy was donated by OOA and the weight was borrowed from an old oceanographic project. Pictures of these can be seen at right in figures 32 and 33. Polysteel was used for the ground line because it would support the weight of the primary anchor during deployment. Also should both buoys be lost, the buoyant polysteel ground-line would provide a nice loop and a great target for grappling to recover the gear. Polysteel was also used for the secondary mooring line because it's cheap relative to its strength and buying in bulk is more economical.

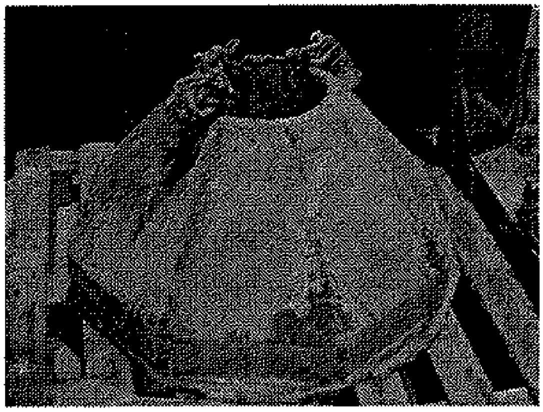

Figure 32: Secondary anchor

Figure 33: Secondary spar buoy

Figure 34: Prepared mooring lines

CHATPER IV

SYSTEM TEST

Dynamic Analysis

The objective of this test was to predict the loads on the mooring line in order to make sure the system will not fail and to see if an adverse resonant condition existed. Only the primary leg was considered as it bore the most weight and was more important. To do this, a mathematical and physical model were designed and tested given a sine wave as input. Results predict that the proposed design will remain intact and the line will not break. The maximum predicted load from the mathematical model was 5000N, which was lower than the physical model, which predicted the maximum load as 6010N. The estimated working load of the mooring line proposed for the actual system is 66720N or 15000lbs. The predicted loads are well within the limitations of the actual system specifications.

The breaking strength of the nylon and polysteel line in ¾" dimension were both 15,000lbs. Our primary anchor was only 700lbs in water and 1200lbs in air. However, a dynamic analysis of the primary mooring was conducted to find out exactly what type of loads the mooring might experience. This test would also provide the safety factor associated with the rope. The primary mooring was modeled using

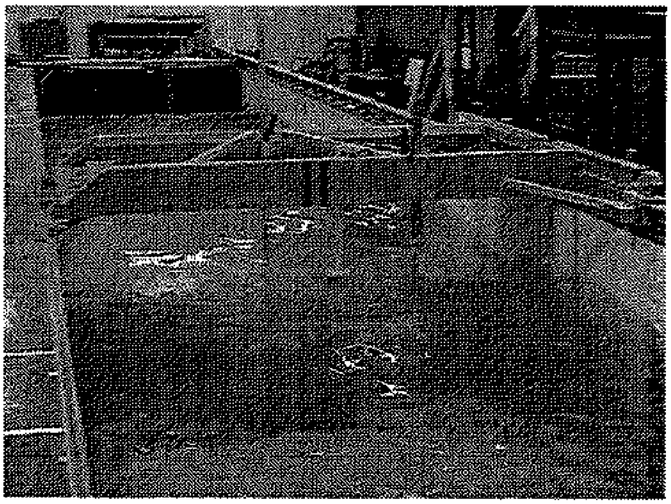

Figure 35: Dynamic testing in wave tank

computational methods such as Simulink and Mat-lab as well as physically modeled and tested in the Jere Chase OE 120ft wave tank, which can be seen in figure 35.

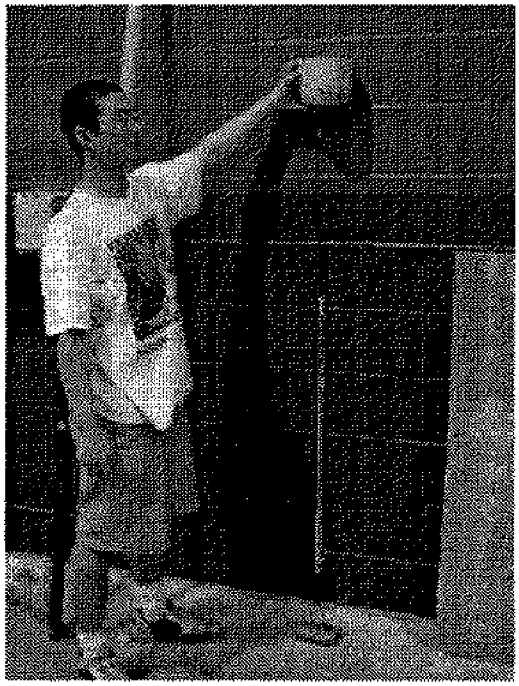

Figure 36: Physical model

The physical model can be seen at right in figure 36. The float at top is connected to tarred line, which is attached to elastic members taken from a bungee cord. The weight of the anchor at the time of the test was assumed to be 1500lbs. This figure was modeled using concrete and lead weights. The spring constant of the actual system was scaled to this dimension and the elastic was tested with known weights. All of these factors were scaled with Froude's methods and can be seen in appendix C, Model Scaling Methods. The rope would experience the highest loads during deployment so this was the condition modeled. The Gulf Challenger was approximated with the float seen in the figure, which was a much better wave follower and would provide the worst-case scenario (largest loads). A ¼ bridge waterproof load cell was placed in line between the anchor and the mooring line. Test equipment and interconnection table can be seen in appendix C, Equipment Interconnection Schematic. This data was plotted against wave staff data and can be seen in appendix C, Test Data. A summary of sampling conditions can be seen in appendix C, Sampling Conditions.

The anchor, rope, buoy system can be mathematically modeled as a mass-spring-damper system, much like the suspension in your car. This can be seen below along with its Simulink counterpart in figures 37 and 38. Parameters from the actual system and the scaled down version were run through the model separately. The comparisons of the two tests are as follows. These results were obtained by scaling the maximum, minimum, and average tension from the physical test and comparing it to the scaled up mathematical model. The safety factor was determined to be 11.

Model	Min. Tension (N)	Av. Tension (N)	Max. Tension (N)
Physical	2338	4048	6010
Mathematical	3005	4000	5050
% Difference	21.20	1.19	15.97

Table 1: Results from dynamic analysis

Mathematical Model

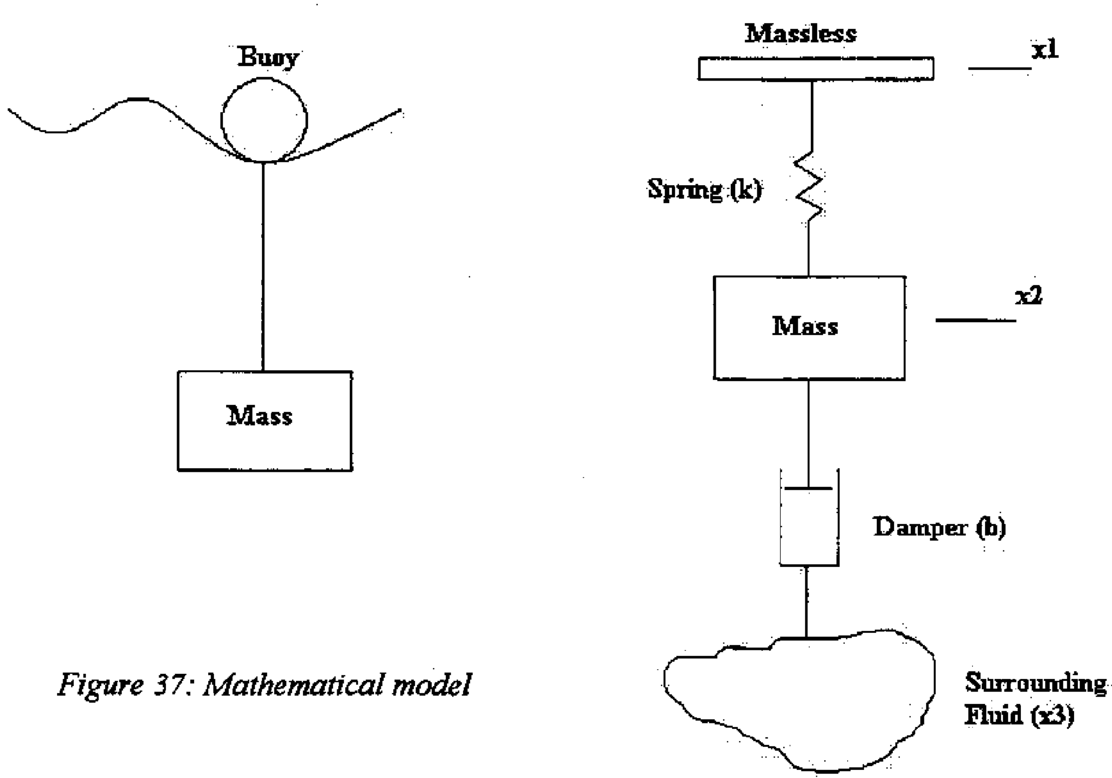

Figure 37: Mathematical model

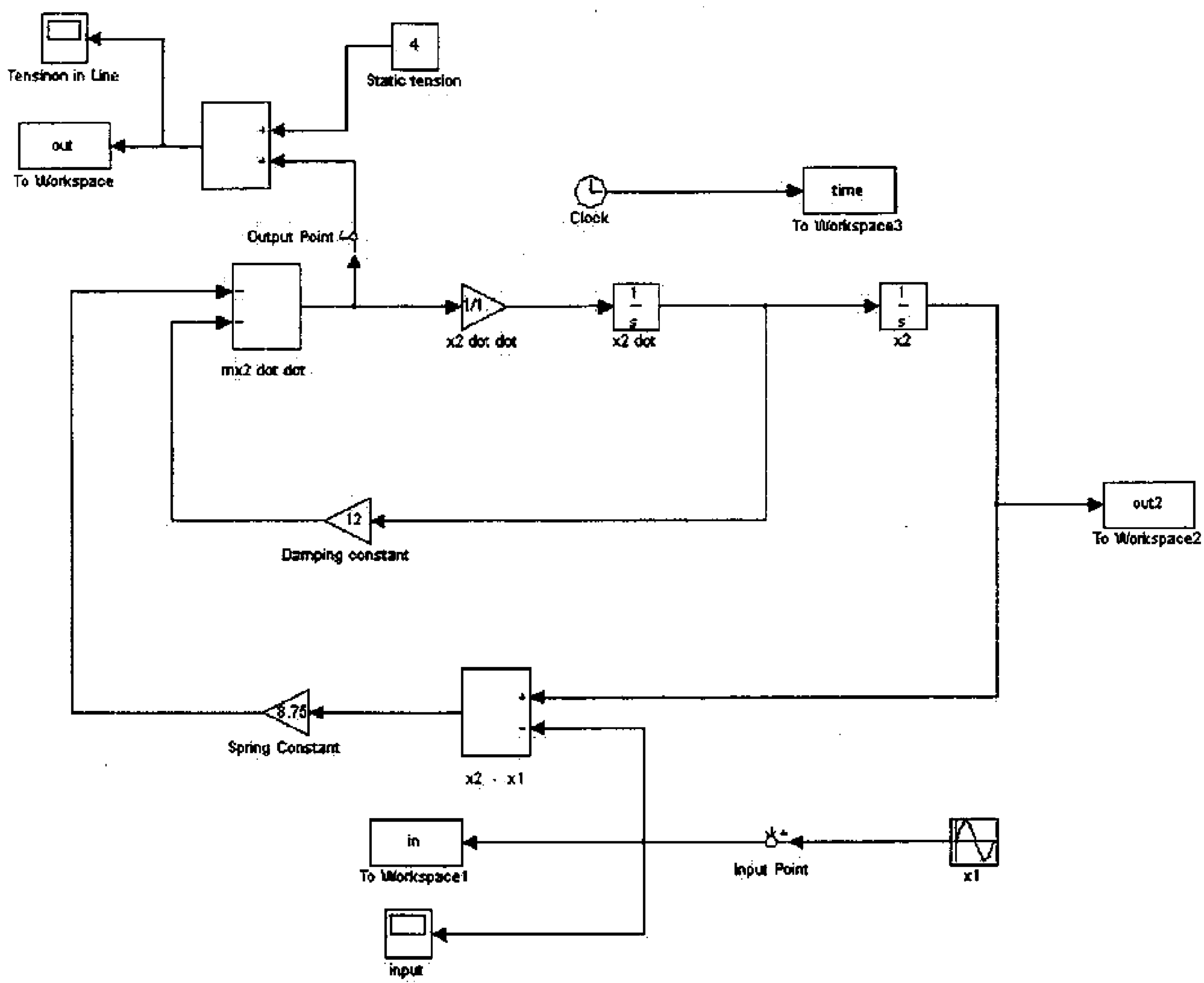

Figure 38: Simulink model

The equation of motion for this system was determined to be

$$m\ddot{x}_2 + k(x_2 - x_1) + b\dot{x}_2 = 0$$

Where: m = mass, including virtual mass
k = spring constant
b = damping constant
x_1 = position of float
x_2 = position of mass

System Function

Upon completion of the entire system, including mooring and trap, the main components of the system were assembled and tested in the OE Engineering tank. One of the main reasons for this test was the sphere. The lights were activated and the sphere was sealed before it was secured in the trap, which was placed on top of the anchor. The

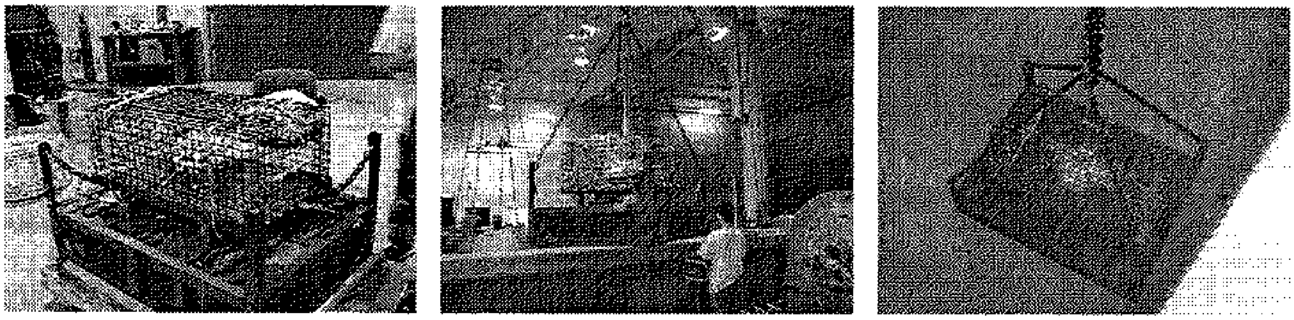

Figure 39: Complete set up for trap during system function test

test demonstrated that the sphere functioned properly and did not leak. The hope was to work out any unforeseen bugs before the actual deployment. The method of assembly was then practiced to make deployment in the field easier and go smoother. Shown above and below in figures 39 and 40 is a series of photos taken during the test, which lasted 2 days.

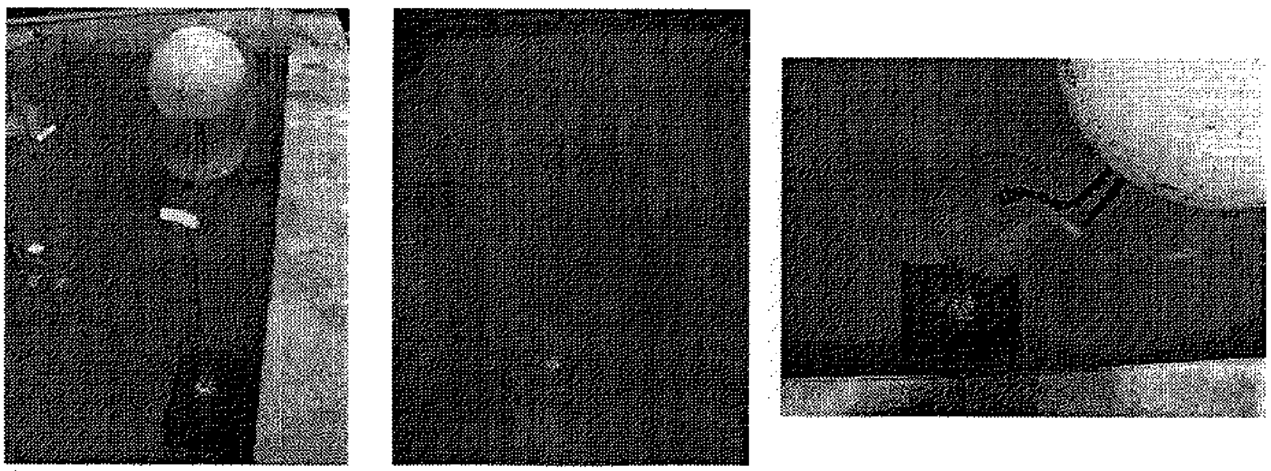

Figure 40: Anchor/trap interaction with sub-surface buoy

CHAPTER V

DEPLOYMENT AND RETRIVAL PROCESS

The mooring system was designed for a specific deployment and retrieval process. First, the surface buoy and the sub-surface buoy are dropped in the water, and the primary line is let out. Then, the primary anchor is picked up by the A-frame of the Challenger and lowered to the bottom with the winch using the intermediate ground line. The line between two anchors is designed to be longer than the depth of the water, so that the secondary anchor does not need to be deployed until the primary anchor hits the bottom. The secondary anchor is then lowered down to the bottom with the secondary mooring line and the secondary buoy is dropped. For retrieval, the process is simply reversed.

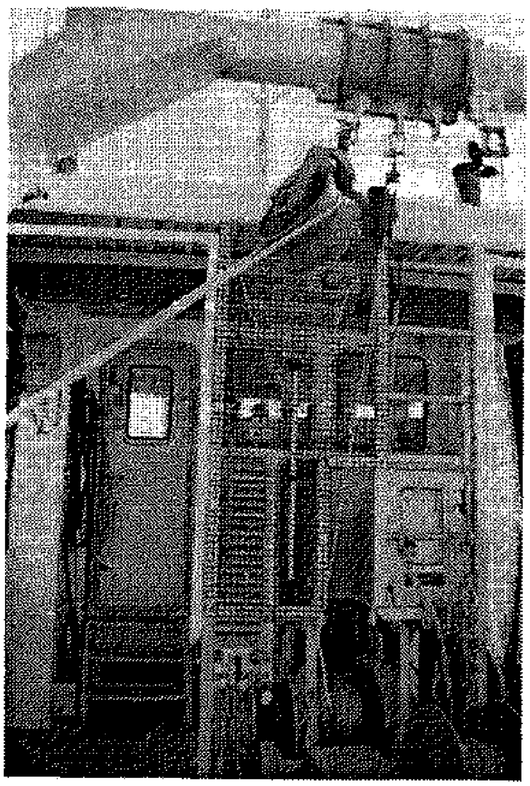

Figure 41: A-frame and winch

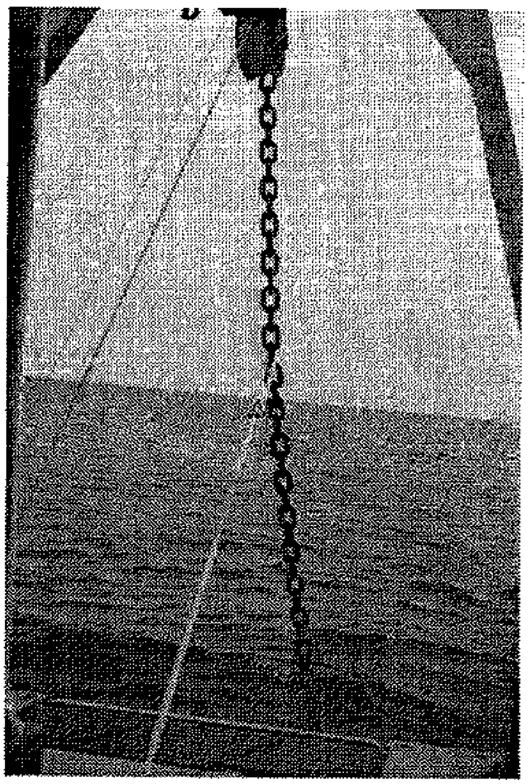

Figure 42: Retrieval in process

In the actual process, the deployment went almost exactly as it was planned. There were no major problems. However, there was a small problem for the retrieving process because the secondary buoy was missing. It was assumed to be pulled under by either wave or a drag net and sank. The retrieval had to be done with primary mooring line, which presented a few minor problems. First, the weld on the shackles on surface buoy had to be ground off to disconnect the chain. Second, The sub-surface buoy had to be disconnected because it was in-line and obviously would not pass through the winch. Each time the line was disconnected from the winch and a safety line was used to hold the line. Even though the primary line was not designed for retrieval, there weren't any major problems, and everything was successfully retrieved.

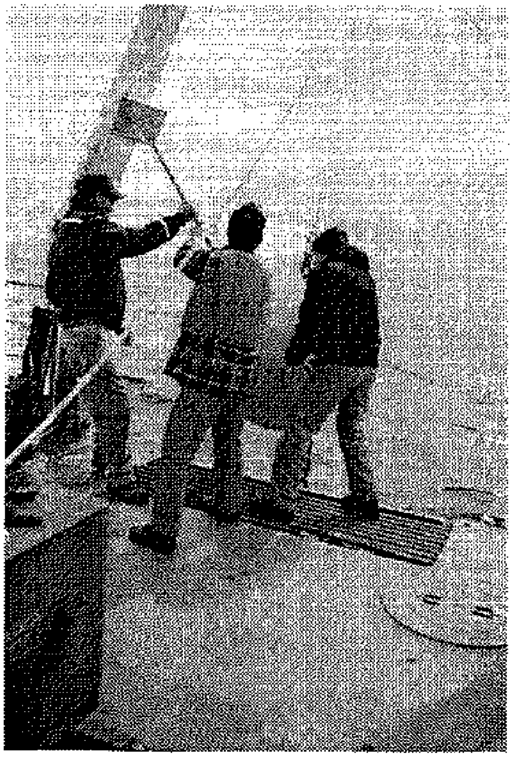

Figure 43: Retrieving primary buoy

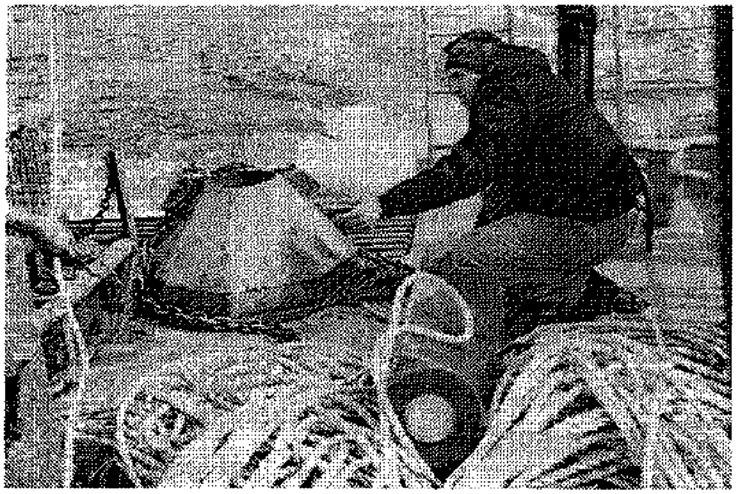

Figure 44: Retrieved components

CHAPTER VI

RESULTS AND CONCLUSION

Results

The trap contained 7 hake, 3 different species of shrimp, and 4 Jonah crabs upon retrieval. No squid were found in the trap or in the stomachs of the hake. A dissection of the hake can be seen in figures 45 and 46 with the other contents of the trap. The fact that squid were absent could be caused by several reasons. There might not have been any squid in the vicinity, they might have entered and escaped, been scared off by the fish, shrimp or other activity, or were just not attracted to the light. The wide assortment of animals found in the trap suggests a broad appeal of bright light in an environment devoid of light. It is therefore reasonable to think the cause was one of the other three.

Figure 45: Catch of the day

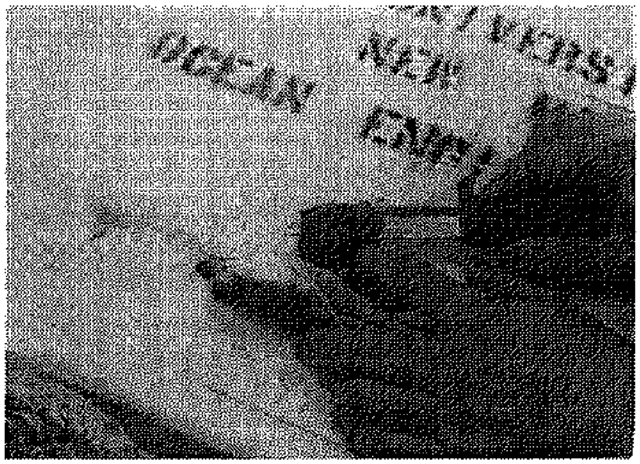

Figure 46: Dissecting

The trap was dropped off at 43 02.77 N 069 58.87 W, and picked up at 43 02.82 N 069 58.94 W. Wave data from the 10 day period can be seen in appendix D, Sea Conditions 3/19 – 3/29. A severe Nor'easter blew through the Gulf of Maine between the 23 and 25 of March, which created large waves. Data taken from buoy 44011 in the Gulf of Maine can be seen on the next page in figure 47. Nor'easters always create a severe sea conditions because they have a much greater fetch then storms that blow off the land.

This allows the waves to pile up much higher because the wind has a greater area of influence. The 25ft waves seen in the graph are therefore expected.

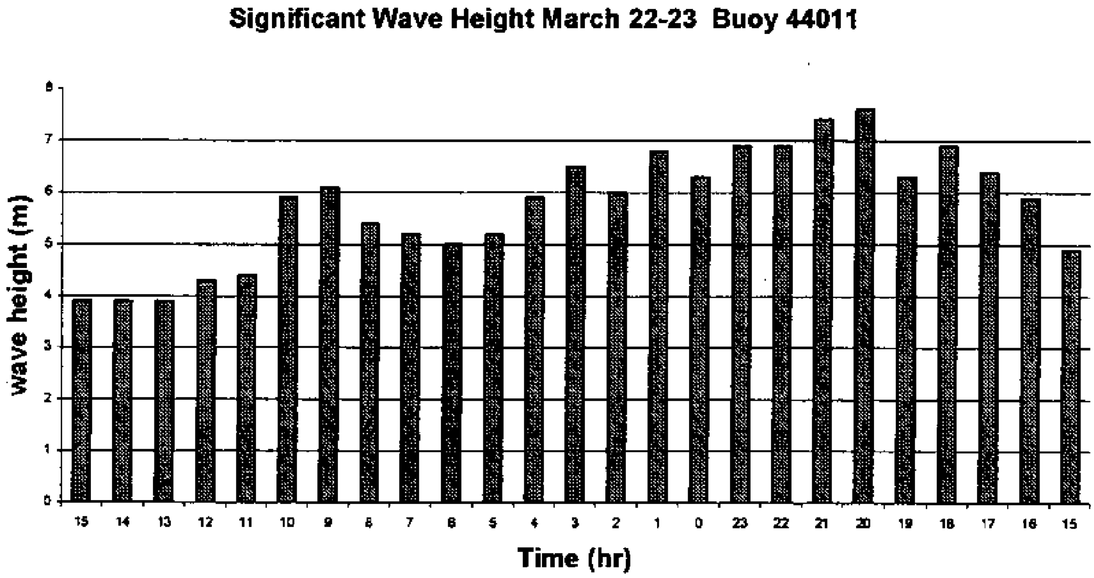

Figure 47: Significant wave height data (taken at buoy 44011)

The trap did not capture any squid but there was significant interest in the light as demonstrated by the catch. The design is viable and with modifications will be more likely to catch squid. The mooring system proved very adequate. The secondary mooring did fail but this can be attributed to the less than ideal buoy. This float was not rated for offshore conditions and did not have enough reserve buoyancy. It was probably sucked under by a large wave or dragged under by a boat. A more robust buoy would have a greater chance of survival. The reason that this buoy was used was because it was free and the risk associated with it was acceptable because it was the secondary line to the system.

There is no way to really know what happened while the trap was down but one way to check it would be to put a camera inside the trap during deployment. This would give real insight into how the trap performed and if squid were present. Other improvements would be modifications of the entrances. The slant-type openings were too large and need to be changed. This is what is most likely responsible for 18" hake entering the trap. The trap should also be left down for a shorter time period to minimize the accumulation of by-catch. Suspending the trap a few feet off the bottom would prevent crabs and other benthic species from entering. Experiments with sound could also be conducted to deter fish from entering and entice squid. The color to the light might also be changed and a flash pattern added. The light could also be made brighter if the time period is shortened. Also the trap was put down on the edge of the squid's known domain. If deployed in deeper water, the trap would have a higher chance of encountering squid.

BUDGET

Glass Instrument Housing	395
LED	88.50
Batteries	93.80
Sub-surface Buoy	200
High Flyer	40
Buoy Light	150
Hardware (shackles, thimbles, etc.)	184
Rope	601
Boat Time	895
Total	$2647.30

REFERENCES

Bertreax, Henri O., (1995) "Coastal and Buoy Engineering", Woods Hole Oceanographic Inst., MA 02543

Bolker, Jessica and Gabriela Martinez, (2000) "Collection of butterfly squid in the Gulf of Maine", Hubbard Proposal – Project Description, University of New Hampshire

Chakrabarti, Subrata Kumar, (1994) "Offshore Structure Modeling", World Scientific Publishing Co, Singapore, pg 32-36

Doherty, Peter J., (1987) "Light Traps: Selective but Useful Devices for Quantifying the Distributions and Abundances of Larval Fishes", Bulletin of Marine Science, 41(2): 423-431

Open University, The, (1989) "Seawater: It's Composition Properties and Behaviour", The Open University, Open University Team, Pergamon Press, New York

White, Frank, (1999) "Fluid Mechanics, Fourth Edition", McGraw Hill Inc, Boston, pg 458

APPENDICES

APPENDIX A: LURE SYSTEM

1) Instrument Housing Specifications
2) LED Specifications
3) Battery Specifications
4) Resistance/Duration Calculations

APPENDIX B: "S" CONFIGURATION BUOYANCY CALCULATION

APPENDIX C: DYNAMIC ANALYSIS

1) Model Scaling Methods
2) Equipment Interconnection Schematic for Data Acquisition
3) Test Data
4) Sampling Conditions

APPENDIX D: SEA CONDITIONS 3/19 – 3/29

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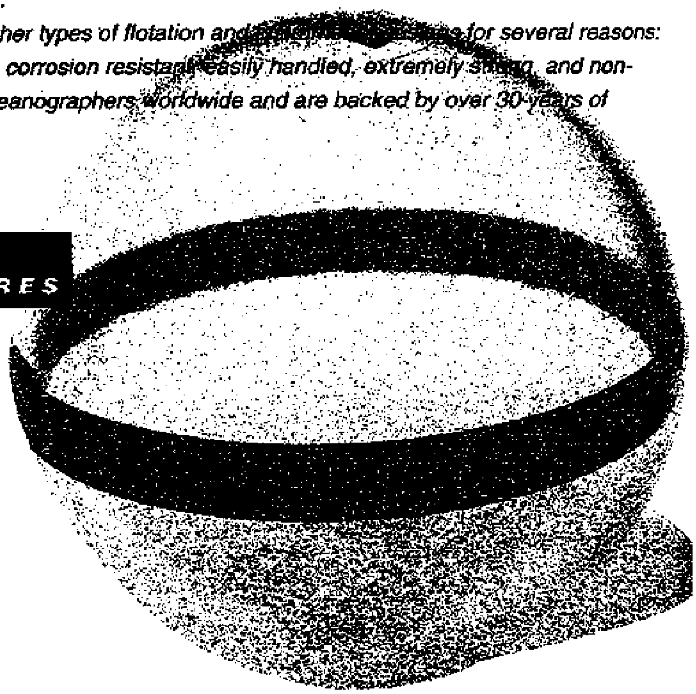
Instrument Housing Specification

***DEEP SEA GLASS SPHERES** are a unique, reliable, and cost-effective alternative for flotation and the housing of electronic instruments in the marine environment. Benthos is the world's leading manufacturer of deep sea glass spheres and instrument housings. Ongoing improvements continue to insure their high reliability in extreme environments. Advanced assembly techniques and the patented VacuSealed® closure method consistently result in high quality, long-life spheres. Benthos continues to pressure test every sphere prior to shipment, assuring their integrity in the field.*

Deep sea glass spheres are superior to other types of flotation and [illegible] for several reasons: they are transparent, lightweight, inexpensive, corrosion resistant, easily handled, extremely strong, and non-polluting. As a result, they are preferred by oceanographers worldwide and are backed by over 30 years of experience in deep sea technology.



DEEP SEA GLASS FLOTATION SPHERES

Benthos patented VacuSealed® glass floats and instrument housings are manufactured from precision-molded hemispheres to exact specifications. The edge of each hemispheres is ground flat to extreme tolerances. When used for flotation, the hemispheres are matched, mated, and then evacuated to an absolute internal air pressure of less than 0.3 atmospheres. After evacuation, a sealant and protective tape are applied around the equator. Spheres sealed in this method are nearly impossible to open due to the force exerted upon them by the atmospheric pressure. In the case of the 43.2 cm (17 inch) diameter float, this force is in excess of 880 kg (2000 lbs.)

SPECIFICATIONS

Type:	Low expansion borosilicate		
Thermal Coefficient of Expansion:	$36 \times 10^{-7}/°C$		
Specific Gravity:	2.22		
Young's Modulus:	62 GPa (9×10^{6} p.s.i.)		
Poisson's Ratio:	0.20		
Refractive Index:	1.48		
Thermal Conductivity:	0.0023 calorie cm/cm² sec°C		
Specific Heat:	0.18 calorie/gm°C		
Dimensions, Weight, and Depth Data	**Sphere Model 2040-10V**	**Sphere Model 2040-13V**	**Sphere Model 2040-17V**
Outside Diameter:	25.4 cm (10 in.)	33 cm (13 in.)	43.2 cm (17 in.)
Inside Diameter:	23.6 cm (9.3 in.)	30.5 cm (12 in.)	40.4 cm (15.9 in.)
Weight in Air:	4.1 kg (9 lbs.)	9.07 kg (20 lbs.)	17.7 kg (39 lbs.)
Net buoyancy:	4.5 kg (10 lbs.)	10.4 kg (23 lbs.)	25.4 kg (56 lbs.)
Depth Rating:	9000 m (29,500 ft.)	9000 m (29,500 ft.)	6700 m (22,000 ft.)

LED Specifications

DEC-06-2000 17:19 NICHIA

発光素子 | 青緑色LEDランプ BLUISH-GREEN LED LAMP

717-285-2323

■特長 Features

- ●高光度・高光出力
  High luminous intensity,high power
- ●高色純度
  High color purity
- ●量子井戸構造
  Quantum well structure

■応用例 Application Examples

- ●交通信号
  Traffic signals
- ●鉄道信号
  Railroad signals

■製品名表示方法 Identification for Product Types

N S P E 5 △ 0 S
①

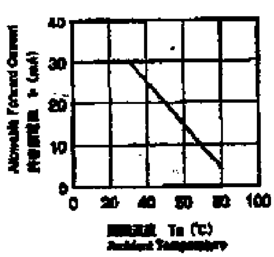
①指向特性 Directivity
1 : 30°   9 : 10°

■絶対最大定格 (Ta=25℃) Absolute Maximum Ratings

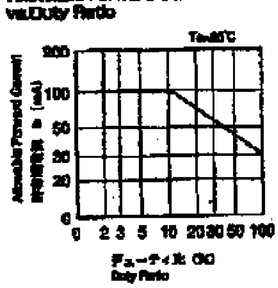
順方向電流 DC Forward Current(mA)	パルス順方向電流※ Pulse Forward Current(mA)	逆電圧 Reverse Voltage (V)	許容損失 Power Dissipation(mW)	動作温度 Operating Temperature(℃)	保存温度 Storage Temperature(℃)
IF=30	IFP=100	VR=5	PD=120	Topr: -30~+80	Tstg: -30~+100

※パルス幅10ms以下、デューティ比1/10以下 Pulse width≦10msec. Duty ratio≦1/10

●許容順電流-周囲温度特性
Allowable Forward Current vs.Ambient Temperature



●許容順電流-デューティ比特性
Allowable Forward Current vs.Duty Ratio



■電気的・光学的特性 (Ta=25℃) Electro-Optical Characteristics

品名 Type	順方向電圧 DC Forward Voltage VF (V)		逆方向電流 DC Reverse Current IR (μA)	光度 Luminous Intensity Iv (cd)	半値幅 Half Width Δλ (nm)	色度座標※ Chromaticity Coordinates x	y
	Typ.	Max.	Max.	Typ.	Typ.	Typ.	Typ.
NSPE 510S	3.5	4.0	50	0.85	35	0.10	0.55
NSPE 590S	3.5	4.0	50	2.8	35	0.10	0.55
Condition	IF=20mA		VR=5V	IF=10mA			

※CIE (国際照明委員会) 標準表色系 : The ICI standard colorimetric system.

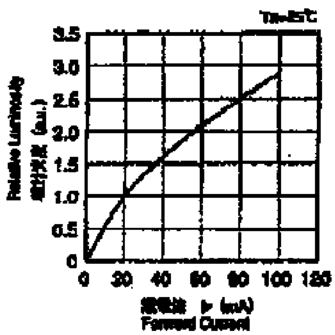
East Coast Dial

10.4 10mA
20.8 20mA

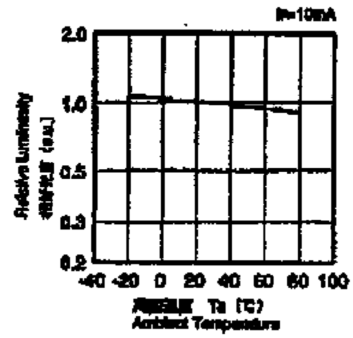
248-552-6585

■代表的特性　Typical Characteristics

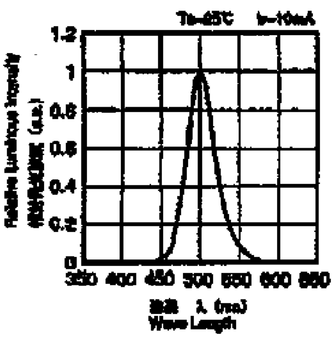
●相対光度-順電流特性
Relative Luminosity
vs.Forward Current



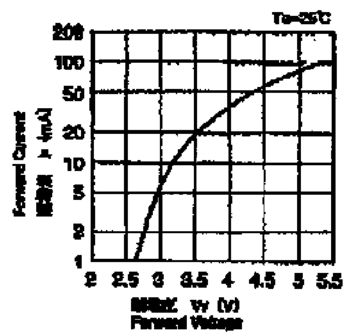
●相対光度-周囲温度特性
Relative Luminosity
vs.Ambient Temperature



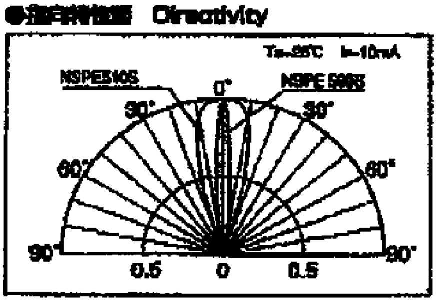
●発光スペクトル
Luminous Spectrum



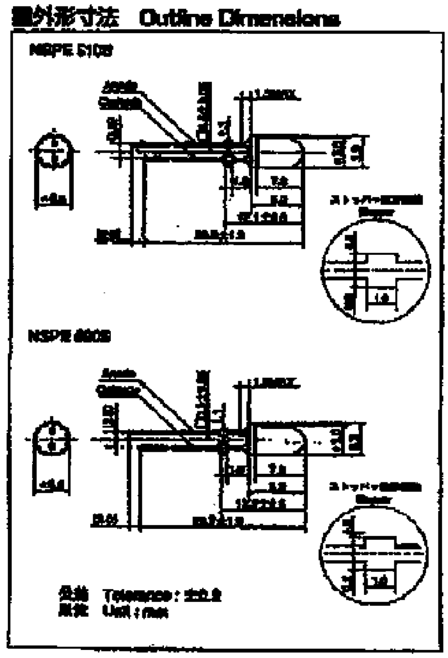
●順電流-順電圧特性
Forward Current vs.Forward Voltage



●指向特性図　Directivity

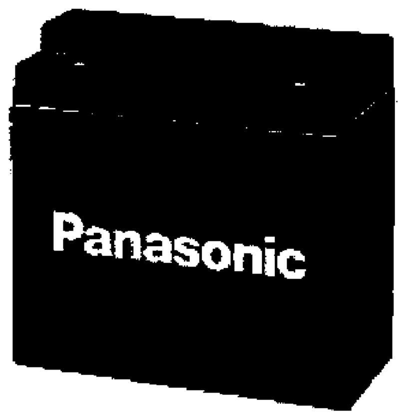


■外形寸法　Outline Dimensions



SEALED LEAD ACID BATTERIES: INDIVIDUAL DATA SHEET

LC-X1220P/LC-X1220AP



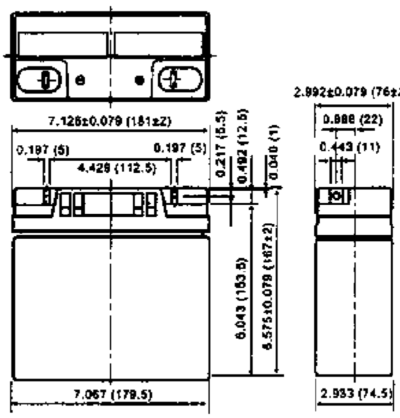
Photo/Label for reference only.

(a) The photo and dimensions represent LC-X1220P.

For main and standby power supplies. Expected trickle life: Approx. 6 years at 25°C, Approx. 10 years at 20°C.

Dimensions (mm)

Terminal type: LC-X1220P: M5 bolt and nut
LC-X1220AP: M5 threaded post



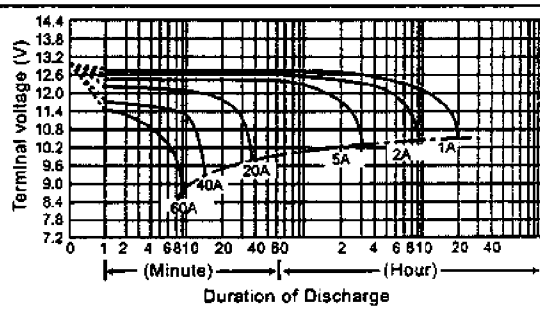
Battery case resin: Standard (UL94HB) Color is black.
Optional (UL94V-0) Color is grey.

Specifications

Nominal voltage		12V
Nominal capacity (20 hour rate)		20Ah
Dimensions	Length	7.126 inches (181.0 mm)
	Width	2.992 inches (76.0 mm)
	Height	6.575 inches (167.0 mm)
	Total Height	6.575 inches (167.0 mm)
Approx. mass		14.56 lbs (6.6 kg)
Standard Terminals and Resin	UL94HB M5 Bolt and Nut	LC-X1220P
Optional Terminals and Resin	UL94HB M5 Threaded Post	♦ LC-X1220AP
	UL94V-0 M5 Bolt and Nut	♦ LC-P1220P
	UL94V-0 M5 Threaded Post	♦ LC-P1220AP

♦ Please contact Panasonic for availability on optional items. Optional items may be subject to minimum order quantities.

Discharge characteristics 77°F (25°C) (Note)

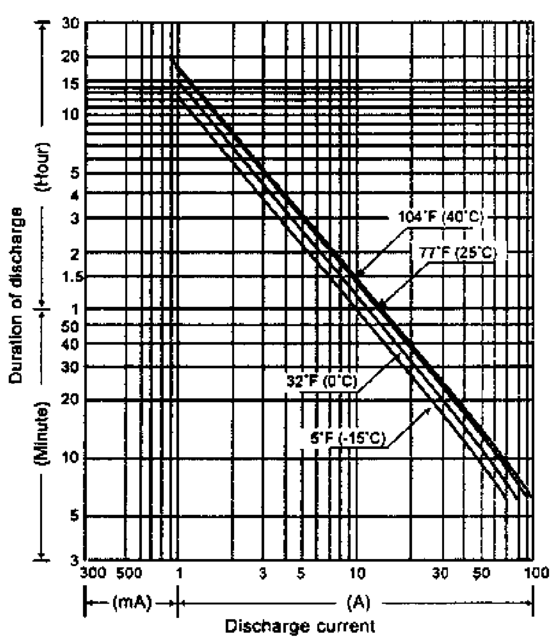


Characteristics

Capacity (note) 77°F (25°C)		20 hour rate (1.2A)	20Ah
		10 hour rate (2.2A)	18Ah
		5 hour rate (3.8A)	16Ah
		1 hour rate (14A)	12Ah
		1.5 hour rate discharge Cut-off voltage 10.5 V	9.8A
Internal resistance		Fully charged battery 77°F (25°C)	Approx. 11mΩ
Temperature dependency of capacity (20 hour rate)		104°F (40°C)	102%
		77°F (25°C)	100%
		32°F (0°C)	85%
		5°F (-15°C)	65%
Self discharge 77°F (25°C)		Residual capacity after standing 3 months	91%
		Residual capacity after standing 6 months	82%
		Residual capacity after standing 12 months	64%
Charge Method (Constant Voltage)	Cycle use (Repeating use)	Initial current	8 A or smaller
		Control voltage	14.5V to 14.9 V (per 12V cell 25°C)
	Trickle use	Initial current	3 A or smaller
		Control voltage	13.6V to 13.8V (per 12V cell 25°C)

(Note) The above characteristics data are average values obtained within three charge/discharge. Cycles not the minimum values.
(Note) For cycle use of the battery, please contact us in advance.

Duration of discharge vs. Discharge current (Note)



Resistance Calculation

Battery Voltage: $V_b := 12\text{volt}$

LED Current: $I_{LED} := 20\text{mA}$ @ typical forward voltage of 3.5volt

LED Resistence: $R_{LED} := \frac{3.5\text{volt}}{I_{LED}}$ $R_{LED} = 175\,\Omega$

Resistance needed: $R := \frac{V_b}{I_{LED}} - 3R_{LED}$ $\boxed{R = 75\,\Omega}$

Duration Calculation

Battery Amp-Hour: $A_{hour} := 20\text{amp}\cdot\text{hr}$

Current through a series of 3 LED's: $I_{LED} := 20\text{mA}$

Total Current from battery: $I_{total} := 5\cdot I_{LED}$ $I_{total} = 0.1\,\text{A}$

Total hours of duration: $T_{duration} := \frac{A_{hour}}{I_{total}}$ $\boxed{T_{duration} = 200\,\text{hr}}$

$\boxed{T_{duration} = 8.333\,\text{day}}$

APPENDIX B:

"S" CONFIGURATION BUOANCY CALCULATION

"S" Configuration Buoyancy Calculations

Specific gravity is the ratio of a materials density to the density of water. It is a non-dimensional number and can be used in buoyancy calculations with any units.

The "s" type curve in the primary mooring is created by balancing the buoyancies of the nylon and polystell rope. Nylon and polysteel are negatively and positively buoyant, respectively.

Total length of rope = 131m

$$L_t := 40\text{m}$$

Density of Saltwater at 4C

$$\rho_{sw} := 1027.7\frac{\text{kg}}{\text{m}^3}$$

Nylon specific gravity = 1.14

$$sg_n := 1.14$$

linear density:

$$ld_n := .2162371749\frac{\text{kg}}{\text{m}}$$

Polysteel specific gravity = 0.93

$$sg_p := 0.93$$

linear density:

$$ld_p := .1714984491\frac{\text{kg}}{\text{m}}$$

linear buoyancy caculation, (100m sample):

1) Find weight of water displaced.

$$\frac{(100\text{m}\cdot ld_n)}{sg_n} = 18.968\,\text{kg}$$

2) Find weight of rope.

$$ld_n\cdot 100\text{m} = 21.624\,\text{kg}$$

3) Linear buoyancy

$$lb_{n100} := \frac{(100\text{m}\cdot ld_n)}{sg_n} - ld_n\cdot 100\text{m}$$

$$lb_n := \frac{lb_{n100}}{100}$$

$$lb_n = -0.027\,\text{kg}$$

$$\frac{(100\text{m}\cdot ld_p)}{sg_p} = 18.441\,\text{kg}$$

$$ld_p\cdot 100\text{m} = 17.15\,\text{kg}$$

$$lb_{p100} := \frac{(100\text{m}\cdot ld_p)}{sg_p} - ld_p\cdot 100\text{m}$$

$$lb_{p100} = 1.291\,\text{kg}$$

$$lb_p := \frac{lb_{p100}}{100}$$

$$lb_p = 0.013\,\text{kg}$$

Balance Buoyancy:

The section of the ropes that will be in equilibrium is 40m. This is the section in between the top loop of polysteel and the bottom trough of nylon.

Bouyancy polysteel = Buoyancy of Nylon
means equilibrium.

Using this relation, it can be shown that:

$$L_p := \frac{-(40m \cdot lb_n)}{(lb_p - lb_n)}$$

$$L_p = 26.916\,m$$

$$L_n := L_t - L_p$$

$$L_n = 13.084\,m$$

APPENDIX C:

DYNAMIC ANALYSIS

1) Model Scaling Methods
2) Equipment Interconnection Schematic for Data Acquisition
3) Test Data
4) Sampling Conditions

Model Scaling

Initial assumptions:

- Let ρ for salt water = 1025 kg/m³
- Concrete anchor physical size is 0.9144 m wide x 1.219 m lg x 0.2413 high
- Test wave height = 0.2 m
- Average actual wave height for ocean location = 2 m
- Average actual wave period for ocean location = 5 sec
- Froude scaling factor λ = 0.2 / 2 = 0.1

Using Froude scaling theory[1], the model's scaled parameters are summarized as follows:

Model Parameter Scaling Summary		
Parameter	**Actual**	**Model**
Wave Height	2 m	0.2 m
Period	5 sec	1.581 sec
Damping Coefficient (b)	1200 kg/m	12 Kg/m
Spring Constant (k)	875.6 N/m	8.756 N/m
Mass (in water)	528 kg	0.528 kg*
Added Mass[2]	1042.88 kg	1.0429 kg
Virtual Mass[2]	1570.88 kg	1.5709 kg

* Model mass measured and confirmed

[1] Chakrabarti, Subrata Kumar, Offshore Structure Modeling, World Scientific Publishing Co, Singapore, 1994, pg 32-36

[2] Berteaux, Henri O., Coastal and Buoy Engineering, Published by Author, Woods Hole, Ma 02543, pg 86

Virtual and Actual Mass Calculations

The added mass and virtual mass were determined as follows:

$2a = 0.9144$ m $\Rightarrow$ $a = 0.4572$ m

$2b = 0.2413$ m $\Rightarrow$ $b = 0.1207$ m

$k_1 = 1.271$ (Given constant[2])

Added mass = $k_1 * \rho * \pi * a^2 * 1.219$ = **1042.883 kg**

Virtual mass = actual mass + added mass = 528 + 1042.883 = **1570.88 kg**

Model physical size

Length = $1.219 * \lambda$ = 0.1219 m (4.8")

Width = $0.9144 * \lambda$ = 0.09144 m (3.6")

Height = $0.2413 * \lambda$ = 0.02413 m (0.95")

Determine Damping Constant b

Given dimensions of anchor:

3 ft wide x 4 ft long (planar area)

Fluid damping = b = C_D (ρV^2 A ½) ⇒ b = C_D (ρ A) ^{2}

From linear interpolation[3] ⇒ C_D = 2.1

ρ = 1025 kg / m³ @ 20° C, 1 atm, 30% salinity (1.989 slug/ ft³)

A = 3 ft x 4 ft = 12 ft²

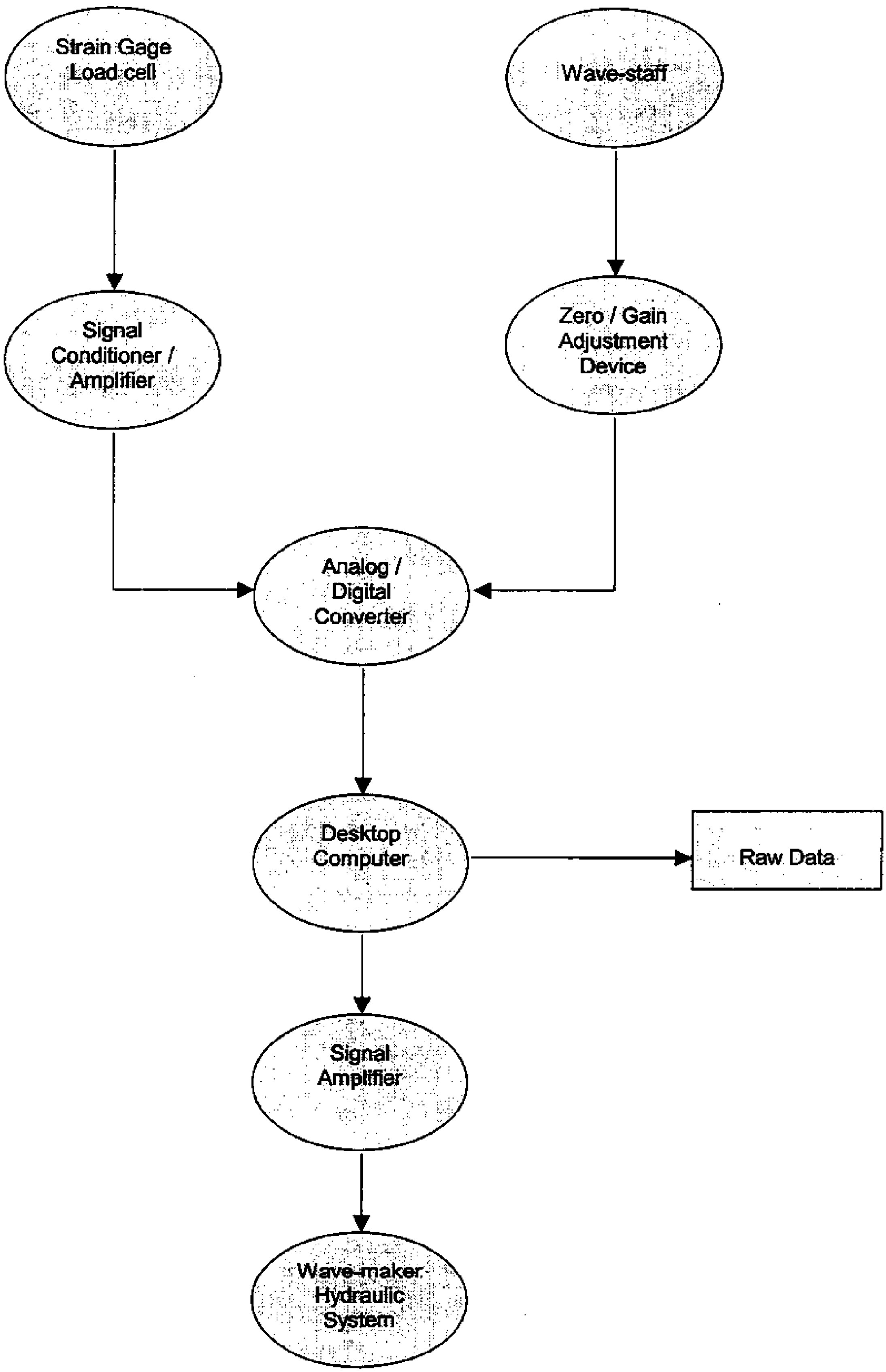
V^2 = (x2 dot – x3dot) ^{2}

b = C_D (ρ A) ½ ⇒

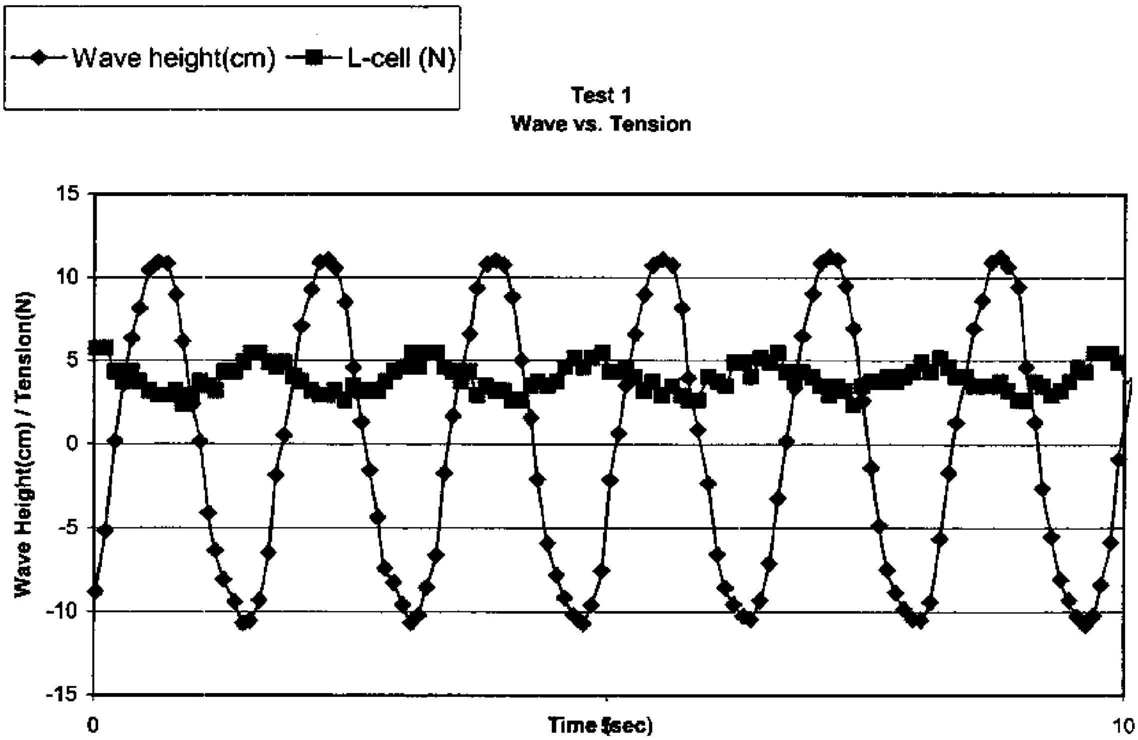
b = (2.1) (1.989) (12) (½) ⇒ **25.059 lb * s² / ft² = 1200 kg/m**

[3] White, Frank, Fluid Mechanics, pg 458

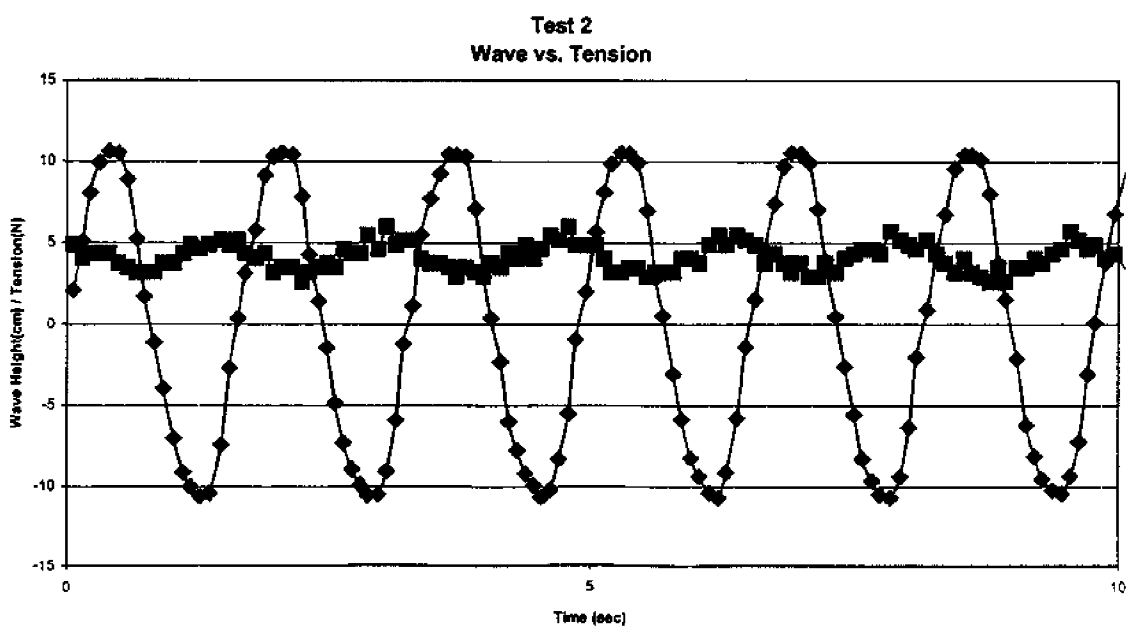
Equipment Interconnection Schematic for Data Acquisition



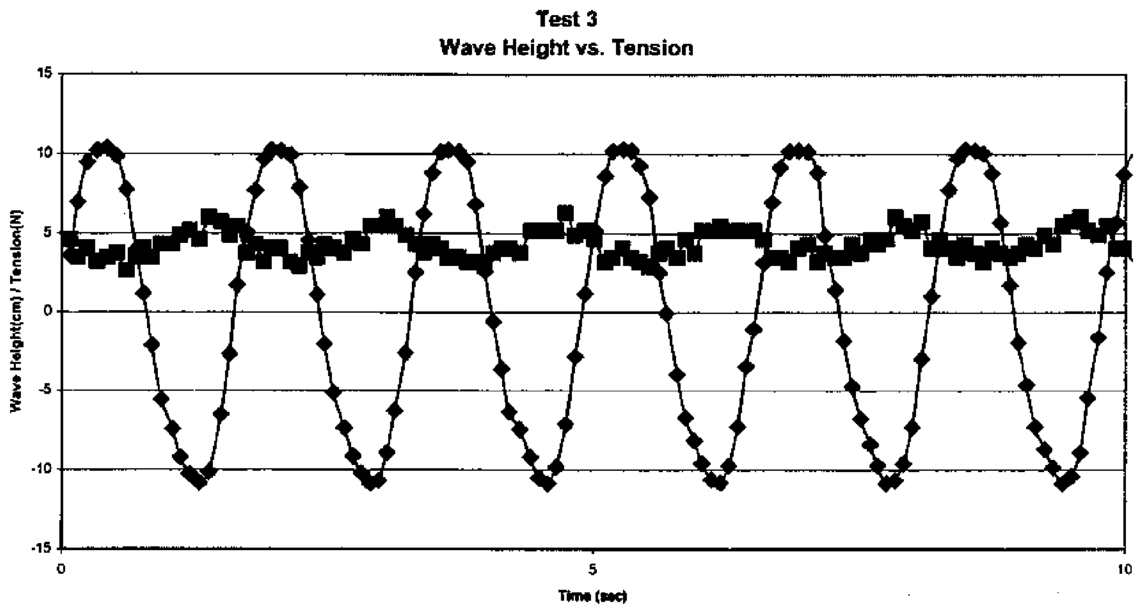
Test Data



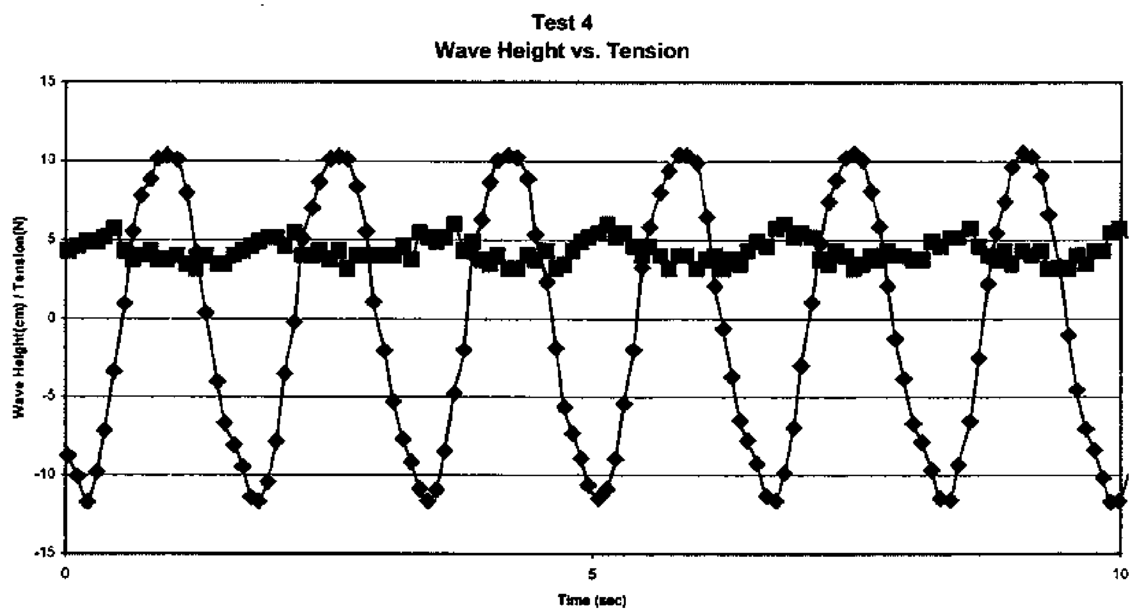
Wave height(cm)
L-cell (N)
Test 1
Wave vs. Tension
15
10
5
0
-5
-10
-15
Wave Height(cm) / Tension(N)
0
10
Time (sec)



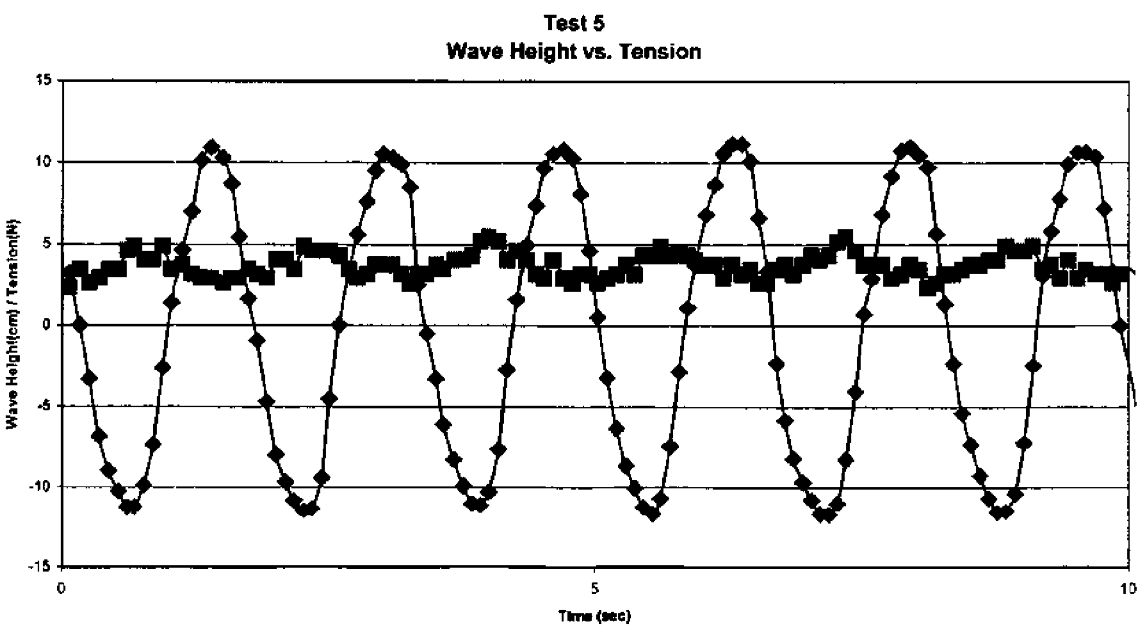
Test 2
Wave vs. Tension
15
10
5
0
-5
-10
-15
Wave Height(cm) / Tension(N)
0
5
10
Time (sec)



Test 3
Wave Height vs. Tension
15
10
5
0
-5
-10
-15
Wave Height(cm) / Tension(N)
0
5
10
Time (sec)



Test 4
Wave Height vs. Tension
15
10
5
0
-5
-10
-15
Wave Height(cm) / Tension(N)
0
5
10
Time (sec)



Test 5
Wave Height vs. Tension
15
10
5
0
-5
-10
-15
Wave Height(cm) / Tension(N)
0
5
10
Time (sec)

Test Sampling Conditions

Test Sampling Conditions Summary			
Test Number	Sampling Rate		Comments
	Frequency [Hz]	Duration [sec]	
Static 1	15	20	Two static tests were conducted to check for possible drift in instrumentation
Static 2	15	20	
Dynamic 1	15	20	Three tests conducted under identical conditions to check for drift impact
Dynamic 2	15	20	
Dynamic 3	15	20	
Dynamic 4	15	60	Longer duration chosen to evaluate possible term effects
Dynamic 5	25	60	

APPENDIX D:

SEA CONDITIONS 3/19 – 3/29

Standard Meteorological Data at Buoy# 44011 from 3/19/2001 to 3/29/2001

Taken from National Buoy Data Center website: http://seaboard.ndbc.noaa.gov/data/realtime/44011.txt

YYYY	MM	DD	hh	WD	WSPD	GST	WVHT	DPD	APD	MWD	BARO	ATMP	WTMP	DEWP	VIS	PTDY	TIDE
2001	03	29	14	070	3.0	4.0	1.2	7	MM	MM	1030.5	4.7	4.4	MM	MM	+2.2	MM
2001	03	29	13	060	3.0	4.0	1.2	6	MM	MM	1029.9	4.7	4.4	MM	MM	+1.6	MM
2001	03	29	12	060	5.0	6.0	1.4	7	MM	MM	1029.2	4.4	4.4	MM	MM	+1.1	MM
2001	03	29	11	290	3.0	3.0	1.4	6	MM	MM	1028.3	4.3	4.4	MM	MM	+1.0	MM
2001	03	29	10	290	4.0	5.0	1.5	6	MM	MM	1028.3	4.3	4.4	MM	MM	+1.1	MM
2001	03	29	09	270	5.0	6.0	1.6	6	MM	MM	1028.1	4.3	4.4	MM	MM	+1.5	MM
2001	03	29	08	270	7.0	8.0	1.6	6	MM	MM	1027.3	4.0	4.4	MM	MM	+1.7	MM
2001	03	29	07	270	8.0	9.0	1.5	6	MM	MM	1027.2	4.0	4.4	MM	MM	+2.1	MM
2001	03	29	06	270	7.0	8.0	1.6	7	MM	MM	1026.6	4.0	4.4	MM	MM	+1.5	MM
2001	03	29	05	270	6.0	7.0	1.7	6	MM	MM	1025.6	3.9	4.4	MM	MM	+0.6	MM
2001	03	29	04	280	6.0	8.0	1.7	7	MM	MM	1025.1	3.9	4.4	MM	MM	+0.8	MM
2001	03	29	03	280	7.0	8.0	1.7	7	MM	MM	1025.1	3.9	4.4	MM	MM	+1.6	MM
2001	03	29	02	280	7.0	9.0	1.8	7	MM	MM	1025.0	3.9	4.4	MM	MM	+2.2	MM
2001	03	29	01	270	8.0	10.0	1.9	7	MM	MM	1024.3	3.6	4.4	MM	MM	+2.2	MM
2001	03	29	00	270	8.0	10.0	1.9	7	MM	MM	1023.5	3.6	4.4	MM	MM	+2.0	MM
2001	03	28	23	270	9.0	11.0	2.2	6	MM	MM	1022.8	3.5	4.4	MM	MM	+1.7	MM
2001	03	28	22	260	10.0	12.0	2.1	7	MM	MM	1022.1	3.6	4.4	MM	MM	+1.1	MM
2001	03	28	21	260	11.0	12.0	1.9	6	MM	MM	1021.5	3.6	4.4	MM	MM	-0.0	MM
2001	03	28	20	270	10.0	11.0	1.9	6	MM	MM	1021.1	3.6	4.4	MM	MM	-0.8	MM
2001	03	28	19	270	10.0	12.0	2.0	7	MM	MM	1021.0	3.5	4.4	MM	MM	-0.8	MM
2001	03	28	18	270	9.0	11.0	2.0	7	MM	MM	1021.3	3.2	4.4	MM	MM	-0.6	MM
2001	03	28	17	260	10.0	12.0	1.8	7	MM	MM	1021.9	3.1	4.4	MM	MM	+0.4	MM
2001	03	28	16	260	9.0	10.0	2.1	7	MM	MM	1021.8	3.1	4.4	MM	MM	+0.8	MM
2001	03	28	15	280	8.0	10.0	1.8	8	MM	MM	1021.9	3.1	4.4	MM	MM	+1.0	MM
2001	03	28	14	270	8.0	9.0	1.9	8	MM	MM	1021.5	3.0	4.4	MM	MM	+1.0	MM
2001	03	28	13	270	8.0	10.0	2.0	7	MM	MM	1021.0	2.8	4.3	MM	MM	+1.1	MM
2001	03	28	12	280	8.0	9.0	2.2	7	MM	MM	1020.9	2.8	4.3	MM	MM	+1.5	MM
2001	03	28	11	280	8.0	10.0	1.9	7	MM	MM	1020.5	2.9	4.3	MM	MM	+1.6	MM
2001	03	28	10	280	9.0	11.0	2.2	6	MM	MM	1019.9	2.8	4.3	MM	MM	+0.8	MM
2001	03	28	09	280	9.0	11.0	2.1	8	MM	MM	1019.4	2.8	4.3	MM	MM	-0.0	MM
2001	03	28	08	280	10.0	12.0	1.9	7	MM	MM	1018.9	2.8	4.3	MM	MM	-0.6	MM
2001	03	28	07	300	10.0	11.0	2.1	7	MM	MM	1019.1	2.0	4.3	MM	MM	-0.3	MM
2001	03	28	06	270	8.0	10.0	2.0	8	MM	MM	1019.4	1.4	4.3	MM	MM	+0.0	MM
2001	03	28	05	250	9.0	11.0	1.9	8	MM	MM	1019.5	1.6	4.3	MM	MM	+0.5	MM
2001	03	28	04	270	8.0	10.0	2.1	7	MM	MM	1019.4	1.1	4.3	MM	MM	+0.5	MM
2001	03	28	03	280	9.0	11.0	2.2	8	MM	MM	1019.2	1.7	4.4	MM	MM	+1.2	MM
2001	03	28	02	270	8.0	10.0	1.9	8	MM	MM	1019.0	1.6	4.4	MM	MM	+1.3	MM
2001	03	28	01	280	7.0	9.0	2.0	8	MM	MM	1018.9	1.6	4.4	MM	MM	+2.4	MM
2001	03	28	00	290	8.0	9.0	2.1	8	MM	MM	1018.0	1.6	4.4	MM	MM	+2.4	MM
2001	03	27	23	300	9.0	11.0	2.3	6	MM	MM	1017.7	1.3	4.4	MM	MM	+3.0	MM
2001	03	27	22	300	10.0	12.0	2.6	8	MM	MM	1016.5	2.0	4.4	MM	MM	+2.3	MM
2001	03	27	21	320	11.0	13.0	2.9	8	MM	MM	1015.6	2.1	4.4	MM	MM	+2.3	MM
2001	03	27	20	320	9.0	11.0	2.8	8	MM	MM	1014.7	2.0	4.4	MM	MM	+2.1	MM
2001	03	27	19	340	11.0	13.0	2.3	8	MM	MM	1014.2	0.8	4.4	MM	MM	+2.3	MM
2001	03	27	18	350	5.0	6.0	1.9	8	MM	MM	1013.3	2.3	4.4	MM	MM	+1.4	MM
2001	03	27	17	360	6.0	7.0	1.8	7	MM	MM	1012.6	2.7	4.4	MM	MM	+0.9	MM
2001	03	27	16	280	8.0	10.0	2.0	8	MM	MM	1011.9	3.2	4.4	MM	MM	+0.9	MM
2001	03	27	15	300	5.0	7.0	1.8	6	MM	MM	1011.9	3.1	4.4	MM	MM	+1.7	MM
2001	03	27	14	280	8.0	10.0	1.8	6	MM	MM	1011.7	3.4	4.4	MM	MM	+2.0	MM
2001	03	27	13	280	9.0	11.0	1.9	6	MM	MM	1011.0	2.6	4.4	MM	MM	+2.5	MM
2001	03	27	12	260	12.0	15.0	1.3	8	MM	MM	1010.2	2.5	4.4	MM	MM	+1.6	MM
2001	03	27	11	320	6.0	8.0	1.5	8	MM	MM	1009.7	3.8	4.4	MM	MM	+0.4	MM
2001	03	27	10	100	6.0	8.0	1.6	10	MM	MM	1008.5	4.3	4.4	MM	MM	-1.4	MM
2001	03	27	09	080	8.0	9.0	1.6	8	MM	MM	1008.6	4.3	4.4	MM	MM	-2.3	MM
2001	03	27	08	080	5.0	6.0	1.4	8	MM	MM	1009.3	4.3	4.4	MM	MM	-2.4	MM
2001	03	27	07	070	7.0	9.0	1.4	8	MM	MM	1009.9	4.1	4.3	MM	MM	-2.4	MM
2001	03	27	06	060	7.0	8.0	1.3	11	MM	MM	1010.9	4.3	4.3	MM	MM	-1.8	MM
2001	03	27	05	080	6.0	8.0	1.2	8	MM	MM	1011.7	4.3	4.3	MM	MM	-1.7	MM
2001	03	27	04	080	7.0	8.0	1.2	11	MM	MM	1012.3	4.3	4.4	MM	MM	-1.1	MM
2001	03	27	03	070	7.0	8.0	1.0	11	MM	MM	1012.7	4.0	4.4	MM	MM	-1.2	MM
2001	03	27	02	080	7.0	8.0	1.1	11	MM	MM	1013.4	3.9	4.4	MM	MM	-0.4	MM
2001	03	27	01	090	6.0	8.0	1.0	13	MM	MM	1013.4	3.6	4.4	MM	MM	-0.7	MM
2001	03	27	00	080	6.0	6.0	1.1	8	MM	MM	1013.9	3.5	4.4	MM	MM	-0.4	MM
2001	03	26	23	070	6.0	7.0	1.1	8	MM	MM	1013.8	3.2	4.4	MM	MM	-0.9	MM
2001	03	26	22	060	5.0	6.0	1.1	8	MM	MM	1014.1	3.6	4.7	MM	MM	-0.7	MM
2001	03	26	21	070	4.0	5.0	1.1	8	MM	MM	1014.3	3.6	4.6	MM	MM	+0.0	MM
2001	03	26	20	060	4.0	5.0	1.1	8	MM	MM	1014.7	3.6	4.4	MM	MM	+0.5	MM
2001	03	26	19	030	4.0	4.0	1.2	13	MM	MM	1014.8	3.6	4.5	MM	MM	-0.0	MM
2001	03	26	18	030	4.0	5.0	1.1	8	MM	MM	1014.4	3.6	4.7	MM	MM	-0.6	MM
2001	03	26	17	050	5.0	6.0	1.2	8	MM	MM	1014.2	3.6	4.6	MM	MM	-0.4	MM
2001	03	26	16	050	5.0	6.0	1.2	7	MM	MM	1014.6	3.5	4.4	MM	MM	+0.0	MM
2001	03	26	15	050	5.0	6.0	1.3	8	MM	MM	1015.0	3.6	4.4	MM	MM	+0.3	MM
2001	03	26	14	040	5.0	7.0	1.3	8	MM	MM	1014.6	3.6	4.4	MM	MM	+0.0	MM
2001	03	26	13	030	5.0	7.0	1.4	8	MM	MM	1014.4	3.5	4.4	MM	MM	-0.3	MM
2001	03	26	12	030	5.0	6.0	1.6	8	MM	MM	1014.7	3.2	4.4	MM	MM	-0.3	MM
2001	03	26	11	030	5.0	6.0	1.6	8	MM	MM	1014.4	3.1	4.4	MM	MM	-0.6	MM

2001	03	26	10	040	3.0	5.0	1.8	10	MM	MM	1014.7	2.9	4.3	MM	MM	-1.0	MM
2001	03	26	09	030	2.0	3.0	1.8	8	MM	MM	1015.0	2.9	4.3	MM	MM	-1.3	MM
2001	03	26	08	010	2.0	3.0	1.9	9	MM	MM	1015.0	2.9	4.3	MM	MM	-1.1	MM
2001	03	26	07	360	1.0	1.0	1.7	8	MM	MM	1015.7	2.9	4.3	MM	MM	-0.8	MM
2001	03	26	06	360	1.0	2.0	1.8	8	MM	MM	1016.3	3.1	4.3	MM	MM	-0.8	MM
2001	03	26	05	330	1.0	2.0	1.9	8	MM	MM	1016.1	3.1	4.3	MM	MM	-0.9	MM
2001	03	26	04	290	3.0	4.0	2.1	8	MM	MM	1016.5	3.2	4.4	MM	MM	-0.7	MM
2001	03	26	03	290	4.0	5.0	2.0	9	MM	MM	1017.1	3.2	4.3	MM	MM	+0.7	MM
2001	03	26	02	280	5.0	6.0	2.4	9	MM	MM	1017.0	3.2	4.3	MM	MM	+1.3	MM
2001	03	26	01	270	5.0	6.0	2.5	9	MM	MM	1017.2	3.2	4.4	MM	MM	+1.9	MM
2001	03	26	00	260	6.0	8.0	2.8	10	MM	MM	1016.4	3.3	4.4	MM	MM	+1.4	MM
2001	03	25	23	270	7.0	9.0	2.9	10	MM	MM	1015.7	3.3	4.5	MM	MM	+1.0	MM
2001	03	25	22	260	7.0	9.0	3.0	10	MM	MM	1015.3	3.6	4.7	MM	MM	+0.5	MM
2001	03	25	21	260	7.0	9.0	3.1	10	MM	MM	1015.0	3.9	4.7	MM	MM	+0.4	MM
2001	03	25	20	260	9.0	11.0	2.9	10	MM	MM	1014.7	4.0	4.7	MM	MM	+0.4	MM
2001	03	25	19	250	9.0	11.0	2.8	10	MM	MM	1014.8	4.0	4.4	MM	MM	+0.7	MM
2001	03	25	18	260	9.0	11.0	2.6	10	MM	MM	1014.6	4.0	4.4	MM	MM	+1.2	MM
2001	03	25	17	250	8.0	10.0	2.9	9	MM	MM	1014.3	4.3	4.4	MM	MM	+1.3	MM
2001	03	25	16	260	8.0	9.0	2.7	9	MM	MM	1014.1	4.4	4.4	MM	MM	+1.6	MM
2001	03	25	15	260	7.0	9.0	2.6	9	MM	MM	1013.4	4.7	4.3	MM	MM	+1.6	MM
2001	03	25	14	250	6.0	7.0	2.3	9	MM	MM	1013.0	4.8	4.3	MM	MM	+2.1	MM
2001	03	25	13	260	6.0	7.0	2.4	9	MM	MM	1012.5	4.8	4.3	MM	MM	+2.4	MM
2001	03	25	12	270	6.0	7.0	2.6	8	MM	MM	1011.8	4.8	4.3	MM	MM	+3.0	MM
2001	03	25	11	280	6.0	7.0	2.9	9	MM	MM	1010.9	4.8	4.3	MM	MM	+2.8	MM
2001	03	25	10	270	7.0	8.0	2.9	9	MM	MM	1010.1	4.7	4.3	MM	MM	+2.7	MM
2001	03	25	09	260	7.0	8.0	2.8	9	MM	MM	1008.8	4.8	4.3	MM	MM	+1.8	MM
2001	03	25	08	270	8.0	10.0	3.0	9	MM	MM	1008.1	4.8	4.3	MM	MM	+1.7	MM
2001	03	25	07	250	8.0	10.0	2.9	9	MM	MM	1007.4	5.1	4.3	MM	MM	+0.9	MM
2001	03	25	06	260	8.0	10.0	3.3	9	MM	MM	1007.0	5.1	4.3	MM	MM	+0.8	MM
2001	03	25	05	260	9.0	11.0	2.9	9	MM	MM	1006.4	5.2	4.3	MM	MM	+0.5	MM
2001	03	25	04	250	9.0	11.0	2.9	9	MM	MM	1006.5	5.5	4.3	MM	MM	+0.9	MM
2001	03	25	03	270	8.0	10.0	3.0	9	MM	MM	1006.2	5.2	4.3	MM	MM	-0.0	MM
2001	03	25	02	280	11.0	14.0	2.9	10	MM	MM	1005.9	5.9	4.3	MM	MM	-1.2	MM
2001	03	25	01	230	5.0	7.0	3.2	9	MM	MM	1005.6	6.7	4.3	MM	MM	-1.5	MM
2001	03	25	00	220	8.0	9.0	3.2	10	MM	MM	1006.1	7.1	4.3	MM	MM	-0.9	MM
2001	03	24	23	220	6.0	7.0	3.9	10	MM	MM	1007.1	5.6	4.3	MM	MM	+0.0	MM
2001	03	24	22	220	7.0	9.0	3.6	10	MM	MM	1007.1	5.6	4.3	MM	MM	+0.0	MM
2001	03	24	21	230	8.0	10.0	4.1	9	MM	MM	1007.0	5.5	4.4	MM	MM	+0.0	MM
2001	03	24	20	240	11.0	14.0	4.1	10	MM	MM	1007.1	5.6	4.4	MM	MM	+0.0	MM
2001	03	24	19	240	11.0	13.0	4.5	9	MM	MM	1007.3	5.5	4.3	MM	MM	+0.8	MM
2001	03	24	18	250	10.0	13.0	4.3	10	MM	MM	1007.0	5.5	4.3	MM	MM	+1.1	MM
2001	03	24	17	250	11.0	14.0	4.5	9	MM	MM	1007.0	5.5	4.3	MM	MM	+1.7	MM
2001	03	24	16	260	12.0	15.0	4.1	8	MM	MM	1006.5	5.5	4.3	MM	MM	+2.3	MM
2001	03	24	15	260	12.0	15.0	4.4	10	MM	MM	1005.9	5.5	4.3	MM	MM	+2.7	MM
2001	03	24	14	260	14.0	18.0	4.7	10	MM	MM	1005.3	5.2	4.3	MM	MM	+3.2	MM
2001	03	24	13	260	13.0	16.0	4.5	10	MM	MM	1004.2	5.2	4.3	MM	MM	+3.1	MM
2001	03	24	12	260	13.0	16.0	4.3	10	MM	MM	1003.2	5.1	4.3	MM	MM	+2.5	MM
2001	03	24	11	260	13.0	16.0	4.3	10	MM	MM	1002.1	4.8	4.3	MM	MM	+2.1	MM
2001	03	24	10	270	13.0	16.0	4.1	10	MM	MM	1001.1	4.7	4.3	MM	MM	+1.5	MM
2001	03	24	09	270	14.0	17.0	4.1	10	MM	MM	1000.7	4.7	4.3	MM	MM	+1.5	MM
2001	03	24	08	260	13.0	16.0	4.3	11	MM	MM	1000.0	4.7	4.3	MM	MM	+1.4	MM
2001	03	24	07	260	12.0	15.0	4.5	10	MM	MM	999.6	4.8	4.3	MM	MM	+1.6	MM
2001	03	24	06	250	11.0	14.0	4.5	11	MM	MM	999.2	5.1	4.3	MM	MM	+1.0	MM
2001	03	24	05	260	10.0	13.0	4.4	11	MM	MM	998.6	4.4	4.3	MM	MM	-0.0	MM
2001	03	24	04	250	11.0	14.0	4.5	10	MM	MM	998.0	5.1	4.3	MM	MM	+0.6	MM
2001	03	24	03	240	10.0	13.0	4.8	11	MM	MM	998.2	5.0	4.3	MM	MM	+1.3	MM
2001	03	24	02	250	9.0	12.0	4.8	11	MM	MM	998.4	4.8	4.3	MM	MM	+2.4	MM
2001	03	24	01	250	11.0	13.0	5.1	10	MM	MM	997.4	5.1	4.3	MM	MM	+2.5	MM
2001	03	24	00	250	10.0	12.0	5.0	10	MM	MM	996.9	4.4	4.3	MM	MM	+3.1	MM
2001	03	23	23	250	11.0	14.0	5.3	11	MM	MM	996.0	4.8	4.3	MM	MM	+3.1	MM
2001	03	23	22	250	13.0	16.0	5.1	11	MM	MM	994.9	4.8	4.3	MM	MM	+2.3	MM
2001	03	23	21	250	13.0	17.0	5.5	11	MM	MM	993.8	4.7	4.3	MM	MM	+1.4	MM
2001	03	23	20	240	13.0	17.0	5.4	11	MM	MM	992.9	4.4	4.4	MM	MM	+0.7	MM
2001	03	23	19	250	14.0	17.0	5.1	11	MM	MM	992.6	4.4	4.0	MM	MM	+0.6	MM
2001	03	23	18	250	13.0	18.0	5.0	11	MM	MM	992.4	4.0	4.0	MM	MM	+0.8	MM
2001	03	23	17	250	14.0	17.0	5.2	11	MM	MM	992.2	4.2	3.9	MM	MM	+1.5	MM
2001	03	23	16	250	13.0	17.0	4.8	11	MM	MM	992.0	3.9	3.9	MM	MM	+2.3	MM
2001	03	23	15	250	12.0	16.0	5.0	13	MM	MM	991.6	3.9	3.9	MM	MM	+2.0	MM
2001	03	23	14	250	12.0	16.0	4.8	13	MM	MM	990.7	3.8	3.9	MM	MM	+1.3	MM
2001	03	23	13	240	12.0	15.0	5.5	13	MM	MM	989.7	4.3	3.9	MM	MM	+0.4	MM
2001	03	23	12	220	11.0	13.0	5.2	13	MM	MM	989.6	4.7	4.3	MM	MM	+0.3	MM
2001	03	23	11	230	9.0	12.0	5.2	13	MM	MM	989.4	5.1	4.4	MM	MM	+0.0	MM
2001	03	23	10	240	9.0	12.0	5.9	13	MM	MM	989.3	5.2	4.7	MM	MM	-0.5	MM
2001	03	23	09	240	8.0	11.0	6.1	13	MM	MM	989.3	5.5	4.4	MM	MM	-1.0	MM
2001	03	23	08	220	7.0	9.0	5.4	13	MM	MM	989.2	6.6	4.4	MM	MM	-1.2	MM
2001	03	23	07	190	3.0	4.0	5.2	13	MM	MM	989.8	5.9	4.7	MM	MM	-0.7	MM
2001	03	23	06	200	2.0	3.0	5.0	13	MM	MM	990.3	5.9	4.7	MM	MM	-0.3	MM
2001	03	23	05	200	2.0	4.0	5.2	13	MM	MM	990.4	6.0	4.4	MM	MM	-0.9	MM
2001	03	23	04	210	2.0	3.0	5.9	13	MM	MM	990.5	6.5	4.7	MM	MM	-0.8	MM
2001	03	23	03	220	3.0	5.0	6.5	13	MM	MM	990.6	6.7	4.7	MM	MM	+0.0	MM
2001	03	23	02	180	5.0	6.0	6.0	13	MM	MM	991.3	7.1	4.7	MM	MM	-0.4	MM

2001	03	23	01	170	6.0	8.0	6.8	13	MM	MM	991.3	7.1	4.7	MM	MM	+0.0	MM
2001	03	23	00	160	6.0	8.0	6.3	13	MM	MM	990.8	7.9	4.7	MM	MM	-0.9	MM
2001	03	22	23	150	6.0	8.0	6.9	13	MM	MM	991.7	7.4	4.4	MM	MM	-1.6	MM
2001	03	22	22	120	6.0	8.0	6.9	13	MM	MM	991.1	6.7	4.3	MM	MM	-3.5	MM
2001	03	22	21	110	8.0	11.0	7.4	13	MM	MM	991.7	8.2	4.0	MM	MM	-5.5	MM
2001	03	22	20	120	12.0	15.0	7.6	13	MM	MM	993.3	8.3	3.9	MM	MM	-6.3	MM
2001	03	22	19	100	12.0	14.0	6.3	13	MM	MM	994.6	7.8	3.9	MM	MM	-7.1	MM
2001	03	22	18	100	11.0	13.0	6.9	13	MM	MM	997.2	7.8	3.9	MM	MM	-6.3	MM
2001	03	22	17	100	11.0	14.0	6.4	13	MM	MM	999.6	7.9	3.9	MM	MM	-5.4	MM
2001	03	22	16	110	12.0	14.0	5.9	11	MM	MM	1001.7	8.2	3.9	MM	MM	-4.8	MM
2001	03	22	15	100	12.0	14.0	4.9	11	MM	MM	1003.5	8.0	3.9	MM	MM	-4.5	MM
2001	03	22	14	100	13.0	16.0	4.3	11	MM	MM	1005.0	8.2	3.9	MM	MM	-4.0	MM
2001	03	22	13	090	11.0	14.0	3.9	10	MM	MM	1006.5	7.2	3.6	MM	MM	-3.5	MM
2001	03	22	12	100	12.0	14.0	4.2	9	MM	MM	1008.0	7.9	3.6	MM	MM	-3.5	MM
2001	03	22	11	090	12.0	14.0	4.2	9	MM	MM	1009.0	7.5	3.9	MM	MM	-4.2	MM
2001	03	22	10	090	13.0	15.0	3.9	9	MM	MM	1010.0	7.4	4.0	MM	MM	-4.8	MM
2001	03	22	09	090	12.0	14.0	3.8	8	MM	MM	1011.5	7.4	4.3	MM	MM	-5.0	MM
2001	03	22	08	100	11.0	13.0	3.9	9	MM	MM	1013.2	7.5	4.3	MM	MM	-4.7	MM
2001	03	22	07	100	11.0	13.0	3.3	8	MM	MM	1014.8	7.5	4.3	MM	MM	-4.7	MM
2001	03	22	06	090	11.0	12.0	3.0	7	MM	MM	1016.5	7.3	4.3	MM	MM	-4.0	MM
2001	03	22	05	090	11.0	13.0	2.6	7	MM	MM	1017.9	7.1	4.3	MM	MM	-3.4	MM
2001	03	22	04	100	11.0	13.0	2.5	7	MM	MM	1019.5	7.2	4.3	MM	MM	-2.8	MM
2001	03	22	03	100	11.0	13.0	2.1	6	MM	MM	1020.5	7.1	4.2	MM	MM	-2.3	MM
2001	03	22	02	100	11.0	13.0	2.0	6	MM	MM	1021.3	6.7	4.0	MM	MM	-2.7	MM
2001	03	22	01	090	11.0	13.0	2.0	6	MM	MM	1022.3	6.3	4.0	MM	MM	-2.1	MM
2001	03	22	00	100	11.0	13.0	1.9	6	MM	MM	1022.8	6.1	4.1	MM	MM	-3.0	MM
2001	03	21	23	100	11.0	14.0	2.0	5	MM	MM	1024.0	5.9	4.4	MM	MM	-2.9	MM
2001	03	21	22	090	11.0	13.0	1.9	5	MM	MM	1024.4	5.9	4.3	MM	MM	-3.9	MM
2001	03	21	21	090	10.0	12.0	1.6	5	MM	MM	1025.8	5.8	4.3	MM	MM	-3.0	MM
2001	03	21	20	090	9.0	11.0	1.6	5	MM	MM	1026.9	5.6	4.3	MM	MM	-3.0	MM
2001	03	21	19	090	9.0	10.0	1.4	4	MM	MM	1028.3	5.9	4.3	MM	MM	-1.5	MM
2001	03	21	18	090	8.0	9.0	1.4	13	MM	MM	1028.8	5.6	4.4	MM	MM	-1.3	MM
2001	03	21	17	090	6.0	8.0	1.3	13	MM	MM	1029.9	5.6	4.7	MM	MM	MM	MM
2001	03	21	16	080	8.0	9.0	1.3	9	MM	MM	1029.8	5.5	4.7	MM	MM	MM	MM
2001	03	21	15	080	7.0	9.0	1.1	13	MM	MM	1030.1	5.5	4.7	MM	MM	MM	MM
2001	03	21	11	070	6.0	7.0	0.9	13	MM	MM	1031.2	4.3	4.4	MM	MM	+0.0	MM
2001	03	21	10	060	5.0	6.0	0.9	14	MM	MM	1031.2	3.9	4.4	MM	MM	-0.7	MM
2001	03	21	09	050	5.0	5.0	0.9	14	MM	MM	1031.3	3.9	4.4	MM	MM	-1.5	MM
2001	03	21	08	050	4.0	4.0	1.0	14	MM	MM	1031.3	3.9	4.4	MM	MM	-0.8	MM
2001	03	21	07	060	3.0	3.0	0.9	14	MM	MM	1031.9	3.9	4.3	MM	MM	+0.0	MM
2001	03	21	06	070	2.0	2.0	0.9	14	MM	MM	1032.8	3.9	4.4	MM	MM	+0.4	MM
2001	03	21	05	050	2.0	2.0	0.9	14	MM	MM	1032.1	3.9	4.0	MM	MM	-0.9	MM
2001	03	21	04	040	2.0	3.0	0.9	14	MM	MM	1032.1	3.9	4.3	MM	MM	-0.9	MM
2001	03	21	03	040	3.0	3.0	0.9	7	MM	MM	1032.4	3.9	4.7	MM	MM	-0.4	MM
2001	03	21	02	020	1.0	1.0	0.9	7	MM	MM	1033.0	3.8	4.7	MM	MM	+1.0	MM
2001	03	21	01	050	1.0	1.0	0.9	6	MM	MM	1033.0	3.9	4.7	MM	MM	+1.7	MM
2001	03	21	00	030	2.0	2.0	0.8	6	MM	MM	1032.8	4.0	4.7	MM	MM	+1.4	MM
2001	03	20	23	020	3.0	3.0	0.9	6	MM	MM	1032.0	4.3	4.3	MM	MM	+0.8	MM
2001	03	20	22	030	4.0	4.0	0.9	6	MM	MM	1031.3	4.4	4.3	MM	MM	+0.0	MM
2001	03	20	21	030	3.0	4.0	1.0	6	MM	MM	1031.4	4.5	4.3	MM	MM	+0.0	MM
2001	03	20	20	030	4.0	4.0	1.1	5	MM	MM	1031.2	4.4	4.4	MM	MM	+0.0	MM
2001	03	20	19	030	5.0	5.0	1.1	7	MM	MM	1031.3	4.3	4.4	MM	MM	-0.6	MM
2001	03	20	18	010	5.0	6.0	1.2	5	MM	MM	1031.3	4.2	4.4	MM	MM	+0.0	MM
2001	03	20	17	010	6.0	7.0	1.3	5	MM	MM	1031.4	4.1	4.4	MM	MM	+0.0	MM
2001	03	20	16	360	6.0	7.0	1.4	5	MM	MM	1031.9	4.0	4.4	MM	MM	+1.4	MM
2001	03	20	15	360	7.0	8.0	1.3	5	MM	MM	1031.4	3.9	4.4	MM	MM	+1.1	MM
2001	03	20	14	010	7.0	8.0	1.3	6	MM	MM	1031.2	3.6	4.4	MM	MM	+1.7	MM
2001	03	20	13	010	7.0	9.0	1.4	6	MM	MM	1030.5	3.3	4.4	MM	MM	+2.1	MM
2001	03	20	12	010	7.0	9.0	1.4	6	MM	MM	1030.3	3.2	4.3	MM	MM	+2.7	MM
2001	03	20	11	360	7.0	8.0	1.5	7	MM	MM	1029.5	3.2	4.3	MM	MM	+3.0	MM
2001	03	20	10	360	7.0	9.0	1.6	7	MM	MM	1028.4	3.2	4.3	MM	MM	+1.9	MM
2001	03	20	09	360	7.0	9.0	1.6	6	MM	MM	1027.6	3.5	4.3	MM	MM	+1.9	MM
2001	03	20	08	020	9.0	10.0	1.8	6	MM	MM	1026.5	3.6	4.3	MM	MM	+1.4	MM
2001	03	20	07	020	7.0	9.0	2.0	6	MM	MM	1026.5	3.9	4.3	MM	MM	+1.5	MM
2001	03	20	06	020	9.0	10.0	2.2	7	MM	MM	1025.7	3.9	4.1	MM	MM	+1.4	MM
2001	03	20	05	020	9.0	11.0	2.2	7	MM	MM	1025.1	4.0	4.2	MM	MM	+1.3	MM
2001	03	20	04	010	10.0	13.0	2.3	7	MM	MM	1025.0	4.0	4.3	MM	MM	+2.0	MM
2001	03	20	03	360	10.0	13.0	2.3	7	MM	MM	1024.3	4.3	4.3	MM	MM	+1.8	MM
2001	03	20	02	350	11.0	12.0	2.0	7	MM	MM	1023.8	4.8	4.4	MM	MM	+1.9	MM
2001	03	20	01	330	9.0	11.0	2.2	7	MM	MM	1023.0	4.7	4.4	MM	MM	+2.0	MM
2001	03	20	00	330	9.0	11.0	2.0	7	MM	MM	1022.5	4.4	4.4	MM	MM	+2.2	MM
2001	03	19	23	330	9.0	11.0	2.0	8	MM	MM	1021.9	4.3	4.4	MM	MM	+2.9	MM
2001	03	19	22	330	9.0	11.0	2.1	8	MM	MM	1021.0	4.3	4.3	MM	MM	+2.2	MM
2001	03	19	21	330	11.0	13.0	2.0	7	MM	MM	1020.3	4.0	4.0	MM	MM	+1.8	MM
2001	03	19	20	330	9.0	11.0	2.0	7	MM	MM	1019.0	4.0	4.0	MM	MM	+0.9	MM
2001	03	19	19	330	10.0	11.0	2.1	7	MM	MM	1018.8	3.9	4.0	MM	MM	+1.1	MM
2001	03	19	18	330	10.0	11.0	2.4	7	MM	MM	1018.5	3.9	4.0	MM	MM	+1.1	MM
2001	03	19	17	330	9.0	11.0	2.4	7	MM	MM	1018.1	3.9	4.0	MM	MM	+1.0	MM
2001	03	19	16	330	9.0	10.0	2.2	7	MM	MM	1017.7	4.0	4.0	MM	MM	+1.3	MM
2001	03	19	15	330	9.0	11.0	2.2	7	MM	MM	1017.4	4.0	4.0	MM	MM	+1.7	MM
2001	03	19	14	330	9.0	11.0	2.1	6	MM	MM	1017.1	4.0	4.1	MM	MM	+2.2	MM