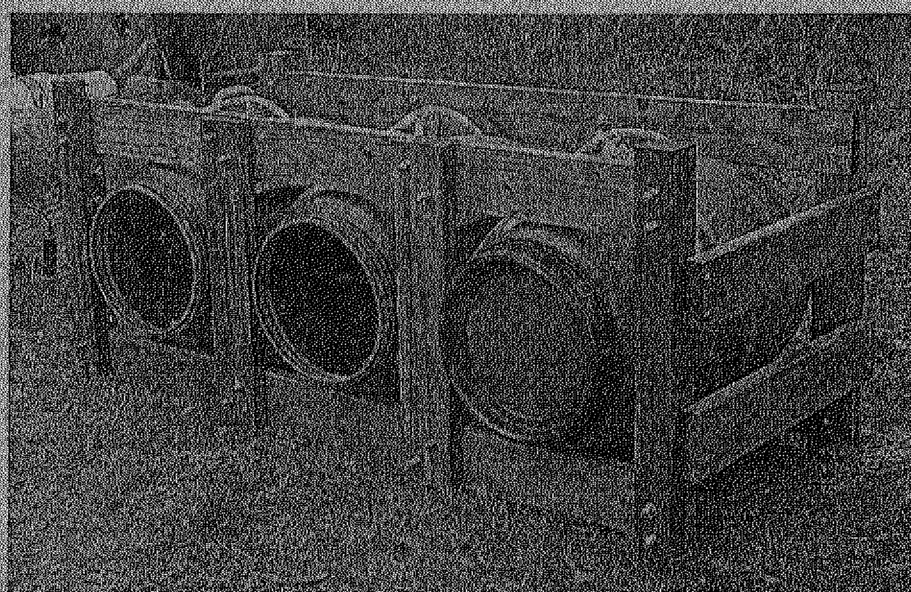
Project S.H.E.L.L.

Self-contained Hagfish Environment for Life-cycle Learning



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Sea Grant
New Hampshire

THE UNIVERSITY OF NEW HAMPSHIRE:
OCEAN TECHNOLOGY

ACKNOWLEDGMENTS

The work done by Project S.H.E.L.L. is the result of research sponsored in part by the National Sea Grant College Program, NOAA, Department of Commerce, under grant #NA16RG1035 to the New Hampshire Sea Grant Program.

The members of Project S.H.E.L.L. would like to thank the following people for their support of this project through advice, equipment, and financial means during the 2001-2002 academic year.

The Dr. Stacia Sower Laboratory

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Postdoctoral Research Associate Mickie Powell

The Crew of the R/V Gulf Challenger

Captain Paul Pelletier

Byran Soares, Debbie Brewitt

Dr. Larry Harris

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UNHMP-TR-SG-02-13

Abstract

*Millions of pounds of Atlantic Hagfish (Myxine glutinosa) are captured along the Atlantic coast every year. However, very little is known about the lifecycle of these primitive vertebrates and they remain one of the few animals that scientists have not been able to successfully breed in captivity. Many biologists, fishermen, and environmentalists would benefit from information about hagfish reproduction and lifecycle. Professor of Biochemistry and Molecular Biology at the University of New Hampshire, Dr. Stacia Sower, has hypothesized that hagfish will be more likely to reproduce in captivity if they are contained in their natural environment. With that in mind, Dr. Sower organized a team of undergraduate mechanical engineering and biology students to form the project group, S.H.E.L.L. (**S**elf-contained **H**agfish **E**nvironment for **L**ife-cycle **L**earning). The specific objective of the S.H.E.L.L. team was to design and build a self-contained habitat that is suitable for containing hagfish for two to six months at a time in their natural environment, located 400ft below the surface of the Atlantic Ocean.*

The S.H.E.L.L. team developed a habitat design that consisted of three, 55-gallon, plastic, Greek Pickle barrels contained in a truss framing system. A finite element analysis of the design was combined with data about material degradation in saltwater to determine the most appropriate and cost-effective framing materials. Ultimately, the frame was constructed of pressure treated lumber and secured together with stainless steel bolts. Holes were drilled in each barrel to allow the seawater to easily circulate through the barrels. An incident in which one barrel was damaged in transport prompted the group to add railings to the habitat to protect the ends of the barrels.

The habitat appeared to be adequately robust and functional in the ocean. However, the deep-water mooring / buoy system failed and the habitat was lost during the second trial period. The S.H.E.L.L. team has made several suggestions for improvements to the mooring system and feel that this habitat could be successful with an adequate buoy and anchor system.

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Introduction

Background

The Atlantic Hagfish (*Myxine glutinosa*) is a member of the most ancient lineage of vertebrates, the Agnathans (Bardack, 1998). Agnathans are jawless and are the only vertebrates that did not develop jaws. There are approximately 60 species of hagfish in the world today (Fernholm, 1998). Atlantic hagfish are known to live at depths of 100-1500m on the ocean floor in various substrates (Martini, 1998). At one time, it was widely believed that hagfish were functional hermaphrodites. It is possible that their single, unpaired sex organ develops sperm only in the posterior portion, and later, eggs in the anterior portion. However, that theory is currently in question and conclusive evidence has not been obtained to fully support or discount it.

Hagfish are valued for their skins, which are processed into "eel-skin" leather boots, bags, wallets and other products in Korea. Additionally, Koreans consume nearly 5 million pounds of hagfish meat each year (Honma, 1998). Millions of pounds of hagfish are harvested along the Atlantic coast every year for export. However, since the reproductive patterns of hagfish are essentially unknown, it is very difficult to determine the effects that this is having on the hagfish population. Fishermen, biologists, and environmentalists could all benefit greatly from a broader understanding of hagfish lifecycle and reproduction. It may also be possible to create a profitable aquaculture business based upon hagfish breeding.

One of the main goals in studying hagfish is to collect a fertilized hagfish egg. A fertilized hagfish egg has not been successfully harvested since 1891. This task is particularly complicated by the fact that scientists have not even developed conclusive methods of distinguishing between male, female, or the possibly of hermaphroditic hagfish. Mating patterns and egg laying habits are just a few of the other characteristics that are still unknown today, despite years of research. Dr. Stacia Sower, a neuroendrocrinologist and a Professor of Biochemistry and

Molecular Biology, hopes to obtain the answers to many of the questions about hagfish reproduction while conducting her research at the University of New Hampshire. During her research, Dr. Sower has hypothesized methods of distinguishing male hagfish from females, how to induce reproduction, and has developed a synthetic gonadotropin-release hormone that is injected into selected hagfish. In the past, teams of undergraduate students have worked with Dr. Sower to help develop a cage system that can be used to hold a selected number of hagfish at the bottom of the ocean at a depth that the fish can naturally be found in. It has been theorized that holding the hagfish in their natural environment will be more likely to result in hagfish reproduction.

Project Goals and Objectives

This academic year (September 2001 to May 2002), Dr. Sower organized a team of undergraduate mechanical engineering and biology students to form the project group, S.H.E.L.L. - **S**elf-contained **H**agfish **E**nvironment for **L**ife-cycle **L**earning. The specific objectives of the S.H.E.L.L. team were to design, build, and test a self-contained habitat that is suitable for containing hagfish for two to six months at a time on the ocean floor, 400ft below the surface.

If this habitat proved to be robust and functional, Dr. Sower and her students would be able to use it in the future to attempt to breed hagfish in captivity.

Work of Previous Teams

Teams of undergraduate students have been formed in previous years with similar goals and objectives. These groups developed a habitat design that used a 55-gallon *Greek pickle* barrel to hold 6 to 8 hagfish at the bottom of the ocean. Small holes were drilled in the barrel to allow water to circulate through the habitat but not allow the hagfish to escape. A concrete paving stone was bolted inside of the barrel to ensure a particular orientation on the ocean floor. Handles were secured to the opposite side of the barrel. The handles were used for loading, unloading, moving, and attaching buoy lines to the habitat.

Approximately 12 habitats of this design were constructed and launched in various locations off the coast of New England. Several weaknesses of this design were soon identified. The barrels were unprotected and several were severely damaged by the harsh ocean conditions. The habitats were also inadequately anchored and the majority of them were lost.

Materials and Methods

Design Criteria

- Functionality

  The habitat must be able to hold 6-12 hagfish, in an enclosure that they cannot escape, and that will not be dangerous to them, for 6 months at a time.

- Mechanical Integrity

  The Habitat must remain intact and functional, through harsh ocean conditions, for up to 6 months at a time.

- Affordable

  The ocean tech students are allotted a limited budget to work with. The habitat should cost less than $200 to construct. This will allow enough remaining funds for the boat trips to maintain the habitat.

- Weight tradeoffs

  The habitat must be heavy enough to limit movement under water but not so heavy that it cannot be moved by 4 to 5 people on land.

- Ease of use

  The habitat should have large, easily accessible, easily secured, openings for loading and unloading hagfish and sand.

- Anchoring system

  The anchoring system must be both functional and moveable.

- Buoy System

  The habitat must be well marked with a robust buoy system so that it can be easily located and retrieved.

- Harness system

  The habitat must have a secure method for lifting and lowering it.

Analysis of Previous Design

The first step in the design process was to closely examine the work of previous teams. The habitat that was developed by the TRENCH team during the 2000-2001 academic year was analyzed closely. The following traits were identified:

Table 1: Positive and Negative Characteristics of TRENCH Design

Sub-Assembly	Positive Characteristics	Negative Characteristics
Barrels	The lids are easy to open and very secure when closed.	The barrels and lids are not durable enough to withstand all of the impacts that they will encounter on the ocean floor during rough seas.
	The opening Is large enough to provide full access to the inside of the container.	The barrels and lids become increasingly brittle with prolonged exposure to sunlight (during storage) and low temperatures (during use).
	The barrel material is easy to work with; it is lightweight for portability and very easy to drill through.	Barrels are too lightweight to be used independently in the ocean; weight must be added just to cause the barrel to sink.
	Small pieces of line were attached to each barrel to form a handle. This made the barrels significantly easier to work with and created a perfect location to attach the buoy line to.	The holes that were drilled in the barrels to secure the handles were large enough to allow the hagfish to escape through.
	The holes that were drilled in the barrels for water circulation seemed to be an appropriate size. They were large enough to allow water to circulate but not so large that the hagfish could escape.	Some of the holes were drilled in a location that allowed the sand within the habitat to leak out.
	The barrels are inexpensive ($12 each) and easy to acquire.	

Sub-Assembly	**Positive Characteristics**	**Negative Characteristics**
Mooring System	The weights that were added to the inside of each barrel not only help to increase the weight of the barrel but also ensure that the barrel will lie in a particular orientation on the ocean floor.	The habitats drifted and the majority were lost. The mooring system was insufficient to secure the habitats in the desired locations.
Buoys	The buoys were a bright, neon color. This helps in both the retrieval process and to prevent others from accidentally coming in contact with the habitat.	The buoys may have been inappropriate for the weight of the habitats because they provided too much upward buoyant force as compared to the weight of the habitat.
	The buoys were marked with the UNH laboratory phone number. This may increase the likelihood that the habitat would be returned if someone else accidentally acquired it or found it in an unusual location.	The movement of the waves caused repetitive force on the habitat.
		The buoys were inflatable and would fail if they were punctured.
Lines	The braided nylon lines were lightweight and durable; they seemed to work very well for this purpose. However, the diameter of line that is appropriate is highly dependent upon the weight of the habitat system. Lines will need to be sized for the particular system that they are going to be used with.	If the design is significantly altered, new lines need to be purchased.

Conclusions Regarding Analysis of Previous Design

The previous team, T.R.E.N.C.H., incorporated many positive aspects into their habitat design. It was decided that the new design should build upon the framework of the T.R.E.N.C.H. design while focusing heavily on improving or eliminating all of the negative characteristics.

Figures 1 and 2 show the barrels, used by the T.R.E.N.C.H. team, that were incorporated into the new habitat design:

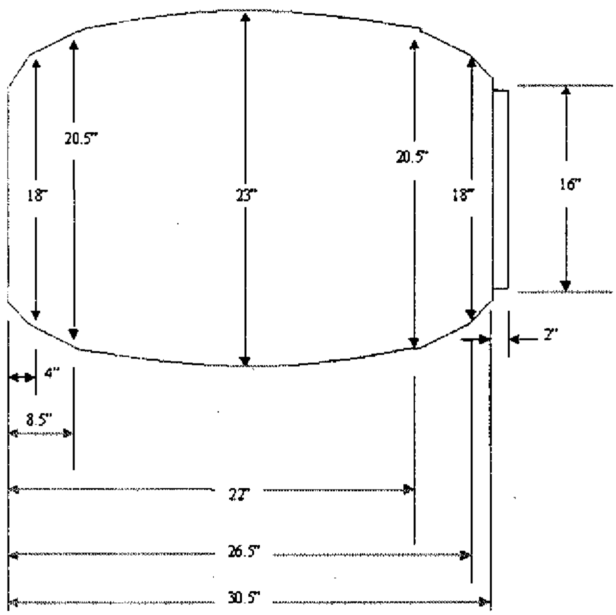
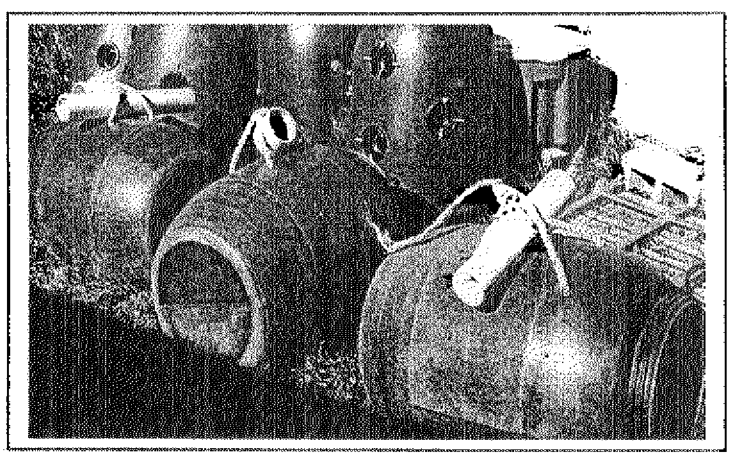


Figure 1: The barrel, used by the TRENCH team, shown with dimensions

Figure 2: Photograph of the barrels used by team TRENCH



Habitat Design

Each negative characteristic of the T.R.E.N.C.H. design was closely examined. A solution was developed to compensate for each problem.

Strength, durability, and weight characteristics:

- It was determined that the strength, durability, and weight could all be increased by constructing a protective frame around the barrel. Building the frame around several barrels, instead of just one, could further increase the weight while also improving stability.

Several different frame systems were proposed, however the one shown in Figures 3 and 4 appeared to be the most desirable choice. Alternative designs are outlined in Appendix B of this report.

Figure 3: The chosen frame design with dimensions

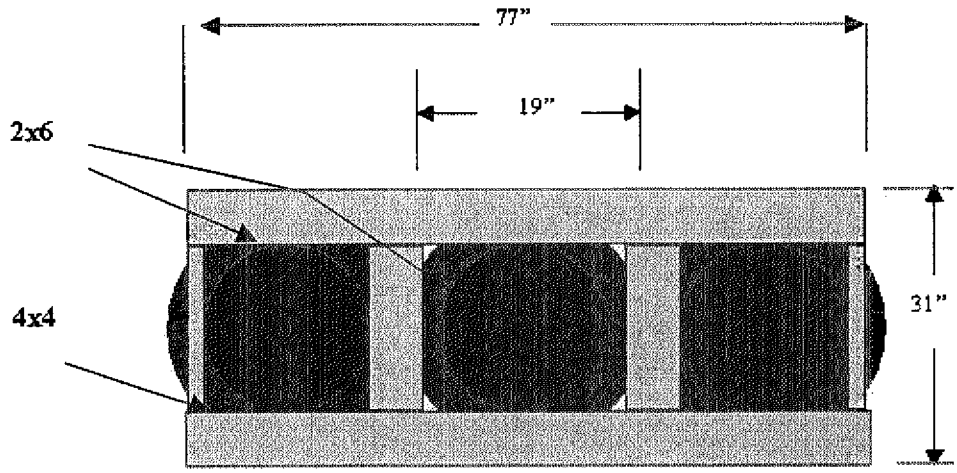
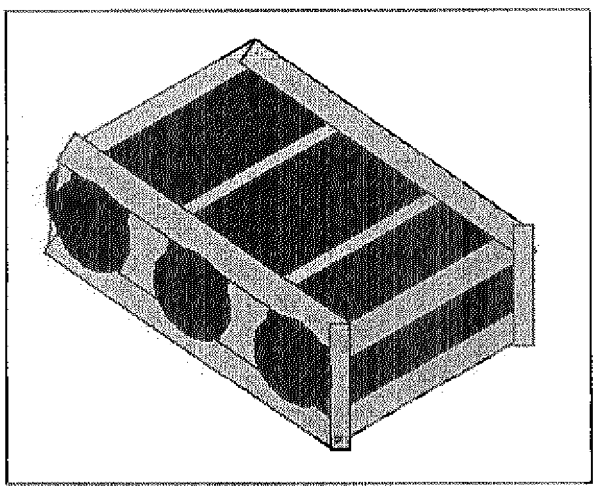


Figure 4: Perspective view of the selected frame

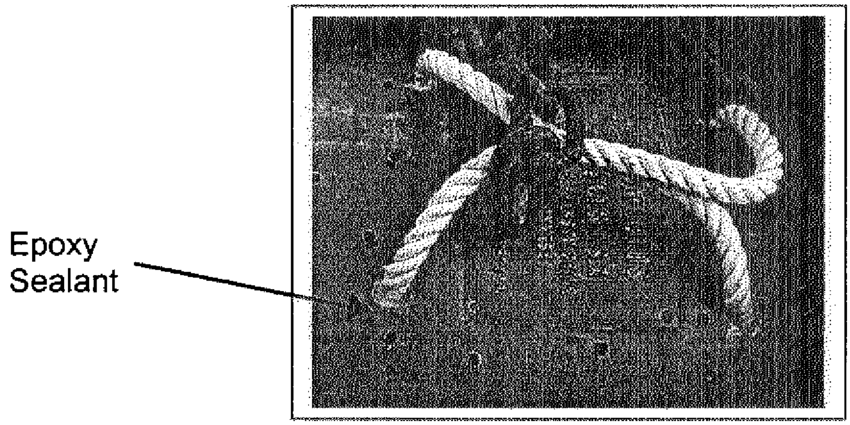


The chosen frame design grouped three barrels together in a stable configuration. This design allowed easy access to the barrel openings and appeared to protect the barrels so that the strength and durability of the barrels would be greatly increased.

Holes in the barrels:

- A marine-grade epoxy sealant was used to fill all of the holes that were determined to be undesirable. See Figure 5.

Figure 5: (Below) Epoxy was used to seal holes around the handles



Mooring system:

- It was determined that a more robust mooring system would need to be implemented to reduce the chances of losing the habitat.

A simple, cement block mooring of an appropriate weight would adequately anchor the system. See Figure 6. A 1000-pound, cement mooring block was graciously donated to the S.H.E.L.L. team by the Ocean Engineering Dept.

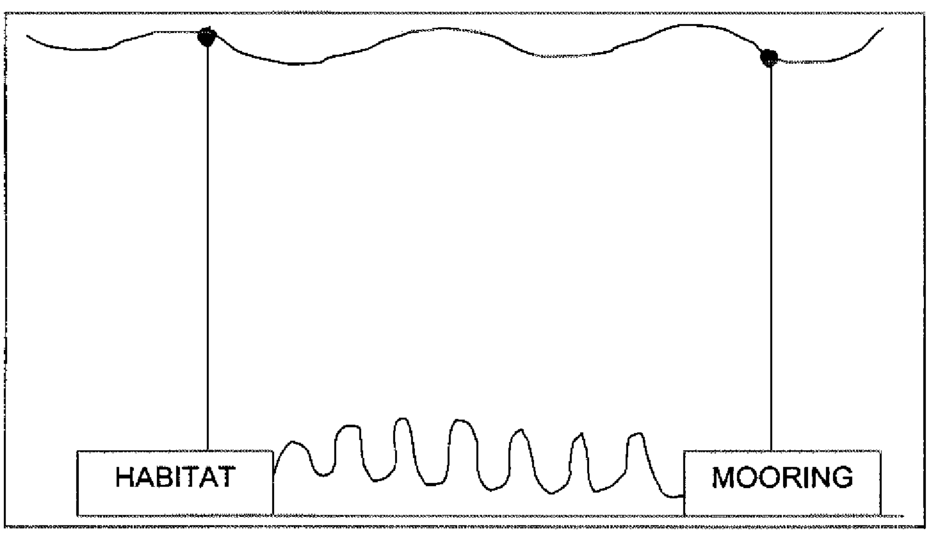


Figure 6: Mooring system

Buoys:

- A passing fisherman could puncture the surface buoy and cause it to sink. A trawler ball, attached just below the inflatable buoy, was used to ensure that even a deflated buoy would remain afloat.

- A sub-surface buoy was used to maintain a constant tension on the lower portion of the line. This prevented the rope from slamming down into the habitat and then yanking upward with each successive wave. Each trawler ball provides 7 lbs of buoyant force and is rigid enough to remain buoyant at depths up to 450m. Two trawler balls were attached to the lines approximately 30 feet below the surface.

Analysis

To calculate the strains, stresses, and deflections that the habitat would encounter, a Finite-Element Analysis (FEA) of the design was performed. Finite Element Analysis is a process of analyzing a complex structure of varied geometry by breaking it up into many smaller elements of known, uniform geometries. These smaller elements can be examined individually and pieced back together to form a realistic model of the entire structure. This process can be quite tedious to do "by-hand", with many equations to solve. Many FEA software packages are available to greatly increase the speed, accuracy, and level of complexity of the analysis. These software packages may be implemented to solve for the deflections, stresses, and strains of any almost any type of system. MARC/Designer (1996, Marc Analysis Research Corp.) was implemented in the analysis of this system.

The first step of the FEA was to develop a slightly simplified model that could be easily analyzed using the MARC software program. The habitat was modeled using 16 nodes and 28 elements as shown in Figure 7.

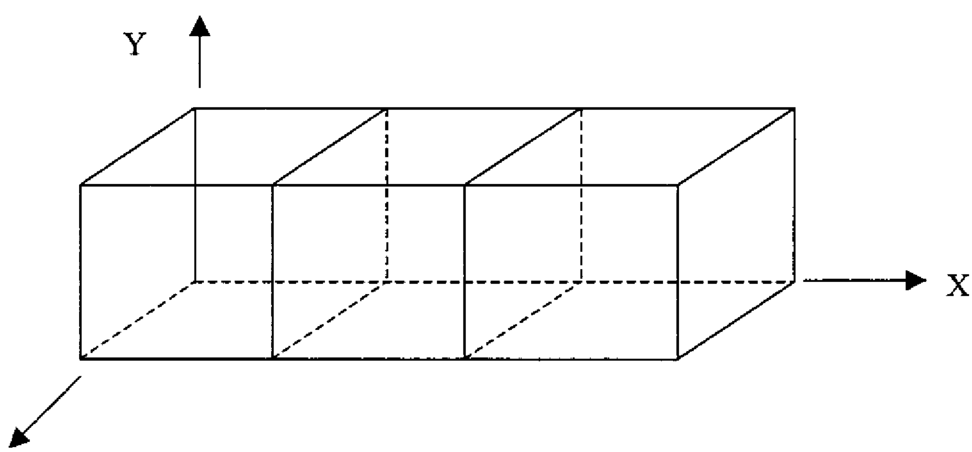


Figure 7: Nodal Model

A node is defined as the junction point between two or more elements. The greater the number of nodes and elements, the more accurate the model becomes. The simple model shown above was further divided to create 44 nodes and 56 elements. Figure 8 shows the model with the nodes numbered. Figure 9 shows the model with each element numbered.

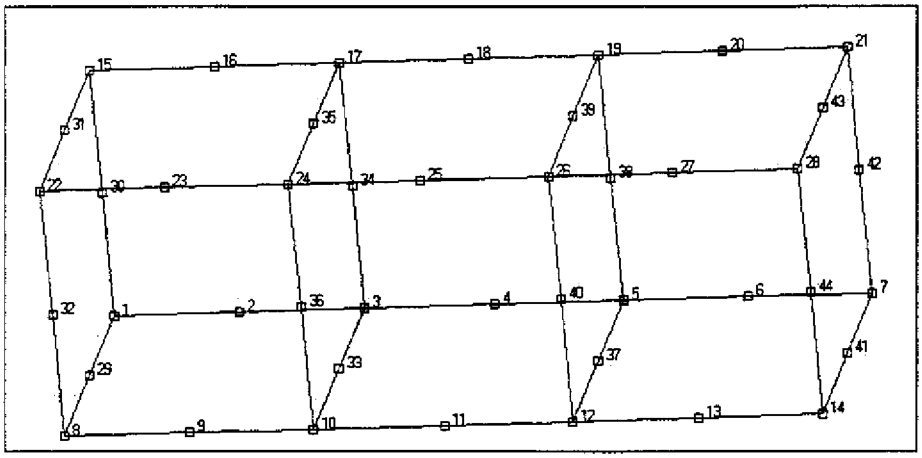


Figure 8: Numbered Nodes

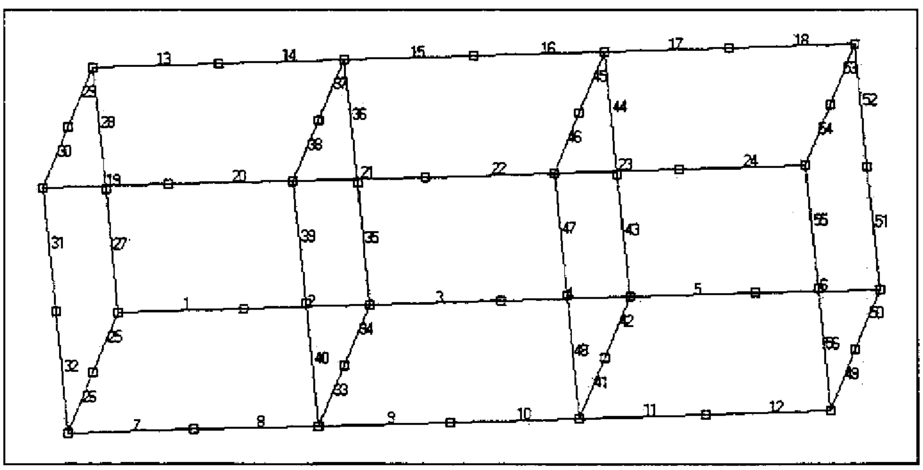


Figure 9: Numbered Elements

The next step in the preparation of the FEA model was to apply boundary conditions. The formation of the boundary conditions depends upon the particular loading scenario that is being analyzed. In this case, the crucial deflection, stress, and strain data were obtained through analysis of the most detrimental loading scenario. The habitat may encounter a severe impact as it lands on the ocean floor. However, there are an infinite number of orientations at which the habitat may impact. This leaves the loading condition poorly defined and extremely difficult to model. The weight of the habitat will reduce when it is under water. Therefore, one of the most detrimental loading conditions occurs while the habitat is on land, during the loading and unloading process. This loading scenario is well defined, experienced frequently, can be accurately modeled using the MARC FEA software. The following boundary conditions were developed for this system:

1. On land, the fully loaded habitat weighs approximately 750 pounds with a wooden frame or 900 pounds with a steel frame. The harness system is comprised of four chains. One chain connects to each of the four corner posts and all of the chains are connected together by a shackle at the center of the trap. Each chain carries ¼ of the entire weight of the system. The weight is represented in vector form. In the case of a wooden frame, the (vertical) y-component is –187.5 pounds for each chain. This increases to –225 pounds for a steel frame system.
2. The lower four corners of the habitat are constrained.
3. Each barrel (weighing 100 pounds each) can be modeled as 2 point-loads, of –50-pounds each, in the y-direction, on the lower side of the habitat.

Figure 10 illustrates all 3 boundary conditions and their locations.

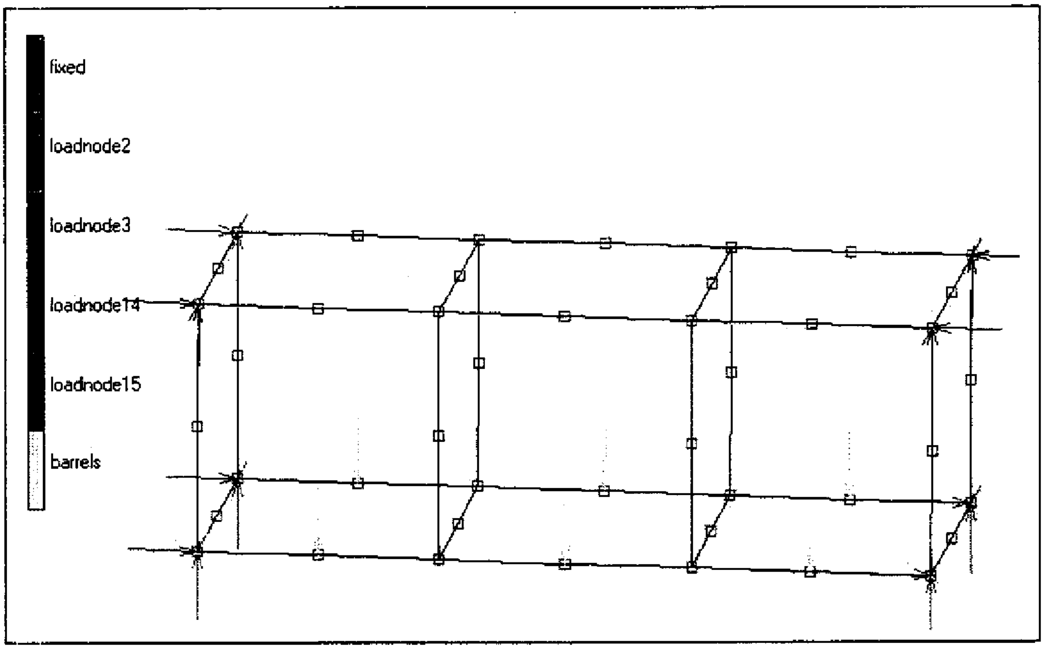


Figure 10: Boundary Conditions

The final step in the formation of the FEA model is to input the specific material and geometric properties of the construction materials. Two possible framing material options were examined: steel and pressure-treated wood.

Pressure treated wood:

Young's Modulus (E=1.8 X 10^6 psi), Poisson's Ratio (ν=0.3)

The first FEA model was constructed based upon wooded beam elements. The beams used in this model have 5 different orientations with 5 different moments of inertia and local coordinate axes. Figure 11, shows the calculated moments of inertia for each orientation. Figure 12 shows the habitat with the appropriate wooden beam orientations.

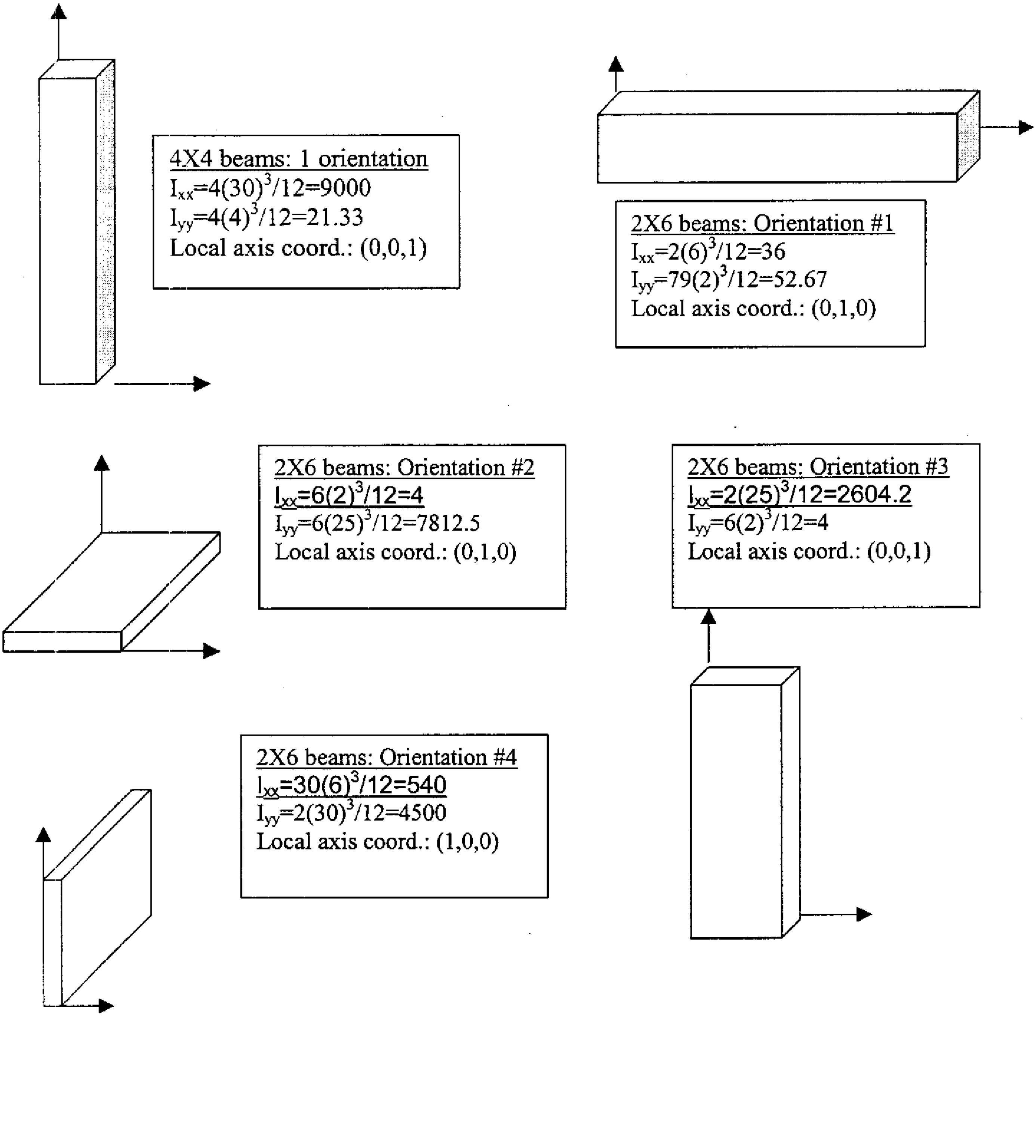


Figure 11: Various Beam Orientations

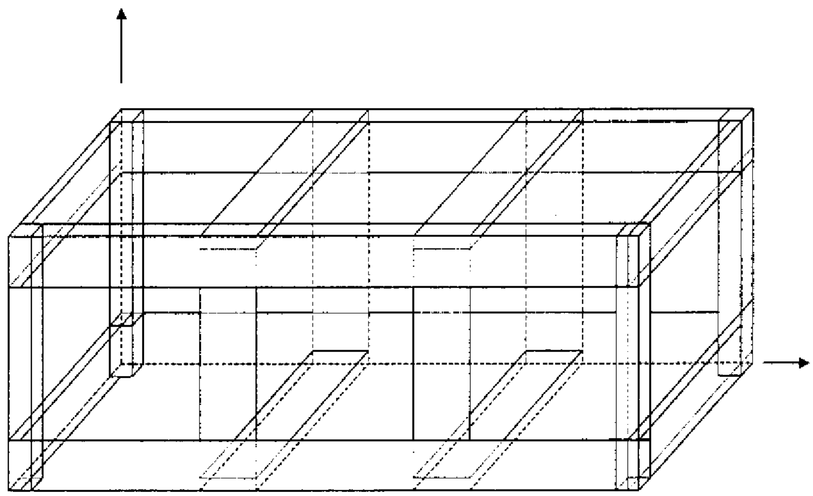


Figure 12: Habitat/Beam Orientation

The FEA analysis, completed using the MARC/Designer Software, revealed that the maximum deflection in the y-direction is –0.0038 inches under this loading condition with a wooden frame. This supports the theory that wood is an adequate building material. It can be concluded that pressure treated wood is sufficient for the purposes of the S.H.E.L.L. habitat as long as the wood does not show significant degradation after prolonged exposure to the ocean.

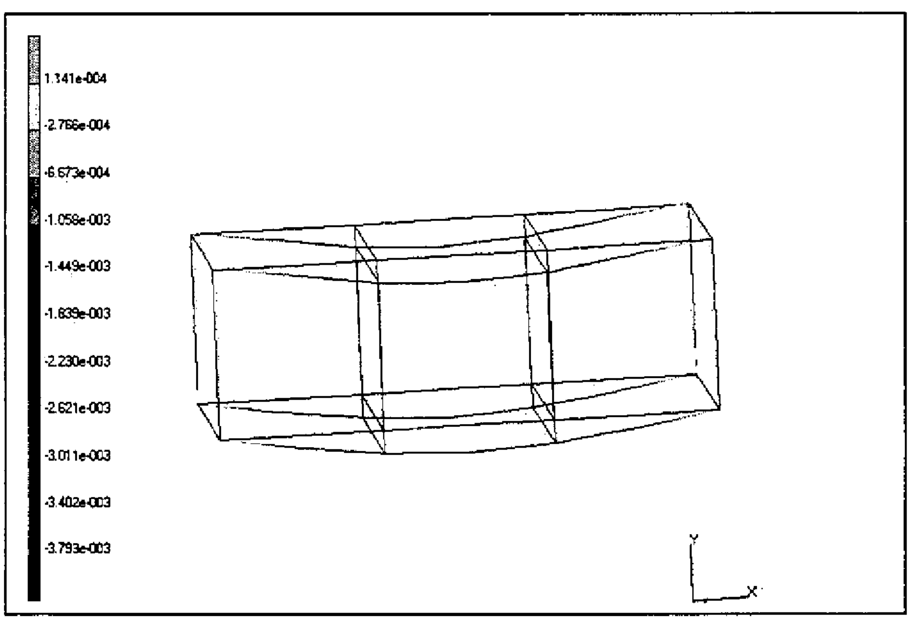


Figure 13: Magnified deflection of wooden habitat under max-loading condition

Steel:

Young's Modulus ($E=29 \times 10^6$ psi), Poisson's Ratio ($\nu=0.27$)

Using the process outlined above, the model was re-analyzed using 1" x 4" solid, rectangular, steel bars as the primary frame material. The FEA software reported a maximum deflection of –0.0002 inches. Figure 14 illustrates the deflection of the steel frame.

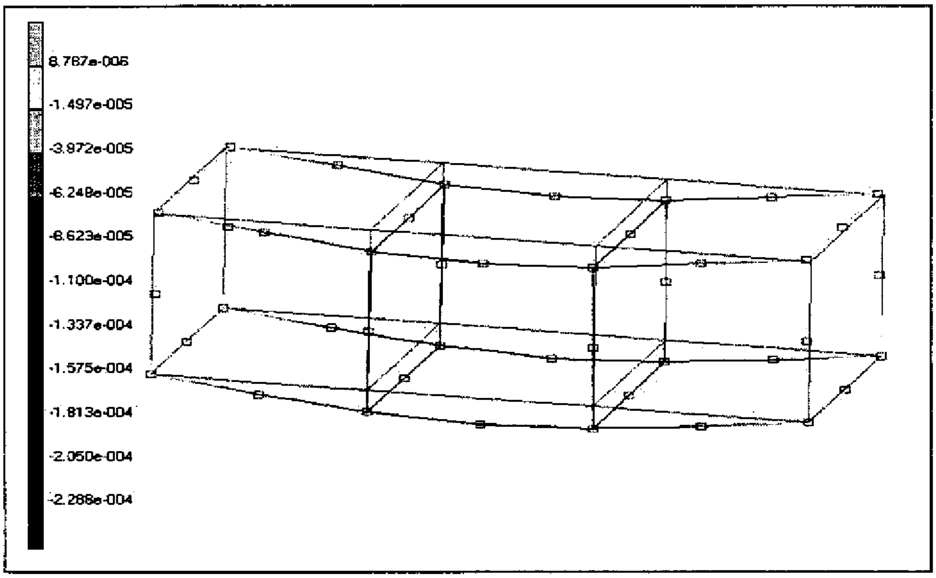


Figure 14: Magnified Deflection of the steel habitat under max-loading

The maximum stresses were well below the yield stress of the steel. Therefore, both steel and pressure-treated wood will both provide more than sufficient strength prior to their exposure to the application environment.

Materials Selection

Pressure treated wood was selected as the primary framing material. Wood is a very appealing construction material because it is inexpensive, readily available, and very easy to work with. The FEA analysis showed that the wooden was more than structurally adequate prior to exposure to salt water. The decision to utilize wood was also supported by extensive research regarding the degradation of wood during exposure to salt water. The following information was gathered to support the usage of wood in a marine application:

> "...CCA protects against attack by decay fungi, insects, and most types of marine borers. CCA-treated wood is used in decks, fences, poles, piling, and bridge timbers." (USDA Forest Service Forest Products Laboratory, 2000)

> "Wood has been the marine construction material of choice ever since man launched his first boat. When exposed to the often severe buffeting of both wind and waves, the flexibility of wood can yield superior resistance as compared to rigid construction materials. In addition, wood can't rust, won't corrode, and doesn't spall. In the event structural damage does occur, wood can usually be repaired in a more efficient and less costly way than other construction materials. Repairs can be made in all kinds of weather, in both wet and dry environments, often using nothing more complicated than ordinary carpentry tools. Furthermore, wood is a renewable resource with several environmental advantages." (Hayson, 2001)

The following information directly supports the decision to use pressure-treated wood in an application where it would be used very closely to the hagfish:

> "...leachate from untreated pilings had a greater adverse effect on organism survival than leachate obtained from CCA-treated wood pilings, the study's author concluded that the primary constituents of the CCA-treated wood pilings were not present in the leachate at concentrations which would adversely affect the survival of the organisms." (Springborn Laboratories, 1993)

> "Hatchery-reared oysters showed no significant differences between dock and reference sites in percent survival, growth, or

> bioaccumulation of metals after six weeks of exposure. Our results suggest that, in macrotidal estuarine environments, wood preservative leachates from dock pilings have no acutely toxic effects on four common estuarine species, nor do they affect the survival or growth of juvenile oysters over a six-week time period." (South Carolina Department of Natural Resources, Marine Resource Division, 1995)

Stainless steel bolts, washers, nylock nuts and screws were used to join the pieces of the wooden frame together. Stainless steel was selected because it has a very high resistance to corrosion and will provide adequate strength for this application.

Overview of Completed Habitat Design

Figure 15: (L-R) Aimee Oberhaus, Lindsey Hathway, and Sara Thomas working on the SHELL habitat 11/8/01

Construction of the chosen habitat began on November 8, 2001. The habitat consisted of a pressure-treated wood frame which contained three 55-gallon barrels.

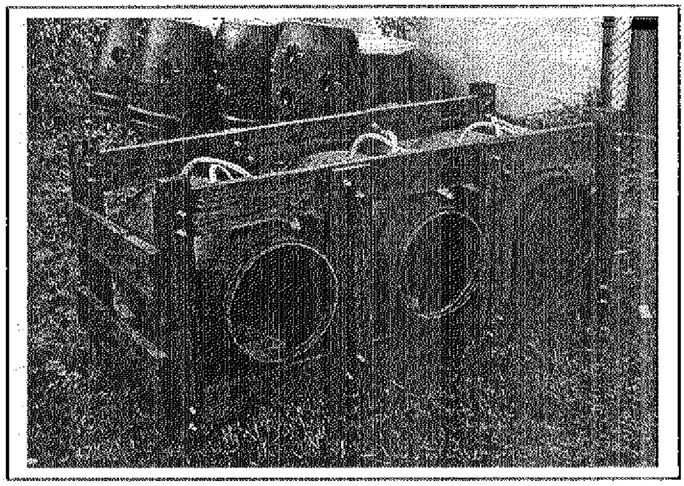


Figure 16: Front view of the completed habitat

The wooden frame was fastened together with all stainless steel hardware. Main structural components were secured with 6" long stainless bolts and Nylock nuts.

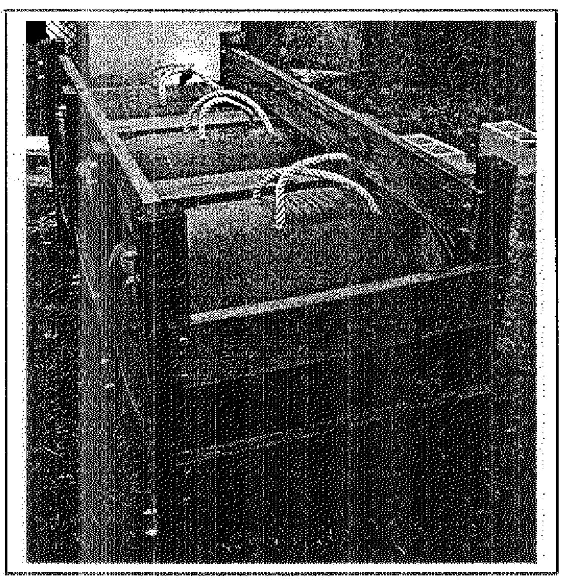
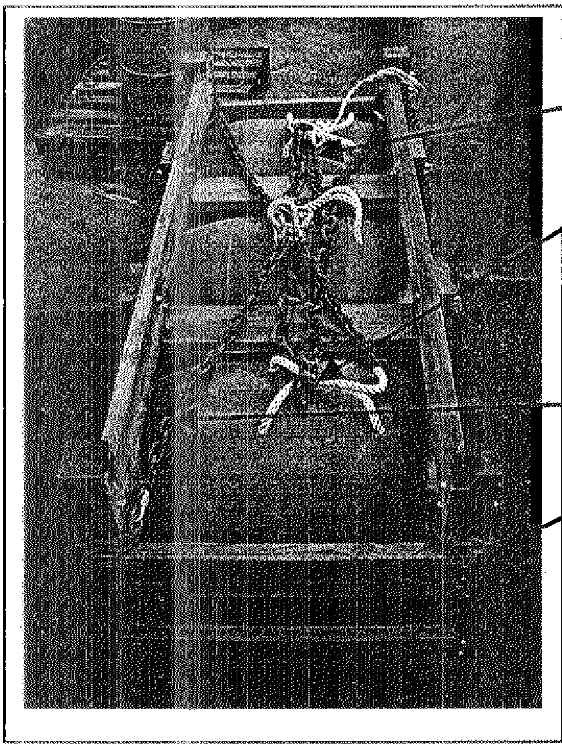


Figure 17: Side profile of the completed habitat



Harness 1: One chain runs through the handles of each barrel and connect to one shackle

Harness 2: Four chains total, one around each support beam shackled together in the center. That shackle is attached to the main lifting shackle.

Figure 18: Harness system

The harness system was designed to distribute the weight of the habitat equally on the four end posts. This system was also backed by a safety harness that attached directly to the barrels. This ensured that even if the frame were to break apart, the barrels would still remain attached to the buoy line.

Deployment

First Deployment

Launch Site:

The first launch site for the habitat was at the University of New Hampshire Aquaculture pen (42°56'70" latitude, 70°38'45" longitude), located off the Isles of Shoals. This site was selected for the ease of monitoring the habitat, as well as the shallower waters, which are protected from commercial fishing.

The plan for the first deployment was to retrieve a mooring and then drop the habitat and mooring at the Aquaculture pen. On November 15, 2001 the R/V Gulf Challenger went to Shell Island, where a mooring had previously been marked. Due to the position of the mooring to shore, as well as complications with the line, the mooring was unable to be retrieved. A decision was made to proceed with the habitat launch without a mooring.

The habitat was prepared for launch by the addition of seventy-five pounds of sand and eight hagfish to each barrel. Four medium and four large hagfish were placed in each barrel, hoping that both male and females were present in each barrel.

Once the barrels were sealed, the habitat was lowered into the water using the boat's A-frame winch, Figure 19 . At this time, sand was seen leaking from the back of the middle barrel as a result from damage during transport, Figure 20. The habitat was still launched to a depth of 172 feet where it remained for two weeks.

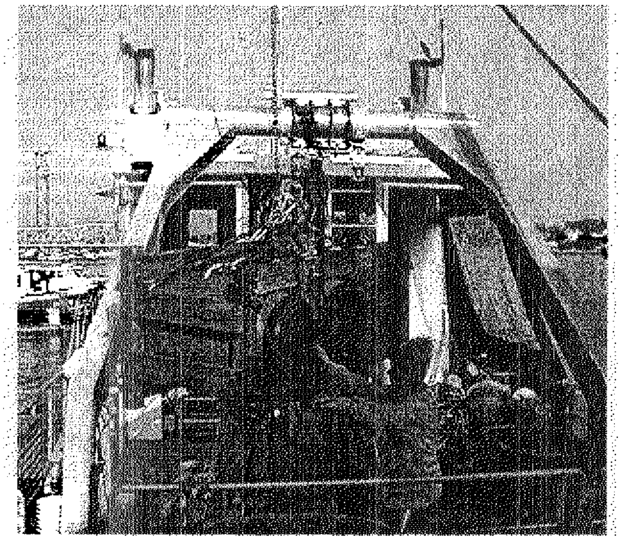


Figure 19 : Habitat being lifted by the A-frame winch.

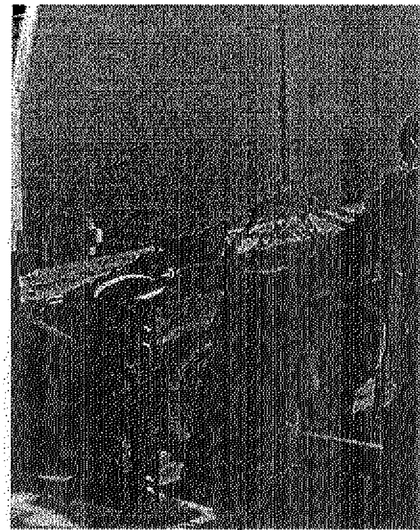


Figure 20 : Sand leaking from a crack in the middle barrel.

Retrieval/Observations

Due to the damage of the barrel, plans were made to bring the habitat up after two weeks in order to assess the damages and make repairs. Possible design modifications were also planned in order to protect the lids and back of the barrels from further damage.

On December 1, 2001 the habitat was recovered from the UNH Aquaculture pen site. During the retrieval, the front of the habitat struck the side of the boat. Once on deck the damage was assessed; one of the barrel lids had been cracked in the collision. The lids were then removed and the hagfish were examined. All twenty-four were alive, but no eggs were present. After inspection the hagfish were released into the ocean. Upon further examination of the habitat, it was noticed that a significant amount of sand had been lost. Of the original 225 pounds of sand, only 60 pounds was recovered.

Because of the damages acquired during the first deployment, the habitat was taken to UNH in order for modifications to be made before the second launch.

Improvements

Protection of the barrels and lids was the main focus for improvements to be made on the habitat. Besides damage done during transport, possible damage could be inflicted when the habitat is on the ocean floor, which may be a rocky substrate. During storms and high winds the habitat could be displaced and collide with rocks or other objects in the ocean. These conditions made it necessary for further protection of the barrels to be applied to the habitat.

The front and rear of the habitat needed to be protected, while allowing easy accessibility to the lids. The rear of the habitat was built out by attaching a 2x4 board to each of the 4x4 corner posts. 2x6 boards were attached at the top and bottom of the built out 4x4 posts, as seen in Figure 21. All boards were attached using 6" galvanized lag bolts.

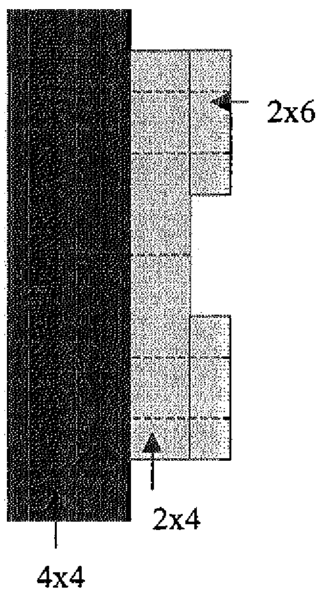


Figure 21: Side view of attached rear crossbeams.

The front of the habitat also needed protection, but the lids needed to be easily accessed in order to add and remove sand and hagfish from the barrels. As on the rear of the habitat, 2x4s were added to the 4x4 corner posts. Three shorter 1x3 pieces were attached to the 2x4s, as seen in Figure 22.

Another 2x4 was attached to the 1x3 pieces on each end. Prior to attachment of the second 2x4s, 4' stainless steel bolts were inserted into the 2x4s. Two bolts were placed in each 2x4, with the head of the bolt being captured between the 2x4s on each 4x4 post, as seen in Figure 23. The openings created by the 1x3 boards allowed for access to the bolt heads using a crescent wrench. 2x6 boards were then attached to the habitat by the bolts, on both the top and bottom. Wing-nuts were used to secure the 2x6 boards in place. The end of each bolt had been pre-drilled, and stainless steel cotter pins were inserted into these holes to prevent the wing-nuts from backing off the bolts. The final modifications can be seen in Figures 24 and 25.

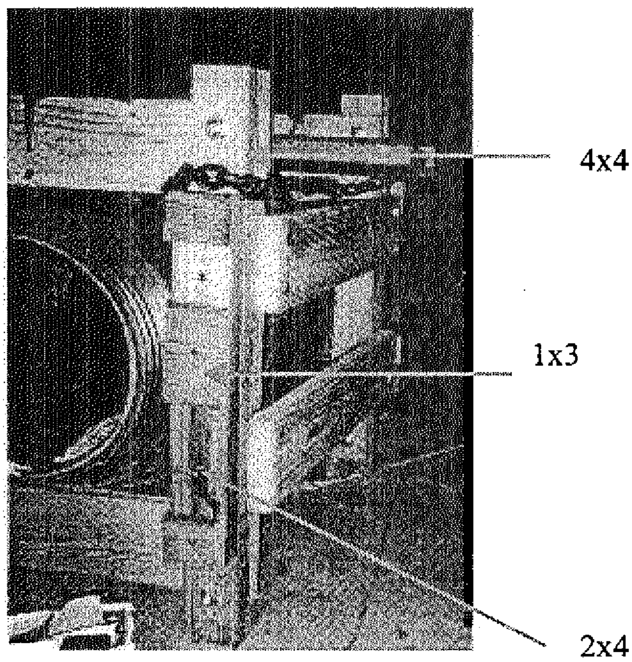


Figure 22: The front of the habitat, built out for modifications

Figure 23: Side view of attached front crossbeams.

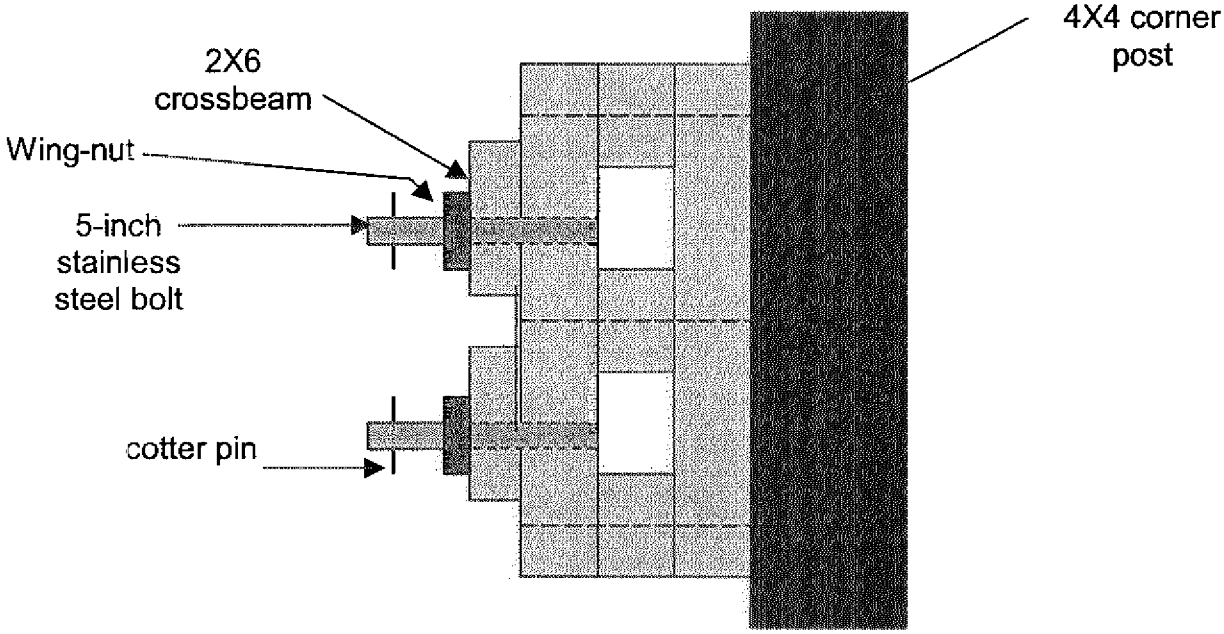
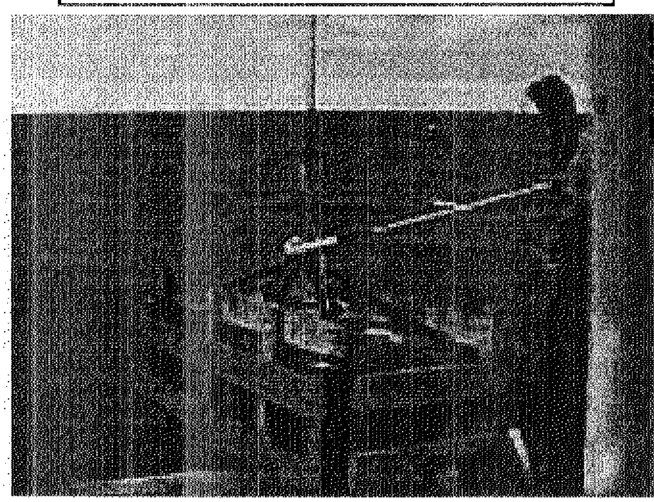
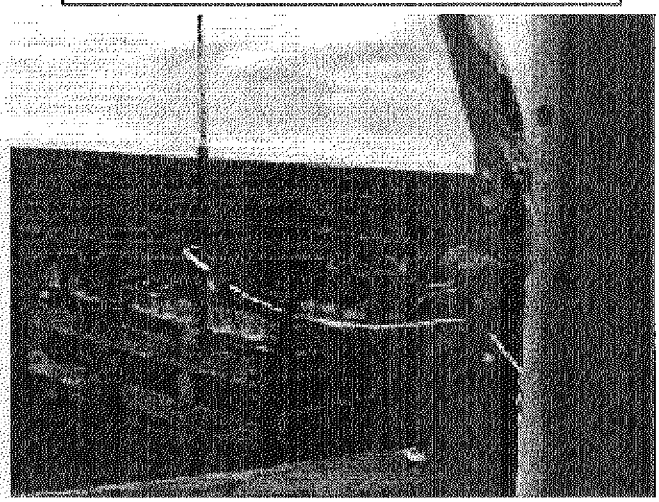


Figure 24: Modifications made to the habitat, view 1

Figure 25: Modifications made to the habitat, view 2





In addition to barrel protection, the crack in the center barrel and the drilled holes on the bottom-side of the barrels needed to be filled. The crack was a concern because it allowed an escape route for the hagfish. A marine grade epoxy was used to seal the crack on both the inside and outside of the barrel. The same epoxy, along with nylon patches, were added to the holes on the bottom 1/3 of the barrel, which were responsible for the sand loss during the first deployment. The holes on the sides and tops of the barrels were left uncovered to allow the water to flow through the barrels.

The incorporation of a mooring into the design was also important for the habitat re-launch. The mooring was essential for use as an anchor to secure the habitat in its location. A 1000-pound mooring was donated from the Ocean Engineering department at UNH to be used in the second launch.

Second Deployment

Launch Site

The second launch site was intended to be at Jeffrey's Ledge, where depths of 500+ feet could be obtained. Due to National Oceanic and Atmospheric Administration (NOAA) regulations, the habitat was not permitted to be deployed at Jeffrey's Ledge without a permit. Time constraints limited the ability of Project S.H.E.L.L. to obtain a permit for Jeffrey's Ledge. During the time of deployment (February), many areas off the New England coast were restricted due to whale migration patterns (NOAA, 2002).

Once Jeffrey's Ledge was no longer an option for deployment, other sites were examined. The launch site needed to be in a non-regulated area, with desired depths of 500 feet. Old Scantum (42° 53.672' N, 70° 26.433' W) was chosen as the deployment site. The area was open to commercial fishing, and it had depths of 400+ feet.

The habitat and mooring were launched at Old Scantum on February 23, 2002, to a depth of 392 feet. 100 pounds of sand and eight hagfish were added to each barrel prior to launch. The habitat was connected to the mooring by a 750 foot rope. Both the habitat and mooring had a 600 foot rope to the surface that was attached to a sub-surface and surface buoy. All three ropes were ¾" braided nylon rope, with a weight limit of 1500 pounds.

Retrieval/Observations

David Goethel, a local fisherman out of Hampton, NH, provided information about the launch location. David relayed that it was shrimping season, and Old Scantum is a prime location for fishermen. With this information, high fliers were purchased to add to the already existing buoys. High fliers are vertical standing reflective buoys that can be seen over wave crests, and greatly increase the visibility of the buoys.

A trip was made on March 19, 2002 to check the status of the habitat, and to add the high fliers. After an extensive search, it was determined that the habitat of S.H.E.L.L. was lost, thus the high fliers were not used.

Due to the high incidence of vandalism to many past UNH research experiments, it was concluded that the loss of the habitat was most likely due to vandalism. The habitat could have been damaged in a number of ways, leading to its disappearance. The buoys may have been cut off or destroyed, or the trap may have been moved or tangled up accidentally during trawling.

Recommended Improvements

Vandalism is one of the greatest threats to research done with the use of the underwater habitat. The best way to improve the habitat would be modifications to the buoy system. It is recommended that a robust steel buoy be used, along with a chain to attach the habitat to the surface buoy. This system would prevent damage to the buoy and lines, increasing the likelihood of the retrieval of the habitat. Use of high fliers and radar reflectors would be useful in locating the habitat on the open water.

It is also recommended that a permit be acquired through NOAA, at least one month prior to the deployment of the habitat. The Coast Guard should also be notified of the location of the trap. They will post a notice of the coordinates to the fisherman. This may prevent accidental tangling with their lines.

Concluding Remarks

The S.H.E.L.L. habitat appeared to be functional and durable in the ocean environment. It is believed that this system would require very few modifications to become fully functional if it were reproduced in the future. This habitat design grouped several hagfish containers together in a wooden truss frame to increase the weight, durability, and stability of the habitat system. Important knowledge was gained regarding materials selection, deployment restrictions, and vandalism. The information in this report should prove to be very helpful to future teams in the development of another habitat structure. The next team may succeed based upon the groundwork laid during this project... or they may just bring the next team one step closer as well.

Budget

Ocean Tech:

Materials: wood, nuts, bolts, screws, epoxy	$309.72
Boat Trips (5)	$1350.00
Total:	**$1659.72**

Items paid for by the Stacia Sower Laboratory:

Rope, eyelets, subsurface buoys	$549.80
High fliers	$117.00
Boat Trips (3)	$810.00
Bait	$28.00
Total	**$1504.80**
Combined Total	**$3164.52**

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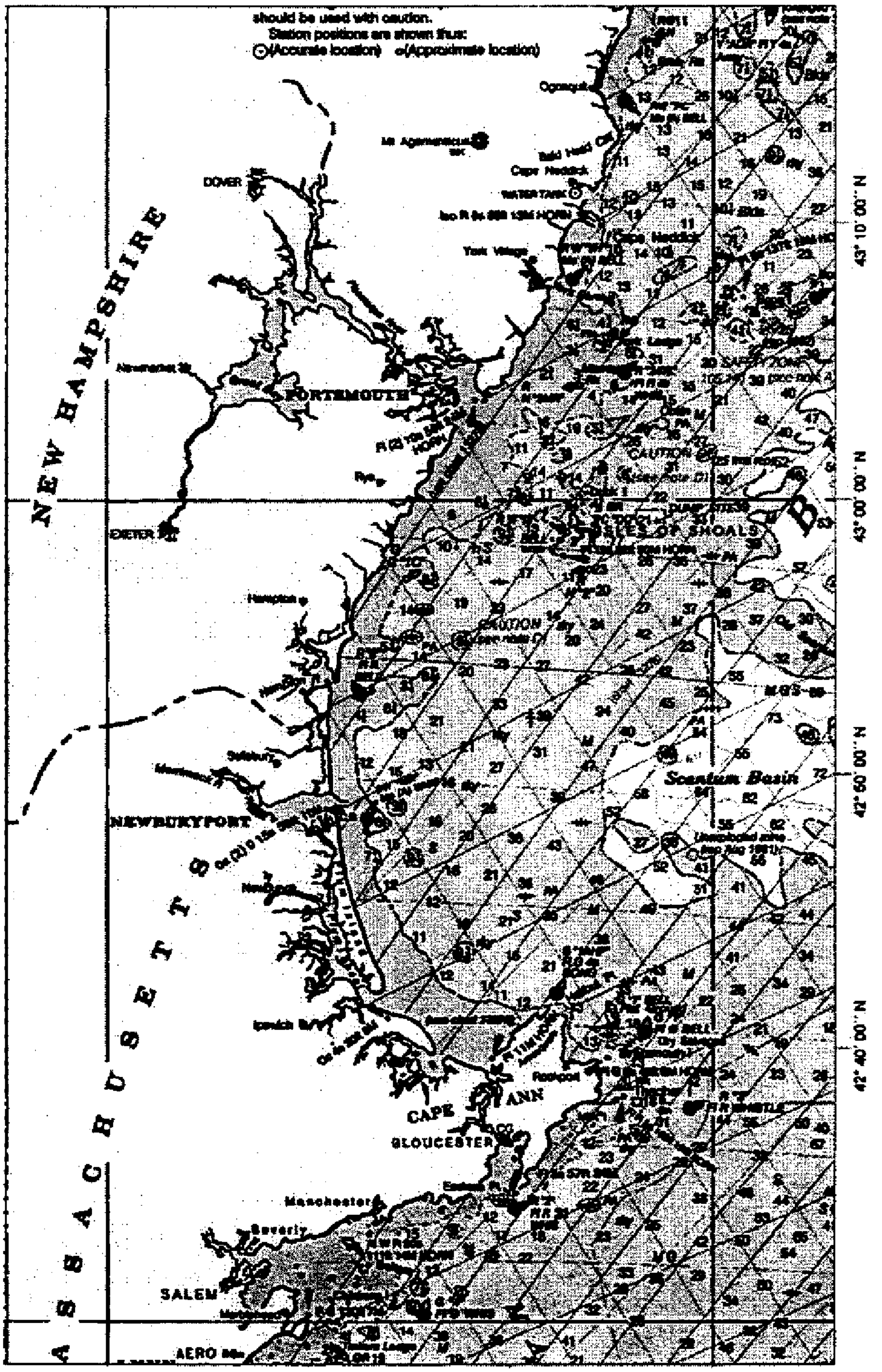
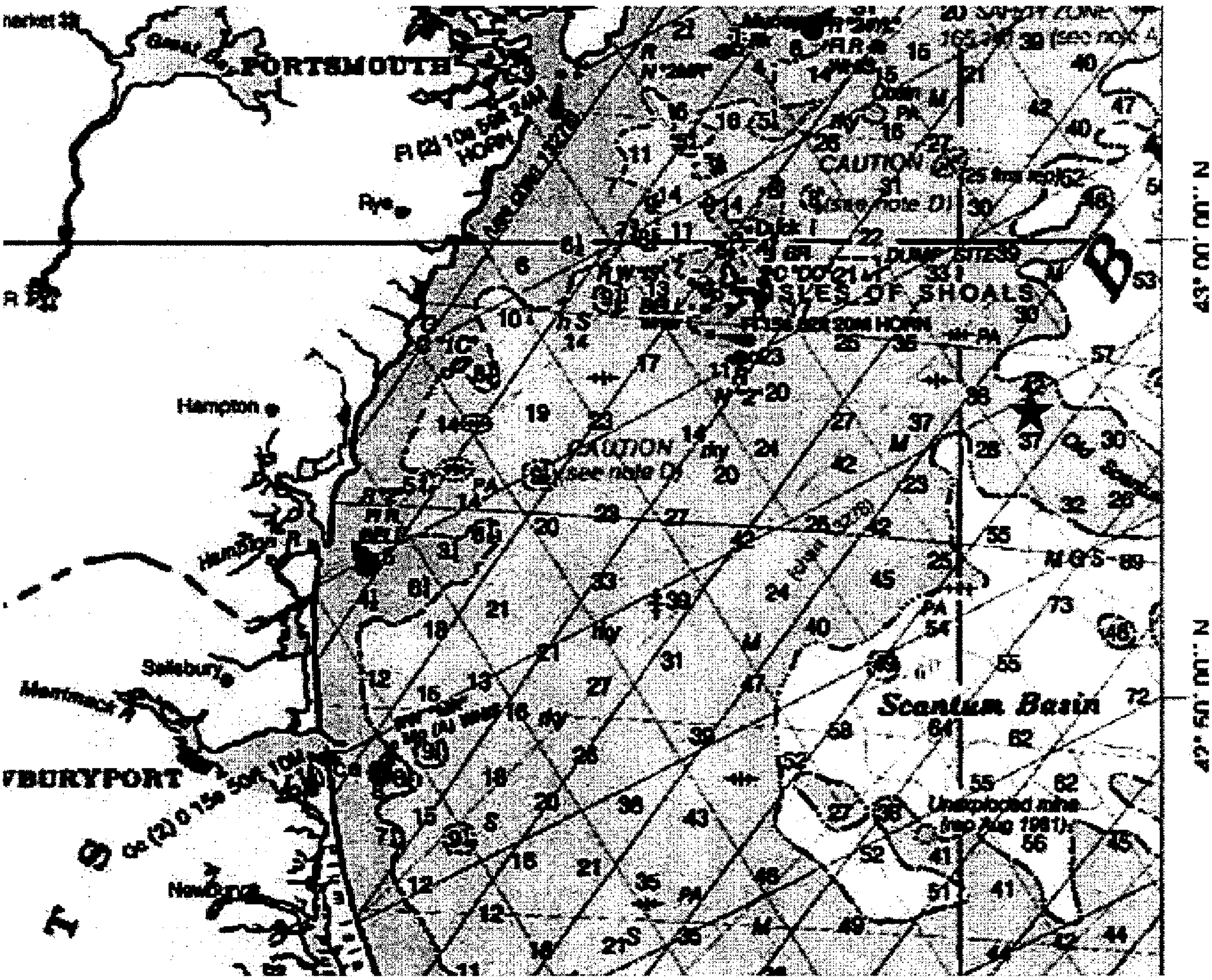
Appendix A: Maps

New Hampshire and Massachusetts Coast Line



Nautical Map showing Old Scantum



Appendix B: Alternative Design Options

Several alternative designs were investigated before the final design was chosen. Two concepts in particular are shown below:

The first design concept involved the addition of a protective frame to each individual barrel. See Figure 26. This would increase the weight, stability, and durability of the barrel. However, a network of several barrels will accomplish this task more effectively and efficiently.

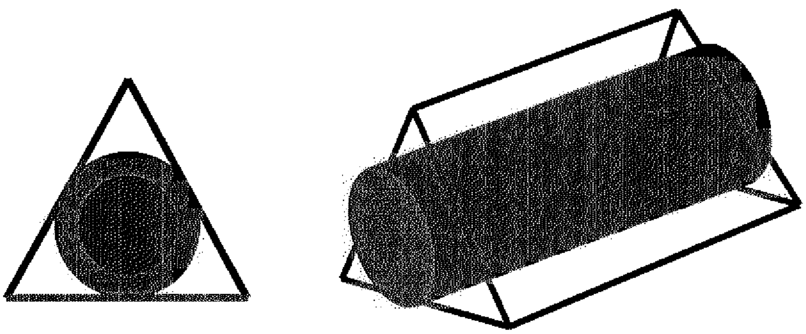


Figure 26: Prism design idea

Another design idea that was explored involved attaching several barrels to one large mooring. See figure 27. This idea was dismissed due to the likelihood that the barrels will collide on the sea floor and break. This system would also be difficult to deploy and retrieve because all of the barrels would collide and their lines would tangle together.

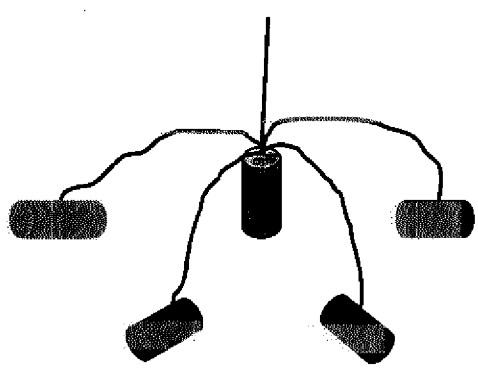


Figure 27: Series of barrels attached to a single mooring