Juvenile Codfish Netpen

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Abstract

Throughout the late 1980's and into the 1990's, the New England off-shore commercial fishing industry suffered from increasing depletion in ground fish stocks. This trend led to the closing of many traditional fishing grounds. The University of New Hampshire has proposed an aquaculture solution involving hatcheries, intermediate growth pens, and off shore harvesting pens for Atlantic Codfish. This project has researched and constructed a prototype for the intermediate growth pen described in the University of New Hampshire's proposal for commercializing aquaculture in five years. The intermediate netpen is to be located in estuaries of the New England Seacoast.

The designed intermediate netpen successfully meets the requirements introduced by the codfish's cannibalistic behavior, the dynamic environment of the Portsmouth Harbor, the limited expenditures, and the system's need to be located in navigatable water ways. The netpen consists of three net columns so the codfish can be sorted into size classes where cannibalism is not common. The high currents of the Portsmouth Harbor are avoided by selecting the Portsmouth Yacht Club's sheltered cove as the netpen site. The limited expenditures have been used to purchase low cost materials which often meant finding alternative means to doing the job. Finally, the ability to use navigable waters was granted once the netpen was made submersible. A depth of ten feet from the surface will clear the keel of most small vessels.

The constructed intermediate netpen successfully operated during its second tank test. The second tank test showed that the netpen was capable of being submerged to its required ten feet. The cage easily rotated leading to the conclusion that the proposed method of changing any fouled or damaged nets was feasible. With the test being successful, this system proved its ability to function as a prototype for the intermediate netpen for the University of New Hampshire's codfish growth experiments next year.

Introduction

Objective

The goal of this project has been to design, develop, and test an intermediate phase netpen for raising juvenile cod from ten grams to one pound.

Justification

New England's fisheries are in a state of decline. Due to severe overfishing, the groundfish populations of Georges Bank have recently collapsed posing an enormous economic threat to the New England fishing community. The situation is so serious that the National Marine Fisheries Service (NMFS) was forced to close approximately 20% of Georges Bank to relieve some of the pressure on cod populations. But if additional regulatory measures aren't taken soon, the rest may be closed by next year. The situation is grim, but the race for solutions is on.

In the 1980s, Norway was faced with a similar crisis. Overfishing in the late 1970s reduced the Barents Sea codfish (*Gadus morhua*) populations to dangerously low levels. As fishing constitutes the bulk of Norway's economy, the Norwegian government monitored the situation closely. In the early 1980s, a high degree of cod spawning was observed, providing some glimmer of optimism, but fishing quotas remained unregulated. By 1987, fishing pressure reached an all-time high and the cod populations collapsed. As a result, the inshore fishery was devastated, effecting every coastal community. Inevitably, the impact was felt by the offshore trawlers too.

In 1988, the Norwegian office of fisheries economics instituted strict fishing quotas, and with the cooperation of the Russian fishing industry, quotas were cut even more severely the following year. Norway reduced its annual catch from 342,000 tons to 113,000 tons, significantly reducing the pressure on natural populations. But these cuts had serious economic repercussions. To help reduce fishing pressure and to assist the ailing fishing community, the government instituted a vessel buy-back program. Over 20% of the nation's largest commercial trawlers were purchased by the government. Some were resold to other nations. Some, including many of the smaller coastal boats, were scrapped. The Norwegian fishermen also received assistance from unemployment insurance, and there was strong government encouragement to explore alternative strategies, including the development of hatcheries and the potential for codfish aquaculture.

Coupled with strict quota limits, government subsidies, scientific research and time, Norway has recovered from the Barents Sea crisis. Natural codfish populations have rebounded and the fishery is doing very well. In 1994, Norway landed over 250,000 tons of cod. Things are looking better there, but the Norwegians are cautious; they will not allow populations to crash again.

But overfishing by other countries continues to threaten codfish populations. Iceland's cod populations have crashed. They have instituted measures to reduce fishing pressure, but if a species population is driven too low, it's niche may be exploited by more opportunistic species. And if they take hold, they may exclude the original species from ever returning. This may be the case in Iceland. Canada was forced to entirely shut down its cod fishery off Newfoundland in 1992. However, fishing pressure there was so severe that populations continued to plunge by 30% even after fishing grounds were closed. It could be the turn of the century before Canada sees any significant recovery in cod populations.

Figure 1

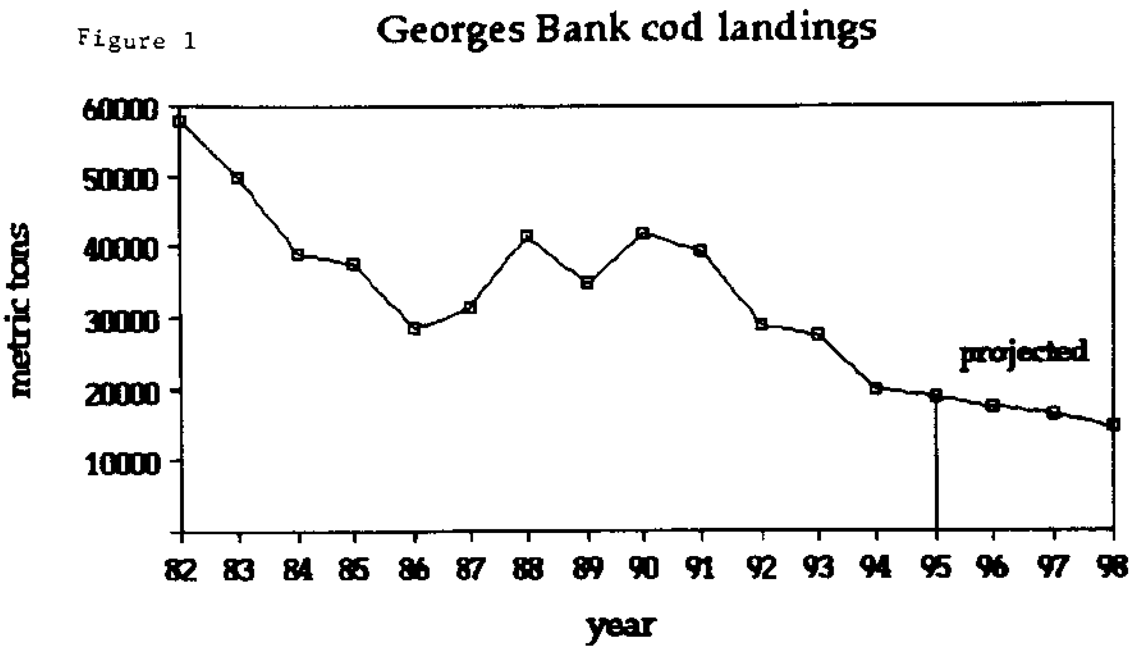

Fig. 1: Graph depicting the steady decline of cod landings on Georges Bank due to unregulated fishing. Source: NMFS Northeast Science Center, Woods Hole, Ma.

Here in New England, we need to make some very difficult decisions concerning the future of the groundfishery (see Fig. 1 above). Recovery of our depleted Georges Bank stock demands that we halt all groundfishing for the rest of this decade. Amendment 7 was developed for just this purpose, but the livelihood of a centuries old tradition is at stake. A vessel buyback program like that developed in Norway hasn't been instituted here, and unemployment insurance is unavailable to the New England fisherman. So how is the fishing community to survive through this difficult period?

Since November of 1994, the National Marine Fisheries Service has granted over $1.4 million to researchers exploring aquaculture solutions. The development of fish hatcheries, growout facilities and open-water netpens will assess the potential for commercial aquaculture as an alternative to traditional fishing techniques. The potential for stock enhancement is also being assessed. The University of New Hampshire received a $329,000 grant to explore the potential for commercial codfish aquaculture, involving the hatching of cod and subsequent growout in netpens to a market size. The project detailed in this report focuses on a method for raising juvenile codfish to a one pound size in open water netpens. The results of this UNH SeaGrant funded project will contribute to the larger UNH project.

So the New England fishery is at the threshold of a new era. We have no choice but to allow the natural cod populations to rebuild themselves by reducing fishing mortality to levels as near zero as possible. We must also rebuild the economic base for an industry in danger of extinction itself. With the world's growing demand for fish, aquaculture may become an integral component of the modern fishing industry.

Codfish Biology

The Atlantic Codfish belongs to the order Gadiformes and is a close relative to other economically important food fishes like haddock and pollack. The cod's biology is characterized by a keen adaptability to different environmental and feeding conditions. Such adaptability makes the cod particularly interesting for research, and shows potential for aquaculture in New England.

The cod is distributed throughout the entire North Atlantic. Large stocks are found along Greenland and Iceland, and down the European continent to the Bay of Biscay. Their northern distribution is limited by the north Barents Sea. In Norwegian waters there are two large stocks; the North Arctic and the inshore stocks. On the North American side, cod occur down to North Carolina in four distinct groups, the largest two being Georges Bank and the Gulf of Maine, followed by the smaller stocks found in Southern New England and the Middle Atlantic area (Bigelow 1953; Godo 1991; Serchuk and Wigley 1992).

As may be expected from a diverse geographic distribution, cod are able to adapt to a wide range of environmental conditions. They live in water with depths ranging from surface to 250 fathoms and temperatures that can span from below 0 to 20 degrees Celsius. Cod can also adapt from the normal salinity (35 ppt) of the open ocean to the near freshwater of the Baltic Sea (13ppt) (Godo 1991; Bigelow 1953).

The cod's life can be divided into four stages: egg and larva stage, the pelagic fry stage, the initial bottom dwelling stage, and the sexually mature stage (Godo 1991). Spawning may occur in March-April and eggs will develop while floating in the upper water column. Hatching and condition of the eggs depends strongly on the water temperature, but typically occurs in two to four weeks (Godo 1991). The larvae are about 4mm long at hatching and drift throughout the water column feeding from its yolk sack (Bigelow 1953). Upon the dissipation of the yolk sack, larvae are faced with the challenge of finding food in the environment. This transition is considered the most critical for the cod's survival. Through the summer and fall the young cod fry will seek the ocean floor, where their growth rate and mortality depend on food availability. Cannibalism and predation claim a great number of fry at this time. But as they grow in length, the likelihood of cannibalism and predation decreases, and the few surviving fish will grow through the 2 - 10 year sexually immature stage to sexual maturity. Once the cod reaches sexual maturity, they will spawn annually for the rest of their lives. An average female will produce 1-5 million eggs during a multiple spawning period lasting two months. However, about 0.1% of this number will survive to spawn a new generation (Canadian Department of Fisheries and Oceans).

Figure 2

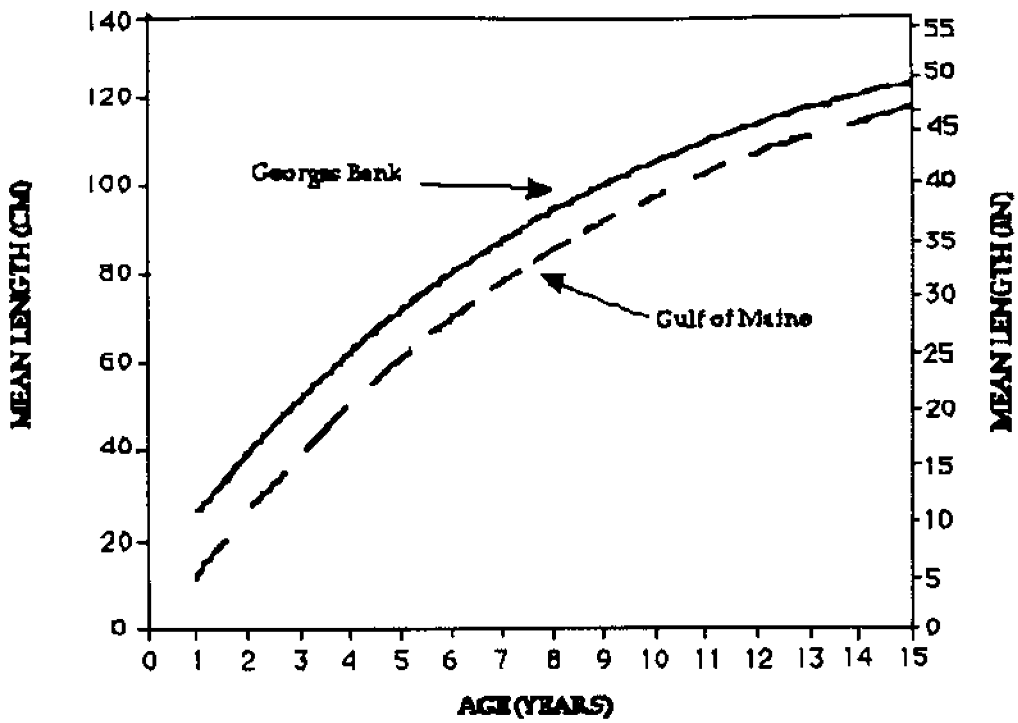

Figure 2. Growth of two Atlantic Cod stocks of the North American coast. Sexual maturity on Georges Bank is reached at a length of 146 cm; sexual maturity in the Gulf of Maine is reached at 148 cm. Source: NOAA Technical Memorandum NMFS-F/NEC66.

As eggs and larvae, cod are involuntarily moved around by oceanic currents. However, once they take to the bottom, cod are able to suit their seasonal needs by undergoing migrations. The migration length varies greatly according to where the cod lives. In general, migrations are marked by journeys between regions of overwintering, feeding, and spawning activity. Each region is visited at a time when environmental conditions are in favor of the particular activity (Godo 1991). The close proximity of spawning and feeding grounds in the Gulf of Maine and Georges Bank makes for relatively short migrations (Bigelow 1953). In contrast, Barents sea and Norwegian cod stocks may travel hundreds of nautical miles to reach their respective spawning grounds (Godo 1991). The cod will feed less during overwintering than the rest of the year due to relatively low metabolism in the much colder water.

The cod's diet varies greatly with age, environment, and season. Prey size will generally increase with the growing fish size. Prey items range from zooplankton to crustaceans to other fish, including their own species. Crustaceans and mollusks are usually the most important and may include copepods, amphipods, sea clams, mussels, crabs, lobsters, shrimp, and squid. Cod will also pursue and feed on many fish species, in particular, herring, capelin, shad, mackerel, menhaden, silversides, young hake and haddock (Bigelow 1953). In general, cod are opportunistic feeders, and will eat whatever is available at the time. During the spawning season of March and April they will fast in order to devote all energy to reproduction.

Design Requirements

Site selection: physical and geographic parameters

When raising fish in openwater netpens, it is critical to choose a site that meets as many of the fishes biological and physical need as possible. However, coastal habitat, particularly in New England, is often privately owned or in busy commercial waterways. Consequently, finding a suitable location can be problematic. From an engineering standpoint, it is necessary to have a site that is relatively sheltered from severe wave turbulence, and biologically, it must have sufficient flow to supply the fish with O_2 and clean water to facilitate maximum growth. Portsmouth Harbor has many small coves which serve our needs well (see Fig. 3).

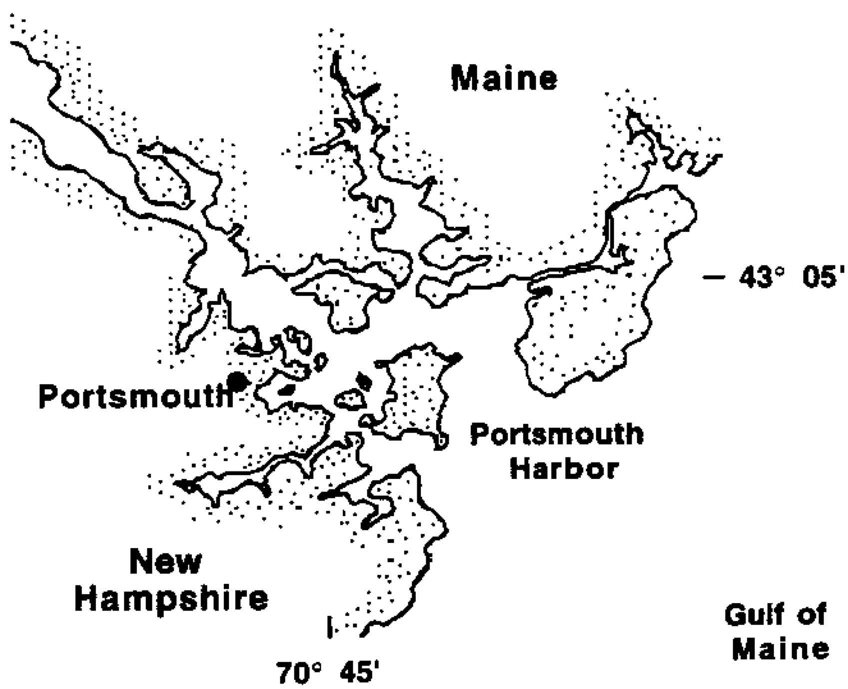

Figure 3

Fig. 3: Portsmouth Harbor. The harbor contains many small coves which offer conditions suitable for netpens.

Little is known of the effects of salinity on cod. Cod have adapted to stable low-salinity habitats like the Baltic Sea, and are observed locally entering the mouths of estuaries. Seasonal drops in salinity which correspond with spring runoff can drop salinities from 30 to 20‰ in Portsmouth Harbor. But this is well within the optima for cod. We maintained a small population of cod at the Coastal Marine Laboratory in New Castle, NH over the winter of 94-95. Salinities dipped to the high teens in April of 95 and didn't have any noticeable effects on the cod. Nor did the extreme low water temperatures.

Water temperatures in Portsmouth Harbor during the winter months can drop to 1°C. Ice, however, should not be a problem as the netpen will be submerged when in use, and will be situated in water currents. These cold temperatures will reduce growth to a minimum, whereas, warmer water from September to April will facilitate maximum growth rates. The cold water temperatures also decrease the growth rate of fouling organisms which can complicate netpen operations.

Rearing Codfish Juvenilies

The netpen designed and constructed in this project serves as a juvenile (intermediate) growing unit that will link hatchery reared codfish to offshore grow-out netpens. Codfish enter the intermediate phase in September at a length of 10cm and an approximate weight of 10 grams. Fish will be maintained through the winter months in these estuarine based netpens and exit to the offshore site at approximately 30cm, or 1 pound (448 grams) weight, in the month of April. This stage of growth may take up to 18 months in wild cod stocks. However, work performed by Braaten (1984) suggests that it can be done with cultured fish in six or seven months with regular feedings of well formulated diets (high protein, low carbohydrates and fats). Success in adding one pound weight per month to juveniles during the spring and summer has also been reported by Jon Moire of Sea Farms Plantations, Newfoundland. High growth rates like these may be accomplished in the Portsmouth (NH) estuarine region, but will rely heavily on the formulation of a proper dry diet here in the United States. Such a diet should consist of 40% protein content, which may be an economically limiting factor, as food cost may constitute up to 40% of production costs (Huse 1991). In addition to diet, growth rates may be impared by water quality.

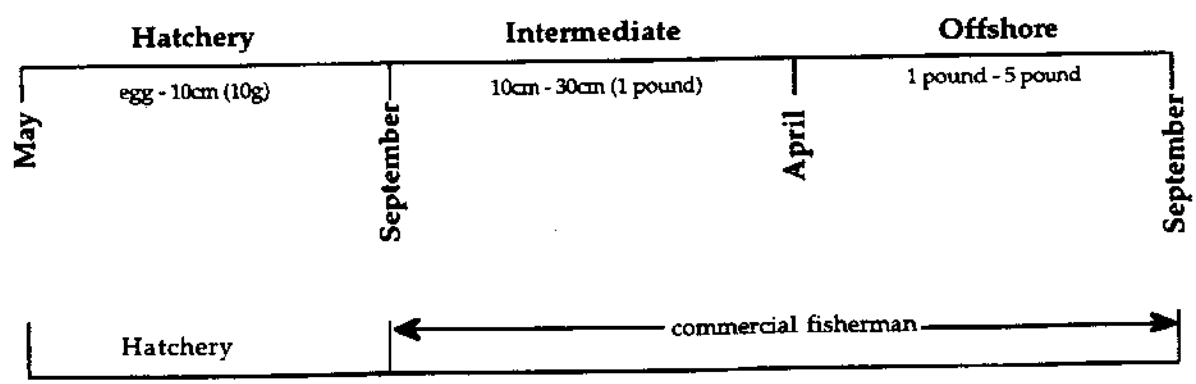

Figure 4: Timeline of 18 month codfish aquaculture program. This project focuses on the 8 month intermediate phase. Lengths and weights indicate size of fish at entry and exit, respectively.

When the codfish grow through the intermediate phase of the program, it is expected that differential growth will lead to cannibalism within the netpen. Such cannibalism can be a major source of mortality, thus reducing the number of fish going into the offshore phase of the program. The cannibalistic nature of codfish was investigated by Ottera and Folkvord (1993). They found cannibalism to be most prevalent when relative size ratios are 2:1 for fish greater than 10 grams. That is, a fish 20cm is very likely to cannibalize a 10cm fish. By tightening this gap, cannibalism is likely to diminish. Integrating these findings into the intermediate netpen design, it was decided that codfish would be seperated among compartments in the following way: (1) 10cm - 15cm (2) 15cm - 20cm (3) 20cm - 30cm. In order to maintain these size classes of codfish, an efficient means of sorting was also implemented into the design of the intermediate netpen (mechanics to be discussed later). Codfish will be graded out of the final compartment and transported to offshore netpens, allowing vacancy for new fish to enter the intermediate cage from the hatchery.

It has been shown that salmon will school and cruise around at a steady pace, thus utilizing the whole area of the netpen. This cruising behavior has shown to maximize growth rates of the contained salmon and is the primary reason for circular columned netpens. Codfish do not cruise, but tend to stay relatively still or shift slowly about in the netpens (Huse 1991). This behaviour allowed us to build the compartments of the intermediate pen as a square column, thus maximizing our volume within a square anti-predator cage, and allowing the entire system to take a rectangular shape for mechanical reasons to be discussed later. Although density experiments have not yet been carried out with codfish, no adverse effects have been observed for densities higher than what is normal for salmon pens (Huse 1991). Such conditions may allow us to stock as much as 70-85 pounds of codfish per cubic meter.

When codfish juveniles come from the hatchery in a healthy state and weaned onto a dry feed, mortalities usually occur from handling accidents, cannibalism, and disease. Various diseases are a major factor in restricting large scale production of cod fry. From 1989-1990, about 30-35% of total marine fish fry (cod, turbot, halibut) produced, died as a result of infectious disease. Captive codfish are very susceptible to viruses, bacteria, fungi, and several parasitic invertebres (Rodseth 1991). Although the sources of disease are many, very few treatments are liscensed to fight them (in the US), and the aquaculturists is often restricted to one drug or vaccine to fight a large variety of antagonists. Effective control of infectious disease can only be obtained through close cooperation between research, administration, and the industry. In addition to feeding, sorting, stocking, and harvesting of codfish within the intermediate netpen, the fish farmer must also acquire knowledge of the diseases he/she can expect to be a problem and implement an organized health monitoring entity for the system.

Although the techniques and research of codfish aquaculture are still in their infancy in the United States, the federal government has taken it's first steps toward success by realizing the current state of Georges Bank fisheries and the problematic future of the Gulf of Maine stocks. They have looked to university research, as well as, small business to demonstrate the feasibility of aquaculture in New England. We have learned much about codfish aquaculture from the Norwegians, however, the environmental, topographical, and political differences between our countries may only allow us to use a small portion of this knowledge. Instead, success in the U.S. will come from the development of an aquaculture program that is customized to the resources that a region (ie. New England) has to offer. Further knowledge must be gained in the areas of optimal current tolerance, stocking densities, feed nutrition, and disease control within the United States in order to demonstrate the feasibility of large-scale codfish aquaculture development. In addition to these factors, coastal states must find a compromise between the interests of inshore fishermen who rely on these waters for sustained fisheries (ie. lobster), and aquaculture ventures which may use inshore waters for intermediate "nursery" netpens.

Recommended biolological criteria for juvenile codfish netpen.

- Due to the presence of seals in the Portsmouth harbor during the winter months, the netpen should provide protection from such aggresive predators.
- Since vegetative activity is minimal during the winter months, fouling of biomass on the nets will be negligable from September to May.
- The cannibalistic nature of codfish makes it necessary to develop an efficent sorting mechanism to seperate fish into the following size classes:
  1) 10cm - 15cm
  2) 15cm - 20cm
  3) 20cm - 30cm
- Fish will enter into the netpen at 10cm (10g) and exit to offshore netpens at 30cm (1lbs.).
- Densities of 70 - 85 lbs. per cubic meter may be acheived for this netpen.
- The behaviour of codfish in netpens allows us to utilize squared columns to maximize volume within the rectangular frame.
- Chemical parameters like temperature, salinity, and oxygen are within codfish tolerance levels in sites in close proximity to the open ocean/estuary interface.

Design Procedure

Proposed Time Line

The first step in the design procedure was to propose a time line. Reasonable thought was given and the following completion dates were predicted.

1. Obtain Cod	October 31, 1995
2. Design Selection	December 15, 1994
3. Structural Analysis	January 15, 1995
4. Material Selection and Ordering	January 15, 1995
5. Construction of System	March 30, 1995
6. Testing of System	April 15, 1995
7. Composition of Final Report	April 28, 1995

Alternative Ideas

The next step in the design process was to determine the best system for the outlined requirements. This resulted in two months of brainstorming and research. First, the team extensively brainstormed some ideas of their own. With these ideas, the teams next step was to see what aquaculture systems currently existed. University of New Hampshire Ocean Engineering graduate student Langley Gace constructed the off-shore netpen for the UNH proposal during the summer of 1994. This system was examined as a possible idea. Extensive browsing and reading of the numerous aquaculture magazines and publications lead to some more ideas. This research and the criteria led to two independent decisions; One concerning the need for a platform, and the second pertaining to the functions of the netpen.

The need for a platform:

The criteria determined both the need and functionality of the platform. The need to change nets, access and observe the fish established the desire for a platform. Originally, the netpen was expected to be accessed from the side of a twenty foot vessel, but due to the uncertainty of the waterway's current it was discarded. A securely moored platform proved to be the best solution. A platform which surrounded the netpen allowed for complete access to the fish.

The need for safety in the navigatable waterways of the Portsmouth Harbor, the desire for social acceptance (i.e an eye sore), and fears of vandalism, resulted in the submersibility of the platform. A depth of ten to fifteen feet safely clears all small vessel keels. A variable ballast system with a compressed air supply at the surface allowed for this function.

The functions of the netpen:
Due to the strict requirements placed on the netpen, three functional concepts of the netpen were developed and weighted in the design matrix. These systems allowed for the removal of biofouling, sorting mechanisms, and net changability. The team considered three concepts.

1. Spherical netpen
2. Cylindrical netpen
3. Rectangular netpen

Selection Process

Of the three concepts, the most practical solution had to be chosen. Through the use of a criteria-weighted design matrix, the most practical solution emerged. Below is a brief explanation of how the designs' functionalities compare to the requirements of the criteria, and following is the design matrix. (Table 1.)

Spherical netpen:
One benefit of this system was its method of removing biofouling. By being held partially out of the water, sunlight could dry and kill any accumulating biofouling. The spherical shape allowed it to be rotated so the complete surface could be cleaned of fouling via sunlight. This system had the capability to use rigid predator nets. However, the difficulties outweighed the benefits. The nets could not be changed without use of divers, sorting would have to be handled manually, construction of a large rigid sphere would be difficult, and the codfish's natural ground fish behavior would result in high densities in the small volume of the sphere bottom. This netpen also did not allow for multiple compartments in which the fish could be sorted. These difficulties and lack of functionality led to the disqualification of the spherical netpen.

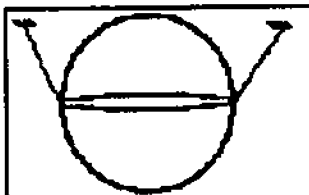

Figure 5:
Spherical Netpen

Cylindrical netpen:
Similar to the spherical netpen, this system could not only utilize sunlight for the cleaning of the biofouling, but also allow for rigid predator nets. Unlike the spherical netpen, this system made it possible to change nets without the use of divers. The structure also allowed for the implementation of a grader sorting mechanism and multiple compartments in which the fish could be sorted. Unfortunately, the natural behavior of the ground fish would result in high densities in the small volume of the cylinders bottom side. These functionalities made this system a strong possibility.

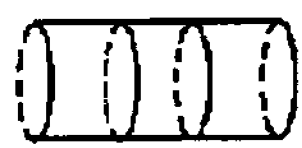

Figure 6:
Cylindrical Netpen

Rectangular netpen:

With the use of removable rectangular net columns within a rectangular frame, this system offered net changing abilities without the need for divers. This resulted in removing biofouling by means of simply changing nets. The rectangular netpen also allowed for rigid predator nets and the implementation of sorting graders. This system easily allowed for multiple compartments and easy sorting within them. Finally, the ground fish behavior of cod would not be affected by the nonconvergent bottom of the rectangular net column. With this netpen meeting all of the necessary design requirements, it was selected as the most practical solution.

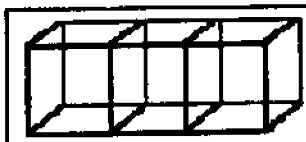

Figure 7: Rectangular Netpen

Table 1: Design Matrix

Criteria	Possible Points	Spherical Netpen	Cylindrical Netpen	Rectangular Netpen
Ease of construction	5	2	3	5
Cost effectiveness	8	5	5	5
Ease of net changing	7	2	4	6
Ease of sorting	8	1	3	6
Ease of biofouling removal	3	2	2	3
Protection from predators	7	7	7	7
Ease of feeding	4	4	4	4
Satisfy codfish biology	7	4	4	6
Total	49	27	32	42

Discussion of Final Selection:

With the rectangular design being the best netpen, it was adapted to fit with the submersible platform. Figures for this system can be seen in Appendix A. The system has been broken down into its four most basic components and discussed.

Platform:
Dimensions of the platform can be seen in Appendix A: *Top View of Platform*, and a detailed figure of the corner plate can be seen in Appendix A: *Top View of Steel Plate*. The function assigned to the platform consisted of two main factors. One being its ability to allow access to the netpen, hence the fish. Refer to Appendix A: *Platform / Cage Orientation* for the a dimensions of the platform and a visual representation of this setup. To fulfill this criteria, the platform was designed to surround the perimeter of the rectangular pen. The clearance between the platform and the netpen allowed for the pen's rotational ability. Also, by surrounding the netpen, more stability was created. The outside of the platform would be 16' x 10'. The second criteria, was the platforms ability to submerge. This is discussed below in the *Ballast System* Section.

Netpen:
With the netpen obviously serving its main functionality of holding the fish, the strict criteria of net changability and implementation of a sorting mechanism had to be applied. The dimensions of the netpen can be seen in Appendix A: *Cage Frame*. To allow for this, the netpen was design to rotate. V-supports were added to each end of the platform and the netpen rotated about a fix pin from each V-support. An exploded view of this system can be seen in Appendix A: *Platform, Cage, and Cage Supports*. The netpen rotated on the cross joint added to each end of the cage frame. This rotation allowed for the user to easily attach a new net column on top of the current net column, rotate the cage 180 degrees, and pulling the old net column out, hence replacing it with the new. This technique could also be used in pulling a grader through the net column resulting in easy sorting. The cage frame would be 12' x 4' x 4', with three equally sized compartments. (4' x 4' x 4')

Ballast System:
The ballast system had to allow the user to raise and lower the cage at will, while also offering a stable platform on which the user could walk. A variable ballast system met this need. Ten uniformly spaced compartments were designed into this system. The layout of these ballast tanks can be seen in Appendix A: *Platform (Long Side), Ballast, Legs* and *Platform (Short Side), Ballast, Legs*. Excess ballast made this system capable of safely holding two people. The last concern with this system was the ability to control the air supply to as many compartments as possible. The chosen design allowed for control over each of the four sides. This allowed for maneuverability during raising and lowering of the system. In raising and lowering the cage, the air would be supplied to the ballast system from the operator's vessel via four supply lines run from the platform to one of the mooring balls. Finally, a manifold would control the air flow to the four lines, hence the four sides. A compressed air supply would be needed to perform this task.

Mooring System:

Due to the non-spacious location of the Portsmouth Yacht Club, a four point mooring system was chosen in order to reduce the systems ability to transverse large distances during each current change. A four point mooring system also allowed for added safety in these heavily traveled waters.

Material Selection

With the design chosen, the codfish team determined the best construction materials. Material selection greatly depended on cost and ability to perform task. Each of the four major components to the system was analyzed.

Platform:

With the platform circumfrencing the netpen, a large amount of material was needed. The team considered aluminum, steel, and wood.

Table 2: Relative Properties of Platform's Material:

Material	Strength	Density	Cost
Aluminum	High	Medium	High
Steel	High	High	Medium
Wood	Low	Low	Low

Due to high cost, aluminum was immediately eliminated. Steel's high strength was needed, but its high density lead to its disfavor. With wood's low strength, it could not be used alone. It was decided that the platform would be constructed of a combination between wood and steel. The planks of the platform would be constructed of wood, while the corners would be re-enforced with steel plates. Each corner / joint would be constructed in an interlocking manner.

With this, 1" x 8" spruce lumber was chosen as the wood, and 1/4" x 18" x 36" was chosen for the steel plates. Gluing the spruce lumber and running planks side by side produced a side's thickness of 2" and a width of 18".

Netpen:

With a length of 12' and a cross section of 4' x 4', the netpen frame needed to be constructed of low density material. Steel's high density lead to discouragement as the bulk material. PVC pipes (2" IPS) were chosen for its light weight and fair rigidity. Steel joints were chosen to hold the netpen together.

In addition to the netpen frame, there existed the net columns. The frames and doors of these structures were constructed PVC pipes and joints. (1.5" IPS) Due to the size variations of fish that would be in each compartment, different mesh sizes were required. 1/4" 1/2" and 3/4" were chosen as mesh sizes.

Ballast System:

Once again the main concern of the materials chosen for the ballast system was cost. Inexpensive, High Density Polyethylene (HDPE) 30-gallon A&W Root Beer barrels served as the variable ballast tanks, while 2" x 10" lumber served as the ballast supports. The air supply for these tanks came from inexpensive 200 psi hydraulic hoses. Finally, the manifold system was constructed of brass. The tanks were fitted with brass 3/4" - 1/2" bushings, and 1/2" nylon barbs.

Mooring System:

With the four point mooring system being used in a location with relatively low currents, 200 lb mushroom anchors fit the mooring needs. Ten foot long 1/2" galvanized chain attached to anchor's lead allowed for the mushroom anchors to rest properly. This chain also acted as a damper to the system. 5/8" nylon rope fit the needs of the mooring lines which were designed at a scope of 3, and 27" diameter Taylor Series balls satisfied the needs of the mooring balls.

Experiments in Marine Environment

With the material selected, two variables needed to be determined before a thorough analysis could be performed. The two variables were the change in weight due to the wood's ability to absorb water, and the maximum current that would be experienced at the sight. Also as a check, the sight's salinity and temperature ranges were found. These were done in two experiments. A summary of both these experiments can be found in Appendix B.

The first experiment determined the amount of water that would be absorbed by the wood in the platform. This experiment was done by submerging two dry pieces of spruce lumber twenty feet under water. This lumber was allowed to soak for 12 days. After these twelve days the wood was weighed and it was compared to the previously measured dry weight.

The second experiment determined the peak current, salinity, and temperature at the chosen netpen sight. The salinity and temperature allowed the biologist and zoologist to determine if the cod could live in these conditions. The current was used to calculate the maximum drag to which the system would be exposed. An Endeco current meter was deployed at the Portsmouth Yacht Club on the morning of March 13, 1995 and retrieved on the morning of March 14, 1995.

Analysis of Final Selection

The first step in analyzing the final selection was to determine the weight of each system component. These weights were applied to the buoyancy analysis to determine what capacity would be needed for the ballast system. Next, drag forces were found in both an oceanic environment and an estuarian environment. The results from the Endeco Current meter were used. These results were applied to the analysis on the system to see if it was capable of enduring such an environment. Then, an analysis on the system during the lifting was done to assure safety. Finally, the needed size for a mooring ball was determined. This analysis is clearly outlined in Appendix C.

Construction of Final Selection

With the material selected and the analysis completed, the construction phase began. Material ordering began in week 1, allowing for construction to begin at the end of week 1. An intense 6 week schedule was proposed and met. Construction began with the platform, then the ballast system and netpen. Finally the mooring system was constructed. The total number of hours constructing this project by all the students was approximately 750.

Testing and Modifying Constructed System

The ability of the constructed system to fulfill the designed requirements of stability, cage rotation, and submersibility was tested in the UNH Ocean Engineering facility. A 2 ton winch lifted the system into the 60' x 40' x 20' tank, where an air compressor supplied air to the ballast system. These tests allowed the team to develop the system into a much safer and properly functioning system through subsequent design modifications.

Results

Experiments

Table 3: Weight Percent Increase for Saturated Lumber

Cross Section of specimen	Percent Increase
1" x 8"	70
2" x 10"	64

Table 4: Current, Salinity, and Temperature of Netpen Site

Measured Quantity	Units	Value
Maximum Current	knots	1.06
Temperature Range	Fahrenheit	37.5 - 36.5
Salinity Range	PPT	29 - 22

Force and Stress Analysis

Table 5: Component Weights

	Out of Water (lbf)		In Water (lbf)	
	Dry	Wet	Dry	Wet
System	2000	2500	750	980
Platform	1700	2000	–	–
Cage	210	400	120	120

Determined safety factors for chosen materials under critical loads

Table 6: Platform's Safety Against Failure during Lift with Saturated Lumber

Side of Platform	Factor of Safety
Long Side - 16'	2.4
Short Side - 10'	2.0

Table 7: Netpen Frame's Safety against Failure during Lift with Pipes Full of Water

Type of lift	Factor of Safety
Supported lift - 3 cradles	9.0
Unsupported lift - No cradles	3.9

Table 8: V-Support's Safety against Stresses Induced by Drag Force

Section	Factor of Safety
Bolts	1.1
Weld	10.6
Pin	31.2

*Note: The pin was a piece of scrap pipe, it was not chosen to have FS of 31.2.

Table 9: Mooring Ball's Safety Against Inability to Suspend the System

	Factor of Safety
Floatation	1.5

Tests on Constructed System

Table 10: System's Ability to Pass Required Functions

Criteria	Tank Test 1	Tank Test 2
Stability	Yes	Yes
Netpen rotation	Yes	Yes
Subermsibility	No	Yes

Expenditures

Table 11: Expenditures by System Component.

Component	Expenditure
Platform	$1493.08
Netpen	$863.10
Ballast System	$722.43
Mooring System	$1365.76
Fish	$560.70
Total Expenditures	**$5005.07**

Discussion of Results

Experiments in Marine Environment

The 70% weight increase from dry to wet lumber found in the 1" x 8" piece and the 64% weight increase found in the 2" x 10" lumber was considered to be significant. The high value of 70% was used in the system analysis.

The small current of 1.06 knots found by Langley Gace on March 14, 1995 was also considered in the system analysis. A safety value of 2 knots was used when calculating drag forces. The temperature range of 37.5 F to 36.5 F was acceptable. And the salinity range from 29 PPT to 22 PPT was within the acceptable limits of the codfish.

Force and Stress Analysis

The system's dry weight of 1 ton was considered high. It was hoped that this could be reduced, but due to the buoyant effects of wood and the need for a stable system while suspended under water, the 750 lbf apparent weight under water was desired. Removal of weight from the platform would weaken the structure and create more difficulties in lowering the cage. With the system's wet weight being 2500 lbf and the maximum ballast lift also being 2500 lbf, some difficulties arose in raising the system. A proposed solution to the ballast system is discussed in the Recommendations.

The drag force of 360 lbf estimated for the estuary gave much confidence to the system's ability to endure the environment of the Portsmouth Harbor. This was shown in the range of safety factors from 1.1 to 31.2 for the material selection. Also, these safety factors are based on a drag force calculated from 2 knots currents not the actual 1.06 knot current; even more safety.

The other concern of being able to successfully lift the cage was relieved with the calculated safety factors on both the platform and cage ranging from 2.0 to 9.0. Also the 1.5 safety factor for the 4 mooring balls was accepted.

Tank Test

The first tank test showed that our system was stable and capable of rotating the net pen. This stability meant that two people could safely stand on the platform, and the ability to rotate gave feasibility to the option of changing nets without divers and sorting fish with the use of graders. Unfortunately, the system was not capable of being submerged. There were two reasons for this. One being that the system was not heavy enough for the water it displaced. The second reason being that the removal of air from the ballast caused the metacentric height to become negative. With this failure, one modification was done. 500 lbf, in the form of steel, was added underneath the structure. This steel gave the platform legs and feet. This resulted in lowering the center of gravity, hence producing a positive metacentric height when the ballast were drained. This also increase the weight of the system so it could be submerged. The second tank test proved that the modification was a success.

Expenditures

The cost of building this system and preparing the site totaled just over $5000. The ballast system cost about $700, while the netpen totaled just over $850. The mooring system came to $1350 and the platform cost about $1500. Inexpensive barrels were used for the ballast system, and cheap wood was used for the planks of the platform. With the material cost being kept to a minimum, alternative design considerations will be needed to bring the costs down to an acceptable level. This is discussed in the Recommendations.

Recommendations

Material Selection

Recommendations concerning the material selection for each of the system components were made in this section.

Platform:

Due to the weakness found in the spruce lumber, two recommendations are offered. Either select a hard wood such as oak, or reinforce the sides of the platform with c-channel or angle iron. Steel structural qualities far out weight its relative cost and added weight.

Netpen:

Two alternative solutions to constructing the netpen are given. One, a much less expensive material, than steel is recommended for the joints. The steel joints totaled almost half of the netpens total expense. An inexpensive aluminum or a reinforced PVC joint is recommended. Two, avoiding pipe joints all together, could be avoided by constructing the netpen frame out of steel. The pieces of steel could easily be welded; hence no joints would need to be purchased.

Ballast System:

The HDPE barrels are highly recommended for their low cost. If a larger system is being constructed it is recommended to either increase the number of barrels or change from 30 gallon barrels to 60 gallon barrels. One problem with the HDPE, is that it is not capable of being used for fixed ballast. It will collapse under water. A more solid foam-filled material is recommended for fixed ballast.

Mooring System:

The success of the 200 lbf mushroom anchors sinking into the gravel bottom at the Portsmouth Yacht Club lead to their recommendation. Also, the 5/8" nylon rope and the 10' of 1/2" galvanized chain is recommended. Since the system was not deployed at the sight, these are only based on speculation.

System Design

Recommnedations concerning the design of each system were made in this section.

Platform:

The design of the platform is recommended assuming the following modifications are made. A form of fix ballast needs to be added to the platform. It needs to added near the top in order to keep the center of buoyancy high. Also a more rigid structure is needed. It is recommended that a rigid steel frame is constructed beneath and a light weight wood frame is added above as a walk way. This will make a more stable system, hence more safety for the end user.

Netpen:

The current netpen is recommended. The rotational feature is considered to be the unique quality that makes this cage exceptionally friendly for the user.

Ballast System:

The current control over the sides of the platform is not recommended. It is recommended that ballast control be done about the corners of the platform. More control can be obtained by controlling more compartments / barrels. If feasible, it would be recommended that control to each compartment be sought. Also a way of adding fixed buoyancy to counteract the increase in weighted caused by the soaked wood. It is recommended that this added buoyancy be uniformly distributed around the platform, and that its buoyancy equal the increase in wood weight.

Mooring System:

To reduce expenses, it is recommended that a four point mooring system not be used. A two point mooring system could reduce the displacement of the cage during tide shifts almost as effectively as a four point mooring system. It is also recommended that one of these two moorings be fixed, hence a currently placed mooring block exceeding a half ton be used as the anchor.

Nomenclature

This section pertains to the variables used in the analysis of Appnedix C.

English:

A	Area
b	base or width
c	Distance from neutral axis to outer surface
C	Coefficent
d,D	Diameter
F	Force
FS	Factor of Safety
h,H	Height
I	Second moment of Inertia
k	Wave number
l, L	Length
M	Moment
n,N	Dimensionless quantity
OD	Outer Diameter
R	Radius
t	Thickness
T	Time
u	fluid velocity or current
V	Volume
w	Width, distributed load, or specific weight.
W	Weight out of water
y	Deflection
z	Distance

Greek:

Δ	Displacement
ΔW	Weight in water, weight - displacemnt ($W - \Delta$)
ρ	Weight density
σ	Angular frequency or normal stress
τ	Shear Stress

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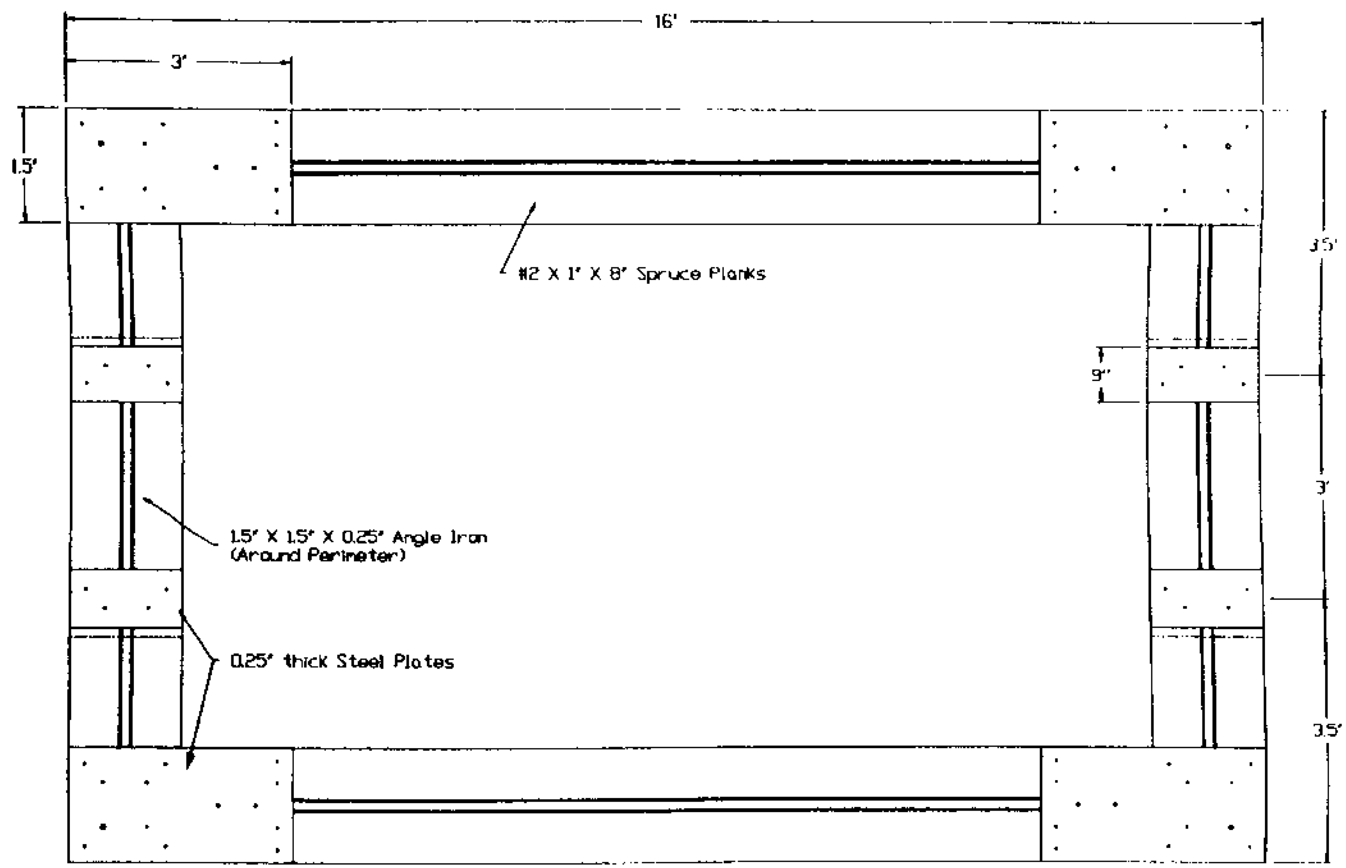
Appendix A: Drawings of Final System

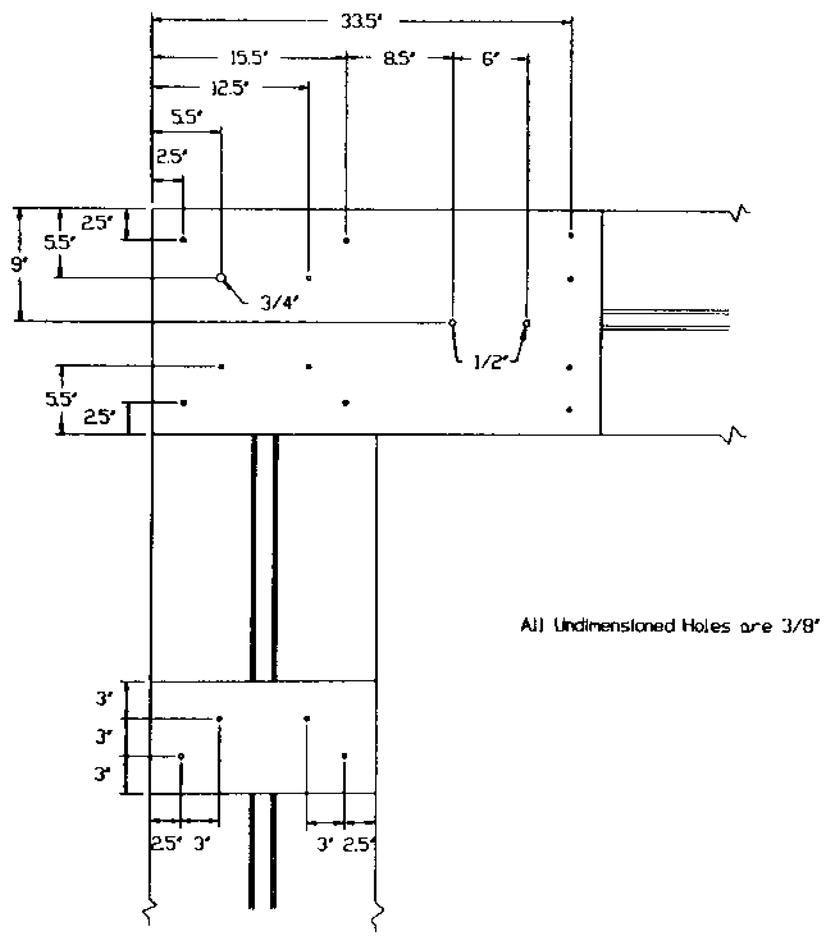
List of Figures:

Figure A 1: Top View of Platform



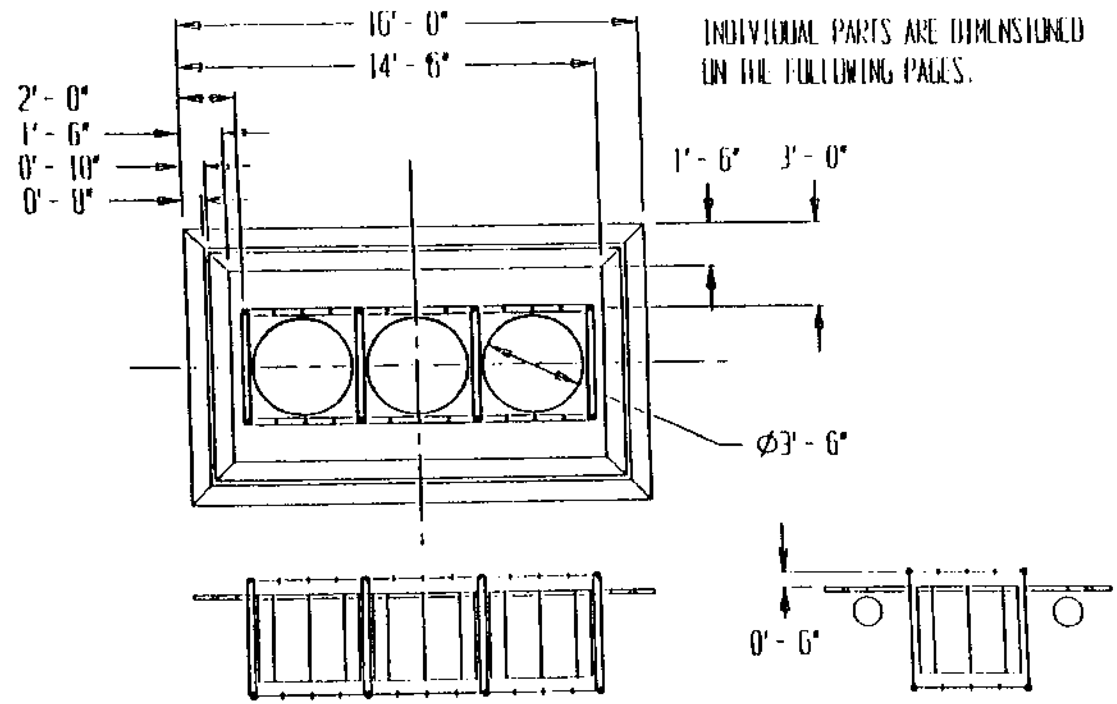
DATE: 4/95	TOP VIEW of PLATFORM UNIVERSITY of NEW HAMPSHIRE	C. MACE C. OBRIEN

Figure A 2: Top View 6f Steel Plates



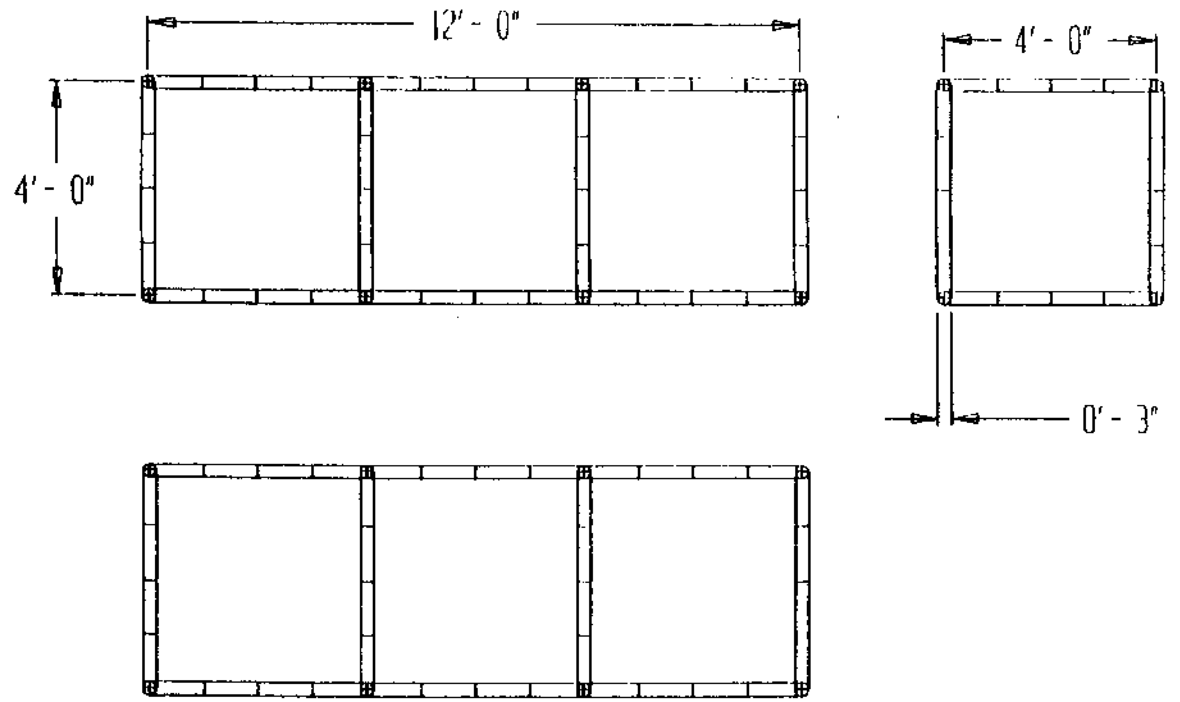
DATE: 4/95	TOP VIEW of STEEL PLATES UNIVERSITY of NEW HAMPSHIRE	C. MACE C. OBRIEN

Figure A 3: Platform/ Cage Orientation



DATE	PLATFORM / CAGE ORIENTATION	CHAD MACE
1/24/95	UNIVERSITY OF NEW HAMPSHIRE	C. O'BRIEN

Figure A 4: Cage Frame



DATE	CAGE FRAME	CHAD MACE
1/23/95	UNIVERSITY OF NEW HAMPSHIRE	C. O'BRIEN

Figure A 5: Platform, Cage, Supports

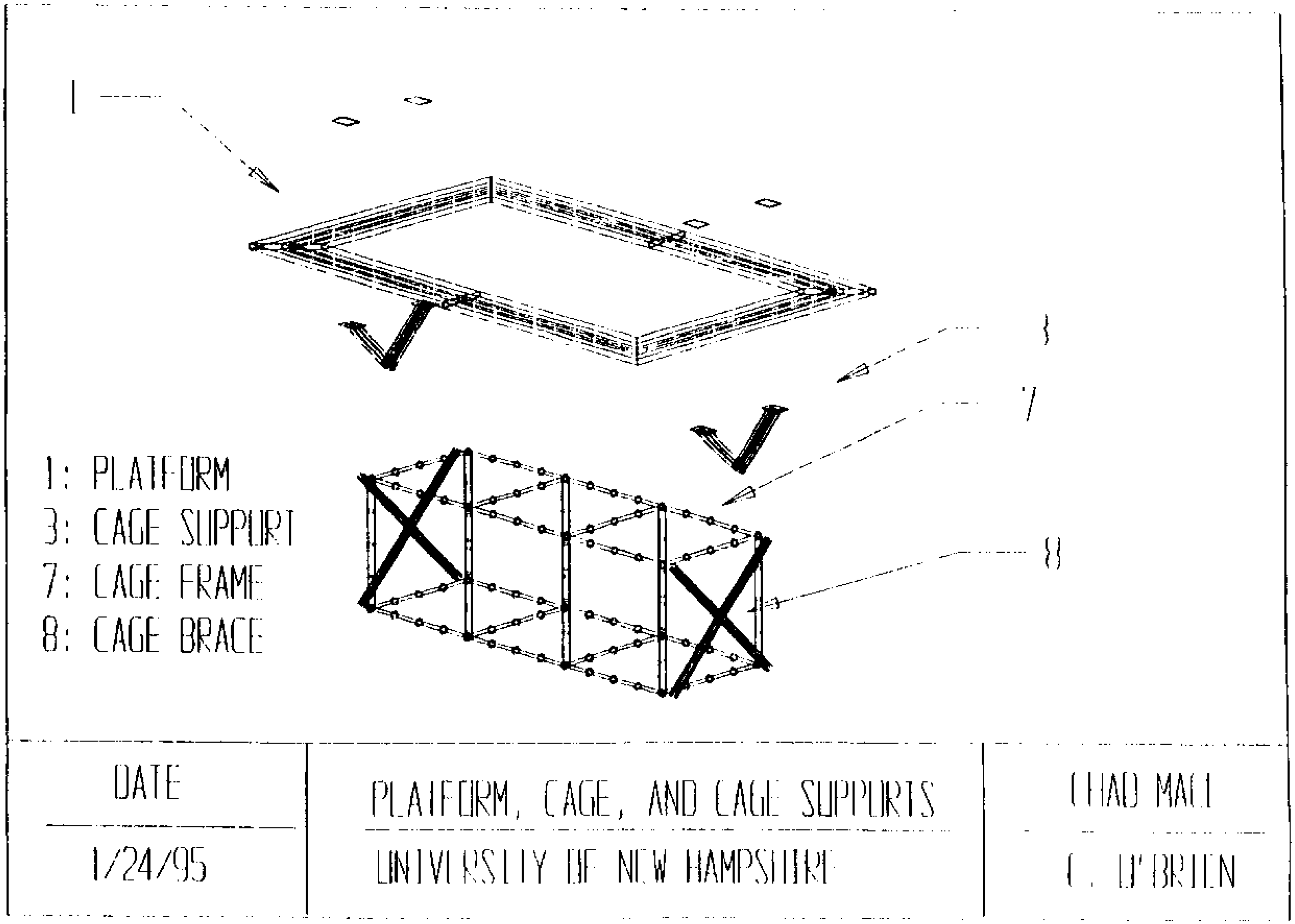
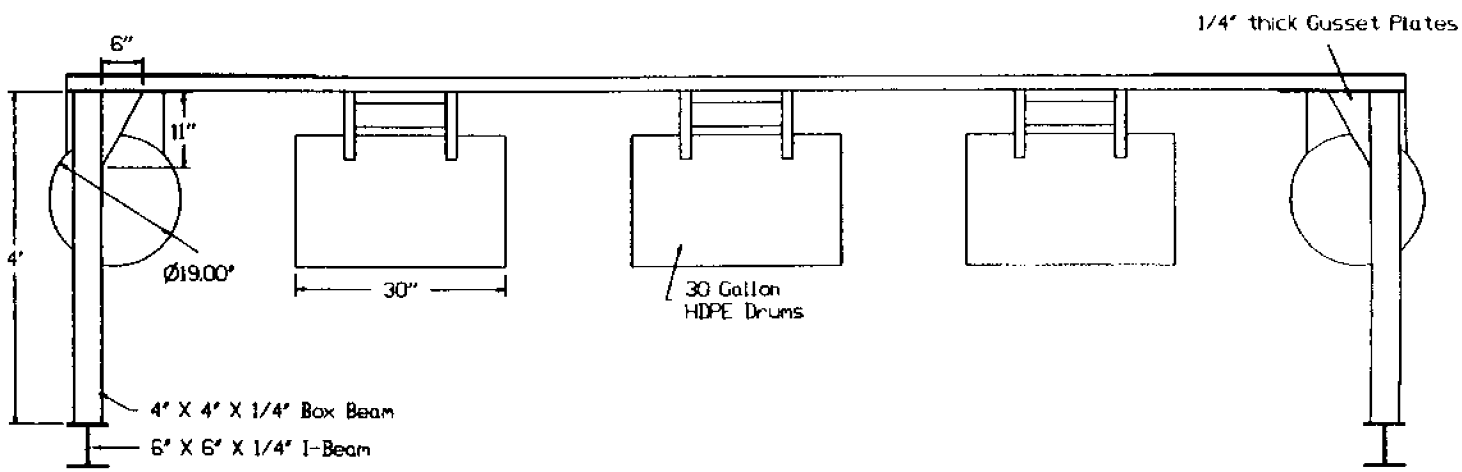
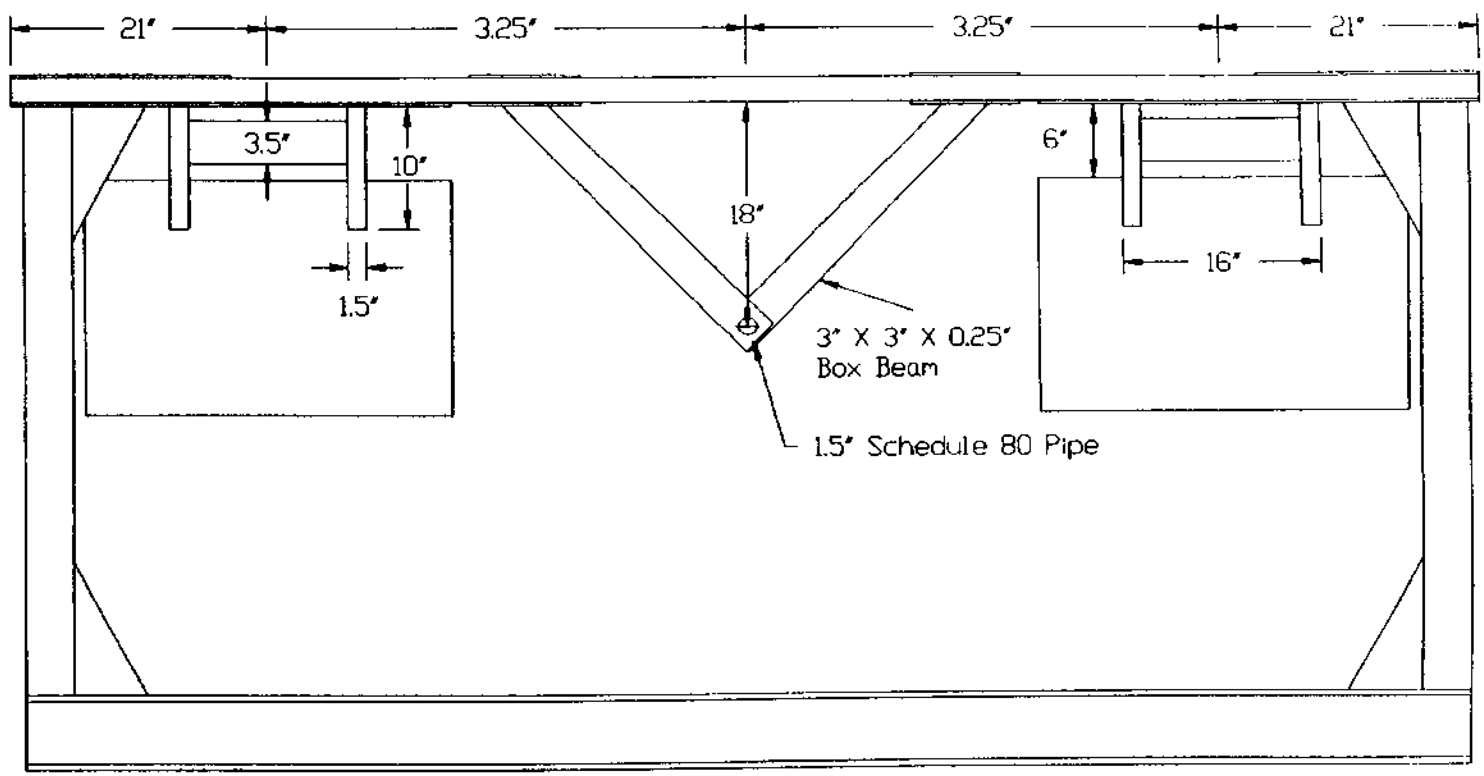


Figure A 6: Platform (long side), Ballasts, Legs



DATE: 4/95	PLATFORM (LONG SIDE), BALLASTS, LEGS UNIVERSITY of NEW HAMPSHIRE	C. MACE C. OBRIEN

Figure A 7: Platform (short side), Ballasts, Legs



DATE: 4/95	PLATFORM (SHORT SIDE), BALLASTS, LEGS UNIVERSITY of NEW HAMPSHIRE	C. MACE C. OBRIEN

Appendix B: Experimental Findings.

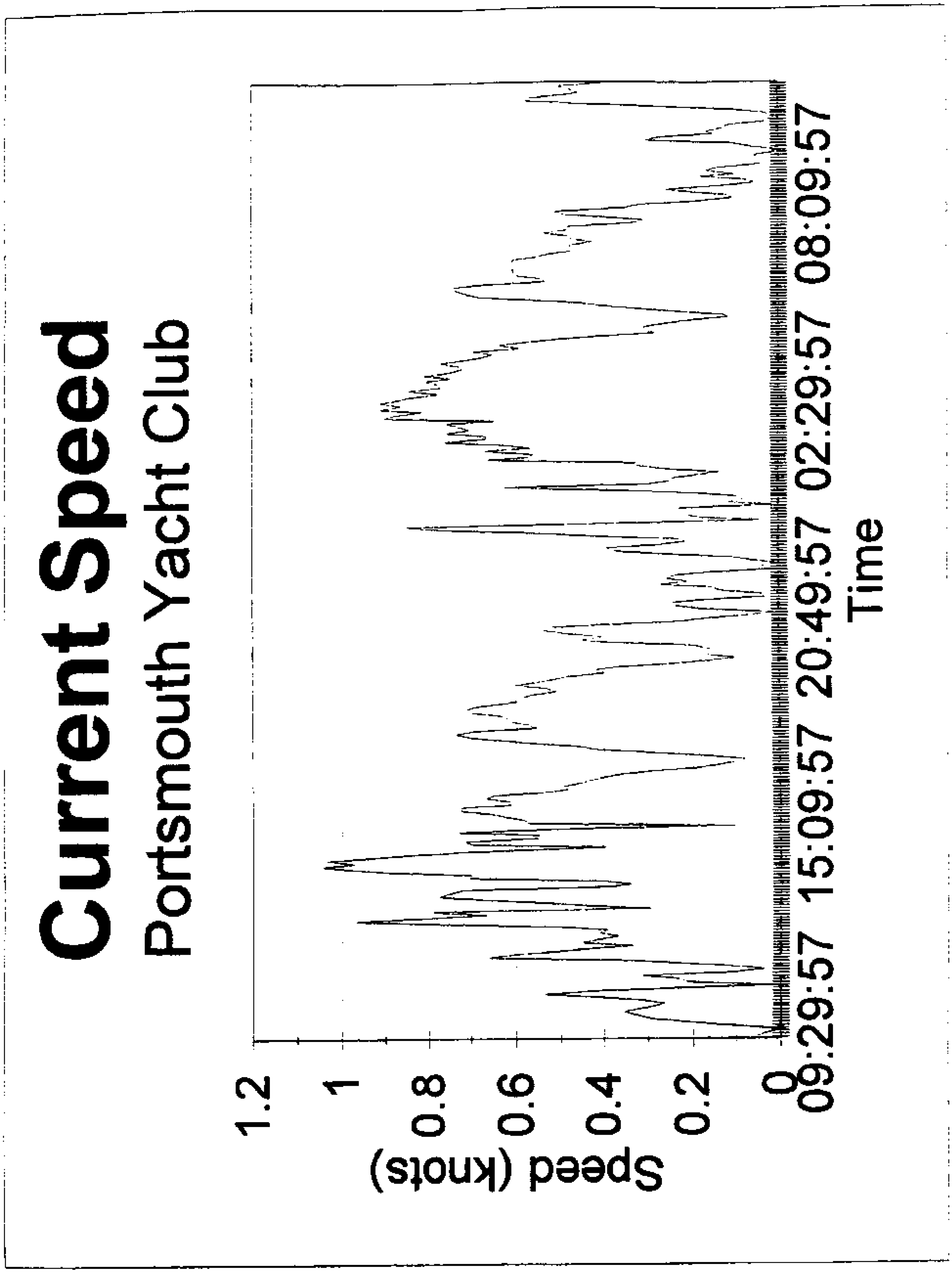
1. Determination of weight increase in wet wood.

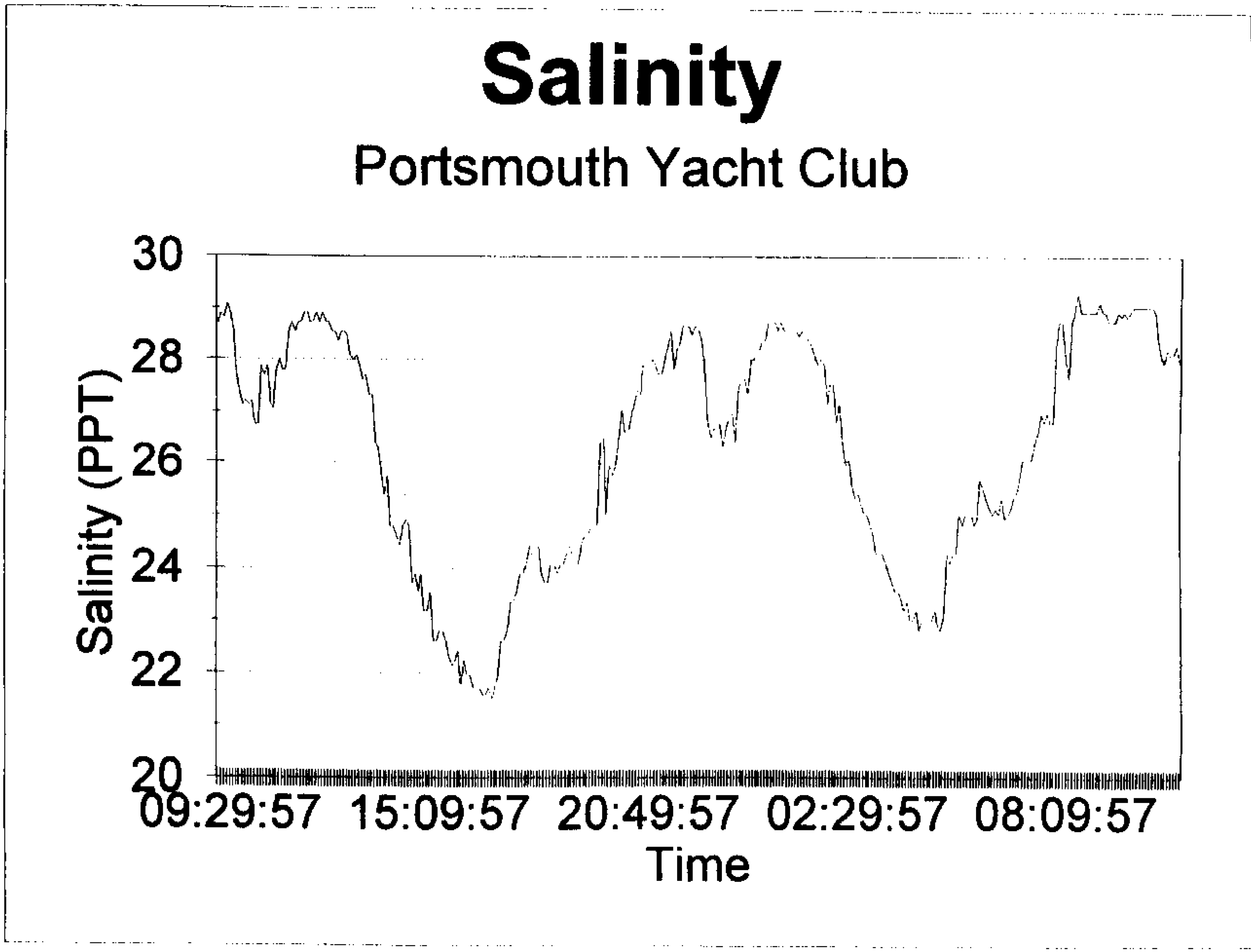
Cross Section of specimen	Dry Weight (lbf)	Wet Weight (lbf)	Percent Increase
1" x 8"	2.73	4.64	70
2" x 10"	5.06	8.31	64

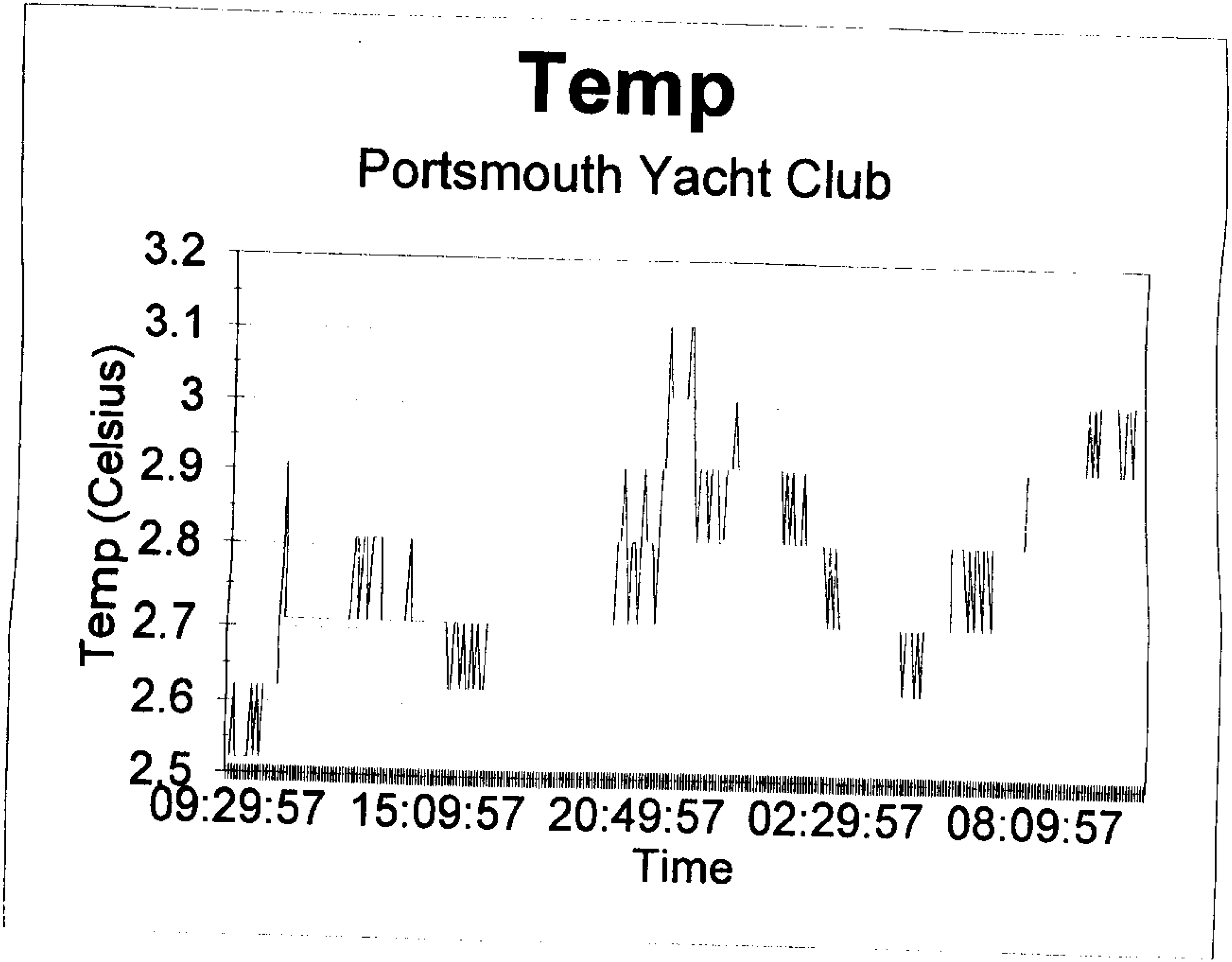
2. Current, Salinity, and Temperature of netpen site.
These measurements were done at a depth of 2-3 meters from March 13, 1995, 8:30 am to March 14, 1995, 11:00 am. The Endeco current meter was deployed by Langley Gace.

Measured Quantity	Units	Value
Maximum Current	knots	1.06
Temperature Range	Fahrenheit	37.5 - 36.5
Salinity Range	PPT	29 - 22

Three plots show this data. They can be seen on the next three pages.


Current Speed
Portsmouth Yacht Club
Speed (knots)
1.2
1
0.8
0.6
0.4
0.2
0
09:29:57
15:09:57
20:49:57
02:29:57
08:09:57
Time


Salinity
Portsmouth Yacht Club
Salinity (PPT)
30
28
26
24
22
20
09:29:57
15:09:57
20:49:57
02:29:57
08:09:57
Time



Temp
Portsmouth Yacht Club
Temp (Celsius)
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
09:29:57
15:09:57
20:49:57
02:29:57
08:09:57
Time

Appendix C: Force and Stress Analysis

Introduction:

This section develops all needed forces which were necessary to estimate the critical stresses on the members of the system. The forces consisted of static weights, buoyant forces, and drag forces. The critical members were modeled as simple members, and their yield strengths were compared to the estimated stresses to varify the chosen safety factors.

Contents:

I. General Information:

A. General Information on Properties of Salt water at 45 F:

These values were taken from Gillmer and Johnson's *Introduction to NAVAL ARCHITECTURE; p.289, Appendix A: Table of Fresh- and Saltwater Properties*

Density: $\rho_{water} := \left(1.9400 \cdot \frac{slug}{ft^3}\right) \cdot g$

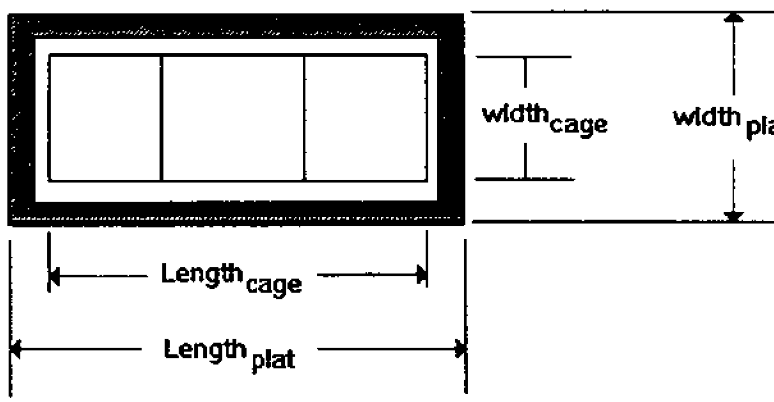
Kinematic Viscosity: $\nu_{water} := 1.5748 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$

B. General Information on Fish Cage System:

This section shows a simple system sketch and gives its dimesions.

System skematic:

Top View:



Side View:

System dimensions:

Platform:

$length_{plat} := 16 \cdot ft$

$width_{plat} := 10 \cdot ft$

$height_{plat} := 3.5 \cdot ft$

Cage:

$length_{cage} := 12 \cdot ft$

$width_{cage} := 4 \cdot ft$

$height_{cage} := 4 \cdot ft$

II. Force Analysis:

A. Weight Calculations:

In this analysis the volumes and weights of all the materials used in construction of the cage were calculated. Densities used were weight densities.

Theory used in determining weights:

Weight = Volume * Density or Weight = Length * Linear Density

1. Weight calculations for each material:

The weight and volume for all of the cage components, then all of the platform components were calculated as follows.

PVC: I.P.S. 2.0", Schedule 120:

Properties taken from: "Physical Properties of Harvel Rigid PVC and CPVC Pipe, Design Properties of Pipe", p 25, PVC Sch 80, 2" I.P.S.

PVC's distributed weight per unit legth. $w_{pvc} := .932 \cdot \frac{lbf}{ft}$

Plastic area. $A_{pvc} := 1.477 \cdot in^2$

Flow area. $A_{flow} := 2.953 \cdot in^2$

Length of PVC used.

$L_{pvc} := 150 \cdot ft$

Calculated weight of PVC.

$W_{pvc} := L_{pvc} \cdot w_{pvc}$ $W_{pvc} = 139.8 \cdot lbf$

Calculated volume of PVC pipe plastic.

$V_{pvc} := A_{pvc} \cdot L_{pvc}$ $V_{pvc} = 1.5 \cdot ft^3$

Calculated flow volume of the PVC pipe.

$V_{flow} := A_{flow} \cdot L_{pvc}$ $V_{flow} = 3.1 \cdot ft^3$

Calculated weight of flow water.

$W_{flow\_water} := V_{flow} \cdot \rho_{water}$ $W_{flow\_water} = 192 \cdot lbf$

Steel joints:

Description and weight was taken from catalog ***Kee Klamp: Structural Slip-On Pipe Fittings*** *(manufacturer publication), pp. 4-6*

Quantity of joints used and weight of each joint:

No. 21: 90 degree SIDE OUTLET TEE:	$N_{21\_9} := 16$	$w_{21\_9} := 2.65 \cdot lbf$
No. 15: 90 degree ELBOW:	$N_{15\_9} := 8$	$w_{15\_9} := 2.65 \cdot lbf$
No. 40: FOUR SOCKET CROSS:	$N_{40\_9} := 2$	$w_{40\_9} := 4.50 \cdot lbf$

Calculated weights for each kind of joint:

$W_{21\_9} := N_{21\_9} \cdot w_{21\_9}$ $\quad W_{21\_9} = 42.4 \cdot lbf$

$W_{15\_9} := N_{15\_9} \cdot w_{15\_9}$ $\quad W_{15\_9} = 21.2 \cdot lbf$

$W_{40\_9} := N_{40\_9} \cdot w_{40\_9}$ $\quad W_{40\_9} = 9 \cdot lbf$

Calculated total weight:

$W_{joints} := W_{21\_9} + W_{15\_9} + W_{40\_9}$ $\quad W_{joints} = 72.6 \cdot lbf$

Lumber:

Calculated volume of lumber: Volume = (thickness) x (width) x (total length)

$V_{walk\_way} := (2 \cdot 1 \cdot in) \cdot (16 \cdot in) \cdot \left[2 \cdot \left(length_{plat} - 3 \cdot ft\right) + 2 \cdot width_{plat}\right]$ $\quad V_{walk\_way} = 10.2 \cdot ft^3$

$V_{arc} := 20 \cdot ((2 \cdot in) \cdot (12 \cdot in) \cdot (18 \cdot in))$ $\quad V_{arc} = 5 \cdot ft^3$

$V_{arc\_brace} := 3 \cdot (2 \cdot in) \cdot (4 \cdot in) \cdot (8 \cdot ft)$ $\quad V_{arc\_brace} = 1.3 \cdot ft^3$

$V_{lumber} := V_{walk\_way} + V_{arc} + V_{arc\_brace}$ $\quad V_{lumber} = 16.6 \cdot ft^3$

Density for dry wood:

$\rho_{lumber\_dry} := \left(.4 \cdot 10^3 \cdot \frac{kg}{m^3}\right) \cdot g$

From Ashby & Jones: Engineering Materials 1; p. 52; Table 5.1: Common Woods.

Calculated weight of dry wood.

$$W_{lumber\_dry} := \rho_{lumber\_dry} \cdot V_{lumber}$$

$$W_{lumber\_dry} = 413.4 \cdot lbf$$

Estimated density for wet lumber:

$$\rho_{lumber\_wet} := 1.7 \cdot \rho_{lumber\_dry}{}^{*}$$

* From experimental data. See Appendix B.

Calculated weight of wet lumber:

$$W_{lumber\_wet} := \rho_{lumber\_wet} \cdot V_{lumber}$$

$$W_{lumber\_wet} = 702.8 \cdot lbf$$

Steel beams, plates, angle iron and bolts:

Calculated volume of steel plates:
Volume = (thickness) x (width) x (length)

$$V_{steel\_plates} := (.25 \cdot in) \cdot (1.5 \cdot ft) \cdot (32 \cdot ft)$$

$$V_{steel\_plates} = 1.7 \cdot 10^{3} \cdot in^{3}$$

Calculated volume of 3" box beam used on the V-support:
Volume = (thickness) x (perimeter) x (length)

$$V_{box\_beam\_vsupport} := (.25 \cdot in) \cdot (12 \cdot in) \cdot (9 \cdot ft)$$

$$V_{box\_beam\_vsupport} = 324 \cdot in^{3}$$

Calculated volume of 4" box beam used as the legs:
Volume = (thickness) x (perimeter) x (length)

$$V_{box\_beam\_leg} := (.25 \cdot in) \cdot (16 \cdot in) \cdot (16 \cdot ft)$$

$$V_{box\_beam\_leg} = 768 \cdot in^{3}$$

Calculated volume of angle iron:
Volume = (thickness) x (perimeter) x (length)

$$V_{angle\_iron} := (2 \cdot 2 \cdot in) \cdot (.125 \cdot in) \cdot (30 \cdot ft) + (2 \cdot 1.5 \cdot in) \cdot (.25 \cdot in) \cdot (40 \cdot ft)$$

$$V_{angle\_iron} = 540 \cdot in^{3}$$

Calculated weight of I beam connecting legs:

Weight per linear foot: $w_{I\_beam} := 15 \cdot \frac{lbf}{ft}$

Chosen length: $L_{I\_beam} := 20 \cdot ft$

From Load and Resistance Factor Design 1st Edition, p.1-36; W6x15.

$$W_{I\_beam} := w_{I\_beam} \cdot L_{I\_beam}$$

Density of steel:

$$\rho_{steel} := \left(7.8 \cdot 10^3 \cdot \frac{kg}{m^3}\right) \cdot g$$

From Ashby & Jones: Engineering Materials 1; p. 52; Table 5.1: Low Alloy Steels.

Total Volume of Steel:

$$V_{steel} := V_{steel\_plates} + V_{box\_beam\_vsupport} + V_{box\_beam\_leg} + V_{angle\_iron} + \frac{W_{I\_beam}}{\rho_{steel}}$$

$$V_{steel} = 2.6 \cdot ft^3$$

Calculated weight of steel pieces:

$$W_{steel\_plates} := \rho_{steel} \cdot V_{steel\_plates} \qquad W_{steel\_plates} = 486.9 \cdot lbf$$

$$W_{box\_beam\_vsupport} := \rho_{steel} \cdot V_{box\_beam\_vsupport} \qquad W_{box\_beam\_vsupport} = 91.3 \cdot lbf$$

$$W_{box\_beam\_leg} := \rho_{steel} \cdot V_{box\_beam\_leg} \qquad W_{box\_beam\_leg} = 216.4 \cdot lbf$$

$$W_{angle\_iron} \quad \rho_{steel} \cdot V_{angle\_iron} \qquad W_{angle\_iron} = 152.2 \; lbf$$

$$W_{I\_beam} \quad w_{I\_beam} \cdot L_{I\_beam} \qquad W_{I\_beam} = 300 \; lbf$$

Estimation of Bolt Weight:

$$W_{bolts} := 20 \cdot lbf$$

Calculated weight of all steel used on the platform:

$$W_{steel} := W_{steel\_plates} + W_{box\_beam\_vsupport} + W_{box\_beam\_leg} + W_{bolts} \cdots + W_{angle\_iron} + W_{I\_beam}$$

$$W_{steel} = 1.3 \cdot 10^3 \cdot lbf$$

High Density Polyethylene (HDPE) drums:

The Quantity,N, of drums and the wieght and volume of each is given below.

The quantity chosen.	$N_{drums} := 10$
Estimated weight.	$W_{drum} := 15 \cdot lbf$
The given volume: 30-gallon drums:	$V_{drum} := 30 \cdot gal$

Calculated volume of all the drums:

$V_{drums} := N_{drums} \cdot V_{drum}$ $\qquad V_{drums} = 40.1 \cdot ft^3$

Calculated weight of all the drums:

$W_{drums} := N_{drums} \cdot W_{drum}$ $\qquad W_{drums} = 150 \cdot lbf$

2. Weight calculations for different sections of the system:

The total weight of the cage, and platform system was calculated.

Total weight of the cage:

Total weight of the cage before going into the water:

$W_{cage\_dry} \quad W_{pvc} \quad W_{joints}$ $\qquad W_{cage\_dry} = 212 \ lbf$

Total weight of the cage after being in the water for a significant amount of time:

$W_{cage\_wet} := W_{pvc} + W_{joints} + W_{flow\_water}$ $\qquad W_{cage\_wet} = 404 \cdot lbf$

Total weight of platform:

Total weight of the platform before going into the water.

$W_{platform\_dry} := W_{lumber\_dry} + W_{steel}$ $\qquad W_{platform\_dry} = 1.7 \cdot 10^3 \cdot lbf$

Total weight of the platform after being in the water for a significant amount of time.

$W_{platform\_wet} := W_{lumber\_wet} + W_{steel}$ $\qquad W_{platform\_wet} = 2 \cdot 10^3 \cdot lbf$

Total weight of complete system (both dry and wet conditions):

Total weight of the system before going into the water :

$$W_{system\_dry} := W_{pvc} + W_{joints} + W_{lumber\_dry} + W_{steel} + W_{drums}$$

$$W_{system\_dry} = 2 \cdot 10^3 \cdot lbf$$

Total weight of the system after being in the water for a significant period of time :

$$W_{system\_wet} := W_{pvc} + W_{flow\_water} + W_{joints} + W_{lumber\_wet} \cdots + W_{steel} + W_{drums}$$

$$W_{system\_wet} = 2.5 \cdot 10^3 \cdot lbf$$

B. Buoyancy Calculations:

Buoyancy for the the complete system and it's sections, including the ballasts was determined.

1. Displacement calculations for the system components:

Apparent weight of complete system:

The weight of the system in the water and the total volume of the complete system before entering the water:

$$V_{dry} := V_{pvc} + V_{lumber} + V_{steel} \qquad V_{dry} = 20.7 \cdot ft^3$$

$$\Delta W_{sys\_dry} := W_{system\_dry} - \rho_{water} \cdot V_{dry} \qquad \Delta W_{sys\_dry} = 753.5 \cdot lbf$$

Apparent weight of the complete system after being in the water for a significant amount of time, assuming the wood has become saturated (70% increase by weight), the PVC pipes have filled with water.

$$V_{wet} := V_{pvc} + V_{lumber} + V_{steel} + .1 \cdot V_{drums} \qquad V_{wet} = 24.7 \cdot ft^3$$

$$\Delta W_{sys\_wet} := W_{system\_wet} - \rho_{water} \cdot V_{wet} \qquad \Delta W_{sys\_wet} = 984.5 \cdot lbf$$

Apparent weight of cage:

Weight of the cage in water with the PVC pipes filled with water.

$$\Delta W_{cage} := W_{cage\_dry} - \rho_{water} \cdot V_{pvc} \qquad \Delta W_{cage} = 116.4 \cdot lbf$$

2. Buoyancy analysis for the ballast system:

The excess buoyancy obtained from the ten 30 gallon drums was considered.

$$F_{lift\_drums} := \rho_{water} \cdot V_{drums} \qquad F_{lift\_drums} = 2.5 \cdot 10^{3} \cdot lbf$$

$$F_{lift\_per\_drum} := \frac{F_{lift\_drums}}{N_{drums}} \qquad F_{lift\_per\_drum} = 250.3 \cdot lbf$$

Excess buoyancy when the system is raised to the surface:
This assumes that 50% of the lumber is submerged below the surface.

$$F_{excess} \quad F_{lift\_drums} \quad W_{system\_wet} \qquad F_{excess} = 20.9 \;\; lbf$$

Consideration of the people on the platform:

Number of people on the platform: $N_{people} \quad 2$

Estimated weight per person: $W_{person} := 200 \cdot lbf$

Total weight of people:

$$W_{people} := N_{people} \cdot W_{person} \qquad W_{people} = 400 \cdot lbf$$

Calculated excess buoyancy with people on the platform:

$$F_{excess\_with\_people} := F_{excess} - W_{people}$$

$$F_{excess\_with\_people} = -420.9 \cdot lbf$$

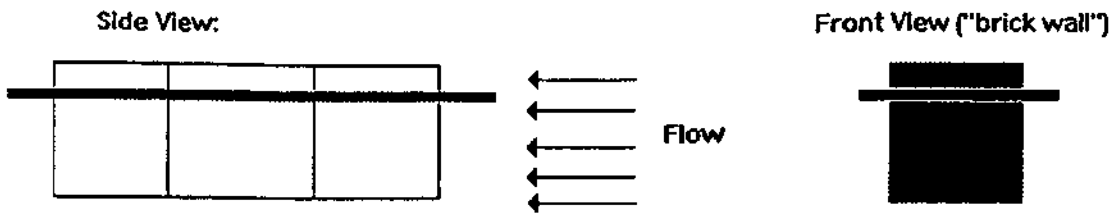
C. Drag Force Analysis:

The purpose of this analysis was to determine the drag forces that would act upon the system in the estuary at the Porsmouth Yacht Club.

1. Drag force analysis in the estuary:

This analysis estimates the drag forces on the cage as though it was fullly blocked.

Model of Fully Blocked Cage:



Definition of Parameters:

Unit Definition:	$knot := 1.7 \cdot \frac{ft}{sec}$
Worst case current for the Piscataqua River	$u := 2.0 \cdot knot$
Estimated for a fully blocked front shield	$C_T := 1.0$
Dimension of cage.	$L := 4 \cdot ft$
Facial area of cage.	$A_1 \quad L^2$ $\qquad A_1 = 16\ ft^2$
Estimation of total area considering the platform.	$A \quad 20 \cdot ft^2$

Calculation of Drag Forces:

Using a safety factor: $FS := 2.0$

Drag Force on Complete System.

$$F_{estuary\_drag\_syst} := \frac{1}{2} \cdot FS \cdot C_T \cdot A \cdot \frac{\rho_{water}}{g} \cdot u^2$$

$$F_{estuary\_drag\_syst} = 449 \cdot lbf$$

Drag Force on Cage.

$$F_{estuary\_drag\_cage} := \frac{1}{2} \cdot FS \cdot C_T \cdot A_1 \cdot \frac{\rho_{water}}{g} \cdot u^2$$

$$F_{estuary\_drag\_cage} = 359 \cdot lbf$$

*Due to the extremely high wave forces of the open ocean, the cage will be placed in an estuary of the Piscataqua River. Therefore, all drag forces in the following analyses will be the worst case forces determined from this "Drag force analysis in the estuaries".

III. Stress Analysis:

This section analysis the stress on the four major system components: the PVC cage frame, the platform, the cage V-support, and the mooring system.

A. Stress Analysis of the PVC Frame:

Three cases were analyzed. One being the cage free floating in the water, and the second being the crane lift out of the water, and the third being the cage placed in a high drag environment.

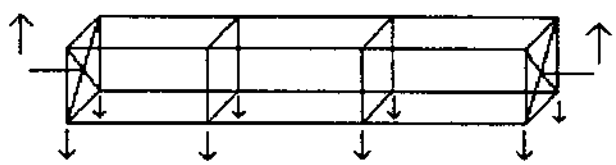
1. Stress analysis of the PVC frame suspended in water:

The total weight in the water which were calculated in "Weight calculations for the different sections of the system" will be used to estimate the static loading felt by the cage frame. This weight considers the joints, PVC plastic and flow volume filled with water.

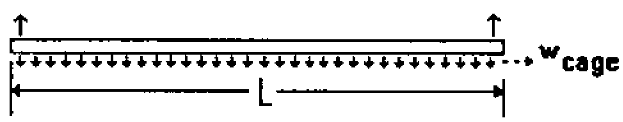
Mathematical model:

Assuming four (12 ft) PVC pipes will support the entire weight of the wet frame.

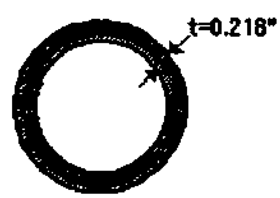
Actual loading of cage while in the water.



Model



Cross section of pipe:



$OD := 2.375 \cdot in$

Cage dimension: $L := 12 \cdot ft$

Property of PVC: $I_{pvc} := .868 \cdot in^4$ *Properties taken from Physical Properties of Harvel Rigid PVC and CPVC Pipe: p. 25; Table: Design Properties of Pipes, PVC Sch 80, 2" I.P.S.*

$I_{4pvc} := 4 \cdot I_{pvc}$ Four pipes bearing the load.

Distributed load due to cage's weight:

$$\Delta W_{cage\_wet} := W_{cage\_wet} - \rho_{water} \cdot V_{pvc} \qquad w_{cage} := \frac{-\Delta W_{cage\_wet}}{L}$$

$$w_{cage} = -25.7 \cdot \frac{lbf}{ft}$$

Maximum bending moment: $M_{max} := \dfrac{w_{cage} \cdot L^2}{8}$

From Potter's Fundamentals of Engineering; p. 10-9; Table 10.2; Number 5; Support Beam.

$$M_{max} = -462.6 \cdot ft \cdot lbf$$

Distance from center to outer edge. $c := \dfrac{OD}{2}$

Maximum bending stress: $\sigma_{max} := \dfrac{M_{max} \cdot c}{I_{4pvc}}$

From Potter's Fundamentals of Engineering; p. 10-6; Equation 10.3.1. (negative was taken to show tension)

$$\sigma_{max} = -1.9 \cdot 10^3 \cdot \frac{lbf}{in^2}$$

Tensile strength of PVC: $\sigma_{YS} := 7450 \cdot psi$

From Physical Properties of Harvel Rigid PVC and CPVC Pipe (manufacturer publication)

$$\sigma_{YS} = 7.5 \cdot 10^3 \cdot psi$$

Safety factor: $FS := \left| \dfrac{\sigma_{YS}}{\sigma_{max}} \right|$

$$FS = 3.9$$

Young's Modulus: $E_{pvc} := 420 \cdot 10^3 \cdot psi$

From Physical Properties of Harvel Rigid PVC and CPVC Pipe (manufacturer publication)

Maximum deflection: $y_{max} := \dfrac{5 \cdot w_{cage} \cdot L^4}{384 \cdot E_{pvc} \cdot I_{4pvc}}$

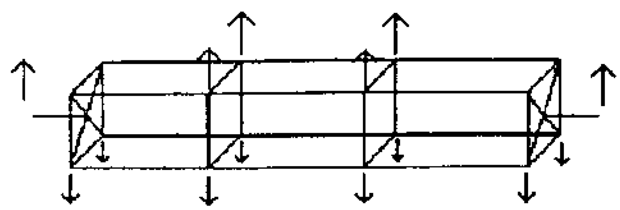
From Shigley's Mechanical Engineering Design; p. 738, Table A-9, # 7.

$$y_{max} = -8.2 \cdot in$$

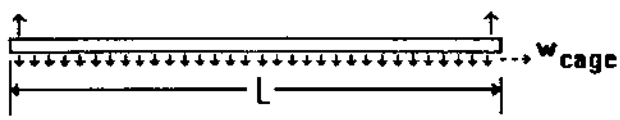
2. Stress analysis of PVC frame supported while being lifted out of the water:

This will be modeled as a pinned beam.

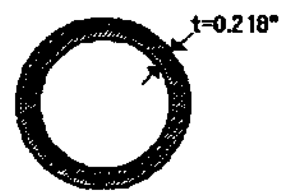
Actual force distribution on cage:



Model:



Cross section of PVC pipe:



Length of unsupported section: $L := 4 \cdot ft$

Distributed load due to cages weight: $w_{cage} := \frac{W_{cage\_wet}}{L}$

$w_{cage} = 101.1 \cdot \frac{lbf}{ft}$

Maximum bending moment: $M_{max} := \frac{w_{cage} \cdot L^2}{8}$

From Potter's Fundamentals of Engineering; p. 10-9; Table 10.2; Nubmer 5; Support Beam.

$M_{max} = 202.2 \cdot ft \cdot lbf$

Distance from center to outer edge. $c := \frac{OD}{2}$

Maximum bending stress: $\sigma_{max} = \frac{M_{max} \cdot c}{I_{4pvc}}$ *From Potter's Fundamentals of Engineering; p. 10-6; Equation 10.3.1. (negative was taken to show tension)*

$$\sigma_{max} = 829.9 \cdot \frac{lbf}{in^2}$$

Tensile strength of PVC: $\sigma_{YS} := 7450 \cdot psi$ *From Physical Properties of Harvel Rigid PVC and CPVC Pipe (manufacturer publication)*

Safety factor: $FS := \frac{\sigma_{YS}}{\sigma_{max}}$

$$FS = 9$$

Young's Modulus: $E_{pvc} := 420 \cdot 10^3 \cdot psi$ *From Physical Properties of Harvel Rigid PVC and CPVC Pipe. (manufacturer publication)*

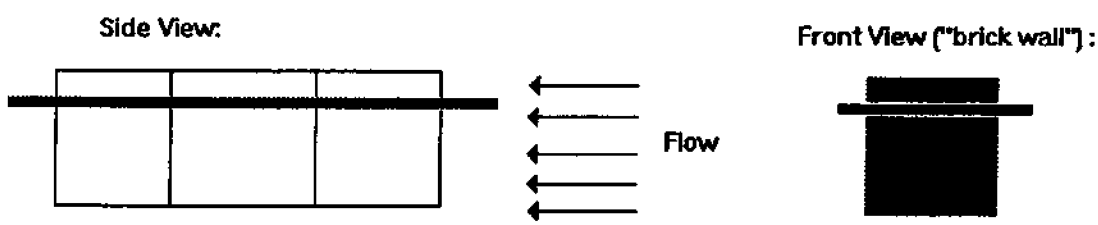
Maximum deflection: $y_{max} := \frac{5 \cdot w_{cage} \cdot L^4}{384 \cdot E_{pvc} \cdot I_{4pvc}}$ *From Shigley's Mechanical Engineering Design; p. 738, Table A-9, # 7.*

$$y_{max} = 0.4 \cdot in$$

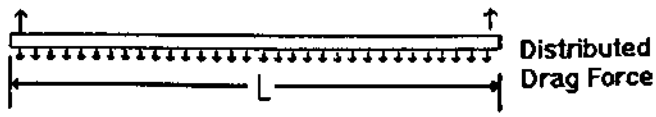
3. Stress analysis of PVC frame resistant to the drag force.

This will be analyzed as fixed cantilever beam.

Drag Force on Cage Frame:



Model



Dimension: $L := 4 \cdot ft$

Distributed load: $w := \frac{F_{estuary\_drag\_cage}}{L}$

$w = 90 \cdot \frac{lbf}{ft}$

Maximum moment: $M_{max} := w \cdot \frac{L^2}{12}$ *From Shigley's <u>Mechanical Engineering Design</u>; p. 742, Table A-9, # 16.*

$M_{max} = 120 \cdot lbf \cdot ft$

Distance from neutral axis to outer surface: $c := \frac{OD}{2}$

$c = 1.2 \cdot in$

Maximum bending stress: $\sigma_{max} := \frac{M_{max} \cdot c}{I_{4pvc}}$

$\sigma_{max} = 491 \cdot psi$

Tensile stress for PVC: $\sigma_{TS\_PVC} := 7450 \cdot psi$ *From <u>Physical Properties of Harvel Rigid PVC and CPVC Pipe.</u> (company)*

Safety Factor: $FS := \frac{\sigma_{TS\_PVC}}{\sigma_{max}}$

$FS = 15.2$

B. Stress Analysis of the Platform:

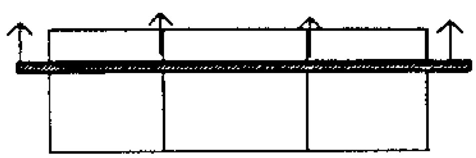
1. Stress analysis of the long side of platform:

Lifting a saturated wooden platform with attached cage out of the water was assumed to be the worst case. Ballast drums were assumed empty of water, while the PVC cage frame was assumed to be filled with water. As bio-fouling of the lumber could be difficult to remove, 150 lbs of bio-fouling was considered.

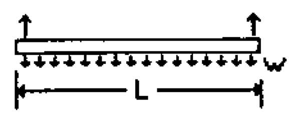
Mathematical Model

The Platform will be supported during lift as shown.

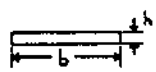
Actual load during lift:



Model:



Platform cross section:



$b := 8 \cdot in$ $\quad h := 2 \cdot in$ $\quad I := 2 \cdot \left(\frac{b \cdot h^3}{12}\right)$ $\quad I = 10.7 \cdot in^4$

$c := \frac{h}{2}$ $\quad c = 1 \cdot in$

The weight of the cage and steel is directly supported by the bracing. Therefore,
the load on the lumber will be due only to the weight of wet lumber, the ballast drums, and bio-fouling.

Loaded weight: $\quad W_{load} := W_{lumber\_wet} + W_{drums} + W_{angle\_iron}$

Distributed Load: $\quad w_{distributed} := \frac{W_{load}}{length_{plat}}$

$$w_{distributed} = 62.8 \cdot \frac{lbf}{ft}$$

Length of analyzed section: $\quad L := \frac{length_{plat}}{3}$

$$L = 5.3 \cdot ft$$

Maximum bending moment: $M := \frac{w_{distributed} \cdot L^2}{8}$

From Potter's Fundamentals of Engineering; p. 10-9; Table 10.2; Nubmer 5; Support Beam.

$M = 223.3 \cdot lbf \cdot ft$

Maximum bending stress: $\sigma_{max} := \frac{M \cdot c}{I}$

From Potter's Fundamentals of Engineering; p. 10-6; Equation 10.3.1. (negative was taken to show tension)

$\sigma_{max} = 251.2 \cdot psi$

Maximum bending stress parallel to grain of lumber: $\sigma_{max\_bend} := 600 \cdot psi$

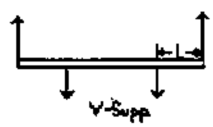
From Materials Data Book; p. 240; Table 11-6; Spruce - Commercial.

Safety factor: $FS := \frac{\sigma_{max\_bend}}{\sigma_{max}}$

$FS = 2.4$

2. Stress analysis of the short side of platform:

The short side of the platform was modeled as shown:



Moment arm to V-Structure: $L := 3.5 \cdot ft$

Maximum bending moment: $M_{max} := \frac{W_{box\_beam\_vsupport} + W_{cage\_dry}}{4} \cdot L$

$M_{max} = 265.7 \cdot lbf \cdot ft$

Maximum bending stress: $\sigma_{max} := \frac{M_{max} \cdot c}{I}$

From Potter's Fundamentals of Engineering; p. 10-6; Equation 10.3.1. (negative was taken to show tension)

$\sigma_{max} = 299 \cdot psi$

Safety factor:

$$FS = \frac{\sigma_{max\_bend}}{\sigma_{max}}$$

$$FS = 2$$

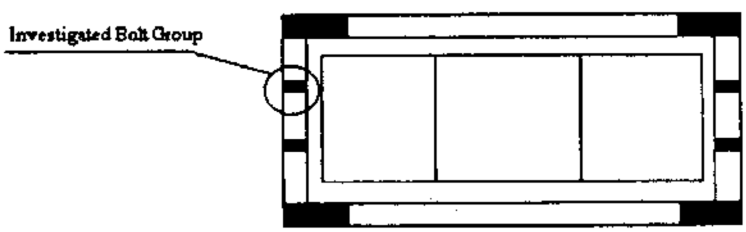
C. Stress Analysis of V-Support:

This section calculates the stress on the V-support's bolt group, base weld, and pin joint.

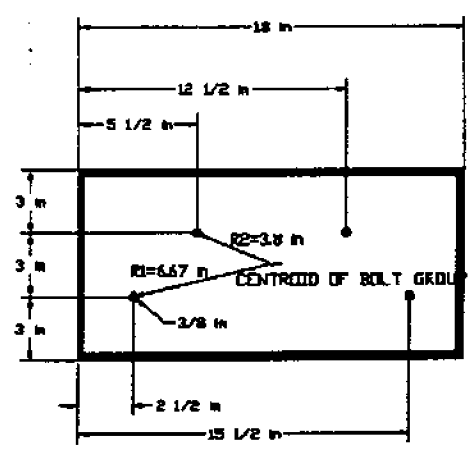
1. Stress analysis of the V-support bolt group:

The 3/8 inch bolts which connect the 'V'-structure to the platform were analyzed for shear and tensile stress: Using the endurance limit of the bolt, the safety factor was determined.

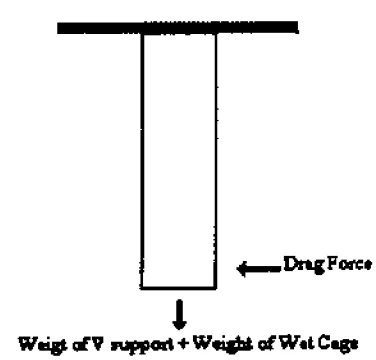
Top view of platform:



Investigation of one bolt group:



Side View of V Support:



Using the methodology described by *Shigley, "Mechanical Engineering Design", pp355-370,* the normal and shear stresses were determined, summed vectorially, then used to find the maximum stress in the bolt.

Shear Stress

The primary shear force, τ*, is caused by the drag force, while the secondary shear stress is caused by resultant moment about the bolt group centroid.

Drag force: $F_{drag} := 500 \cdot lbf$

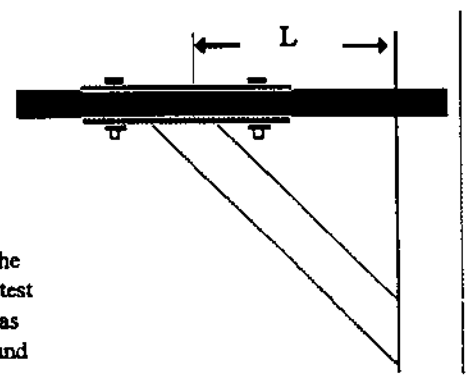
Bolt Diameter: $d := \frac{3}{8} \cdot in$

Primary shear load:

$F := \frac{F_{drag}}{4}$ The drag is resisted by 2 V supports, hence 4 bolt groups.

$F_{bolt} := \frac{F}{4}$ There are 4 bolts in each bolt group.

Secondary Shear Load:



Moment acting on one of the bolt groups:

$L := 1.5 \cdot ft$

$M_R := L \cdot F$

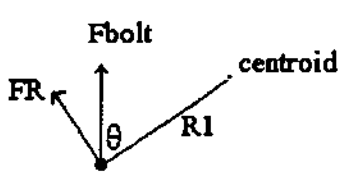
This is the moment reaction about the centroid of the bolt group. The bolt load from this moment is greatest at the bolts located the farthest from the centroid (as shown in the diagram of the bolt group), and is found by:

$R_1 := 6.67 \cdot in$ $R_2 := 3.8 \cdot in$ $F_R := \frac{M_R \cdot R_1}{2 \cdot R_2^2 + 2 \cdot R_1^2}$

From Shigley's Mechanical Engineering Design; p. 363; Equation 8-43.

Vector sum of the two shear loads:

From the geometry of the bolt group:



$\theta := 13 \cdot deg$

$$F_{shear} := \left[\left(F_R \cdot \cos(\theta) + F_{bolt} \right)^2 + \left[F_R \cdot (\sin(\theta)) \right]^2 \right]^{\frac{1}{2}}$$

Total Shear Stress:

$$\tau_{max} = \frac{F_{shear}}{\left(\pi \cdot \frac{d^2}{4}\right)}$$

From Shigley's Mechanical Engineering Design; p. 359; Equation 8-39.

$$\tau_{max} = 1.4 \cdot 10^3 \cdot \frac{lbf}{in^2}$$

Normal Stress

The worst case scenario of the bolt losing contact with the members was considered. Normal stresses are caused by bending stress due to the drag force, and tensile stress from the weight of the cage and V support.

Normal Bending Stress:

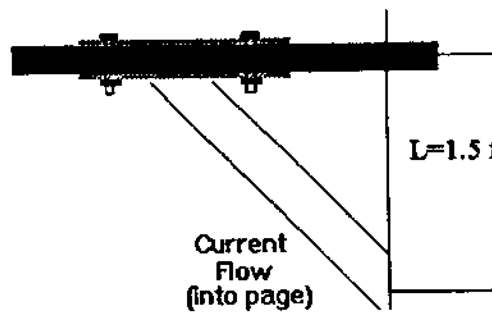
$$L = 1.5 \cdot ft$$

$$c := \frac{d}{2}$$

$$I_{bolt} := \frac{d^4 \cdot \pi}{64}$$

$$\sigma_b := \frac{F_{bolt} \cdot L \cdot c}{I_{bolt}}$$

Side View of Platform:



Normal Tensile Stress:

The two V supports each have 8 bolts. Therefore, in the worst case, each bolt alone would support 1/16 of the total cage weight, and 1/8 the weight of one V support.

$$W_{cage\_wet} = 404 \cdot lbf$$

$$W_{box\_beam\_vsupport} = 91 \cdot lbf$$

$$\sigma_t := \frac{\left(W_{cage\_wet} \cdot \frac{1}{16} + W_{box\_beam\_vsupport} \cdot \frac{1}{8}\right)}{\left(\frac{d^2 \cdot \pi}{4}\right)}$$

Total Normal Stress:

$$\sigma_{total} := \sigma_t + \sigma_b$$

Total Stress on Bolt:

$$\sigma_{max} := \left[\sigma_{total}^{2} + \left(3\cdot\tau_{max}\right)^{2}\right]^{\frac{1}{2}}$$

$$\sigma_{max} = 1.1\cdot 10^{5}\ \cdot\text{psi}$$

Tensile Strength: $\sigma_{TS\_bolt} := 120\cdot 10^{3}\cdot\text{psi}$ — *From Shigley's Mechanical Engineering Design; p. 341; Table 8-4; SAE Grade No. 5.*

Safety factor:

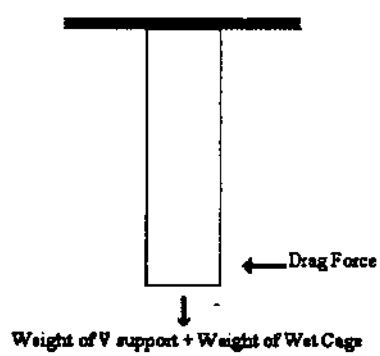
$$FS := \frac{\sigma_{TS\_bolt}}{\sigma_{max}}$$

$$FS = 1.1$$

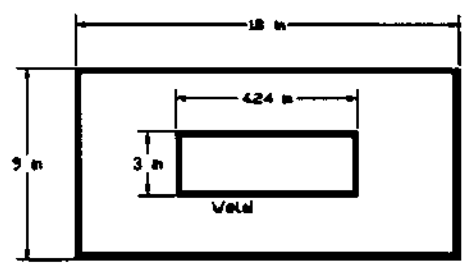
2. Stress analysis of the V-support base weld:

A cantilever analogy with to determine the maximum bending stress in the weld of the V-structure. Shear and normal stresses were calculated in the same manner as those for the bolt group. Shear stress in the weld is caused by the drag force. Normal stress is caused by the moment reaction from the drag force, as well as the tensile stress due to the V support's weight..

Free Body Diagram of V-structure:



Sketch of the Weld:



Description of weld:

Weld size: $d := 3\cdot\text{in}$ $\quad b := 3\cdot\sqrt{2}\cdot\text{in}$ $\quad h := .25\cdot\text{in}$

Area of the weld: $A := 1.414\cdot h\cdot(b + d)^{*}$ — **From Shigley's Mechanical Engineering Design; p. 397; Table 9-3*

$$A = 2.6\cdot\text{in}^{2}$$

Area moment of inertia: $I_u := \frac{d^2}{6}\cdot(3\cdot b + d)$*

$I := (.707\cdot h)\cdot I_u$ *

*From Shigley's *Mechanical Engineering Design*; p. 397; Table 9-3*

Polar Moment of Inertia: $J := .707\cdot h\cdot\frac{(b+d)^3}{6}$*

Applied load: $F := \frac{1}{4}\cdot F_{estuary\_drag\_cage}$

Each of the four welded plates was assumed to take 1/4 of the drag.

$F = 90\cdot lbf$

Moment arm: $L := 1.5\cdot ft$

Shear Stress in the Weld

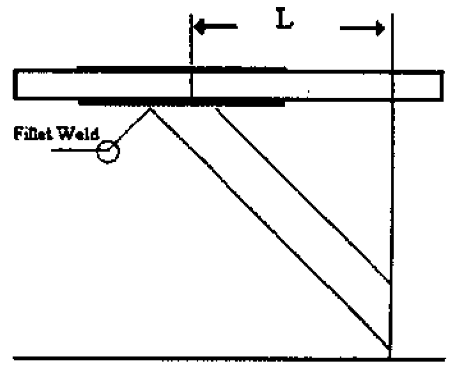
Primary Shear Stress:
Primary shear is caused by the drag force: $\tau_1 := \frac{F}{A}$

Secondary Shear Stress:
Secondary shear is caused by the moment reaction about the centroid of the weld:

Maximum bending moment: $L = 1.5\cdot ft$

$M_{max} := F\cdot L$

$M_{max} = 135\cdot lbf\cdot ft$



Maximum Radius:

From the geometry of the weld, the maximum radius from the weld centroid to any point in the weld was found:

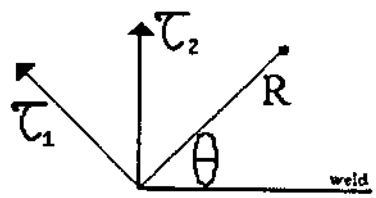
$$R := \left(3^2 + 4.24^2\right)^{\frac{1}{2}}\cdot in$$

Secondary Shear:

$$\tau_2 := \frac{M\cdot R}{J}$$

equation 9-6, p.390, Shigley

Vector Sum of Shear Stresses:



From geometry, $\theta = \operatorname{atan}\left(\dfrac{3}{4.24}\right)$

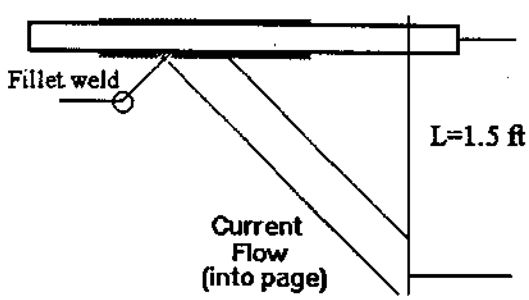
$$\tau_{total} := \left[\left[\tau_1\cdot(\sin(\theta))\right]^2 + \left(\tau_1\cdot\cos(\theta) + \tau_2\right)^2\right]^{\frac{1}{2}}$$

Normal Stress

Tensile Stress due to Weight (assuming that each of the 4 welds holds 1/4 the wet cage weight and 1/2 the weight of one V support):

$$\sigma_t := \frac{\dfrac{W_{cage\_wet}}{4} + \dfrac{W_{box\_beam\_vsupport}}{2}}{A}$$

Maximum bending stress:



$$M_b := F \cdot L$$

$$\sigma_B := \frac{M_b \cdot R}{I}$$

Total Normal Stress: $\sigma_{normal} := \sigma_B + \sigma_t$

Total Stress: $\sigma_{total} := \sqrt{\sigma_{normal}^{\;2} + 3\cdot\tau_{total}^{\;2}}$

$$\sigma_{total} = 3\cdot 10^3 \cdot psi$$

Yield strength for steel: $\sigma_{YS\_Steel} := 32 \cdot 10^{3} \cdot psi$

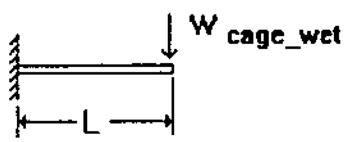
Safety factor: $FS := \dfrac{\sigma_{YS\_Steel}}{\sigma_{total}}$

$FS = 10.6$

3. Stress analysis of the V-support Pin Joint:

The pin joint which allows the cage to rotate will have to support the full weight of the cage during rotation.
The maximum load experienced by the pin was analyzed. This pin was analyzed as a cantilever beam fixed at one end.

Free Body diagram of Pin:



Pin length: $L := 1 \cdot ft$

Second moment area of inertia: $I := .391 \cdot in^{4}$

Properties taken from Waddel's Construction Materials: p. 25; Table: Design Properties of Pipes, Sch 80, 1 1/2" I.P.S.

Maximum bending moment: $M_{max} := W_{cage\_wet} \cdot L$

From Potter's Fundamentals of Engineering; p. 10-9; Table 10.2; Nubmer 1; Beam Fixed at One End..

$M_{max} = 404.4 \cdot lbf \cdot ft$

Maximum bending stress: $\sigma_{max} := \dfrac{M_{max} \cdot c}{I}$

From Potter's Fundamentals of Engineering; p. 10-6; Equation 10.3.1. (negative was taken to show tension)

$\sigma_{max} = 2.3 \cdot 10^{3} \cdot psi$

Yield stress for steel: $\sigma_{YS\_steel} := 500 \cdot 10^{6} \cdot \dfrac{kg \cdot m}{sec^{2} \cdot m^{2}}$

From Ashby & Jones: Engineering Materials 1; p. 79; Table 8.1: Low-Alloy Steels (lowest value).

$\sigma_{YS\_steel} = 7.3 \cdot 10^{4} \cdot psi$

English units

Safety factor: $$FS = \frac{\sigma_{YS\_steel}}{\sigma_{max}}$$

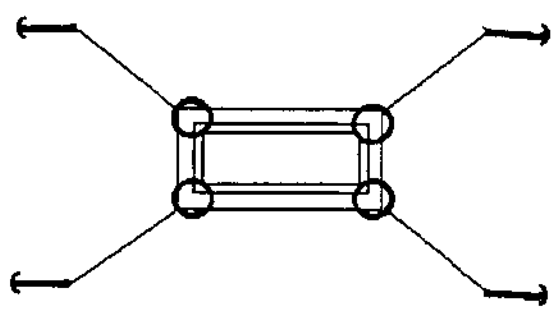
$$FS = 31$$

D. Mooring System Analysis:

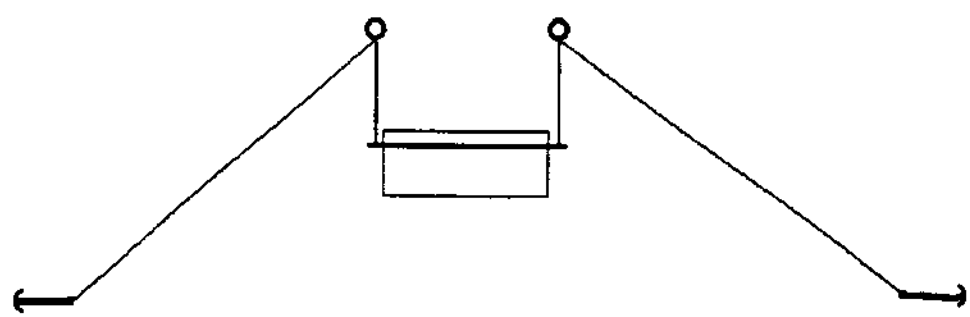
This analysis was done to determine the required mooring-ball sizes, line strengths and anchor weight. Initially the system was considered such that the mooring balls did not sink and that the mooring block is fixed. A drawing of this system can be seen below. With this assumptions, the tension in the mooring can be used to determine the minimum weight required to hold the cage in place.

A. Mooring Balls:

Top View of Mooring System:



Side View of Mooring System:



Submerged cage weight: $$\Delta W_{sys\_wet} = 984.5 \cdot lbf$$

Float:

Geometry:

$$r_{float} := 13.5 \cdot in$$

$$V_{float} := \frac{4}{3} \cdot \pi \cdot r_{float}^3$$

$$V_{float} = 6 \cdot ft^3$$

Maximum buoyant force:

$$F_{float} := \rho_{water} \cdot V_{float}$$

$$F_{float} = 372.3 \cdot lbf$$

Total buoyant float force: $N_{floats} := 4$

$$F_B := N_{floats} \cdot F_{float}$$

$$F_B = 1.5 \cdot 10^3 \cdot lbf$$

Safety Factor: $FS := \frac{F_B}{\Delta W_{sys\_wet}}$

$$FS = 1.5$$

Appendix D: Break Down of Expenditures

Expenditures by Company Totals:

Company Names	Expenditures
Barrels for Sale: Irene Masten	$120.00
Brooks Pharmacy	$8.76
Deborah II: Merril Blake	$500.00
F.W. Webb Company	$1092.43
Great Northern Docks	$210.00
Handy Hardware	$36.37
Houghton True Value	$509.31
Jackson Laboratory	$340.00
Memphis Net and Twine Co.	$163.10
Mill Steel	$706.80
New England Fish and Gear	$1025.76
Old Fish Market	$21.00
Portsmouth Fish Co-Op	$7.00
STAR Lumber	$240.60
Toys 'R Us	$23.94
Sub-Total	$5005.07
Paid from Outside Source	$1771 76
Total	$3233.31

*Note: The project had a budget of $3340.00.

Expenditures by Company Orders:

Barrels for Sale: Irene Masten
Route 4, Box 422, Northwood, NH 03201
ph: 603-942-3533

Item Description	Quantity	Unit Price	Net Cost
Barrel: 30 gal.	10	$ 12.00	$ 120.00
Total:			$ 120.00

Brooks Pharmacy
Durham, NH 03824

Item Description	Quantity	Unit Price	Net Cost
Slide film, Exto: 24 exposures	1	$6.99	$6.99
Poster Board: For Templates	3	$0.59	$1.77
Total:			$8.76

Deborah II
Merril Blake
Hampton, NH 03824

Item Description	Quantity	Unit Price	Net Cost
One day's use of boat and gear to catch codfish	1	$ 500.00	$ 500.00
Total:			$ 500.00

F.W. Webb Company
10 Sumner Drive
Dover, NH 03820
fx: 749-5572
ph: 749-3100
Contact: Dick, Will Lyoma

Item Description	Quantity	Unit Price	Net Cost
PVC Pipe: 2" x 1' x Sch.80	150	$1.142	$171.30
Kee-Klamp #21-9 S.O.Tee	16		Joints
Kee-Klamp #15-9 112 90	8		Total
Kee-Klamp #40-9 112 Socket CR	2		$532.80
Ballast System: Hosing, Manifold			$240.90
Total Spent:			$1092.43

Great Northern Docks

Item Description	Quantity	Unit Price	Net Cost
Dock Floats: 10" x 18" x 24"	4	$52.50	$210.00
Total:			$210.00

Handy Hardware
Dover, NH
603-742-2054

Item Description	Quantity	Unit Price	Net Cost
Hex Cap Bolts: 3/8" x 3"	50	$0.242	$12.10
CPVC Pipe: 3/4" x 10'	1	$3.79	$3.79
CPVC Elbows: 3/4" x 45degrees	8	$0.30	$2.40
Eye Bolts: 3/8" x 5"	16	$1.09	$17.44
Lock Washers: 3/8"	16	$0.04	$.064
Total:			$36.37

Houghton True Value
6 Jenkins Courts
Durham, NH 03824
*Itemization will be done once the itemized receipts can be located.

Item Description	Quantity	Unit Price	Net Cost
Spent:			$509.31
Total:			$509.31

Jackson Laboratory
Newington, NH

Item Description	Quantity	Unit Price	Net Cost
1/2 Day use of Gulf Challenger	2	$170.00	$340.00
Total:			$340.00

Memphis Net and Twine Co.
2481 Matthews Ave.
P.O. 8331
Memphis, TN 38108
ph: 800-238-6380

Item Description	**Quantity**	**Unit Price**	**Net Cost**
Net: 1/4" x 6' x 1' Stock # 1007	30	$2.21	$66.30
Net: 1/2" x 6' x 1lb Stock # 1012	5	$9.89	$49.45
Net: 3/4" x 6' x 1lb Stock # 856	5	$7.62	$38.10
Total P.O:			**$163.10**

Mill Steel
Manchester, NH
ph: 603-626-7351 or 800-244-7351
fx: 603-626-7820
Contact: Donna

Item Description	**Quantity**	**Unit Price**	**Net Cost**
Box Beam: 3" x 3" x 1/4" x 10'	1	$44.00	$44.00
Plates: 1/4" x 18" x 36"	10	$22.00	$220.00
Pipe: 1/2" x 10" Sch. 80	1	$38.00	$38.00
Angle Iron: 2" x 2" x 1/8"	2	$15.00	$30.00
Angle Iron: 1.5" x 1.5" x 1/4"	2	$20.40	$40.80
Modification Costs			$336.00
Paid by Outside Source (Chad Mace)			- $2.00
Total:	12		**$706.80**

New England Fish and Gear
200 Spaulding Turnpike
Portsmouth, NH
ph: 603-436-2836

Item Description	Quantity	Unit Price	Net Cost
Mooring System			$1025.76
Total P.O:			$1025.76

Old Mill Fishmarket
New Castle, NH

Item Description	Quantity	Unit Price	Net Cost
Pounds of Shrimp for fish	12	$1.75	$21.00
Total:			$21.00

Portsmouth Fishermen's Cooperative, INC. Concession
P.O. Box 4159
Portsmouth, NH 03802-4159
ph: 603-436-8927

Item Description	Quantity	Unit Price	Net Cost
Shrimp for fish food			$7.00
Total:			**$7.00**

STAR Lumber
450 High Street
Somersworth, NH
ph: 603-742-2108

Item Description	Quantity	Unit Price	Net Cost
Spruce Lumber: Plaform			$240.60
Total:			$240.60

Toys 'R Us
Newington, NH

Item Description	Quantity	Unit Price	Net Cost
Hoola-Hops for Fouling Test	6	$3.99	$23.94
Total:			$23.94