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Analysis and evaluation of a bioengineered submerged breakwater

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ANALYSIS AND EVALUATION OF A BIOENGINEERED SUBMERGED BREAKWATER

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ABSTRACT

Louisiana's coastline has received national attention due to rapid erosion rates estimated from approximately 60 to 100 square kilometers per year. The disappearance of coastal areas jeopardizes public and private infrastructure, property values, aquatic ecosystems, and standards of living.

In order to resolve the erosion problem, innovative solutions have been explored that may improve effectiveness and cost efficiency. This research involves a technology, termed an "oysterbreak", which is a bioengineered submerged breakwater. This structure promotes oysters to form a dense structure that dissipates wave energy. Since the structure is biologically dominated, initial material use is modest.

The oysterbreak was evaluated through a series of experiments. Settlement patterns were analyzed by quantifying the biological fouling on the structure during its deployment in Grand Isle, Louisiana for one year. Secondly, settlement preference on materials was analyzed in a tank under various flows. To investigate further, the wave interactions with various scaled designs were also analyzed in a wave tank. The transmission, reflection, and dissipation characteristics were determined as growth occurred. Lastly, a predictive model was developed from the results.

Experiments suggest that a uniform distribution pattern could be expected in the absence of predation. Also, it was shown that mortar coating was superior for oyster settlement to PVC pipe and commercially available oyster tubes. The wave tank experiments concluded that wave transmission through the structure decreased as growth occurred. It was also shown that a structure with 2 vertical slats/meter, could be used to effectively dissipate waves.

The predictive model developed suggests that the oysterbreak can be used in field conditions. The model showed that after one year of growth, an oysterbreak 20 meters wide has the capacity to reduce wave energy by 70%. This prediction is consistent with other submerged breakwater designs. The results of these experiments will be used to design, deploy and monitor full scale oysterbreaks.

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 The Land Erosion Problem in Louisiana, USA

Louisiana's coastline has received national attention due to rapid erosion rates. Recent estimates vary from approximately 60 square kilometers per year in 1997 (WILLIAMS et al., 1997; COLEMAN et al. 1998) to approximately 100 square kilometers per year in 2000 (BARRAS et al., 2003). Although erosion is occurring in most coastal areas, Louisiana suffers from the highest erosion rates and "accounts for 90 percent of the coastal marsh loss in the Nation" (USACE, 2004). Even National Geographic claims, "Louisiana is losing its protective fringe of marshes and barrier islands faster than any place in the U.S. (BOURNE, 2004). These high erosion rates are due partly to subsidence and frequent hurricanes (WILLIAMS et al., 1997). On the other hand, these problems are partly due to past anthropogenic activity, including levees and water diversions, which heavily contribute to Louisiana's high land loss rates. The disappearance of the coastal areas jeopardizes public and private infrastructure, property values, and standards of coastal living. The Louisiana's coastal area is estimated to lose an additional 1,327 square kilometers by the year 2050 (BARRAS et al., 2003).

Although focus has been on the eroding shores, the problem extends far beyond the coastline. A diverse ecosystem thrives in these complex coastal environments, which are in danger of dissolving into the Gulf of Mexico. The tremendous fishing industry is believed to be a direct result of the nutrients and nursery grounds provided by this estuarine environment. The extensive coastal wetlands also provide protection for densely populated cities during tropical storms and hurricanes that impact Louisiana's coastline year after year. For these reasons, among others, coastal erosion rates must be reduced or deposition stimulated in these environments.

1.2 The Coastal Areas of Louisiana

Louisiana's coastal area is made up of the Deltaic Plain of the Mississippi River and the Chenier Plain. These areas are greatly influenced by the Mississippi and the Atchafalaya Rivers. The coastal environment is dominated by wetlands and muddy coastlines. Most of Louisiana's coastline has a very low slope (COLEMAN et al. 1998).

There are a few types of coastal scenes that are very common in Louisiana. A typical scene found in many of the bays and inland marshes is depicted in figure 1.1. The salt marshes are dominated in areas by marsh grass, *Spartina alterniflora*. At the land-water interface the grass is usually taller and thicker than the inland grasses. In areas where conditions permit, there are intertidal oyster beds, while other areas contain subtidal oyster reefs near the bank. These oyster beds and grasses help stabilize the coast in these fragile areas (BRUNO AND BERTNESS, 2001; PENNINGS AND BERTNESS, 2001).

Another common scene on Louisiana's coast is the one shown in figure 1.2. Many of the open Gulf coastlines have sandy beaches, especially in the Chenier Plain. The beaches in these regions are separated from the brackish marshes by a small ridge. This ridge is the only barrier keeping the salty Gulf water and waves from invading these marshes and drastically altering the environment. This could result in large scale wetland destruction (WILLIAMS et al., 1997).

Occasionally, subtidal oyster reefs can be found offshore. These immense natural submerged breakwaters protect the beaches from storms and wave erosion by dissipating wave energy. The study of how artificial and natural reefs have protected shorelines has been conducted in the past. Hamaguchi et. al. (1991) investigated the effects of an artificial reef on the Niigata coast in Japan. They found that a significant amount of sand was deposited landward of this artificial reef. This reef was developed to mimic the effects of the natural coral reefs in the area (HAMAGUCHI et. al., 1991).

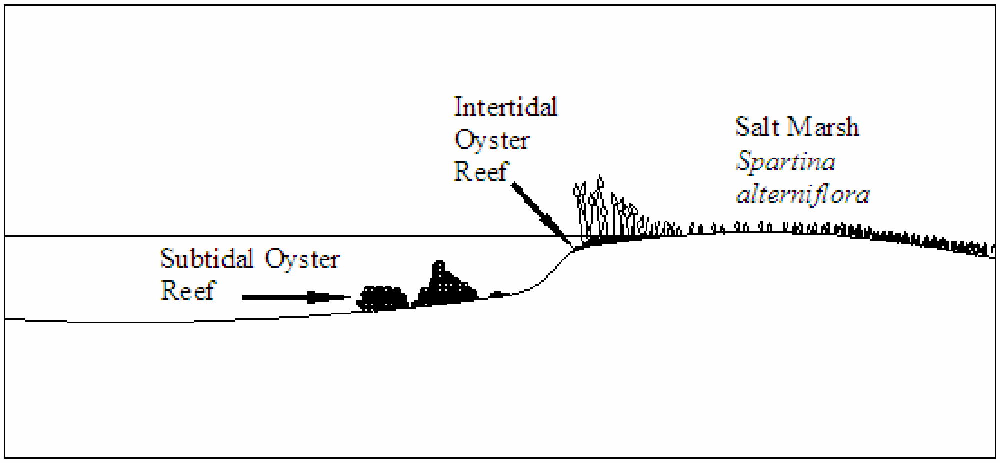

Figure 1.1. A picture depicting a typical marsh scene. The inland areas are dominated by marsh grass, Spartina alterniflora. There are intertidal oyster bed in regions that are conducive to their growth. Also, subtidal oyster reefs are found in some upper regions of the bays.

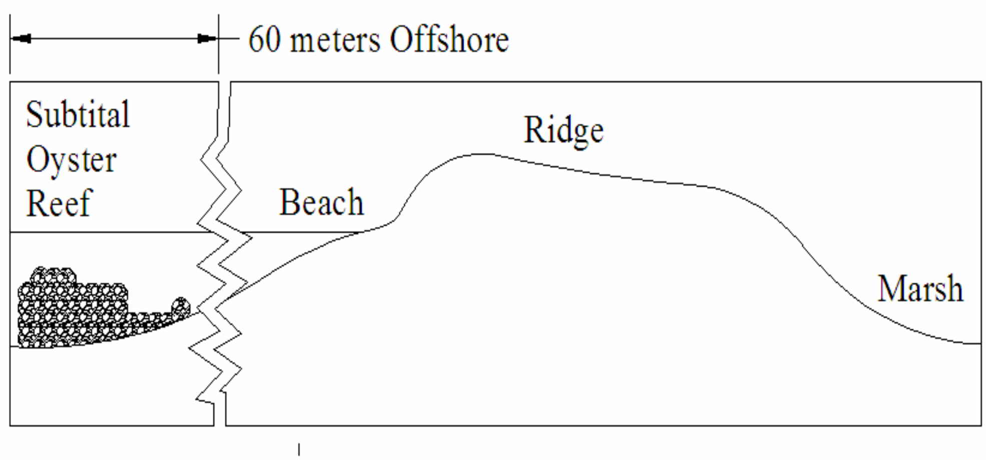

Figure 1.2. A picture depicting a typical coastal setting on the Louisiana coastline. These types of settings are common to the Chenier Plain. A subtidal oyster reef could be found further offshore. In many cases, the beach is only separated from the brackish marsh by a small ridge.

These types of fragile coastal zones are vulnerable to extreme wave action. A major threat to Louisiana's coastline is the frequency of tropical storm and hurricane activity in the Gulf of Mexico. There are numerous storms as well as hurricanes that impact Louisiana's coasts. Figures 1.3 and 1.4 illustrate the destruction to barrier islands due to hurricane land fall. Barrier islands are natural protection against hurricanes for coastal Louisiana. However, hurricanes are not the only cause of wave erosion. Winter cold fronts can cause major damage to the inland side of barrier islands and bay areas. In winter, cold winds from inland create high frequency waves in areas not accustomed to such high wave action. This can result in significant amounts of erosion, as seen in figure 1.5 (STONE et al., 1997).

Figure 1.3. Image shows one of the Isle Dernieres barrier islands. (Picture courtesy Dr. Greg Stone, Coastal Studies Institute, Louisiana State University.)

Figure 1.4. Image shows one of the Isle Dernieres barrier islands after Hurricane Lilli and tropical storm Isadore. Notice how the beach has been breached and the entire island is opened up to wave action. (Picture courtesy Dr. Greg Stone, Coastal Studies Institute, Louisiana State University.)

Figure 1.5. This photograph depicts a typical example of the high frequency waves generated by winter cold fronts in Grand Isle, Louisiana. These small waves cause a great deal of erosion on the inland side of barrier islands and marsh.

1.3 Erosion Control Techniques

Attempts to impede coastal erosion have been made throughout south Louisiana's coast. Various low cost methods of reducing erosion have included the use of Christmas trees, automobile tires, sand bags, plants, and coastal mats (WOOD, 1990). More widely accepted methods include beach nourishment and rock breakwater installation (MENARD, 2001; FINKL, 2002). Recently, Louisiana has been focused on large-scale projects, such as breakwater systems and river diversions (LDNR, 2004; USACE 2004). Each of these techniques has drawbacks, thus indicating a need for more effective approaches to erosion control and habitat enhancement.

1.4 Submerged Breakwaters as Tools for Erosion Control

In the past, many tools have been utilized in an effort to stabilize the ever changing coastal environment. Finkl (2002) composed a review depicting trends in shore protection research appearing in the Journal of Coastal Research. He found that 20% of the studies between 1984 and 2000 featured some type of coastal structure. The majority of these publications were investigating some aspect of hard structure performance.

The structure applicable to this research is the submerged breakwater. These structures are sometimes called reef breakwaters. In contrast to other breakwaters, these structures are designed to allow waves to break directly above or overtop them. Although these structures may seem less effective than emerged breakwaters, they are preferred due to their other attributes. Submerged structures for instance, are more aesthetically pleasing than emerged structures, which is particularly important in resort areas. Another advantage of submerged structures is the reduced amount of material needed, which decreases the expense of breakwater installation.

There have been many studies of the performance of these types of structures in various environments (Carver, 1997; Cox, 1991; Dean, 1997; Hamaguchi, 1991). The success and failure of these projects have led to the development of analytical models of wave interaction with submerged structures (Lee and Lan, 1995; Lee and Chen, 1999; Liu et al., 1999; Townsend and Haritos, 1993; XP and AT, 1994; XP 2002; Zhuang and Lee, 1996).

1.5 Oyster Reefs as a Tool for Erosion Control

There is increasing interest in oyster reefs used to restore eroding coastlines. Historically, oyster reefs have lined Louisiana's coast and provided a lucrative shellfish industry. Oyster reefs also provide shelter to many marine organisms and stabilize the salt marshes of Louisiana. Although there are extensive reefs in coastal Louisiana, many areas have been harvested without replenishment. Areas now devoid of oyster reefs, such as Vermilion Bay, Louisiana, are consequently experiencing serious erosion problems (BAHR, 2002).

There has been an effort to find different methods of restoring oyster reefs in various estuaries around the world. This research has led to experiments using oyster shell, concrete, and rubber tire chips as oyster cultch material (O' BEIRN et al., 2000). Oysters have been used on the coast of South China as submerged breakwaters for shoreline protection. The people of the Zhujiang Delta construct standing plates of rock and cement to stimulate oyster growth (WALKER, 1988). In Louisiana, a private company made an attempt at creating artificial oyster reefs. These were bulky iron frames lined with shell filled bags (GAGLIANO, 1993). It has also been suggested that oyster reefs should be used as a method of coastal restoration in a Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) project (FORET, 2003; LDNR, 2004).

1.6 The Biology of Oysters

Oysters are primitive animals. They are sessile invertebrates that secrete a calcareous shell. Louisiana is home to the American or Eastern oyster, *Crassostrea virginica*. The optimal salinity range for oysters is 8-30 ppt, which occurs in many of Louisiana's coastal area. Oysters have predators which include the oyster drill, crab, red drum and humans (SHUMWAY, 1996). Oysters are also susceptible to disease and toxic algal blooms. Oysters are filter feeders, therefore are prone to adsorbing toxins in the water (FORD and TRIPP, 1996).

The oyster is a mollusk that has a swimming larva stage, termed a veliger. They usually spawn in late spring throughout the summer. They begin spawning when the water temperature is approximately 20ºC. Oysters usually undergo mass spawning events. The life cycle of the oysters is shown in figure 1.6. When the oysters spawn, the sperm and eggs are released into the water for external fertilization, and the formation of trochophore larvae. As differentiation occurs, the trochophore larvae are transformed into the veliger larvae stage. Then, the larvae are transported by currents and active swimming to a spot where it can attach to a surface. The pediveliger larva is formed after 21 days and has a foot that allows it to attach to a desirable location (THOMPSON et al., 1996).

While crawling or swimming, the oyster pediveligers have a finite amount of mobility. They can swim vertically in a range of 1.0 to 3.1 mm/s (MANN and RAINER, 1990). They transport themselves to higher velocity currents that allow them the ability to search out a suitable place of attachment over distances. There is evidence that oyster larvae preferably attach to other oyster shells (THOMPSON et al., 1996). They are gregarious organisms, which mean they form cluster colonies or reefs, like the formation shown in figure 1.7 (SCORE, 2004).

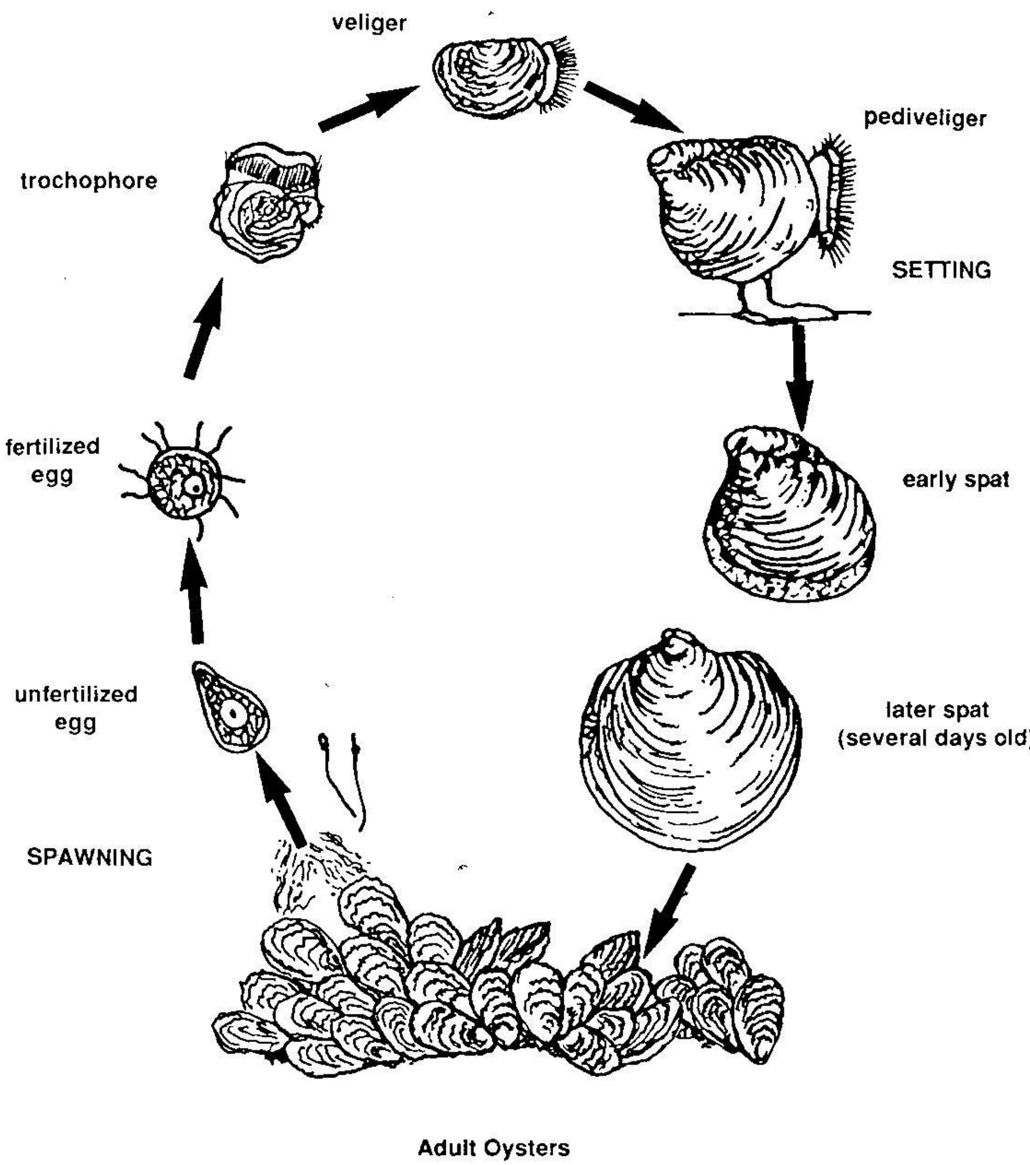

Figure 1.6. A description of the life cycle of the Eastern oyster, *Crassostrea virginica*. (modified from Berrigan et al., 1991).

Figure 1.7. A picture courtesy of South Carolina Oyster Restoration and Enhancement coalition (SCORE) website. This photograph shows the three dimensional structure oyster reefs can form.

1.7 Oyster Growth Patterns

Investigations of the biological settlement patterns on the oysterbreak are described within this text. The examination of marine biological processes and how they apply to the design of biologically dominated structures makes this research unique. The purpose of these experiments is to examine marine biological fouling communities', especially oysters, attachment and survival patterns on the oysterbreak.

While research exists for oyster reefs located along the northern shore of the Gulf of Mexico (BROWN and SWEARINGEN, 1998), settlement patterns on structures, such as the oysterbreak, have not been thoroughly investigated. Evidence from regions across the globe suggests the importance of the potential ecosystem services of oyster reefs in coastal Louisiana. Studies have examined structure and function of natural and artificial reefs along the Atlantic coast and especially within the Chesapeake Bay, documenting some of the important benefits provided by healthy oyster reefs (e.g., BARTOL et al., 1999; BREITBURG et al., 2000; HARDING and MANN, 2001; SAOUD et al., 2000). Studies have hinted at paradigms involving the biological fouling of natural and artificial structures (BROWN and SWEARINGEN, 1998; BARTOL and MANN, 1997; DELORT et al. 2000; DITTMAN et al., 1998). It is imperative that accurate descriptions of biological attachment and survival are utilized in the design of biologically dominated structures.

1.8 Bioengineered Oyster Reef Design

A structure that would promote the formation of oyster reefs in the shape of submerged breakwaters was designed in spring 2002 and built at the LSU Department of Biological and Agricultural Engineering. This structure was termed an “oysterbreak” (figure 1.8) and was designed to stimulate the growth of biological structures in an optimal shape to serve as submerged breakwaters. Oyster reefs can form immense structures that can protect shorelines and coastal communities from storms by reducing wave energy. The goal of the oysterbreak is to provide a support structure for oyster establishment while maintaining its lightweight characteristics. Unlike other artificial oyster reefs, which simply provide cultch for oyster attachment (GAGLIANO, 1993; HARDING and MANN, 2001), the oysterbreak is engineered to stimulate oyster growth in a configuration that will effectively dissipate wave energy (figure 1.8). As oysters grow on the structure, the oysterbreak will become primarily composed of biologically created material. A similar technology, termed the Reef Ball™, has been used in Florida and the Bahamas as a way to establish coral reefs. Investigation on their wave dissipating effects was conducted at the U.S. Army Corps of Engineers Coastal & Hydraulic Engineering Lab (HARRIS, 2002).

Figure 1.8. Picture of oysterbreak in Grand Isle, LA. The oysterbreak was placed in the water close to the pier for convenient access and monitoring.

1.9 Relevant Parameters and Current Theories

In addition to the biological considerations of the oysterbreak, the wave-structure interaction must also be considered. In order to create a proper design for the oysterbreak, knowledge of the relevant parameters must be gained. Figure 1.9 depicts a simple example of the variables involved in the wave-structure interaction. As a wave approaches the structure, it has an associated wave height and wave length. The wave's interaction with the structure depends on the characteristics of each. The structural dimensions are critical to the effective reduction of wave height. The structure width, height and porosity are all related to the structure's performance.

In an attempt to relate specific parameters to the performance of a submerged breakwater, Ahrens' (1987) work established criteria which most designs follow. An empirical model that relates depth, crest width, and porosity to the wave damping effect of a submerged rock breakwater was developed through his work. This model was used as a bench mark for current work.

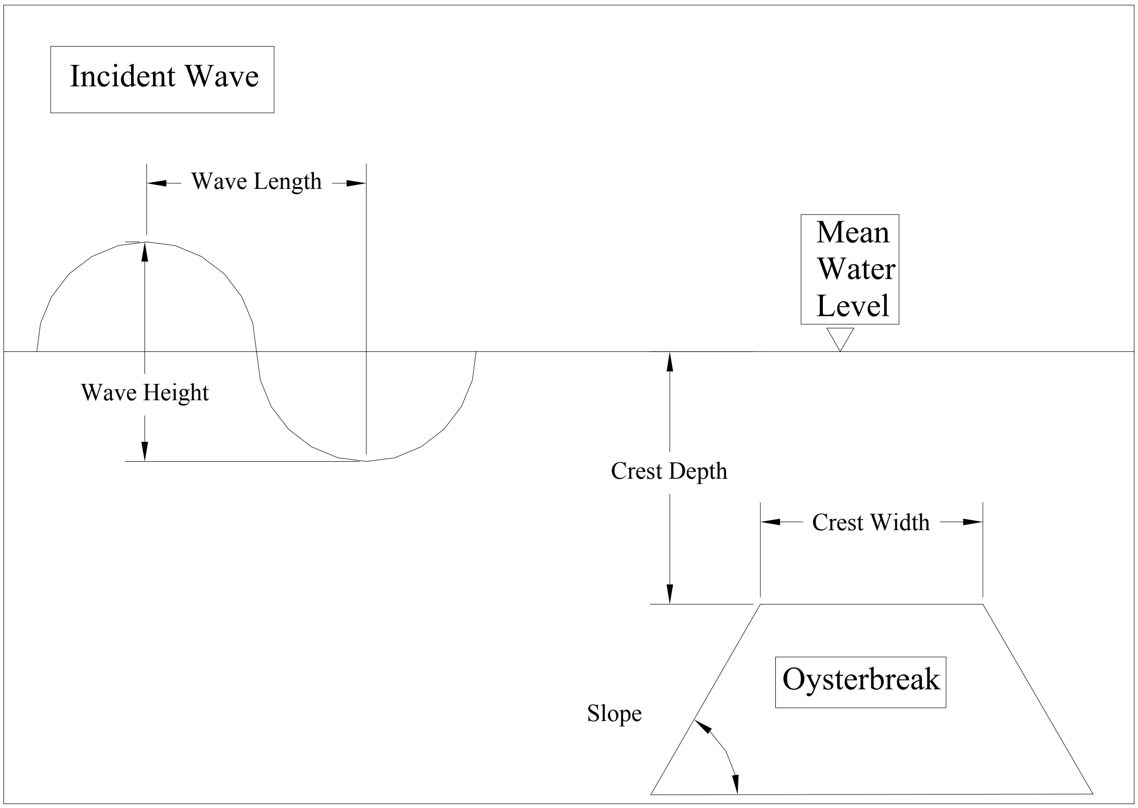

Figure 1.9. Structural dimensions and wave characteristics are the important parameters relevant to wave dissipation.

Most studies involving submerged breakwaters use rock or rubble for construction. For design purposes, the rock or rubble size is of great importance. The issue of stability in various wave conditions has been the driving force for selection of rubble size (AHRENS, 1989; VIDAL et al., 1995; YU et al., 2002). Once this parameter is established, the porosity of the structure can be defined. Since the porosity of the structure has a great effect on the wave dissipation, the crest width has to be modified to adjust for porosity effects (AHRENS, 1987; ARAKI et al., 2001).

In addition, the porosity of a submerged breakwater presents a challenge to any attempt at a predictive model. The porosity can change the complexity of the flow in a number of ways during various wave conditions. The study of the effects of a structure's porosity on wave damping characteristics has been under investigation. Phenomena, such as flow separation, have been studied in porous structures to determine whether the coefficients of drag or inertia are the dominating factors (SARPKAYA and ISAACSON, 1981). The use of numerous empirical and numerical methods models have been developed to quantify the performance of submerged porous structures (HUANG et al., 2003; TWU et al., 2002; WU et al., 2001).

1.10 Wave Tank Experiments

The effects of porosity and density of the oysterbreak were investigated in a physical wave tank. Scaled physical model tests were conducted to determine the effects of porosity change on wave dissipation. Since the oysterbreaks porosity changes with time due to growth, the effects of growth had to be simulated. In order to determine the effects of density, vertical slats were added to the oysterbreak. To determine the desired spacing of vertical slats needed, multiple designs were investigated.

The goal of these experiments was to determine the effects of oyster growth and density on the wave dissipation characteristics of the oysterbreak. Theoretically, the method and function of the oysterbreak is simple. A structure is constructed in the shape of a submerged breakwater. This structure is designed to provide a large amount of surface area for oysters and other bio-fouling marine organisms to attach while using a minimum amount of material. As the oysters grow, the structure increases in density. Therefore, a minimum amount of material is needed at the time of initial deployment; however, as oyster growth occurs, the structure becomes more effective at dissipating waves. Preliminary experiments revealed a feasible design for the oysterbreak, which included an A-frame truss connected by horizontal beams. A vertically spaced beam wall was also found to be effective at dissipating waves. A similar conclusion of vertically spaced porous wall- wave interaction was drawn from experiments conducted by Wu et al. (2001) and Huang et al. (2001).

1.11 Objectives

The overall goal of these experiments was to evaluate the oysterbreak's ability to serve as a submerged breakwater. Analysis of the oysterbreak was conducted to gain knowledge of biological fouling patterns and wave-structure interaction. The first objective was to determine if there was a trend in oyster settlement and survival with respect to depth (H_o: $\sigma_{depth\ 1} = \sigma_{depth\ 2} = \sigma_{depth\ 3} = \sigma_{depth\ 4} = \sigma_{depth\ 5}$). The second objective was to determine if oyster spat settlement depended on material type (H_o: $\sigma_{material\ 1} = \sigma_{material\ 2} = \sigma_{material\ 3} = \sigma_{material\ 4}$). The third objective was to determine if oyster spat settlement depended on flow (H_o: $\sigma_{flow\ 1} = \sigma_{flow\ 2} = \sigma_{flow\ 3} = \sigma_{flow\ 4}$). The fourth objective was to determine the abundance of spawning with respect to time (H_o: $\sigma_{time\ 1} = \sigma_{time\ 2} = \sigma_{time\ 3} = \sigma_{time\ 4} = \sigma_{time\ 5}$). The fifth objective was to determine if the growth on the oysterbreak affected the wave interaction (H_o: $\sigma_{growth\ 1} = \sigma_{growth\ 2} = \sigma_{growth\ 3}$). The sixth objective was to determine if the density of the oysterbreak affected the wave interaction (H_o: $\sigma_{density\ 1} = \sigma_{density\ 2} = \sigma_{density\ 3} = \sigma_{density\ 4}$). Once these phenomena were explored, a predictive model was developed to evaluate this technology in a variety of environments.

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CHAPTER 2: EVALUATION OF SETTLEMENT PATTERNS ON A BIOLOGICALLY DOMINATED SUBMERGED BREAKWATER

2.1 Introduction

The first set of experiments was designed to investigate the biological settlement patterns on the oysterbreak. Since erosion problem areas in most Louisiana bays are ideal environments for oyster growth (SHUMWAY, 1996; DITTMAN et al., 1998; OWEN, 1953), it was important to quantify some of these patterns. The uniqueness of this research was the examination of marine biological processes and how they applied to the design of biologically dominated structures. Since this structure is designed to attract oysters, the focus was on oyster settlement patterns. In addition, other organisms, such as barnacles and bryozoans, were explored. These organisms can compete for space and food with oyster larvae attaching to the oysterbreak. They can also be predators of small oyster larvae.

When designing the oysterbreak, it was important to understand the ecology of an artificial reef and try to quantify any patterns that occur. Studies of seasonal spawning patterns were conducted in Fouchon by Brown and Swearingen (1998). This work gave good insight for the best time of oysterbreak deployment. Bartol et al. (1999) conducted experiments on spatial variations of intertidal reefs. Bartol's work suggested that better growth occurred at deeper depths on oyster shells. These works gave great insight into the general processes involved, but a quantitative relationship was still needed to create an effective design. These tests focused on describing biological attachment and survival, which were then utilized in the design of biologically dominated structures.

The following experiments tried quantify growth patterns on this type of structure.

The objective of these experiments was to establish some criteria for growth on the oysterbreaks. In addition, a prototype oysterbreak was needed to establish its resilience in marine conditions.

2.2 Environmental Conditions in Study Area

The prototype oysterbreak was deployed at Grand Isle, Louisiana in August 2002 and remained there until removed in late July 2003. The oysterbreak was placed 50 meters offshore on the north side of the island. The water was approximately 2.2 meters deep at high tide. The environmental water data was collected from the USGS Hydrowatch site (USGS, 2004). The data was used for the Barataria Bay Pass USGS site 073802515 at latitude of 29º16'32"N and a longitude of 89º56'29"E. The structure was placed approximately 1.6 kilometers away from the USGS site at approximately 29º12'28"N latitude and 89º2'15"E longitude. The water temperature ranged from 13ºC in January to 32ºC in August. The salinity ranged from 22 to 25 parts per thousand (ppt). The tidal range is approximately .5 meters in this area of the Gulf of Mexico. Hurricane Lili (category 4) and Tropical Storm Isadore both affected this study site in early October 2002.

2.3 Construction

The prototype frame was constructed from schedule 80 PVC 2 inch (5 cm) nominal diameter pipe. This material was selected because of its nontoxic properties to biological organisms and chemical stability. It has an approximate density of 2.608 g/cm^3, which is similar to limestone with a density range of approximately 2.5-2.8 g/cm^3. The structure's dimensions were approximately 1.5 meters tall, 4 meters wide and 5 meters long (figure 2.1). All pieces were glued into place using PVC glue. After the entire frame was built, 5-millimeter holes, spaced about 10 centimeters apart, were drilled through the pipes. While the frame was being constructed, the French tubes™ were placed in Barataria Bay for one week to allow a biological film, containing bacteria and algae, to develop on the surface. Then the tubes were placed in a tank with approximately 30 million oyster pediveligers. The tubes were left in the tank for 2 weeks to allow the resulting spat to reach 1-millimeter in size. Then, the frame was transported to Grand Isle, and the tubes were attached one by one to the frame with 25-centimeter UV-resistant zip ties. The French tubes™ were attached to the frame underwater to minimize oyster mortality due to desiccation.

2.4 Methods of Evaluating Biological Fouling Patterns

2.4.1 Submerged Breakwater Analysis

The oysterbreak was removed from the water and inspected for predators on a monthly basis. Predators included gastropods, polyclad flatworms, and crabs. The most destructive predator, the southern oyster drill, *Strominata haemastoma*, was found in high numbers on the structure and removed when the structure was inspected. There was an unusually large number of oyster drills present in this area due to the presence of oysters nearby. This resulted in high predation pressure on oysters trying to colonize the submerged breakwater.

After one year of deployment of the oysterbreak, it was brought back to the laboratory. The French tubes™ were taken off the structure and biological counts were performed. Identification was based on taxonomy described in Gosner (2000). Five tubes at heights approximately 30 centimeters apart were saved from each side of the structure (see figure 1.7). The total number of oysters, oyster scars, barnacles and serpulids (tubeworms) were counted on each tube. The percent cover of bryozoans was estimated by counting the number of times they intersected 3 centimeter intervals on various transects along the tubes.

2.4.2 Temporal Spawning Patterns

Spat plates were used to estimate the proportional recruitment of oysters with time on the oysterbreak. The method of estimation used was similar to other studies of recruitment on natural oyster reefs (see SUPAN, 1983; BANKS and BROWN, 2002). The 20 centimeters x 20 centimeters quarry tiles were placed between 3.8 centimeter PVC pipes to make vertical racks. These racks were placed vertically on either side of the structure. The top plate was positioned 36 centimeters below the water surface at low tide. These spat plates were checked every two weeks during oyster spawning season. The plates were returned to the laboratory for counting. Plates were counted for oysters, oyster scars, barnacles, and bryozoans. The percent cover of bryozoans were estimated by counting the number of times an organism intersected 1 square centimeter over the smooth surface of the plates.

2.4.3 Flow, Material, and Height Experiments

An additional experiment was set up to describe the effects of material, flow, and height on the distribution of spat settlement. In order to correctly identify these factors, predators were excluded. This attempt to determine the effects of flow on settlement was similar to work done by Turner et al. (1994). The experiment was conducted in a tank with a diameter of 4.2 meters and a water level of 1.2 meters. The tank was filled with sand-filtered bay water. The water quality parameters of this experiment were a salinity of 23 ppt, pH of 8.64, and an average temperature of 29 ºC. This was comparable to the environmental conditions in Barataria Bay, where the oysterbreak was located. Four .6 x 1.2 x .9 meter rectangular boxes were constructed from 1 inch (2.5 cm) nominal diameter schedule 40 PVC pipe. Each of the four boxes had one of the following attached: black plastic mesh, schedule 40 PVC pipe, PVC pipe coated with Flexbond™ mortar, or French tubes™. The frames were arranged in the tank as shown in figure 2.1. The environmental parameters collected included salinity, temperature, and pH. The flow was measured with a Marsh-McBirney portable water flow meter (model 201-D). The flow was measured at 8, 40, 70 and 90 centimeters off the bottom of the tank. The flow was taken at various radial positions: the wall of the tank, 1 meter away from the tank, and at the center of the tank. The structures were left in the tank for 3 weeks. The tank was then drained and the structures were removed. Material was removed from each structure at various heights of 8, 40, 70, and 90 centimeters from the bottom of the tank. The mesh material was cut into six 5 x 120 cm sections. The French tubes™ and PVC pipes were marked into four 0.3 meter sections. Four transects were randomly selected for each pipe. Oysters greater than 1 mm in diameter were counted as they intersected transects. The number of oysters in each 0.3-meter section was averaged for all transects. The number of oysters found was compared between pipe sections and heights using analysis of variance statistics. An α value of 0.05 was used for significance in the comparisons.

2.5 Results and Discussion

2.5.1 Spatial Variation on Submerged Breakwater

The results of the biological counts on the submerged breakwater shown in figures 2.2-2.6 reveal significant differences with height for oyster scars and serpulids ($F = 16.93$, $p = .0041$, and $F = 31.70$, $p = .0010$, respectively). Initial oyster growth appeared to be excellent, with high levels of wild spat setting and secondary spat setting on the initial oysters approximately one month after initial deployment. Extensive oyster scarring was found on the structure due to oyster predation. Even though this suggests good initial growth, very few live oysters were found greater than 1 cm (figures 2 and 3).

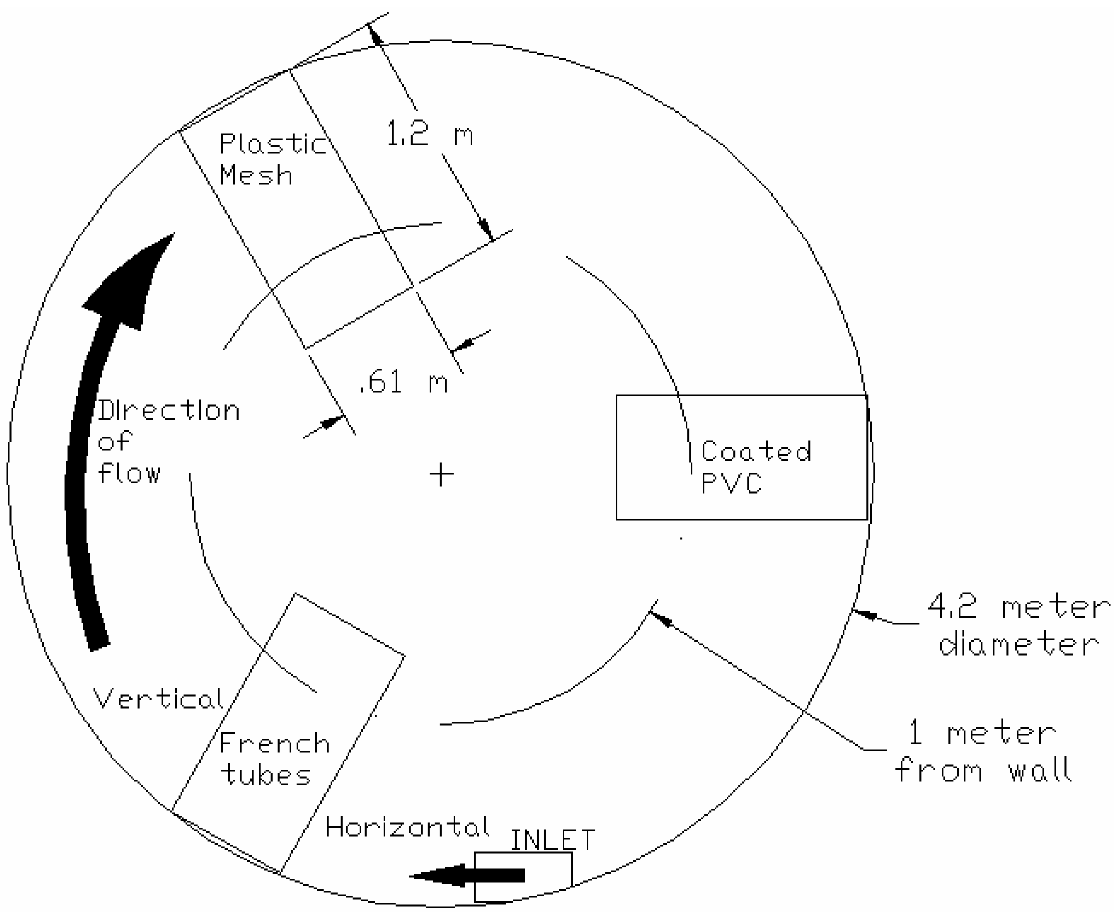

Figure 2.1. Layout of predator exclusion experiments. The tank had a diameter of 4.2 meters and the water depth was 1.2 meters.

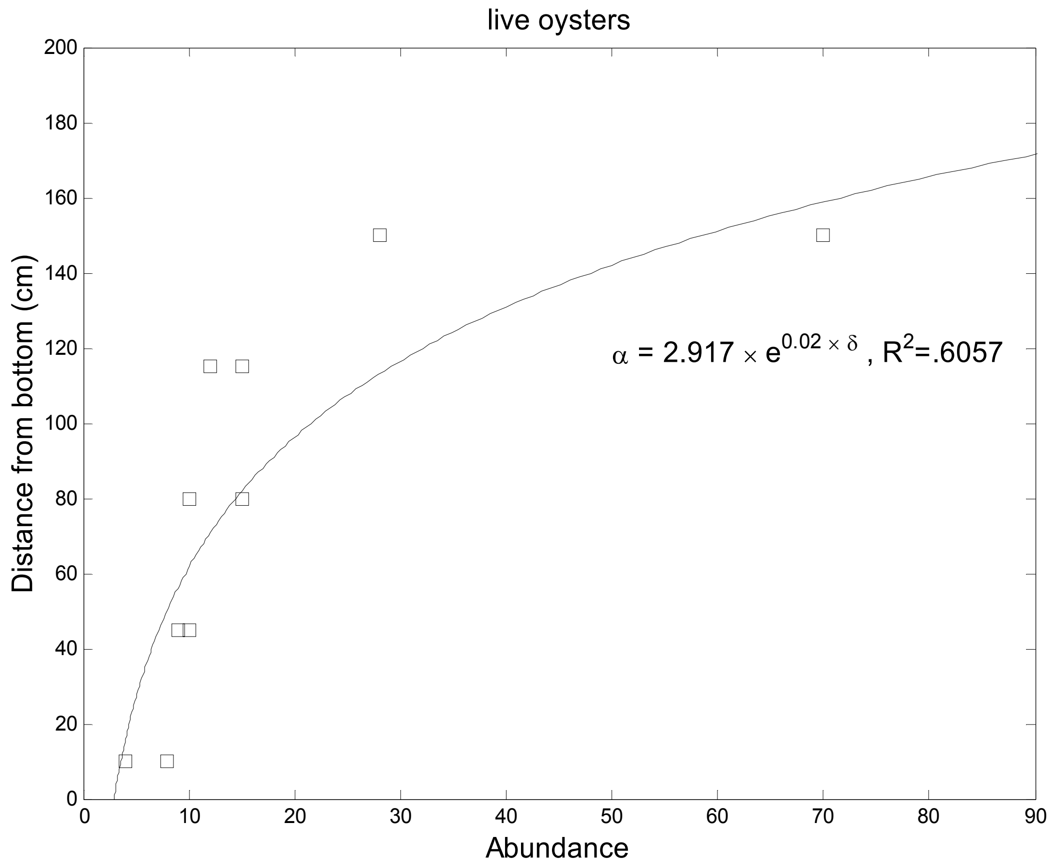

Figure 2.2. Plot of live oysters found on French tubes™ at distances from sea floor. The abundance followed the relationship shown in the figure with $R^2 = .6057$. The variables in the equation are abundance, α, and distance from bottom (cm), δ.

Even though oyster drill predation decimated the oyster population on the oysterbreak, it was shown that some definite trends existed in the recruitment and survival of the oyster distribution. A similar relationship between organism abundance and height was seen in work by Brown and Swearingen (1998). Even though oysters seemed to be more abundant at the top of the structure, this could be due to oyster drill predation pressure from the bottom. Some oysters were able to grow on the interior of the tubes. Apparently, the oyster drills could not easily access them at that location. However, their growth is likely limited in that area due to physical limitations, if not lack of food. If the predation pressure was lower, it would be expected that a substantial increase of live oysters would be identified. The probable abundance of live oysters can be predicted from the amount of oyster scars found on the oysterbreak, see figure 2.3.

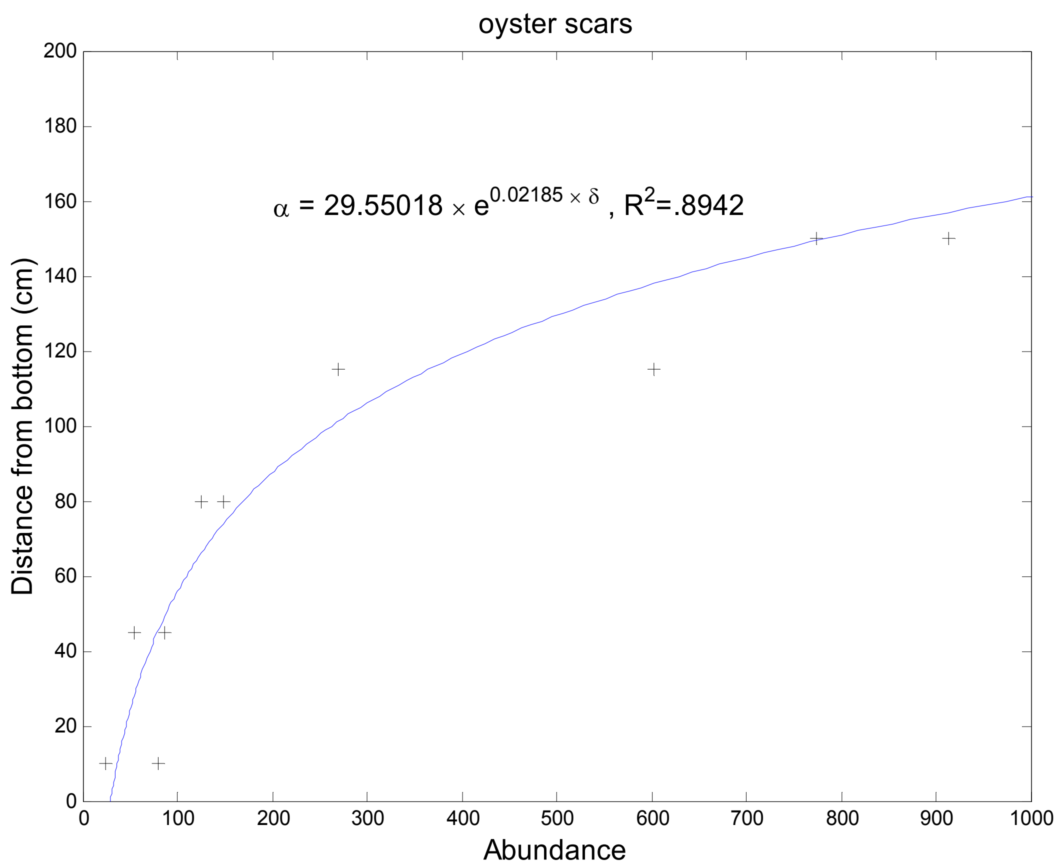

Figure 2.3. Plot of oyster scars found on French tubes™ at distances from sea floor. Oyster scars were found in a much higher abundance than live oysters. The abundance followed the relationship shown in the figure with R^2 = .8942. The variables in the equation are abundance, α, and distance from bottom (cm), δ.

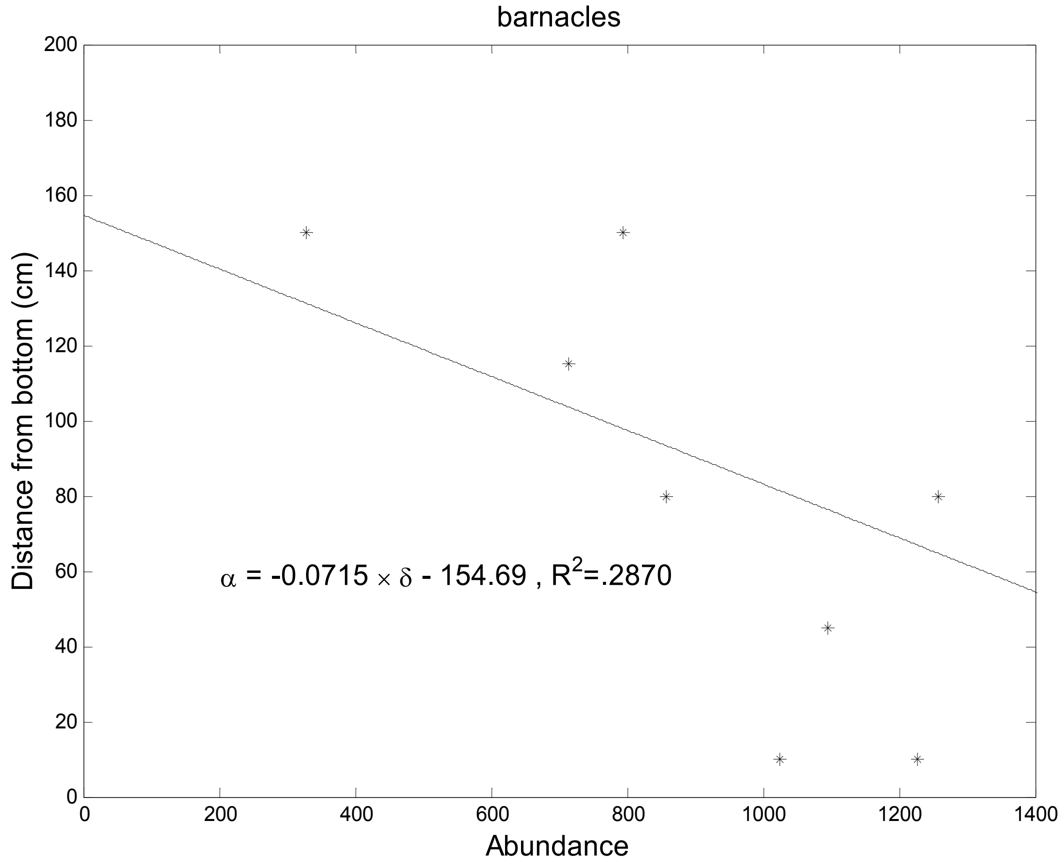

Figure 2.4. Plot of barnacles found on French tubes™ at distances from sea floor. The abundance followed a very weak correlation shown in the figure with $R^2 = .2870$. The variables in the equation are abundance, α, and distance from bottom (cm), δ.

The abundance of barnacles was an order of magnitude greater that the oysters. They increased in abundance towards the bottom of the structure. Barnacle scars were found on the French tubes, although not as numerous as the oysters. Most of the PVC pipe on the structure was covered with barnacles and bryozoans. The barnacles may have been another contributing factor as to why the oysters were skewed towards the top of the structure.

Bryozoan abundance was present shortly after the deployment of the oysterbreak. This may have impacted the amount of oysters settling on the oysterbreak in the spring.

These established colonies of bryozoans may have impeded the settlement of oyster larvae through predation pressure.

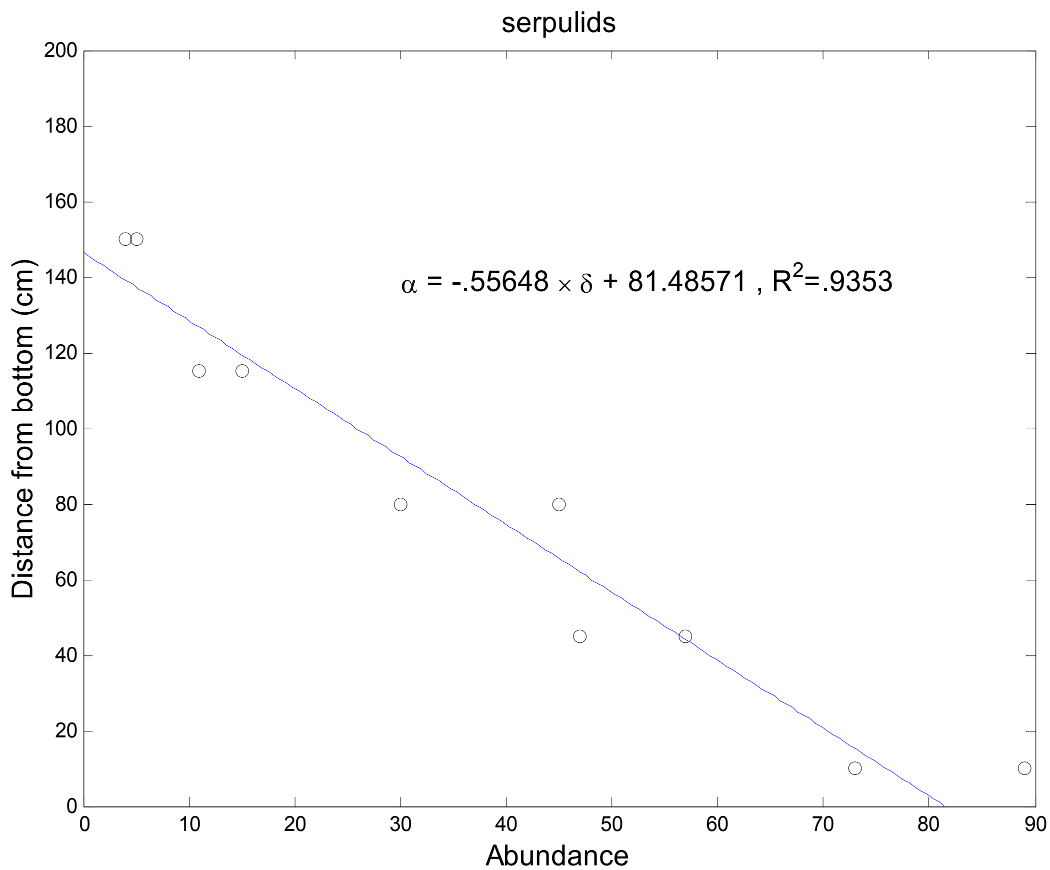

Figure 2.5. Plot of serpulids found on French tubes™ at distances from sea floor. The abundance followed a strong correlation shown in the figure with $R^2 = .9353$. The variables in the equation are abundance, α, and distance from bottom (cm), δ.

The abundance of serpulids increased in a linear fashion towards the bottom. These benthic organisms migrated from the bottom of the oysterbreak. These organisims probably exuded a minimal predation pressure on the oysters. The oyster drills did not seem to predate on the serpulids. Since, these are relatively small organisims, they most likely did not compete for space with the oysters. When extracting the oysterbreak for examination, many mud crabs (*Xanthidae*) were also found on the structure. In addition to oyster drills, mud crabs are also predators of oysters.

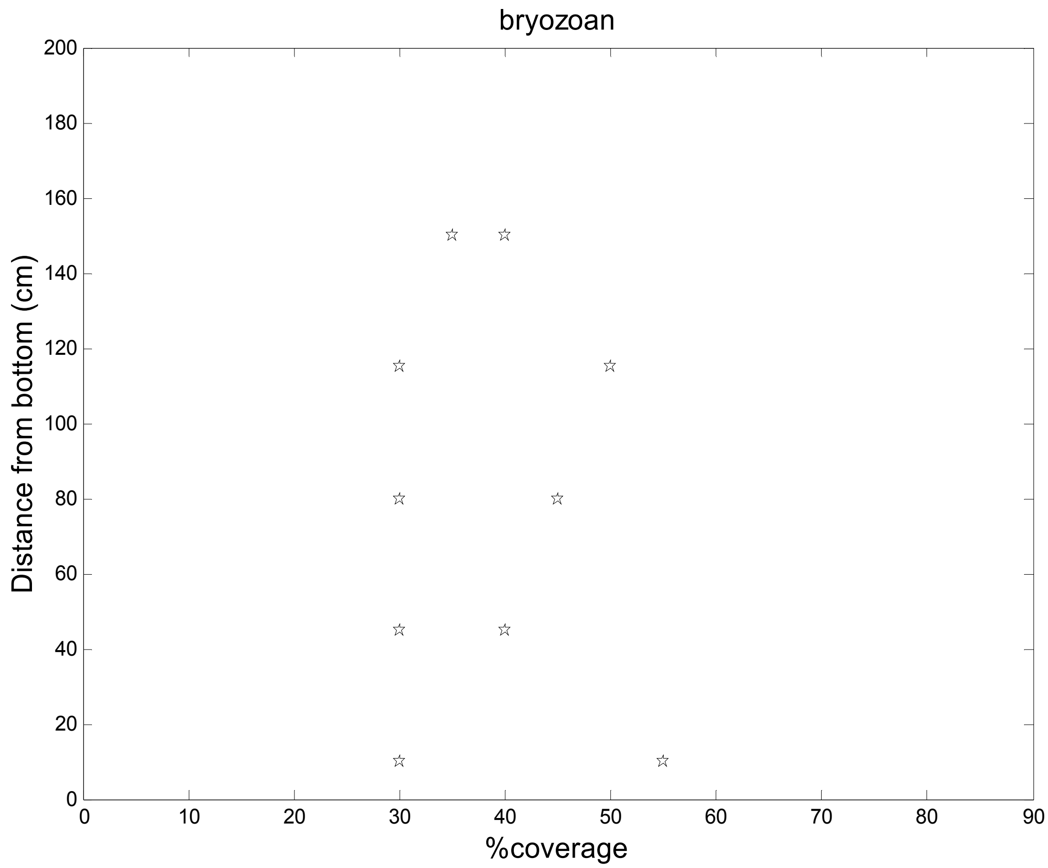

Figure 2.6. Plot of bryozoan coverage on French tubes™ at distances from sea floor. The amount of coverage did not show significant differences with the distance from the bottom (F=0.05, p=.8229, df=1).

The abundance and variety of organisms were correlated with location of the tubes relative to the ocean floor. The following trends were found for each organism:

Live oysters

$\alpha = 20917e^{0.02*\delta}$, $R^2 = .6057$ (figure 2.2)

Oyster scars

$\alpha = 29.55018e^{0.02185*\delta}$, $R^2 = .8942$ (figure 2.3)

Barnacles

α = -0.0715* δ-154.69, R^2 = ..2870 (figure 2.4)

Serpulids

α = -.55648* δ + 81.48571 , R^2 = .9353   (figure 2.5)

Where,

α = abundance of organism,

δ = distance from sea floor.

2.5.2 Temporal Spawning Patterns

When looking at the recruitment near the oysterbreak, there was a significant difference with time for all organisms measured ($F = 11.61$, $p < .0001$). The most abundant organism found to settle on the plates was *Balanus* (sp. barnacle), see figure 8. The plates deployed in early spring and late summer were completely covered with barnacles. The plates deployed in May and June showed more diverse organism recruitment, see figures 2.7-2.10. July had an increased amount of barnacle recruitment. This could have interfered with oyster recruitment because the surfaces of the plates were almost completely covered with barnacles. This would not give much of an opportunity for oysters to find a place to settle.

In early May, there was no apparent recruitment from oysters. In addition, serpulids, barnacles, and bryozoans were found in small numbers during that time (figure 2.8-2.10). On the other hand, in late May, barnacles and oysters dominated recruitment numbers.

In late June, serpulids, oysters, barnacles, and bryozoans were found on the plates. More barnacles and serpulids seemed to be found on the bottom plates, while more bryozoans were found on the top plates. Oysters seemed to be slightly more abundant towards the bottom, but no significant difference was found with respect to height ($F=2.29$, $p=.2199$). This may have been due to the competition with the bryozoans.

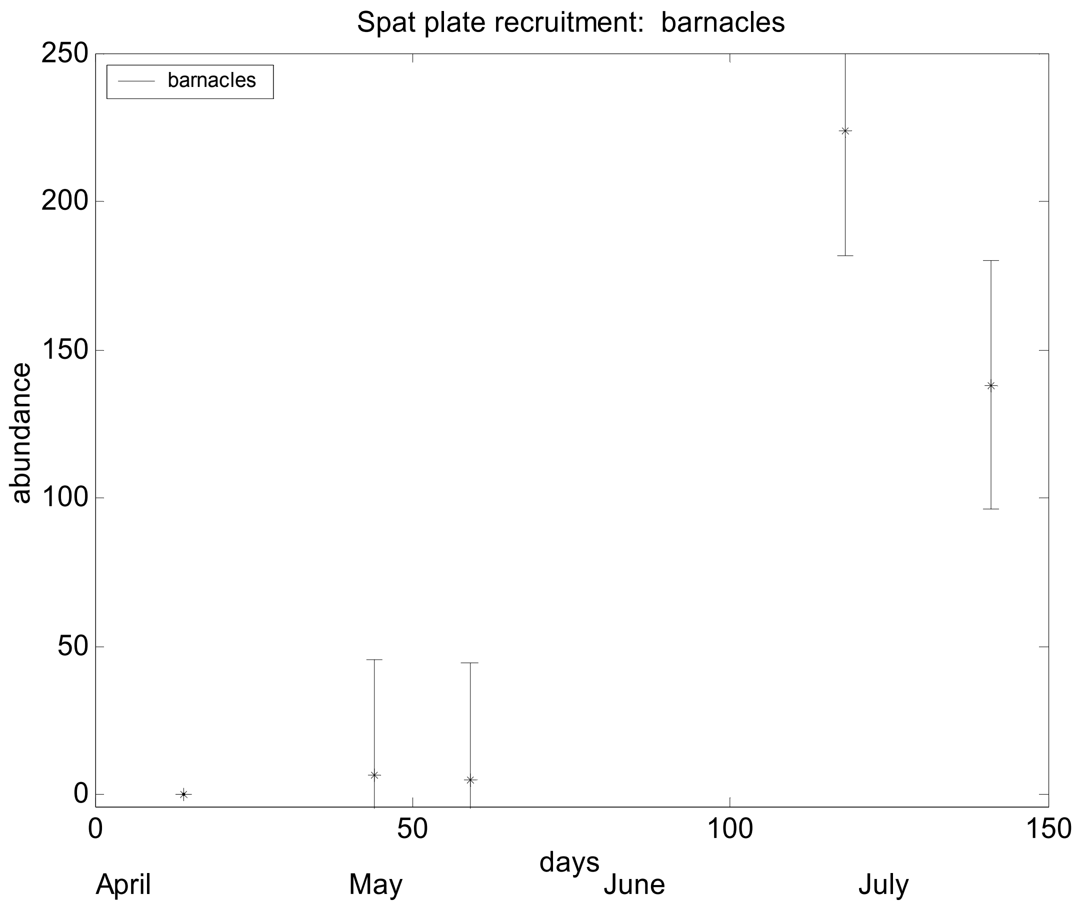

Figure 2.7. Plot of barnacle recruitment in spring and summer of 2003. Barnacles had an increase in recruitment around late June and early July.

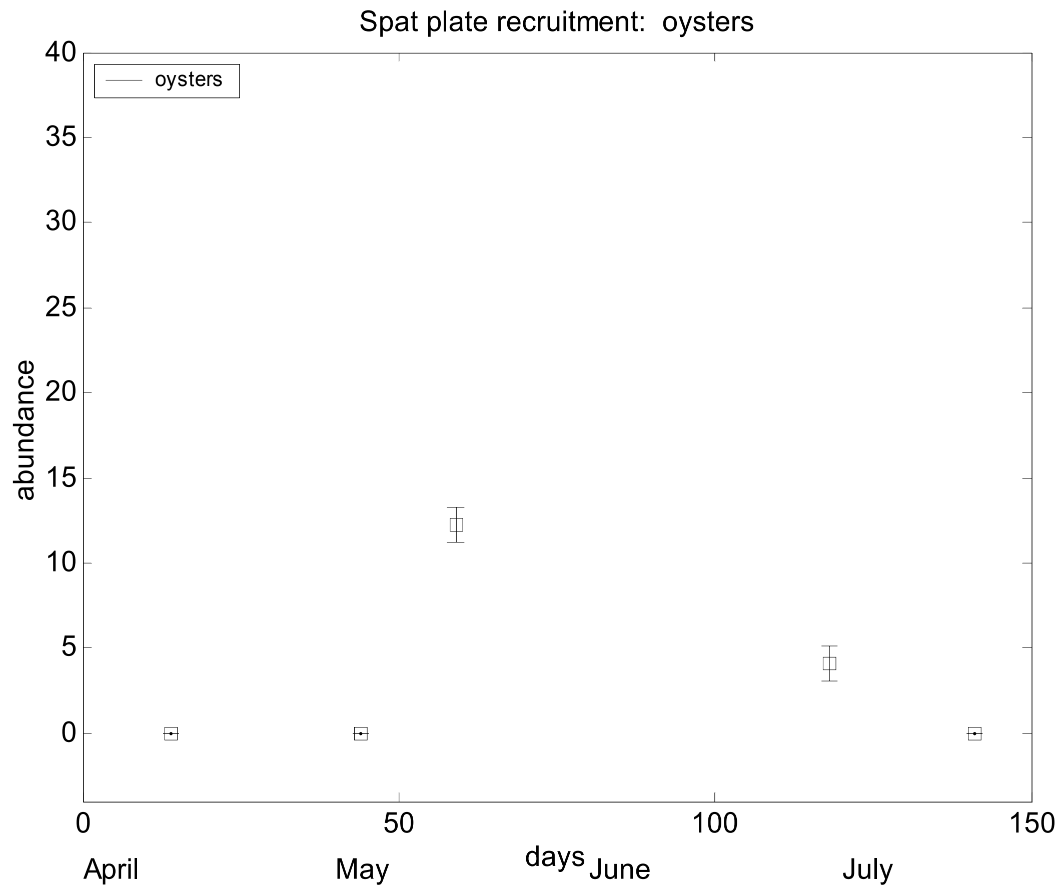

Figure 2.8. Plot of oyster recruitment in spring and summer of 2003. Oysters appeared more predominant in May, but spat was found during periods in late June.

The spat plates allowed the possibility to count oyster scars and these were included in the counts. Since there was no correlation with height, one could assume that the predation was a major factor in the height distribution on the French tubes™. The temporal results of recruitment are similar to those found in other studies in that region (BROWN and SWEARINGEN, 1998). The early spring recruitment was dominated by barnacles and bryozoans, while during summer months oysters were apparently spawning.

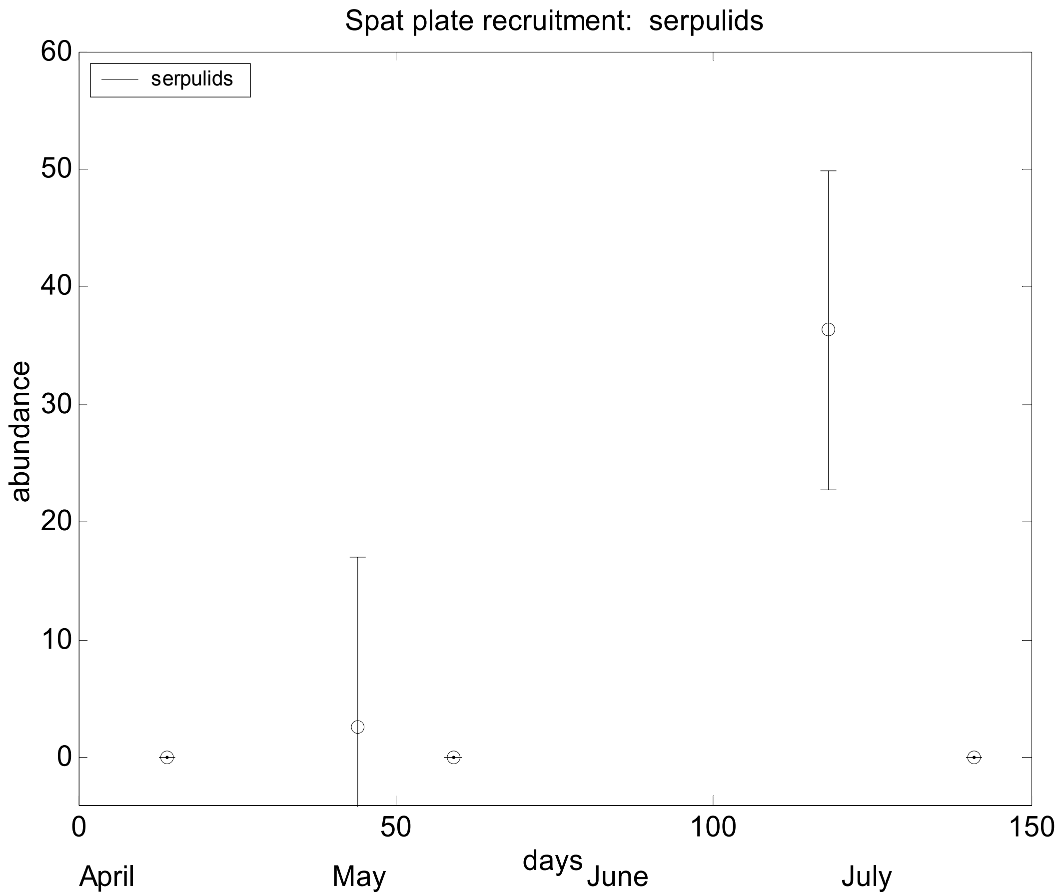

Figure 2.9. Plot of serpulid recruitment in spring and summer of 2003. Much of the serpulid recruitment was found to be in late June.

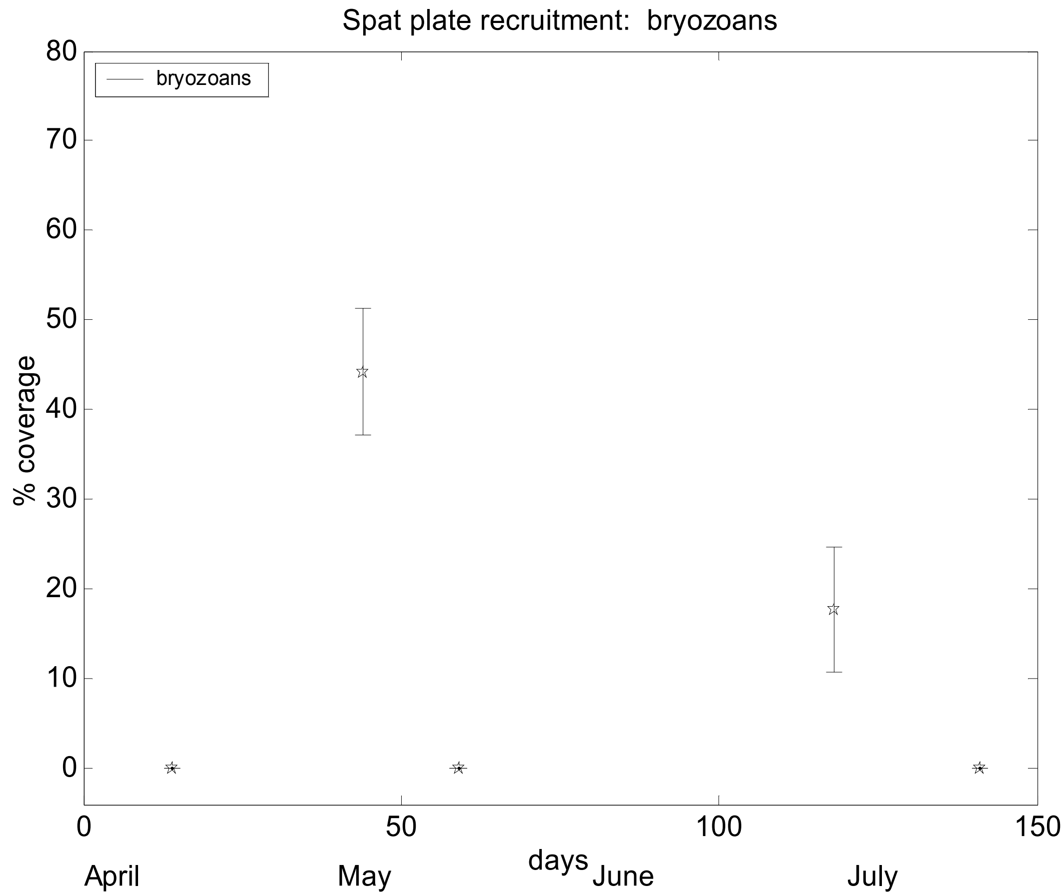

Figure 2.10. Plot of bryozoan recruitment in spring and summer of 2003. Most of the bryozoan recruitment was found to be in May, although some were found on plates in July.

2.5.3 Flow, Material, and Height Experiments

These experiments, when compared to the prototype experiments, clarified the effect that predators have on settlement patterns. The highest current in the tank was found at the top of the water column next to the wall at 1.5 cm/s and the lowest current was 0 cm/s in the center of the tank (figure 2.11). There was no significant difference of spat settlement with various flows for the coated PVC or the French tubes ($F=.79$ $p=.6268$ and $F=1.06$ $p=.4005$, respectively).

The different materials have a significant effect on the abundance of oyster spat identified. The plastic mesh and the PVC pipe had no apparent oyster settlement. The mortar coated PVC had significantly more oyster spat than the French tubes ($F=27.67$ $p<.0001$). The French tubes had no significant differences with height or distance from wall ($F=.88$ $p=.4696$ and $F= .28$ $p=.8417$, respectively). The mortar coated PVC had no significant differences with height, but did have significant differences with distance from wall ($F=2.01$ $p=.1394$ and $F= 3.94$ $p=.0362$, respectively). There seemed to be an optimum at around 60 cm from the wall. A very weak relationship was found to follow the curve $\alpha=-0.0306x\delta^2+3.6229x\delta+109.56$ with $R^2=.3649$, where abundance is "α" and distance from the wall is "δ". Thus, without predators, no relationship between abundance and height was found.

The type of material had an impact on oyster settlement. The coated PVC was the most effective. The mortar used was a dark color. Since oyster larvae are believed to be negatively phototactic (SHUMWAY, 1996), this dark surface may have attracted them. On the other hand, the black plastic mesh had no apparent oyster settlement. Another contributing factor may have been the arrangement of the structures. The French tube structure was placed in front of the inlet. This made the environment around it very turbulent, which may have made settlement difficult for the oysters. In order to distinguish this variance, more replications in various positions need to be done.

It is believed that the oysters did not settle close to the wall because of the density of algae. The nature of the flow in rotation caused a build up of algae on the outside edge and the bottom. In the absence of predation, there is no apparent settlement pattern due to flow or height, see figures 2.12 and 2.13. Thus, design of future oysterbreaks would not consider a skewed settlement pattern unless significant predation pressure is present.

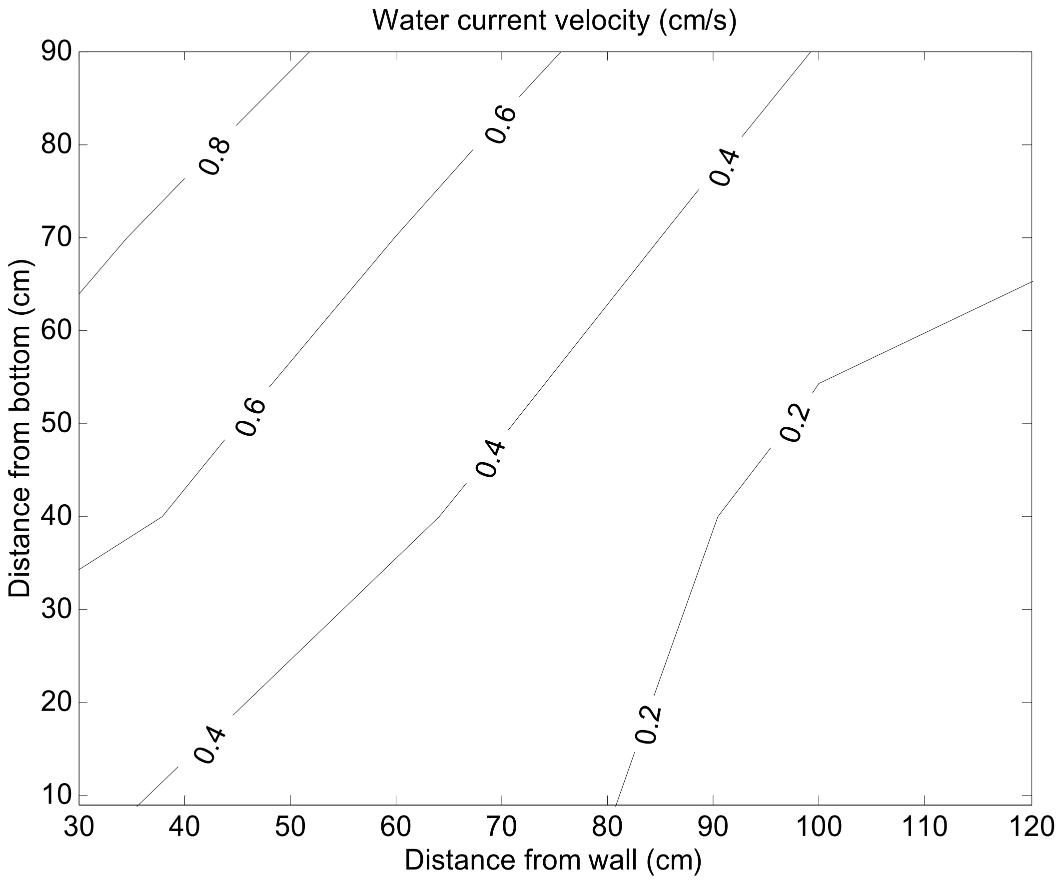

Figure 2.11. Contour plot shows current velocity in tank for predator exclusion experiment. The highest velocity was found at the top of the water column by the outside wall.

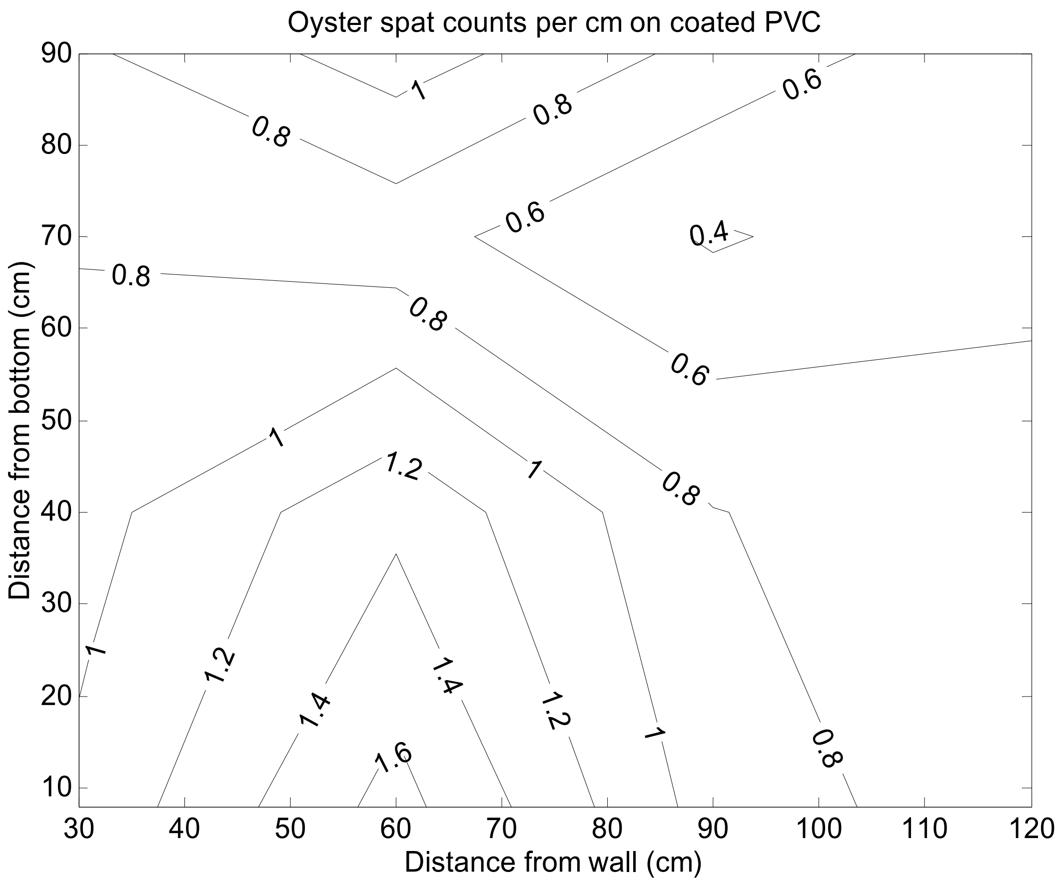

Figure 2.12. Contour plot showing oyster spat per centimeter found on transects on coated PVC.

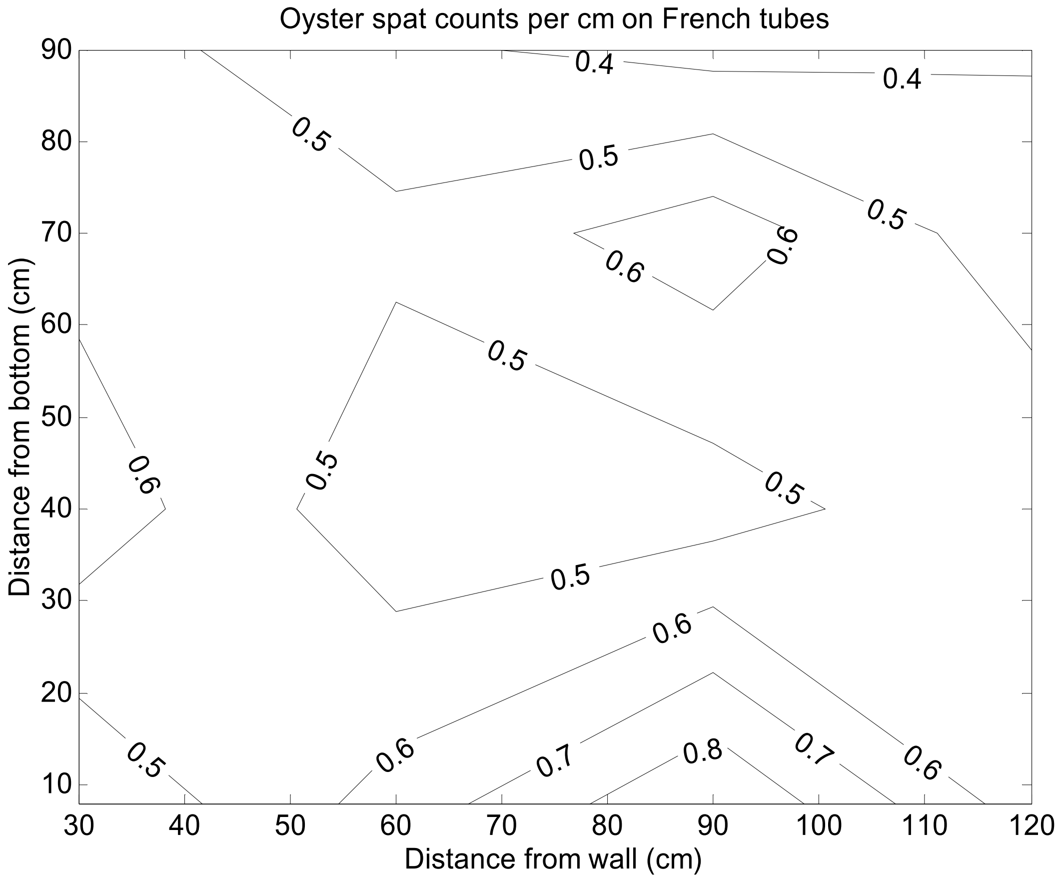

Figure 2.13. Contour plot showing oyster spat per centimeter found on transects on French tubes™.

2.6 Conclusion

The design of an oysterbreak as a method of erosion control requires knowledge of physical and biological processes involved. It is important to understand how the design would be altered in various environments. The results from Grand Isle, LA show the impact that predation can produce on growth patterns. Oyster drill and mud crab predation produced a skewed distribution pattern of oysters toward the top of the structure. In the absence of such predation pressure, a more uniform growth pattern throughout the structure would be expected. It was shown that no significant settlement differences were found with height or flow. Thus, when designing an oysterbreak, a uniform distribution of oyster settlement and survival could be assumed in the absence of heavy predation. It was also shown that cement type material would be an excellent choice as a building material. Cement can have a rough, hard surface ideal for oyster attachment. Also, the calcium carbonate in the cement mixture is very similar to oyster shells. Future work could involve testing mixtures of organics, such as cotton seed, with cement for oyster substrates. These organics would promote bio-film production that would make the surface more desirable to oyster larvae. Some preliminary experiments revealed that a cottonseed – cement mixture attracted more oysters and larger oysters than PVC or French Tubes™.

The upper regions of coastal bays have a lower salinity (below 15 ppt) where oyster drill populations are minimal if not nonexistent. In these areas, you would expect a significant increase in growth and survival. Future research should include the deployment of multiple oysterbreaks in areas of optimal growth conditions. This would produce knowledge of the system dynamics and resilience of this kind of artificially induced ecosystem. Future research could involve selective fouling materials. Other future research could include the effects of growth and design on erosion abatement characteristics.

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CHAPTER 3: WAVE TANK ANALYSIS OF A BIOENGINEERED SUBMERGED BREAKWATER

3.1 Introduction

Physical model tests were conducted to determine the effects biological growth and density of the oysterbreak on wave interaction. Since the oysterbreaks porosity changes with time, the effects of growth were considered. To determine density effects, the desired amount of vertical slats needed was investigated. The overall goal of these experiments was to determine the effects of oyster growth and density on the wave interaction characteristics of the oysterbreak. The methods used for these experiments are found in the next section.

3.1.1 Simulation of Environmental Conditions

The environmental conditions were modeled from typical conditions in Terrebonne Bay, Louisiana. The data were acquired from the Coastal Studies Institute's WAVCIS station 11 (WAVCIS, 2004). This station has a depth of 1.22 meters.

Two design waves were determined by calculating average conditions in the Terrebonne Bay coastal area. A time series of 9 months was acquired from the WAVCIS archived data. The time frame extended from September 2002 to June 2003. This data neglected some of the mid-summer wave conditions. The wave heights and wave periods from this data were plotted in a frequency diagram (figures 3.1 and 3.2). The design waves were selected from this frequency of occurrence. A wave height of .35 meters (1.15 ft) and a wave period of 3.5 seconds were selected for modal conditions. A wave height of .54 meters (1.77 ft) and a wave period of 5 seconds were selected for higher energy conditions.

3.1.2 Dimensional Analysis

The physical model experiment was conducted in a 1:4 scale. Since the interaction of wave and structure was considered, the Froude number was used in dimensional analysis

(Murphy, 1950). Sarpkaya and Isaacson (1981) noted that at high Reynold's numbers, the drag coefficient becomes independent of the Reynold's number. Since the structures are in a very turbulent environment, the forces are dominated by the inertia and not the skin friction.

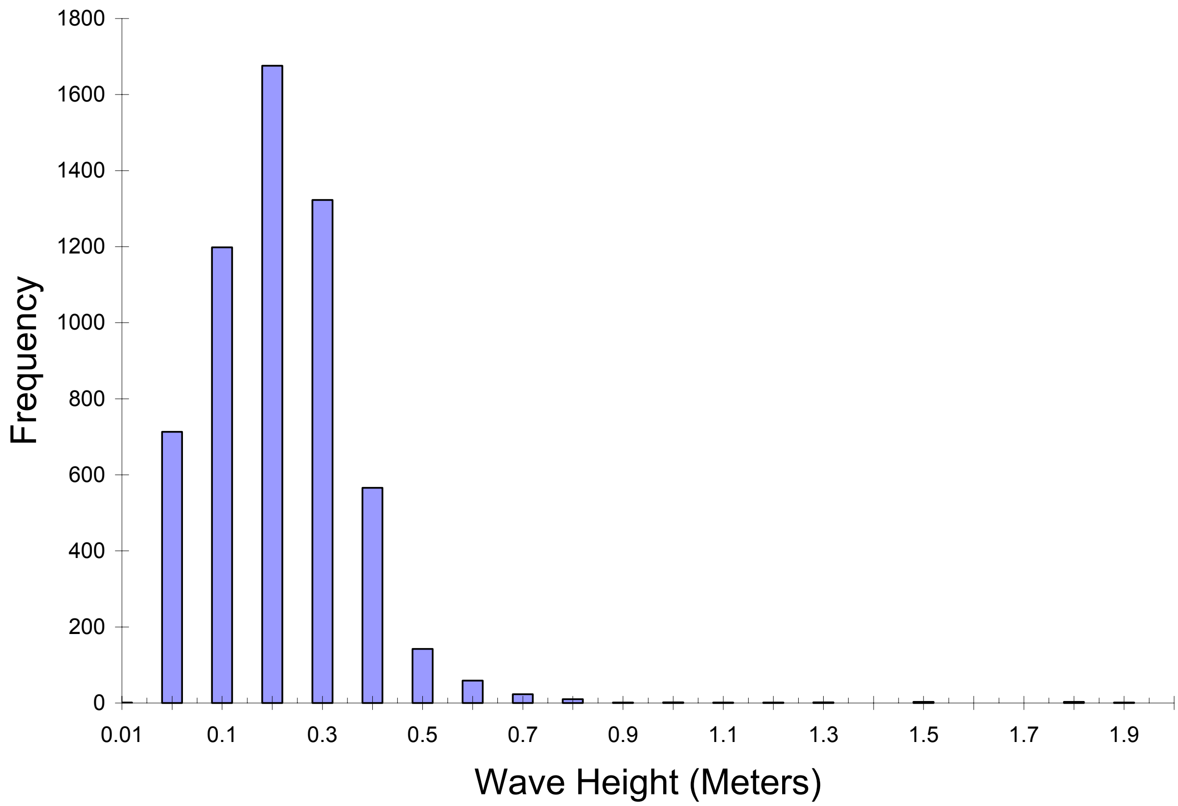

Figure 3.1. Histogram depicts wave heights conditions at WAVCIS station 11 in Terrebonne Bay, Louisiana from September 1, 2002 to June 1, 2003.

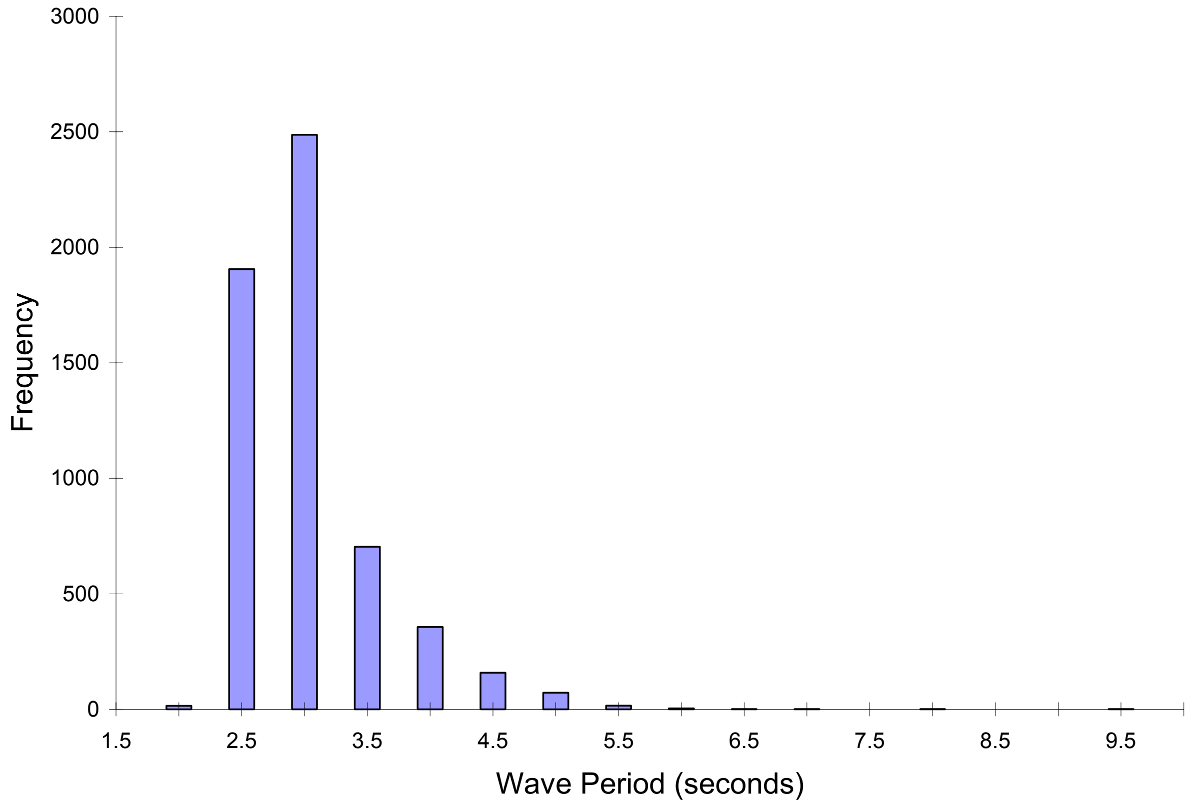

Figure 3.2. Histogram depicts wave period conditions at WAVCIS station 11 in Terrebonne Bay, Louisiana from September 1, 2002 to June 1, 2003.

Therefore, the general shape characteristics of the structure are more dominant than the roughness of the structure in this turbulent environment. In this situation, the Froude number would be more appropriate for dimensional analysis.

Using the Froude number to maintain similitude, the following relationship between the physical model and the prototype was established:

$$\frac{U_m}{\sqrt{g \times L_m}} = \frac{U_p}{\sqrt{g \times L_p}} \qquad \text{Equation 3.1}$$

Where U is the water particle orbital velocity, g is gravity, and L is the length describing the wave (i.e. wave height and wavelength). Subscripts $_m$ and $_p$ were used to distinguish the physical model and the prototype, respectively.

By solving Equation 3.1 for U_m and using a 1:4 length scale, velocity can be represented as:

$$U_m = \frac{U_p}{2} \qquad \text{Equation 3.2}$$

The wave generator in the wave tank is used to generate sinusoidal waves. Due to the shallow environment in the wave tank and the field conditions, trachoidal waves are formed. Second Order Wave Theory is the most appropriate under these circumstances. On the other hand, the waves are sinusoidal when generated. Therefore, the Linear Wave Theory is applicable in these scaling conditions. If the Second Order Wave Theory was used instead, the scaling equations would change. Assuming the Linear Wave Theory is applicable for these conditions, the following equation is used to describe the horizontal component of water particle velocity for transitional waves (Dean and Dalrymple, 1984).

$$U = \frac{HgTCosh[2\pi(z+d)/L]}{2LCosh[2\pi d/L]}\cos\theta \qquad \text{Equation 3.3}$$

The horizontal velocity, U, of water particles in a water column accelerates and decelerates as a wave passes. The particle position and the depth of the water column are represented by z and d, respectively. The wave height, period and length are represented by H, T, and L, respectively.

A ¼ scale for the terms in the hyperbolic cosine portion of equation 3.3 was used, and then substituted into equation 2 for both the prototype and the model. The following relationship was formed by canceling terms:

$$\frac{H_m T_m}{L_m} = \frac{H_p T_p}{2L_p} \qquad \text{Equation 3.4}$$

Because a 1:4 length scale was used, the following relationships of wave length and wave height were acceptable:

$$L_m = L_p/4 \qquad \text{Equation 3.5}$$

$H_m = H_p/4$ Equation 3.6

When these equations are substituted into Equation 3.4, the following relationship for wave period is established:

$T_m = T_p/2$ Equation 3.7

By using these relationships, suitable design waves were determined for the physical model experiments.

3.2 Methods and Materials

3.2.1 Building the Physical Models

Four types of iron rebar structures were constructed at a ¼ scale to be tested in the experiments (figure 3.3). The structures had an extruded trapezoidal shape. Horizontal bars were welded to the frame with 3 centimeter spacing between centers. The trapezoid has a crest width at the top of 40 centimeters and 76 centimeters at the base. The sides of the structure had a slope of 45°. The structure was 18 centimeters tall and 122 centimeters long. In order to determine the wave dissipating effects of increasing the density of the structure, four types of structures were constructed. All structures had the same general dimensions, but had different numbers of vertical sections (or slats) consisting of 3 cm spaced horizontal bars. The different types of structures had 2.63, 6.58, 9.21, and 14.5 slats /meter (figure 3.3). The slanted slats were taken into consideration because they impacted the waves. In the field, these slats would also be taken into account. Therefore, the slats/meter was calculated by taking all slats (vertical and slanted) and divided that number by the width of the oysterbreak. In addition to these structures, a rock breakwater was constructed from crushed cinder blocks for comparison. The mean rubble diameter was approximately 10 cm, and the general size and shape was approximately the same as the rebar structures.

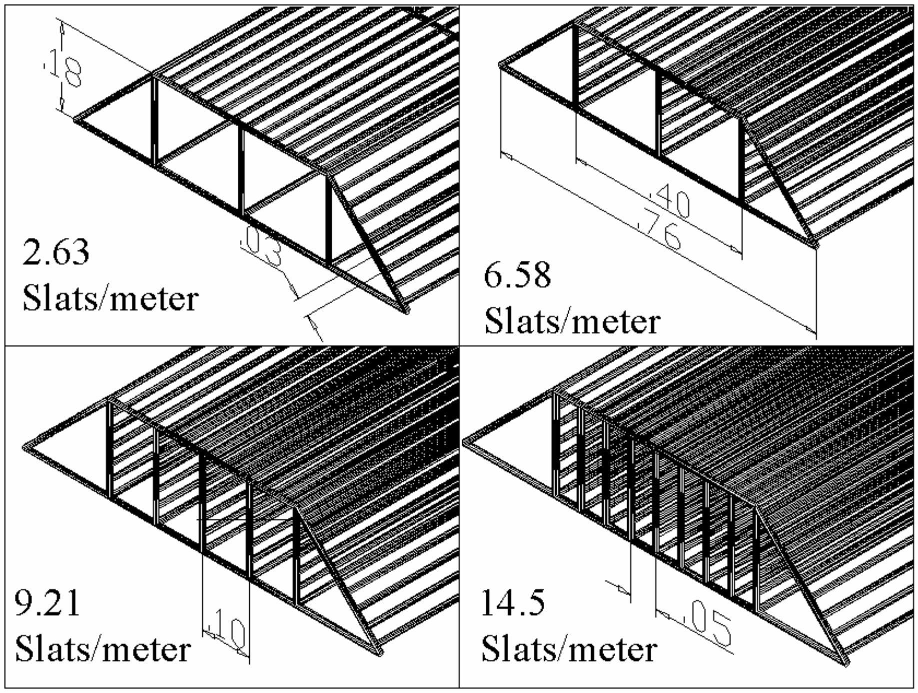

Figure 3.3. AutoCAD drawing showing the four structures used in the wave tank experiments.

3.2.2 Simulation of Growth

The effects of growth were examined by simulating three growth stages. Each of the four structures were used with each of the growth stages. The structures were dipped into a mixture of Type II Portland cement and organic material until the desired thickness was accomplished. The organic material included mostly cotton seed and garden mulch. These organic additives created a realistic texture that was similar to what may occur as oysters attach to an oysterbreak. The growth stages included a zero growth or initial stage, an intermediate growth stage, and a mature growth stage with average radii of .005, .008, and .012 meters, respectively. There were twelve total structures constructed for experimentation.

3.2.3 Wave Tank Setup and Procedure

The waves were measured using Druck© pressure sensors with a range of 5 psi gage (model PDCR 1830). They were connected to a 23X Campbell Scientific micrologger that recorded data at a frequency of 33 Hz. As waves passed over the pressure sensors, data were viewed on a computer screen in real time. Data from the 23X was downloaded and saved following each test. Pressure sensors were placed directly in front and behind the oysterbreak and rigidly attached to an aluminum flat bar to insure the consistency of placement and spacing. The experimental setup is shown in figures 3.4 and 3.5.

The scaled design waves were consistently produced in the wave tank as regular waves. Regular waves were generated in the wave tank by a MTS Portable Piston Wave generator system that includes a wave generator assembly, a motor controller, and an MTS 407 Controller. There were two types of regular waves generated in the wave tank. The first wave type had an average wave height of .087±.009 meters and a wave period of 1.89±.015 seconds. The second wave type had and average wave height of .135±.009 meters and a wave period of 2.35±.005 seconds.

In order to minimize the reflection in the wave tank, wave absorbers were placed at the end of the tank on the beach slope. The wave absorbers used consisted of fibrous mats constructed from coconut husks. These were placed on the beach to reduce wave reflection on the beach and backwash that could interfere with the pressure sensors' readings. The arrangement of the pressure sensors relative to the oysterbreak structure can be seen in figure 3.6.

The slope of the sandy bottom was taken into consideration. The average slope of the bottom of the tank was approximately .054. Surveys of the slope were conducted before and after each repetition of the experiment. Seven transects perpendicular to the wave board and 0.61 meters apart were averaged to get the mean slope. The slope was planed before the beginning of each repetition to reduce the effects it might have on wave forms. Analysis of Variance statistics using SAS© software were run on the mean slopes to make sure the slopes were approximately the same.

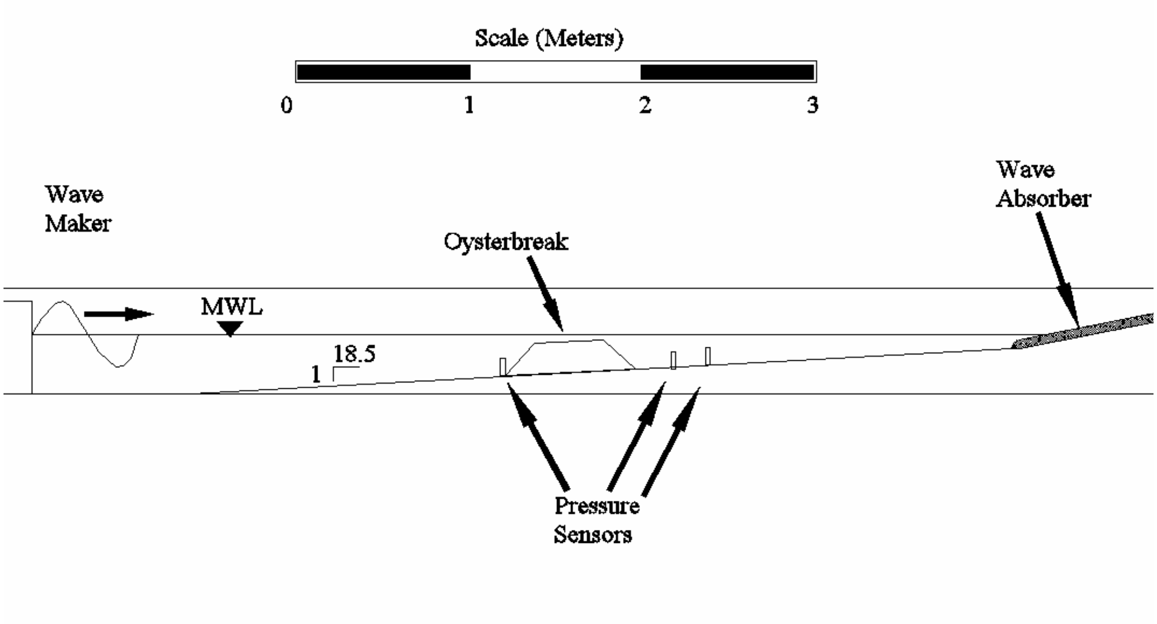

Figure 3.4. Cross sectional view of the experimental setup in the wave tank in meters. The slope and mean water level (MWL) were approximately the same for all tests.

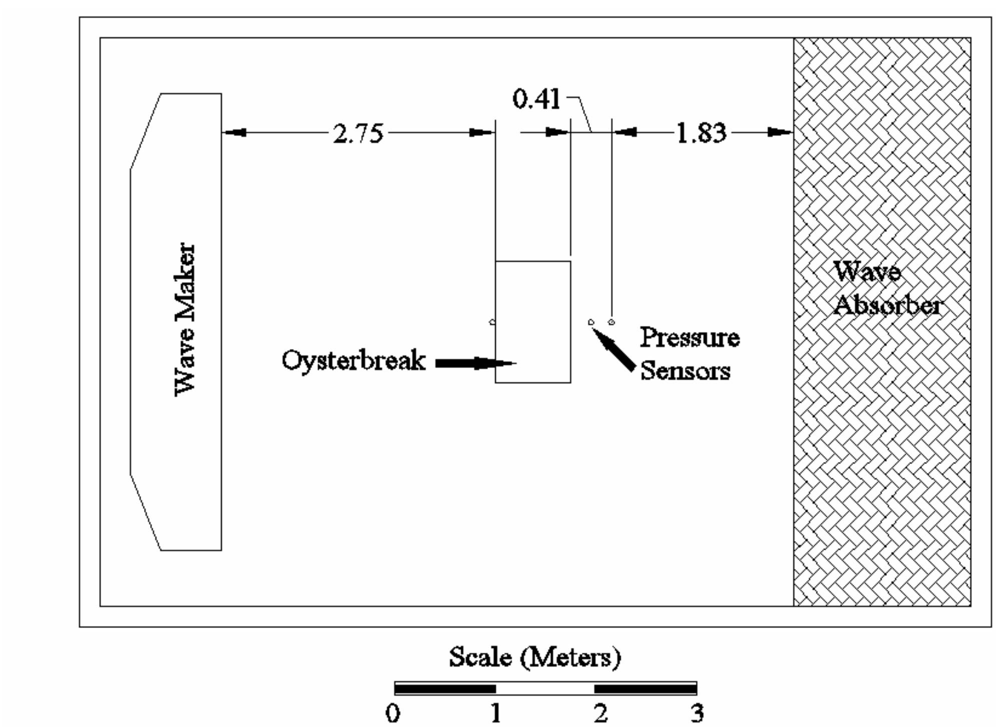

Figure 3.5. Plan view of the experimental setup in the wave tank. The position of the pressure sensors relative to the wave generator, oysterbreak and wave absorber was the same for all tests.

The following procedure was used for each repetition.

Before each repetition:

1. The slope was surveyed.
2. The tank was filled to a MWL of .35 meters.
3. The pressure sensors were checked to see if any calibration was necessary.

Then each of the twelve structures and the rock breakwater was placed in the tank individually and subjected to the two wave types. After the testing of each structure, it was removed and the two wave types were generated with the absence of a structure to act as a control.

The following was performed for each of the structures.

1. The structure was placed in the tank.
2. The two wave types were generated for approximately 1 minute.
3. The structure was removed and the two wave types were generated again without the structure.

After all of the structures were tested, the tank was drained. Then a survey was conducted to determine the slope at the end of the experiments. The slope was then planed to a uniform state. Wave heights were then calculated by taking the average wave height (maximum peak to minimum trough) for the duration of each test. The transmission coefficients, K_t, were taken as the ratio of the transmitted wave height behind the structure (pressure sensor 3) to the wave height in the same position without the structure. Reflection coefficients, K_r, were calculated as the portion above 1 for the ratio of wave height directly in front of the structure (pressure sensor 2) to the wave height at the same position without the structure. The dissipation coefficients, K_d, were calculated as

$K_t^2 + K_r^2 + K_d^2 = 1.0$ (Ahrens, 1987). Equation 8

This methodology produced repeatable and useful results, which will be reported with respect to wave transmission, reflection, and dissipation.

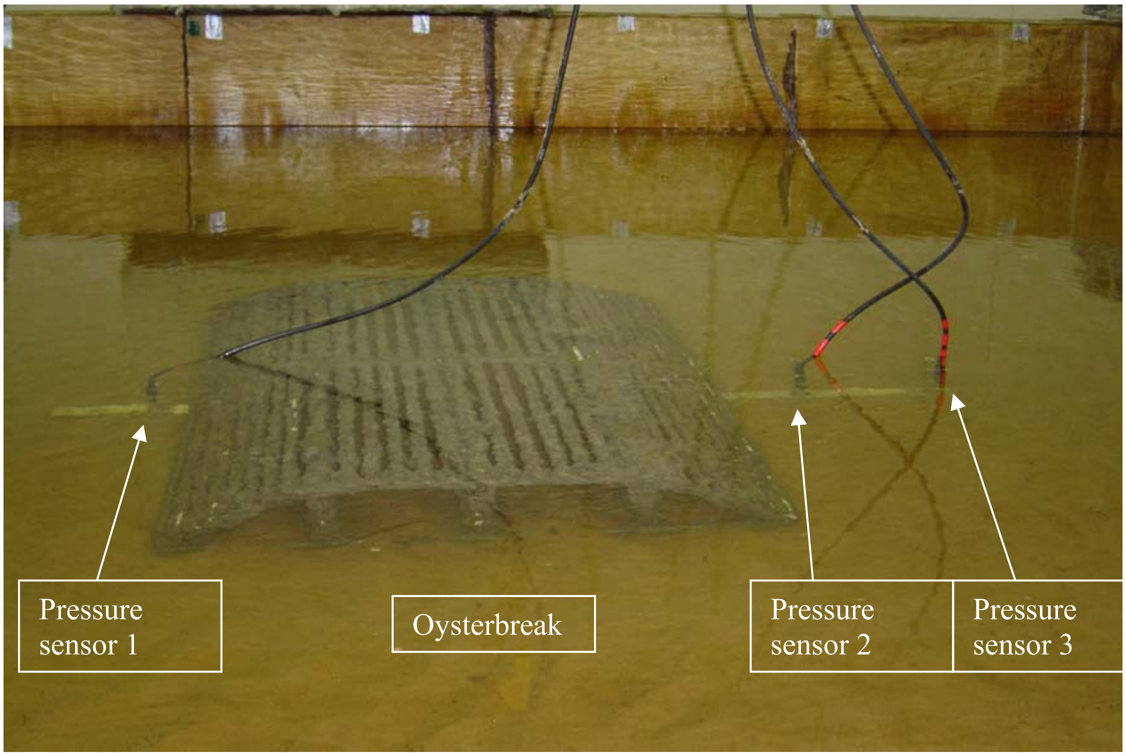

Figure 3.6. Photograph of the oysterbreak in the wave tank. The pressure sensors were placed in the following arrangement for each run.

3.3 Results

3.3.1 The Structures' Effects on Wave Breaking

The two wave types had breaking characteristics that were affected by the introduction of all versions of the structure. The surface elevation with time was estimated by pressure sensors for each of the oysterbreak structures. Wave type 1 consisted of low crested sinusoidal waves. It can be seen in figures 3.7 and 3.8 how the waves interacted with an example of the oysterbreaks. The first wave type had an average wave height of .087±.009 meters. The wave period had a value of 1.89±.015 seconds.

In general, the waves interacting with the zero growth stage were impacted minimally. The wave height was slightly lowered at the wave peak. The waves interacting with the intermediate growth stage transformed into spilling breakers over the structure. The final growth stage produced waves that were breaking over the structure. Without the presence of the structures, type 1 waves were breaking on the wave absorbing material with considerable force (figure 3.7).

Wave type 2 consisted of steep trachoidal waves. The second wave type had an average wave height of .135±.009 meters. The wave period for this larger wave was 2.35±.005 seconds. These high energy waves were plunging breakers in the absence of the structures (figure 3.8).

With the introduction of the structures to the high energy wave, type 2, there was a considerable effect on how and where the waves broke (table 3.1). For most of the structures, there was a general trend of wave breaking as growth occurred. The initial growth stage forced the wave to break earlier and lessened the plunging breakers energy. The introduction of the intermediate growth structures caused the waves to break directly on them. The final growth stage produced a surging breaker that almost dissipated all energy as it approached the shore (see videos in Appendices G).

3.3.2 Wave Transmission

Wave transmission decreased as simulated growth occurred on the structure. The initial growth stages of the structures were slightly less effective at reducing wave transmission than the constructed breakwater of the same size (figure 3.9). At the intermediate growth stage the denser structures were more effective and approached Ahren's predicted value, 0.74, for a rock breakwater of comparable size with a mean stone diameter size of 2 cm. Also, at the intermediate growth stage the 2.63 and the 6.58 slats/meter structures were not significantly different ($p=.8462$, $df=6$).

Table 3.1. Table of where the type 2 waves were breaking with and without the introduction of the oysterbreak structures. This data reveals that with the introduction of the structures the wave breaking moves toward the structure. As the structure increases in density the wave breaking moves directly over the structure.

		Breaking distance from Wave Generator (meters)		Change in wave breaking position (m)	Distance of breaking from center of structure (m)
Radial Growth (m)	Structure (slats/m)	With Structure	Without Structure		
0.005	2.63	3.87	3.99	-0.12	1.13
0.005	6.58	3.51	4.02	-0.52	0.76
0.005	9.21	3.75	3.96	-0.21	1.01
0.005	14.47	3.69	4.05	-0.37	0.94
0.008	2.63	3.37	3.90	-0.53	0.63
0.008	6.58	3.57	4.05	-0.49	0.82
0.008	9.21	3.23	4.05	-0.82	0.49
0.008	14.47	3.14	4.02	-0.88	0.40
0.012	2.63	2.83	3.99	-1.16	0.09
0.012	6.58	2.80	4.02	-1.22	0.06
0.012	9.21	2.74	3.93	-1.19	0.00
0.012	14.47	2.77	3.90	-1.13	0.03

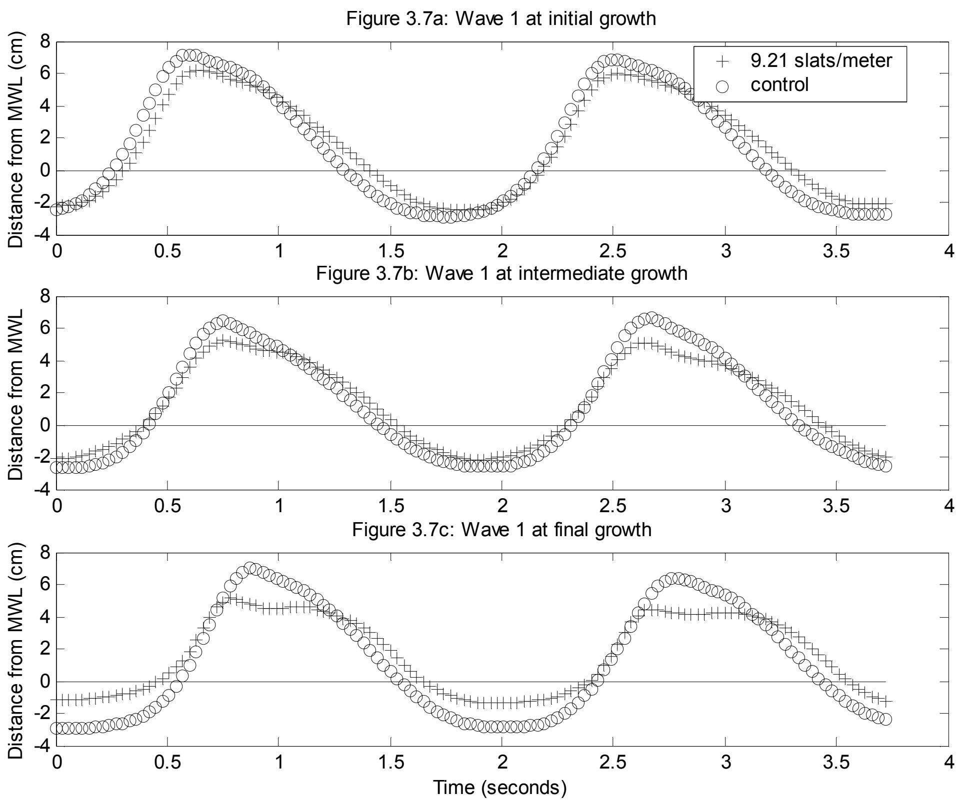

Figure 3.7. Graphs show the water level change for the type 1 wave with and without the structure in place. The wave form graphs for the initial (a), intermediate (b), and final (c) growth stages of the structure are shown. These graphs show how the wave dissipation increases as growth occurs on the oysterbreak.

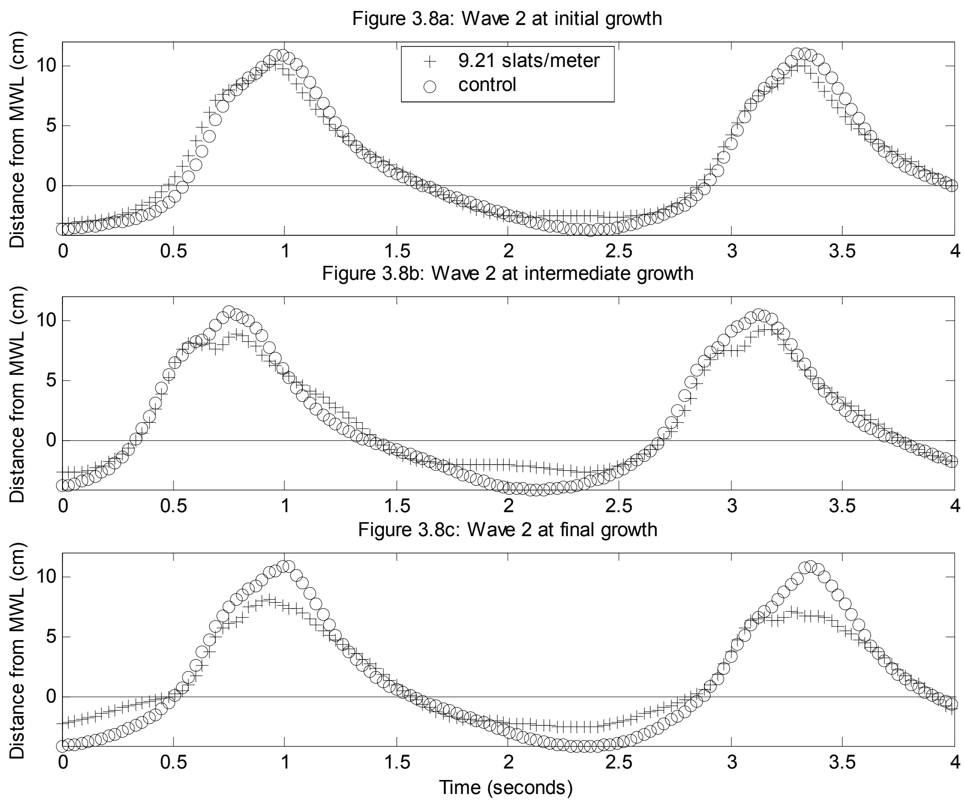

Figure 3.8. Graphs show the water level change for the type 2 wave with and without the structure in place. The wave form graphs for the initial (a), intermediate (b), and final (c) growth stages of the structure are shown. These graphs show how the wave dissipation increases as growth occurs on the oysterbreak.

The 9.21 and the 14.5 slats/meter structures were also not significantly different (p=.8109, df=6). In the final growth stage, all versions of the oysterbreak were between 0.67 and 0.78, which in the range of Ahren's predicted value, 0.74 (table 3.2). The 2.63 and 14.5 slats/meter were not significantly different (p=.1805, df=6). The 6.58 and 9.21 slats/meter structures were not significantly different (p=.7080, df=6). The 9.21 and 14.5 slats/meter structures were not significantly different (p=.9279, df=6).

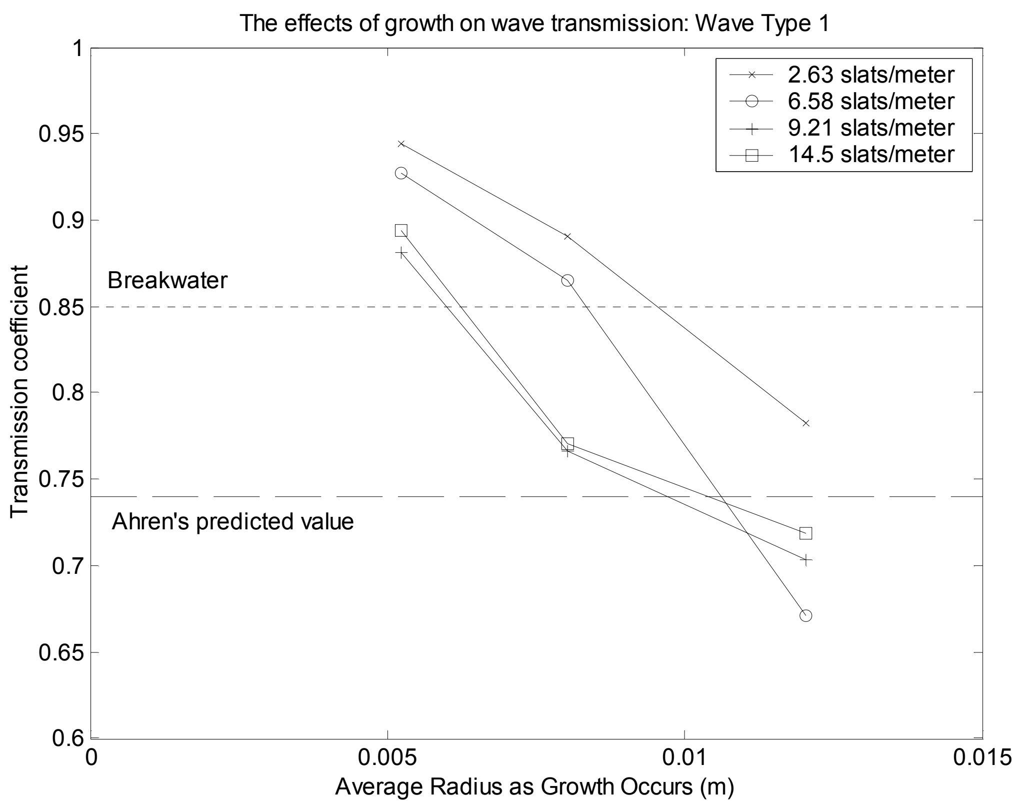

Figure 3.9. Graph depicting the transmission coefficients as growth occurs for each of the structures under wave condition 1. Oysterbreak values are compared with the physical breakwater and predicted values.

Table 3.2. Table of the average and standard deviation of the transmission coefficient for each of the structures tested under wave condition 1.

Wave Type 1		
Radial Growth (m)	Slats/meter	Transmission Coefficient
0.005	2.63	0.944 ± 0.049
0.005	6.58	0.927 ± 0.040
0.005	9.21	0.881 ± 0.053
0.005	14.47	0.894 ± 0.052
0.008	2.63	0.891 ± 0.068
0.008	6.58	0.865 ± 0.052
0.008	9.21	0.766 ± 0.068
0.008	14.47	0.771 ± 0.064
0.012	2.63	0.783 ± 0.028
0.012	6.58	0.671 ± 0.075
0.012	9.21	0.704 ± 0.060
0.012	14.47	0.719 ± 0.063
Physical Rock Breakwater		0.847 ± 0.108
Ahren's predicted value for a breakwater with 2.0 cm mean stone diameter		0.740 ± 0.027

For wave type 2, the values of transmission were less differentiated between structures. On the other hand, each of the structures' transmission coefficients were reduced proportional to the radial growth (figure 3.10). The most effective structure was the 9.21 slats/meter, even though this was not the densest of the structures. The least effective structure was the 2.63 slats/meter, which was the most porous structure. In the initial growth stage, the structures performed similarly. The 9.21 and the 14.5 slats/meter structures were not significantly different (p=.7125, df=6). In the intermediate growth stage, the structures performed as well or better than the physical rock breakwater, which had a transmission coefficient of 0.87. The 9.21 and the 14.5 slats/meter structures were not significantly different in the intermediate growth stage (p=.1325, df=6). In the final growth stage, all structures, except the 2.63 slats/meter, 0.80, achieved transmission coefficients as low as the predicted value, 0.73, for a rock breakwater in (table 3.3). The 9.21 and the 14.5 slats/meter structures were significantly different, where the 9.21 slats/meter structure had the lower transmission coefficient value, 0.72 (p=.0007, df=6).

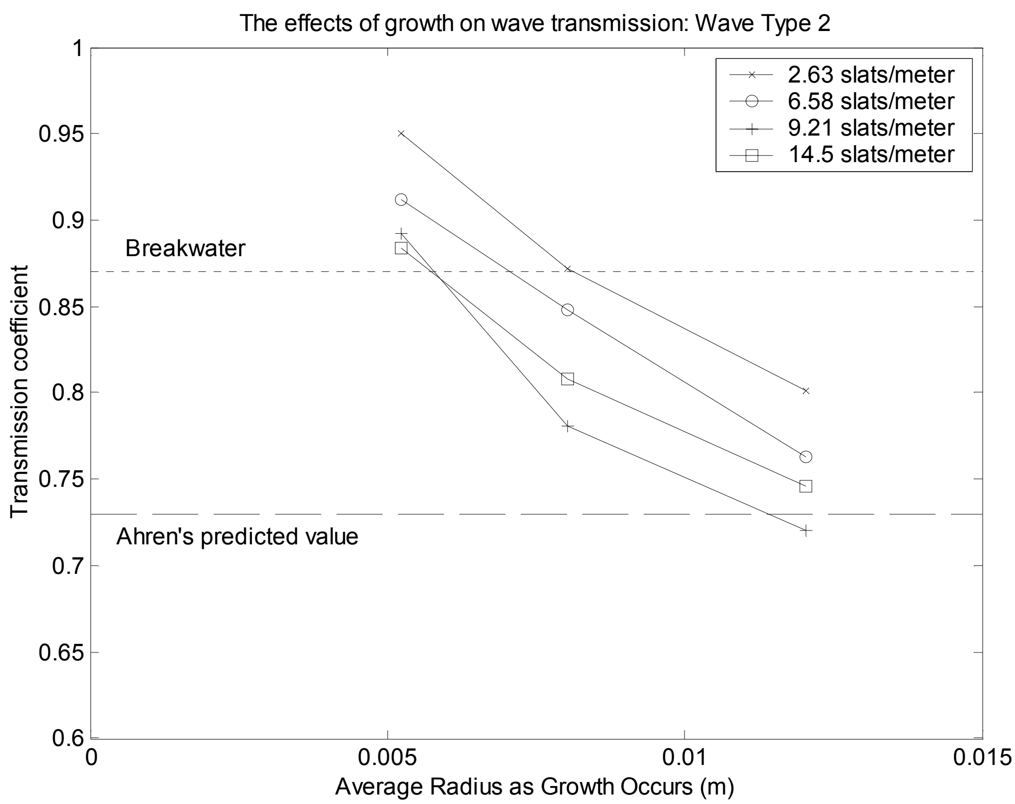

Figure 3.10. Graph depicting the transmission coefficients as growth occurs for each of the structures under wave condition 2. Oysterbreak values are compared with the physical breakwater and predicted values.

Table 3.3. Table of the average and standard deviation of the transmission coefficient for each of the structures tested under wave condition 2.

Wave Type 2		
Radial Growth (m)	Slats/meter	Transmission Coefficient
0.005	2.63	0.950 ± 0.015
0.005	6.58	0.912 ± 0.026
0.005	9.21	0.892 ± 0.035
0.005	14.47	0.884 ± 0.043
0.008	2.63	0.872 ± 0.027
0.008	6.58	0.848 ± 0.026
0.008	9.21	0.781 ± 0.048
0.008	14.47	0.808 ± 0.053
0.012	2.63	0.801 ± 0.043
0.012	6.58	0.763 ± 0.047
0.012	9.21	0.721 ± 0.061
0.012	14.47	0.746 ± 0.045
Physical Rock Breakwater		0.871 ± 0.050
Ahren's predicted value for a breakwater with 2.0 cm mean stone diameter		0.731 ± 0.023

3.3.3 Wave Reflection

Wave reflection is important because it causes scouring of structures. The higher the reflection, the more scouring occurs at the toe of the structure. Traditional rubble mound breakwaters are concerned with this because it causes the rocks to be undermined and the structure collapses. The oysterbreak structure is not as vulnerable, because it is a fabricated unit.

In wave condition 1, there was a general increase in the reflection coefficient as growth occurred. The values approached the physical breakwater values, 0.137, in the final growth stage, but never reached it (figure 3.11). In the intermediate growth stage, the 6.58 and 9.21 slats/meter values were not significantly different (p=.8126, df=6). In addition, the 2.63 and 14.5

slats/meter values were not significantly different (p=.8732, df=6). In the final growth stage, the 9.21 slats/meter had the highest value of reflection at 0.123, and the 14.5 was the lowest at 0.095 (table 3.4).

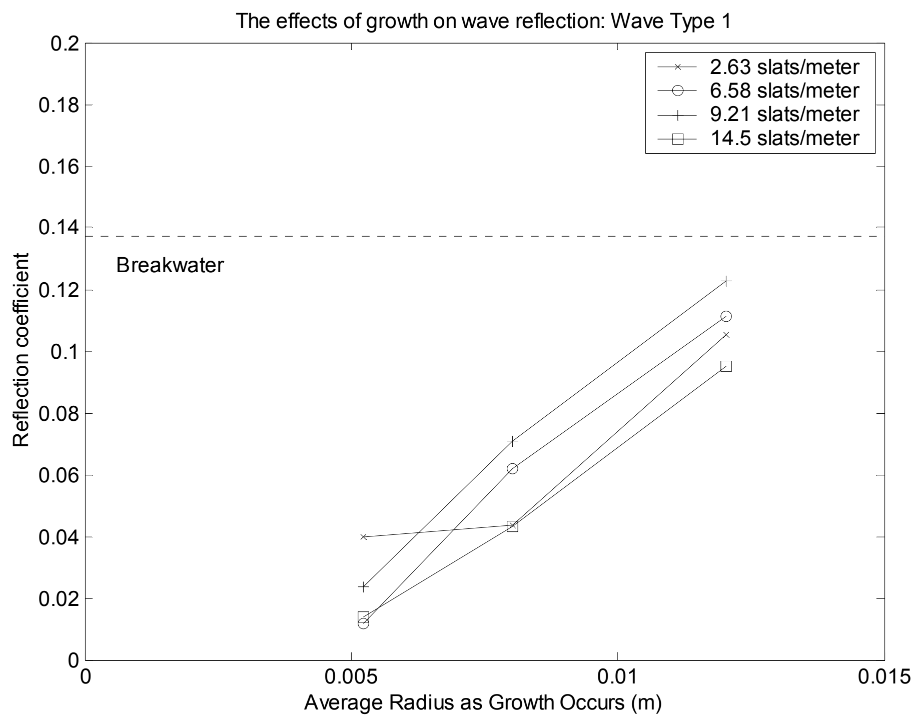

Figure 3.11. Graph depicting the reflection coefficients as growth occurs for each of the structures under wave condition 1. Oysterbreak values are compared with the physical breakwater values.

Table 3.4. Table of the average and standard deviation of the reflection coefficient for each of the structures tested under wave condition 1.

Wave Type 1		
Radial Growth (m)	Slats/meter	Reflection Coefficient
0.005	2.63	0.040 ± 0.045
0.005	6.58	0.012 ± 0.022
0.005	9.21	0.023 ± 0.052
0.005	14.47	0.014 ± 0.036
0.008	2.63	0.044 ± 0.052
0.008	6.58	0.062 ± 0.068
0.008	9.21	0.071 ± 0.057
0.008	14.47	0.043 ± 0.022
0.012	2.63	0.105 ± 0.046
0.012	6.58	0.111 ± 0.062
0.012	9.21	0.123 ± 0.077
0.012	14.47	0.095 ± 0.058
Physical Rock Breakwater		0.137 ± 0.060

In wave condition 2, the trends for reflection coefficients were much different (figure 3.12). At the final growth stage, the structure producing the highest reflection was 14.5 slats/meter, at a value of 0.420, followed by 9.21 and 6.58 slats/meter, at values of 0.350 and 0.334, respectively. The lowest value was the 2.63 slats/meter structure at a value of 0.243. The 6.58 and 9.21 slats/meter structures performed similarly at all growth stages. The initial growth stage produced the lowest reflection values for all configurations. All of the structures achieved values below 0.099 (table 3.5).

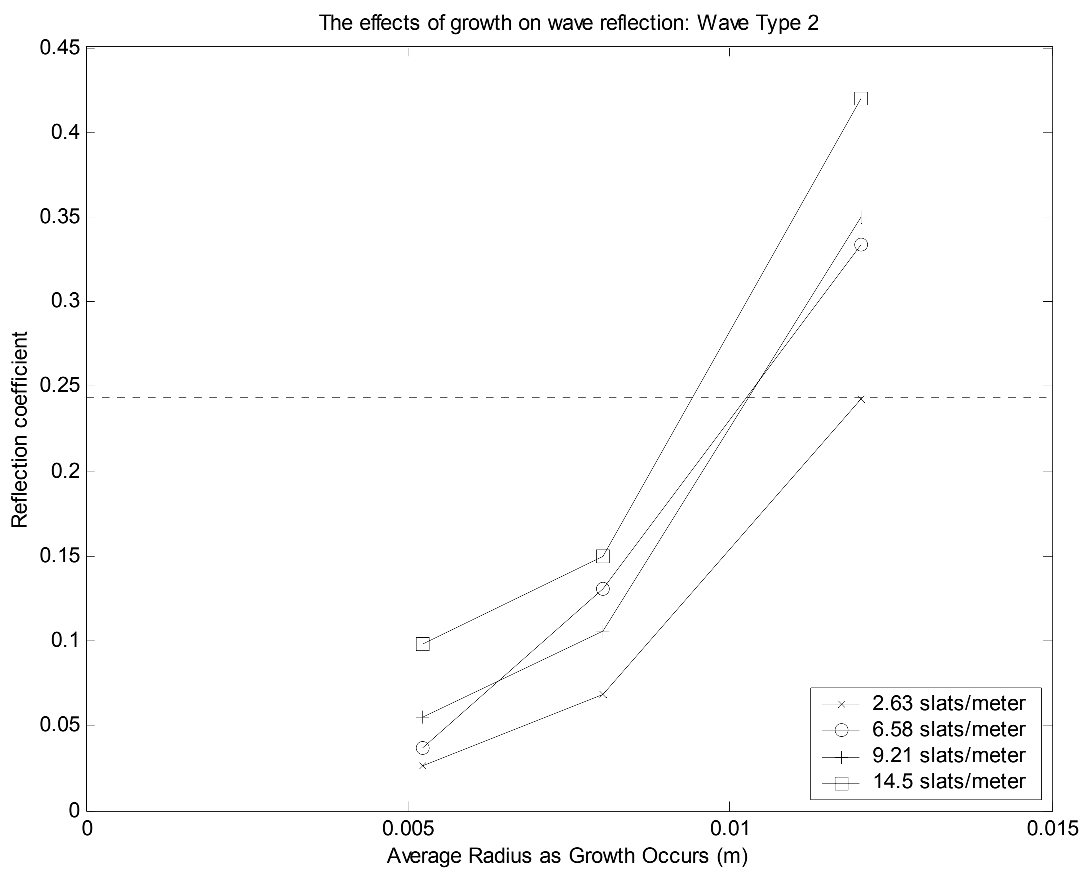

Figure 3.12. Graph depicting the reflection coefficients as growth occurs for each of the structures under wave condition 2. Oysterbreak values are compared with the physical breakwater values.

Table 3.5. Table of the average and standard deviation of the reflection coefficient for each of the structures tested under wave condition 2.

Wave Type 2		
Radial Growth (m)	Slats/meter	Reflection Coefficient
0.005	2.63	0.026 ± 0.030
0.005	6.58	0.037 ± 0.017
0.005	9.21	0.055 ± 0.026
0.005	14.47	0.099 ± 0.096
0.008	2.63	0.069 ± 0.023
0.008	6.58	0.131 ± 0.039
0.008	9.21	0.105 ± 0.132
0.008	14.47	0.150 ± 0.038
0.012	2.63	0.243 ± 0.085
0.012	6.58	0.334 ± 0.089
0.012	9.21	0.350 ± 0.170
0.012	14.47	0.420 ± 0.071
Physical Rock Breakwater		0.243 ± 0.103

3.3.4 Wave Dissipation

For wave type 1, the 9.21 and 14.5 slats/meter structures performed the same. In general, the wave dissipation increased to a maximum as growth occurred. From the initial to the final growth stage, the wave dissipation increased and approached a value of .50 (figure 3.13). The 2.63 and 6.58 slats/meter structures performed similarly in the initial and intermediate growth stages, but in the final growth stage were significantly different (p=.0349, df= 6). The values were less than those for the physical breakwater, 0.253, in the initial growth stages. The values were the same for the 9.21 and 14.5 slats/meter structures in the intermediate growth stages, with values of 0.40. All of the structures were superior at dissipating wave energy to the physical breakwater in the final growth stages, although the 6.58 slats/meter structure had a much higher value of 0.530 (table 3.6).

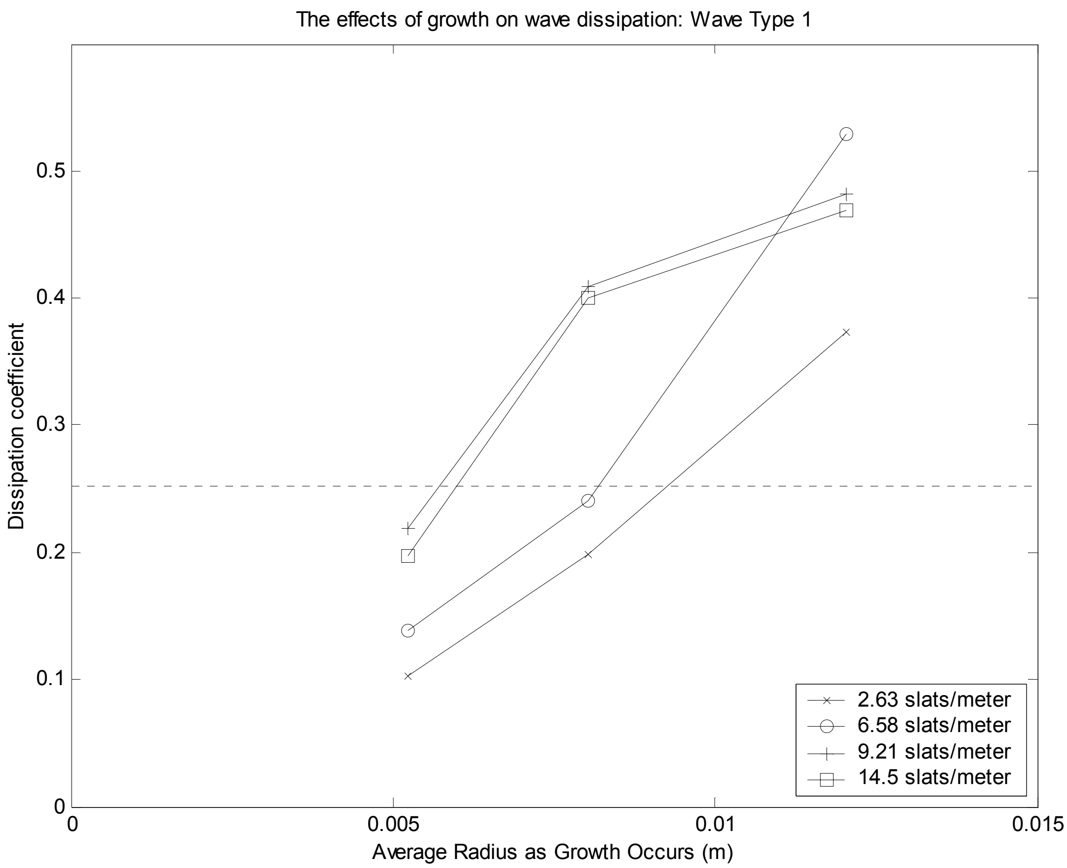

Figure 3.13. Graph depicting the dissipation coefficients as growth occurs for each of the structures under wave condition 1. Oysterbreak values are compared with the physical breakwater values.

Table 3.6. Table of the average and standard deviation of the dissipation coefficient for each of the structures tested under wave condition 1.

Wave Type 1			
Radial Growth (m)	Slats/meter	Dissipation Coefficient	
0.005	2.63	0.103 ± 0.088	
0.005	6.58	0.138 ± 0.073	
0.005	9.21	0.219 ± 0.093	
0.005	14.47	0.197 ± 0.092	
0.008	2.63	0.198 ± 0.118	
0.008	6.58	0.241 ± 0.084	
0.008	9.21	0.401 ± 0.100	
0.008	14.47	0.400 ± 0.093	
0.012	2.63	0.374 ± 0.041	
0.012	6.58	0.530 ± 0.130	
0.012	9.21	0.482 ± 0.076	
0.012	14.47	0.469 ± 0.082	
Physical Rock Breakwater		0.253 ± 0.177	

In wave condition 2, the difference in wave dissipation was more distinct between structures (figure 3.14). The dissipation coefficients of the physical breakwater, 0.172, and the 6.58, 9.21, and 14.5 slats/meter structures (0.138, 0.219, and 0.197, respectively) were similar in the initial growth stage. The dissipation coefficient of the 2.63 slats/meter structure, 0.103, was significantly less than the rest of the structures at this growth stage. In the intermediate growth stage, the 9.21 slats/meter was the highest, 0.401, and the 2.63 slats/meter was the lowest values, 0.198, for the dissipation coefficients. The final growth stage values seemed to stabilize around 0.30, which was superior to the 0.17 value of the physical breakwater (table 3.7).

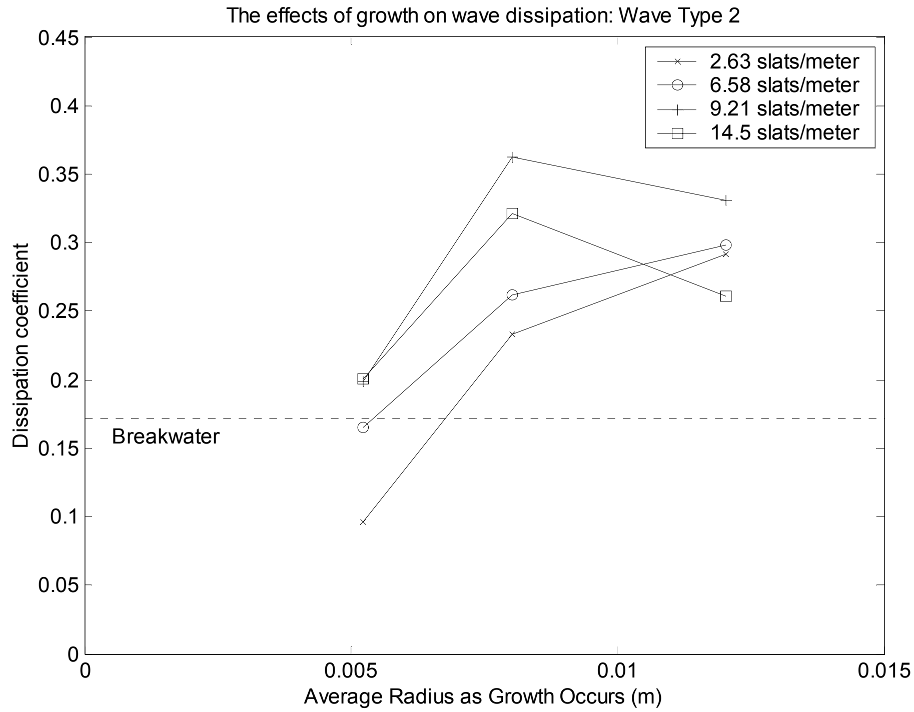

Figure 3.14. Graph depicting the dissipation coefficients as growth occurs for each of the structures under wave condition 2. Oysterbreak values are compared with the physical breakwater values.

Table 3.7. Table of the average and standard deviation of the dissipation coefficient for each of the structures tested under wave condition 2.

Wave Type 2		
Radial Growth (m)	Slats/meter	Dissipation Coefficient
0.005	2.63	0.096 ± 0.028
0.005	6.58	0.166 ± 0.048
0.005	9.21	0.199 ± 0.061
0.005	14.47	0.200 ± 0.105
0.008	2.63	0.233 ± 0.049
0.008	6.58	0.262 ± 0.038
0.008	9.21	0.362 ± 0.082
0.008	14.47	0.322 ± 0.086
0.012	2.63	0.292 ± 0.077
0.012	6.58	0.298 ± 0.089
0.012	9.21	0.331 ± 0.147
0.012	14.47	0.261 ± 0.085
Physical Rock Breakwater		0.172 ± 0.041

3.4 Discussion

The results of the wave tank experiments demonstrate a trend that wave transmission decreases as growth occurs. However, transmission does not necessarily decrease as slats are added to the structure. Since the transmission coefficient is a good measure of the erosion reducing properties of the oysterbreak could reduce erosion, it will be discussed in detail. A regression model was run to describe the transmission as the growth and slats/ meter are manipulated. The following equation was found for the transmission coefficient in wave condition 1 to have an R^2 value of 0.683:

$$K_t = 1.172 - 28.119r - 0.026\psi + .001\psi^2 \qquad \text{Equation 9.}$$

This equation represents the transmission coefficient, K_t, where r is growth and ψ is the slats/meter on the structure. Another equation was found for the transmission coefficient in wave condition 2 to have an R^2 value of 0.735:

$$K_t = 1.1115 - 21.950r - 0.021\psi + 0.001\psi^2 \qquad \text{Equation 10.}$$

In both equations, there is an optimum number of slats/ meter. In practice, the best design would minimize the number of slats/meter (i.e. cost) and maximize the efficiency in reducing wave energy. In addition, the various numbers of slats/meter have almost the same transmission coefficient as the oysterbreak accumulates growth and matures. Therefore, the optimal design would have to balance the cost with how fast the final transmission coefficient was needed for a specific situation. The majority of final growth stage values approached the predicted values of a comparable size rock breakwater using Ahrens' model. Thus, for design purposes Ahrens' model can be used to predict wave transmission at the final growth stage.

Because the breaking waves were moved toward the pressure sensors with the introduction of the structures, this may have produced conservative results. As the waves steepened and broke, they were sometimes directly over the pressure sensor (table 3.1). This may have produced results that were more conservative than those found in other studies (e.g. Ahrens, 1987). These values were compared under the same conditions in order to maintain consistency.

In addition to the overall porosity of the structure affecting the wave transmission, the reflection and dissipation coefficients were also affected. The reflection coefficients increased due to an increase in density and growth. The 6.58 and the 9.21 slats/meter structures produce similar reflection coefficients in both wave conditions. This could be due to the fact that the reflected wave was not penetrating deep into the structure before being reflected. Therefore, the number of slats/ meter did not greatly affect the reflection coefficients.

On the other hand, there appeared to be an optimum design for the maximum wave dissipation. As the slats/meter were increased in the structure, the wave dissipation increased to a certain point. Therefore, the densest structure may not be needed to achieve desired wave dissipation. In other words, the 9.21 slats/ meter structure seemed to be the optimum design for the oysterbreak. Independent of structure type, the dissipation coefficient seemed to reach a maximum in both wave conditions.

3.5 Conclusion

The wave interaction of the oysterbreak structures was effectively described in the experiments. The wave transmission coefficients were determined to decrease as growth occurred on the structures. The reflection coefficients increased as growth occurred on the structures. Most importantly the dissipation coefficients increased as growth occurred and a maximum value was achieved.

For design purposes, the Ahrens' predictive model can be used in the design of an oysterbreak. Even though the transmission coefficients do not correspond at early stages of growth on the oysterbreak, they correspond very well at the later growth stages.

Additionally, there was a maximum number of slats/meter needed to effectively dissipate wave energy. The 9.21 slats/meter structure was the most effective at dissipating wave energy for both conditions. For future designs at full scale, 2.3 slats/meter would be used. On the other hand, this would be dependent on cost, because the addition of any vertical slats made a huge difference in the performance of the oysterbreak.

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CHAPTER 4: DEVELOPMENT OF A PREDICTIVE MODEL

4.1 Oysterbreak Transmission Number

In order to relate the results from the wave tank experiments, a dimensionless number was developed. This number, the oysterbreak transmission number, relates the wave height, wave length, growth stage, and density of the structure. The transmission coefficient was plotted with respect to the oysterbreak transmission number (figure 4.1) in order to find a relationship. An equation was created, which successfully describes that relationship (equation 4.1).

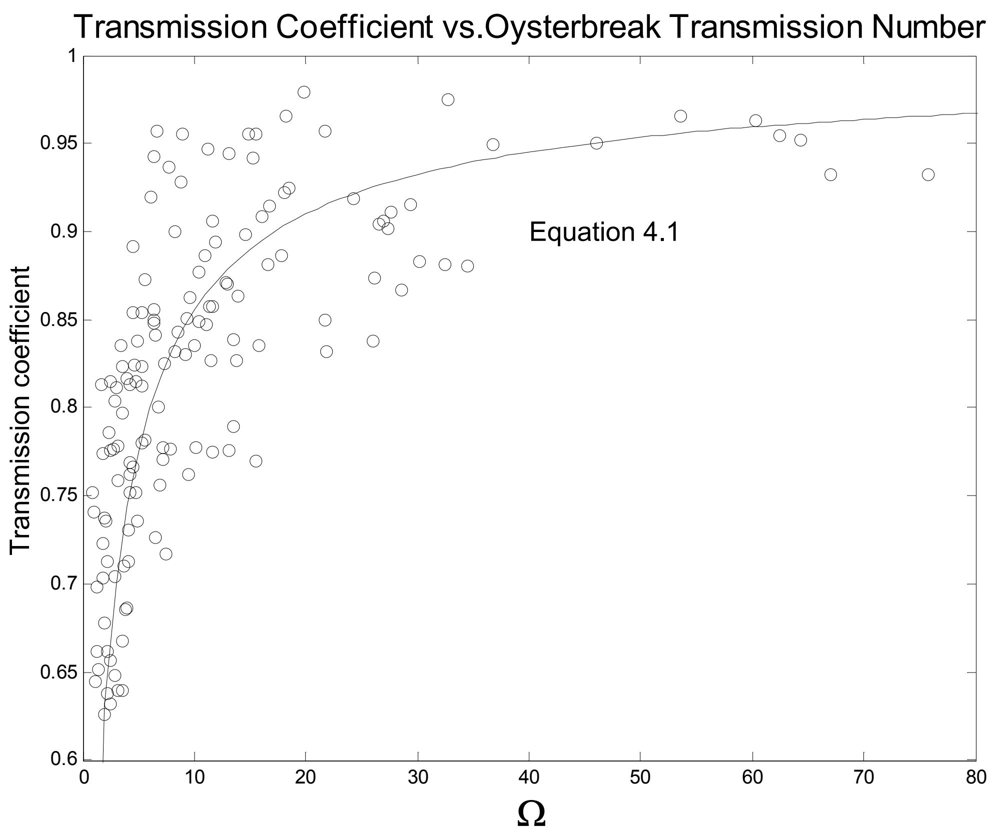

Figure 4.1. Oysterbreak transmission number, $\Omega = \frac{H_w^{\ 2}}{L_w \times \left(r^2 \times \Psi\right)}$

$$Kt = \frac{1}{1 + \left(\frac{L_w \times r^2 \times \Psi}{H^2} \right)^{.7721}}$$ Equation 4.1

It was found that the transmission coefficient, Kt, was related to the wave height (m), H_w, wave length (m), L_w, radial growth on the horizontal bars (m), r, and the number of slats per meter inside the oysterbreak, Ψ.

4.2 The Predictive Capacity

Equation 4.1 was used to calculate predicted values for the wave tank conditions. These values were compared to observed values in the experiments. A linear regression was performed on a direct comparison of predicted values to observed values which resulted in a R^2 value of 0.58 (figure 4.2). The scatter in the plot is due to the physical parameters in the wave tank. Reflection from the sides of the tank caused a variation in the wave height readings. Also, the slope of the bottom was slightly different for each of the runs. Even with these variations, this model seems to be a fairly good prediction. Next, a plot was made of the observed values, and the predicted transmission coefficient values versus an overall density change (r x Ψ). It was observed that the values correlated well at the lower densities. On the other hand, the densest structures predicted generally lower transmission than the observed values (figure 4.3).

Since the structures in the wave tank were of a specific crest width, equation 4.1 can only be used as a predictive model for that particular wave crest length. However, Ahrens' (1987) predictive model takes into account the other structural parameters (equation 4.2).

$$K_t = \frac{1}{1.0 + \left(\frac{h_c}{d_s}\right)^{1.188} \left(\frac{A_t}{d_s L_p}\right)^{0.261} \exp\left[0.529\left(\frac{F}{H_{mo}}\right) + 0.00551\left(\frac{A_t^{3/2}}{d_{50}^2 L_p}\right)\right]} \qquad \text{Equation 4.2}$$

This equation is valid for $\frac{F}{H_{mo}} < 1.0$. The transmission coefficient, K_t, is inversely proportional to a set of dimensionless numbers. The ratio of crest height of the structure, h_c, to depth of submergence at the toe of the structure, d_s, is the first term. The second term is the ratio of total area of the cross section of the structure, A_t, to the depth of submergence and wave length, L_p. The third term is an exponential of two additive terms. The first being a ratio of freeboard, F, to incident wave height, H_{mo}, which is a common ratio when relating structure height. The second additive term is a ratio of the area of the cross section of the structure to the mean stone diameter, d_{50}, and the wave length.

If the oysterbreak predictive model is to be compared with Ahrens' model, a few assumptions must be made. First it was assumed that the percent difference of how the oysterbreak performs relative to the predicted value of Ahrens' remained the same for all wave conditions. Secondly, it was assumed that the spacing of the horizontal bars directly correlated with the mean stone diameter in Ahrens' model. Thirdly, it was assumed that the density of the oysterbreak produced transmission coefficient values equal to those predicted by Ahrens' for the oysterbreaks minimum transmission coefficients (see Chapter 3).

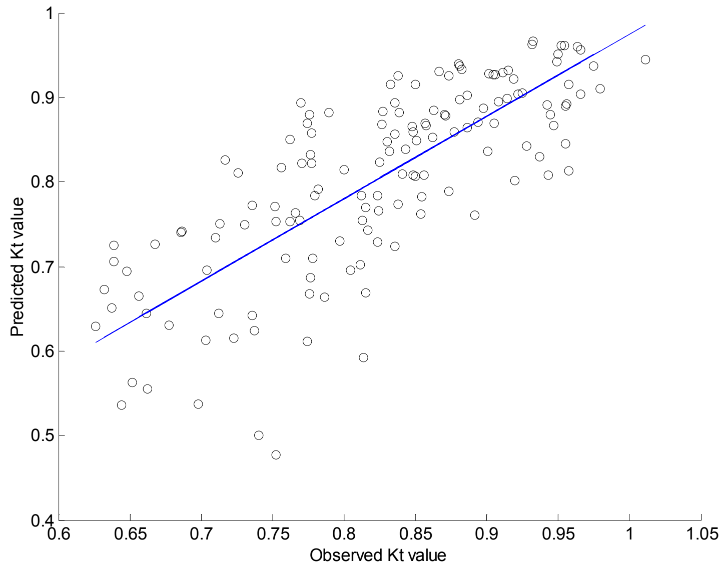

Figure 4.2. Graph showing the correlation between the observed value and the predicted value. The predictive model results in an R^2 of .58.

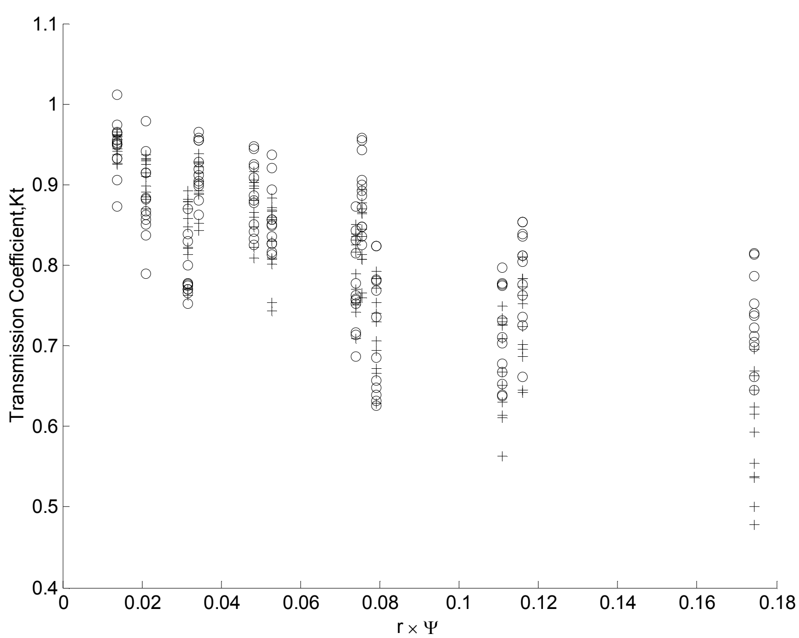

Figure 4.3. Comparison of predicted transmission coefficient values, +, and observed transmission coefficient values, o, as a function of radial growth x density.

4.3 Using the Model

The relationship between the wave tank experiments and the field conditions was necessary to utilize this model. To do this, Ahrens' model was incorporated into the current field model. The relationship is as follows:

$$K_t = Ahrens_{field} + \left(1 - Ahrens_{field}\right)\left(\frac{\left(1 - Ahrens_{wave\tan k}\right) - \left(1 - K_{tw}\right)}{\left(1 - Ahrens_{wave\tan k}\right)}\right) \quad \text{Equation 4.3}$$

where K_t is the predicted value in the field conditions and K_{tw} is the predicted value in the wave tank. In equation 4.3, it is assumed that the percent difference between the oysterbreak values and Ahrens' predicted values remains the same for variations in structure dimensions and wave type. This equation predicts the transmission coefficient in the field, K_t. The Ahrens predicted value for the field is used to size the structure and get the transmission value in the right magnitude. Adjustments are made to this value using a percent difference ratio established in the wave tank. In conclusion, a predictive model was made to predict the transmission coefficient of different conditions over time. This model was written in MatLab® and results are described in the next section (Appendices).

4.4 Running the Model

The model was implemented by varying specific parameters and plotting them to determine their effects. The wave type, structure crest width, growth rate, freeboard, and spacing of horizontal beams were varied.

4.4.1 Change in Wave Type

The first comparison was done by varying the wave type (figure 4.4). The first wave had a wave height of 0.35 meters and a wave period of 3.78 seconds. The second wave had a wave height of 0.54 meters and a wave period of 5 seconds. The third wave had a wave height of 1 meter and a wave period of 5 seconds.   The model was run over a time period of 3 years with a growth rate of 7 cm/yr. The oysterbreak had a crest width of 10 meters and a crest height of 0.72 meters. The density of the structure was 2 slats/meter. The spacing of the horizontal beams was 0.12 meters. The depth at the toe of the structure was 1.11 meters.

The structure's ability to reduce the transmission coefficients was impacted considerably by the wave type. The first two waves had approximately the same transmission coefficient at the final growth stage, 0.64. However, the larger wave did not reach that point until 3 months later. The largest wave produced the lowest transmission coefficient at the final growth stage, 0.60. These results are congruent with on the observations made from the wave tank experiments.

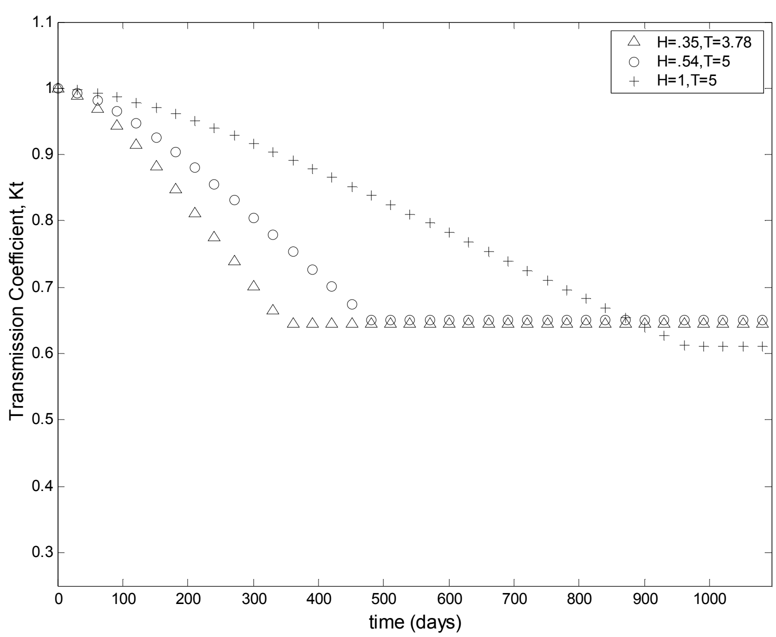

Figure 4.4. Transmission coefficient as a function of time with a change in wave type. Wave height is in meters and wave period is in seconds.

4.4.2 Change in Crest Width of the Oysterbreak

The second comparison was made by varying the crest width of the oysterbreak (figure 4.5). There were four different crest widths of 7, 10, 15, and 20 meters. The wave had a constant wave height of 0.4 meters and a wave period of 4 seconds. The model was run over a time period of 3 years with a growth rate of 7 cm/yr. The oysterbreak had a crest height of 0.72 meters. The density of the structure was 2 slats/meter. The spacing of the horizontal beams was 0.12 meters. The depth at the toe of the structure was 1.11 meters.

The structural crest width had caused a reduction in the minimum transmission coefficient attainable by the oysterbreak. All of the structures achieved their minimum value in the same time period. The 7 meter structure had a minimum transmission coefficient of 0.72 at approximately 400 days. The 10 meter structure had a minimum transmission coefficient of 0.65 in the same amount of time. The 15 meter structure had a minimum transmission value of 0.50, and the 20 meter structure had a minimum value of 0.35. These trends in the reduction of transmission coefficients is consistent with Ahrens' theory (Ahrens, 1987).

4.4.3 Change in Density of Oysterbreak

The third comparison was made by varying the density of the oysterbreak (figure 4.6). There were four different variations of density in this comparison. The densities included 0.5, 1, 2, and 3 slats/meter. The model was run over a time period of 3 years with a growth rate of 7 cm/yr. The oysterbreak had a crest width of 15 meters and a crest height of 0.72 meters. The spacing of the horizontal beams was 0.12 meters. The wave had a wave height of 0.4 meters and a wave period of 4 seconds. The depth at the toe of the structure was 1.11 meters.

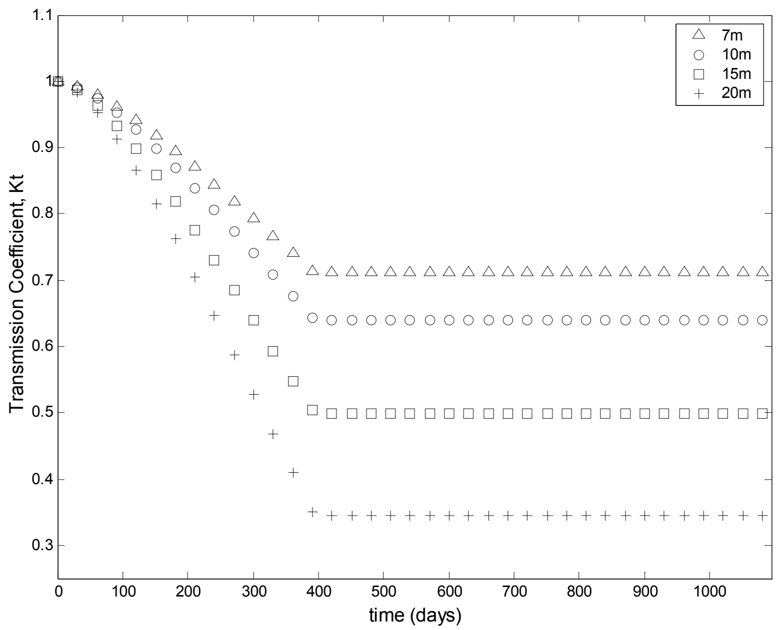

Figure 4.5. Transmission coefficient as a change in crest width of the structure.

The density changes of the oysterbreak produced similar patterns to the ones observed in the wave tank. There appeared to be an optimum number of slats/meter necessary to achieve a desired effect. The same transmission coefficient was achieved by all of the structures in the final growth stage, at a value of 0.35. The addition of slats/meter only modified the rate at which the transmission coefficient was reduced over time. The difference between the 2 and 3 slats/meter was less than the 0.5 and 1 slats/meter structures, which implies there is a point where the increasing of density does not significantly reduce the transmission coefficient.

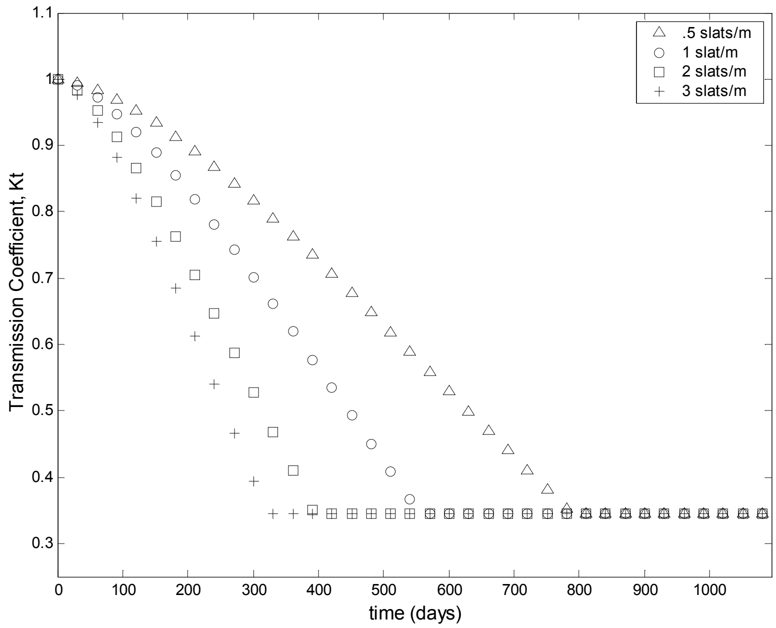

Figure 4.6. Transmission coefficient as density changes in the structure.

4.4.4 Change in the Growth Rate

The fourth comparison was made by varying the growth rate of the oysters on the oysterbreak (figure 4.7). There were four different growth rates tested in this comparison. The growth rates included 1, 2, 3, and 4 cm/yr. The model was run over a time period of 8 years. The spacing of the horizontal beams was 0.12 meters. The density of the structure was 3 slats/meter. The oysterbreak had a crest width of 20 meters and a crest height of 0.72 meters. The wave had a wave height of 0.4 meters and a wave period of 4 seconds. The depth at the toe of the structure was 1.11 meters.

The goal of this comparison was to determine what growth rate of oysters would not be adequate for the success of the oysterbreak. If the time period allowed for a successful deployment was 4 years, the oysterbreak would have reached full maturity in that frame of time. The only growth rate which did not meet this requirement was the lowest, 1 cm/yr. This growth rate did not achieve full maturity until 6 yrs. At 4 years, the transmission coefficient was only 0.60.

This analysis of growth rate would be excellent for design purposes, as it could determine the growth rate necessary for a specific site. In turn, a desired transmission coefficient could be established based upon the needs of the site. Various crest widths and structure densities could be evaluated to determine the best design. Cost to install the structure would then be considered.

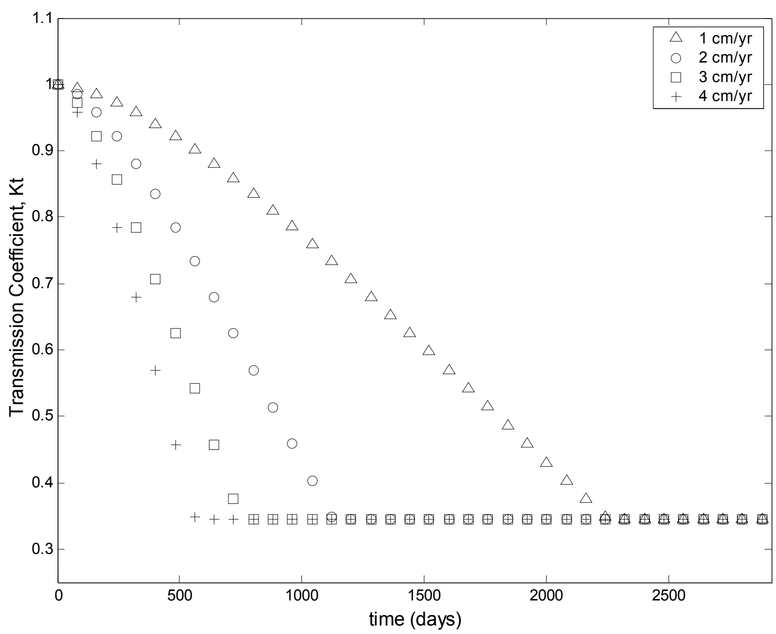

Figure 4.7. Transmission coefficient as growth rate changes.

4.4.5 Change in Crest Height of the Oysterbreak

The next comparison was made by varying the crest height of the oysterbreak (figure 4.8). There were three heights tested for this comparison. The heights included: 0.65, 0.70, and 0.75 meters. The model was run over a time period of 500 days. The spacing of the horizontal beams was 0.12 meters. The density of the structure was 2 slats/meter. The oysterbreak had a crest width of 20 meters. The wave had a wave height of 0.4 meters and a wave period of 4 seconds. The depth at the toe of the structure was 1.11 meters.

The goal was to analyze the effect of the rise in the crest height. It is suspected that as the oysters grow past the crest height (towards the water surface) the transmission coefficient would be reduced further. This was not taken into consideration for the purposes of this model; however, this factor has a significant effect. By increasing the crest height by 0.1 meters, the transmission coefficient is reduced from 0.50 to a value of 0.20. This factor could be included in future models. On the other hand, the results of this model will give conservative values based on the assumption that the crest height remains the same over time.

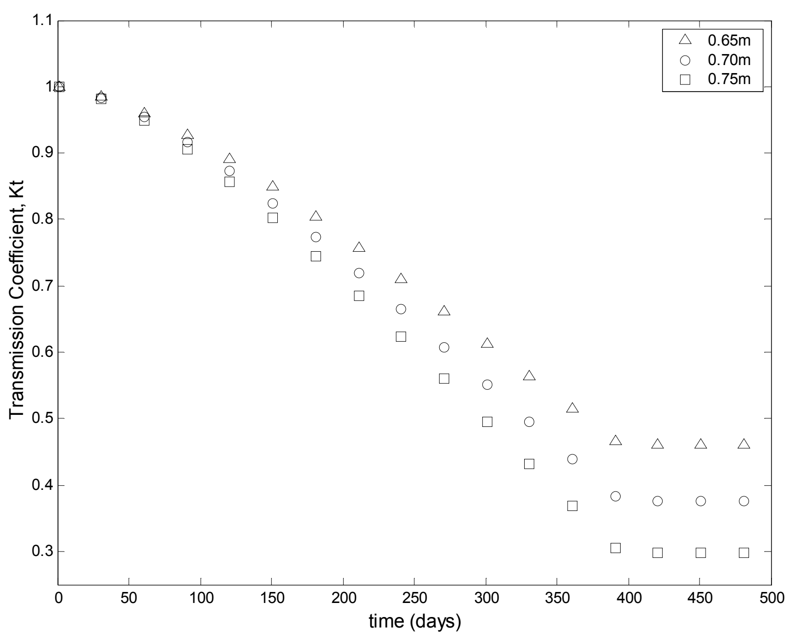

Figure 4.8. Transmission coefficient as the structure crest height changes.

4.4.6 Change in the Spacing of Horizontal Beams

The last comparison was made by varying the spacing of the horizontal beams on the oysterbreak (figure 4.9). There were four different spacings tested in this comparison.

The spacings included: 0.10, 0.12, 0.14, and 0.16. The model was run over a time period of 3 years. The density of the structure was 2 slats/meter. The oysterbreak had a crest width of 20 meters and a crest height of 0.72 meters. The wave had a wave height of 0.4 meters and a wave period of 4 seconds. The depth at the toe of the structure was 1.11 meters.

It was assumed that the spacing of the horizontal beams was directly correlated with the mean stone diameter in Ahrens' model. This assumption could not be fully confirmed in the wave tank experiments. The results indicate that the transmission coefficient decreases as spacing decreases. Although this implication is logical in theory, further experimentation is necessary for this relationship.

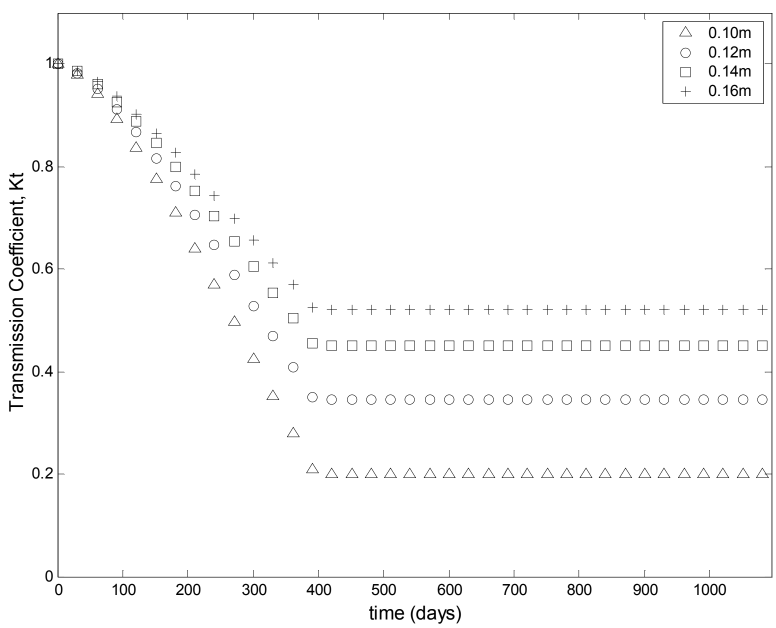

Figure 4.9. Transmission coefficient as spacing of the horizontal beams changes.

4.5 Limitations to the Predictive Model

This model was developed from the results produced by the wave tank experiments. Although Ahrens' model was developed through a different experimental setup, it was beneficial to relate the two models. The wave tank experiments and Ahrens' work were done on different scales and the wave tank setup was slightly different. On the other hand, the model developed through this work correlated well with the results from the wave tank (see figure 4.2). This model was established to predict the transmission coefficients from the time of deployment till the oysterbreak reaches full maturity. This model does not take into account any vertical growth of oysters toward the surface. However, the largest constraint of this model is its lack of verification in the field. In conclusion, while the model raises many questions it was useful in revealing fundamental trends between growth and wave reduction.

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CHAPTER 5: CONCLUSION

5.1 Settlement Patterns

Good oysterbreak design depends on depth of knowledge of physical and biological processes. It is important to understand how to alter the design for various environments and desired outcomes. The Louisiana coastal areas are ideal environments for oyster growth. The results from Grand Isle, LA, show the impact that predation can produce on growth patterns. In the absence of such predation pressure, a uniform growth pattern may be expected. The upper regions of coastal bays have a lower salinity where oyster drill populations are minimal if not nonexistent. In these areas, one would expect a significant increase in growth and survival. These are areas where the oysterbreak would be very successful. Future research should include the deployment of multiple oysterbreaks in areas of optimal growth conditions. This would produce knowledge of the system dynamics and resilience of this kind of artificially induced ecosystem. Future research should include selecting good fouling materials for oysterbreak construction. Other future research should include the effects of growth on shoreline change.

5.2 Wave Interaction

The wave interaction characteristics of the oysterbreak were determined in the wave tank experiments. The wave transmission coefficients were determined to decrease as growth occurred on the structures. The reflection coefficients increased as growth occurred on the structures. Most importantly the dissipation coefficients increased as growth occurred and a maximum value was achieved.

For design purposes, the Ahrens' predictive model can be used in the design of an oysterbreak. The oysterbreak transmission coefficients achieved similar values as the predicted Ahrens' values at the final growth stage. An oysterbreak will reduce wave energy at a mature growth stage very similar (or perhaps better due to vertical growth of oysters) to a rock submerged breakwater. Therefore, Ahrens' model may be used to size the oysterbreak for specific wave conditions.

Additionally, there was a maximum number of slats/meter needed to effectively dissipate wave energy. The 9.21 slats/meter structure was the most effective at dissipating wave energy for both wave conditions tested. It was also shown that a full size structure with 2 vertical slats/meter, could be used to effectively dissipate waves.

5.3 Modeling

The model developed through this correlates well with the results from the wave tank. The model would have to be verified in the field to determine its predictive capacity. None of the variables seemed to reveal any unexpected results. The spacing of the horizontal beams would have to be investigated more to support the assumption that the mean stone diameter correlates with it. The increase in height, due to vertical migration of oyster growth should be developed further in the model. As a whole, the model seemed to fit the data fairly well for the lower to intermediate densities. The higher densities were assumed to follow Ahrens predicted values. Also, a vertical growth component should be added into the model, which will cause the transmission to decrease further.

5.4 Future Work

The next step in this research would be to conduct a demonstration project in order to evaluate this technology in a real world situation. A proposed demonstration project is currently nominated for a CWPPRA project. This demonstration project would proceed in two parts. Part 1 would include the first year of study which will be on a small scale. In year 1, testing of three modular designs, examples shown in figures 5.1 and 5.2, will be carried out at a selected site. This would be done to prove out the construction, deployment, and applicability of these types of structures in the study site. Once the concept is proven on the small scale, a large scale operation, Part 2, would be implemented. A composite structure is planned for construction and deployment in the same scale as adjacent submerged rock breakwaters. A 50' x 600' structure is proposed to be constructed from the modular units tested in Part 1 of the project.

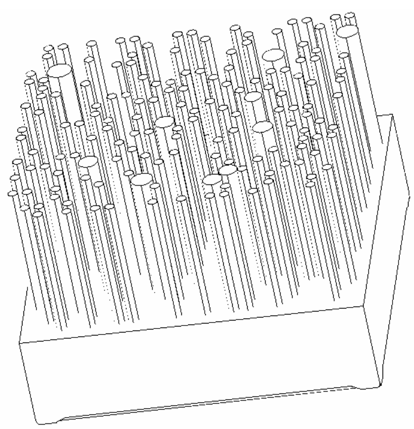

Figure 5.1. Picture of an example of a type of oysterbreak (a.k.a. the wave brush). This model includes a concrete base enhanced with organics and oyster shell. The top is composed of vertical bamboo rods.

The demonstration project would elaborate on the results found in Grand Isle and the wave tank experiments. Monitoring would be conducted on the oysterbreaks for a 5 year period. Wave dissipation and shoreline change would be evaluated every couple of months. The oyster growth would be measured by size, abundance, health (i.e. disease proliferation), and predation. Environmental parameters such as water temperature, salinity, and turbidity would also be measured. In the end, the design will be evaluated on its ability to survive and successfully inhibit erosion in the field.

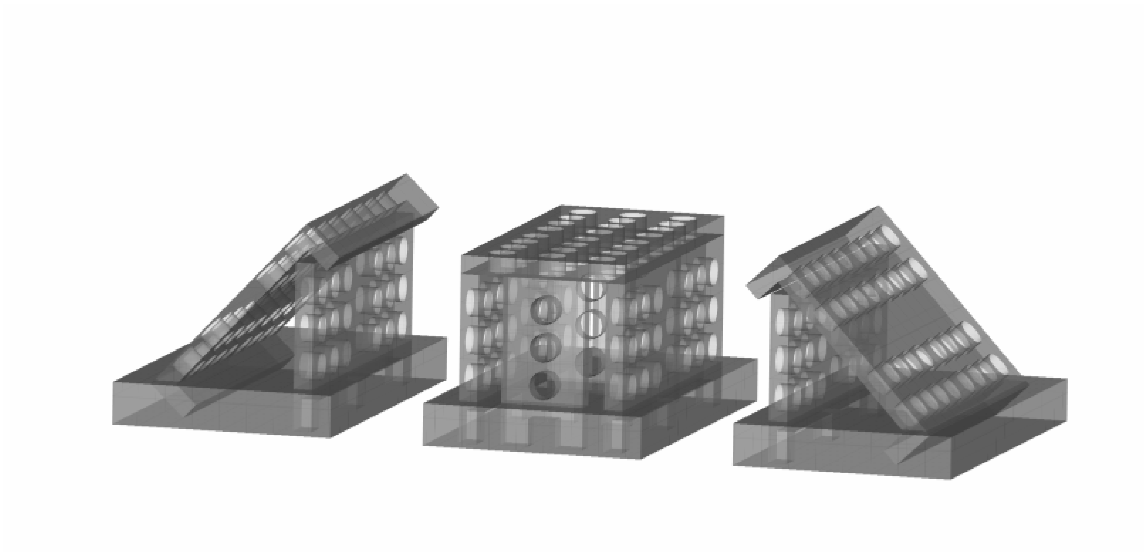

Figure 5.2. Picture of the concrete oysterbreak. It consist of modular units that could be placed together to create a composite structure of any width. Each modular unit is composed of porous faces that act as the vertical slats did in the wave tank.

In addition to the wave dissipation characteristics, the oysterbreak would be designed to attract a maximum number of oysters. A few preliminary experiments have been conducted with various mixtures of cement. Additives such as cotton seed, oyster shell and a foaming agent have been used (see figure 5.3). A mixture of cotton seed and cement was placed in Grand Isle, Louisiana with other materials such as PVC and French tubes. The cement mixture had larger and more abundant oyster populations than the other materials after 1 month. This suggests that this would be a superior material for oyster attraction. The idea would be to add organic materials (i.e. protein) to the cement and let it slowly release into the surrounding environment.

The further development of the model could be done through a demonstration project. A relationship between the growth of the oysters on the structure, wave dissipation and shoreline change should be established. In addition, many models have not taken into account the muddy bottoms that are so common in Louisiana. Hopefully, through the development of this model, this technology can be effectively utilized in a variety of environments.

Figure 5.3. Photograph of a cross section of concrete-cotton seed mixture. This mixture was placed in Grand Isle, Louisiana during oyster spawning season. It was seen that a significantly larger size oyster was growing on it compared to PVC placed in the same place (by 10x).

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APPENDIX A: GRAND ISLE OYSTERBREAK RAW DATA

French Tube Counts

DATE: 11/21/02

French Tube	Full Oysters (1)	Oyster Scars (2)	Barnacles (3)	Phoronid Worms (4)	Bryozoan Coverage (5)
Top	28	914	329	5	40%
Top	70	774	795	4	35%
3	12	270	715	11	50%
3	15	602	1486	15	30%
2	15	125	858	45	45%
1	9	86	1095	57	40%
1	10	54	1663	47	30%
Bottom	4	80	1025	73	55%
Bottom	8	25	1226	89	30%

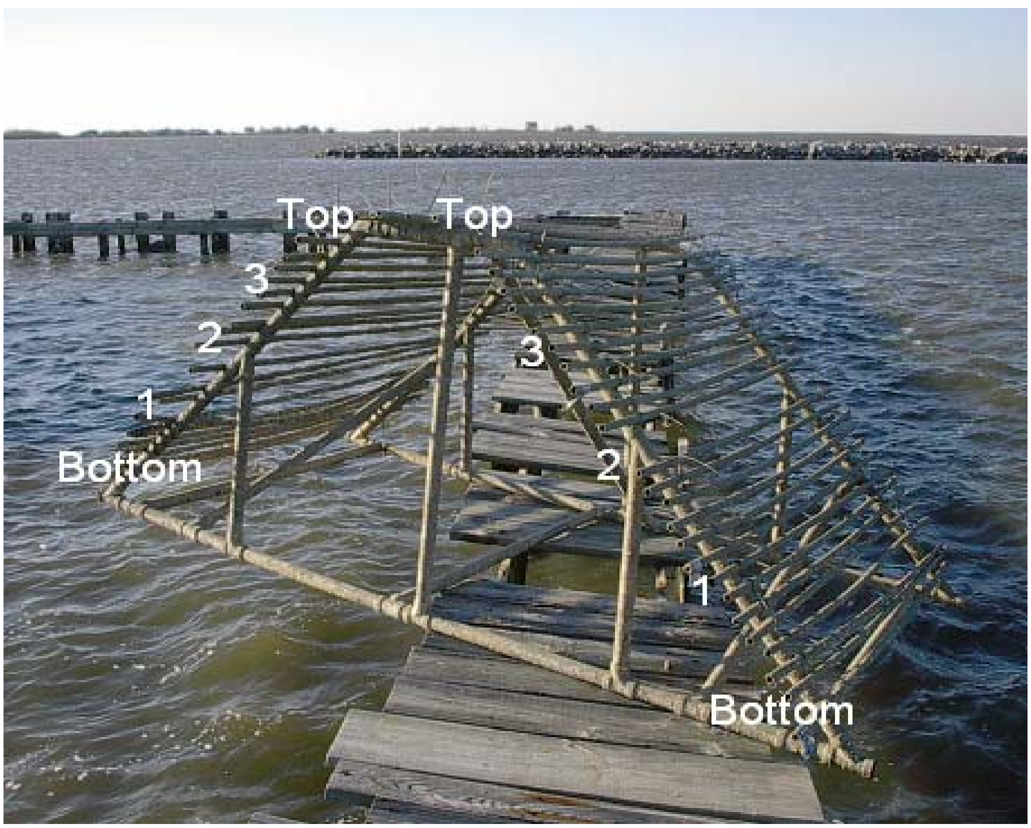

Figure A.1. Picture of the oysterbreak showing the position of the tubes taken from it.

APPENDIX B: OYSTER MEASUREMENTS

Oyster Measurements			Date 6/20/2003			
Oyster	Mass (kg)	Volume (L)	Density (kg/L)	Length (mm)	Height (mm)	Width (mm)
1	0.2	0.15	1.33	62	105	43
2	0.15	0.1	1.50	59	97	30
3	0.15	0.1	1.50	62	95	49
4	0.1	0.05	2.00	52	98	50
5	0.1	0.05	2.00	51	83	25
6	0.15	0.1	1.50	60	122	28
7	0.25	0.15	1.67	66	109	54
8	0.15	0.1	1.50	62	97	39
9	0.15	0.1	1.50	65	117	31
10	0.3	0.2	1.50	65	143	47
11	0.35	0.2	1.75	67	131	55
12	0.25	0.15	1.67	64	122	47
13	0.2	0.1	2.00	76	107	38
14	0.1	0.1	1.00	57	122	27
15	0.15	0.1	1.50	70	82	49
16	0.15	0.1	1.50	58	111	32
17	0.2	0.1	2.00	61	85	43
18	0.1	0.05	2.00	67	70	25
19	0.15	0.1	1.50	68	89	38
20	0.15	0.1	1.50	54	79	32
AVG	**0.175**	**0.11**	**1.62**	**62.3**	**103.2**	**39.1**
Std. dev.	**0.0678621**	**4.16754**	**0.2671861**	**6.165267**	**19.1520234**	**9.9042787**

APPENDIX C: TUBE COUNTS IN FLOW EXPERIMENTS

Type	Length	Count
CoatedPVC	120	151
CoatedPVC	120	116
CoatedPVC	120	106
CoatedPVC	120	86
CoatedPVC	90	155
CoatedPVC	90	119
CoatedPVC	90	135
CoatedPVC	90	204
CoatedPVC	60	244
CoatedPVC	60	178
CoatedPVC	60	201
CoatedPVC	60	381
CoatedPVC	30	251
CoatedPVC	30	151
CoatedPVC	30	124
CoatedPVC	30	191
FrenchTubes	120	79
FrenchTubes	120	65
FrenchTubes	120	66
FrenchTubes	120	121
FrenchTubes	90	72
FrenchTubes	90	91
FrenchTubes	90	71
FrenchTubes	90	139
FrenchTubes	60	61
FrenchTubes	60	121
FrenchTubes	60	76
FrenchTubes	60	83
FrenchTubes	30	110
FrenchTubes	30	69
FrenchTubes	30	84
FrenchTubes	30	132

Type	Height	Count
CoatedPVC	90	101
CoatedPVC	90	134
CoatedPVC	90	77
CoatedPVC	90	47
CoatedPVC	90	59
CoatedPVC	90	75
CoatedPVC	90	77
CoatedPVC	90	88
CoatedPVC	90	86
CoatedPVC	90	168
CoatedPVC	90	99
CoatedPVC	90	82
CoatedPVC	70	87
CoatedPVC	70	46
CoatedPVC	70	52
CoatedPVC	70	104
CoatedPVC	40	95
CoatedPVC	40	116
CoatedPVC	40	83
CoatedPVC	40	160
CoatedPVC	40	83
CoatedPVC	40	109
CoatedPVC	40	71
CoatedPVC	40	179
CoatedPVC	8	191
CoatedPVC	8	94
CoatedPVC	8	71
CoatedPVC	8	159
FrenchTubes	90	51
FrenchTubes	90	30
FrenchTubes	90	98
FrenchTubes	90	61
FrenchTubes	90	41
FrenchTubes	90	62
FrenchTubes	90	50
FrenchTubes	90	44
FrenchTubes	90	38
FrenchTubes	90	57
FrenchTubes	90	30
FrenchTubes	90	61
FrenchTubes	70	57

APPENDIX C: TUBE COUNTS IN FLOW EXPERIMENTS

Type	Height	Count
FrenchTubes	70	60
FrenchTubes	70	61
FrenchTubes	70	83
FrenchTubes	40	52
FrenchTubes	40	60
FrenchTubes	40	56
FrenchTubes	40	88
FrenchTubes	8	34
FrenchTubes	8	62
FrenchTubes	8	48
FrenchTubes	8	156

APPENDIX D: VELOCITY MEASUREMENTS IN FLOW EXPERIMENTS

7/31/2003

Grand Isle Flow Experiments

Water depth = 4 ft.

Velocity Profile

REP 1

		Wall velocity (ft/s)	3 ft inward(ft/s)	Center (ft/s)
SIDE BY THE INLET	Surface d=0	.2 ft/s	.17 ft/s	0 ft/s
	Middle d= 1.5 ft	.15 ft/s	.05 ft/s	0 ft/s
	Bottom d= 3 ft	.12 ft/s	.03 ft/s	0 ft/s
OPPOSITE SIDE	Surface d=0	0.8 ft/s	0.05 ft/s	0 ft/s
	Middle d= 1.5 ft	0.7 ft/s	0.05 ft/s	0 ft/s
	Bottom d= 3 ft	0.4 ft/s	0.05 ft/s	0 ft/s

REP 2

		Wall velocity (ft/s)	3 ft inward(ft/s)	Center (ft/s)
SIDE BY THE INLET	Surface d=0	0.2	0.17	0
	Middle d= 1.5 ft	0.15	0.05	0
	Bottom d= 3 ft	0.12	0.03	0
OPPOSITE SIDE	Surface d=0	0.8	0.05	0
	Middle d= 1.5 ft	0.7	0.05	0
	Bottom d= 3 ft	0.4	0.05	0

REP 3

		Wall velocity (ft/s)	3 ft inward(ft/s)	Center (ft/s)
SIDE BY THE INLET	Surface d=0	0.5	0.2	0
	Middle d= 1.5 ft	0.3	0.05	0
	Bottom d= 3 ft	0.2	0.05	0
OPPOSITE SIDE	Surface d=0	0.45	0.2	0
	Middle d= 1.5 ft	0.25	0.05	0
	Bottom d= 3 ft	0.15	0.05	0

APPENDIX E: SPAT PLATE COUNTS

DATE	ORGANISM	COUNT
514	barnacles	7
514	barnacles	5
514	barnacles	6
514	barnacles	6
514	barnacles	4
514	barnacles	4
514	barnacles	10
514	barnacles	10
514	bryozoans	34
514	bryozoans	10
514	bryozoans	40
514	bryozoans	90
514	bryozoans	10
514	bryozoans	25
514	bryozoans	50
514	bryozoans	95
514	oysters	0
514	oysters	0
514	oysters	0
514	oysters	0
514	oysters	0
514	oysters	0
514	oysters	0
514	oysters	0
514	serpulids	8
514	serpulids	1
514	serpulids	0
514	serpulids	6
514	serpulids	0
514	serpulids	1
514	serpulids	0
514	serpulids	5
529	barnacles	8
529	barnacles	4
529	barnacles	5
529	barnacles	7
529	barnacles	10
529	barnacles	4
529	barnacles	2
529	barnacles	1
529	bryozoans	0
529	bryozoans	0
529	bryozoans	0
529	bryozoans	0
529	bryozoans	0
529	bryozoans	0
529	bryozoans	0
529	bryozoans	0
529	oysters	14

APPENDIX E: SPAT PLATE COUNTS CONTINUED

DATE	ORGANISM	COUNT
529	oysters	6
529	oysters	20
529	oysters	11
529	oysters	10
529	oysters	13
529	serpulics	0
529	serpulids	0
529	serpulids	0
529	serpulids	0
529	serpulids	0
529	serpulids	0
529	serpulids	0
529	serpulids	0
625	serpulids	213
625	barnacles	338
625	barnacles	470
625	barnacles	489
625	barnacles	71
625	barnacles	68
625	barnacles	107
625	barnacles	23
625	bryozoans	25
625	bryozoans	15
625	bryozoans	10
625	bryozoans	15
625	bryozoans	40
625	bryozoans	12
625	bryozoans	10
625	bryozoans	15
625	oysters	2
625	oysters	2
625	oysters	7
625	oysters	8
625	oysters	4
625	oysters	2
625	oysters	2
625	oysters	6
625	serpulids	5
625	serpulids	4
625	serpulids	11
625	serpulids	6
625	serpulids	5
625	serpulids	18
625	serpulids	27
625	serpulids	38

APPENDIX F: WAVE TANK DATA

Rep	slope	Wave	growth	structure	r	Kt
1	0.051771	1	0	0	0.005225	0.873496
1	0.051771	1	0	6.948	0.005225	0.927667
1	0.051771	1	0	11.58	0.005225	0.82533
1	0.051771	1	0	20.843	0.005225	0.891566
1	0.051771	1	5.592375	0	0.008021	0.85713
1	0.051771	1	5.592375	6.948	0.008021	0.816741
1	0.051771	1	5.592375	11.58	0.008021	0.686303
1	0.051771	1	5.592375	20.843	0.008021	0.661475
1	0.051771	1	13.6305	0	0.01204	0.766321
1	0.051771	1	13.6305	6.948	0.01204	0.626239
1	0.051771	1	13.6305	11.58	0.01204	0.651846
1	0.051771	1	13.6305	20.843	0.01204	0.752189
1	0.051771	2	0	0	0.005225	0.965623
1	0.051771	2	0	6.948	0.005225	0.957387
1	0.051771	2	0	11.58	0.005225	0.908455
1	0.051771	2	0	20.843	0.005225	0.955403
1	0.051771	2	5.592375	0	0.008021	0.850096
1	0.051771	2	5.592375	6.948	0.008021	0.835355
1	0.051771	2	5.592375	11.58	0.008021	0.756401
1	0.051771	2	5.592375	20.843	0.008021	0.762282
1	0.051771	2	13.6305	0	0.01204	0.777189
1	0.051771	2	13.6305	6.948	0.01204	0.685795
1	0.051771	2	13.6305	11.58	0.01204	0.667721
1	0.051771	2	13.6305	20.843	0.01204	0.722911
2	0.053286	1	0	0	0.005225	0.905851
2	0.053286	1	0	6.948	0.005225	0.862308
2	0.053286	1	0	11.58	0.005225	0.841045
2	0.053286	1	0	20.843	0.005225	0.824526
2	0.053286	1	5.592375	0	0.008021	0.789786
2	0.053286	1	5.592375	6.948	0.008021	0.813207
2	0.053286	1	5.592375	11.58	0.008021	0.758888
2	0.053286	1	5.592375	20.843	0.008021	0.735716
2	0.053286	1	13.6305	0	0.01204	0.751608
2	0.053286	1	13.6305	6.948	0.01204	0.65652
2	0.053286	1	13.6305	11.58	0.01204	0.774314
2	0.053286	1	13.6305	20.843	0.01204	0.740671
2	0.053286	2	0	0	0.005225	0.963086
2	0.053286	2	0	6.948	0.005225	0.918611
2	0.053286	2	0	11.58	0.005225	0.880934
2	0.053286	2	0	20.843	0.005225	0.847511
2	0.053286	2	5.592375	0	0.008021	0.837652
2	0.053286	2	5.592375	6.948	0.008021	0.848776
2	0.053286	2	5.592375	11.58	0.008021	0.716816
2	0.053286	2	5.592375	20.843	0.008021	0.85376
2	0.053286	2	13.6305	0	0.01204	0.774633
2	0.053286	2	13.6305	6.948	0.01204	0.769337
2	0.053286	2	13.6305	11.58	0.01204	0.778078

Rep	slope	Wave	growth	structure	r	Kt
2	0.053286	2	13.6305	20.843	0.01204	0.737204
3	0.052921	1	0	0	0.005225	0.950129
3	0.052921	1	0	6.948	0.005225	0.965296
3	0.052921	1	0	11.58	0.005225	0.94462
3	0.052921	1	0	20.843	0.005225	0.900299
3	0.052921	1	5.592375	0	0.008021	0.979235
3	0.052921	1	13.6305	20.843	0.01204	0.813541
3	0.052921	2	0	0	0.005225	0.952218
3	0.052921	2	0	6.948	0.005225	0.911094
3	0.052921	2	0	11.58	0.005225	0.921965
3	0.052921	2	0	20.843	0.005225	0.905542
3	0.052921	2	5.592375	0	0.008021	0.915054
3	0.052921	2	5.592375	6.948	0.008021	0.894032
3	0.052921	2	5.592375	11.58	0.008021	0.843223
3	0.052921	2	5.592375	20.843	0.008021	0.837908
3	0.052921	2	13.6305	0	0.01204	0.870207
3	0.052921	2	13.6305	6.948	0.01204	0.823174
3	0.052921	2	13.6305	11.58	0.01204	0.710364
3	0.052921	2	13.6305	20.843	0.01204	0.786299
4	0.054514	1	0	0	0.005225	0.949192
4	0.054514	1	0	6.948	0.005225	0.955433
4	0.054514	1	0	11.58	0.005225	0.876915
4	0.054514	1	0	20.843	0.005225	0.942672
4	0.054514	1	5.592375	0	0.008021	0.942036
4	0.054514	1	5.592375	6.948	0.008021	0.8559
4	0.054514	1	5.592375	11.58	0.008021	0.752098
4	0.054514	1	5.592375	20.843	0.008021	0.804221
4	0.054514	1	13.6305	0	0.01204	0.770361
4	0.054514	1	13.6305	6.948	0.01204	0.648398
4	0.054514	1	13.6305	11.58	0.01204	0.677587
4	0.054514	1	13.6305	20.843	0.01204	0.644533
4	0.054514	2	0	0	0.005225	0.954496
4	0.054514	2	0	6.948	0.005225	0.901745
4	0.054514	2	0	11.58	0.005225	0.92481
4	0.054514	2	0	20.843	0.005225	0.886385
4	0.054514	2	5.592375	0	0.008021	0.882843
4	0.054514	2	5.592375	6.948	0.008021	0.857209
4	0.054514	2	5.592375	11.58	0.008021	0.831647
4	0.054514	2	5.592375	20.843	0.008021	0.854189
4	0.054514	2	13.6305	0	0.01204	0.838702
4	0.054514	2	13.6305	6.948	0.01204	0.779997
4	0.054514	2	13.6305	11.58	0.01204	0.797006
4	0.054514	2	13.6305	20.843	0.01204	0.815312
5	0.056486	1	0	0	0.005225	0.974884
5	0.056486	1	0	11.58	0.005225	0.850971
5	0.056486	1	0	20.843	0.005225	0.848226
5	0.056486	1	5.592375	0	0.008021	0.863184
5	0.056486	1	5.592375	6.948	0.008021	0.919875
5	0.056486	1	5.592375	11.58	0.008021	0.712931
5	0.056486	1	5.592375	20.843	0.008021	0.776604
5	0.056486	1	13.6305	0	0.01204	0.800416
5	0.056486	1	13.6305	6.948	0.01204	0.632158

APPENDIX F: WAVETANK DATA CONTINUED

Rep	slope	Wave	growth	structure	r	Kt
5	0.056486	1	13.6305	11.58	0.01204	0.703487
5	0.056486	1	13.6305	20.843	0.01204	0.69824
5	0.056486	2	0	6.948	0.005225	0.880453
5	0.056486	2	0	11.58	0.005225	0.832271
5	0.056486	2	0	20.843	0.005225	0.835525
5	0.056486	2	5.592375	0	0.008021	0.881341
5	0.056486	2	5.592375	6.948	0.008021	0.827082
5	0.056486	2	5.592375	11.58	0.008021	0.762054
5	0.056486	2	5.592375	20.843	0.008021	0.726018
5	0.056486	2	13.6305	0	0.01204	0.769581
5	0.056486	2	13.6305	6.948	0.01204	0.781682
5	0.056486	2	13.6305	11.58	0.01204	0.730766
5	0.056486	2	13.6305	20.843	0.01204	0.704138
6	0.054021	1	0	0	0.005225	1.01123
6	0.054021	1	0	6.948	0.005225	0.955471
6	0.054021	1	0	11.58	0.005225	0.94702
6	0.054021	1	0	20.843	0.005225	0.957392
6	0.054021	1	5.592375	0	0.008021	0.914345
6	0.054021	1	5.592375	6.948	0.008021	0.849863
6	0.054021	1	5.592375	11.58	0.008021	0.815069
6	0.054021	1	5.592375	20.843	0.008021	0.811296
6	0.054021	1	13.6305	0	0.01204	0.777071
6	0.054021	1	13.6305	6.948	0.01204	0.639286
6	0.054021	1	13.6305	11.58	0.01204	0.637787
6	0.054021	1	13.6305	20.843	0.01204	0.662069
6	0.054021	2	0	0	0.005225	0.931967
6	0.054021	2	0	6.948	0.005225	0.904609
6	0.054021	2	0	11.58	0.005225	0.886323
6	0.054021	2	0	20.843	0.005225	0.871112
6	0.054021	2	5.592375	0	0.008021	0.866962
6	0.054021	2	5.592375	6.948	0.008021	0.826542
6	0.054021	2	5.592375	11.58	0.008021	0.776824
6	0.054021	2	5.592375	20.843	0.008021	0.81213
6	0.054021	2	13.6305	0	0.01204	0.775819
6	0.054021	2	13.6305	6.948	0.01204	0.735732
6	0.054021	2	13.6305	11.58	0.01204	0.639249
6	0.054021	2	13.6305	20.843	0.01204	0.712414

APPENDIX G: WAVE TANK VIDEOS

SEE ATTACHED CDR FOR FILES

Click on files below to play videos of wave tank experiments. Videos will play through a QuickTime media player.

Control at wave condition 1

Control at wave condition 2

Rock breakwater at wave condition 1

Rock breakwater at wave condition 2

9.21 slats/meter structure at final growth in wave 1

9.21 slats/meter structure at final growth in wave 2

14.5 slats/meter structure at intermediate growth in wave 1

14.5 slats/meter structure at intermediate growth in wave 2

APPENDIX H: MATLAB PROGRAM

```
% All dimenstions are in meters, seconds, and days.
% time is represented in days.
% growth rate is in cm per year
% The radial growth is in meters and is represented as a function of time.
% The density is represented as slats/meter(full scale is four divided by what was
done in the wave tank.


% Input values of the real world conditions into the values below
time=[1:30:1095]
growthrate=7
density= 2
spacing=.16
WaveHeight=.4
WavePeriod=4
Depth=1.11
CrestWidth=20
CrestHeight=.72

% Scaling equations and matrices manipulation
growth=growthrate/36500.*time
r=growth/8
dens=density*4
sp= .03
sp1=sp-.001
z=(r >sp1)
q=(r<sp1)
z2=z.*sp1
q2=q.*r
r2=z2+q2

% These values are for what was observed in the wavetank
T=WavePeriod/2
hc=0.2032
ds=Depth/4
At=0.12129
Lp=T*sqrt(9.81*ds)
F=hc-ds
Hmo=WaveHeight/4
d50=0.02
```

APPENDIX H: MATLAB PROGRAM CONTINUED

```
% Run Ahrens equation for conditions in the wavetank
Aw=1/(1.0+(hc/ds)^1.188*(At/(ds*Lp))^.261*exp(.529*(F/Hmo)+.00551*(At^(3/2)/(d
50^2*Lp))))

% This is the oysterbreak transmission variable
x=Hmo^2./(Lp.*r2.^2.*dens)

% This is the predictive equation for predicting the wave transmission coefficient in
the wavetank
Ktw=1./(1+x.^-.7721)

% Matrices manipulation to set the transmission coefficient equal to Ahrens
predicted value when the transmission
% gets to the same value as Ahrens model predicted value
% (See Chapter 2: the difference between Ahrens predicted model and the final
growth were not significant)
Ktw1=(Ktw <Aw)
Ktw2=(Ktw>Aw)
Ktw3=Ktw1.*Aw
Ktw4=Ktw.*Ktw2
Ktw5=Ktw3+Ktw4

% ratio relating the predicted value to Ahrens predicted value
% This will allow the prediction of various sizes of the structure assuming that the
ratio stays the same in field conditions
ratio= ((1-Aw)-(1-Ktw5))./(1-Aw)

% These values are for the field wave conditions
% d50 is assumed to be the separation of the horizontal bars on the oysterbreak.
T=WavePeriod
hc=CrestHeight
ds=Depth
a=CrestWidth
b=2*hc+a
At=hc/2*(a+b)
Lp=T*sqrt(9.81*ds)
F=hc-ds
Hmo=WaveHeight
d50=spacing
% Ahrens predictive model to estimate minimum transmission achievable for that
size structure in those conditions
Ar=1/(1.0+(hc/ds)^1.188*(At/(ds*Lp))^.261*exp(.529*(F/Hmo)+.00551*(At^(3/2)/(d
50^2*Lp))))
```

APPENDIX H: MATLAB PROGRAM CONTINUED

```
% Formula to estimate the transmission coefficient in the specific conditions set for
a specific structure size and shape
% as growth occurs on the structure

Ktr= Ar + (1-Ar).*ratio ;

% Set Kt to not go above 1
Kta=(Ktr>1)
Ktb=(Ktr<1)
Ktc=Ktr.*Ktb
Ktd=Ktc+Kta

% Open figure and plot Kt as a function of time
FIGURE
plot(time,Ktd,'k+')
axis([0 1095 0 1.1])
xlabel('\fontsize{12} time (days)')
ylabel('\fontsize{12} Transmission Coefficient, Kt')
```

VITA

Matthew Campbell was born December 10, 1978, in Shreveport, Louisiana. He grew up in a small neighborhood in Haughton, Louisiana. In the spring of 1997, he graduated from Haughton High School in Haughton Louisiana. After high school he went off to Louisiana State University as a third generation Tiger. He entered the Biological Engineering Department in September 1998. He graduated from the department in May 2002. On October 5, 2002, he married his beautiful wife, Felicia. The summer after graduating, he took a teaching associate position in the Department of Biological and Agricultural Engineering at LSU. After a year, he enrolled in the graduate school. He graduated in December 2004.