The uplift resistance of Spartina Alterniflora in a Louisiana salt marsh

James Madison Bouanchaud III

Louisiana State University and Agricultural and Mechanical College

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_theses

Part of the Civil and Environmental Engineering Commons

Recommended Citation

https://digitalcommons.lsu.edu/gradschool_theses/3044

This Thesis is brought to you for free and open access by the Graduate School at LSU Digital Commons. It has been accepted for inclusion in LSU Master's Theses by an authorized graduate school editor of LSU Digital Commons. For more information, please contact gradetd@lsu.edu.
THE UPLIFT RESISTANCE OF SPARTINA ALTERNIFLORA IN A LOUISIANA SALT MARSH

A Thesis

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

in

The Department of Civil and Environmental Engineering

by

James M. Bouanchaud III
B.S., Louisiana State University, 2011
December 2013
ACKNOWLEDGEMENTS

I would like to thank my parents, Madison and Kay, and my brother, Stephen, for being positive role models and extreme supporters throughout my academic career. I believe without their unending support and care I would not be where I am today.

I want to express my most sincere thanks to my graduate advisor and committee chair, Dr. Guoping Zhang, for his charisma and positive attitude toward my research. I would also like to thank Dr. Murad Abu-Farsakh and Dr. Jongwon Jung for serving as committee members.

I would like to give special recognition to my fellow graduate students Hem Raj Pant and Kyle Parker for providing great friendship and support throughout my time as a graduate student. I would also like to thank Dr. Jie Gu for assisting with data collection.

I want to thank Louisiana State University, the DHS Southern Regional Research Initiative (SERRI), and the Louisiana Office of Coastal Protection and Restoration (OCPR) Coastal Sciences Assistantship Program for providing funding that made this research possible. I want to recognize LUMCON for providing tremendous support for our data collection trips.
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS ........................................................................................................ ii

LIST OF TABLES .................................................................................................................... iv

LIST OF FIGURES .................................................................................................................. v

ABSTRACT .............................................................................................................................. vii

1 INTRODUCTION .................................................................................................................... 1
   1.1 Background Information ............................................................................................. 1
   1.2 Objectives .................................................................................................................... 2
   1.3 Organization of Thesis ............................................................................................... 3

2 LITERATURE REVIEW ....................................................................................................... 4
   2.1 Importance of Vegetation to Coastal Marshes ............................................................ 4
   2.2 Biomechanical Properties of Vegetation ..................................................................... 4
      2.2.1 Composition of Stems ........................................................................................ 5
      2.2.2 Effects Caused By Turgor Pressure .................................................................. 7
   2.3 Plant Uprooting Failures ............................................................................................. 8
   2.4 Characteristics of *Spartina Alterniflora* .................................................................. 9
   2.5 Development of a Testing Apparatus to measure uprooting resistance ................. 11
      2.5.1 Previous Testing Methods from Literature ......................................................... 11

3 TESTING DEVICES AND METHODOLOGY .................................................................... 13
   3.1 Field Site Locations and Descriptions ......................................................................... 13
   3.2 Apparatus Developed for Testing *S. Alterniflora* ...................................................... 13
   3.3 Field Testing Procedure ............................................................................................. 16

4 RESULTS AND DISCUSSION ............................................................................................. 21
   4.1 Terrebonne Bay Data .................................................................................................. 21
   4.2 Bay Jimmy Data ......................................................................................................... 24
   4.3 Overall Data ............................................................................................................... 27
   4.4 Effects of Oil Contamination ...................................................................................... 33
   4.5 Recommendations for Improvement to Future Studies ............................................ 34

5 CONCLUSION ..................................................................................................................... 37

6 REFERENCES ....................................................................................................................... 39
LIST OF TABLES

Table 4.1 Summary of Data Collection Trips.................................................................................. 21
Table 4.2 Summary of Failure modes of Samples Collected.............................................................. 31
LIST OF FIGURES

Figure 1.1 Projected land loss in Louisiana through 2050. (USGS, 2011) .................................. 1
Figure 2.1 Stress vs. Strain curve for a plant cell (Niklaus, 1989) ........................................... 6
Figure 2.2 Effects of Turgor Pressure on plant cells. (Niklaus, 1992) ....................................... 8
Figure 2.3 Vegetation Providing (a) Slope Failure Resistance and (b) Shallow Soil Stabilization. .................................................................................................................. 9
Figure 2.4 Spartina Alterniflora in Terrebonne Bay ................................................................. 10
Figure 2.5 S. Alterniflora resisting waves .............................................................................. 11
Figure 3.1 Aerial Image of Terrebonne Bay ............................................................................ 14
Figure 3.2 Aerial Image of Bay Jimmy .................................................................................... 14
Figure 3.3 Testing Setup for Uprooting Resistance ................................................................. 16
Figure 3.4 Worm Geared Winch mounted to the top of the tripod......................................... 18
Figure 3.5 Inline Load Cell used to measure the uprooting force ...................................... 19
Figure 3.6 U-Clamp Fastened to Plant Stem ......................................................................... 19
Figure 3.7 Hole in the ground left after plant has been uprooted. .................................... 20
Figure 3.8 Photo showing operator installing U-Clamp ......................................................... 20
Figure 4.1 Comparison of Uprooting Force vs Stem Diameter in Terrebonne Bay ........ 22
Figure 4.2 Comparison of Uprooting Resistance in Terrebonne Bay with Stem Height. 23
Figure 4.3 Comparison of Stem Height and Stem Diameter in Terrebonne Bay .......... 23
Figure 4.4 Uprooting Resistance vs. Stem Diameter in Bay Jimmy ................................. 24
Figure 4.5 Uprooting Resistance vs Stem Height in Bay Jimmy ........................................ 25
Figure 4.6 Relationship of Stem Height and Stem Diameter in Bay Jimmy ................. 26
Figure 4.7 Uprooting Resistance vs Stem Diameter for all samples collected ............ 27
Figure 4.8 Uprooting Force vs Stem Height for all data collected. .................................. 28
Figure 4.9 Comparison of Stem Height and Stem Diameter from all samples collected.

........................................................................................................................................... 29

Figure 4.10 Failure modes observed in the field. ................................................................. 31

Figure 4.11 Box and Whisker Plot of breaking force. ......................................................... 32

Figure 4.12 Breaking Force vs Stem Diameter for all plants failed at the stem. .......... 33
ABSTRACT

The uprooting resistance of *Spartina Alterniflora* was measured in Terrebonne Bay and Bay Jimmy, both of which are located in Louisiana. The parameters collected included plant uprooting resistance, stem diameter, and stem height. Seasonal variations and site specific properties were considered. A device was designed and constructed that was able to perform the specific testing under the constraints of the field site. The device consisted of a winch mounted to a tripod and connected to an inline load cell to measure the uprooting resistance. The data sets were analyzed to determine the relationship between the uprooting resistance and the physical properties of the plant (stem diameter and stem height). The data also examined to see the effects that contamination of the Bay Jimmy site. This vegetation data has the ability to be used in large scale models that consider the role that vegetation plays in wave attenuation and storm surge reduction.
1 INTRODUCTION

1.1 Background Information

The erosion of coastal wetlands is currently a huge issue in the United States. These wetlands are being destroyed at an alarmingly fast rate. The processes that cause this land loss are attributed to both natural and human causes. Examples of natural events that cause erosion of coastal wetlands include strong hydrodynamic forces from waves, powerful storms including both tropical and extratropical cyclones, and storm surge. Human actions that contribute to the disappearance of coastal wetlands include wake from heavy marine traffic, creation of river diversions and other control structures such as levees and dams, and pollution discharge. In the time period of 1932-2010, the total coastal area lost in Louisiana was 1,883 square miles, and the rate of loss from 1985-2010 was 16.57 square miles per year (Couvillion et. al., 2011). Louisiana is projected to lose an additional 513 square miles by 2050. This land loss is

Figure 1.1 Projected land loss in Louisiana through 2050. (USGS, 2011)
shown in Figure 1.1.

The coastal wetlands are very valuable to the state of Louisiana. They provide protective barriers against powerful storms and also present a means to make a living through commercial fishing and other activities for the people living nearby. The protection and restoration of these wetlands is vital for the people of Louisiana to continue their way of life in the future. One way of maintaining the wetlands is studying the native vegetation’s ability to resist the forces that exist in its environment.

1.2 Objectives

The objective of this research is to determine the required tensile force to remove the vegetation from the ground. The breaking force obtained will then be compared to the physical properties, including stem height and stem diameter, of the vegetation. Since many types of vegetation exist, this study focuses on a specific species, *Spartina Alterniflora*, at two different sites. The main objectives of this research include:

1. Determining the tensile force that is required to remove the plant from the ground.
2. Determining if a relationship of stem height and stem diameter to the breaking force exists.
3. Comparing results from different sites to determine if the possibility of a universal relationship exists.
4. Studying the effect that crude oil contamination has on the vegetation.
5. Determine if seasonal variation has any potential effect on the vegetation’s response.
1.3 Organization of Thesis

Chapter 1 of the document gives background information on coastal erosion and discusses the objectives of the study.

Chapter 2 reviews literature concerning vegetation’s role in a coastal marsh and its potential to reduce erosion. The biomechanical properties of vegetation are examined in addition to reviews of devices used to test uprooting resistance of vegetation.

Chapter 3 covers the testing process and equipment used in gathering data.

Chapter 4 presents and discusses the results of the data collected for this study in addition to discussing recommendations for future research.

Chapter 5 summarizes and concludes the work that was conducted.
2 LITERATURE REVIEW

2.1 Importance of Vegetation to Coastal Marshes

Vegetation plays an important role in a coastal wetland’s ability to resist erosive processes caused by hydrodynamic forces and wind driven forces. Many studies have shown that healthy vegetation in a coastal wetland has shown the ability to reduce the height of the waves acting upon the marsh (Knutson et al., 1982; Feagin et al., 2009; Roland et al., 2005). The reduction in wave height is significant because the erosive turbulent stresses caused by the waves are reduced. Another important contribution from vegetation to the stability of a coastal wetland is its ability to trap sediment. With the reduction in turbulent stresses from the flow, some suspended sediment in the water column is removed and trapped by the vegetation (Lopez and Garcia, 1998). Another added benefit of vegetation is the increased soil shear strength in the upper layers due to the rooting systems of the vegetation (Mickovski et al., 2009; van Eerdt, 1985). Higher soil shear strength means that the soil has a greater ability to resist failure. The combination of the stems above the ground and the roots below the ground provide a coastal marsh with the ability to resist erosion and maintain stability when hydrodynamic forces are acting on them.

2.2 Biomechanical Properties of Vegetation

The biomechanical properties of vegetation are studied to gain a better understanding of behavior and response when subjected to external loads. Some of the more common properties studied are stiffness, bending strength, and tensile strength. Stiffness is a property that describes the vegetation’s capacity to resist deformation when an external loading is applied to the plant. The bending strength of the vegetation
describes the ability of the plant to resist a load causing the plant to bend. The stiffness and bending strength of vegetation are important properties for determining the vegetation’s resistance to fluid flow. These properties are a function of the plant’s size, shape, and cellular composition. The tensile strength of the plant describes the vegetation’s resistance to uplifting forces. Tensile strength is important because it reflects the vegetation’s ability to resist forces that cause uprooting from the soil.

2.2.1 Composition of Stems

The plant’s stem contains tissues and fibers that affect the biomechanical properties of the plant. The mechanical behavior of the cell wall is due to the material properties of the cellulose, which has a high tensile strength and capacity for extension (Niklas, 1992). The plants also possess strong, stiff fibers that are embedded in soft tissues (Schlugasser and Witzum, 1992; Niklas, 1992). These stiff fibers, which are made of cellulose material, are considered the main source of strength within the stem, and the strength contribution from the soft tissue is negligible except for the fact that it fixes the stiff fibers within the stem (Schlugasser and Witzum, 1997). The arrangement of these fibers within the stem is considered to be anisotropic. This fact allows the plants to achieve stability against bending and tension, but the plant is susceptible to local failures in portions of the stem with a smaller amount of stiff tissues due to the anisotropic arrangement (Schlugasser and Witzum, 1997). Figure 2.1 demonstrates the different responses of a plant stem as the stress on the stem increases. There are four regions shown:

- Linear Elastic region: This is the region where the stress and strain have a linear correlation and no permanent deformation occurs in this region.
Elastic Buckling region: When the loading on the plants cells reaches a point at which permanent deformation begins to occur the plant cells are undergoing an elastic buckling that causes cells to lose some of their original shape. At this point the cells can still function structurally.

Plastic Collapse Region: This is the region that represents loading on the plants cells that is approaching the maximum capacity of the plants strength. As the load reaches this maximum capacity cells being to collapse.

Densification Region: When the loading exceeds the plastic collapse region and reaches densification, the response of the plant cells depends upon what type of load is applied. For plant cells subjected to tensile loading the cells will fracture, and for plant cells subjected to compressive loading the cells will crush. In both instances the plant has reached a point...
to where it no longer possesses any viable way to sustain a loading. It is important to note that the strain will increase significantly as the loading continues throughout this region.

2.2.2 Effects Caused By Turgor Pressure

Turgor pressure is another factor that contributes to plant stiffness. Turgidity refers to the degree of hydration within cellular protoplasts (Niklas, 1992). A formal definition of turgor pressure is the difference between water potential and solute potential. Turgor pressure does not change stiffness determined from the second moment of area of the plant, but does alter the apparent stiffness of the plant (Niklas, 1989). The effect of turgor pressure is felt by the plant when the cells are placed in a state of axial tension, which is similar to pre-stressing a structural element (Niklas, 1992). A higher turgor pressure corresponds to a higher stiffness value for the plant. It is important to note that when a plant is dead that the contribution from turgor pressure is negligible when measuring plant stiffness. Figure 2.2 shows the effect that the introduction of Turgor Pressure has on Plant Stiffness. Figure 2.2A shows an initial plant with a stiff wall enclosing soft tissues. When Turgor Pressure is introduced in Figure 2.2B, the soft tissue in the stem changes to become a stiff element in Figure 2.2C.

The “core” shown in Figure 2.2C provides additional strength to the plant stem, and allows the plant to withstand more force. This additional strength provides the plant with stronger resistance to potential dangers such as roaming animals, strong wind forces, and wave forces.
2.3 Plant Uprooting Failures

The use of vegetation as a means of soil stabilization is an inexpensive alternative to more traditional geotechnical methods. Vegetation has been used as a means to protect against shallow slope failures (Fig 2.3a) or to stabilize shallow topsoil (Fig 2.3b).

![Diagram of soil stabilization using vegetation](image)

Figure 2.2 Effects of Turgor Pressure on plant cells. (Niklaus, 1992)

The mechanism for the slope stabilization is the placement of roots through the soil shear plane to provide additional resistance to circular failure. The problem with the reinforcement rises when the critical shear plane occurs below the depth of root...
penetration. If the slope fails below the depth of the roots, the vegetation, as a result will be uprooted and be unable to reestablish growth. When the vegetation is subjected to an uplift force, the roots, soil, and plant stem serve as resistance to failure. The plant stem is able to hold a tensile load because of the cellulose, which has a high tensile capacity, in the cell walls, and the turgor pressure that has developed within the stem. The stem also transfers load to the root system, which acts an anchor against pullout from the soil. The ability of the roots to successfully resist the load is determined by the tensile capacity of the roots in conjunction with the frictional interface between the soil and the roots. The amount of friction that exists between the soil and roots depends upon several factors including but not limited to soil composition, soil properties, root composition, root density, root depth, and microbial activity.

![Diagram of vegetation providing failure resistance and shallow soil stabilization.](image)

**Figure 2.3** Vegetation Providing (a) Slope Failure Resistance and (b) Shallow Soil Stabilization.

### 2.4 Characteristics of *Spartina Alterniflora*

*Spartina Alterniflora*, also known as smooth cordgrass, is the dominant emergent grass species found growing along tidal saltmarshes of the Atlantic and Gulf Coasts (USDA-NRCS, 2005). This plant is used in the restoration of coastal marshes because
of its capacity to absorb wave energy and trap sediments. This plant possesses several characteristics that allow it to survive in many different environments. Smooth cordgrass can grow in the pH range of 3.7 to 7.9 and has a salinity tolerance of up to 35 parts per thousand (USDA-NRCS, 2005). Spartina Alterniflora is classified as a warm season perennial with the seed head emerging around September or October, and the pollination process is wind driven (USDA-NRCS, 2005). The plant’s growth and density along the shore depends on the site conditions such as elevation, shoreline slope, and the site’s vulnerability to flooding (USDA-NRCS, 2005). The plant typically grows to a height of two to seven feet with diameter up to half an inch (USDA-NRCS, 2005).

Figure 2.4 *Spartina Alterniflora* in Terrebonne Bay
2.5 Development of a Testing Apparatus to measure uprooting resistance

This study required the use of a device that was capable of measuring the tensile strength of *Spartina Alterniflora* in the field. Since site access is by marine vessel only, the device needed to be portable, light, and easily stored within a boat. Research indicated that no device meeting the required specifications was available commercially, and so a device was designed and was constructed to meet the requirements necessary to carry out the field tests. Below is a sampling of some of the devices and testing methods that were reviewed.

2.5.1 Previous Testing Methods from Literature

Many studies have been performed to determine the uprooting strength of different plant species. The method used by Mickovski in 2005 to test Vetiver grass utilized a 3 mm diameter PVC rope that was attached to the plant with a loop and was connected to a digital force gage. The rope was pulled parallel to the surface to apply
the load. In a study performed by Stokes in 2007 on bamboo, a similar method was used, but the pulling device was anchored to a nearby tree. Other researchers extracted samples from the field and performed tests in the laboratory (Feagin et al. 2009; De Baets et al., 2008).

After reviewing these different methods and others, the conclusion was reached that none were suitable for the research required for this project. Laboratory tests are not ideal because the plants are moved from their native setting and the results may not reflect all factors affecting the process. The process employed by Stokes is not possible because no vegetation exists in a saltmarsh capable of sustaining the load from a pulling device. Mickovski’s method is not ideal either because the operator may sink in the soft soil while performing the test.
3 TESTING DEVICES AND METHODOLOGY

Data for this research was collected from two different sources. Testing was conducted on in-situ samples at both Terrebonne Bay and Bay Jimmy. The sampling was performed using the apparatus designed and constructed for this research.

3.1 Field Site Locations and Descriptions

The first site for this research is located in Terrebonne Bay (Fig. 3.1) near Cocodrie, LA. The coordinates for this site are 29° 13’ 25.06” N, 90° 36’ 21.4” W. This location is a saltmarsh that consists of mostly *Spartina Alterniflora*, and shows no visible signs of pollution or contamination. The second research site is located in Bay Jimmy (Fig 3.2), which is just west of the Mississippi River and near Barataria Bay. The site is located at 29° 26’ 40.23” N, 89° 53’ 19.93” W. This site is similar to the Terrebonne Bay location with respect to the fact that it has an abundant population of *Spartina Alterniflora*. The main difference is that the Bay Jimmy location is heavily contaminated with crude oil from the Deepwater Horizon Oil Spill that occurred in 2010.

3.2 Apparatus Developed for Testing *S. Alterniflora*

The device (Fig. 3.3) required to perform tests in the field needed to meet the following performance criteria:

1. Possess a relatively low weight because the device must be carried on site to different locations on the marsh.
2. Possess the ability to be stored efficiently because limited space exists while traveling to the site.
Figure 3.1 Aerial Image of Terrebonne Bay

Figure 3.2 Aerial Image of Bay Jimmy
3. Ability to make adjustments in the marsh with ease because the availability of tools or other adjustment devices is limited due to the transportation process.

4. Possess an easily repeatable procedure so that multiple samples can be taken efficiently.

5. Possess the ability to resist sinking into the marsh, when the surface conditions were very weak.

After evaluating several options, the chosen design included the following components: tripod with slight modification, worm geared winch, 3/16" braided steel wire, in-line tension measuring load cell with data logger, a U-shaped clamp, and wooden bearing plates.

The tripod was chosen as the frame because it was lightweight, and folded so that it could be easily stowed. An aluminum mount was added to the head of the tripod so that the winch could be easily attached. A worm geared winch was selected instead of a ratcheting winch because of the ratcheting winch’s potential to have a malfunction in the field. Another advantage of the worm geared winch is that its design allows for more consistent spooling of the wire. The capacity of the winch is 2,000 pounds. The steel wire, which was included with the purchase of the winch, is very durable and also has the same high capacity load rating. The load cell has a 500 pound capacity, and the data logger supplies the voltage to the load cell in addition to recording the data. The U-shaped clamp is used to connect the plant to the steel wire. The bearing plates have holes drilled in them so that the tripod legs can be placed through the holes. The load applied to the tripod is distributed to each of the three legs and then to the bearing
plates, which are in contact with the surface. The purpose of the bearing plates is to prevent the tripod legs from sinking into the soft surface soil.

![Figure 3.3 Testing Setup for Uprooting Resistance](image)

### 3.3 Field Testing Procedure

The instructions to prepare and to operate the device in the field are described as follows:

1. The first step before assembling the device for use is to select a site that is suitable for testing. The site should not have any plants that have been damaged by any means of human activity, which means do not select a site where people are walking or placing equipment.
2. Place the bearing plates on to the ground with enough spacing so that the sampling area below the tripod head will not be affected by any load transmitted to the soil from the bearing plates.

3. Place the tripod legs through the holes of the bearing plates and make sure that the tripod head is leveled.

4. Place the winch on the aluminum mount and secure it using the bolt. Make sure that the steel wire is placed through the center hole in the tripod.

5. Connect the load cell to wire using the eye bolts and make sure that the load cell is zeroed.

6. Connect the end of the steel wire to the plant using the U-bolt clamps. Make sure that the connection is secure by using a wrench to tighten the nuts on the clamp.

7. Before beginning the test, manually inspect the connection to ensure enough friction exists between the clamp and the connected elements.

8. Begin the test by turning the turning the shaft on the winch to pull on the wire. The pulling should be done at a constant rate and should cease when the plant is removed from the ground. It is important that the operator never steps between the legs of the tripod in order to prevent any kind of disturbance that may alter the results of the test.

9. Make sure to remove the plant from the clamp and label it. Place the plant in a bucket containing seawater so that the plant can be measured upon returning home.
The plants selected for testing should be chosen randomly and without bias. The testing device should be moved to another location on site after at most 5 tests to ensure that the results are valid and have not been affected by the previous tests. A total of 15 samples were taken per trip to account for variability.

Figure 3.4 Worm Geared Winch mounted to the top of the tripod.
Figure 3.5 Inline Load Cell used to measure the uprooting force

Figure 3.6 U-Clamp Fastened to Plant Stem
Figure 3.7 Hole in the ground left after plant has been uprooted.

Figure 3.8 Photo showing operator installing U-Clamp
4 RESULTS AND DISCUSSION

After tests were performed in the field, the plants were measured for stem height and stem diameter. The diameter is measured at approximately one fourth of the stem height as measured from the bottom of the plant specimen. The stem height is determined by measuring from the base of the plant to the last green leaf coming off of the plant. The measurements are taken with a ruler for stem height and a caliper for stem diameter. Table 4.1 summarizes the locations visited.

Table 4.1 Summary of Data Collection Trips

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/13/11</td>
<td>Terrebonne Bay</td>
</tr>
<tr>
<td>3/5/2012</td>
<td>Terrebonne Bay</td>
</tr>
<tr>
<td>3/26/12</td>
<td>Bay Jimmy</td>
</tr>
<tr>
<td>4/18/12</td>
<td>Bay Jimmy</td>
</tr>
<tr>
<td>7/6/12</td>
<td>Terrebonne Bay</td>
</tr>
<tr>
<td>7/23/12</td>
<td>Terrebonne Bay</td>
</tr>
<tr>
<td>12/11/12</td>
<td>Terrebonne Bay</td>
</tr>
</tbody>
</table>

4.1 Terrebonne Bay Data

Figure 4.1 shows the Stem Diameter of each plant tested compared with its corresponding uprooting force. The linear regression shows a coefficient of determination value of 0.15781, which indicates that the relationship of stem diameter to the uprooting force is not very strong, but it does suggest that possibly the stem diameter does possess some influence in the uprooting resistance of the plant. The
data shows a loose positive correlation between stem height and stem diameter, but the stem diameter cannot be used as a sole predicative measurement for estimating the uprooting force in Terrebonne Bay.

Figure 4.2 shows the stem height of each plant compared with the uprooting force recorded in the field. The linear regression provides the coefficient of determination value of 0.00348, which is incredibly low. Given the nature of the relationship, the stem height likely possesses no influence over the uprooting resistance of the plant in the field. Since there is not a very strong relationship between uprooting resistance and stem diameter, the next step in evaluation would be to see if a damaged stem alters the results.

\[
y = 55.705x + 17.218 \\
R^2 = 0.1568
\]

Figure 4.1 Comparison of Uprooting Force vs Stem Diameter in Terrebonne Bay
Figure 4.2 Comparison of Uprooting Resistance in Terrebonne Bay with Stem Height.

Figure 4.3 Comparison of Stem Height and Stem Diameter in Terrebonne Bay
Figure 4.3 shows the relationship between stem height and stem diameter. This data is interesting because the coefficient of determination, which is 0.04649, shows that there is no significant relationship between the stem height and the stem diameter. This result also implies that a combination of the stem height and the stem diameter of the plant are independent of each other. The growth rate of each one must be controlled by different elements within the coastal environment in which this vegetation grows.

4.2 Bay Jimmy Data

![Image](image.png)

Figure 4.4 Uprooting Resistance vs. Stem Diameter in Bay Jimmy

The measured uprooting resistance compared with the stem diameter in Bay Jimmy is shown in Figure 4.4. The data shows a coefficient of determination of 0.56233 and a positive linear relationship between the stem diameter and the uprooting resistance.
The measured correlation here is much higher than the one in Terrebonne Bay, albeit with a smaller data set. This relationship does imply that for the stem diameter in Bay Jimmy may be much more of a controlling variable on the uprooting resistance due to the conditions of the site.

Figure 4.5 shows the relationship between the stem height and the uprooting resistance measured in Bay Jimmy. The coefficient of determination for this data set is 0.31517 and the relationship of this data is generally positive. Like the relationship with stem diameter shown previously, the relationship between uprooting force and stem height is shown to be increasing based on the limited data acquired from this site. The coefficient of determination value also implies that there is a slight correlation between the stem height and the uprooting resistance.

![Breaking Force vs Stem Height in Bay Jimmy](image)

\[ y = 0.4843x + 16.584 \]

\[ R^2 = 0.3152 \]

Figure 4.5 Uprooting Resistance vs Stem Height in Bay Jimmy
Figure 4.6 examines the relationship between the measured stem height and stem diameter in Bay Jimmy. Like the relationship with the uprooting force, the relationship between the stem diameter and stem height demonstrates a somewhat positive correlation. The coefficient of determination is 0.43008 and shows that a correlation between stem height and stem diameter does exist in Bay Jimmy. This result is different than that of Terrebonne Bay, which did not demonstrate any correlation between the two measured physical properties of the plant. It is important to note that this data is much more limited than that of Terrebonne Bay.
4.3 Overall Data

Figure 4.7 examines the measured uprooting resistance against the stem diameter for the combined data from Terrebonne Bay and Bay Jimmy. The coefficient of determination from the linear regression is 0.15766. This trend shows that the stem diameter possesses some impact on the uprooting force, but does not possess enough influence to be considered as a sole predicative measure. Also, the data is skewed toward that of Terrebonne Bay because the number of samples collected in Terrebonne Bay exceeds that of the samples collected in Bay Jimmy.

Figure 4.7 Uprooting Resistance vs Stem Diameter for all samples collected

\[ y = 50.048x + 17.258 \]

\[ R^2 = 0.1577 \]
In Figure 4.8, the relationship between stem height and stem diameter in all plants sampled is shown. The coefficient of determination for this data set is 0.00541, which shows little or no significance. This trend implies that the stem diameter does not possess any influence on the measured uprooting resistance of the vegetation, and that this parameter should not be used in predicative models. Like the previous data set, this data is skewed in the direction of the data collected from Terrebonne Bay due to the fact that the number of samples collected is much greater than the samples collected from Bay Jimmy.

![Graph showing the relationship between pulling force and stem height.](image-url)

Figure 4.8 Uprooting Force vs Stem Height for all data collected.
Figure 4.9 examines the overall relationship between the stem height and stem diameter. The data set shows that the relationship between the height and diameter is not very strong. The coefficient of determination is shown as 0.12133. This value implies that while some correlation is present between the two values, the significance of the correlation is weak and more than likely the two parameters are influenced by different environmental conditions. The data reflects the large amount of samples collected in Terrebonne Bay compared with Bay Jimmy.

Figure 4.9 Comparison of Stem Height and Stem Diameter from all samples collected.
While the samples were taken, the method of failure was also noted. The vegetation can fail in three different ways:

1. The stem of the plant would break or tear at some portion above the ground or more commonly at the point where the stem entered into the ground to connect to the roots.

2. The soil in which the plant is rooted could fail which would result in the plant pulling out of the ground after the roots had broken.

3. The roots of the plant would fail and the plant would then be uprooted after the surrounding soil, which supports the plant, yielded under the loading.

The visual difference between the second and third failure modes mentioned is very difficult to distinguish in the field because both are failures that occur below the ground. Due to the nature of the testing process in the field and in the interest of time, the last two were not separated in the data and recorded together. Figure 4.10 shows the recorded failure modes of each data set, which is marked by the date. Items listed as “stem” refer to the first failure mode mentioned and items refered to by the term “root” reflect failure modes 2 and 3. Figure 4.10 shows some interesting results. As time passes the vegetation fails in the stem portion above ground more often. This trend is most likely due to the plant gaining strength as it matures during the growing seasons. Observations from the field indicate that the plant failure mechanism may also be influenced by other factors in the environment. The time of day with respect to the tidal sequence, the moisture content of the soil, and the nutrients provided to the vegetation may also affect the plant’s failure mechanism.
Another interesting trend observed is the variation of the breaking force over time. Figure 4.11 is a box and whisker plot representing all of the breaking forces recorded. The green triangles in the center represent the median force, while the upper and lower
bound of the box represents the 75% and 25% quartile values. The lines extending from the box show the maximum and minimum value recorded. An interesting trend noticed is that as the plants begin to grow, they gain strength. This trend continues throughout the growing season until the vegetation begins to grow dormant and die off. In the summer time, the variability was much higher, which indicates that some of the plants were able to thrive in the current living conditions.

Figure 4.11 Box and Whisker Plot of breaking force.

Figure 4.12 examines the breaking force with respect to the plant’s diameter that failed by stem failure.
Figure 4.12 Breaking Force vs Stem Diameter for all plants failed at the stem.

The figure shows that there is not a stronger relationship between breaking force and those plants that failed only at the stem. This result is interesting because it is assumed the plants failing at the stem would have a higher correlation to the uprooting force because the testing device was connected to the stem of the plant. The assumption is that the stem was not strong enough to sustain loading and successfully transfer it to the soil and roots of the vegetation.

4.4 Effects of Oil Contamination

The Bay Jimmy site location used in this study has been contaminated by crude oil that came from the BP Oil Spill that occurred in the spring of 2010 off the coast of Louisiana. This site still possessed visible contamination even 1 year after the incident
occurred. The crude oil on this site was prevalent in several different ways. In some areas of the site the oil had formed a hard and rubbery cover over the surface soil. In other areas the oil could be found under the first inch of soil. The vegetation was definitely affected by the oil. The most notable difference is the effect that the oil had on the relationship between stem height and uprooting force. The coefficient of determination for Bay Jimmy data is 0.315, while it was only 0.003 for the location in Terrebonne Bay. Looking at the relationship between the stem diameter and the uprooting force, the coefficient of determination in Bay Jimmy is almost 4 times higher at 0.56 than that of Terrebonne Bay. Coupling this data leads to the conclusion that the oil contamination caused the plants to adapt to the conditions. The resulting adaptation was to transfer the burden of uprooting resistance more toward the stem. This adaptation is most probably due to the fact that the oil had an adverse affect in the surround soil and root system. Since the other support systems of the vegetation were diminished the plant shifted the burden of resistance to the stem.

4.5 Recommendations for Improvement to Future Studies

The main improvement that can be made for this study is to the testing process. Due to the nature of the device used and testing procedure implemented, the time required to perform a single test could last for up to an hour. Usually, the time required per test varied between 30 and 45 minutes. Since the field site visits are limited due to time and funding, a more efficient testing method would allow for more data collection in the time allotted while on site. The first improvement that can be made is to the connection used to attach the vegetation to the testing device. A connection that does
not require the use of bolts and screws would significantly reduce the time and effort in the testing process.

A more desirable connection device would possess the following characteristics:

1. Easily adjustable range to allow for easy connection to plants with varying stem diameter.

2. A gentle contact surface that is also able to provide a high amount of friction. This feature allows for testing with great confidence that the stem will not be damaged before the test begins.

3. A connection that has not extraneous parts required for attachment either to the plant or the testing device. Having extra parts, especially small ones, causes for a great amount of time to be wasted and creates potential for the pieces to be lost while in the field testing.

The bearing plates for the tripod could be changed to have a circular pattern and made from a different material. The circular pattern would allow for an easier placement before the testing and would allow for a smaller size. The smaller size would help to eliminate the damage done to the surrounding vegetation by the placement of the bearing plates. A material such as a plastic would be a much more suitable material because it would provide a much longer life to the bearing plates. The bearing plates used in this study were made of wood and after repeated use suffered an extensive amount of fatigue.

For future studies, the collection of more parameters is needed. This study demonstrated that the stem height and stem diameter have some small influence on the uprooting force, but they were different at the two testing locations. Parameters that
characterize the testing location more fully would prove to be extremely beneficial for developing a predicative model for the uprooting resistance of *Spartina Alterniflora*. Potential parameters include but are not limited to:

- **Soil shear strength:** this parameter characterizes the soil's resistance to failure from loading.
- **Plant root density:** having an understanding of the density of the root system could provide an indication of the total resistive capacity of the vegetation. This is significant because the loading is transferred to the root system through the stem.
- **Plant root depth:** the depth of the root system can indicate the amount of friction between the root and soil. The degree of friction that exists could potentially influence the amount of uprooting resistance that the plant possesses.
5 CONCLUSION

Coastal erosion is rapidly taking away the coast in the northern portion of the Gulf of Mexico. The people that live in the region are greatly affected since many utilized the marshes and wetlands as a means to make a living. Preventative measures have been investigated, such as placing break waters or coastal armoring, in attempt to reduce the wave energy that is applied to the coastline. Some researchers have proposed that placing native vegetation in desolate areas can help to reduce the wave energy felt on the shoreline. Little is known, however, about the mechanical properties of the vegetation and its viability long term. This study aimed to investigate the vegetation’s, specifically *Spartina Alterniflora*, ability to resist uplift forces in hopes of determining a universal relationship with the uprooting force to the vegetation’s stem height and stem diameter. The study covered the dates between December 13, 2011 to December 12, 2012.

This study determined that *S. Alterniflora* begins its growing season around March and April and continues its growth process through the winter time. The data from the Terrebonne Bay site indicates that no significance exists between the uprooting force and the stem height. The relationship between the stem diameter and uprooting force shows some small correlation. This small correlation implies that the stem diameter possesses some influence over the uprooting capacity of the vegetation. The site location in Bay Jimmy indicates that the plant stem height and stem diameter have a much stronger correlation to the uprooting resistance. The proposed reason is that the oil contamination on this site reduced the effects of the other factors the influence the uprooting resistance of the vegetation. This study also observed that the plant uprooting
forces increased as the growing season progressed. The uprooting forces peaked in the late summer time.

This study recommended some changes and improvements for future studies that include modifying the connection to the plant to improve testing capacity and improving the bearing plates in a manner that provides them more durability. Other parameters such as soil shear strength, root density, and rood depth are recommended for future research and investigations. The intent and hope of these modifications and recommendations is that the uprooting resistance can be accurately described by a predicative model and be used as a means to help curb the disturbing trend of coastal erosion.
6 REFERENCES


VITA

James M. Bouanchaud III is from New Roads, Louisiana. He is a 2006 graduate of Catholic High School in Baton Rouge, Louisiana. He entered LSU in the summer of 2006 and graduated in May 2011 with a B.S. in Civil Engineering with a minor in Structural Engineering.

He enrolled in the graduate program at LSU in August 2011 to pursue a M.S. in Civil Engineering with a concentration in Geotechnical Engineering under the advisement of Dr. Guoping “Gregg” Zhang. His interests include geotechnical engineering, structural engineering, and coastal engineering.