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A Comparison Of Installation Methods And Maintenance Practices Of Protected Side Armoring

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A Comparison Of Installation Methods And Maintenance Practices Of Protected Side Armoring

A Thesis

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ABSTRACT

The IPET (Interagency Performance Evaluation Taskforce) Team's significant finding is if the levees had armoring, the HSDRRS would have an element of resiliency. IPET defines resiliency as "The ability to withstand, without catastrophic failure…beyond those intended or estimated in the design. …resilience refers to the ability to withstand higher than designed water levels and overtopping without breaching" (USACE, 2007).

In the analysis of armoring products, two criterions usually govern. First, the ability for the armoring to resist overtopping velocity from storms greater than the 100 year authorized level. Second, does the product facilitate installation and maintenance post-Katrina? This thesis will help expand the knowledge base and hopefully the comfort level of armoring products so that we may widen our range of resources. Different products and their methods for installation and maintenance will be presented. The result of one full-scale field test performed by USACE Armoring Team is described.

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I. INTRODUCTION

A. Scope of Thesis

The scope of this thesis will concentrate on the viable application and maintenance of armoring products to the New Orleans Hurricane Storm Damage Risk Reduction System (HSDRRS). The System is shown in Figure 1 and displays the overtopping rate at each project reach. A test section at the Army Corps of Engineers Concrete Mat Fabrication yard in St. Francisville, LA was implemented to determine which armoring products could be viable to the HSDRRS. This location was considered because a ring levee protects the facility from annual flooding due to high river stages and overtopping could be experienced. But most importantly, this levee is not part of the Hurricane Storm Damage Risk Reduction System (HSDRRS) and could be used without compromising the integrity of the New Orleans System's first line of defense in an event of a hurricane.

For the purpose of this study, only installation and maintenance factors are collected. Hydraulic information on the products installed is taken from the manufacturer's specifications. The hydraulic loads that the Hurricane Storm Damage Risk Reduction System (HSDRRS) will experience during a 500 year storm event with a 50% confidence level were produced by Hydraulics and Hydrology Branch at the New Orleans District U.S. Army Corps of Engineers. A summary of the hydraulic overtopping rates are shown in Figure 1. Given the availability of the product's performance and the USACE-NOD Hydraulic and Hydrology (H&H) models, the only questions left to answer is:

1. Can this product be installed and viable in the New Orleans Hurricane Storm Damage Risk Reduction System (HSDRRS)?

2. Will the Levee Boards be able to maintain the products once the ownership is transferred?

The answers to these questions are important to the viability and consideration of these products. If their installation sequences are too elaborate then they may not be considered due to the time limitations in the project's construction phase. If the product itself poses problems during maintenance, which generally consist of mowing grass once to every other month, then the product may not be considered because of these troubles.

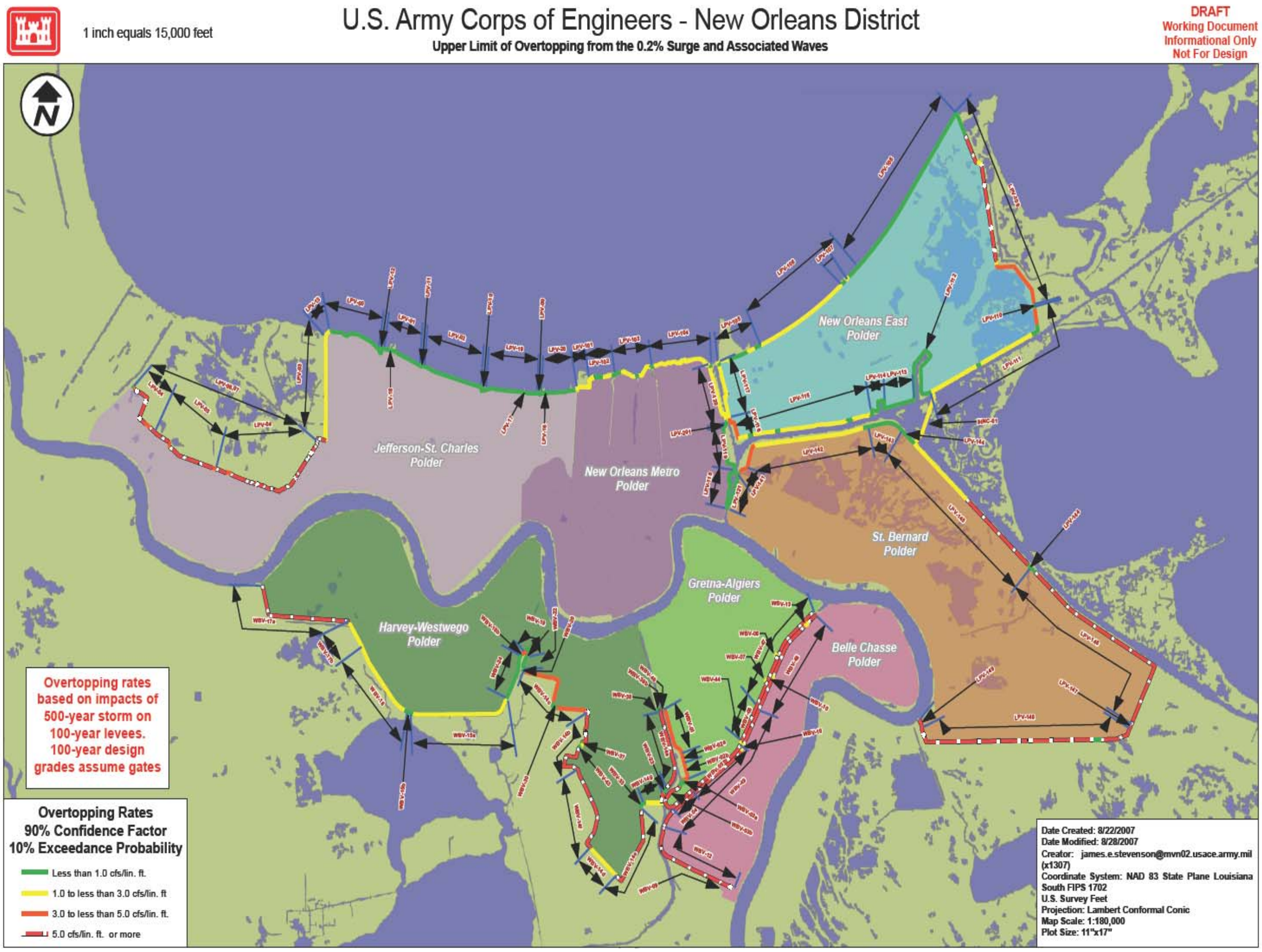


Figure 1: The Hurricane Storm Damage Risk Reduction System (HSDRRS) at 100 year elevations and with a 500 year storm event applied.

An Armoring Conference was organized in August 2007, where all known manufactures of armoring products, Levee Board Members and Engineers across all disciplines of USACE were invited to participate is a Round Table Discussion on the definition of armoring. Below is the definition of armoring that the Armoring Team developed:

Definition of Armoring

"A natural or artificial material placed on or around a levee, floodwall, or other structure to reduce damage and protect from catastrophic damage (damage that compromises or undermines the structural integrity and design intent) when confronted with overflow and overtopping from a storm in excess of the design event. The minimum armoring for levees shall be grass. Armoring is only one of the components of resilience." (Armoring Team)

B. Location and Description of Study Sites

Figure 2: The St. Francisville Casting Field located 30 miles north of Baton Rouge and has been operating since 1961.

As mentioned in the Introduction of this thesis and shown in Figure 2, the St. Francisville Concrete Mat Casting Field was selected for this test section for two main reasons:

1. A ring levee protects the facility from annual flooding due to high river stages and overtopping could be experienced.

2. But most importantly, this levee is not part of the Hurricane Storm Damage Risk Reduction System (HSDRRS) and could be used without compromising the integrity of the New Orleans System's first line of defense in an event of a hurricane.

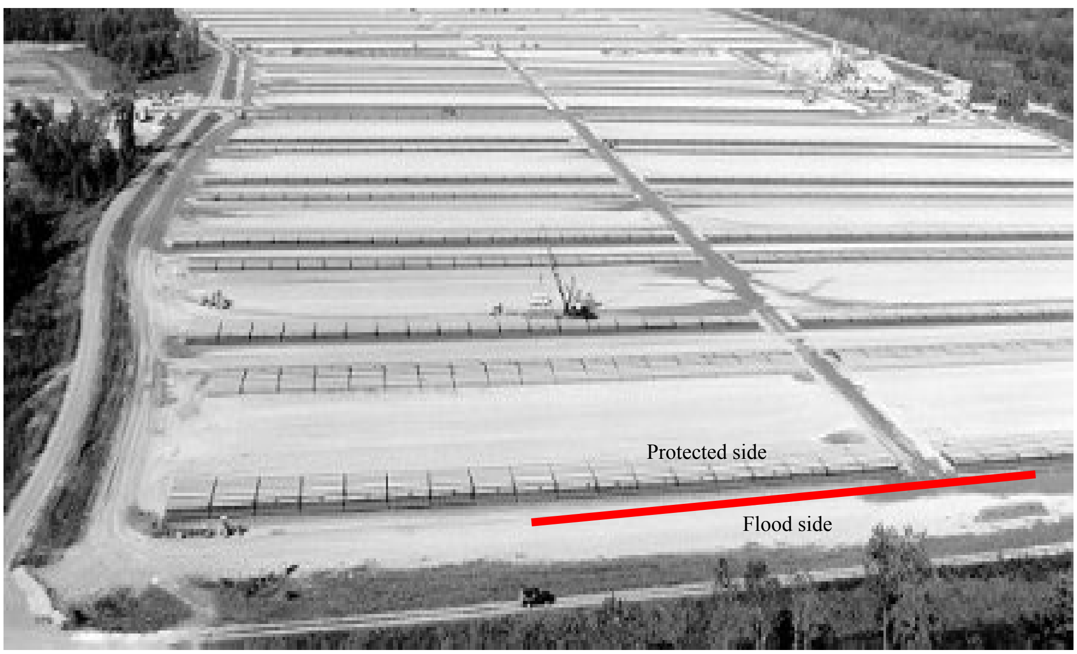


Figure 3: The red line in the photo represents the levee reach where the armoring products were installed.

These products will be monitored for maintenance concerns for 3 cycles. The full length of this study reach is 600' as shown in Figure 3 by a red line. The

five products and the grass only section is laid out in 100’ running lengths and are shown in the following order from right to left in Figure 4:

1. Articulated Concrete Mats (ACM)-USACE product
2. Anchored Reinforced Vegetation System (ARVS)- Propex product
3. PP12- Wester Excelsor product
4. Enkamat S- Profile product
5. Grass only-Hydromulching by
6. Tapered Articulated Concrete Block (ACBs)- Contech product

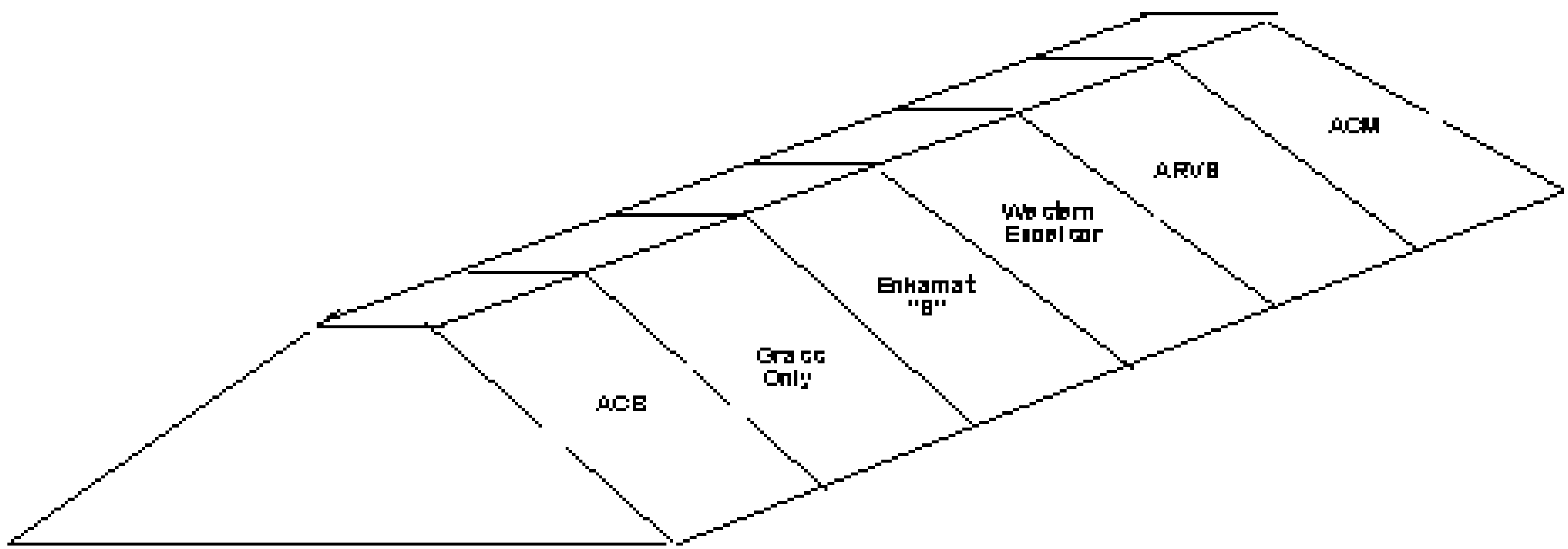


Figure 4: Schematic of armoring product layout.

NOTE: ACB—Articulated Concrete Block
ARVS—Anchored Reinforced Vegetation System
ACM—Articulated Concrete Mat

II. BACKGROUND AND LITERATURE REVIEW

A. The New Orleans Area

New Orleans is the largest urban area in the United States that is below sea level. Because most of the area is lower than surrounding water elevations, the area is protected from storm surges and tidal inflow by a system of levees and floodwalls. The construction of these system features are the responsibility of the U.S. Army Corps of Engineers through the approval and appropriation of funds from the United States Congress. Once construction is completed, the local sponsor, who matches Congress' funding at an agreed upon ratio, will claim ownership and maintain the system feature for the life of the project. Since Hurricanes Katrina and Rita, the U. S. Army Corps of Engineers has repaired the systems damages and is undergoing several phases of design. Phase 1 is to restore the system to its originally authorized elevations. This is easier said than done. Several factors have changed since the initial authorization of these project elevations. One is that sea level is rising. With this change in sea level elevation, the system needed to be remodeled and the effects of this updated information were significant. The second factor was the settlement of the protection. Over the years, the levees, floodwalls and structures in the New Orleans area have settled due to the soil subsidence. In most instances, the magnitude of future settlement was known but the sea level changes compounded the overall systems deficiency. Another significant factor was the design storm of record. We knew

very little on the effects of surge and hydraulic loads as it relates to the duration of a storm in the Gulf and the surge and rainfall that can be generated from a variety of hurricane conditions. A Category 2 Hurricane versus a Category 4 Hurricane can have the same hydraulic effects on the Hurricane Protection System.

B. Hurricanes Katrina and Rita

According to NOAA (National Oceanic and Atmospheric Administration), the Saffir-Simpson Hurricane Scale is a 1-5 rating based on the hurricane's present intensity. This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf and the shape of the coastline, in the landfall region. Note that all winds are using the U.S. 1-minute average. A Category 5 Hurricane contain winds greater than 155 mph and storm surge generally greater than 18 ft above normal.

Hurricane Katrina, a category 5 storm over the Gulf of Mexico, was still responsible for at least 81 billion dollars of property damage when it struck the U.S. Gulf Coast as a category 3. It is by far the costliest hurricane to ever strike the United States.

The Greater New Orleans continuous system of levees and floodwalls were put to the test during Hurricanes Katrina and Rita. These levees and floodwalls were intended to be designed to withstand Category 3 Hurricanes. The

Saffir-Simpson Scale fails to measure the storm surge that comes with a Hurricane that was larger before making landfall. Hurricane Katrina was a Category 5 in the Gulf of Mexico but when it made landfall it was reduced to a Category 3. The storm's path and strength is shown in the following NOAA graphic Figure 5.

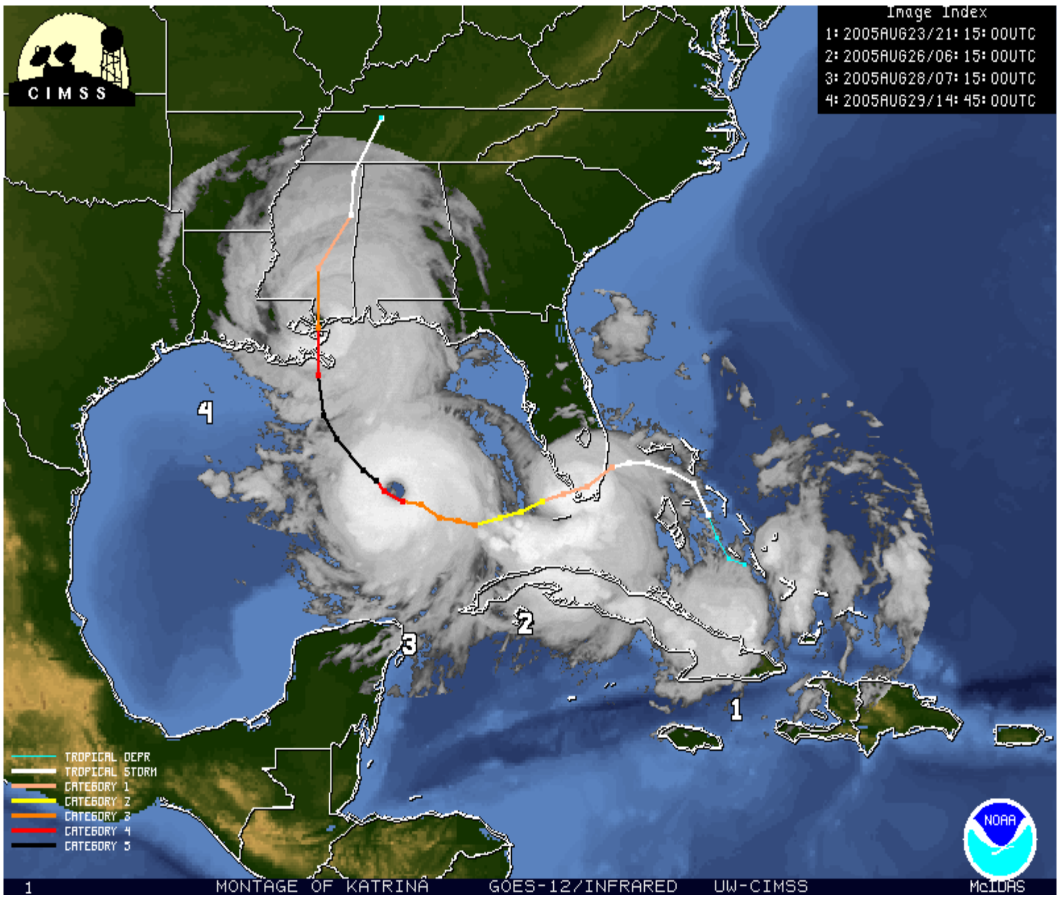


Figure 5: Hurricane Katrina's path and strength according to NOAA.

The storm surge that made land was more in association to a Category 5 storm than a Category 3. The levees and floodwalls were overwhelmed and overtopped with waves and surge currents and sometimes a combination of wave

and surge conditions as shown in Photo 1 (captured during Hurricane Katrina in New Orleans East).

Photo 1: This photo was taken during Hurricane Katrina in New Orleans East at the Paris Rd. Bridge

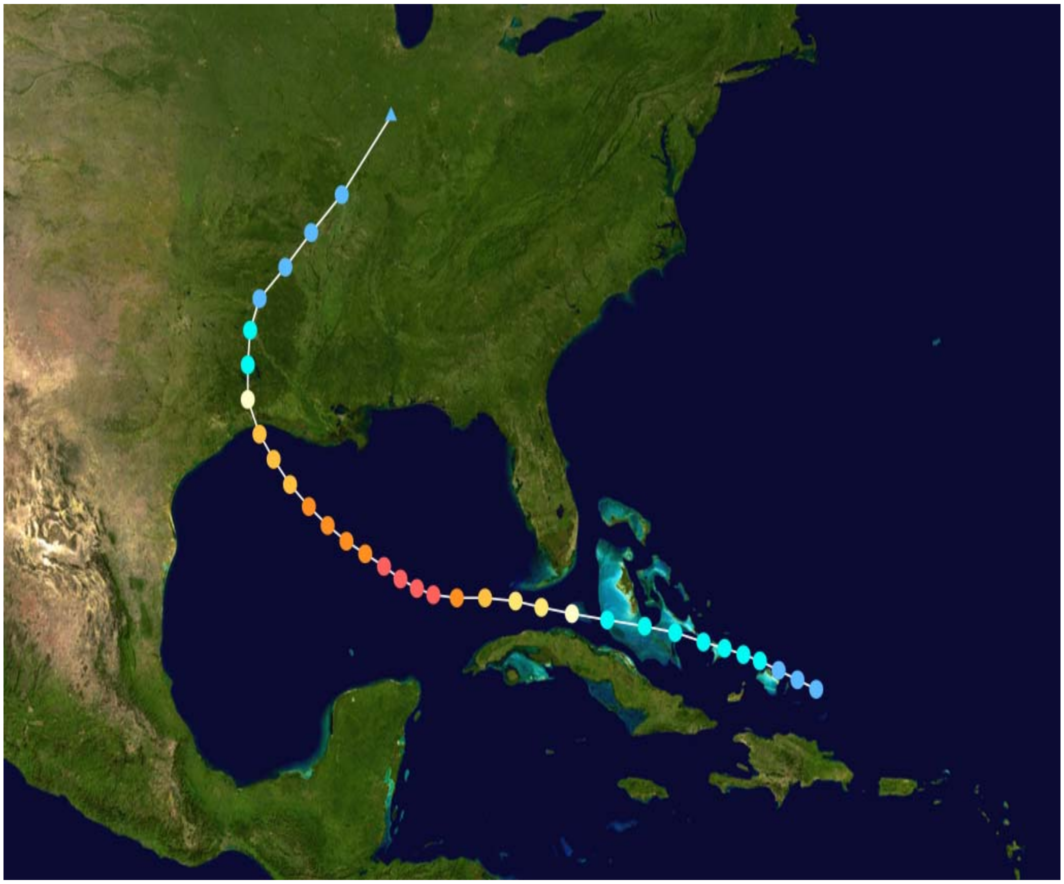
The conditions shown in Photo 1 caused scouring to the protected side on the earthen levees and the hardened (concrete/sheetpile) floodwalls. In some areas the scouring was extensive and breaches to the system occurred. Photos 2 show's the effects of the storm surge that was captured in Photo 1.

Photo 2: This photo is of the same location in photo #1 showing the damages that were incurred. Scouring around the bridge supports was extensive.

Photo 3 shows the damages that occurred to the protected side on floodwalls. One can see the sheetpile under the floodwall which indicates a scour hole about 5 feet deep. Unlike the earthen levees, which are sloped and therefore the free flow overtopping just ran its course down the slope, the floodwalls height creates a downpour of water that remains on the face of the floodwall whereby creating a concentrated scouring effect at the base of the floodwall stem. On average, the depth of scour on the protected side of the floodwalls that were overtopped ranged from 2-8 feet. This is a very large reduction in the levee/floodwall section that is used in the design to resist the water load to top of

the wall. The design does not consider any loss of section due to overtopping and scouring.

Photo 3: The damages to the floodwalls on the protected side when wave overtopping occurred is shown in this photo.



<u>Figure 6:</u> Hurricane Rita's path and strength from www.wikipedia.org

According to wikipedia, Hurricane Rita was the fourth-most intense Atlantic hurricane ever recorded and the most intense tropical cyclone ever observed in the Gulf of Mexico. Rita caused $11.3 billion in damage on the U.S. Gulf Coast in September 2005. Rita was the seventeenth named storm, tenth hurricane, fifth major hurricane, and third Category 5 hurricane of the historic 2005 Atlantic hurricane season.

Rita made landfall on September 24 between Sabine Pass, Texas and Johnsons Bayou, Louisiana, as a Category 3 hurricane on the Saffir-Simpson Hurricane Scale. It continued on through parts of southeast Texas. The storm

surge caused extensive damage along the Louisiana and extreme southeastern Texas coasts and completely destroyed some coastal communities. The storm killed seven people directly; many others died in evacuations and from indirect effects.

New Orleans's levee system had already sustained heavy damage from Hurricane Katrina before Rita's outer bands of rain fell on the city. On Friday, September 23, the day before landfall, rising water due to Hurricane Rita poured through breaches in the patched Industrial Canal levee in New Orleans' devastated Ninth Ward, as reported by the Army Corps of Engineers. Water entered the Ninth Ward over two 32-foot (10 m) wide patches in the levee as of about 9 a.m. CDT on Friday, September 23. Water in the Ninth Ward was reported to be waist-deep at 11 a.m. CDT on Friday. By approximately 5 p.m. CDT, water had begun gushing through another patch in the London Avenue Canal into the surrounding Gentilly neighborhood. Some pumping stations were abandoned. By Saturday night, September 24, water from a 150-foot gap in the Industrial Canal levee flooded some areas of the Ninth Ward to eight feet deep. Louisiana Governor Kathleen Blanco reported that 700,000 homes lost power in 41 of the state's 64 parishes.

C. Main failure mechanisms

1. Introduction

Another aspect of the HSDRRS is that the system constructed, with the exception of the few sections constructed with T-walls, did not include protection

against overtopping. The structures were designed to perform with water elevations up to overtopping, but not beyond.

Levees were designed to provide protection up to the estimated water elevations for the Standard Project Hurricane (SPH). They were not designed to withstand overtopping. Overtopping generated very high velocities over the crest and back sides of the levees, leading to a high potential for scour and erosion. There was no armoring or uniform use of erosion resistant soils in the levee sections.

"Velocities from 10 to 15 ft/sec were calculated for the back sides of the levees along St. Bernard Parish, while the front sides of the levees experienced velocities of about one-third of those on the back side. Since erosion potential is related to the cube of velocities, the erosion potential on the back side of the levees was up to 10 times greater", (USACE, 2006, pg. 1-6). USACE post hurricane inspection of these levees determined that all failures were caused by erosion of the back face.

The performance of the 50 major breaches experienced by the HSDRRS during Katrina, all but four were due to overtopping and erosion. For levees, the scour eroded the backsides and tops of the levees due to high velocities of the overtopping waves in areas of erosion susceptible soils creating breaching. There was no evidence of systemic breaching caused by erosion on face or water sides of the levees exposed to surge and wave action. This could be because the overtopping relieved stresses. The levees largely performed as designed, withstanding the surge and waves until overtopping, at which time they became

highly vulnerable to erosion and breaching, especially those constructed by hydraulic fill.

The second area of significant difference dealt with the performance of the levees, specifically along the Mississippi River Gulf Outlet (MRGO). Interagency Performance Evaluation Taskforce (IPET) analysis of this phenomena included regional analysis of the surge and wave hydrographs along the levee sections, detailed modeling of wave action and currents in proximity to the levees and analysis of erosion process for the materials comprising the levees. The IPET analysis and physical evidence at the sites show that the systemic issue for levee performance was overtopping and the subsequent erosion from waves and ultimately surge. Where waves were incident perpendicular to the levees, the overtopping waves created velocities on the protected side of the levees up to three times those experienced on the front (water) exposed sides. This created a potential for erosion 10 times more severe on the crest and protected sides of the levees, (USACE, 2006).

2. The protected side of levees

Based on the report "Overview of Hydraulic and Armor Design of Overtopped Levees and Floodwalls" by Jurriaan de Jong, during Katrina most earthen levees that were overtopped and overflowed, exhibited the following identifiable stages of leeside erosion progression (de Jong, 2006):

Stage A: Initial overtopping causes surface, sheet and rill erosion at weak spots that develops into a series of cascading overfalls. Erosion can be initiated at any point on the leeside slope. The highest forces develop from the backside slope down to the backside toe, and the crown is initially not exposed to these large hydraulic forces. The cascading overfalls develop into one large headcut that migrates from the slope to the crest such that the erosion width approximately matches the overtopping width.

Stage B: The headcut continues to migrate from the backside crest (crown) to the floodside crest.

Stage C: The crest drops as a breach begins to develop.

Stage D: The breach opening erodes out to the toe and the breach widens.

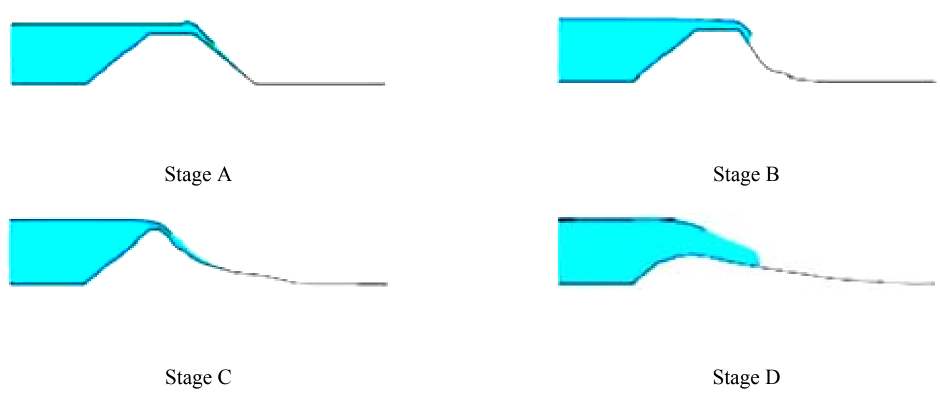


Figure 7: Stages of leeside erosion progression

Another main failure mechanism, which often occurs as a result of overtopping and overflows, is inner slope macro-instability. Inner slope

macro-instability occurs when a part of the inner slope shifts along a deep slip circle. This may happen during floods when an increase of water pressure combines with a decrease in shear resistance in the slip circle. Infiltration by extreme precipitation, overflow or overtopping can saturate the top layer, increasing the risk of macro instability. This type of failure would most likely occur during stage B or C in Figure 7.

3. Loading of levees

The different approaches to determine the loading exerted on the protected side of levees by overflow, overtopping or a combination of both is presented in the following paragraphs. Figure 8 illustrates a typical levee section and the flow patterns that can be seen when water elevation exceeds the levee crown elevation

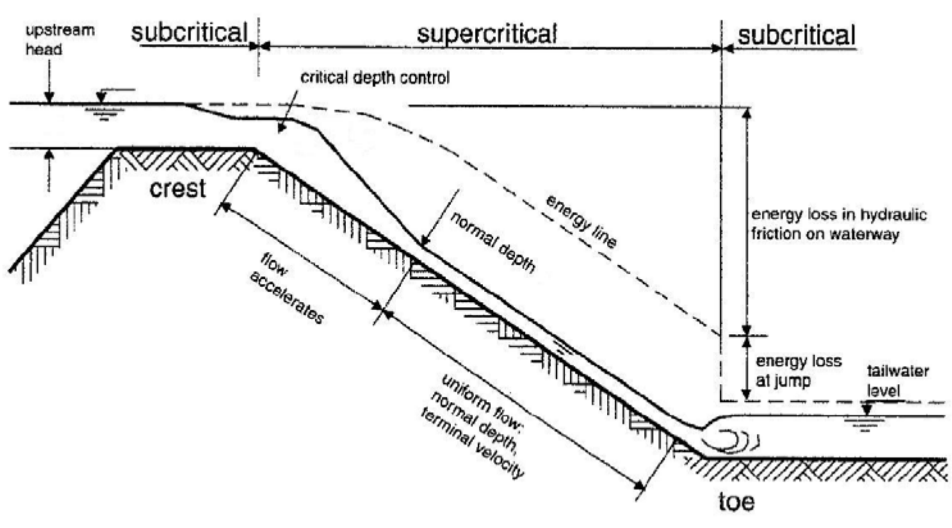


Figure 8: Elevation showing flow down a typical levee.

a.) Overtopping

The discharge caused by wave overtopping will reach a maximum when the wave top reaches the levee and a minimum when the wave trough reaches the levee. For the design of the protected side armoring the critical discharge will be required as this will cause the normal loading. It is proposed to multiply the average discharge with a factor 3 to calculate the critical discharge.

The approach to assess the loading by overtopping is elaborately described in "Technical report wave run-up and wave overtopping at dikes", (van der Meer, 2002). This recent report, which has a long history, is based on extensive research and is used as a guideline for safety assessments and design of levees in The Netherlands.

b.) Overflow

The second loading the system will experience is the flow velocity on the *protected side* of a levee as a result of overflow. The super-critical flow on the protected side slope will accelerate until the gravitational forces are balanced as shown in Figure 9.

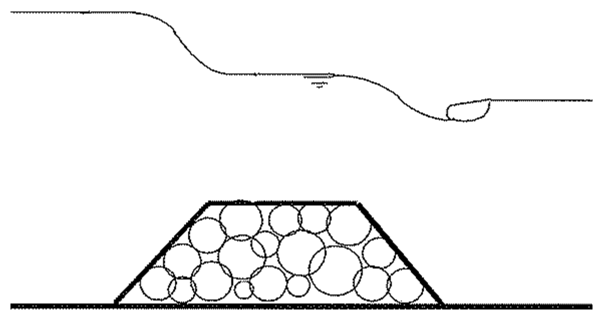


Figure 9: Typical levee under overflow conditions.

c.) Combined overtopping and overflow

Combined overtopping and overflow is based on the introduction of an equivalent wash-over height to account for the extra discharge caused by wave action. When comparing the approach for overtopping with the approach for combined overtopping and overflow for a situation with no freeboard, ideally the results of both approaches should be more or less the same.

D. Interagency Performance Evaluation Taskforce (IPET)

The following mission statement and five categories come from a presentation given by ASCE External Review Panel on 9-10 March, 2006 titled

"*Interagency Performance Evaluation Task Force:* Strategic Overview

Performance Evaluation and Interim Results"

> IPET's Mission…"to provide credible and objective scientific and engineering answers to fundamental questions about the performance of the hurricane protection and flood damage reduction system in the New Orleans metropolitan area."—Chief of Engineers

<u>The Flood Protection System:</u>
What were the design criteria for the pre-Katrina hurricane protection system, and did the design, as-built construction, and maintained condition meet these criteria?

<u>The Storm:</u>
What were the storm surges and waves used as the basis of design, and how do these compare to the storm surges and waves generated by Hurricane Katrina?

<u>The Performance:</u>
How did the floodwalls, levees, pumping stations, and drainage canals, individually and acting as an integrated system, performing response to Hurricane Katrina, and why?

<u>The Consequences:</u>
What have been the societal-related consequences of the Katrina-related damage?

<u>The Risk:</u>
Following the immediate repairs, what will be the quantifiable risk to New Orleans and vicinity from future hurricanes and tropical storms?

i. IPET Report-Summary of Findings

The System: The system did not perform as a system. In some areas it was not completed, and in others, datum misinterpretation and subsidence reduced its intended protective elevation. The capacity for protection varied because of some structures that provided no reliable protection above their design elevations and others that had inadequate designs leaving them vulnerable at water elevations

significantly below the design intent. The designs of the levee floodwall structures along the outfall canals were particularly inadequate. A series of incremental decisions that went from the original “barrier” plan to the “parallel protection” structures ultimately constructed systematically increased the inherent risk in the system without recognition or acknowledgment (USACE, June 2008, pg I-2***)***.

The Storm: Katrina created record surge and wave conditions along the east side of New Orleans and the coast of Mississippi. Peak water levels along the Plaquemines and St. Bernard levees and within the Inner Harbor Navigation Canal (IHNC) were significantly higher than the structures leading to massive overtopping and eventually breaching. Wave heights during Katrina were typically similar to those assumed for the design of the structures, except for Plaquemines Parish where they were higher than the design assumptions. Wave periods, however, were three times longer than the design assumptions, particularly along the east side of St.Bernard and Plaquemines Parishes. The longer period and more energetic waves created much greater potential for run-up and overtopping. Conditions within Lake Pontchartrain were roughly equal to the design criteria for the shoreline structures. The Mississippi River Gulf Outlet channel, presumed to be a major factor in propagating storm surge into the IHNC, was demonstrated to have little impact on storm water levels for large storms (USACE, June 2008, pg I-2***)***.

The Performance: With the exception of four foundation design failures, all of the major breaches were caused by overtopping and subsequent erosion. Reduced protective elevations increased the amount of overtopping, erosion and subsequent flooding, particularly in Orleans East. Ironically, the structures that ultimately breached performed as designed, providing protection until overtopping occurred and then becoming vulnerable to catastrophic breaching. The levee-floodwall designs for the 17th Street and London Avenue Outfall Canals and IHNC were inadequate for the complex and challenging environment. In four cases the structures failed catastrophically prior to water reaching design elevations. A significant number of structures that were subjected to water levels beyond their design limits performed well. Typically, in the case of floodwalls, they represented more conservative design assumptions and, for levees, use of higher quality, less erodible materials (USACE, June 2008, pg I-2***)***.

The Consequences: Approximately 80 percent of New Orleans was flooded, in many areas with depth of flooding exceeding 15 ft. The majority, approximately two-thirds overall in areas such as Orleans East Bank and St. Bernard, of the flooding and half of the economic losses can be attributed to water flowing through breaches in floodwalls and levees. There were at least 727 fatalities in the five parishes in and around New Orleans, and over 70 percent of the fatalities were people over age 70. The poor, elderly, and disabled, the groups least likely to be able to evacuate without assistance, were disproportionately impacted. Direct property losses exceeded $20 billion, and 78 percent of those losses were

in residential areas. There was an additional loss of over $7 billion in public structures and utilities. The indirect consequences were equally disastrous. The breakdown in New Orleans' social structure, loss of cultural heritage, and dramatically altered physical, economic, political, social, and psychological character of the area are unprecedented in the United States. In themselves, these create a formidable barrier to recovery. Where water depths were small, recovery has been almost complete. In areas where water depths were greater, little recovery or reinvestment has taken place (USACE, June 2008, pg I-3***)***.

The Risk: The prototype risk assessment process can identify the areas most vulnerable to future flooding and with the highest residual risk. Given more consistent levels of protection that will exist in the 2009 time frame, in many areas, level of risk is closely associated with the property values and population densities in the sub-basins and the elevation of the area (potential for deep flooding) The exception is in the areas bounded by the IHNC where the reliability of protection will be lower because of legacy structures (types and elevation) and continued threat of high surge and wave conditions. Final risk results will be published at the completion of the risk analysis (USACE, June 2008, pg I-3***)***.

ii. IPET Report*-Summary of Lessons Learned*

The System: Planning and design methods need to be system-based, allowing a more in-depth analysis of how a combination of structures and measures will

perform together. These methods need to be able to consider the performance of the system beyond the design criteria, including the life cycle value of resilience and redundancy in the design. Dynamic factors such as subsidence and changing hazard levels must be included. This requires an ability to develop and evaluate adaptive designs, protective concepts that allow planned augmentation to deal with expected changes as well as some ability to accommodate the unexpected. An accurate reference datum and monitoring of structure elevations, as well as the effective operation and maintenance of the hurricane protection system, are essential parts of this process. All assets that factor in the capability to provide protection, such as pump plants and closure structures, must be included in the overall analyses, even if they are not a formal part of the protection system. With rapid changes in new knowledge and engineering practice, it is essential to continuously review and update technical guidance used in planning and design as well as providing an effective mechanism for the engineering community to adopt and mature new methods, The Standard Project Hurricane (SPH) methodology used to develop design criteria for the original system is outdated and should no longer be used. More flexible and robust probability-based methods are available that will provide better definition of the future hazard faced by protective structures (USACE, June 2008, pg I-4***)***.

The Storm: Sophisticated models that incorporate high-resolution spatial data and high quality wind fields are essential to accurately characterize storm surge and waves. This is particularly true in an area such as New Orleans with complex

shoreline comprised of both natural (marshes and ridges) and man-made barriers (levees and transportation corridors). These models need increased capabilities to accurately simulate the impact of barrier islands, marsh, and wetlands on surge and wave conditions. The interaction of the surge and wave conditions with structures such as levees and floodwalls requires special detailed modeling to accurately account for wave run up and overtopping, and to examine levee/wall response to dynamic loadings. Typically, very few measurements of waves and surge are made along the entire periphery of a HPS as part of a monitoring program. That was the case for this HPS. Large storms such as Katrina can cause failure of instrumentation intended to record the surge and wave environments created by the storm, and did so in this case. This creates a difficult problem for conducting analyses of a storm and its impacts. High-water marks were the only reference information reasonably available around the region for calibrating and validating surge modeling. Only a relatively small percentage of these marks (15 percent) were considered accurate enough for use, pointing to the need for more robust instrumentation that can survive storms as well as rigorous standards for evaluating the quality of high-water marks (USACE, June 2008, pg I-4***)***.

The Performance: Hurricane protection structures need to be designed as a part of a complete system-based approach to protection, providing balanced and uniform levels of protection from the perspectives of time, level of hazard, and reliability. Designs need to be conservative enough to accommodate unknowns. Designs need to consider dynamic wave loadings in situations where waves are

present. The unanticipated failure mode defined in the IPET analysis for the outfall canal floodwalls is not the only potential failure mode for these structures not considered in the original designs. With the rapid expansion of knowledge and practice, it is necessary to frequently review the adequacy of existing infrastructure in the context of that new knowledge and have processes in place to respond expeditiously to any performance limitations that arise. Resilience should be factored in to all designs to prevent catastrophic failures and to protect the integrity of the hurricane protection system itself. The maintained condition of the levees is an important factor in their overall performance and should be monitored more rigorously and through evaluations that extend beyond visual inspections (USACE, June 2008, pg I-5***)***.

The Consequences: Even without the significant catastrophic breaching that occurred, the flooding and direct losses from Katrina would have been the worst in the history of the region. However, approximately half of the direct losses may have been averted if breaching had not occurred. This reduction in direct losses would likely have dramatically reduced the indirect consequences of the event. Together, this may have enabled a more rapid and systematic recovery. Resilience in the hurricane protection system would have provided that advantage.
Mapping the economic and human health and safety consequences of Katrina has created a powerful information base from which risk assessments and future planning priorities can be informed. Estimating the future distributions of population and property in the uncertain recovery and re-development

environment proved very difficult. The scenario development accomplished to provide some insights into possible consequences of future hurricane events proved a feasible and valuable approach. Environmental losses were an essential component to the overall assessment of consequences, but they proved to be difficult to characterize beyond the short term, in part because of the already significant levels of contamination existing in the region. Not nearly enough information is available on the long-term impacts of saltwater intrusion and flooding on freshwater marshes, or the conditions and rates of recovery that can be expected (USACE, June 2008, pg I-5***)***.

The Risk: Risk assessment provides a new and more comprehensive method to understand the inherent vulnerability for areas protected by complex protection systems and subjected to uncertain natural hazards. It provides a direct view into the sources of vulnerability, providing a valuable tool for public officials at all levels to focus resources and attention on the most serious problems and to seek solutions that reduce risk through both strengthening the reliability of the physical structures and reducing exposure of people and property to losses. Given a relatively uniform level of reliability of the protection system, the relative risk values are largely related to elevation (below sea level) and the value of property or number of people who occupy those areas. The emergency response preparedness and efficiency of evacuation prior to a storm is a key component to reducing risk to life and human safety (USACE, June 2008, pg I-5***)***.

E. USACE Authority

FACT SHEET—Selective Armoring of Levees

APPROPRIATIONS TITLE: Flood Control and Coastal Emergencies

STUDY NAME/PROJECT: Armoring of Levees and Floodwalls- Lake Pontchartrain, Louisiana, and Vicinity (Hurricane Protection) (LPV), New Orleans to Venice, Louisiana (Hurricane Protection) (NOV), and West Bank and Vicinity, New Orleans, Louisiana (Hurricane Protection) (WBV) - (Plaquemines, St. Bernard, Orleans, Jefferson and St. Charles Parishes, Louisiana)

CONGRESSIONAL DIRECTION SOURCE: P.L. 109-234,Title II, Chapter 3, Flood Control and Coastal Emergencies, pages 38 (120 STAT. 455); and Title II, Chapter 3 of the Joint Explanatory Statement of the Committee of Conference, Flood Control and Coastal Emergencies, page 115.

DESCRIPTION OF ADDED WORK: P.L. 109-234 Title II, Chapter 3, Flood Control and Coastal Emergencies, page 38 (120 STAT. 455), hereinafter "4th Supplemental", provides : "For an additional amount for 'Flood Control and Coastal Emergencies', as authorized by section 5 of the Act of August 18, 1941 (33 U.S.C. 701n), for necessary expenses relating to the consequences of Hurricane Katrina and other hurricanes, $3,145,024,000, to remain available until expended: *Provided*, That the Secretary of the Army is directed to use the funds appropriated under this heading to modify, at full Federal expense, authorized

projects in southeast Louisiana to provide hurricane and storm damage reduction and flood damage reduction in the greater New Orleans and surrounding areas; . . . $170,000,000 shall be used for armoring critical elements of the New Orleans hurricane and storm damage reduction system: . . . "The Flood Control and Coastal Emergencies Section of Title II, Chapter 3 of the Joint Explanatory Statement of the Committee of Conference, Flood Control and Coastal Emergencies, page 115, states "Funds totaling $3,145,024,000 are recommended to continue repairs to flood and storm damage reduction projects. These projects are to be funded at full Federal expense. . . . Additionally, the Conferees include: . . .$170,000,000 for levee and floodwall armoring; . . ."

DECISION DOCUMENT: Congress authorized this work in the absence of an agency decision document. A Project Description Document (PDD) will be developed to support the anticipated work.

RECOMMENDED IMPLEMENTATION PLAN FOR ADDED WORK: The project area encompasses the hurricane protection projects included on the east bank of the Mississippi River in St. Charles, Jefferson, Orleans and St. Bernard Parishes (Lake Pontchartrain & Vicinity), on the east and west banks of the Mississippi River in Plaquemines Parish (New Orleans to Venice), and on the west bank of the Mississippi River in Jefferson, Plaquemines and Orleans Parishes (West Bank and Vicinity). The project will consist of armoring against erosion and scour of selected portions of levees and floodwalls in critical areas of

the above hurricane protection projects. The critical areas include: transition points where levees and floodwalls abut; where pipelines cross levee alignments; at floodwalls, particularly those in densely populated areas; and where levees are directly exposed to large sections of open water (i.e. the New Orleans East and St. Bernard levees adjacent to Lake Borgne that suffered massive damage during Hurricane Katrina). Plans will vary with location and conditions and a process of prioritization will be developed to select the most critical areas for armoring within the projects.

The funds provided for the Selective Armoring of the Lake Pontchartrain and Vicinity and West Bank and Vicinity Projects will be used to selectively armor the raised levees and constructed floodwalls that will provide the levels of protection necessary to achieve the certification required for participation in the National Flood Insurance Program administered by FEMA. Selective armoring will consist of placing some form of armoring in the locations of the Hurricane Storm Damage Risk Reduction System (HSDRRS) that showed signs of severe erosion during Hurricane Katrina. These areas include transitions between earthen levees and floodwalls, the area behind floodwalls that are subject to erosion if the wall is overtopped, areas where pipelines or other utilities cross levees, etc. Additionally, as stated in the authorizing language, the levees along the Mississippi River Gulf Outlet will be armored to prevent against erosion from overtopping. Selective armoring is an integral part of the overall levee/floodwall design. As such, the armoring design will be conducted by the project specific design teams. The design costs will be federally funded. The recommendations

for work to be performed under this feature of the 4th Supplemental will be performed utilizing a hurricane system wide approach that, to the extent possible, is coordinated with the potential plans that will be developed for the Louisiana Coastal Protection and Restoration (LaCPR) Project.

Implementation of the Selective Armoring authorized feature will be captured in the project specific Project Delivery Documents (PDDs) and will not require a separate PDD. Compliance with all environmental laws will be completed during preparation of the project specific PDDs, prior to construction contract award.

F. INFORMATION ON THE ARMORING TEAM

Based on IPET's findings and Congress's Authority, the Armoring Team was formed with a dedicated core Project Management Team and a representative from each discipline across USACE, from engineering to real estate to environmental. The team was tasked to develop design criteria that would be applied consistently across the Hurricane Protection System. The team was also tasked to research products that would serve as armoring throughout the system. The Armoring Workshop was organized to bring the manufacturers together to help USACE with this research. The details of the workshop are described below.

<u>ARMORING WORKSHOP:</u> An Armoring workshop was held in the New Orleans District offices on August 29th, 30th and 31st 2007. One of the main

purposes of the workshop was to showcase some of the latest materials, methods and techniques available for protecting levees and floodwalls from the effects of overtopping and erosion. Members of the design teams and other interested persons of the U.S. Corps of Engineers (USACE) were invited. Vendors and manufacturers were informed prior to the workshop that the focus of this particular event would be on the armoring of the protected sides of the levee systems. Of special interest were those products and services that could provide protection against a specific range of overflow water velocities and shear stress levels. The range of the hydraulic loading discussed had been identified following numerous post-Katrina studies and modeling.

Specific objectives for the workshop were to:

(1) Provide an opportunity for armoring-system vendors and manufacturers to showcase their products and answer questions specific to the New Orleans HSDRRS;

(2) Provide design and project management teams and consultants with an opportunity to dialogue with vendors and manufacturers of armoring systems regarding their composition, strength and application methods; and

(3) To provide a means of identifying, organizing and assimilating the vast number of potential design solutions available to the design teams.

The Armoring Team's work offers the opportunity to examine risk at the sub-basins, basins (parishes), or system-wide levels. It also allows examination of the impact of changes in the character of the protection for a given reach, providing a system-based approach to examine how alternative protection measures can reduce risk. This can include relatively simple to very sophisticated measures. Simple measures might include armoring existing structures, elevating levees, and use of erosion-resistant materials, seepage berms, or relief wells. More sophisticated approaches could include replacing I-walls with T-walls and adding surge gates at the ends of the outfall canals. With limited modification, the analysis could include different types of approaches such as large surge barriers between Lake Pontchartrain and Lake Borgne.

III. METHODOLOGY OF INVESTIGATION

The normal tolerable velocities of various armoring materials are set out in Figure 10 of CIRIA 116 (Hewlett, et al 1987). As a summary of the information in CIRIA 116, the recommended velocity ranges for various armoring materials are set out in

Table 1.

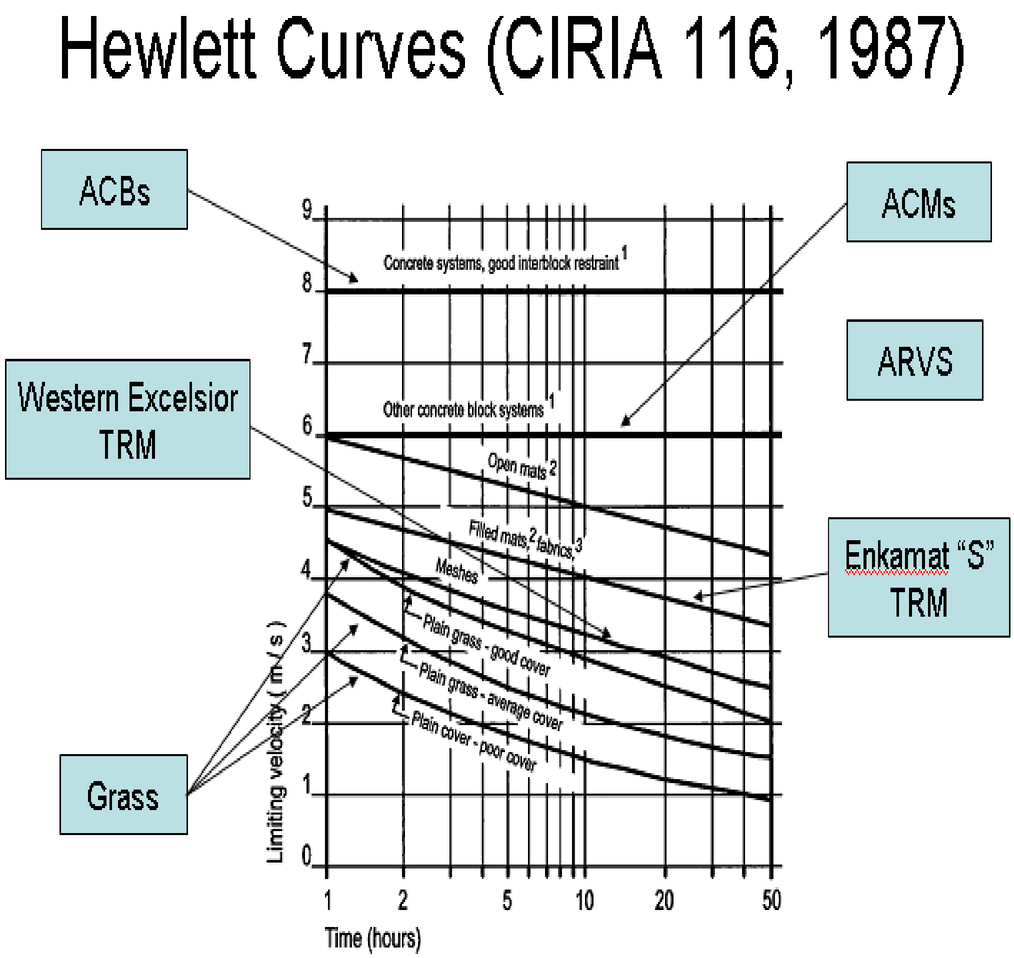


Figure 10: Hewlett Curves (CIRIA 116, 1987).

	Maximum Velocity (and associated storm duration)		
Armoring Material	1 to 2 hours	2 to 5 hours	5 to 50 hours
Good Grass Cover	11.5 f/s	9.8 f/s	6.5 f/s
Filled Mat	14.5 f/s	13.1 f/s	9.8 f/s
Open Mat	18 f/s	16.5 f/s	13.1 f/s
Concrete System	19.5 to 8 f/s	19.5 to 8 f/s	19.5 to 8 f/s

Table 1: Range of maximum velocities.

A. Installation

Several variables were noted for comparison of each product to be installed. The variables below represent the concerns that have been expressed by those involved in the Armoring Conference. The members involved ranged from Levee Board Members, Engineers, and product vendors. These variables are limited and are as follows:

1. A representative of each product installed was invited to witness the installation of their product.
2. The installers were given the standard installation instructions to install the products.
3. It was documented each time the installers incorrectly performed a step in the process.
4. It was also documented each time the product representatives corrected the installation process.
5. The number of laborers required for the installation.
6. The equipment needed to install the product.
7. The time it took to install 100’ of the product.

B. Maintenance

Several variables were noted for comparison of each product to be maintained. The variables below represent the concerns that have been expressed by those involved in the Armoring Conference. The members involved ranged from Levee Board Members, Engineers, and product vendors. These variables are limited and are as follows:

1. The mowing blade was adjusted to cut the grass to leave 3" of blades left. This is the optimal length the grass should be cut. Any shorter, the roots would not be at its peak strength.

2. Special attention was placed on the ends/transitions of the different materials during the mowing to watch for the ends being pulled up by the mower cutting blade.

3. Or if concrete, does the cutter blade clip the blocks where the edges are not flues.

4. Does exposed armoring become more exposed.

5. Levee Board Members (LBM) were present for the initial maintenance mowing.

6. Feedbacks from the LBM were documented and their recommendations included in the future designs of armoring.

IV. PROCEDURE AND RESULTS

A. *Installation*

i. Articulated Concrete Mats (ACM)-USACE product

The ACM segment of this test was installed prior to this thesis concept. Its placement was used as a reference to the rest of the products. The same installation crew that installed the ACMs was employed to do this program so that we would have consistency over all the products. Their feedback is recorded in Tables 2 and 3 along with the other products that were observed during this period of installation.

ii. Anchored Reinforced Vegetation System (ARVS)- Propex product

Propex Pyramat Anchored Reinforced Vegetation System (ARVS) is the first product to be installed. This product is a patented woven technology composed of a unique, three-dimensional matrix of polypropylene yarns. These yarns are designed in a uniform, dimensionally stable and homogenous configuration of pyramid-like structures, and they feature our patented X3® fiber technology specially created to lock soil in place. HPTRMs exhibit extremely high tensile strength as well as superior interlock and reinforcement capacity with both soil and root systems. They stand up to the toughest erosion applications where high loading and/or high survivability conditions are required, including maintenance access, steep slopes, arid and semi-arid environments, pipe inlets and

outlets, structural backfills, utility cuts, potential traffic areas, abrasion, high-flow channels and/or areas where greater factors of safety are desired. Figure 11 shows the process of installing this product on a levee slope.

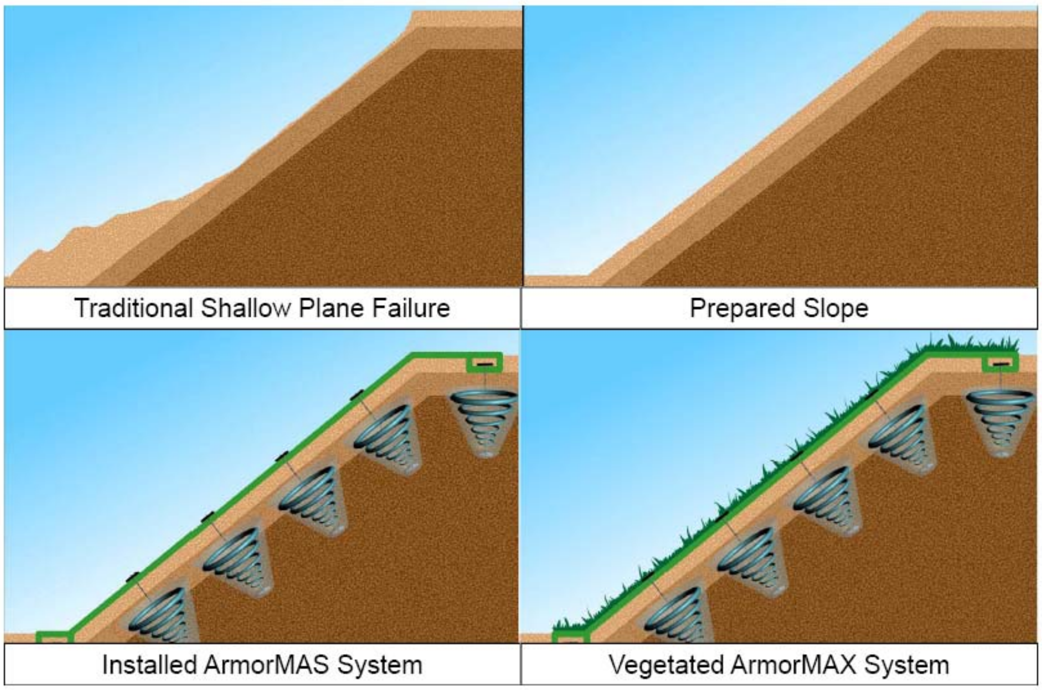


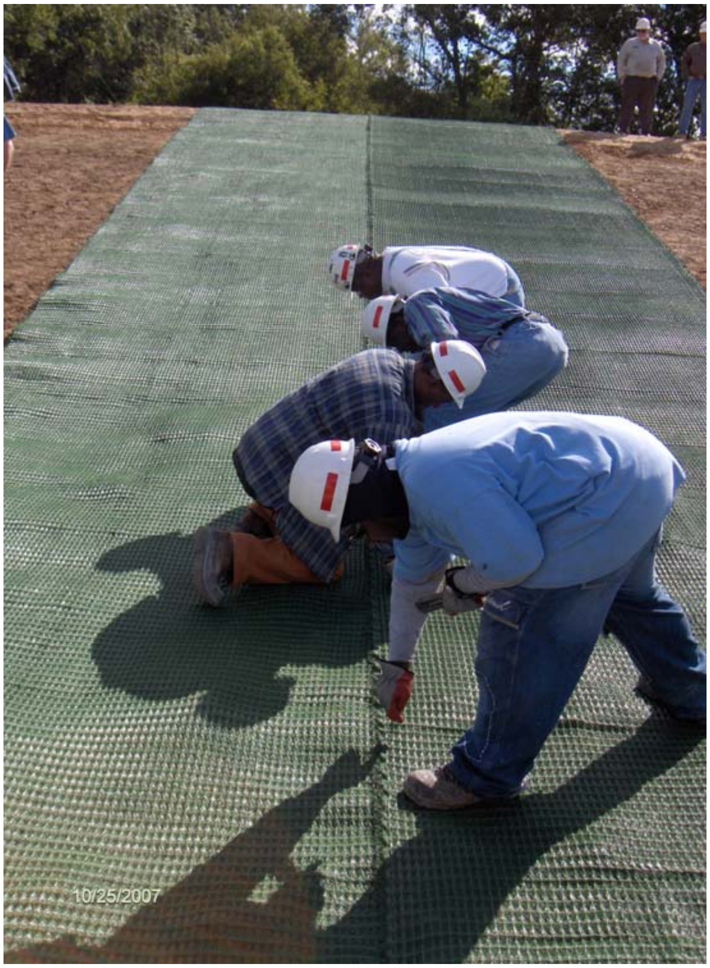
Figure 11: Manufacture's Installation Sequence (www.acfenvironmental.com).

Pyramat's superior characteristics provide a longer design life than our first and second generation standard TRMs, and meet the definition of HPTRM as defined by the U.S. EPA Storm Water Fact Sheet, "Turf Reinforcement Mats" (EPA 832-F-99-002) and FHWA FP-03 Specifications Section 713.8. Installed Cost is between $12-18/sy. The start of the roll was laid to have contact with two (2) sides of the trench were lined with the ARVS woven mat starting from the bottom of the trench. The next roll is overlapped with the previous one by 6" along the 100 foot length of the test section. The trench is backfilled with the

same excavated clay material and then compacted to manufactorer's specification. The mat roll is rolled over the newly filled and compacted trench to create a closed tube like anchor system.

<u>Photo 4</u>: Armoring product #1 is a Propex product called Pyramat. It is a mat that is anchored with the system is the box photographed above to the right.

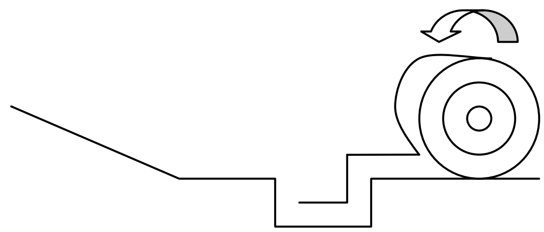
<u>Photo 5</u>: Anchored Reinforced Vegetation System (ARVS) mat rolls lined up and trench is backfilled.



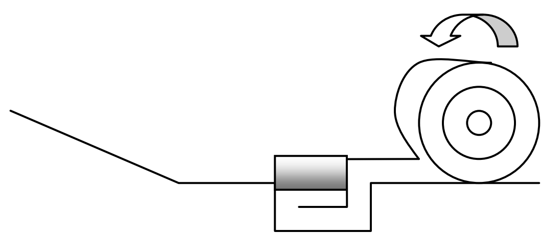
The mats are rolled out from the toe crossing over the crown and back to the opposite toe on the flood side of the levee section. The next roll with its overlap of approximately 6" is then rolled and so on for the length of the test section. Staples are placed ever 2 feet along the overlap to join the two rolls together as show in Photo 6.

Photo 6: Workers are overlapping the mat by 6" and inserting staples to connect them to establish a unit.

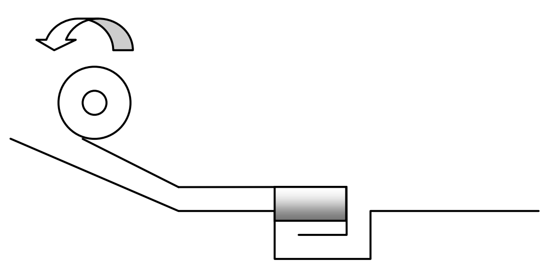
Close to 16 workers during the height of construction and down to 6 when installation was minimal.



Step 1



Step 2



Step 3

Figure 12: Anchored Reinforcement Vegetative System (ARVS) Step-by-step installation process.

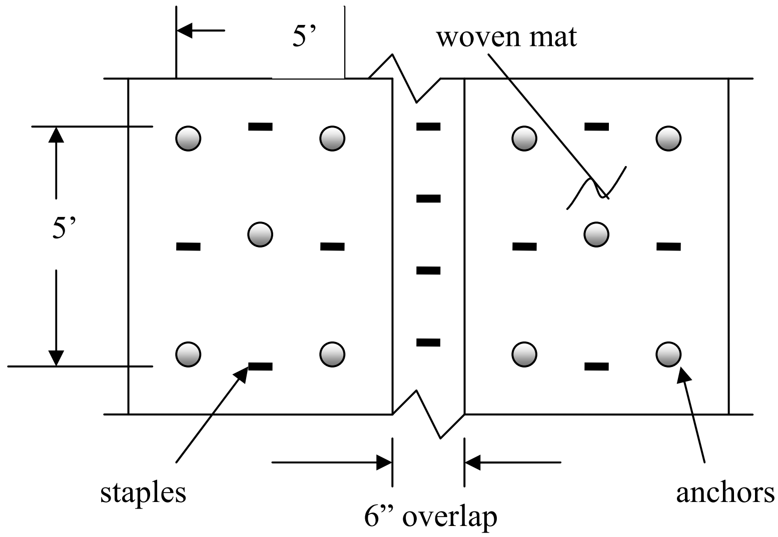


Figure 13: ARVS staple installation layout.

Staples were hard to hammer in. They were too soft and flimsy. The levee material and compaction is very mature and is not a good representation of the conditions we will be facing with new levee construction. Staples were bent and poking out is areas where the soil was too hard. Again, in new levee construction we anticipate that soil conditions to be soft and therefore this installation difficulty should not be a concern, but in this test section the installers are not concerned with the staples perturbing out which could cause problems later in the maintenance stage of this study. This will be monitored closely for the effects of this improper installation. It still may be an issue in future levee construction.

The installers were not monitored by the vendor representatives to place in appropriate locations therefore spacing was off. Anchors were also very difficult to install because of the mature soil conditions. The excavator was modified to speed up the installation process. The drill bit was welded onto the bucket. Five

(5) drill bits were broken, 2 using the excavator and 3 using the hand held drill. The mat itself is very durable and easy to work with. It keeps its form and structure & provides a workable surface with surface traction for workers to maneuver. Its woven construction is very tight and there are concerns with this products ability to allow grass growth in-between the woven fabric. Anchor installation stopped due to broken bits with no more in reserve. The work was nearly a third complete and took 4 hours.

Photo 7: Manual drilling of the anchors.

Photo 8: Anchor cable is pulled in tension and crimp.

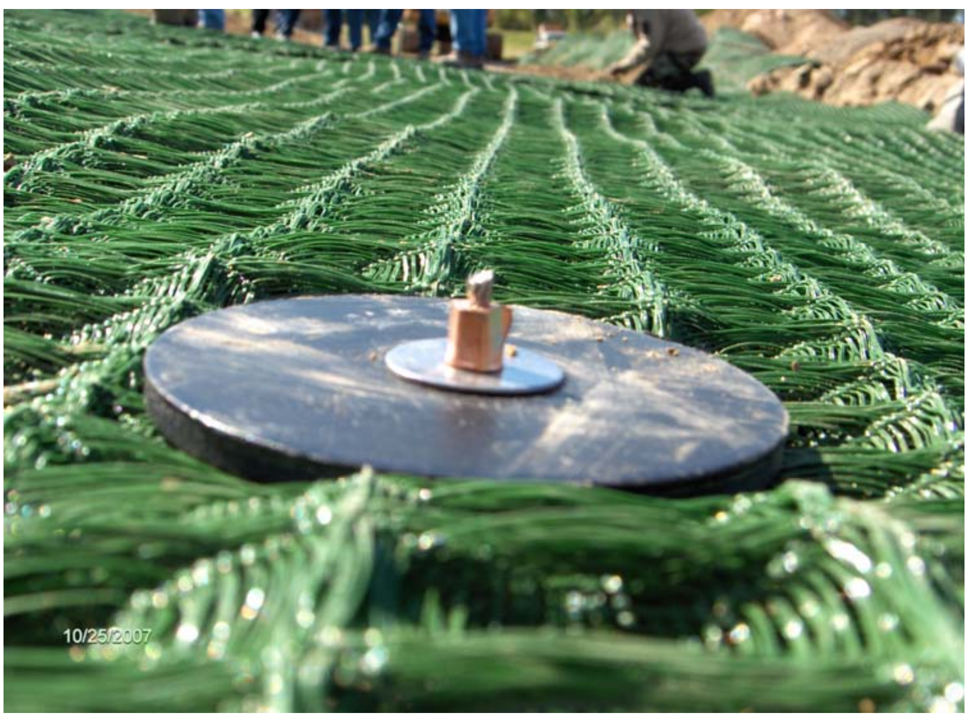


Photo 9: Excess anchor cable is cut to eliminate stickup.

Photo 10: Due to manual anchor drilling being problematic, the drill bit is welded to the excavator bucket and the anchors are mechanically installed.

Photo 11: The ARVS is rolled out and anchors are spaced for placement.

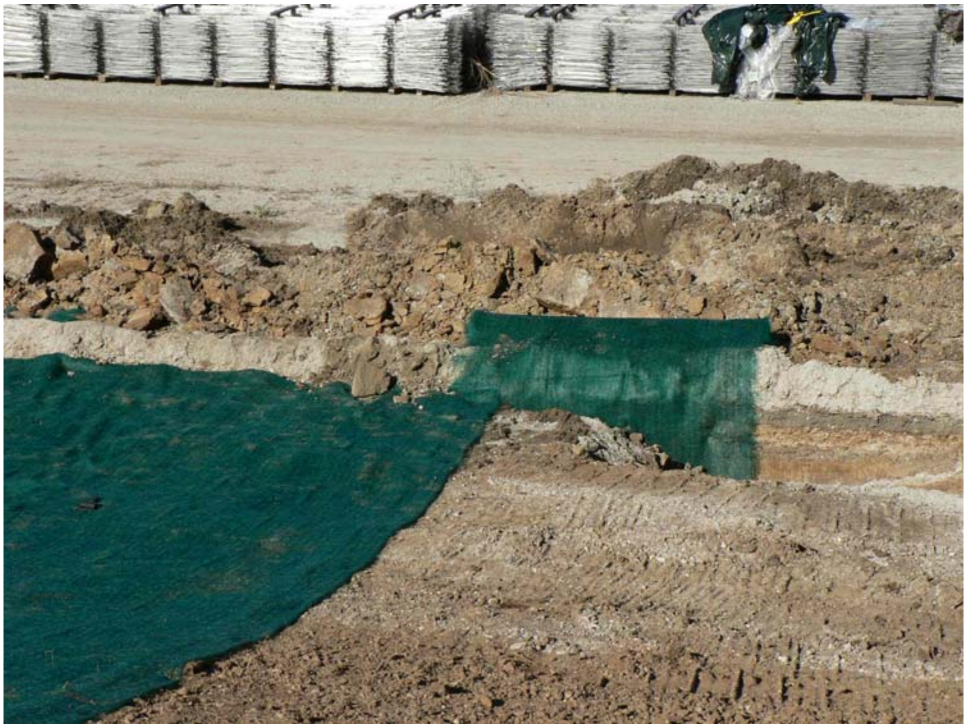
iii. PP12-Turf Reinforcement Mat (TRM)-Wester Excelsor product

Western Excelsior mesh was installed in the trench, the trench was backfilled and the mesh was rolled out using the same process and steps that were used during the Anchored Reinforced Vegetation System (ARVS) installation. The staples are still installed as the pervious product, but the only difference is that this system does not use anchors in its installation. This product is not as tightly woven as the ARVS. This product has a lesser strength than the previous. It took three (3) hours to completely install this product.

Photo 12: Overview of the ARVS installed and the Western Excelsior mats start of roll out.

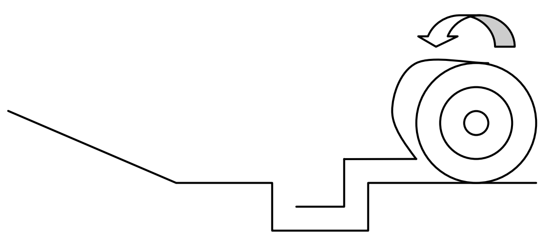
When asked which material they preferred to work with, the installers responded with the ARVS system because the surface of the mesh was very slippery on the Western Excelsior mesh. This surface made it very unsafe for the workers to casually walk on the mesh and the installation, although much faster than the ARVS, could have gone faster with less safety concerns on the forefront of the installers minds. The ends of the mesh unraveled and the mesh structure is not easily kept. The mesh is also not as consistent as the Woven fabric the ARVS system uses. Curious to see how this product holds up to the machine equipment during the topsoil placement over the various turf reinforcement mats (TRMs).

Photo 13: Western Excelsior mats placed is trench in the same fashion as the ARVS.

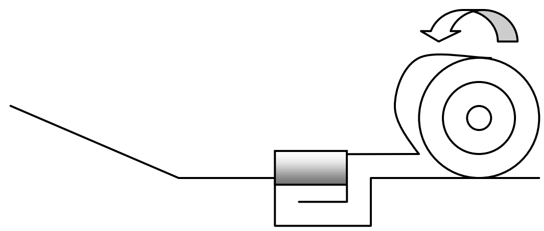


<u>Photo 14:</u> The trench is backfilled and the mat is rolled over the trench creating an anchor.

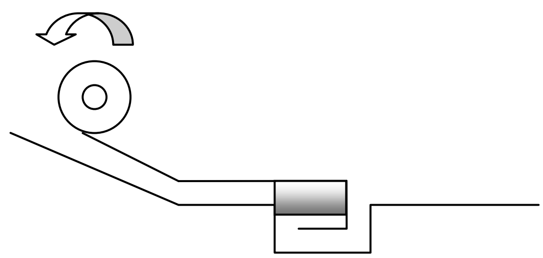
Figure 16 will illustrate the manufacturer's installation guide for levee slope application. The process suggested in the guide was closely followed and easily implemented in this segment of installation.



<u>Step 1</u>



Step 2



Step 3

Figure 14: Turf Reinforcement Mat (TRM) Step-by-step installation process.

Photo 15: Only tools needed are this installation are staples and a hammer.

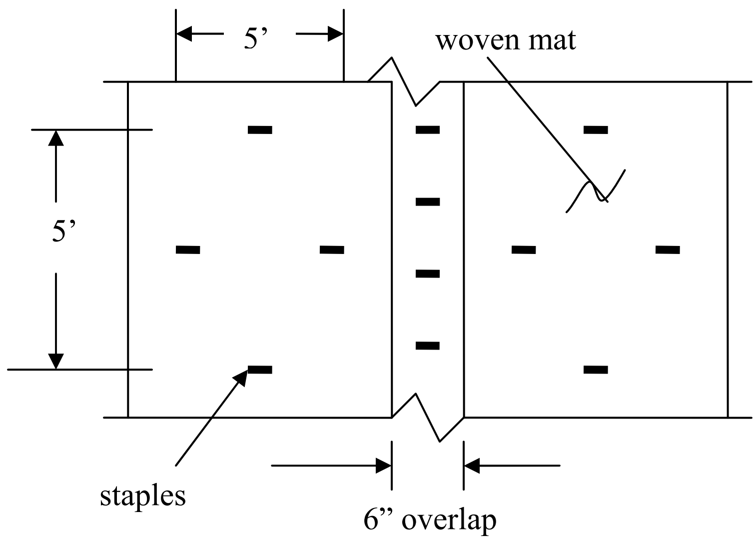
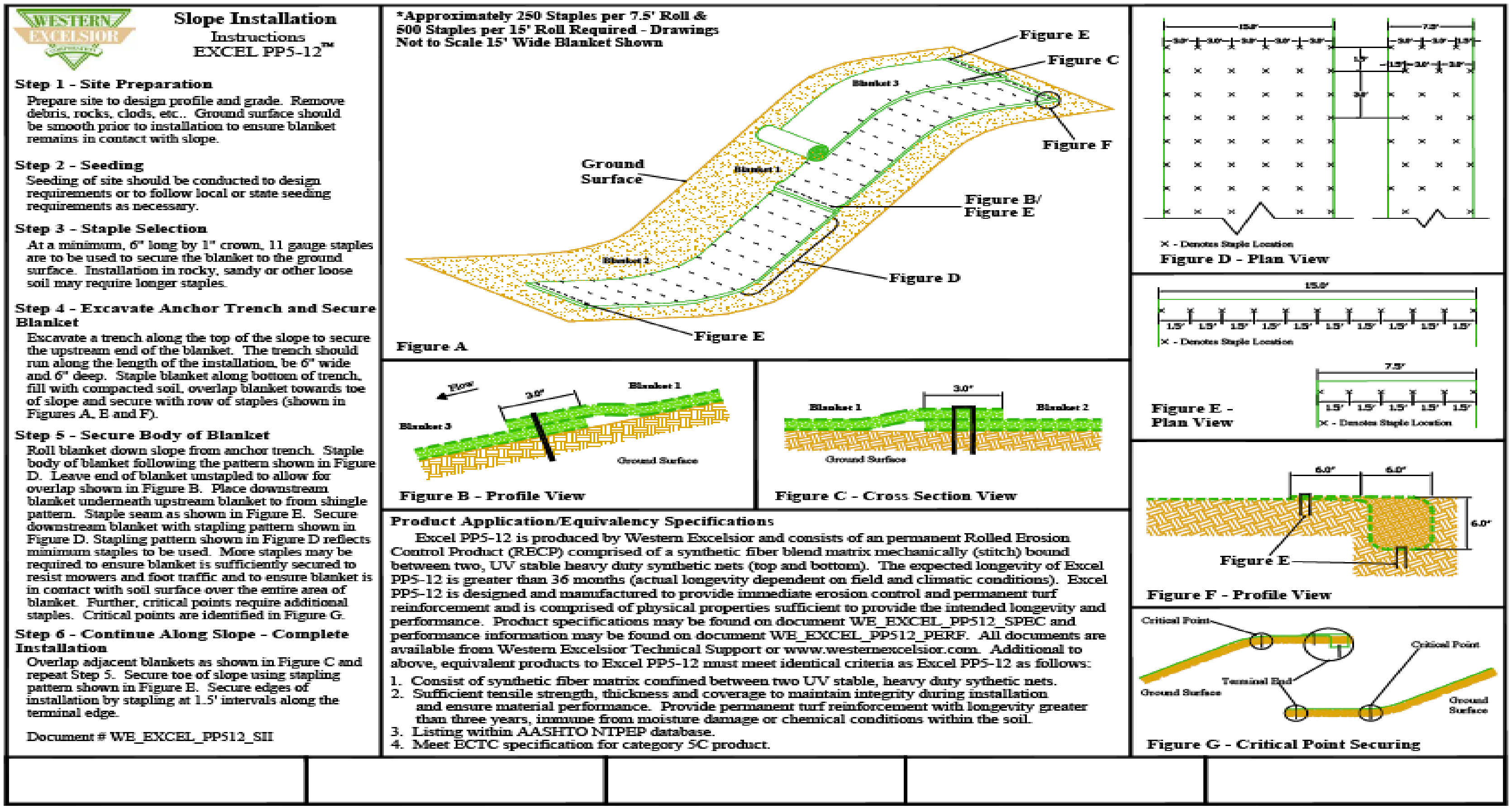


Figure 15: Turf Reinforcement Mat (TRM) staple installation layout.

Photo 16: Overview of the Western Excelsior Mat fully installed.



Slope Installation
Instructions
EXCEL PP5-12™

Step 1 - Site Preparation
Prepare site to design profile and grade. Remove debris, rocks, clods, etc.. Ground surface should be smooth prior to installation to ensure blanket remains in contact with slope.

Step 2 - Seeding
Seeding of site should be conducted to design requirements or to follow local or state seeding requirements as necessary.

Step 3 - Staple Selection
At a minimum, 6" long by 1" crown, 11 gauge staples are to be used to secure the blanket to the ground surface. Installation in rocky, sandy or other loose soil may require longer staples.

Step 4 - Excavate Anchor Trench and Secure Blanket
Excavate a trench along the top of the slope to secure the upstream end of the blanket. The trench should run along the length of the installation, be 6" wide and 6" deep. Staple blanket along bottom of trench, fill with compacted soil, overlap blanket towards toe of slope and secure with row of staples (shown in Figures A, E and F).

Step 5 - Secure Body of Blanket
Roll blanket down slope from anchor trench. Staple body of blanket following the pattern shown in Figure D. Leave end of blanket unstapled to allow for overlap shown in Figure B. Place downstream blanket underneath upstream blanket to from shingle pattern. Staple seam as shown in Figure E. Secure downstream blanket with stapling pattern shown in Figure D. Stapling pattern shown in Figure D reflects minimum staples to be used. More staples may be required to ensure blanket is sufficiently secured to resist mowers and foot traffic and to ensure blanket is in contact with soil surface over the entire area of blanket. Further, critical points require additional staples. Critical points are identified in Figure G.

Step 6 - Continue Along Slope - Complete Installation
Overlap adjacent blankets as shown in Figure C and repeat Step 5. Secure toe of slope using stapling pattern shown in Figure E. Secure edges of installation by stapling at 1.5' intervals along the terminal edge.

Document # WE_EXCEL_PP512_SII

***Approximately 250 Staples per 7.5' Roll & 500 Staples per 15' Roll Required - Drawings Not to Scale 15' Wide Blanket Shown**

Product Application/Equivalency Specifications
Excel PP5-12 is produced by Western Excelsior and consists of an permanent Rolled Erosion Control Product (RECP) comprised of a synthetic fiber blend matrix mechanically (stitch) bound between two, UV stable heavy duty synthetic nets (top and bottom). The expected longevity of Excel PP5-12 is greater than 36 months (actual longevity dependent on field and climatic conditions). Excel PP5-12 is designed and manufactured to provide immediate erosion control and permanent turf reinforcement and is comprised of physical properties sufficient to provide the intended longevity and performance. Product specifications may be found on document WE_EXCEL_PP512_SPEC and performance information may be found on document WE_EXCEL_PP512_PERF. All documents are available from Western Excelsior Technical Support or www.westernexcelsior.com. Additional to above, equivalent products to Excel PP5-12 must meet identical criteria as Excel PP5-12 as follows:

1. Consist of synthetic fiber matrix confined between two UV stable, heavy duty sythetic nets.
2. Sufficient tensile strength, thickness and coverage to maintain integrity during installation and ensure material performance. Provide permanent turf reinforcement with longevity greater than three years, immune from moisture damage or chemical conditions within the soil.
3. Listing within AASHTO NTPEP database.
4. Meet ECTC specification for category 5C product.

Figure 16: Manufacturer's installation guide (www.westernexcelsior.com).

iv. Enkamat S- High Density Turf Reinforcement Mat (HDTMR)-Profile product

Enkamat is a flexible three-dimensional mat for erosion protection on the most varied slope types. The open Enkamat product is particularly suitable for use on steep dry slopes exposed to wind and rain and hence prone to erosion. Enkamat creates an artificial root structure preventing soil eroding from steep slopes, river banks, landfill containments and other vulnerable areas. Once laid on slopes, Enkamat is seeded and filled with soil. Vegetation can then take root and develop easily.

Photo 17: Section of the Enkamat Mat.

Photo 18: Start of Enkamat product installation.

Photo 19: The Enkamat S is being placed in the trench as the two previous geosynthetics.

Photo 20: Close-up of Enkamat S shows the grid that runs through the mat and the side that should be in contact with the ground should be the smoother side.

Figure 17 demonstrates the installation process the manufacturer suggests for sequence of construction. The installers followed the guide easily and having a representative at the time of installation help insure that the quality of construction was there.

General Enkamat Installation

Enkamat is packaged in rolls that are easy to ship, store and install. No heavy equipment is needed for installation of matting and a roll can be handled by one or two workers.

Site Preparation

Whether slope or channel, the site must be shaped to the design specifications (grade, geometry, density of soil, etc.) and then dressed to be free of soil clods, clumps, rocks, or vehicle imprints of any significant size that would prevent the Enkamat from lying flush to surface contours.

Anchor Trench

Anchor trenches are required to securely fasten the Enkamat to the ground surface. In channel applications, the initial anchor trench is installed at the beginning of the channel and intermediate check slots are spaced at approximately 25 feet* intervals downstream depending on flow conditions and whether you soil fill or not. The Enkamat is installed into the bottom of the trench and fastened with pins spaced 3 feet apart. The anchor trench / intermediate check slots are then backfilled and compacted in a manner as to not damage the Enkamat.

** In lieu of excavated check slots, a double row of pins [or a number 1 or 2 rebar pinned across the mat] may be used at 25-foot intervals.*

Enkamat Installation

Roll the Enkamat down the slope or channel. The overlap between rolls is 3 to 4 inches. The splice between rolls is between 2 and 3 feet. Shingle the roll in the direction of water flow. Install pins down the center of each mat (mat is 3.25 feet wide), staggering them between the outside pins with a spacing interval of 3 to 5 feet. Pins pattern will vary depending upon application, soil type, slope or channel slope, geometry, etc. A rule of thumb for estimating the amount of pins required for a project is:

1:1 to 2:1 slopes
3-4 pins per sq/yd

3:1 lesser slopes
2-3 pins per sq/yd

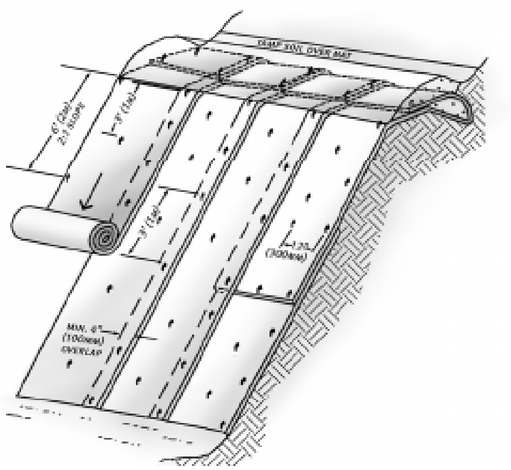


Figure 17: Manufacturer's installation guide (www.colbond-usa.com).

v. Grass only-Hydromulching

In the following sections a brief description of the erosion resistance of turf is presented. In general a distinction is made between good, average and poor coverage. Coverage is, in most case, a measure of how much grass coverage is in a set portion with is measured in percent coverage, 100% is full and 0% is bare.

Erosion resistance against flow—

In Krystian W. Pilarczyk, *Dikes and revetments*, the following figure is presented, which provides a basic idea on the erosion resistance of grass under influence of flow.

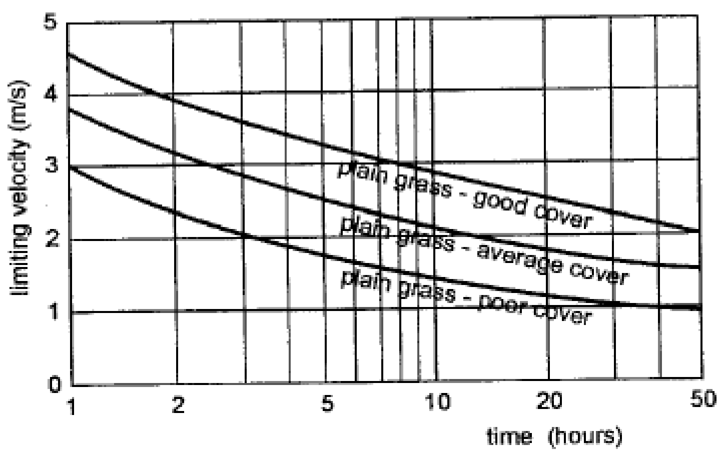


Figure 18: Limiting velocities for plane grass.

As Figure 18 shows, the better grass coverage the more the levee slope can withstand a higher velocity. This is why maintenance is so vital to the integrity of the levee flood control structures. The maintenance of the levees around the New Orleans area in grossly underfunded and also not emphasized as a critical element of the structure as a whole. With poor grass coverage, sometimes caused by

scalping the grass blades to stretch the duration of the following scheduled maintenance, the capacity to withstand high velocities is greatly reduced by 1.5 m/sec at the onset of the time test.

Erosion resistance against waves—

The following distinction on the erosion resistance of turf under influence of wave attack is presented:

a. Wave height < 0.4m:

- A good turf is generally not seriously damaged within a period of 1 to 2 days (the turf itself remains intact)
- A turf in a bad conditions is damaged quickly and holes up to 0.2m-0.4m depth develop within 24 hrs
- Turf of acceptable quality as a sandy subsoil may be effected severely within 24 hrs. Holes with a depth of 0.3m may develop.

b. 0.4m < Wave height < 1.0 m:

- An acceptable or good turf is affected only slightly within a period of 1 day or two days. The vegetation is damaged within 24 hrs.
- Turf in a bad condition is affected severely. Within 36 hrs holes with a depth of several decimeters may occur.

c. 1.0m < Wave height < 1.4m

- An acceptable or good turf may yield within 15-20 hrs, under the condition that the subsoil is sufficiently resistant against erosion and no large damages are present.
- When large damages are present a turf of good or acceptable quality will yield within several hours.
- When the quality of the turf is bad, deep erosion takes place within several hours.

The rate of erosion is mainly determined by the quality of the turf and less by that of the subsoil.

Photo 21: The process of hydro-mulching must be evenly sprayed to cover the required area.

Once all 4 armoring material were installed, the process of hydro-mulching took place on November 1, 2007. Hydro-mulching on all test areas consisted of approximately 1.2 acres of levee. The materials for this portion of the project consist of: 1 bag of hulled Bermuda grass seed, 1 bag of winter rye grass seed, and 54 bags of Enviroblend mulch. The hydro-mulching machine holds 100 gallons of water and was filled up 6 times, while adding 9 bags of much and 8lbs each of Bermuda and Rye grass seed per load. A rate of 2000lbs per acre was used. All armoring materials and test area were hydro-mulched on both sides of the levee project.

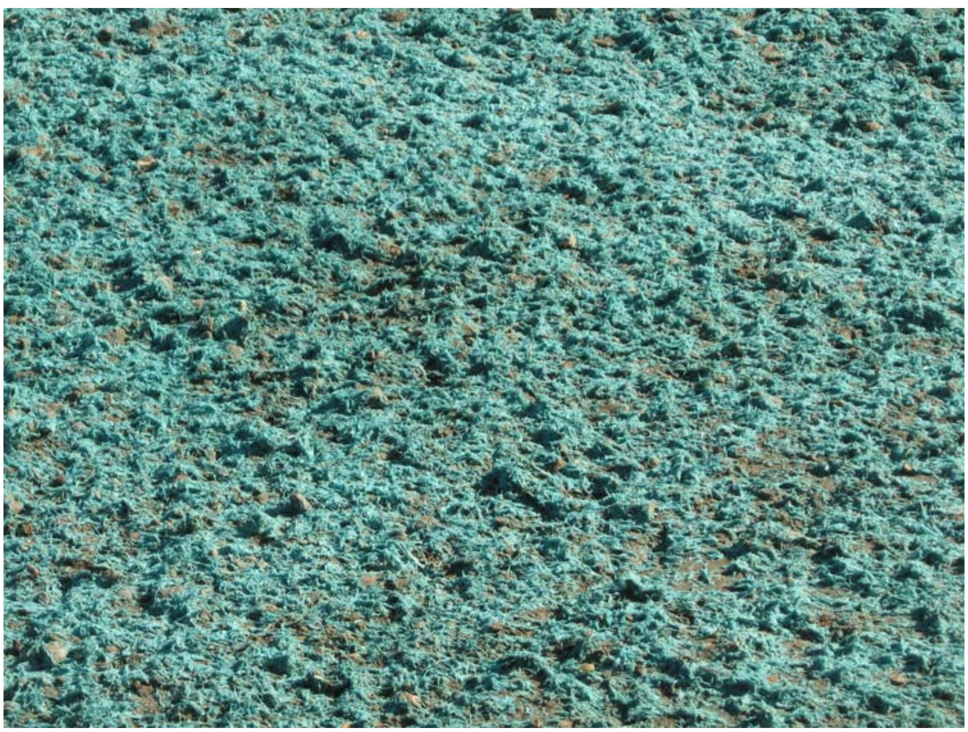


Photo 22: Hydro-mulching completed.

vi. Tapered Articulated Concrete Block (ACBs)- Contech product

Armortec Articulated Concrete Blocks are being offloaded. Six trucks were needed to deliver the quantity needed for this test section. The levee was graded 8” deeper than the rest of the levee reach to accommodate the blocks thickness so that the final levee grade would be even throughout the entire 500’ study reach. All block dimensions are 17.4" x15.5". Each block is strung together by a continuous nylon rope to form a sheet which is 8’ x 20’.

Photo 23: Here we see a filter fabric installed under the crushed stone.

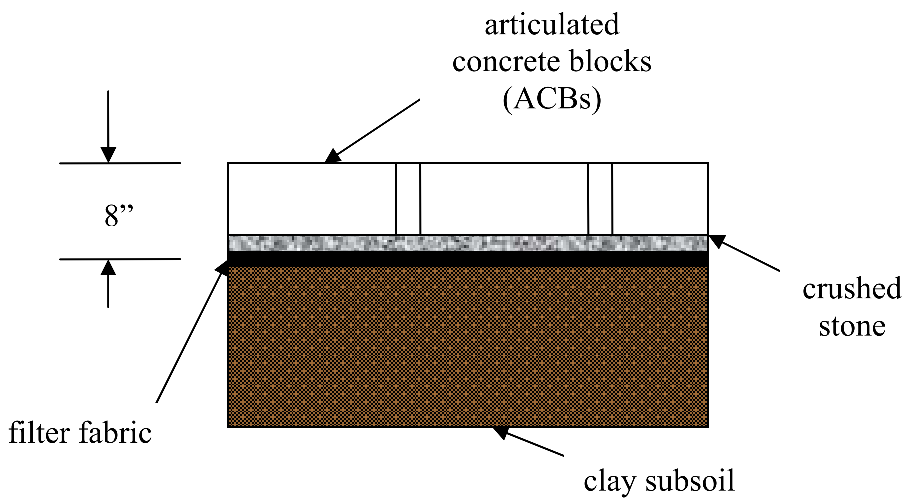
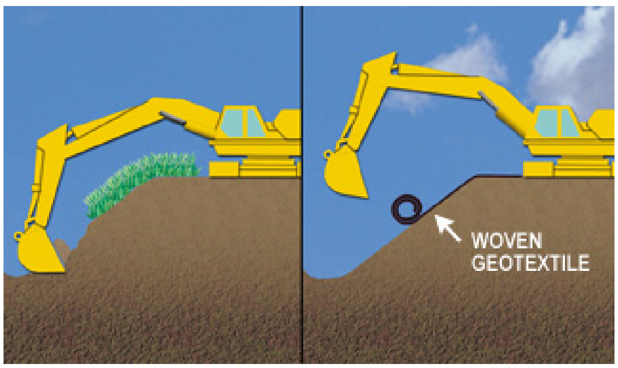


Figure 19: Section of the Articulated Concrete Block with the crushed stone beneath it and the filter fabric between the subsoil and the crushed stone.

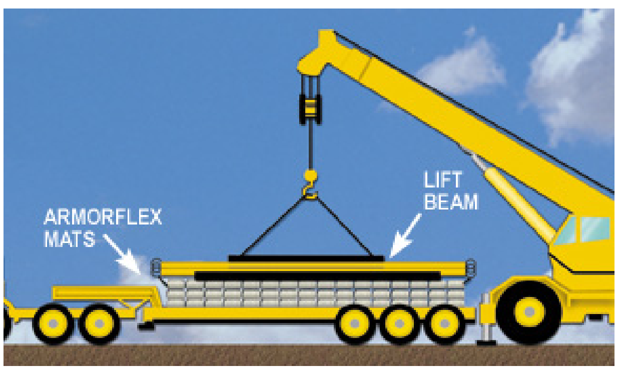
Off loading the sheets of ACB with spreader bar was very easy, but placement was very difficult with the equipment available. One crane was able to place a row of sheets along the trench near the toe and also a row above that. But for the rows past those, the crane was not able to reach to place the sheet that crossed over the levee crown and on the other side of the crown (the flood side of the levee section). The spreader bar was attached to the excavator and the work resumed. The time it took to place the first sheet was approximately 20 minutes with the crane. The sheets that lined up to it, which was placed by using the crane, took approximately 30 minutes. The remainder of the sheets that were installed by using the excavator took a lot of time lining up the blocks. Because the sheet of blocks are so flexible, which is good for conforming to the ground surface as it settles and compacts overtime in an uninformed way, this is detrimental for installation purposes. Each time the sheet is not in line with the adjacent sheet already installed, the whole process must start over. The first sheet

installed using the excavator took over one hour to install. When asked how they liked this product, the installation crew expressed their dislike for this product. They said it required too many steps and too many different mediums which will require a change in process each time.

ArmorFlex Installation Guidelines

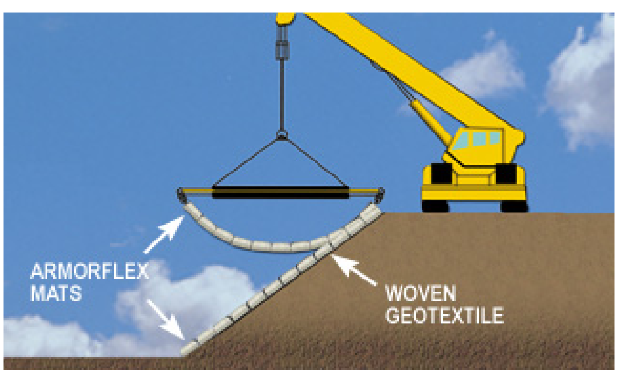


1. ArmorFlex® arrives on-site as a system of factory-assembled mats. ArmorFlex is placed on a site-specific geotextile which has been placed on a prepared subgrade using conventional construction equipment.



2. Mats are supplied on 42' trailers, up to 1600 sq. ft. per truck.

3. Mats can be handled with a spreader bar which is provided by Armortec™ with the initial load.



4. Permanent anchorage can be achieved by connecting the mat cables to patented anchors such as "Helix" or "Duckbill."

5. Mats subject to wave attack should be blinded with a sand/gravel mixture. Above-normal waterline mats may be topsoiled and seeded to give a "green" effect.

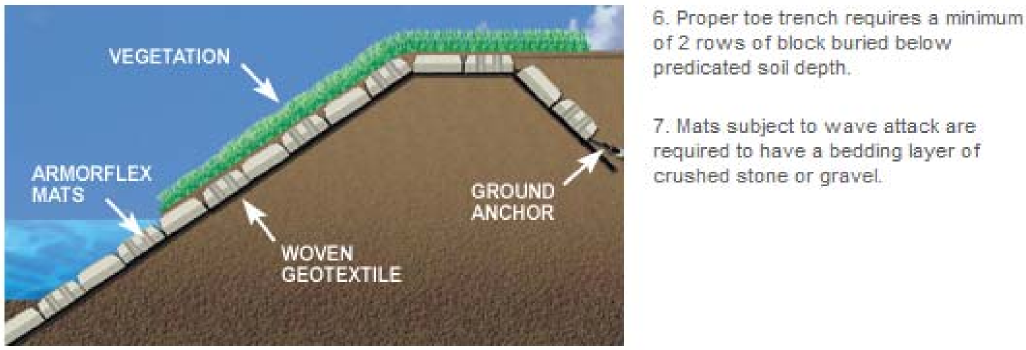


Figure 20: Manufacturer's installation guide (www.contech-cpi.com).

Figure 20 shows the step-by-step installation procedure. The procedure was altered slightly during this test to gather information on the installation of rock bedding to provide a drainage and filtration system for rain water.

Photo 24: Tampered Articulated Concrete Blocks (ACBs) from Armortec are installed.

Photo 25: Blocks are installed at the crown with the spreader bar attached to the excavator.

If this product was needed because of the overtopping rates that call for it, it is recommended that the proper equipment be used and that a large enough work area be used. Each sheet installed was 8’ x 20’ and weights 100 psf for a total of 16,000 pounds per sheet. The offloading requires at least the area for an 18 wheeler and a backhoe.

In the case of future construction, this material thickness could provide additional height to the levee. For example, if the levee is intended to be at elevation +24.0 and the blocks in conjunction with the crushed stone bedding can add an additional 1ft. of levee height, we may capture the benefit of using this product to gain additional protection. Or the cost of the earth work could be reduced and the thickness of this product could be used to capture the remaining

elevation needed. With the cost of clay material, in the post-Katrina market, this could be significant cost savings.

Photo 26: Four photos above show each product backfilled with about 1" topsoil.

In some cases topsoil was seen to be more than 1". This could be a problem with the TRMs. The grass roots may not reach far enough down to merge with the TRM and bonding. This is an ideal situation for maintenance though. As for the ACB, the depth of topsoil is not as large of a concern.

Monthly reports of the products' progress are captured in Appendix A. Visual inspections of the grass growth over the months of November through April were noted and the migration of the grass roots through the reinforcement.

During these months, the temperature and rain fall data were gathered to correlate the elements with the grass growth inspected and are located in Appendix B.

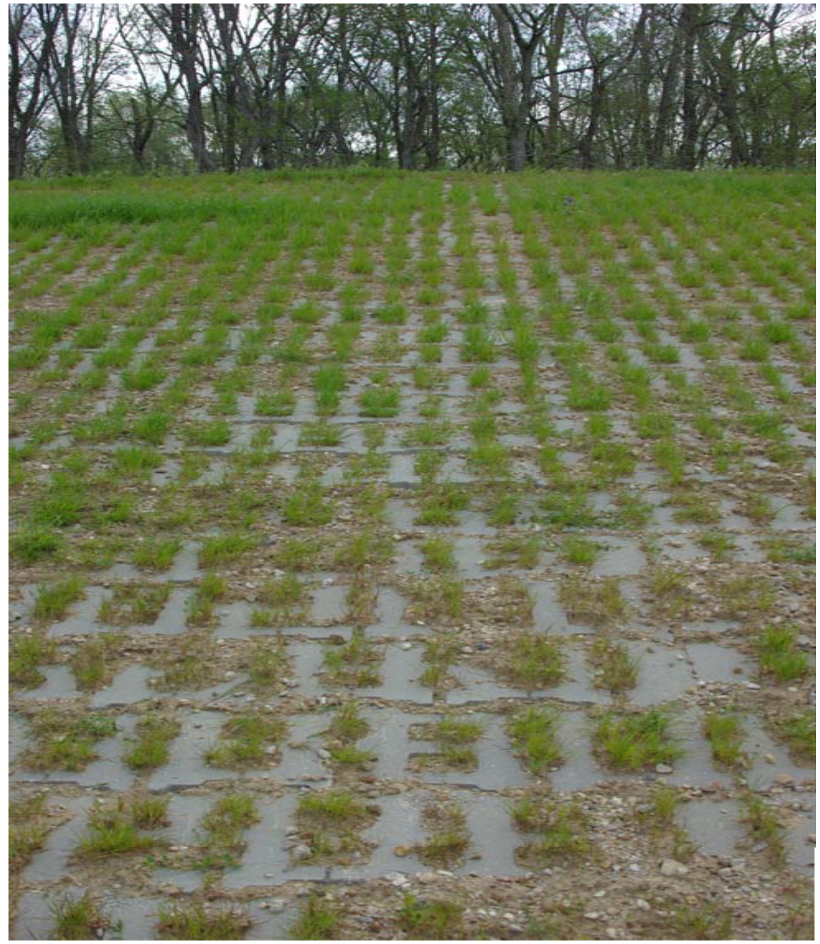
Comparisons of the products to one another will be discussed in the Comparison segment of this thesis. This comparison is limited to feedback from the installers, results of the installation, workability and cost.

B. Maintenance

As anticipated, the first maintenance cut occurred in March 2008 and the photos in this section show a successful first mowing pass. All the parish levee board members present at the Armoring Conference were invited to witness the maintenance of this test section. They have extensive experience with the hazards and problems that these products can pose to people, maintenance machines and the levee structure itself. Their recommendations will be covered in the appropriate section of this report.

<u>Photo 27:</u> This photo captures the start of the maintenance process which was captured via video by local TV channels.

<u>Photo 28:</u> Grass cutting completed at the crown of the levee.



<u>Photo 29:</u> Results of the ACBs after mowing.

Photo 30: Observation of insects that may cause armoring stability problems.

Photo 31: Entire levee mowed.

On April 12th, the St. Francisville Facility was overtopped by excessive rain events that pushed the Mississippi River waters over the ring levee. This was an unexpected event, but one that adds a very necessary level of evaluation of these products.

Photo 32: Signs of the Enkamat under distress after mowing.

Photo 33: Result of ACB after overtopping and being under water for several weeks.

<u>Photo 34:</u> Grass only section of the levee alignment shows nearly 2 feet of scouring at the crown of the levee.

This overtopping situation was planned in a future test that would have been more controlled but very costly. The outcome of this event shortened the initial maintenance cycle from 3 to 1 but now adds a level of hydraulic and erosion feedback that is needed for a better comparison.

Photo 35: More of the Enkamat exposed after the flooding.

Photo 36: With the facility being under water for several weeks, all the grass died leaving the reinforcement mats without reinforcement.

V. COMPARISON OF PRODUCTS

Tables 2 and 3 summaries the results after monitoring the installation of each product, documenting the process of grass growth to the point of mowing, witnessing the initial maintenance cut with the Levee Board Members (LBM) and implementing their feedback, and supervising the overtopping event that surprised this experiment.

The top three parameters for installation are labor, equipment and time. The other parameters can easily be addressed by sharing with the manufacturers our finding on how to make their instructions user-friendly. With labor, time and equipment being the top parameters, this could add considerable cost and time to the projects. The ARVS is the most labor intensive and time consuming with regards to installation. The ACB needs the most in equipment for installation. Because of the weight and size of the ACB a crane and an 18 wheel truck is needed were as the others only need a regular work truck for transportation and no crane.

The given parameters for maintenance are not as clear cut as that for installation. Table 3 shows that the Enkamat is the worst with respect to maintenance. During the overtopping event the top soil eroded more and more than what was observed during the mowing.

Given the information collected in Table 2 and 3, the installation and maintenance issues with each product is better laid out for selection of armoring for specific needs in different areas of the Hurricane Protection System as illustrated in Figure 1.

INSTALLATION PARAMETERS	representative present	standard installation provided	installers incorrectly performed a step	representatives corrected the installation process	number of laborers	equipment needed	time (hr)
Articulated Concrete Block (ACB)	yes	yes	yes	yes	6	backhoe w/ spreader bar	8
Grass Only	yes	yes	no	no	3	none	1
Enkamat	yes	yes	yes	no	6	rubber mallet	5
Western Excelsior	no	no	no	no	6	rubber mallet	3
Anchored Reinforced Vegetative System (ARVS)	yes	yes	yes	yes	16	drill 3' drill bit rubber mallet	12
Articulated Concrete Mats (ACM)	yes	no	no	no	6	backhoe w/ spreader bar	6

Table 2: Comparison of Installation Parameters.

MAINTENANCE PARAMETERS	mowing 3" depth	problems with transitions	cutter blade concrete clip	exposed armoring more exposed	(LBM) present for initial mowing	recommendations included in future	level of overtopping resistance
Articulated Concrete Block (ACB)	yes	yes	yes	yes	yes	yes*	high
Grass Only	yes	no	N/A	no	yes	none	low
Enkamat	yes	yes	N/A	yes	yes	none	low
Western Excelsior	yes	no	N/A	no	yes	none	low
Anchored Reinforced Vegetative System (ARVS)	yes	no	N/A	yes	yes	yes**	mid
Articulated Concrete Mats (ACM)	yes	no	no	no	yes	none	high

* Bedding be excluded from the steps is possible. Gravel bedding may cause problems during maintenance.
** Anchors may cause injuries to pedestrians in populated areas where levee is used for recreation.

Table 3: Comparison of Maintenance Parameters.

VI. RECOMMENDATION

a. Installation Considerations

1. Impact of the armor on the design of the existing structure:

   Details connecting to existing floodwalls should be considered and recommendations from the manufacturer should be implemented.

2. Site access and maneuverability requirements:

   With the requirement required to install the concrete products due to its weight and size, these products should not be used in confined work areas.

3. Quality of transitions is important in keeping the armor material from being exposed to the mower blades. Intense quality control from the product representatives should be applied in these areas during installation.

4. Safety requirements maybe important in areas where levees are used frequently for recreation.

5. Possibility to remove, reinstall and recycle armor as lifts is scheduled on the levees over time due to anticipated section settlement.

b. Maintenance Program Recommendations

The Armoring is made up of two major components: the armoring and the hydraulic mulch. A proper maintenance program is necessary to ensure that the function of the armoring system will perform as it was designed - minimizing erosion and protecting the established vegetation during extreme storm events. The following five (5) areas have been identified as important when it comes to the maintenance program. These include Initial Installation, Vegetation Establishment (and Density), Fertilization, Monitoring Performance and Mowing.

1. Initial Installation

The initial installation is of primary importance for the success of the armoring to meet the performance objective - to minimize erosion and protect the vegetation once established. If the armoring is installed incorrectly initially, then the actual performance of the armoring will likely be substandard. The critical part of the installation is to ensure that the armoring is always in direct contact with the soil, so that the interaction between the armoring, soil and root structure of the vegetation will take place. Another key part of the installation, which is actually a design issue, is to choosing vegetation that is common to the area. Blending some type of annual grass or grasses that germinate quickly (like Rye Grass but will only last the first growing season) can be considered. This will aid the desired perennial grasses in establishing itself (hardy grasses typically take a longer time to germinate).

2. Vegetation Establishment

The second most important part is to establish the vegetation in order to achieve maximum performance of the armoring. This is where the second component, hydraulic mulch greatly enhances the establishment of vegetation. Hydraulic mulch creates an erosion control layer to protect the underlying soils and it will retain 15 times its weight in moisture to ensure vegetation grows even during dry spells. The three parts for seed germination and establishment of vegetation include temperature, moisture and soil makeup. Obviously temperature can not be controlled. However, seeding is performed typically in the spring or fall to reduce the possibility of extreme hot or cold weather during the germination phase. Moisture can be controlled by adequately watering. Within the first two weeks after seeding, typically water needs to be applied to enhance seed germination and develop healthy vegetation. Periodic water application after that may be required depending on the weather. An important point to remember is to ensure adequate soil moisture for optimum germination and vegetation growth. Avoid over-watering (soils becoming overly saturated). The water applied should be sprayed and not jetted (stream flow) to prevent any artificial catalyst of erosion. It has been recommended that the density (or coverage) of the vegetation should be at least 50% established within the first six (6) months and 90% after 1 year. If the adequate density is not established then over seeding should take place to ensure the proper density of 90% is achieved. An appropriate seed mixture should be required by a qualified agronomist with knowledge of native soils.

3. Monitoring Performance

A qualified inspector should perform periodic monitoring. This should particularly be done after storm events to check for erosion, scour, debris or any significant sediment accumulations. If erosion or scour has occurred, it is recommended that the trouble area be reworked by re-placing the soil and re-seeding. Debris and any significant sediment accumulations should be removed to reduce restriction to vegetation growth. The levee slopes should also be reviewed to ensure proper slope stability. The monitoring program should also identify the condition of the vegetation growth and density, as well as, signs of stress caused by weather conditions or flow events.

4. Mowing

Mowing is important in establishing and maintaining a good vegetated cover. When the upper portion of the vegetation is removed, the plant produces more sugars and begins storing more starches in the root. This results in more plant growth and in essence, to achieve a knitting affect of the vegetation into the soil and the armoring which in return, inhibits erosion, retains soil moisture, reduces heat stress and controls broadleaf infestation. This results in overall healthy vegetation and increases the aesthetics of the area. In general, mowing should be done at least twice a year and perhaps more depending on the type of vegetation selected. A minimum cut height of 3” is recommended, but 6” is ideal. Mowing should be done when the ground is dry to minimize rutting that might be caused by heavy maintenance equipment in otherwise wet channels.

5. Fertilization

Many soils require additional fertilizer to enhance establishment of vegetation. Supplemental applications might be required yearly, based on soil conditions and vegetation growth, to increase and maintain the strength of established vegetation. Ensure that fertilizer is applied at recommended rate and does not burn the existing vegetation.

VII. CONCLUSION

The main conclusion is that the knowledge on armoring of crest and leeside of levees, floodwalls and transitions is very limited. However, based on a literature survey and for a limited number of conditions, approaches have been presented which could be used for design of armor. The questions to answer as the scope of this thesis:

1. Can this product be installed and viable in the New Orleans Hurricane Storm Damage Risk Reduction System (HSDRRS)?

2. Will the Levee Boards be able to maintain the products once the ownership is transferred?

The answer is that each product has its place in the system. Areas of the system will need robust products like Articulated Concrete Blocks and others areas will be suited for grass only. Conversely, the Levee Boards will need further guidance in how their maintenance practices will be renewed with the presences of these armored levees in the protection system.

This thesis acknowledges that elaborate studies and investigations are required to fill in the knowledge gaps and develop the preliminary approaches in general design tools.

Given the existing knowledge gaps and the limited scientific basis for some of the presented approaches, we or others with hydraulic and structural expertise on armoring, should pursue further studies with state of the art capabilities.

Seven Steps for Successful Armoring Selections

1. Select applications
2. Determine functional longevity
3. Anticipate climate (arid, semi-arid, or temperate)
4. Understand traditional solution
5. Predict non-hydraulic stresses (maintenance stresses)
6. Know vegetation type
7. Calculate hydraulic stresses

VIII. REFERENCES

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IX. APPENDICES

Appendix A. Monthly Report of Installation Progress

1. 1 month after installation: November 2007

On November 2007 visit, found four inches of topsoil, in some areas, placed on top of the Anchored Reinforced Vegetation System (ARVS) and the other synthetic Turf Reinforcement Mats (TRMs). Propex's standard recommendation is to seed and place approximately ½" to 2" of topsoil on top of the mat. This is consistent with the installation drawings. The thickness of topsoil on top of an Anchored Reinforced Vegetation System or TRM is important because the systems are designed to have vegetation put roots through the mat. In the case of a thick topsoil layer as there is on the St. Francisville site, the seed will germinate and put roots in the topsoil layer and possibly never reach the mat and interlock with the matrix. A ½" thick layer of topsoil provides a medium for the seed to germinate and forces the roots through the mat to anchor into the soil below. Additionally, the thick layer of topsoil and hydro-seeding used at St. Francisville will not grow grass any faster on the Anchored Reinforced Vegetation System. The Anchored Reinforced Vegetation System's three-dimensional construction uses X3 fibers to create a thick matrix with numerous void spaces that holds seed, soil, and water together resulting in superior vegetative growth.

The thick layer of topsoil covering the test site will affect the results of any future testing planned for this site. The non-penetration of the roots into the mats will result in the soil above the mats being washed away in a hydraulic test and thus not accurately testing the vegetated performance of the armoring

systems. Also, buried under 4" of topsoil will not serve as a real world mechanical test of the individual products ability to withstand damage to non-hydraulic stresses such as monthly mowing. The test installation of the different armoring systems was an excellent learning tool and it was beneficial for Propex to learn what improvements are needed to be made to the installation tools used for levee applications. The process of upgrading these tools and making them out of higher quality steel for applications similar to St. Francisville where the soil has been over compacted will be suggested.

Photo 1: Grass established after 1 month.

2. 2 months after installation: December 2007

On December 2007 visit, the grass establishment was 90% and the Armortec product was still struggling to grow grass. This is typical for this product and due to it high initial strength, the grass growth is not of great concern.

<u>Photo 2:</u> Levee crown progress across all the products.

Photo 3: **ARVS progress.**

Photo 4: **Western Excelsior progress.**

<u>Photo 5:</u> Enkamat progress

<u>Photo 6:</u> Grass only progress

<u>Photo 7:</u> **ACB progress.**

<u>Photo 8:</u> **The ACB progress is behind the other products. The presence of gravel stones from the bedding material is excessive on the surface.**

3. 3 months after installation: January 2007

On January 2008 visit on the 18th, more grass had established on the ACB section of the test alignment. This is attributed to the rain events recorded. These records are available in Appendix B. At this rate the fist maintenance cute should be in two months or so.

<u>Photo 9:</u> Armortec blocks on the protected side

Photo 10: **Grass only and Western Excelsior segment of the test reach on the protected side**

Photo 11: **Enkamat segment of test reach on the protected side**

<u>Photo 12:</u> ARVS protected

<u>Photo 13:</u> ARVS is exposed at the surface.

<u>Photo 14:</u> This photo is a good example of how the grass is growing to interlock with the mat.

<u>Photo 15:</u> ACM grass growth is not healthy.

In general, the grass is progressing well into the mats. In the case of the concrete blocks and the mats, it is lagging behind which is expected do to it lack of ground surface exposed to sunlight.

4. 4 months after installation: February 2008

The rain and temperature recordings have been ideal for the germination process this month. It is planned that the first maintenance mowing will occur in March. The ACB and the ACM are catching up with the mat progress. This will help in the maintenance of these products. The blades from the mower will then not be exposed to the harsh concrete material.

<u>Photo 16:</u> ARVS pushed it to the surface

<u>Photo 17:</u> Great grass growth is localized areas

<u>Photo 18:</u> Enkamat is also exposed

<u>Photo 19:</u> **Grass only section is actually not as advanced as the sections with reinforcement**

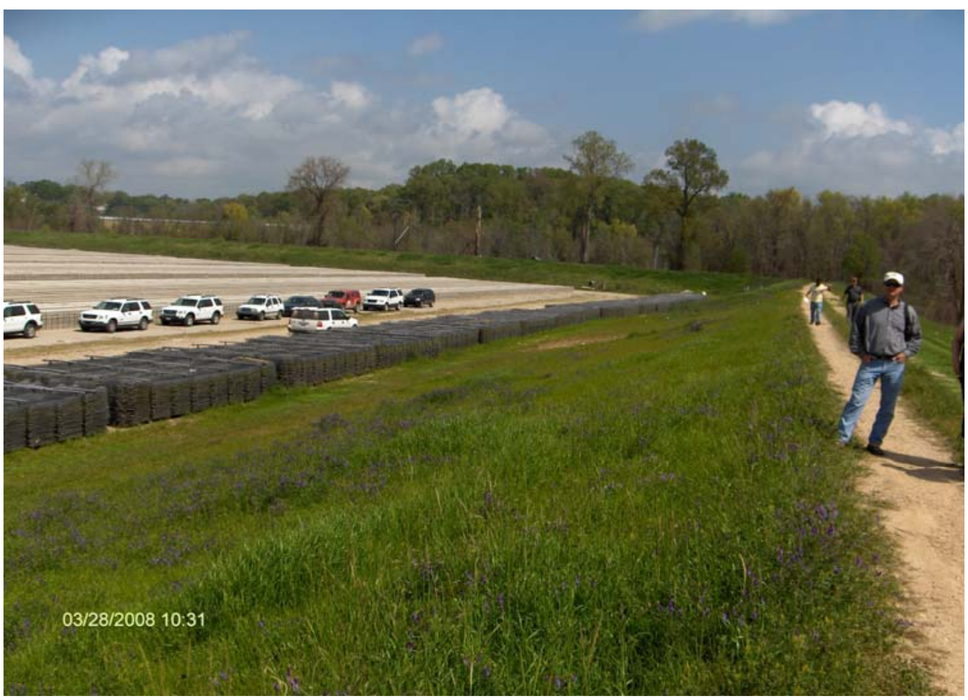
<u>Photo 20:</u> **ACB progress**

Photo 21: ACM progress

5. 5 months after installation: March 2008

As anticipated two months ago, the first maintenance cut occurred and the photos in this section show a successful first mowing pass. All the parish levee board members present at the Armoring Conference were invited to witness the maintenance of this test section. They have extensive experience with the hazards and problems that these products can pose to people, maintenance machines and the levee structure itself. Their recommendations will be covered in the section, VI. Maintenance, of this thesis.

<u>Photo 22:</u> **Grass before cutting. Area shown covers ARVS, Wester Excelsior and Enkamat.**



<u>Photo 23:</u> **Grass before cutting. Area show covers grass only and ACB.**

Photo 24: ACB after mowing

<u>Photo 25:</u> ARVS after cutting

<u>Photo 26:</u> Enkamat after cutting

6. 6 months after installation: 12 April 2008

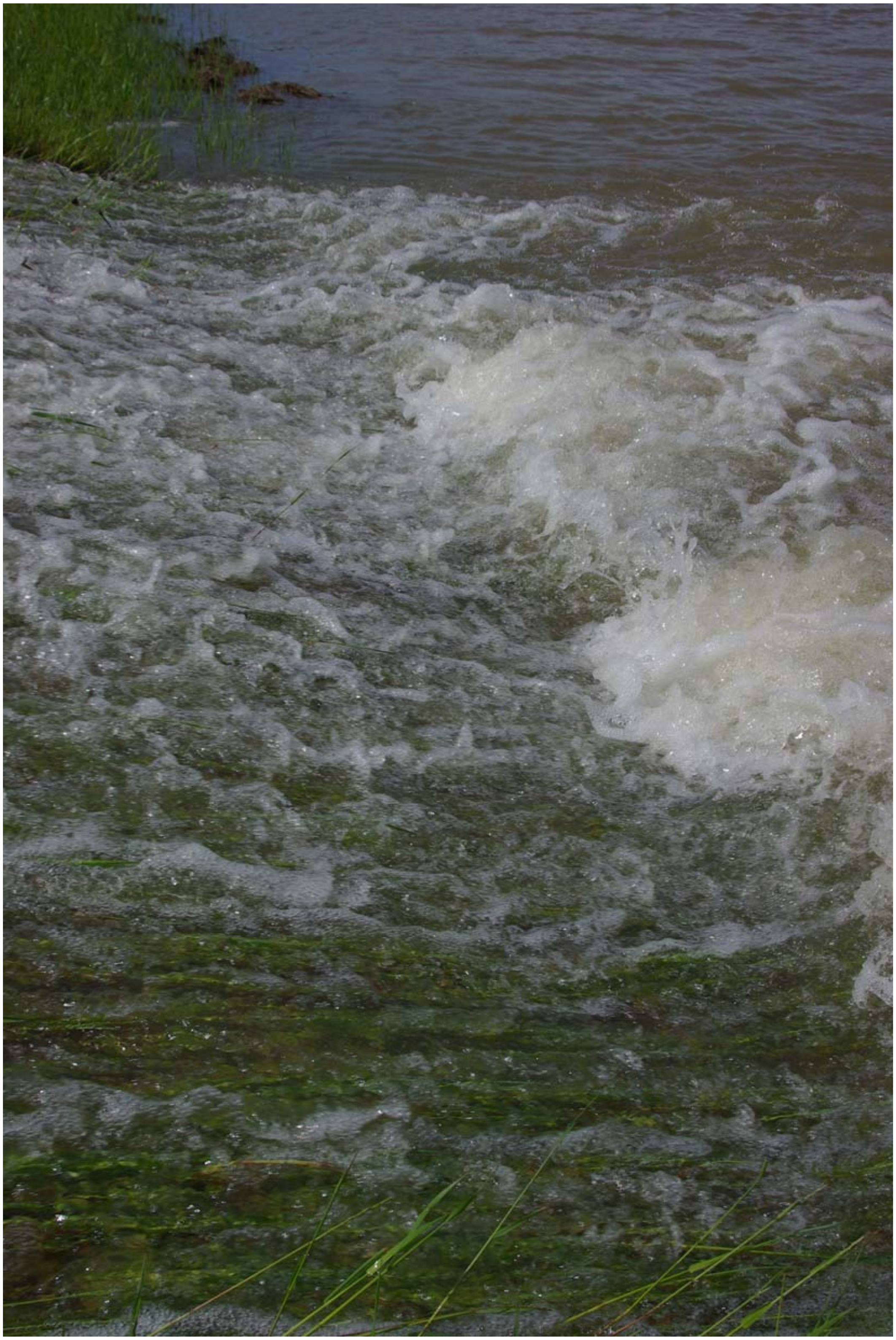
On April 12 the river stages elevated above the levee crown elevation and an unexpected flood event occurred. Although the scope of this thesis does not cover this overtopping event, this occurrence was an added benefit to the test section. Nature allowed the products to be witnessed under similar conditions as a hurricane overtopping event. Photos 27-32 capture the overtopping of the crown at all the segments of the project alignment. The dewatering event is dependent on the river stages. As soon as the river stages decrease enough to dewater the facility, the slope and the toe can be assessed.

<u>Photo27:</u> **Overview of test section with all segments shown.**

<u>Photo 28:</u> Pyramat

Photo 29: Enkamat

Photo 30: ACM



<u>Photo 31:</u> Western Excelsior

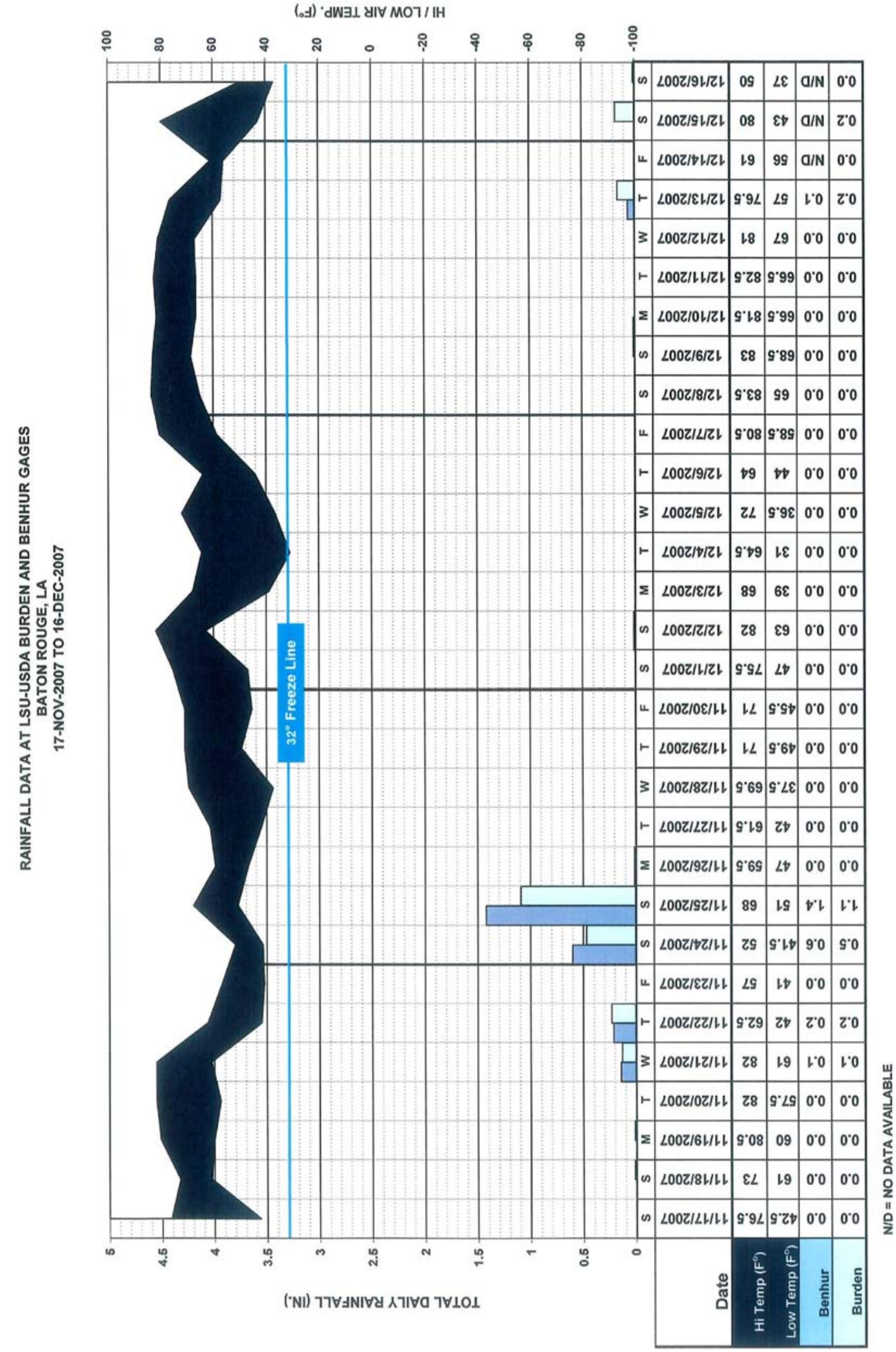
<u>Photo 32:</u> Grass only

7. 7 months after installation: May 2008

Facility was still under water. The test duration was only to be for 6 months but with the high river stages that flooded the facility in St. Francisville, information was included in this thesis to capture some of the effects that the products endured during the overtopping event.

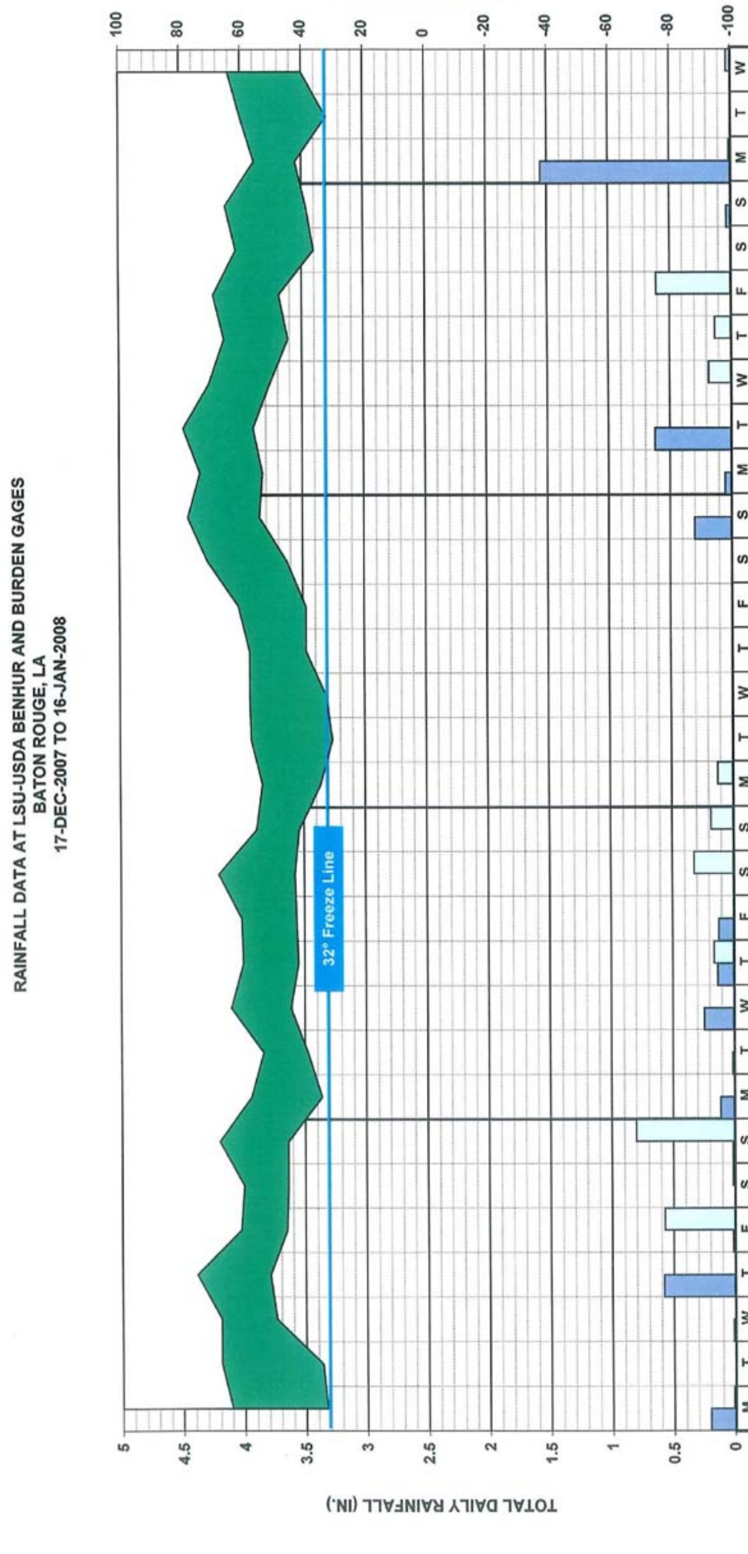
Appendix B. Temperature and Rain fall data

Rain is essential to the germination of the vegetative element that makes up part of the turf reinforcement mats. The following Graphs below shows the temperature as well as the rain fall. Temperature is also a large factor in the growth of grass. This data will be provided each month as a correlation to it progress.



Date	Day	Hi Temp (F°)	Low Temp (F°)	Benhur	Burden
11/17/2007	S	76.5	42.5	0.0	0.0
11/18/2007	S	73	61	0.0	0.0
11/19/2007	M	80.5	60	0.0	0.0
11/20/2007	T	82	57.5	0.0	0.0
11/21/2007	W	82	61	0.1	0.1
11/22/2007	T	62.5	42	0.2	0.2
11/23/2007	F	57	41	0.0	0.0
11/24/2007	S	52	41.5	0.6	0.5
11/25/2007	S	68	51	1.4	1.1
11/26/2007	M	59.5	47	0.0	0.0
11/27/2007	T	61.5	42	0.0	0.0
11/28/2007	W	69.5	37.5	0.0	0.0
11/29/2007	T	71	49.5	0.0	0.0
11/30/2007	F	71	45.5	0.0	0.0
12/1/2007	S	75.5	47	0.0	0.0
12/2/2007	S	82	63	0.0	0.0
12/3/2007	M	68	39	0.0	0.0
12/4/2007	T	64.5	31	0.0	0.0
12/5/2007	W	72	36.5	0.0	0.0
12/6/2007	T	64	44	0.0	0.0
12/7/2007	F	80.5	58.5	0.0	0.0
12/8/2007	S	83.5	65	0.0	0.0
12/9/2007	S	83	68.5	0.0	0.0
12/10/2007	M	81.5	66.5	0.0	0.0
12/11/2007	T	82.5	66.5	0.0	0.0
12/12/2007	W	81	67	0.0	0.0
12/13/2007	T	76.5	57	0.1	0.2
12/14/2007	F	61	56	N/D	0.0
12/15/2007	S	80	43	N/D	0.2
12/16/2007	S	50	37	N/D	0.0

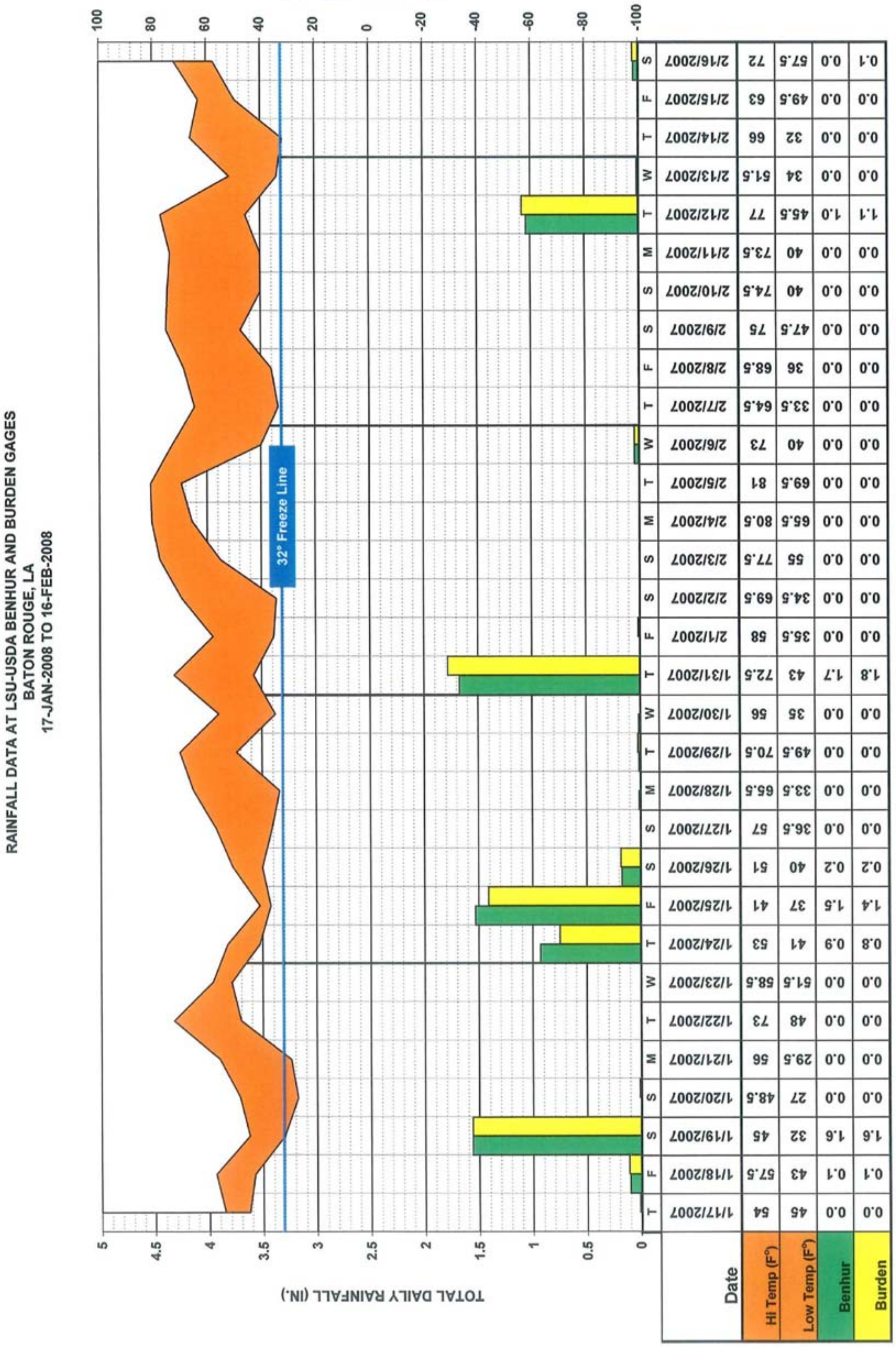
Graph 1: November/December Temperature and Rain data in Baton Rouge, LA.



Date	Day	Hi Temp (F°)	Low Temp (F°)	Benhur	Burden
12/17/2007	M	58	29	0.2	0.0
12/18/2007	T	65	41	N/D	0.0
12/19/2007	W	77.5	46	0.0	0.0
12/20/2007	T	70	59	N/D	0.6
12/21/2007	F	70.5	58	0.0	0.0
12/22/2007	S	74.5	52	0.6	0.8
12/23/2007	S	52.5	33.5	0.0	0.0
12/24/2007	M	49.5	33	0.0	0.0
12/25/2007	T	60.5	38	0.0	0.0
12/26/2007	W	61.5	36.5	0.1	0.2
12/27/2007	T	68	45	0.0	0.0
12/28/2007	F	67.5	51	0.2	0.3
12/29/2007	S	69	46.5	0.1	0.2
12/30/2007	S	63.5	40.5	0.1	0.1
12/31/2007	M	69.5	36	0.0	0.0
1/1/2008	T	53	36	0.0	0.0
1/2/2008	W	42.5	28.5	0.0	0.0
1/3/2008	T	44	24	0.0	0.0
1/4/2008	F	62	30	0.0	0.0
1/5/2008	S	74	49	0.0	0.0
1/6/2008	S	79	54	0.0	0.0
1/7/2008	M	81	69	0.0	0.0
1/8/2008	T	80	59.5	0.3	0.2
1/9/2008	W	66.5	52	0.1	0.1
1/10/2008	T	76	54.5	0.6	0.6
1/11/2008	F	61.5	40.5	0.0	0.0
1/12/2008	S	65.5	37	0.0	0.0
1/13/2008	S	61.5	39	0.0	0.0
1/14/2008	M	60	32	0.0	0.0
1/15/2008	T	63.5	40	0.0	0.0
1/16/2008	W	48.5	45	1.6	1.3

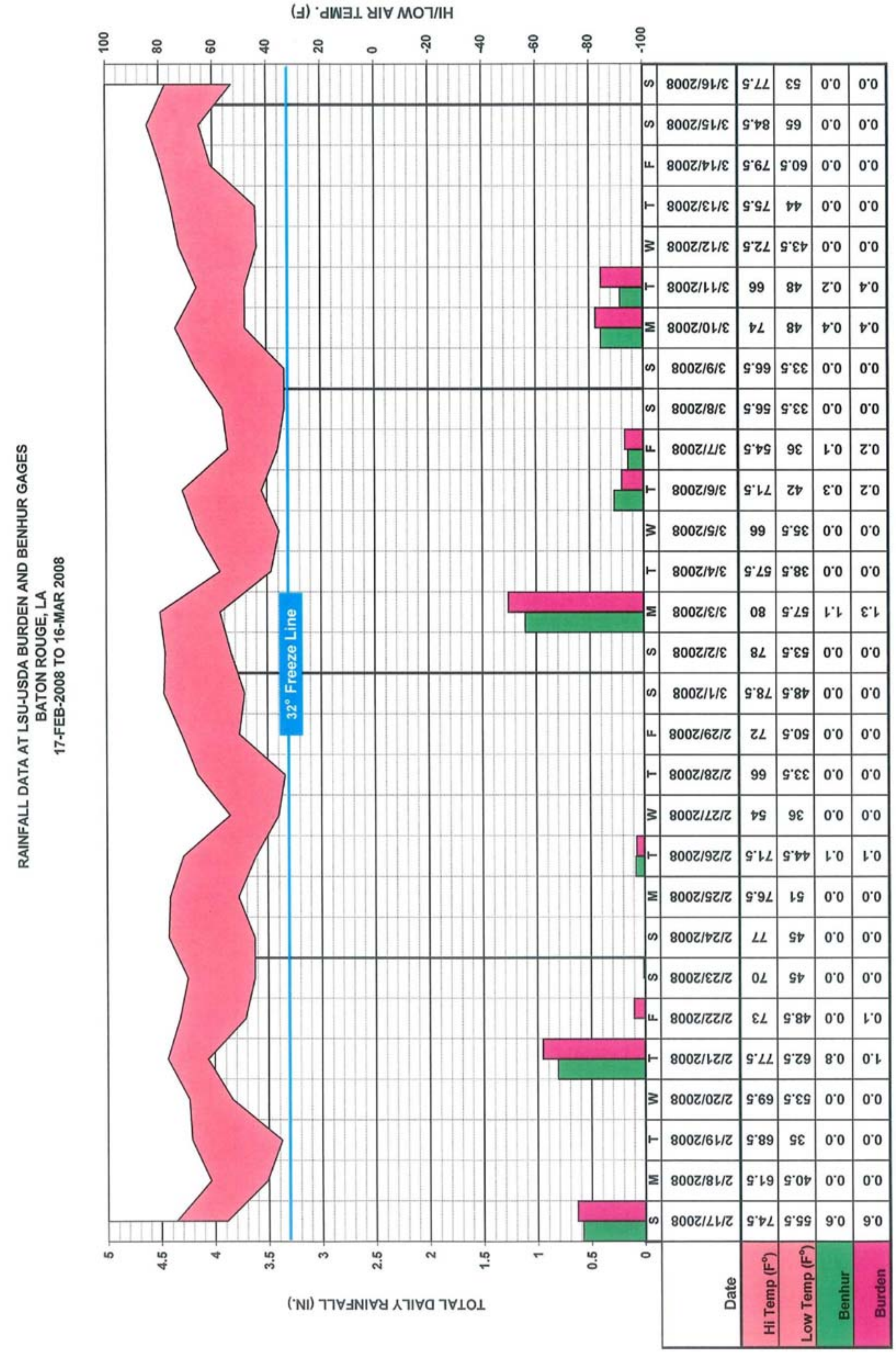
N/D = NO DATA AVAILABLE

Graph 2: December/January Temperature and Rain data in Baton Rouge, LA.



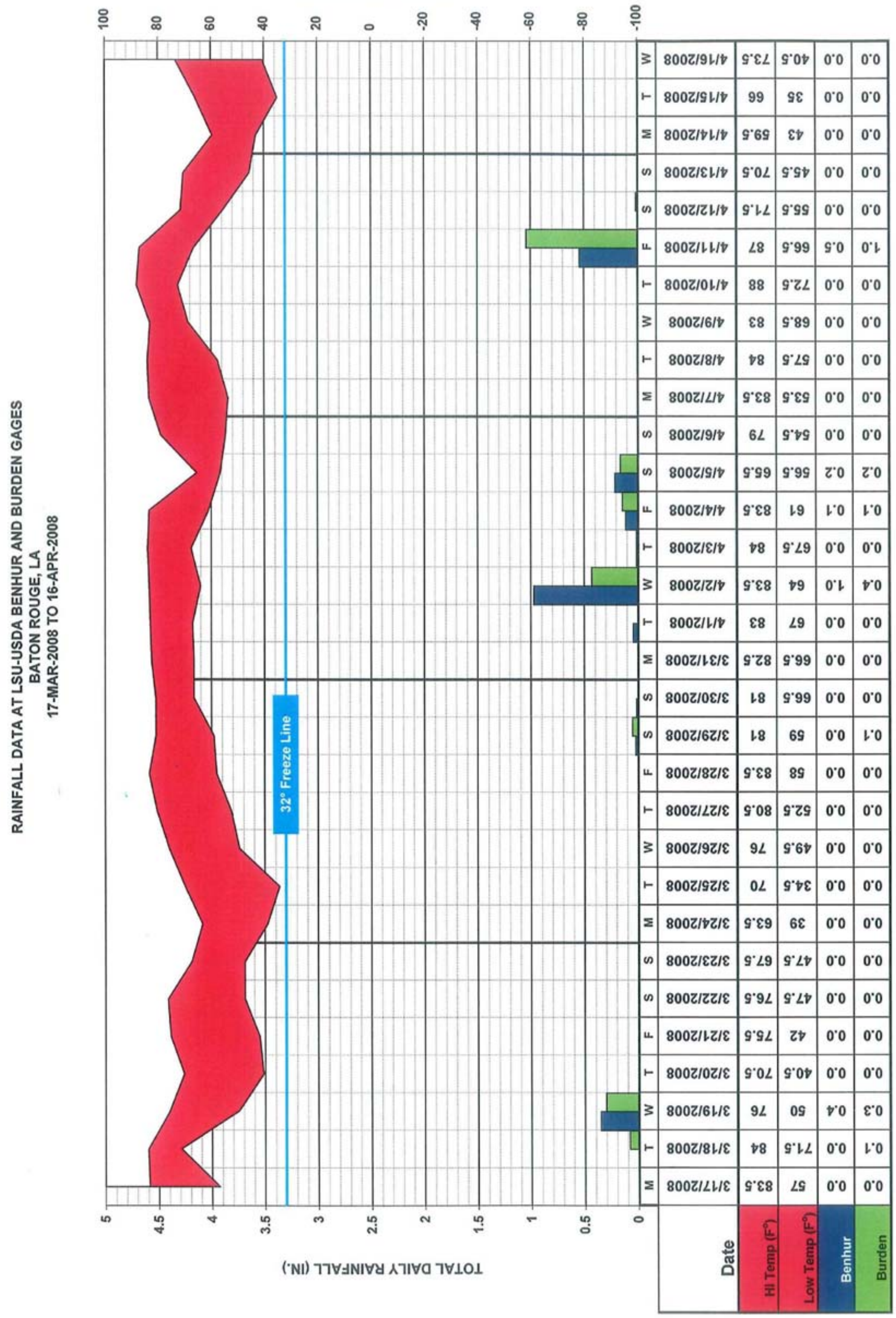
Day	Date	Hi Temp (F°)	Low Temp (F°)	Benhur	Burden
T	1/17/2007	54	45	0.0	0.0
F	1/18/2007	57.5	43	0.1	0.1
S	1/19/2007	45	32	1.6	1.6
S	1/20/2007	48.5	27	0.0	0.0
M	1/21/2007	56	29.5	0.0	0.0
T	1/22/2007	73	48	0.0	0.0
W	1/23/2007	58.5	51.5	0.0	0.0
T	1/24/2007	53	41	0.9	0.8
F	1/25/2007	41	37	1.5	1.4
S	1/26/2007	51	40	0.2	0.2
S	1/27/2007	57	36.5	0.0	0.0
M	1/28/2007	66.5	33.5	0.0	0.0
T	1/29/2007	70.5	49.5	0.0	0.0
W	1/30/2007	66	35	0.0	0.0
T	1/31/2007	72.5	43	1.7	1.8
F	2/1/2007	58	36.5	0.0	0.0
S	2/2/2007	69.5	34.5	0.0	0.0
S	2/3/2007	77.5	55	0.0	0.0
M	2/4/2007	80.5	65.5	0.0	0.0
T	2/5/2007	81	69.5	0.0	0.0
W	2/6/2007	73	40	0.0	0.0
T	2/7/2007	64.5	33.5	0.0	0.0
F	2/8/2007	68.5	36	0.0	0.0
S	2/9/2007	75	47.5	0.0	0.0
S	2/10/2007	74.5	40	0.0	0.0
M	2/11/2007	73.5	40	0.0	0.0
T	2/12/2007	77	45.5	1.0	1.1
W	2/13/2007	61.5	34	0.0	0.0
T	2/14/2007	66	32	0.0	0.0
F	2/15/2007	63	49.5	0.0	0.0
S	2/16/2007	72	57.5	0.0	0.1

Graph 3: January/February Temperature and Rain data in Baton Rouge, LA.

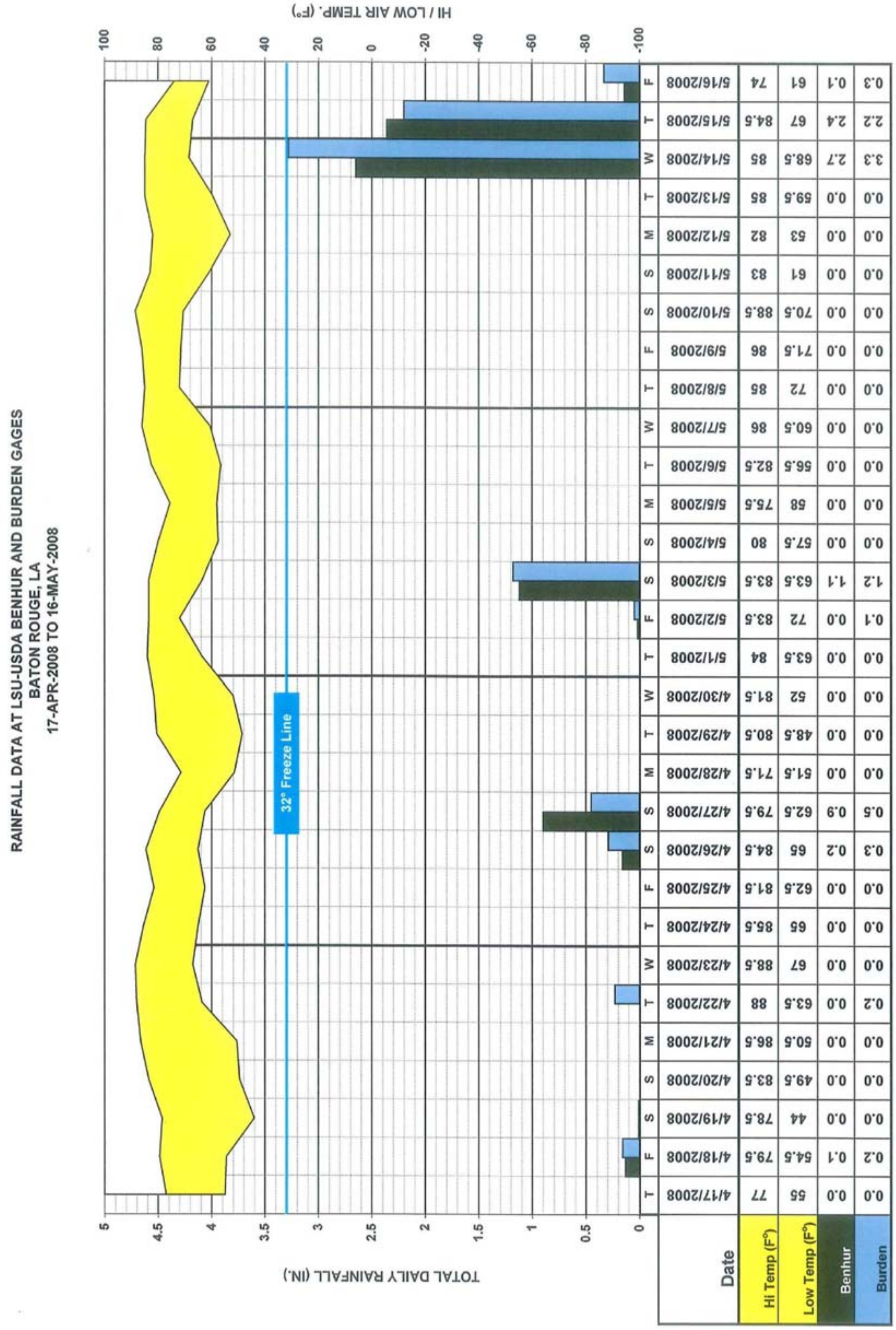


Date		Hi Temp (F°)	Low Temp (F°)	Benhur	Burden
2/17/2008	S	74.5	55.5	0.6	0.6
2/18/2008	M	61.5	40.5	0.0	0.0
2/19/2008	T	68.5	35	0.0	0.0
2/20/2008	W	69.5	53.5	0.0	0.0
2/21/2008	T	77.5	62.5	0.8	1.0
2/22/2008	F	73	48.5	0.0	0.1
2/23/2008	S	70	45	0.0	0.0
2/24/2008	S	77	45	0.0	0.0
2/25/2008	M	76.5	51	0.0	0.0
2/26/2008	T	71.5	44.5	0.1	0.1
2/27/2008	W	54	36	0.0	0.0
2/28/2008	T	66	33.5	0.0	0.0
2/29/2008	F	72	50.5	0.0	0.0
3/1/2008	S	78.5	48.5	0.0	0.0
3/2/2008	S	78	53.5	0.0	0.0
3/3/2008	M	80	57.5	1.1	1.3
3/4/2008	T	57.5	38.5	0.0	0.0
3/5/2008	W	66	35.5	0.0	0.0
3/6/2008	T	71.5	42	0.3	0.2
3/7/2008	F	54.5	36	0.1	0.2
3/8/2008	S	56.5	33.5	0.0	0.0
3/9/2008	S	66.5	33.5	0.0	0.0
3/10/2008	M	74	48	0.4	0.4
3/11/2008	T	66	48	0.2	0.4
3/12/2008	W	72.5	43.5	0.0	0.0
3/13/2008	T	75.5	44	0.0	0.0
3/14/2008	F	79.5	60.5	0.0	0.0
3/15/2008	S	84.5	65	0.0	0.0
3/16/2008	S	77.5	53	0.0	0.0

Graph 4: February/March Temperature and Rain data in Baton Rouge, LA.



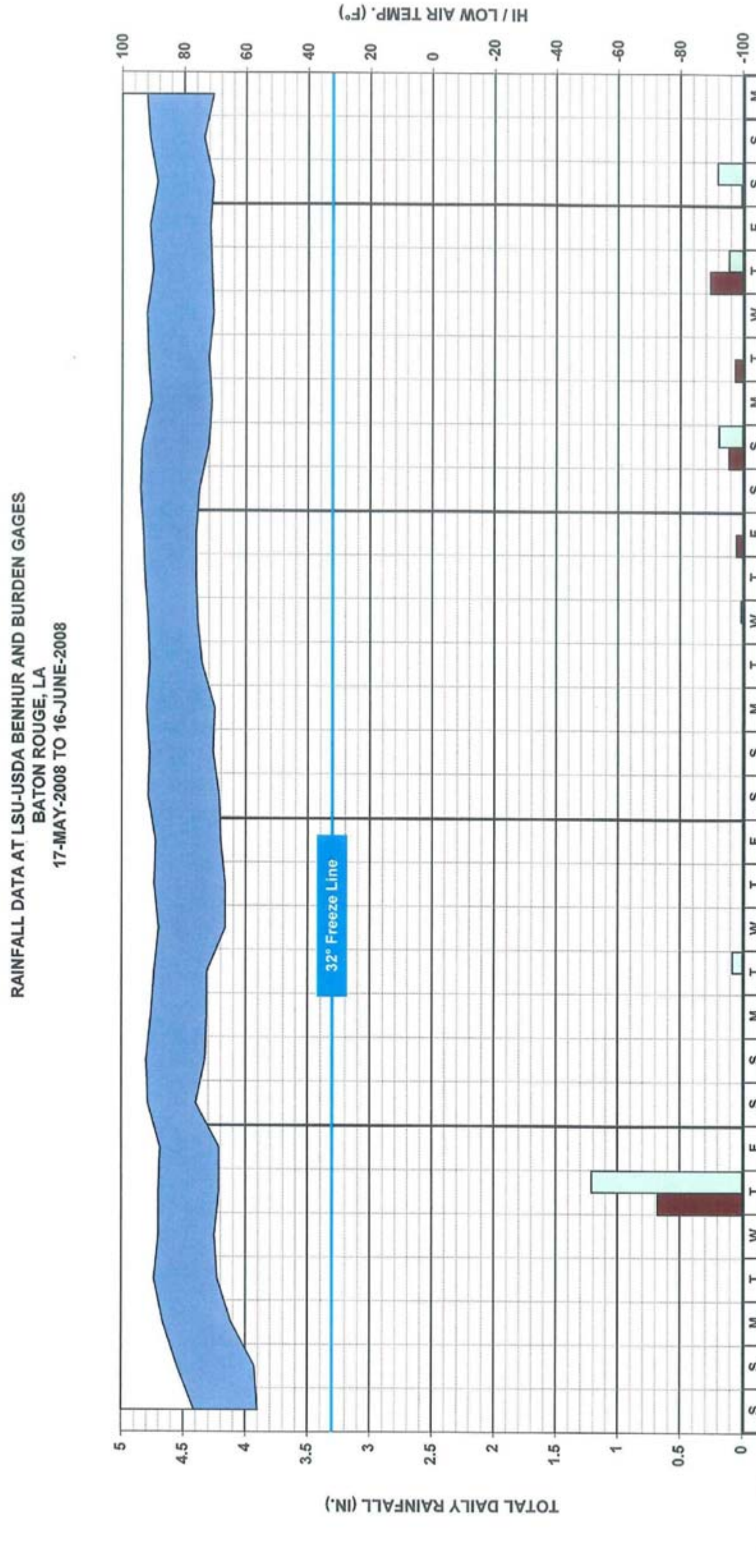
Graph 5: March/April Temperature and Rain data in Baton Rouge, LA.



Date	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T
	4/17/2008	4/18/2008	4/19/2008	4/20/2008	4/21/2008	4/22/2008	4/23/2008	4/24/2008	4/25/2008	4/26/2008	4/27/2008	4/28/2008	4/29/2008	4/30/2008	5/1/2008
Hi Temp (F°)	77	79.5	78.5	83.5	86.5	88	88.5	85.5	81.5	84.5	79.5	71.5	80.5	81.5	84
Low Temp (F°)	55	54.5	44	49.5	50.5	63.5	67	65	62.5	65	62.5	51.5	48.5	52	63.5
Benhur	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.9	0.0	0.0	0.0	0.0
Burden	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.5	0.0	0.0	0.0	0.0

Date	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F
	5/2/2008	5/3/2008	5/4/2008	5/5/2008	5/6/2008	5/7/2008	5/8/2008	5/9/2008	5/10/2008	5/11/2008	5/12/2008	5/13/2008	5/14/2008	5/15/2008	5/16/2008
Hi Temp (F°)	83.5	83.5	80	75.5	82.5	86	85	86	88.5	83	82	85	85	84.5	74
Low Temp (F°)	72	63.5	57.5	58	56.5	60.5	72	71.5	70.5	61	53	59.5	68.5	67	61
Benhur	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	2.4	0.1
Burden	0.1	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	2.2	0.3

Graph 6: April/May Temperature and Rain data in Baton Rouge, LA.



Day	Date	Hi Temp (F°)	Low Temp (F°)	Benhur	Burden
S	5/17/2008	76.5	56	0.0	0.0
S	5/18/2008	82	57	0.0	0.0
M	5/19/2008	86.5	64.5	0.0	0.0
T	5/20/2008	89.5	69	0.0	0.0
W	5/21/2008	88	70	0.0	0.0
T	5/22/2008	88	68.5	0.7	1.2
F	5/23/2008	87.5	68.5	0.0	0.0
S	5/24/2008	91.5	76	0.0	0.0
S	5/25/2008	92	73	0.0	0.0
M	5/26/2008	90.5	72.5	0.0	0.0
T	5/27/2008	89.5	72.5	0.0	0.1
W	5/28/2008	88	66.5	0.0	0.0
T	5/29/2008	89.5	66.5	0.0	0.0
F	5/30/2008	89	68	0.0	0.0
S	5/31/2008	91.5	68.5	0.0	0.0
S	6/1/2008	91	70.5	0.0	0.0
M	6/2/2008	92	70	0.0	0.0
T	6/3/2008	91	74	0.0	0.0
W	6/4/2008	91.5	75.5	0.0	0.0
T	6/5/2008	92.5	76	0.0	0.0
F	6/6/2008	93	76	0.1	0.0
S	6/7/2008	94	75	0.0	0.0
S	6/8/2008	93.5	72	0.1	0.2
M	6/9/2008	90.5	71	0.0	0.0
T	6/10/2008	91.5	72	0.1	0.0
W	6/11/2008	92	70.5	0.0	0.0
T	6/12/2008	90	71	0.3	0.1
F	6/13/2008	91	71.5	0.0	0.0
S	6/14/2008	88.5	70.5	0.0	0.2
S	6/15/2008	91	73.5	0.0	0.0
M	6/16/2008	92	70.5	0.0	0.0

Graph 7: May/June Temperature and Rain data in Baton Rouge, LA.

Appendix C. Equations used in gathering discharge and velocity rates

a.) Overtopping

<u>Step 1: Calculate average discharge</u>

$$q = \sqrt{gH_{m0}^3}\frac{0.067}{\sqrt{\tan\alpha}}\gamma_b\xi_0\exp\left(-4.3\frac{R_c}{H_{m0}}\frac{1}{\xi_0\gamma_b\gamma_f\gamma_\beta\gamma_v}\right) \qquad \text{(Equation 1)}$$

and a maximum of:

$$q_{\max} = \sqrt{gH_{m0}^3}\,0.2\exp\left(-2.3\frac{R_c}{H_{m0}}\frac{1}{\gamma_f\gamma_\beta}\right) \qquad \text{(Equation 2)}$$

with

$\xi_0 = \frac{\tan\alpha}{\sqrt{s_0}}$, $s_0 = \frac{2\pi H_{m0}}{gT_{m-1.0}^2}$ and:

q	=	Average discharge	[ft^3/s/ft]
q_{max}	=	Maximum discharge	[ft^3/s/ft]
g	=	Acceleration of gravity	[ft/s^2]
H_{m0}	=	Significant wave height	[ft]
ξ_0	=	Breaker parameter based on $T_{m-1.0}$	[s]
$T_{m-1.0}$	=	Spectral wave period[1]	[s]
α	=	Angle of average slope	[°]
R_c	=	Crest freeboard in relation to SWL, at position of outer crest	[ft]
γ_b	=	Influence factor for a berm	[-]

γ_f	=	Influence factor for roughness elements	[-]
γ_β	=	Influence factor for angle of wave attack	[-]
γ_v	=	Influence factor for a vertical or very steep wall on a slope	[-]

Step 2: Calculate critical discharge

The discharge caused by wave overtopping will reach a maximum when the wave top reaches the levee and a minimum when the wave trough reaches the levee. For the design of the protected side armoring the critical discharge will be required as this will cause the normative loading. It is proposed to multiply the average discharge with a factor 3 to calculate the critical discharge.

$$q_{cr} = 3q \qquad \text{(Equation 3)}$$

and a maximum of:

$$q_{cr,\max} = 3q_{\max}$$

The approach to assess the loading by overtopping is elaborately described in Technical report wave run-up and wave overtopping at dikes, May 2002. This recent report has a long history, is based on extensive research and is used as a guideline for safety assessments and design of levees in The Netherlands. Although some parts of this report refer to typical Dutch situations, the methods presented in the report to determine wave run-up and overtopping are for general applications.

b.) Overflow

This approach is to calculate the flow velocity on the *protected side* of a levee as a result of overflow. Note that the 1.49 factor is used to convert the Manning's 'n' co-efficient from metric to English units.

Step 1: Calculate discharge

$$q_c = \sqrt{g\left(\frac{2}{3}h_1\right)^3} \qquad \text{(Equation 4)} \qquad \text{with:}$$

q_c	=	Critical discharge	[ft^2/s]
h_1	=	Upstream head	[ft]
g	=	Acceleration of gravity	[ft/s^2]

Step 2: Calculate flow velocity

$$v_o = \left[\frac{1.49\sqrt{\sin\theta}}{n}\right]^{3/5} q_c^{2/5} \qquad \text{(Equation 5)} \qquad \text{with:}$$

q_c	=	Critical discharge	[ft^2/s]
v_o	=	Protected slope velocity	[ft/s]
θ	=	Angle of the backside slope relative to the horizontal	[˚]
n	=	Manning's coefficient in **metric** units	

The steps above, to assess the loading on crests and protected side slopes as a result of overflow, is straightforward and contain the most important parameters. However Manning and roughness coefficients will be required for different types of armor and slopes, to make the formulas more universally

applicable. For both the crests as well as the slopes more or less one approach has been presented.

c.) Combined overtopping and overflow

The approach below is to calculate the discharge on the levee as a result of combination of overtopping and overflow. To take both effects into account an equivalent wash-over height is defined.

Step 1: Calculate equivalent wash-over height

$$h_{eq} = h_1 + \frac{1}{3} H_s \qquad \text{(Equation 6)}$$

with:

h_{eq}	=	Equivalent wash-over height	[ft]
h_1	=	Outer water level relative to the crest	[ft]
H_s	=	Significant wave height	[ft]

Step 2: Calculate critical discharge

$$q_c = \sqrt{g\left(\frac{2}{3}\left[h_1 + \frac{1}{3} H_s\right]\right)^3} \qquad \text{(Equation 7)}$$

with:

g	=	Acceleration of gravity	[ft/s^2]
h_1	=	Outer water level relative to the crest	[ft]
H_s	=	Significant wave height	[ft]
q_c	=	Critical discharge	[ft^2/s]

EXAMPLE

The use of these equations is shown below in examples. These figures are not associated used to determine the velocities of this test section but merely to display the actual computations can be done for any levee configuration.

a.) *Overtopping*

Step 1: Calculate average discharge

$$q = \sqrt{gH_{m0}^3} \frac{0.067}{\sqrt{\tan\alpha}} \gamma_b \xi_0 \exp\left(-4.3 \frac{R_c}{H_{m0}} \frac{1}{\xi_0 \gamma_b \gamma_f \gamma_\beta \gamma_v} \right)$$

(Eq. 1)

and a maximum of:

$$q_{\max} = \sqrt{gH_{m0}^3} \, 0.2 \exp\left(-2.3 \frac{R_c}{H_{m0}} \frac{1}{\gamma_f \gamma_\beta} \right)$$

(Eq. 2)

with

$$\xi_0 = \frac{\tan\alpha}{\sqrt{s_0}} \qquad s_0 = \frac{2\pi H_{m0}}{gT_{m-1.0}^2} = 0.0178$$

and:

q	=	Average discharge	5.92	[ft^3/s/ft]
q_{max}	=	Maximum discharge	0.29	[ft^3/s/ft]
g	=	Acceleration of gravity	9.8	[ft/s^2]
H_{m0}	=	Significant wave height	1	[ft]
ξ_0	=	Breaker parameter based on $T_{m-1.0}$	12.14	[s]
$T_{m-1.0}$	=	Spectral wave period[1]	6	[s]
α	=	Angle of average slope	45	[°]
R_c	=	Crest freeboard in relation to SWL, at position of outer crest line	3	[ft]
γ_b	=	Influence factor for a berm	3	[-]

γ_f	=	Influence factor for roughness elements	3	[-]
γ_β	=	Influence factor for angle of wave attack	3	[-]
γ_v	=	Influence factor for a vertical or very steep wall on a slope	3	[-]

Step 2: Calculate critical discharge

$$q_{cr} = 3q$$ = 17.77 [ft³/s/ft]

and a maximum of: (Eq. 3)

$$q_{cr,\max} = 3q_{\max}$$ = 0.87 [ft³/s/ft]

b.) *Overflow*

Step 1: Calculate discharge

$$q_c = \sqrt{g\left(\frac{2}{3}h_1\right)^3}$$

(Eq. 4)

with:

q_c	=	Critical discharge	31.56	[ft²/s]
h_1	=	Upstream head	7	[ft]
g	=	Acceleration of gravity	9.8	[ft/s²]

Step 2: Calculate flow velocity

$$v_o = \left[\frac{1.49\sqrt{\sin\theta}}{n}\right]^{3/5} q_c^{2/5}$$

(Eq. 5)

with:

q_c	=	Critical discharge	31.56	[ft²/s]

v_o	=	Protected slope velocity	1.40	[ft/s]
θ	=	Angle of the backside slope relative to the horizontal	45	[˚]
n	=	Manning's coefficient in **metric** units	2	

c.) *Combined overtopping and overflow*

Step 1: Calculate equivalent wash-over height

$$h_{eq} = h_1 + \frac{1}{3} H_s$$

(Eq. 6)

with:

h_{eq}	=	Equivalent wash-over height	8	[ft]
h_1	=	Outer water level relative to the crest	6	[ft]
H_s	=	Significant wave height	6	[ft]

Step 2: Calculate critical discharge

$$q_c = \sqrt{g \left(\frac{2}{3} \left[h_1 + \frac{1}{3} H_s \right] \right)^3}$$

(Eq. 7)

with:

g	=	Acceleration of gravity	9.8	[ft/s^2]
h_1	=	Outer water level relative to the crest	6	[ft]
H_s	=	Significant wave height	6	[ft]
q_c	=	Critical discharge	38.56	[ft^2/s]

Appendix D. Products in Groups

A. GRASS

Grass vegetation is the most common form of armoring. Robust grasses provide effective slope protection against erosion from rainfall and some overtopping events. The root structure reinforces the top layer of soil, and the vegetation provides flow resistance that reduces the water velocity resulting in decreased loading. Vegetation interacts with the subsoil and therefore strength of vegetation cover is also dependent on the type of subsoil. Equally important is operation and maintenance of the vegetation. Mowing, pasturing and fertilizing can be dominant factors for the strength of the vegetation cover.

Advantages	**Disadvantages**
Low cost	Limited resistance against wave and current erosion
	Only applicable above the water level
Reported loading limits	
Dependent on duration of loading and quality of the turf (see also Annex 1). For 15-20 hrs a good turf can withstand waves up to 4.9 ft and flow velocities of 6.6-9.8 ft/s	
Literature	
Krystian W. Pilarczyk, Dikes and revetments, 1998	
Technical Advisory Committee for Flood defence in The Netherlands, Technical report erosion resistance of grassland as dike covering, 1997	
Technical Advisory Committee for Flood defence in The Netherlands, Grass cover as a dike revetment, 1999	

B. TRM-Low Capacity

<table>
<tr><td colspan="4"><u>Western Excelsior Corp</u>
28 August 2007</td></tr>
<tr><td>Contact</td><td colspan="3">Chad Lipscomb, PE or
Shannon Leech (Sales Mgr)
PMB #346, 729 Grapevine Hwy
Hurst, TX 76054
Shannon@westernexcelsion.com
Toll Free Phone : 800-833-8573
Cell:
Fax: NA
www.westernexcelsion.com</td></tr>
<tr><td>Presentation Link</td><td colspan="3">pwdesc://CEMVN - New Orleans (PCM)/Documents/Civil Works/HPO, Hurricane Protection Office/Levees, Floodwalls & Armoring/Armoring/Levee Armoring Workshop/Armoring Workshop Presentations/Western Excelsior TRM PPT</td></tr>
<tr><td colspan="4">PRODUCT INFORMATION</td></tr>
<tr><td colspan="4">A rolled erosion control product composed of <u>non-degradable synthetic</u> fibers, filaments, nets, wire mesh and/or other elements, processed into a permanent, <u>three-dimensional matrix of sufficient thickness</u>. TRMs, which may be supplemented with degradable components, are designed to impart immediate erosion protection, enhance vegetation establishment and provide long-term functionality by permanently reinforcing vegetation during and after maturation. Note: TRMs are typically used in hydraulic applications, such as high flow ditches and channels, steep slopes, stream banks, and shorelines, where erosive forces may exceed the limits of natural, unreinforced vegetation or in areas where limited vegetation establishment is anticipated.</td></tr>
<tr><td colspan="4">Excel PP5-8</td></tr>
<tr><td colspan="2">Sheer Resistance: 3.17 psf</td><td colspan="2">Max Permissible Sheer: 6 psf</td></tr>
<tr><td colspan="2">Vegetated Sheer Resistance: 2-12 psf</td><td colspan="2">Max Permissible Velocity: 8 fps</td></tr>
<tr><td colspan="2">Roll width, length & area;
7.5 or 15 ft wide x 120ft long</td><td colspan="2">Coverage: 100 sq yds or 200 sq yds
Roll Weight: 50lbs or 100lbs</td></tr>
<tr><td>Mass</td><td>8 oz/yd</td><td>Thickness</td><td>8 mm</td></tr>
<tr><td colspan="2">Tensile Strength: 20.8 lbs/in
ASTM D6818</td><td colspan="2">Light Penetration 35%</td></tr>
<tr><td>Testing Conditions</td><td>Lab</td><td>Specific Gravity</td><td>Unstated</td></tr>
<tr><td colspan="4">Excel PP5-10</td></tr>
<tr><td colspan="2">Sheer Resistance: 3.17 psf</td><td colspan="2">Max Permissible Sheer: 8 psf</td></tr>
<tr><td colspan="2">Vegetated Sheer Resistance: 2-12 psf</td><td colspan="2">Max Permissible Velocity: 12 fps</td></tr>
<tr><td colspan="2">Roll width, length & area;
7.5 or 15 ft wide x 120ft long</td><td colspan="2">Coverage: 100 sq yds or 200 sq yds
Roll Weight: 63lbs or 126lbs</td></tr>
<tr><td>Mass</td><td>10 oz/yd</td><td>Thickness</td><td>9.3 mm</td></tr>
<tr><td colspan="2">Tensile Strength: 20.8 lbs/in</td><td colspan="2">Light Penetration 25%</td></tr>
</table>

ASTM D6818			
Testing Conditions	Lab	Specific Gravity	Unstated
Excel PP5-12			
Sheer Resistance: 3.36 psf		Max Permissible Sheer: 10 psf	
Vegetated Sheer Resistance: 2-12 psf		Max Permissible Velocity: 15 fps	
Roll width, length & area; 7.5 or 15 ft wide x 120ft long		Coverage: 100 sq yds or 200 sq yds Roll Weight: 75lbs or 150lbs	
Mass	12 oz/yd	Thickness	9.6 mm
Tensile Strength: 20.8 lbs/in ASTM D6818		Light Penetration 20%	
Testing Conditions	Lab	Specific Gravity	Unstated
ARMORING TEAM GUIDANCE			
Not Recommended for Use around d hard transition to include (**but not limited to)** Pump stations, pipeline crossings, wall to levee transitions except with requisite splash pad.			
Notes	The products listed (all 3) are designed to provide immediate erosion control with sufficient thickness and durability to yield functional longevity greater than three years. Pay attention to the sheer and velocities above and review their website listed above before using this product in your design. There is a place for this product but the wide range of values above can best be understood by visiting the manufacturer's website.		

C. TRM-High Capacity

Hanes Geocomponents presented the **Profile** family of products on 28 August 2007			
Contact	Robert H. Fuqua 8150 South Choctaw Drive Baton Rouge, LA 70815 Toll Free Phone : 877-773-7716 Cell: 225-252-2543 Fax: NA http://www.colbond-usa.com/getpage.html?pgid=8&pgtype=5 www.profileproducts.com www.hanesgeo.com		
Presentation Link	www.xyz.ProjectWise.com		
PRODUCT INFORMATION			
Enkamat 7010			
Enkamat 7010 is a permanent Geosynthetic Turf Reinforcement Mat (TRM) to prevent long term soil and vegetation loss resulting from excessive water flow (velocity and sheer stress) in which unreinforced vegetation could not resist.			
Unvegetated Shear Capacity	6.7 lb/sf	Vegetated Shear Capacity	8lb/sf
Unvegetated Velocity Capacity	20 ft/s	Vegetated Velocity Capacity	14 ft/s 50 Hours
Roll width, length & area			
Mass	8 oz/yd	Thickness	.4 inches
Tensile Strength	160 lbs/ft ASTM D5035		
UV resistance	80% at 500 hrs		
Testing Conditions	Flume/lab	Specific Gravity	>1
Enkamat 7020			
Enkamat 7020 is a permanent Geosynthetic Turf Reinforcement Mat (TRM) to prevent long term soil and vegetation loss resulting from excessive water flow (velocity and sheer stress) in which unreinforced vegetation could not resist.			
Unvegetated Shear Capacity	11.2 lb/sf ASTM D7207	Vegetated Shear Capacity	10 to 8 lb/sf 30 min to 50 hr test
Unvegetated Velocity Capacity	20 ft/s ASTM D6460	Vegetated Velocity Capacity	19 to 14 ft/s 30 min or 50 hr test
Roll width, length & area			
Mass	12 oz/yd	Thickness ASTM D6818	.7 inches
Tensile Strength	240 lb/ft ASTM D6818		
UV resistance	80% at 500 hours	ASTM D5035	
Testing Conditions	Flume/lab	Specific Gravity	>1

Roll Dimensions	6.3 ft wide by 90 ft long (63 sq yds per roll)
ARMORING TEAM GUIDANCE	
Not recommended for	Use around hard transitions to include (***but not limited to***) Pump Stations, Pipeline crossing, wall to levee transitions except with requisite splash pad.
Notes	Enkamat is designed to be used with their "Flexterra" system of hydro-mulching (Mfg's limits of performance warranty). Water holding capacity when Enkamat combined with Flexterra is 1500% per ASTM D7367. The combination of Enkamat and Flexterra is termed "GreenArmor" by the manufacturer.

C. ARVS

Propex Inc Turf Reinforcement Mats			
Contact	Randy Thomson 6025 Lee Highway Suite 425 Chattanooga, TN 37422 Phone : 423-899-0444 Fax: 423-899-7619 www.propexinc.com www.geotextile.com		
Presentation Link	www.xyz.ProjectWise.com		
PRODUCT INFORMATION			
PYRAMAT (HPTRM)			
Pyramat is a non-biodegradable anchored & woven High Performance Turf Reinforcement Mat (HPTRM) to prevent long term soil and vegetation loss resulting from excessive water flow (velocity and sheer stress) in which unreinforced vegetation could not resist. This system performs by allowing the roots to bind around the mat forming a contiguous bond between the mat, soil and roots. Appropriate seeding and maintenance establishes a sward of grass sufficient to withstand hydraulic loading in excess of that a plain grass cover.			
Unvegetated Shear Capacity	6 - 8 lb/sf	Vegetated Shear Capacity	15 lb/sf
Unvegetated Velocity Capacity	15 ft/s	Vegetated Velocity Capacity	25 ft/s
Roll width, length & area		8.5 ft x 90 ft x 85 sqr yard (86lb)	
Mass	13.5 oz/ sqr yd	Thickness	.4 inches
Tensile Strength	4000 lbs/ft	Manning's	0.017 -0.035
UV resistance	90% at 6000 hrs		
Testing Conditions	Flume/lab	Specific Gravity	>1
ARMORING TEAM GUIDANCE			
Not recommended for	Use around hard transitions to include (***but not limited to***) Pump Stations, Pipeline crossing, wall to levee transitions except with requisite splash pad.		
Notes	The vegetated capacity of this system is far in excess of normal HPTRM's. The designer should take appropriate caution and scrutinize testing conditions to ensure they are representative of the intended design condition. The Designer should ensure sufficient consultation with the manufacturer to ensure that standard construction details are adhered to.		

D. ACM

<u>Contech</u> presented the **Armortec** family of ACM products on 28 August 2007			
Contact	Richard Kane, National Sales Manager, Erosion Control Specialist 9025 Centre Pointe Drive Suite 400 West Chester, OH 45069 Phone: 513.645.7008 Cell: 513.320.1079 Email: kaner@contech-cpi.com		
Presentation Link	pwdesc://CEMVN - New Orleans (PCM)/Documents/Civil Works/HPO, Hurricane Protection Office/Levees, Floodwalls & Armoring/Armoring/Levee Armoring Workshop/Armoring Workshop Presentations/Contec Conc Interlocking Block PPT		
PRODUCT INFORMATION			
Armorflex **Articulating Concrete Block (ACB) Systems**			
Armorflex			
Unvegetated Shear Capacity	15 lb/sf	Vegetated Shear Capacity	15lb/sf
Unvegetated Velocity Capacity	15 ft/s 2-6 Hours	Vegetated Velocity Capacity	20 ft/s 2-6 Hours
Roll width, length & area			
Mass	lb/100 sf	Thickness	.4 inches
Tensile Strength	160 lbs/ft ASTM D5035		
UV resistance	80% at 500 hrs		
Testing Conditions	Flume/lab	Specific Gravity	2
ARMORING TEAM GUIDANCE			
Not recommended for	Articulated Concrete Blocks Supports vegetative growth Permanent TRM's Increase performance limits of vegetation Natural Vegetation		
Notes	Articulated Concrete Blocks Supports vegetative growth Permanent TRM's Increase performance limits of vegetation Natural Vegetation Also distributors for Geolink™, A-Jacks™, ArmorLoc™, Tensar®, Keystone® Retaining Walls Metric Sheeting, Bin Walls, Modular Gabions, RoaDrain™, Geotextiles/Silt Fence, Pyramat/LandLok, Vista DSM™		

Appendix E. Levee Board Feedback

Maintenance and repair considerations:

- Required skills, equipment and personnel
- Timing, duration, frequency and cost of maintenance
- Signs of deterioration
- Resilience of damaged armor
- Damage repair procedures
- Robustness of repair
- Safety requirements

VITA

April Villa was born June 9, 1974 in Angeles City, Philippines to Dorothea Villa and David Powell. She attended the University of New Orleans and graduated with a Bachelor's Degree in Civil and Environmental Engineering in Dec 1999. She worked for Lanier & Associates from 1999-2001, then accepted a Structural Engineering position with the US Army Corps of Engineers were she still currently works as a Project Engineer for the Inner Harbor Navigation Canal (IHNC)-Surge Barrier Project. She has volunteered to serve as a USACE Structural Engineer in Al Hilla, Iraq in 2003. She served as the Senior Project Manager of the USACE Armoring Team in 2007-2008.