SHORELINE EROSION SEMINAR

Galveston County, Texas

Quantitative Analysis and Design Aspects

TEXAS A&M UNIVERSITY AT GALVESTON 1876

GALVESTON COUNTY BEACH & PARKS

DEC

US Army Corps of Engineers

December 14, 1991

Texas A&M University at Galveston
Auditorium, Building 3007, Pelican Island
200 Seawolf Park Blvd.
Galveston, Texas 77553

SHORELINE EROSION SEMINAR
Galveston County, Texas

Quantitative Analysis and Design Aspects

December 14, 1991

Texas A&M University at Galveston
Auditorium, Building 3007, Pelican Island
200 Seawolf Park Blvd.
Galveston, Texas 77553

SPONSORED JOINTLY BY

Texas A&M University at Galveston
Dannenbaum Engineering Corporation, Houston, Tx.
U.S.Army Corps of Engineers, Galveston District
Galveston County Shore and Beach Preservation Association
Galveston County Beach Park Board of Trustees

SEMINAR CHAIRMEN

Y.H. Wang, Co-Chair
Texas A&M University at Galveston
P.O.Box 1675
Galveston, Texas 77553

A.F. Frankovich, Co-Chair
Dannenbaum Engineering Corporation
3100 West Alabama
Houston, Texas 77098

FOREWORD

The SHORELINE EROSION SEMINAR, GALVESTON COUNTY, TEXAS was organized as a technical conference concerning the quantitative analysis and design aspects of combating beach erosion along the Galveston shoreline. There have been ample discussions and numerous debates on shoreline problems, solutions and management policies in the past. Sometimes these issues generated enormous emotional public outcry. However, feelings without agenda cause stagnation and confusion. This conference is designed to move the process forward by providing an agenda for implementation.

The SHORELINE EROSION SEMINAR started with the employment of conventional means for beach erosion control and followed with some new and emerging technology applications. The purpose of this program structure was to promote a broad exchange of information between regulators and practitioner, scientist and engineer, and environmentalist and developer.

The editor acknowledges generous contributions of the speakers. Some of them traveled long distances from out of state in order to present their ideas. Many papers in the proceedings are derived from the project supported by Galveston County and the Texas Water Commission through Dannenbaum Engineering Corporation. Without their financial support this conference would not have been possible. The approval and encouragement of the sponsors is gratefully acknowledged. Special thanks are due to Mr. Pat Hallisey of the Galveston County Beach Park Board of Trustees for his support and encouragement.

The logistical supports were provided by Mr. Ronnie Barcak who typed and formatted the proceedings, Mr. Paul Wilson, Ms. Rosann Heflin, Ms. Theo Byrne, Ms. Joyce Dryman, and Mr. Charles Lee all contributed to the smooth operation of the conference.

It is hoped the energy exhibited during this initial undertaking will help form a basis for clearer understanding of the technology available to solve Galveston County's problems.

Editor
Y.H. Wang

CONTENTS

* Manuscript not available at the time of printing

OVERVIEW OF GALVESTON COUNTY SHORELINE PROBLEMS

Y.H. Wang*

ABSTRACT: This report identifies the problem areas on the shoreline of Galveston County, establishes objectives for treatment, and suggests options for remedial measures. This is presented in the light of understanding the physical environment and littoral transport processes of a much larger geographical frame.

INTRODUCTION

The Galveston region has several coastal problem areas that need shoreline protection implementation. There are two functional entities that are common to all the project sites; the forcing function such as natural forces in the coastal zone and the response function such as location parameters. Understanding these two functions and their interactions at different project sites will provide valuable information for better project decisions and/or implementation.

When physical environment is mentioned in the coastal region thoughts on natural processes comes to mind.

Location parameters such as the orientation of shoreline, sheltered or exposed, open to long or short fetch, bottom topography, and sediment materials, etc. Natural forces, such as waves, tides, winds, and currents, etc. that shape up the bottom configuration of the coast zone. The interaction of these two, or the natural processes, determine the shoreline change in that region. Shoreline changes are also possible through man's interference of the natural

* Professor and Professional Engineer, Texas A&M University at Galveston, P.O.Box 1675, Galveston, Texas 77553-1675

processes. Both natural and man made shoreline changes can be good or bad depending on whether or not the change induced effects are in the viewers' favor.

The boundary of the Galveston shoreline facing the Gulf of Mexico starts from the intersection of State Highway 124 with Highway 87 at High Island, and ends at San Luis Pass. This shoreline has a general northeast-southwest orientation approximately 60 miles long. Within this stretch of shoreline, there are two natural tidal inlets, Galveston Bay entrance and San Luis Pass, and one man made inlet, Rollover Pass. These inlets are separated approximately equidistant from each other, and all are connected to Galveston Bay. Rollover Pass and Galveston Bay inlets are regulated by structures, San Luis Pass has no regulating structure.

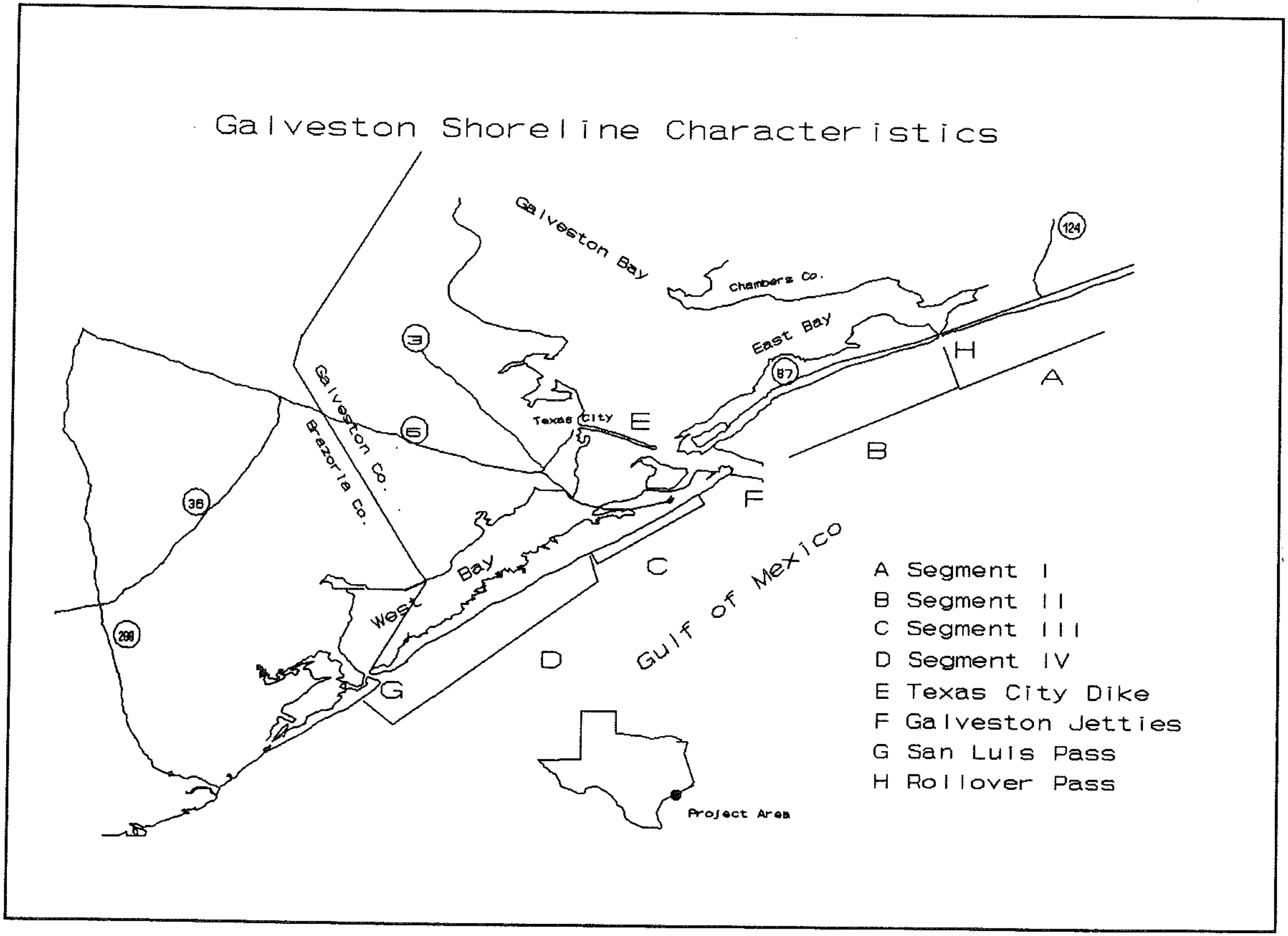
Weather plays an important role in the physical makeup of the shoreline. The history of a location, especially data on shoreline parameters, provides guidelines to the understanding of the site's adjustments to natural forces. Understanding how a shoreline responds to these forces and taking into account all planning and design considerations will lead to an overall view of the location's attributes, therefore opening the door to solving the area's problems.

The prevailing winds are mostly from the south and southeast directions with a speed of up to 15 knots. There are about 15 to 20 northeasters with speeds up to 50 mi/hr passing through this region during winter [1]. In the past century, there have been numerous hurricanes within a 200 mile radius of Galveston. Hurricane Carla in 1961 produced the greatest storm surge on record in the region [2]. High water levels greater than 5 feet can occur once every two to three years [2].

The astronomical tides vary between diurnal and semi-diurnal and are less than 2 feet. The wave climate in this area is generally mild, heights less than 2 feet half of the time. The average magnitude of longshore current is 0.8 ft/sec southwest 56% of the time and 0.67 ft/sec northeast [1].

The general characterization of the Galveston shoreline takes into account the effects of location and natural forces on each of the individual areas, while trying to present an overall view of the region. Since the Galveston region is broken into eight (8) different problem locations, there would be eight different problems to be solved. The key for stabilizing, thereby solving, the shoreline problems is to investigate each individual location and the effects that it has on the other locations.

The Galveston shoreline comprises of two main problems; erosional tendencies and unwanted accretion. Erosion problems occur near the High Island, Rollover Pass, and Galveston west beach, while unwanted accretion may be found in Rollover Bay, Big Reef, and Galveston West Bay. Structures are present and occupy the middle section of County's shoreline. The relationship of all these problem areas need to be investigated, and an overall regional understanding will provide answers to the coastal shoreline problems. The Galveston shoreline can be broken into four major areas for general characterization, as shown in the following figure.


Galveston Shoreline Characteristics
Galveston Bay
Chambers Co.
East Bay
Texas City
Galveston Co.
Brazoria Co.
West Bay
Gulf of Mexico
Project Area
A
B
C
D
E
F
G
H
124
87
3
6
36
288
A Segment I
B Segment II
C Segment III
D Segment IV
E Texas City Dike
F Galveston Jetties
G San Luis Pass
H Rollover Pass

Segment I: Location of this portion is the extreme northeast boundary, High Island to Rollover Pass. East of this segment is Sabine Pass and adjacent coastline that serves as a sediment supply source. Rollover Pass, southwest part of segment, serves as a sediment sink. This segment's shoreline is relatively straight with a northeast orientation.

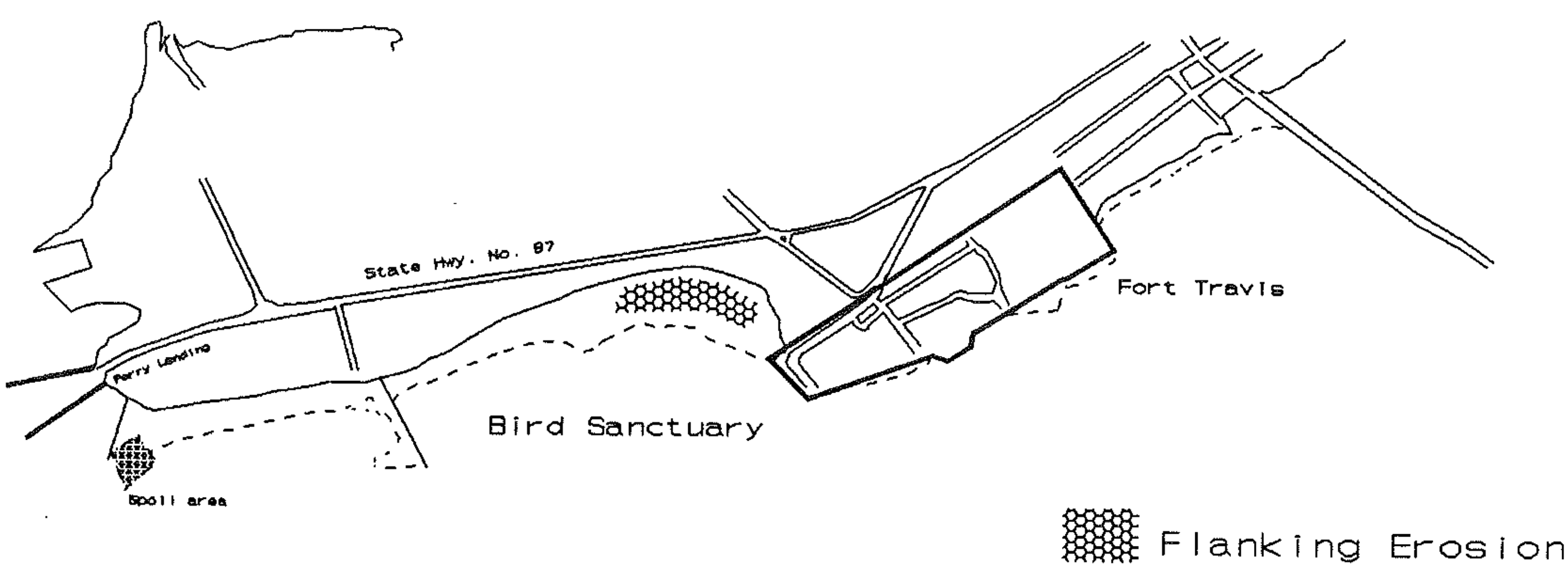
Segment II: This portion is from Rollover Pass to the Galveston Bay entrance. The north jetty serves as the boundary, forming a discontinuity of longshore transport. The shoreline orientation is slightly concave towards the south due to the accumulation of sediment on the north side of the jetty.

Segment III: This area takes into account the Galveston Bay entrance to the west end of Seawall Boulevard. This segment has its littoral processes modified by man made structures. Sediment discontinuity occurs at the south jetty, then is influenced by the groinfield and seawall. Shoreline orientation follows the structures, with little beachfront being present.

Segment IV: This portion contains shoreline from the end of the Galveston Seawall to San Luis Pass. This segment encompasses 18 miles of natural sandy beaches with residential communities intermittently developed along the shoreline. The southwestern end, San Luis Pass, marks the boundary of the Galveston coastline, and serves as a sediment sink.

The following are the individual projects within the Galveston region. Each has its own problems which, by the will of the public, need to be solved. These problems will be investigated and a solution will be given, along with options, in order to stabilize the shoreline.

Bolivar Peninsula Ferry Landing



SHORELINE EROSION ALONG BOLIVAR PENINSULA

There are three problem areas along Bolivar Peninsula, the shoreline between High Island and Gilchrist, Rollover Pass, and the road at the ferry landing. Problems at Rollover Pass and vicinity are complex and will be treated separately in the next section.

SHORELINE BETWEEN HIGH ISLAND AND GILCHRIST

THE PROBLEM AND ANALYSIS: The beach between High Island and Gilchrist is narrow. The waterline is close and parallel to State Highway 87. During severe storms this stretch of highway becomes inundated becoming vulnerable to washing out. The narrow beachfront and closing-in waterline is not an isolated phenomenon, a typical erosional scene is found along the shoreline between Sabine Pass and High Island. Some stretches of Highway 87 is closed to traffic along this section.

THE OBJECTIVE AND SOLUTION: The single objective is to stop shoreline erosion. Since the problem is not isolated, it must be solved as a part of the bigger problem area from High Island to Sabine Pass.

ROAD AT FERRY LANDING

THE PROBLEM AND ANALYSIS: The shoreline erosion immediately after the ferry landing piers on Bolivar Peninsula threatens the integrity of the ferry landing road. The possible cause of the problem may be due to tidal currents interacting with the seawall, in place at Fort Travis, causing flanking erosion. Naturalists have suggested making the shallow water regions between the ferry landing and north jetty a bird sanctuary.

OBJECTIVES: Stop the advancement of flanking at the ferry road location without interfering with the shallow water bird sanctuary.

OPTIONS FOR ATTAINING OBJECTIVES: There are two ways to protect the ferry landing road; use of soft approach and hard structure. In this case the hard structures are preferred over the popular trend of soft approaches for the following reasons.

The softer approach is to fill in the eroded area (approximately 25 acres in size) periodically in cooperation with the annual dredging schedules of the ferry landing piers which amounts to 200,000 cubic yard per year. The major drawback to this option is the reduction of shallow bay area by filling-in with materials. State and federal agencies and environmental groups have all expressed their concerns.

Armoring is another option. The placement of a seawall or rubble mound revetment can be implemented. There are new designs of armoring units for absorbing and dissipating wave energy. These designs are aimed to replacing the vertical bulkhead/seawall in sheltered areas, which may be worth looking into. This type of armoring will be compatible with the Fort Travis shoreline and does not interfere with the natural bird sanctuary.

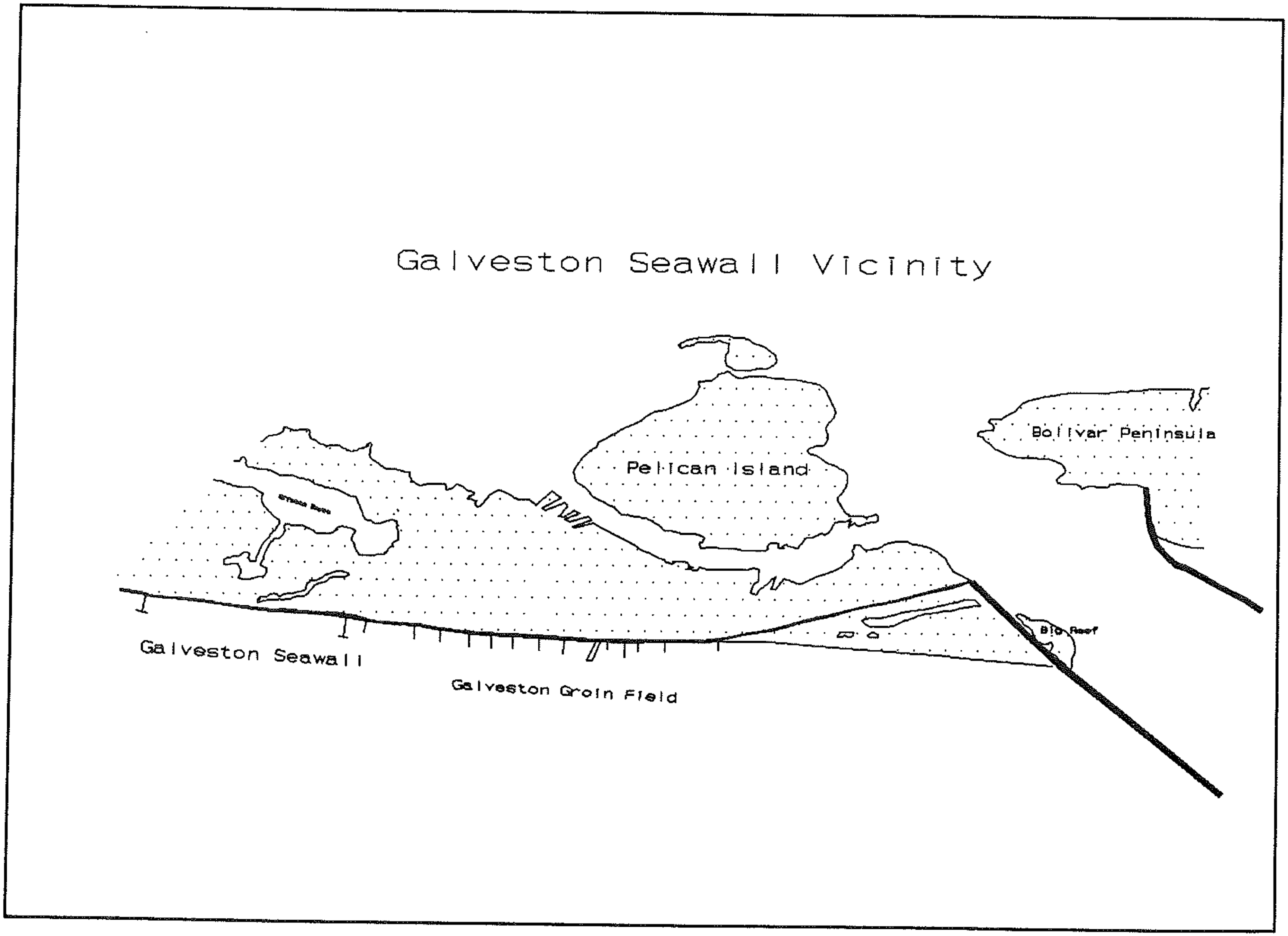
A groin system with proper design of length and spacing can also serve the function of stabilizing the shoreline without reducing the shallow water bay bottom area.

A detached small breakwater segment parallel to the waterline to encourage accretion in the eroding area through natural processes is another option can be worked out.

Finally, the use of the concept of a "feeder beach" could solve both the eroding shoreline problem at the ferry landing road and the silting problem at the ferry landing piers. This may be done by locating a feeder beach site on which the dredging material from the ferry landing piers may be placed and these materials are then distributed by waves and tidal current to the eroding area along the ferry landing road.

ROLLOVER PASS

Rollover Pass was originally constructed by the U.S. Army Corps of Engineers in an effort to create a marine nursery ground in unproductive waters of Galveston East Bay. Ever since the man made cut was open, middle 1950's, excessive erosion has occurred on the downdrift and updrift sides of the cut. Rollover Bay is choked with massive sediment deteriorating the water quality. A comprehensive plan using an integrated system approach was proposed by Wang in "*Preliminary Designs of Improvements at Rollover Pass and Vicinity, Bolivar Peninsula, Texas*" [3].


Galveston Seawall Vicinity
Pelican Island
Bolivar Peninsula
Big Reef
Galveston Seawall
Galveston Groin Field

GALVESTON SEAWALL AND GROIN FIELD

Construction of the Galveston Seawall started in 1902 and now extends 10 miles. The groin field was constructed between 1936 and 1939 with the final configuration completed during 1968-70. The groin field occupies a seawall segment approximately 4.5 miles long. The main purpose of the seawall is for protection of the uplands behind it. The construction of the groin field is for stabilizing the shoreline by impeding littoral sand movement for protection of the seawall foundation. Both structures serve their intended purposes well. In the mean time, however, the degradation of beach in front of the seawall occurs. Today there is no appreciable recreational beach in front of the seawall.

At present, the shoreline along the seawall appears stable, although waves directly pounding at the seawall are observed during rough weather. The integrity and safety of the existing seawall structure must be calculated since the investment of the structure, property, and life behind it is great. This cannot be taken lightly. Suppose a hurricane with the strength of "Hugo" directly hits Galveston Island. This hurricane may produce storm surges in excess of 20 feet with waves of 16 feet in height directly pounding at the seawall, causing scour of the structure toe. The ability and current conditions of the concrete slab and riprap aprons at the structure toe to withstand this scouring power is of interests to coastal engineers.

OBJECTIVES: The primary objective is to restore the beach in front of the Galveston Seawall. A secondary objective is to provide an extra measure of safety and integrity for the seawall under extreme conditions.

OPTIONS FOR ATTAINING OBJECTIVES: Beach nourishment is the most popular shoreline restoration and protection method in the United States. It has been widely adopted along the Pacific, Atlantic, and Gulf of Mexico shorelines. This method allows the designer to provide desired beach width, berm elevation, and beach slope. The results are immediate and impressive. Since the objective is to restore a beach along the seawall for recreational purposes, beach nourishment is the only method that can deliver prescribed beachfront dimensions quickly.

The general technical information on the planning and design details regarding a beach nourishment project may be found in the previous progress report. The following is site specific information that the engineer should take into account in addition to the design considerations given previously. This information is by no means exhaustive.

* Assume the project length will cover the full length of Galveston Seawall. The end conditions of the project area will dictate the behavior and movement of new sand used in the beach nourishment project.

* The continued growth of Stewart Beach, East Beach, and the Big Reef, along with the siltation of San Luis Pass and Galveston West Bay are observable. These phenomena suggests that there is no strong predominant littoral transport direction along the Galveston shoreline. The magnitude and direction of the

longshore currents in Galveston coastal waters suggests that the direction of longshore sediment transport is reversible.

* After beach restoration is completed, it is expected that Stewart Beach, East Beach, and the Big Reef will continue to grow at a faster rate while the erosion rate along Galveston's west beaches will be slowed.

* The Galveston Bay South Jetty and the ship channel at the northeast end of the proposed project area form a discontinuity of littoral transport. While the boundary condition at southwest end of the project area allows the littoral material to move with little obstruction.

* Valuable lessons have been learned from the pilot (mini) beach nourishment project that took place in front of the San Luis Hotel during the Spring of 1985. Sand was trucked in from the east end of the island and dumped in front of the seawall between the groins. This pilot project provided clues on design berm elevation, design slope, overfill factor, erosion modes and rates, and the interaction between groins and the new sand. Unfortunately, the project was not well planned nor monitored to yield accurate scientific data for engineering planning and design purposes.

* Data from the monitoring of the pilot project follows [4].

  ~ The monitoring period was 17 months
  ~ The native beach grain size ranged from 0.10 to 0.42mm
  ~ The borrowed sediment grain size ranged from 0.08 to 0.15 mm
  ~ The borrowed volume was 11,460 cubic meters
  ~ The shoreline retreated 52 meters in 17 months
  ~ 16% of filling material was lost in 17 months
  ~ Losses of beach material were due to: (i) movement to offshore, (ii) end losses, (iii) profile adjustment, and (iv) eolian transport.

* The end losses at groins which confined the dumped nourished sand indicated that the design berm elevation should not be much higher than the storm berm elevation in order to reduce the unwanted losses.

* The eolian transport is significant in the pilot project. If the width of newly nourished beach is to include a parking strip along the seawall base, the eolian transport must be carefully considered.

* The monitoring program indicated a 52 meters of shoreline retreat in 17 months. This high rate of shoreline retreat needs to be reduced. Further study of options for reducing the shoreline retreat rate is highly recommended.

A groin field alone may not be able to attain the primary objective since a groin field is already in place over the middle 4.5 miles of the Galveston Seawall. The existing groin system has variable lengths and spacing between individual elements. If a new groin field is chosen for trapping longshore drift and building a beach, the groin cross-section, groin length, and spacing must be checked and re-calculated.

On the nontechnical aspect, to many individuals, a groin field is not eye pleasing due to the crescent shape and segmentation of the beach.

Among the established methods of shore protection, the offshore breakwater is the one that could be used to protect as well as widen a beach. Projects that employ an offshore breakwater can be found on both the Pacific and Atlantic coasts. The planning and design criteria are given in the previous progress report. Site specific information pertaining to the project area are similar to those eluded earlier, namely, littoral sediment transport characteristics and boundary conditions.

The south jetty cuts off the sediment supply to this region, the littoral transport in front of the seawall is one way from west beach to the South Jetty. The littoral movement in the reverse (southwest) direction carries little material since the groin field is empty. Installation of offshore breakwater can slow down this mainly one way traffic of sediment movement. This would allow the littoral sediment to deposit on the beach in front of the seawall, and to reduce the growth rate of the Big Reef.

Other nontechnical matters equally important in the processes of choosing offshore breakwater as a shoreline protection method are: (i) general public perception of soft versus hard structures and (ii) boating and recreational concerns, although no persistent hazardous situations have been reported in existing offshore breakwater locations.

The price of sand is soaring. The initial investment funds, subject to legislative vote and public referendum, are large. The fast rate of shoreline retreat after nourishment is reported by the mini pilot project at the San Luis Hotel. This provides an incentive to find ways to keep nourished sand on beaches longer.

As to economic considerations, the groin field is already in front of the seawall, to utilize these existing materials for protecting the nourished beach and seawall is natural. In addition, the shoreline and the groin field in front of the seawall have been relatively stable over the years. For these reasons one would logically consider the option of combining beach nourishment with an updated groin field as a means of keeping the sand on the beach longer. Although the beach in front of the seawall is fairly stable, it did not trap the sand to form a beach there.

Whether the combination of nourishment and breakwater will be chosen depends on (i) economical analysis, (ii) the tolerance of hard structure to the soft approach for shoreline stabilization, and (iii) the offshore breakwater being less of an eyesore and not segmenting the beach as a groin.

Of the six major new technologies the dune restoration method does not apply for this case. The beach drain system would not work due to the absence of beach to be drained. Both the dredge material placement technique and the subbottom profile manipulation method have inconclusive results. This leaves only the littoral drift manipulation as a possibility.

The Galveston Bay south jetty cuts off sediment supply at the northeast end of the project area. This renders a one way littoral transport direction toward the northeast. As a result, East Beach and the Big Reef continue to grow and the southwestern portion of the project area experiences a deficiency of sand causing the west beaches to have an erosional trend.

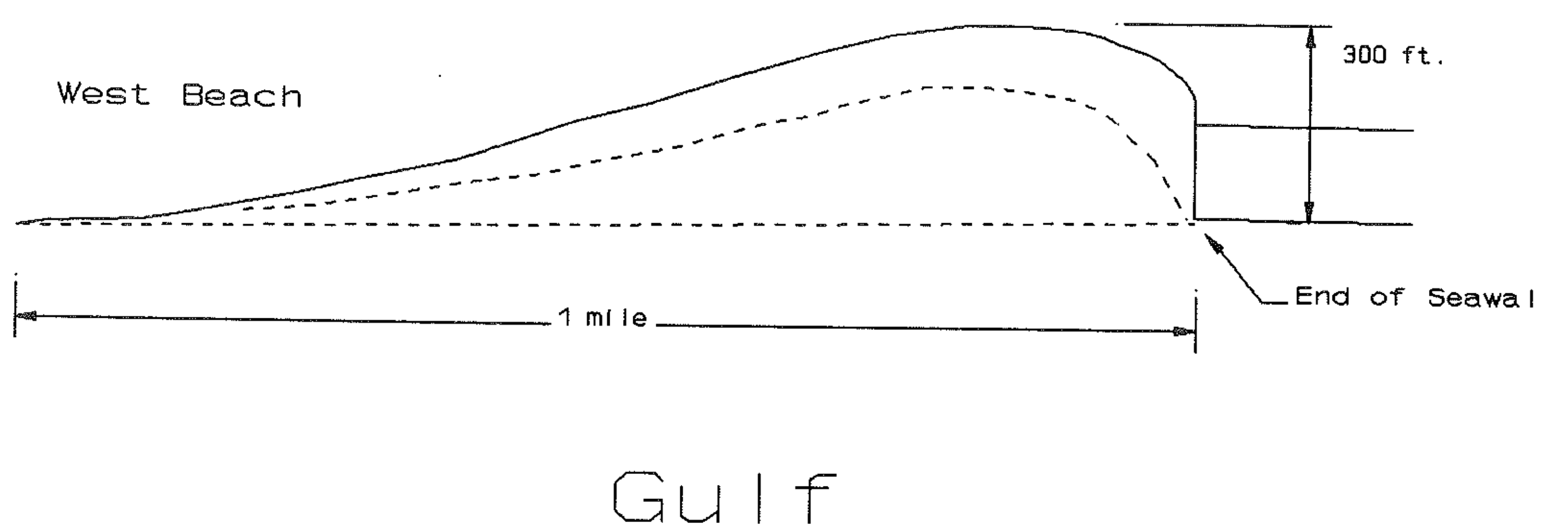
The littoral drift manipulation technique may be employed to slow down the one way littoral transport in the project area, thus, stabilizing the beach in front of the seawall and slowing down the erosion occurring on west beaches. The test project in Miami which employs T-groin and heavy sand has a similar physical setting as Galveston. A close watch on the progress of this test project may aid the decision process for selection of shore protection methods for Galveston.

The choice of the plain beach nourishment method should consider the re-nourishment period. An updated groin field would perform better than the existing groin field, although not by much, unless a completely different system aimed to control direction of littoral drift is employed. The offshore detached breakwater has proven its characteristics of protecting as well as widening a beach, but since it is a hard structure, many consider it an eyesore and/or safety hazard.

The combination of soft and hard structures has merit of keeping sand on beaches longer. This choice should be determined by economical feasibility analysis.

The emerging new technologies are still in their infancy. It would not be good for the first demonstration of these to be implemented in Galveston. This area has suffered and needs proven projects to be employed. It should be encouraged to test some of the new methods, elsewhere, and to initiate new methods of our own at a later date. This would be a necessary condition to elevate the State of Texas to leading position in Coastal Zone Management.

Flanking Erosion at West End of Seawall



WEST END OF GALVESTON SEAWALL

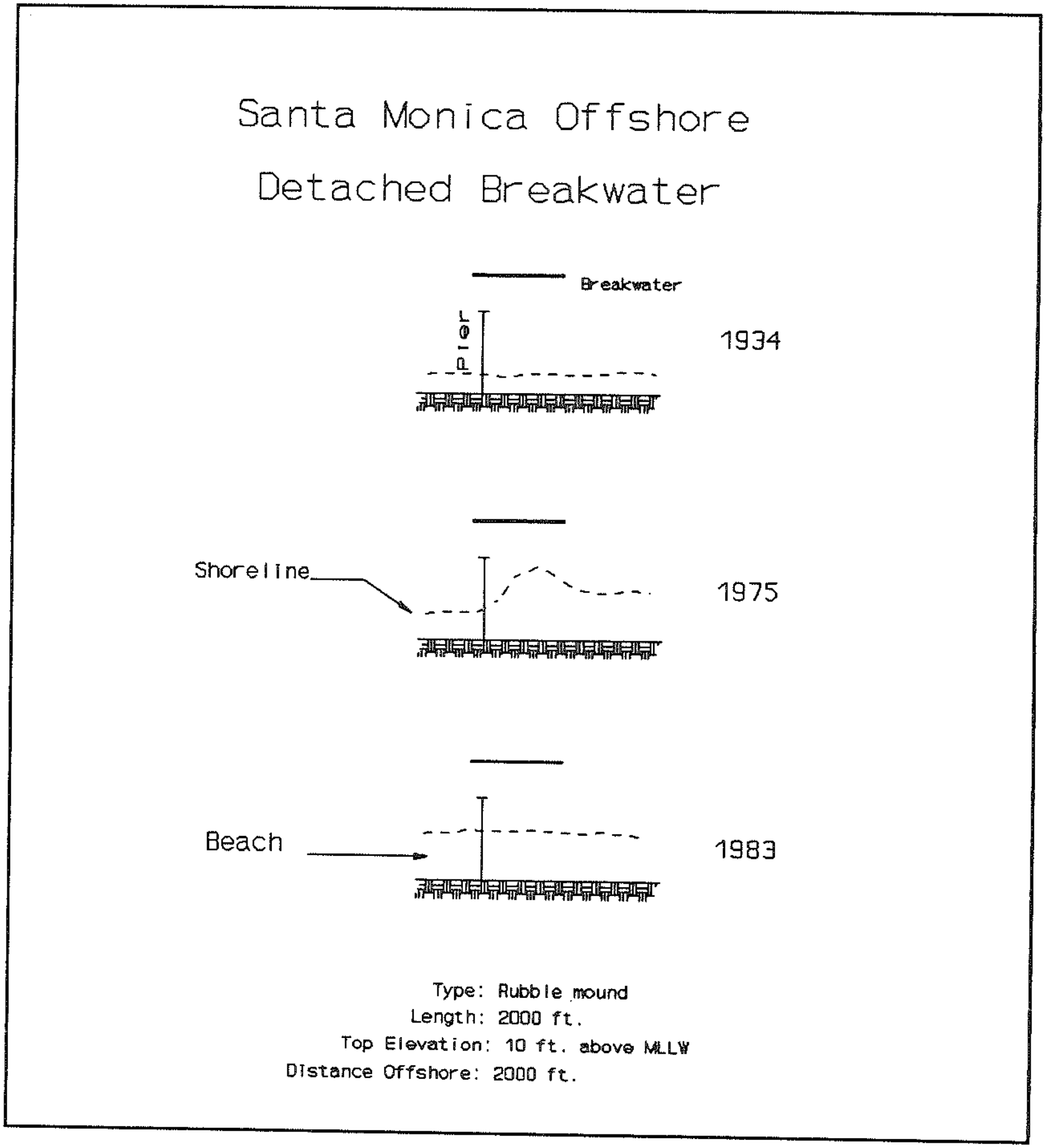
The erosion at the west end of the Galveston seawall is a typical scene of hard structures parallel to the shoreline. This erosion is known as *flanking*. During severe storms State Highway 3005 will become inundated at the west end of the seawall. Since the highway is so close to the water's edge, citizens on the western portion of Galveston Island fear that they may be isolated from the city if the road is washed out at end of seawall.

OBJECTIVE AND SOLUTION: The single objective for this problem area is to stop the flanking at the west end of the seawall. There are a few options available described by the following.

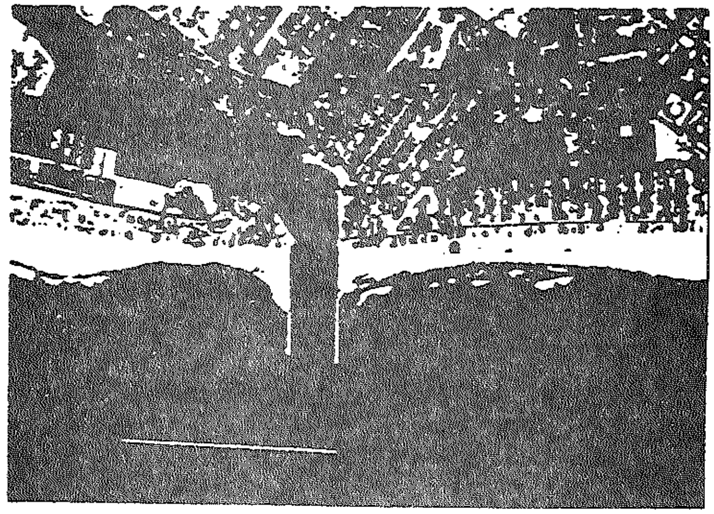
A soft approach to the problem is beach nourishment of the eroded area and prevention of flooding by re-establishing a dune line. Periodic renourishment with high frequency would be anticipated for this method.

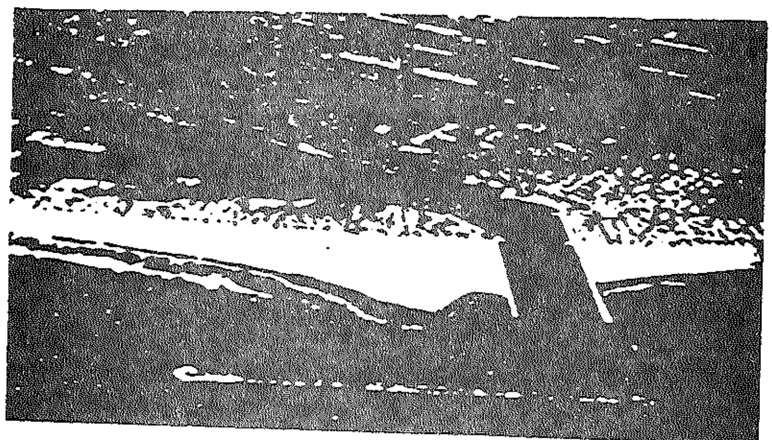
A more permanent solution with infrequent and minimum maintenance is to use an offshore detached breakwater. With proper design of top elevation, permeability, length of structure, and distance offshore, a smooth shoreline which would bridge the seawall and natural beach is achievable. Similar situations are found in Santa Monica and Channel Island shorelines in California. Records of the shoreline evolution at these two locations are shown on the next two pages. These pictures provide a clearer view on the offshore detached breakwaters work.

Other options include a formation of a transition shoreline bridging the seawall and natural beach. This transition may consist of a series of groins with reduced lengths stretching out towards the southwest from end of seawall.



In 1934, when the breakwater was constructed, there was insignificant beachfront present. In the 1960's beach width increased to 800 feet wide. Due to lack of maintenance, the breakwater has slumped over the years. In 1983 the breakwater's top elevation was 6 ft. below MLLW, allowing for an increase in wave energy. This increase has since reached an equilibrium state, providing a smooth and stable beachface.





Channel Islands, California

The above two figures are aerial photographs of Channel Island, California. The top picture, taken in 1965, shows the eroded beach behind the breakwater. The lower picture, taken in the 1980's, shows the formation of a tombolo in the lee of the breakwater. The breakwater information follows:

Type: Rubble mound
Top Elevation: 14 ft. above MLLW
Length: 2300 ft.
Location: 30 ft. bottom contour

The Santa Monica and Channel Island breakwaters indicate the possibility of designing an offshore detached breakwater that allows just enough energy to leak in its lee so that a smooth and stable shoreline is produced.

GALVESTON WEST BEACH

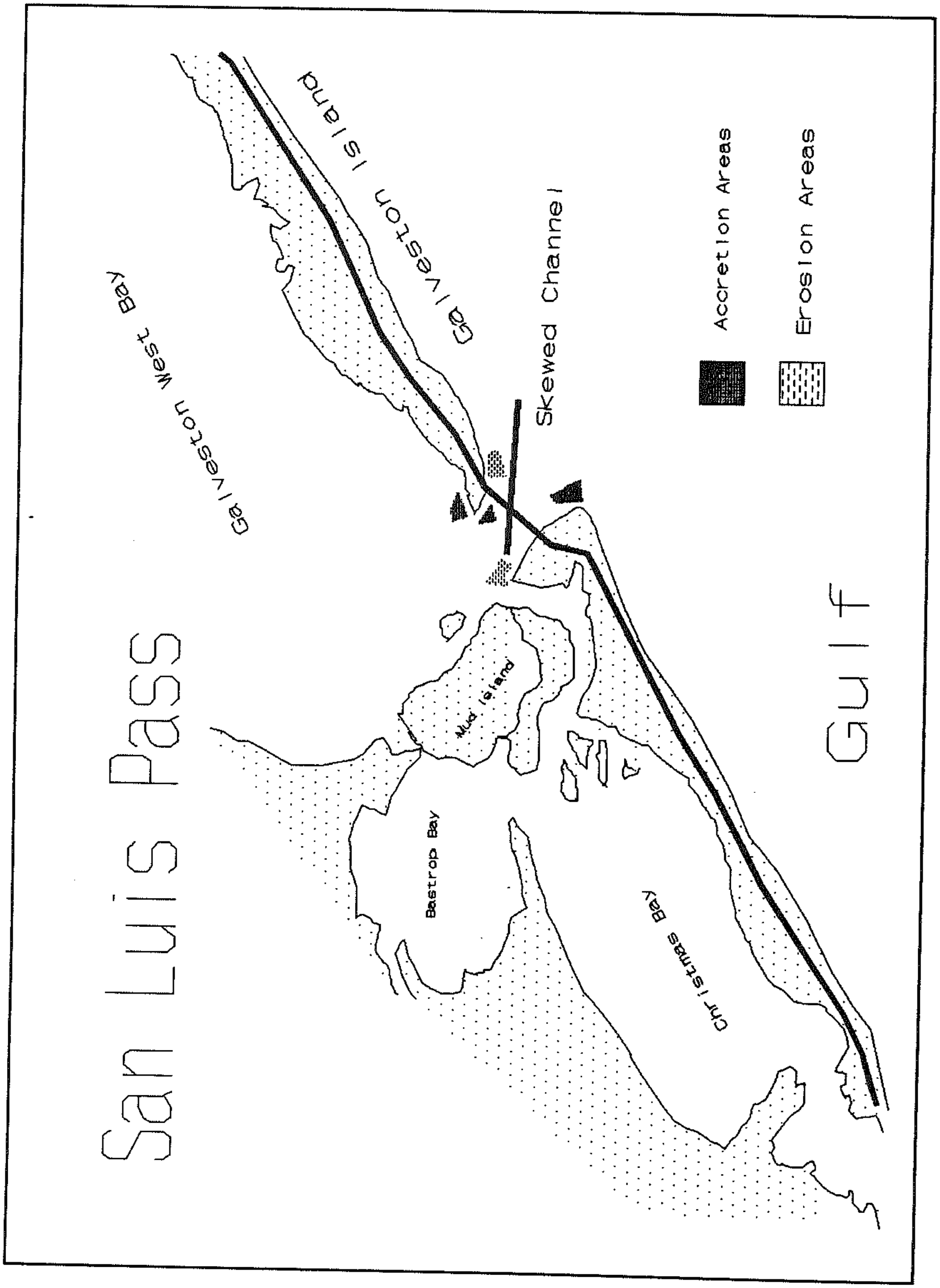
The major problem facing Galveston west beach communities is the retreat of shoreline causing flooding of property during storms. The narrowing of the beach face is also a concern. The west beach problems are categorized: failure of beach accretion, presence of low lying areas, and little protection from storm surge. These three problems will be discussed, along with possible solutions, while keeping in mind the interrelationships of each.

The Galveston south jetty and empty groin field along the seawall provides no sediment supply to the west beach region. Also, the shoaling of San Luis Pass and Galveston west bay indicates a sediment sink providing no sediment. These two boundary conditions set the general erosional trend for the west beach. The west beach of Galveston Island has no appreciable accretion. Large volume of littoral material bypasses the beachfront, continuing downcoast towards San Luis Pass (see San Luis Pass). This has caused numerous problems along the coastline which will be discussed later. Failure of West Beach to build itself, through accretion, has taken away the protective buffer zone that is needed during storm episodes. The *Shore Protection Manual* [5] states that a beachfront buffer zone is one of the best defenses against coastal property loss.

The relationship of upcoast structures, jetties, groins, and seawall, with littoral transport needs to be established so that when these are solved an accretion process can be started at West Beach. While the city has a seawall, the west end is left unprotected from storm surges.

OBJECTIVES: The objectives are to stop coastal land loss, prevent flooding of uplands, and widen the beach face for recreational use.

OPTIONS FOR ATTAINING OBJECTIVES: Use of beach nourishment with dune restoration. An initial beach restoration project is needed to establish a sound shoreline. However, beach nourishment alone can not stop flooding of upland and coastal land losses. The sea level rises during a hurricane, the nourished beach will be submerged under the stormy sea surface. The storm sea level allows the wave to attack higher coastal land and is one of the major causes for land loss, flooding, and property damage. The proper remedial method is to build the duneline before a storm attack. During a storm, the dune line takes the brunt assault of storm and absorbs the destructive energy in order to save the land and property behind it. After the storm, the duneline is quickly restored ready for the next storm. A cost effective with minimal environmental impact method for dune restoration is proposed by Wang called *Nature Assisted Dune Restoration (NADR)* [6]. The raising of land areas by dune restoration, and the implementation of a buffer zone through beach nourishment will stabilize the shoreline and reduce the storm surge damage on coastal property and land.


San Luis Pass
Galveston West Bay
Galveston Island
Skewed Channel
Accretion Areas
Erosion Areas
Mud Island
Bastrop Bay
Christmas Bay
Gulf

SAN LUIS PASS

The recent trend occurring along the western extreme of Galveston Island, San Luis Pass, is that of unwanted massive accretion and erosion along the Pass. These in turn have created the re-alinement of the channel which has skewed toward the northwest direction. It is shown on the San Luis Pass map.

It is observable, the bridge which spans the inlet has a beachfront below; the channel has become narrower and deeper. A stronger tidal current is thus produced and it undermines the bridge piers and erode the shoreline along Mud Island.

The nearby Galveston West Bay area have been filling with sand, circulation of bay waters have been interrupted and the healthiness of bay related businesses have suffered. Solutions to the massive deposit of littoral materials need to be found.

OBJECTIVE: The multiple objectives should include:

* Stabilize the skewed channel which runs through the Pass.

* Revive the smothered bays by restoring the flashing and circulation of the inlet-bay system at San Luis pass.

* Control the sediment movement along the shoreline to reduce the rapid siltation of the inlet-bay areas and the erosional trend at the Gulf shore near the Pass.

APPROACHES TOWARD ATTAINING OBJECTIVES: The San Luis Pass serves as a vital link which connects Galveston West Bay, Bastrop Bay, Christmas Bay and Chocolate Bay. The circulation and flashing pattern of this inlet-bay system is directly related to the well being of the ecosystem in that region. Therefore, a comprehensive system approach toward a solution is recommended. A report similar to the study of Rollover Pass and vicinity is called for [3]. The study should include but not limited to the following.

* Effects of upcoast and downcoast characteristics on the inlet-bay system.

* Impact of man made shoreline protection measures on the inlet-bay system.

* If sand removal from the inlet-bay system is necessary for revive the choked system, then, this removal should be taken into account for replenishment supplies for beach nourishment projects along the seawall and Galveston west beach.

TEXAS CITY DIKE

The Texas City dike opens to a fetch length of approximately 30 miles in the north northeast direction. A northeaster with a wind speed of 50 miles per hour blowing for 3 hours could produce waves in excess of 5 feet high. These waves break against the dike may cause scour at the structure toe as well as dislodgment of armoring units. It seems prudent to send divers to inspect the foundation before any preliminary solutions can be formulated. Once the nature of damages is known, maintenance and repair procedures can then be suggested.

The shoreline between the Dollar point and Tide Gate has the same orientation as the Texas City Dike, therefore it subjects to similar wave actions. Shoreline condition there may need more attention than the Texas City Dike.

GALVESTON BAY SHORELINE EROSION

The major problems facing the shorelines of Galveston Bay is erosion in shallow waters.

SOLUTIONS: Solutions to shoreline erosion in Galveston Bay consists of different employments of material to dampen waves. Vegetation is a natural dampener. As a wave approaches shallow water areas with vegetation (usually grasses) it dissipates energy. Another type of dampening can be employed by man-made materials. The use of man-made materials would serve better than vegetation in that the energy can be calculated and dampening can be implemented to varying degrees. The use of structures with specific shapes and characteristics can be refined to control the energy that waves will posses.

CONCLUSIONS

The problem area on the shoreline of Galveston County are identified. Analyses of the problem areas are done in the light of the physical environment and littoral characteristics of Galveston coast line. Optional methods for protecting the shoreline in each problem area are suggested. The selection process for a protection method in a problem area begins with the economic analysis. Data acquisition is expensive and time consuming. At the planning and preliminary design stages, it is adequate for engineers to use available historical data. For long term considerations, a plan to collect and establish a data base for Texas Coastal Zone Management and Galveston County is very much needed. The final decision should be weighed with technical merit, environmental concerns and economical soundness.

ACKNOWLEDGEMENTS

Special thanks to Mr. Ronnie Barcak, a senior engineering student, who has devoted many hours working on this paper. His work included reading, editing, and typing of the manuscript, along with producing the engineering drawings found in this report. His participation and dedication on this paper is especially acknowledged and appreciated.

The financial supports provided by the Texas Water Development Board and Galveston County through Dannenbaum Engineering Corporation are gratefully acknowledged.

REFERENCES

1. US Army Corps of Engineers (1984) "Galveston county Shore Erosion study. Feasibility Report on Beach Erosion control; Vol. 2: Gulf Shoreline study Site Report," US Army District, Corps of Engineers, Galveston, Texas. p. 185

2. Morton, R.A. (1975) "Shoreline changes Between Sabine Pass and Bolivar Roads: An Analysis of Historical Changes of the Texas Gulf Shoreline." Geological Circular 75-6, Bureau of economic Geology, the University of Texas at Austin, Austin, Texas.

3. Wang, Y.H. (1989) "Preliminary Designs of Improvements at Rollover Pass and Vicinity, Bolivar Peninsula, Texas." Technical Report, MASE Department, Texas A&M University at Galveston, p.156

4. Giardino, J.R., Bednarz, R.S., Bryant, J.T. (1987) "Nourishment of San Luis Beach, Galveston, Texas: An Assessment of the Impact." Coastal Sediments '87, pp. 1145-1157

5. US Army Corps of Engineers (1984), "Shore Protection Manual" Coastal Engineering Research Center, 2 Volumes

6. Wang, Y.H. (1991) "Nature-Assisted Dune Restoration" Proceedings, Coastal Zone '91, Long Beach, California

PROPOSAL FOR IMPROVEMENTS TO ROLLOVER PASS
BOLIVAR PENINSULA, TEXAS

Darrel K. Pelley*

Based on an Initial Study Performed in December, 1989 by:

Dr. Y.H. Wang, PhD
Miles F. Gathright
Nicholas G. Kyprios
Laura L. Robinson
Michael S. Vickers
Michael E. Duncan
William J. Hoffman
Darrel K. Pelley
Mark I. Sales
Jung Ho Yoon

INTRODUCTION

During the fall semester of 1989, a study was performed by a group of students from the Maritime Systems Engineering department of Texas A&M University at Galveston in an attempt to determine causes and solutions for the erosion problem at Rollover Pass, along the upper Texas Coast. This study was inspired and supported by the citizens of the Bolivar Peninsula, Mr. Eddie Barr, Galveston County Commissioner, Mr. Pat Hallisey, director of the Galveston County Beach Park Board, and Dr. Y.H. Wang, Professor of Engineering at the university.

This report will attempt to summarize the findings and suggestions of the study and outline the proposed suggestions made for improvements to be made in the area.

* Naval Architect, Waller Marine, 15311 Vantage Pkwy, Suite 250, Houston, Texas 77032

PROBLEM DISCUSSION

The Rollover fish pass was initially opened in 1954-1955 by dredging a small channel measuring 80 feet wide and 8 feet across through a narrow section of the Bolivar peninsula where the maximum land elevation did not exceed 5 feet above sea level. Instability soon caused the channel to scour to a width of 500 feet wide at the seaward mouth, with water depths of 30 feet in some locations (Ref.1: p.429). In an effort to maintain the structural integrity of the Texas highway 87 bridge crossing the pass, the channel was closed by driving a line of steel sheet piles across its width on the seaward side of the bridge. The pass remained closed for the installation of steel sheet piles along both sides of the pass and was again reopened in 1959-1960. The sheet piles blocking the channel were driven down to a depth of approximately 5 feet below mean sea level (MSL) (Ref.1: p.429) and form a trapezoidal weir to seaward of the bridge and intended to protect the bridge foundations. In the years since the reopening of the pass, accelerated erosion has threatened the property of residents, and highway 87, several sections of which have already been closed between High Island and Port Arthur, Texas.

STUDY JUSTIFICATION

Since the reopening of the fish pass, erosion rates along the gulf coast in that region vary considerably. According to the U.S. Army Corps of Engineers (USACOE), the average annual beach loss in the vicinity is 14 to 16 feet. A comparison of USACOE data and numerous other studies is shown in Table I. Analysis of the data reveals the erosion rates for the southwest side of the pass exceed those for the northeast side by about 2 feet per year on average. The table data is based on a linear distance of 6,900 feet to either side of the pass. The 1984 study conducted by the USACOE concluded the annual quantity of sand lost on the down drift measured area to excess beach erosion was approximately 9000 cubic yards. Additionally, it can be noted that USACOE estimated erosion rates since the opening of the pass have exceeded the pre-pass erosion rates by 3 to 12 feet annually.

In addition to determining how much sand is lost in the area annually, it is necessary to investigate the final destination of displaced littoral material. Visual inspection of the bay area adjacent to the pass on Friday, 20 October 1989 during the ebb tide showed a large percentage of the bay bottom completely exposed. Tidal data for the same day provided by the U.S. Department of Commerce (USDOC Chart 11331-SC) shows a low tide of 0.0 feet above MLLW at 2:39 pm. Evidently, severe sedimentation has occurred in Rollover bay over the past three decades due primarily to the flood dominant characteristics of the inlet. Additionally, it was noted by the design team that maintenance dredging rates for the Gulf Intracoastal Waterway (GIWW) in the area have increased since 1959-1960 when the pass was reopened. The erosion loss data, GIWW maintenance rates, and visual inspection results led directly to a hypothesis that the littoral material disappearing from the beaches along the northeast side of the pass were being deposited in the adjacent bay, while scouring effects on the southwest side of the pass were causing materials to be moved along the coast and redeposited on the east side of the Galveston-Houston entrance.

GALVESTON BAY CLIMATOLOGY

The climate characteristics for the Galveston Bay system including Rollover pass are compiled below in tabular form and are based on statistical information gathered by the design team during the initial phase of the study in December, 1989. The parameters used in the design processes are directly related to the information below:

ANNUAL RAINFALL

The Texas Gulf Coast climate is generally characterized by long, hot summers and relatively short, mild winters. Annual rainfall for the region averages approximately 45 inches. The recorded annual rainfall has a direct effect on the salinity regimes in the East bay system. The east and Rollover bays are fed by tributaries, including the Trinity river and the east bay bayou. The occurrence of long, dry periods corresponds to a slight increase in baseline salinity due to the inability of salt crystals to be evaporated.

WIND CHARACTERISTICS

Wind conditions in the western Gulf of Mexico are characterized by wind velocities of 8 to 15 miles per hour from the south-southeast for more than 60 percent of the year. As a result of these predominant conditions, alongshore littoral transport is generally from east to west. Each year, 15 to 20 fast moving polar fronts pass through the area bringing northerly winds at velocities of up to 50 miles per hour. The period preceding the passage of a front brings strong southerly winds, generating stronger than usual wave activity in the area.

WAVE PROPERTIES

According to the U.S. Army Corps of Engineers (1984), wave heights in the area exceed 4.5 feet only 1 to 3 percent of the time. Wave heights of 2 feet or less occur 25 to 50 percent of the time. Wave conditions in the region can therefore be described as relatively calm.

STORM ACTIVITY

During the period from 1900 to 1984, twelve hurricanes made landfall within 40 miles of Rollover pass. The greatest surge height was recorded in 1961 during hurricane Carla, which came ashore 150 miles southwest of Rollover pass (USACOE 1984). On average, surges greater than 5 feet have occurred in the locale every 2 to 3 years. This erratic storm activity can result in significant beach profile changes.

PROPOSED SOLUTION

It was decided as a direct result of the preliminary research conducted by the group that the solution would consist of three (3) major phases; initial beach nourishment, design and construction of a jetty system at the pass to interrupt the littoral flow of material down the coast, and secondly, implementation of a sand bypass plan to periodically replenish the beaches on the down-drift side of the pass.

BEACH NOURISHMENT

Because of the badly deteriorated beach profile, it was decided that a short term alleviation of the local erosion problem had to be found in order to build the permanent structures and allow the long term program to go into effect. This first phase is to be accomplished in the form of beach nourishment. Simply stated, the beaches would be nourished with borrowed sand, stabilizing the beach profile during the construction phase. In order to implement such a plan, it became necessary to find a suitable borrow site, where the grain size closely matched the assumed grain size missing from the beaches around the pass. On October 20, 1989, members of the design team made core samples from the exposed bay bottom at several locations in the bay during slack water between the ebb and flood tides. After sorting the materials according to grain size. it became apparent that a substantial amount of the material sampled in the bay was compatible to the material missing from the beaches. The results of the grain analysis seemed to provide some evidence that the flood dominant characteristics of the pass were causing littoral material to be drawn into the bay during the flood tidal cycles, choking the bay bottom. The amount of material required for the initial nourishment was calculated based on the following parameters:

1. The 4 mile stretch of nourished beach would have a berm at least 100 feet wide at the completion of the operation.

2. The nourishment would establish a dune line at least 7 feet high running continuously along the entire stretch of beach.

It was decided for cost effectiveness to use a shoreside dragline dredging system to remove 188,000 cubic yards of sand from the bay bottom to the gulf beaches over a stretch extending two (2) miles to either side of the pass. The dredged bay bottom elevation at -3 feet would encourage the formation of wetlands around the fringes of the bay. As the operation moved away from the shore, the dragline would be moved on to a barge and floated into the bay to continue recovery. The recovered material is offloaded to a storage area for drying before being moved by dump trucks to the beach. An alternative method would be to move the material to the beach directly from the barge via a pumping system, although it is assumed that the pumping method would be more costly. The sand is placed on the beach at the feeder beach locations discussed in the by-pass section of the 1989 study and summarized in the by-pass section of this report.

Finally, an attempt to stabilize the dune line would be made through planting naturally occurring dune grasses and allowing them to take over the dune line and effectively anchor the sand in place. Types to be used include Panic Beach Grass (Panicum amarum), and sea oats (Uniola paniculata).

JETTY DESIGN AND CONSTRUCTION

The jetty design team was required to select a jetty size and type consistent with environmental conditions prevalent along the gulf coast and a considerable design lifetime. Several types of common jetties were investigated before the final decision was made. Sheet pile jetties were considered for their low initial investment required for construction, and their relative ease of construction. Indeed, sheet pile jetties were constructed along the Galveston Island coast during the 1930's; however, within thirty years, the outer portions were severely damaged and wasted due to corrosion. This same condition can be observed today at Rollover pass where the sheet piles have deteriorated due over the course of time. A concrete sheet pile jetty, a wall with a concrete cap, was considered for its strength and impermeability to corrosion. Such a structure would have to be pre-stressed and cast in place. Additionally, the salt water environment eliminates the use of steel reinforcement. As a result, the structure would be massive and very expensive to construct. Repairs to damaged sections would be costly and difficult to perform.

The jetty type finally selected is the rubble mound jetty with a granite cover layer, very common along the texas gulf coast, especially along the Galveston seawall. The rubble mound jetty is constructed with a core of quarry stone, finer material being added later to fill the cavities between the large stones and rendering the core sand-tight. The structure is protected by a layer of armor stone. The armor stone, usually granite or concrete must be heavy enough to remain stable against prevalent worst case conditions. Although rubble mound jetties are costly and time consuming to construct, they have a series of advantages not found with the other types:

1. The rubble mound jetty has a normal design lifespan of 100 years based on design environmental criteria.

2. The structure will act as a barrier to prevent the passage of littoral material.

3. Rubble mound jetties are relatively safe against foundation failure and excessive settling.

4. Excessive scour at the toe section of the jetty will be prevented.

5. The required materials are readily available in central Texas.

Following the study of the littoral transport system for the region, it became necessary to determine the required length of the structures. By projecting beyond the breaker zone, it is estimated that 80 to 90 percent of the littoral transport can be blocked. These parameters relate to a jetty length of approximately 800 feet normal to the beach line at the pass. The extreme outer portions of the jetties protrude beyond the 6 foot depth contour offshore of the pass. In order to prevent excessive scour and foundation failure, it was determined through a survey of the park to space the jetties 550 feet apart, with the shoreside end of each jetty resting at the east and west boundaries of the park respectively. Such a spacing allows the natural wave action to keep the channel open without undermining the jetty foundations.

The design environmental criteria selection is based on collected wave data for the region. The design wave height used is the average of the highest 1/3 of all waves encountered. The calculated value was determined to be 8.9 feet.

The U.S. Army Corps of Engineers Design of Breakwaters and Jetties was used to determine the stability coefficient for the structures. The designers selected a value of 2.0 in order to obtain the most conservative results from the stability equation for the unit weight of the cover layer. With a required unit weight of 160 pounds/cu. foot, stones with weights between 4 and 6 long tons each were selected. A cross section of the proposed structure can be found attached herein. The jetty design posses the following characteristics, best summarized in tabular form:

1. The crest elevation will be 6 feet above MLW from the beach to the end of the jetty. The crest elevation is limited by the status of the park as a hurricane washover region. The 6 foot elevation will also allow easy access by recreational fishermen at the park.

2. The minimum thickness for the armor layer is to be 3.7 feet, as determined from the USACOE Shore Protection Manual. Parameters include a unit weight of 8640 pounds per stone, one (1) layer.

3. Since the depth of the structure "is less than 1.5 times the design wave height" [USACOE, SPM], the cover layer must extend all the way to the bottom and onto the bedding layer.

4. A toe berm will be constructed at the ends of the cover layer to improve stability of the cover layer against breaking waves.

The resultant jetty system will tend to cause some scouring directly adjacent to the pass to the west. The implementation of a by-pass system as described below will attempt to alleviate the scour effect while nourishing the beaches along the Bolivar peninsula between Rollover pass and the Galveston entrance.

SAND BYPASS SYSTEM

Very simply stated, sand by-passing is the periodic relocation of sand from a natural collection area to a sand depleted area, usually by-passing a cut or inlet. This technology is not new and has been used with success along the Florida coastline. For the purposes of this study, it was decided to investigate the two most common forms of sand-bypass systems and make a decision as to which system suited the particular application. The first option considered was the fixed by-pass system, by which littoral material is moved via permanently installed machinery at the site, including pumps, pipelines and associated power generation equipment. The second option was the mobile or portable by-pass system, by which sand is moved manually, using earth moving equipment rented or leased only for the duration of operations annually. Following is a brief description of each followed by a summary of characteristics used in the design process.

FIXED BYPASS SYSTEM

As mentioned above, the fixed system employs permanent machinery on location to periodically move littoral material from the deposit zone to the depleted area. A preliminary step to the approach is a foundation pedestal which must be engineered into the rubble mound jetty and sufficiently strong to stand up to the elements over the duration of its useful life span. In this case, the pump house would be located on the eastern side of the pass, approximately one half the distance from the extreme offshore end and the beach line. Within the house would be installed the bypass machinery, pumps, powerpacks and other associated equipment. During operation, a boom fitted with a suction hose would be extended from the pumphouse flat over the deposit area. The material would be pumped through the hose and pump to a pipeline running parallel to the dune line down the beach to the west of the pass. The sand-water slurry would be deposited at or near the dune line with the water and small suspended particles returning to the gulf while the larger grains remained on the beach. This system has been used and proven successful along the Florida coast, where beach maintenance is important to the tourist industry. However, such a system would have a price tag of approximately $2,300,000.00 added to the initial investment of $4,000,000 for the jetty system. Also considered are the maintenance to permanently installed machinery in a salt environment, manning requirements, and upkeep during dormant periods.

MOBILE SAND BYPASS SYSTEMS

The other alternative considered is the mobile or portable by-pass concept. The major components of such a plan involve the use of rented or leased equipment, paid for and maintained only for those periods during which operations commence. A dragline, or bucket loader will be used to scoop littoral material from the deposit area on the east side of the pass. The sand is to be loaded into dump trucks and transported down the beach to a point approximately 700 feet west of the pass. A bulldozer will spread the material out into a feeder beach jutting out from the coast. By placing the feeder beach down current from the pass, the sheltering effect of the pass is minimized and the sand is allowed to be transported down the coast via the naturally occurring littoral transport system in motion along the coast. As can be seen from the cost analysis presented in the following section, the actual annual cost for the operation would be approximately $200,000. The simplicity of the mobile by-pass method allows the plan to be put into effect immediately after the completion of the jetty, as opposed to the time required for the construction of an elaborate fixed pumping system

COST BENEFIT ANALYSIS

The major obstacle to overcome with the solution proposed by the design team was the cost. Preliminary budget estimates predicted that the initial investment for the jetty construction would be near four (4) million dollars. Note that the budget estimate is based on U.S. dollars effective fourth quarter, 1989. A simple cost breakdown for the construction phase of the project follows below:

Phase I, Beach Nourishment

1.	Dredging and transportation of recovered material, based on the total cu. yardage to be moved	$2,250,000
2.	Earth moving equipment	$ 80,000
3.	Barge and Handling Vessel (Lease)	$ 72,000
4.	Insurance and Overhead	$ 360,000
5.	Contingencies and Overhead	$ 600,000
6.	Vegetation	$ 70,000

TOTAL, Phase I $3,432,300

Phase II, Jetty Construction

1.	Cover layer stone, 44,000 LT	$1,100,000
2.	Core stone, 22,000 LT	$ 400,000
3.	Blanket stone, 17,000 LT	$ 309,000
4.	Filler stone, 7,000 LT	$ 136,000
5.	Equipment and Labor	$1,000,000
6.	Engineering and Design	$ 100,000
7.	Contingencies	$ 500,000
8.	Project Management and Supervision	$ 300,000

Based on the predicted 100 year life span of the construction, the total investment relates to a yearly cost of 38,000 to 40,000 dollars per year. Additionally, the maintenance costs incurred for rubble mound jetties are minimal and would be realized primarily in the case of storm damage repair. Since the costs outlined above are effective for the end of

1989, actual construction costs, including staging, logistics and labor rates may be significantly higher. However, through stabilization of the beach profile, and indirectly, the protection of highway 87, the bay, and the adjacent Intracoastal Waterway, an increase in the tourism industry to the area would be realized, along with increased property values and reduced maintenance dredging in the GIWW along the north side of the bay.

Additionally there is a cost involved in the sand by-pass aspect of the project. The cost involved in maintaining the beach profile is annual and does not decrease after a large initial investment. Rather, the cost of by-passing trapped littoral material is "lost" in a sense, meaning that the benefits realized through implementation are not financial. Below is a projection of the annual cost for material by-pass operations based on U.S. dollars effective fourth quarter, 1989:

RENTED EQUIPMENT:			
1.	Dragline	$2.25/cu. yd.	$146,250
2.	Bulldozer		$ 5,000
SHIPPING COSTS:			
1.	Dragline		$ 2,000
2.	Bulldozer		$ 1,000
TOTAL:			$ 154,270
TOTAL INCLUDING 1.15% OVERHEAD			$ 177,410

As can be seen, there is no required investment for equipment other than periodic rentals when sediment builds up at the eastern side of the jetty system. Over a ten year period from the completion of construction and the implementation of sand-bypass technology at Rollover pass, the total expenditure would be nearly $10,000,000. Some further study is required to determine the benefits as a function of predicted property values at the end of the ten year period. At the time of the initial study, the low number of permanent residents made benefits difficult to justify, however, the huge expenditure to reconstruct highway 87 further inland or as an elevated roadway far outweighs the investment outlined in this report.

ENVIRONMENTAL CONCERNS

With the completion of this project, there would be some effects on the local environment. These are included in an itemized format and based on data collected during the study. Statistical data has also been supplied by the U.S. Army Corps of Engineers, Galveston, Texas.

VOLUME CHANGE TO ROLLOVER BAY

Since the initial phase of the program requires the removal of material deposited in the bay from the gulf, there will be a volumetric increase to the bay. The average high tide water depth in the bay at present is between 0.5 and 1.0 feet. The dredging phase of the operation is predicted to increase the average depth to three (3) feet. The removal of the material will effectively triple the water volume in the bay, with the inflow composed of a combination of high salinity water from the gulf and lesser saline water from the east bay.

SALINITY EFFECTS

As we know, the current salinity regime in the Galveston Bay system is the combined result of tidal fluctuation and fresh water inflow from the rivers feeding into the bay. Generally, the eastern sections of the bay have had a significantly lower average salinity than the western portions. For the purposes of the study, a simple program was developed to demonstrate a salinity rise in the rollover bay as a result of local dredging. The parameters used in the run were:

1. Maximum tidal flow over a 25 hour period between 0.7 and 4.2 ft/sec. Flood and ebb tidal values are not discerned, however; the 1972 report by Prather and Sorenson indicated that the pass is a flood-dominant tidal inlet.

2. An average baseline salinity in the bay is assumed to be between 16.9 and 17.2 ppt. with fluctuations of less than 1 ppt. through the year 2045.

3. Gulf of Mexico baseline salinity of 28-29 ppt.

4. Post dredge bay depth of 3 feet on average.

5. Maximum tidal velocity of 6 ft/sec. during the peak of the flood tide.

6. A fixed volume for analysis, i.e. a roughly calculated basin volume.

Results of the program indicated that a rise in salinity of 0.5 to 1.10 ppt. could occur in the bay after dredging, depending of course on rainfall and fresh water inflow from local rivers. Additionally, increased salt wedge penetration into the bay as a result of opening the bay and pass would no doubt contribute to the salinity rise. Under the USACOE plan H50 for widening and deepening the Houston Ship Channel (1986), it was noted that the channel forms a salt barrier between the east and west bays, indicating that the rise in salinity would be local rather than widespread.

BAY FLUSHING

Due to the shape of the bay and its short, direct connection with the gulf, it is assumed that the bay does flush regularly, albeit slowly. The greater depth in the bay combined with the flood dominant characteristics of the pass could conceivably reduce the bay flushing time by up to 10 percent. At present there is a time lag of approximately 4 hours between the occurrences of high tide at the Galveston entrance and the bay side of the pass. This is an indication that during the ebb tidal cycle, water is attempting to move down the bay to the Galveston Entrance rather than exit through the pass. This condition is likely a result of the choking of the bay with sediment.

CONCLUSIONS

Perhaps the simplest conclusion to be drawn from the data is that the proposed plan would be a solution to the erosion problem in the region around Rollover pass. The initial beach nourishment would stabilize the beach profile for a length of time sufficient to construct a jetty system around the cut. In addition to providing nourishment for the badly depleted beaches, the dredging operation in the bay would provide an area for the propagation of wetlands around the fringes of the bay. The new jetty system would interrupt the littoral transport around the pass, trapping sediment in a deposit area on the east side and directly adjacent to the pass. The vacuum effect, drawing large amounts of sediment into the bay would be counteracted by the jetty system. Periodically, the trapped sand would be collected from the deposit area and redistributed along the western side of the pass on feeder beaches. The sand would be moved from the feeder beaches by the natural littoral transport system and down the coast, emulating an uninterrupted littoral flow.

The cost of the operation presents a drawback to the operation, however; it should be noted that the 1989 study did not turn up any low cost effective solutions to the problem. It would seem that the team located the most cost effective method to counteract the erosion problems along the upper Texas coast.

REFERENCES

1. Wang, Y.H., et al. "Preliminary Designs of Improvements at Rollover Pass and Vicinity, Bolivar Peninsula, Texas." A technical report presented at Texas A&M University at Galveston, Galveston, Texas. December, 1989.

2. Morton, Robert A., Shoreline Changes Between Sabine Pass and Bolivar Roads - Geological Circular 75-6; Bureau of Economic Geology, University of Texas, Austin, Texas, 1975.

3. Bales, Jerald D. and Holley, Edward R. Sand Transport in Texas Tidal Inlet; Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 115, No.4. ASCE July, 1989.

4. Prather, S.H. and Sorensen, R.M. A Field Investigation of Rollover Pass, Bolivar Peninsula, Texas. Texas A&M University, College Station, Texas. TAMU-SG-72-202.

5. U.S. Army Corps of Engineers. "Hurricane Wave Statistics for the Gulf of Mexico." Technical Memorandum No.98. USACOE, 1957.

6. U.S. Army Corps of Engineers. Shore Protection Manual, Volumes I and II. Department of the Army, USACOE, 1984.

APPENDIX I
Supporting Statistics and Figures

DETACHED OFFSHORE BREAKWATERS FOR GALVESTON COUNTY

Alan D. Black and Mike Strech*

ABSTRACT: The Gulf Coast regions of Galveston County, especially the west end of Galveston Island and the Bolivar Peninsula, are prone to physical loss of land. One viable solution to combat this erosion is the use of detached offshore breakwaters.

INTRODUCTION

As directed by Galveston County and the City of Galveston, Dannenbaum Engineering Corporation (DEC) has investigated various coastal sites that may warrant some measure to protect them from continued erosion. The focus of this discussion will center on the areas which are not currently protected by structures. Though erosion is very evident at the face of the Galveston seawall, erosion is occurring in many areas along the Gulf Coast and Intracoastal Waterway. The Texas Department of Transportation's 1990 aerial survey of the shorelines have been compared to the results from previous U.S.G.S. maps and some areas were found to exhibit significant erosion at many areas where no shore protection structures exist. If these areas are not incorporated into the County's comprehensive shore protection program, storm force waves would continue to erode existing coastal features.

History shows that the storm force waves are the most significant to the shore line changes that occur in Galveston County, though the daily wave actions also can not be ignored. The recent surveys indicate that these ongoing shoreline changes will impact the existing economic and environmental balance. The Galveston seawall serves as a good example of the economic impacts that a shore protection system can create. Most large-

* Professional Engineers, Dannenbaum Engineering Corporation, 3100 West Alabama, Houston, Texas 77098

scale, tourist-related projects rely on the protection of the seawall and are located accordingly. Without this magnitude of protection, the investors might have been less ambitious with their developments. Even with this seemingly effective protection structure, we can see that the existing west end of the seawall could be the victim of these on-going shoreline changes. When this seawall is compromised, the commercial establishments which are protected by it are also at risk. As the seawall, subdivisions and roadways encroach upon the beach, their disruption of the natural dune build-up processes speeds the beach loss process that threatens the structures. Aerial surveys have shown the relevance of this process at two, west-end Galveston Island subdivisions and also along F.M. 3005. Even the intracoastal water way and its eco-systems are at risk as the Gulf wave actions widen existing (or open new) breaches in the barrier island.

These future losses or changes are the subject of this study to identify sites which can no longer be overlooked. The key to a workable protection system centers on identifying sites that are at risk, prioritizing the mitigation steps, then implementing measures that will result in protecting Galveston County's beaches, land, resource and waterways. As the Flood Emergency Mapping Agency (FEMA) develops legislation to influence coastal developments, mitigation of these problems will serve as the only vehicle for protecting the real estate market and attraction to this island community. A workable protection program would significantly influence FEMA's 10, 30 and 60 year erosion rate estimates which will directly effect construction, insurability and attraction to this area.

HISTORY

These apparent shoreline changes have resulted from various mechanisms influencing the land. Among these, storm wave energy is the most dramatic. Exhibit 1 illustrates the storm surge experienced during Hurricane Carla, 7-12 September 1961, where high water elevations were 8 to 15 feet above mean high water. The wave forces were created by hurricane winds which range between 75 and 125 miles per hour at the eye of the storm. This storm came close to setting a new record highest water level above mean high water for Galveston which was set in August 1915 at 10.1 feet. Where sites are protected by beaches and dune systems, the wave action erodes both as shown in Exhibit 2. The beach can change dramatically during a single storm event by this wave action process. In addition to the wave energy and its impact due to higher water levels, the direction also plays a significant role in the shoreline changing processes. Wave direction can be influenced by tidal changes, wind direction and physical, natural or man-made features. The Gulf Coast is the most susceptible to the highest wind generated waves created by the unobstructed fetch length typical of the open sea. The coast is continually influenced by wind and wave directions which are not normal (perpendicular) to the shoreline. Prevailing condition causes a longshore flow (along the beach) from east to west which carries sediments along with it. Depending on the position of a hurricane, this wind generated wave action can be much more significant during the storm than this normal prevailing condition. This affect, combined with higher surge tides, can erode beaches and dune systems to the point of threatening commercial, public and private developments. Soils are typically classified as fine sands and with very little marine habitat activity that would hold existing submerged features (contours, sand bars, etc.) in place during an extreme storm event. For this reason, the unprotected shorelines are susceptible to the full storm wave energies limited only by the force of the storm.

The Galveston seawall was constructed in 1904 to address the concerns felt after the Hurricane of 1900 "which killed 6,000 people and destroyed 3,600 homes at the island city" [Ref. 5, p.1]. Though this structure has shown good performance in various storms since the seawall construction, the beach has continued to recede. The largest erosion of the seawall beach occurred during the storm of 1915 followed by various cycles of erosion and accretion which resulted in near total loss of the beach between 10th Street and 53rd Street by the year 1934. At this point, a cooperative beach erosion control survey proposed the construction of a groin system between 12th Street and 61st Street. Work continued through 1970 to improve and maintain the seawall and groin field protecting Galveston [Ref. 5, p.25].

Though these projects were essential to protect the city, little has been done to maintain other parts of the island which have also yielded under the force of the major storm events. The recent aerial survey highlights the history of the unprotected beach areas and can be helpful for predicting the future progression of the erosion and accretion process. From this aerial survey and additional field observations, DEC has identified the following sites where new shore protection structures are proposed to be incorporated into the County's shore protection program.

LOCATION	DESCRIPTION
1. Bolivar Peninsula	
Caplen/Crystal Beach	Existing stable dune system occasional beach at auto access points. plus/minus 100 ft. beach replenishment, dune enhancement, and breakwaters
Fort Travis Ferry Landing	Proposed beach replenishment and breakwaters
2. Galveston Island	
61st Street to Pocket Park 1	South end of existing exposed end of seawall, lagoon, significant erosion potential, pocket park structure nearly in front of dune system, proposed beach replenishment, modification to seawall, breakwaters, or seagrass-like fabric

Spanish Grant to 13 Mile Road	Proposed beach replenishment, breakwaters, or fabric
Jamaica Beach to Indian Beach	Proposed beach replenishment, breakwaters, or fabric
Sunbird Beach to San Luis Pass	Proposed beach replenishment, breakwater, or fabric

3. Mainland

Bacliff/Kemah	Ship channel dredging, proposed breakwaters for wetland creation

PROTECTION OPTIONS

For each of the locations where these new shore protection structures are proposed, the facilities will be constructed to complement beach and dune replenishment. The theme of the proposed protection follows a general plan to build-up beach and dune systems to serve as the primary barrier to the forces of a major storm event. The structure's role would complement the beach by reducing the affect of the daily erosion process (to hold the beach in place) and to aid in the energy absorption of the storm wave forces.

To maintain the shoreline given the usual wave climate at a site, the structure would need to limit the erosion effects resulting from longshore drift. This condition occurs at absolute location under consideration and results from non-perpendicular wave direction relative to the shore line. Driven by tidal changes and wind direction, the wave direction may vary form day-to-day or season-to-season. The design of a protection structure must ensure that the longshore drift energy is reduced at the shoreline to negate the associated erosive wave energies.

Storm events magnify this effect with stronger wave forces that approach according to wind direction and magnitude. Since the Galveston area is subject to hurricanes, we can expect the wave direction to vary as the rotational winds move with the storm.

When considering a solution for protecting a given shoreline, we know that there are very few options that can provide consistent and reliable performance for all of nature's variables. Most of the sites under consideration also involve aesthetics since they involve coastal beach fronts which support the tourist trade of the island city. Since these beaches are subject to tourist activities, bulkheads and revetments would not be acceptable. This leaves groins, jetties and breakwaters. Groins and jetties are long structures that project seaward from the shoreline to attempt to trap littoral drift at the shoreline and create an accretion area within its shadow. The existing groin field between 10th Street and 61st Street has shown relatively good performance in front of the seawall, but these structures are not as favorable in swimming areas or where wave direction is close to perpendicular to the shore. More perpendicular wave directions that may occur during a storm could reach the beach without any energy loss due to a groin field. Jetties are more commonly singular structures that protect a specific site usually at channel or tidal inlet where littoral materials are detrimental. For this reason, jetties are not considered appropriate for maintaining or protecting a recreational beach front.

Shore-connected breakwaters, as proposed at the seawall, combine the groin field concept with additional energy dissipation at the seaward end by addition of breakwaters (tees). The concept effectively relocates the littoral zone to the area beyond the ends of the structures leaving a very controlled wave climate in the area between the shoreline and the relocated littoral zone. Since the construction cost would be relatively high for establishing a system of shore-connected breakwaters, DEC feels that these structures would not be suitable at sites where groins are not already in place.

OFFSHORE BREAKWATERS

Offshore breakwaters appear to be the best solution for the task. They are designed to protect as shoreline on the leeward side of this linear structure which is usually oriented parallel to the shore. Offshore breakwaters have been constructed to protect harbors or erodible shorelines, serve as littoral barrier-sediment traps, or a combined function. Examples of some applications in the United States are included in Exhibit 3. This list is not complete and overlooks Louisiana's 43 breakwater installations protecting Highway 82 on that state's Gulf coastline. Unlike jetties and groin fields, these structures affect longshore transport a secondary condition resulting from their primary objective of reflecting or refracting incident wave energies. The structures require less materials (cost) than the shore-connected breakwater, but the engineer can design for similar results by forming a tombolo behind the structure. If desired, natural accretion can result in growth of the shoreline to the point where offshore breakwater becomes connected [Ref. Exhibit 4]. Tombolos usually disappear during a storm and then build-up again during normal conditions. Though this tombolo affect maximizes the length of shoreline for recreational uses, this may not be a preferred condition along the coastal shoreline on Galveston Island. By allowing more wave energy past the offshore breakwater, tombolos can be prevented and longshore transport can continue between the shoreline and structure. In each case, offshore breakwater will perform the required daily and seasonal beach protection while also aiding energy dissipation of storm waves approaching the shore from any direction.

The key to developing a system of offshore breakwaters centers around understanding to site specific marine environment. If one understands the wave direction, significant wave height and range or periods, tidal variations and existing erosive processes, offshore breakwaters can create very predictable results. Exhibit 5 summarizes U.S. Army Corps of Engineer's recommended logic process for arriving to a design condition. As this logic diagram shows, this is unique for each location. The process attempts to simplify the historical and highly variable conditions at a given site down to one design condition. This condition should approximate the most significant daily and seasonal wave climate which is expected to be erosive to the subject site. Extreme storm events are not included in this assessment since the primary purpose for these structures is to protect or accrete the beaches. Though these structures will aid in energy dissipation during a storm, the storm surge will overtop the breakwater and the beaches will erode as a function of the remaining energy. After the storm, one can expect the shoreline to return to a new equilibrium state where beach naturally accrete to the lee of the offshore breakwater.

The primary application of this the DEC study proposes offshore breakwaters along the Galveston Island coastal shoreline. Historical data is readily available and thorough from the storm of 1900 to present. For the purpose of this study, DEC will focus on the littoral drift from east to west that is considered to be the prevailing condition [Ref. 7, p. 12]. The shoreline within the seawall groin fields is self-evident to the influence of this process. There is evidence of littoral drift between each pair of groins where accretion occurs near the base of each groin. The deposits are weighted toward the west side of each pocket and most of the beach has eroded from the middle. This pronounced concave result could be reduced through offshore breakwaters which could limit the longshore transport to a manageable level and result in a much less pronounced concavity as illustrated in Exhibit 6. Though this concept looks very good from the standpoint of long term beach protection, our current understanding of the costs indicate that breakwaters in the groin field may not be as feasible as expected. With the present-day estimated costs of $5,000 per lineal foot for rubble breakwaters and $300 per lineal foot to replenish today's beach to constant 300-foot width, the initial cost for breakwaters would be substantially higher than for beaches. For example, 600 feet of breakwater structure with 1,500 foot space between existing groins, would be 6.7 times more expensive than beach replenishment. When compared to the needs at other unprotected sites previously noted, this additional cost at the seawall seems unjustifiable. Taking future beach replenishment costs into consideration (with 7% inflation), the cost of breakwater structures would pay for an beach replenishment in 15 years, plus 50 percent of a replenishment 30 years from now. For this reason, DEC is recommending beach restoration within the seawall groinfield. Natural littoral transport and extreme storm events will eventually erode the beach, but a less costly beach restoration program can maintain satisfactory protection for the seawall and Galveston properties.

The expected benefits for offshore breakwaters apply more appropriately where sites are not currently influenced by shore protection structures. As noted by earlier presentations, offshore breakwaters could benefit the west end of the seawall where the erosion process is much more active and threatening. Similarly, public and private developments could benefit from offshore breakwater applications. As we had noted from the aerial photograph, these sites are influenced by their impact on the inherent obstruction of landside; natural dune build-up processes. The dunes will continue to erode in front of these structures until the property is loosed or condemned. The low maintenance aspect of offshore breakwaters can provide long term reliable protection for these relatively remote beach and dune systems.

Offshore breakwaters can be created in several ways. Though rubble mounds are most common in the United States, similar effects have been accomplished by structures consisting of cellular sheet-pile, rock-filled concrete caisson, timber crib, precast concrete units and floating concrete cellular designs [Ref. 1, p. 5-61]. The designs can reflect or deflect all of the incident wave energy with more common solid structures or permeable features can permit some wave energy through the structure. If a wide expanse of shoreline is to be protected, multiple breakwaters can be spaced to accomplish the desired cuspate spit or tombolo effect.

Two of these possibilities, non-permeable rubble mounds and permeable or no-permeable, precast concrete units, are under consideration for Galveston County. Each of these have advantages. Rubble mound breakwaters are permanent structures made from quarry stone or concrete equivalents according to availability of materials. Once in place, this structure has low maintenance cost as seen in the seawall groin field and may other applications here in the United States. The U.S. Army corps of Engineers has studied this type of structures and has published very detailed design guidelines. Initial installation would be started by floating construction methods, then as the structure grows to a suitable size, construction could continue from the top. As recommended by the Corps, a plan would be implemented where the breakwaters are constructed in phases. Careful attention would be paid to the effects at the shoreline, and additional length or additional structures could be added in response to the observations. Transportation and stock piling of material could be accommodated by barge where wave climates permit or as appropriate at a given site.

The precast concrete unit breakwaters follow the same principal but have not been as rigorously studied for long term applications. Two of these systems have been considered for this study:

BEACH PRISMS (TM) - Permeable triangular units available in heights ranging from two to six feet. The precast units are 6 to 8 inches thick and typically tied together into workable 10 foot long units (by post tension cables), then placed end-to-end. Earliest know installation showed good accretion in Queenstown, Maryland, 1986.

BEACHSAVER(R) - Manmade reef designed as elongated triangular units that are placed and interlocked together on wide precast or monolithic foundations. The first application was placed in 1984 on the Long Island south shore (New York). Additional installations have been placed in New York and New Jersey.

These precast units are expected to provide similar performance when compared to rubble structures, but the advantages center around the flexible applications for the structures. Like rubble, the precast units could be transported, stock piled and constructed by a floating operation. The same phasing concepts would apply where initial installations could be surveyed for performance. There is an extra advantage of relative ease of movement if the structure is not in the correct location or if the structure is needed at another site. These structures are expected to be more cost effective than rubble structure, though local suppliers may be limited. Both of these manufacturers provide products that are designed for the marine environment and may be the best alternative for demonstration project in the Galveston area.

CONCLUSION

DEC is recommending that the Gulf Coast regions of Galveston County should be the subject of an on-going maintenance program that mitigates the erosion processes that are detrimental to the local economy. A phased approach should identify sites and implement shore protection structures according to erosion rate, relative cost of expected loss and availability of finds. Establishment of an order from most critical is necessary. We have identified three areas where offshore breakwaters should be considered. These include the west end of the Galveston seawall, the west end of Bolivar Peninsula between Fort Travis and the ferry landing and two subdivisions on the west end of Galveston Island. We can expect physical loss of land and property in the near future. If nothing is done, FEMA's work will stifle any additional development in these unstable areas. These offshore breakwaters will effectively stabilize these area and preserve the land's value and usefulness for the future.

REFERENCES

1. "Shore Protection Manual", Department of the Army, Coastal Engineering Research Center, Volume I and Volume II, 1984 fourth edition, Second printing.

2. "The Marine Environment and Structural Design", John Gaythwaite, P.E., Van Nostrand Reinhold Company, N.Y. 1981

3. "Design and Construction of Ports and Marine Structures", Alonzo Def. Quinn, McGraw-Hill Book Company, N.Y. 2nd ed., 1972

4. "Hurricane Defenses Outline", Engineering News-Record, McGraw-Hill, November 4, 1991

5. "Galveston's Bulwark Against the Sea, History of the Galveston Seawall", U.S. Army Corps of Engineers, October 1981

6. "Working Breakwaters", C.S. Hardaway, Jr. and J.R. Gunn, Civil Engineering, October 1991, pp.64-66

7. "National Shoreline Study, Texas Coastal Shores Regional Inventory Report", U.S. Army Engineer, District Corps of Engineers, 1971

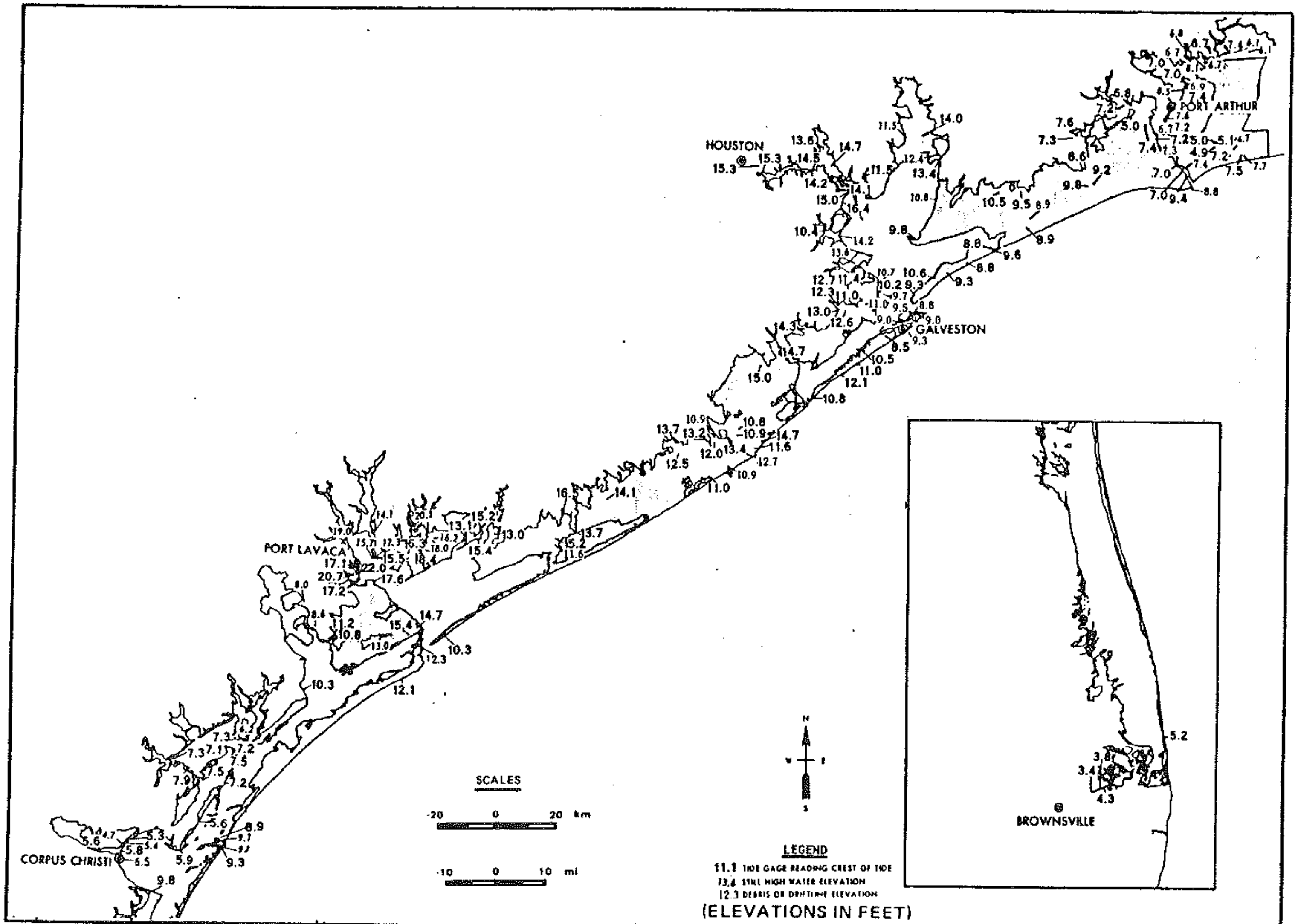


Exhibit 1. High water mark chart for Texas, Hurricane Carla, 7-12 September 1961. (Shaded area indicates the extent of flooding.)

[taken from Ref. 1, Figure 3-55., p. 3-114]

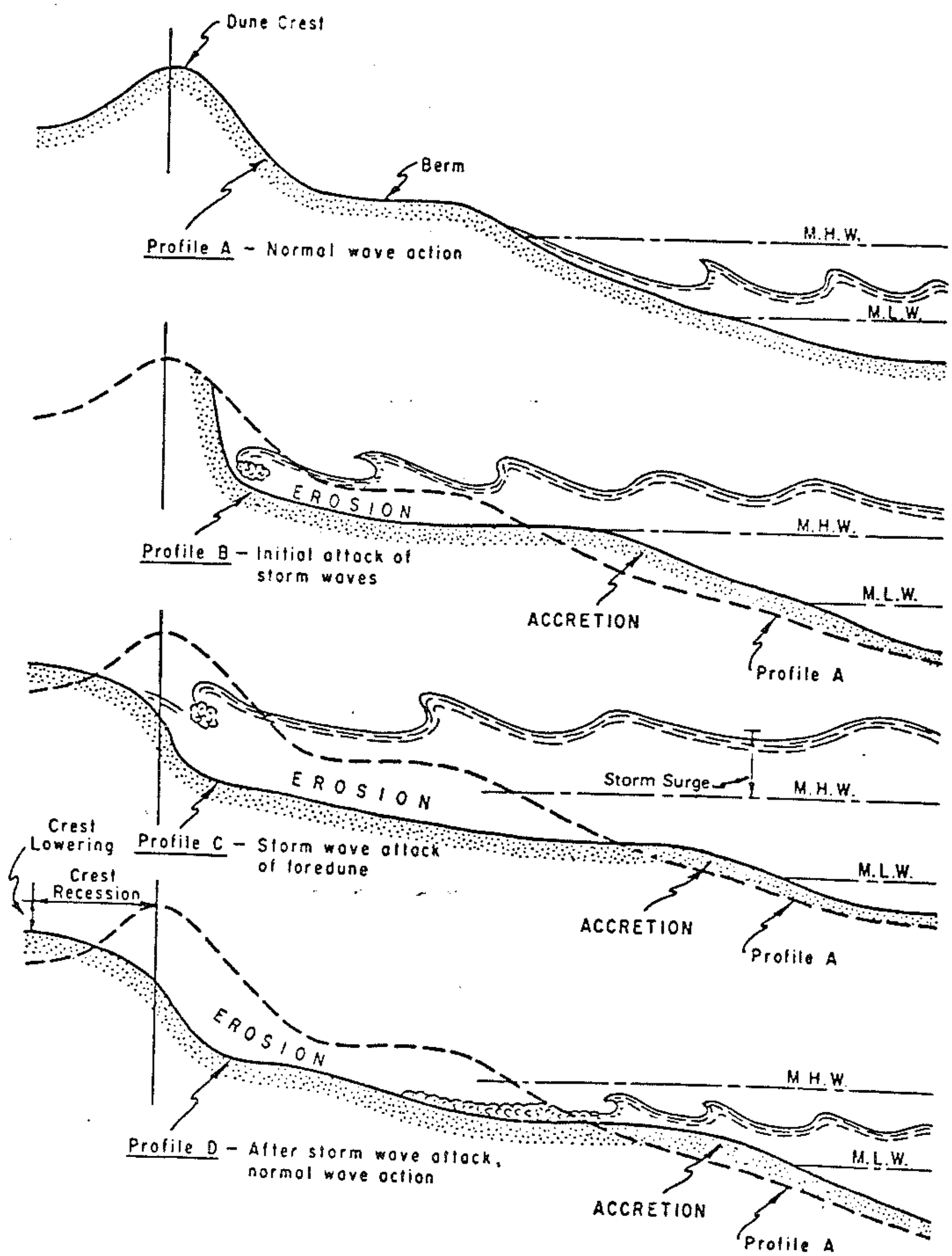


Exhibit 2. Schematic diagram of storm wave attack on beach and dune. [taken from Ref. 1, Figure 1-8, p. 1-12]

Location	Construction date	Purpose	Type	Configuration	Shoreline response
Venice, Calif.	1905	Protect amusement pier	Rubble mound	Single structure; crest elevation: +3.7 meters (+12 feet) MLLW; depth: -1.8 meters (-6 feet) MLLW; length: 183 meters (600 feet); distance offshore: 213 meters (700 feet)	Tombolo connected to structure
Santa Barbara, Calif.	1929	Harbor or refuge	Rubble mound	Originally a single offshore structure; crest elevation: +3.7 meters MLLW; water depth: -7.6 meters (-25 feet) MLLW; length: 434 meters (1,425 feet); distance offshore: 305 meters (1,000 feet)	Tombolo connected quickly; structure extended to shore, 1930
Santa Monica, Calif.	1934	Harbor or refuge	Rubble mound	Single structure; crest elevation: +3.04 meters (+10 feet) MLLW; depth: -7.6 meters MLLW; length: 610 meters (2,000 feet); distance offshore: 610 meters	Periodic dredging has prevented connection of tombolo
Winthrop Beach, Mass.	1935	Shore and seawall protection	Rubble mound	Segmented structure; crest elevation: +5.5 meters MLW; depth: -3 meters (10 feet) MLW; 5 segments 91 meters (300 feet) long; gap size: 30 meters (100 feet); distance offshore: 305 meters	Unconnected feature formed at expense of neighboring shorelines
Waikiki Beach, Hawaii	1938	Shore protection	Rock-filled concrete cribs	Single structure; crest elevation: 0 meter MLW; length: 213 meters; distance offshore: 76 meters (250 feet)	Fill placed which eroded slowly over 8-year period
Lincoln Park, Ill.	1939	Shore and road protection; recreational beach	Steel sheet pile	Single structure connecting the seaward ends of four groins; crest elevation: -1.2 meter (-4 feet) MLW; water depth: -3.7 to -4.3 meters (-12 to -14 feet); length: 457 meters (1,500 feet); distance offshore: 183 meters	Fill placed and held satisfactorily
Channel Islands, Calif.	1960	Harbor entrance protection and sediment trap	Rubble mound	Single structure; crest elevation: +4.3 meters (+14 feet) MLLW; water depth: -9.1 meters (-30 feet) MLLW; length: 700 meters (2,300 feet); distance offshore: 550 meters (1,800 feet)	Large tombolo formed which is periodically bypassed
Haleiwa Beach, Hawaii	1965	Shore protection	Rubble mound	Single structure; crest elevation: +1.5 meters (+5 feet) MLLW; water depth: -2.4 meters (-8 feet) MLLW; length: 49 meters (160 feet); distance offshore: 91 meters	Unconnected tombolo formed
Lakeview Park, Ohio	1977	Shore protection; recreational beach	Rubble mound	Segmented structure with terminal groins; crest elevation: +2.4 meters (+8 feet) low water depth; water depth: -3.0 meters (-10 feet) low water depth; 3 segments 62 meters (205 feet) long; gap size: 49 meters; distance offshore: 76 meters	Series of unconnected tombolos formed
Presque Isle, Pa.	1978	Shore protection; recreational beach	Rubble mound	Segmented structure; crest elevation: +1.8 meters (+6 feet) low water depth; water depth -0.3 meter (-1 foot) low water depth; 3 segments 38 meters (125 feet) long; gap size: 53 and 91 meters (175 and 300 feet); distance offshore 46 meters (150 feet)	Series of smooth tombolos, connected at low water

Exhibit 3. Offshore breakwaters in the United States.

[taken from Ref. 1., Table 5-3, p. 5-62]

Exhibit 4. Breakwater applications in the Chesapeake Bay [Ref. 6. p.65]

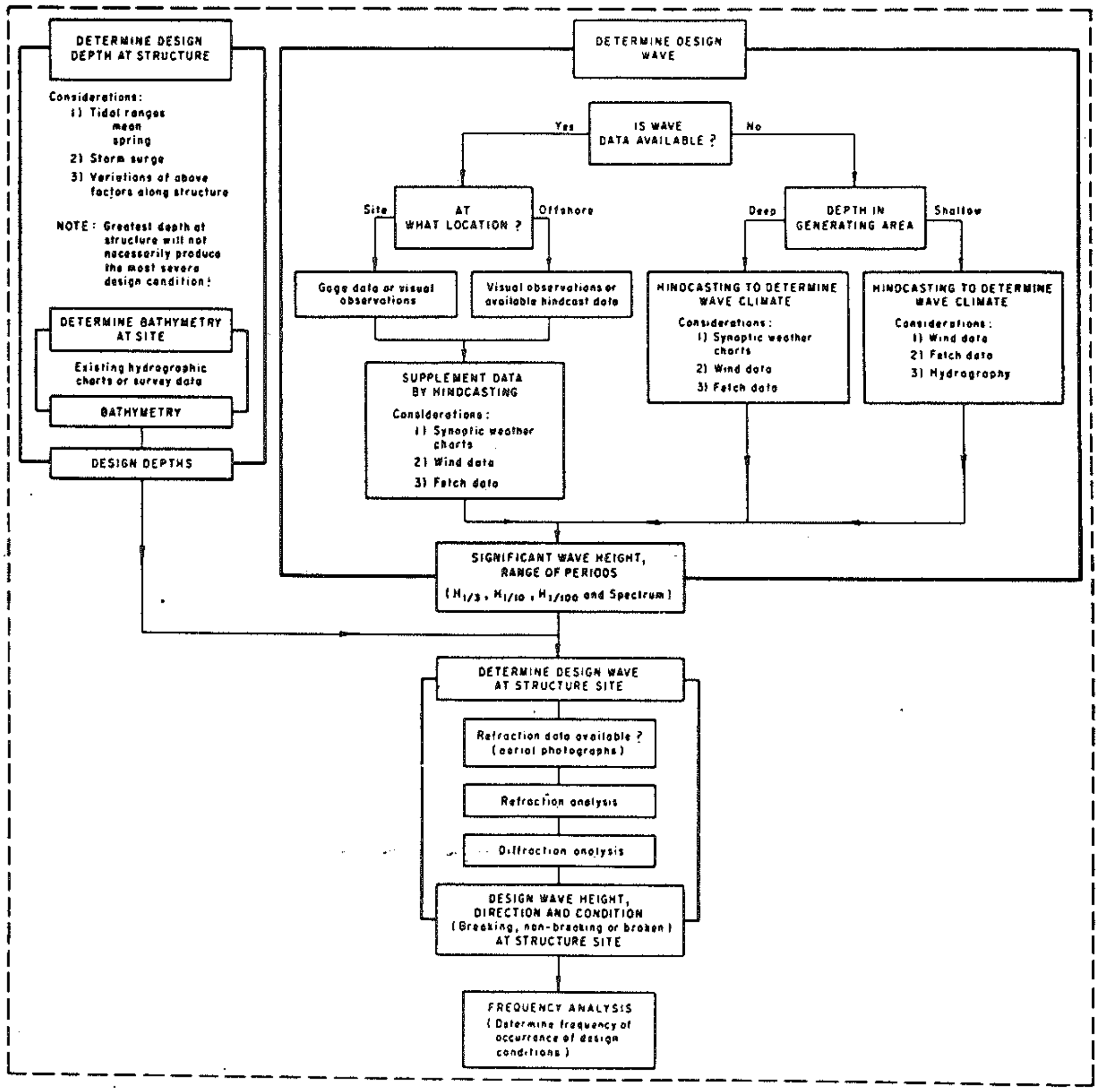


Exhibit 5. Logic diagram for evaluation of marine environment.

[taken from Ref. 1., Figure 7-6, p. 7-17]

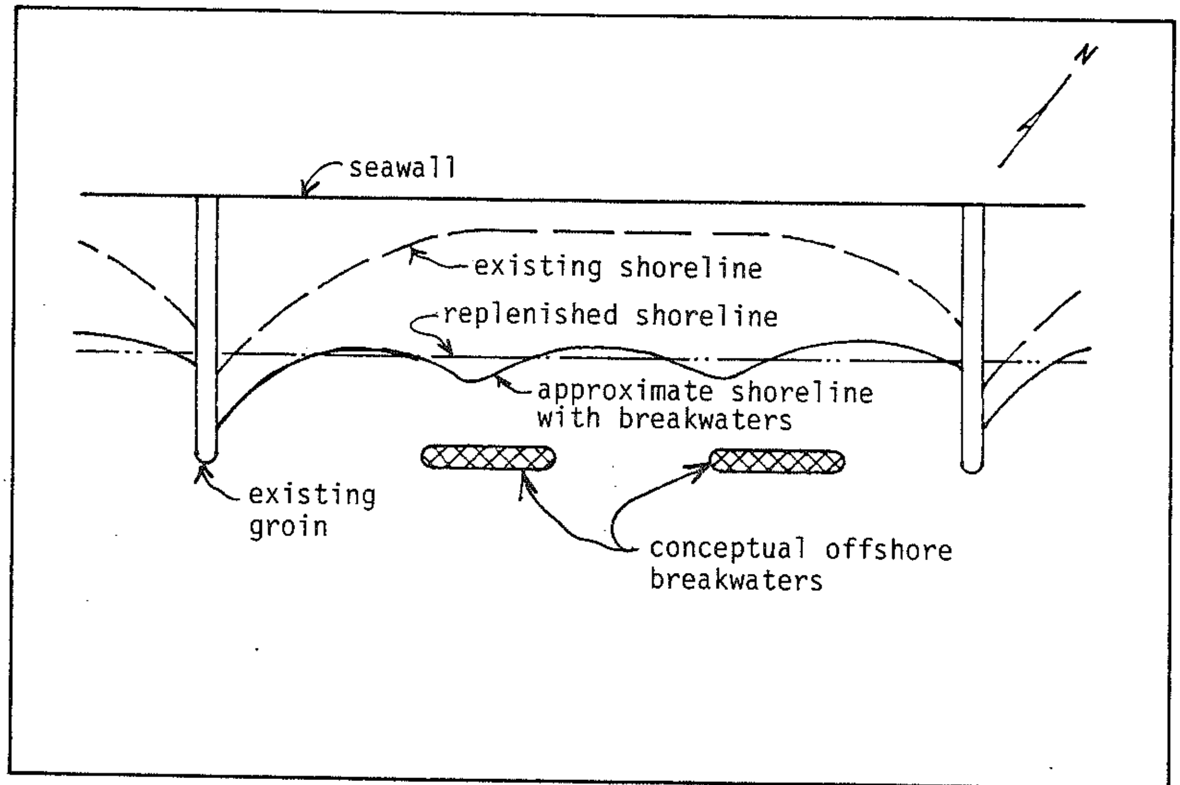


Exhibit 6. Breakwater applications at the Galveston seawall.

DESIGN OF BEACH NOURISHMENT FOR GALVESTON ISLAND

(SEAWALL AND THE WEST END)

By Frank Frankovich

I. SHORELINE MOVEMENT

The Galveston office of the Corps of Engineers, along with the Bureau of Economic Geology, has performed numerous studies along the Texas coast. Each of these studies has indicated that the "prevailing winds along the Texas coast are from the south and southeast. From Louisiana, the coastline extends generally southwest to the coastal bend area of Corpus Christi." Waves generated by the south to southeast winds produce a net littoral transport from northeast to southwest along the upper coast." Frequently during the winter months, and occasionally during other seasons, changes in wind direction reverse the directions of littoral transport for short periods of time. In general, littoral movement of beach and shore material along the gulf shore is interrupted both by artificial structures and by tidal currents through passes between the gulf and inlandbys."(1) See Exhibit "A".(2) The jetties at the entrance to the Galveston Ship Channel (constructed in the late 1880's) have effectively protected the channel from silting. They have also effectively blocked the flow of sediment to Galveston Island, disrupting the littoral process. Though the jetties protect the channel entrance, the channel requires periodic dredging to remove sediments which are carried in from the gulf and out from the bay. In the past, this dredge material has been disposed of in the open gulf or used to fill government land on the east end of Galveston Island and Pelican Island. Land on both Galveston Island and Pelican Island have been substantially elevated due to the placement of dredge material. Tidal currents in and out of the bay have caused an accretion of sediment on the north side of the jetties known as Big Reef. The specific reason for the buildup in the Big Reef area has not been identified, but substantial material is being trapped at this location.

II. PROBLEM AREAS (PRIORITIZED)

Galveston Island can be divided into three basic zones: East Beach, the Seawall, and West Beach. EAST BEACH has continued to accrete since the jetties were constructed in the 1880's. Accretion down drift of jetties is not typical. The classical case of sand movement at an inlet with jetties is for accretion to occur on the up beach and erosion to occur on the down beach. The accretion of sand on East Beach can be attributed to the shoreward transport of dredge material off the south end of the south jetties, and sediment transported from the groin field during seasonal changes and changes in the direction of the wind. Sediments carried shoreward are trapped in an area of no longshore transport which extends from the end of the south jetties to the groin at 10th Street. The seawall was constructed in several sections (see Exhibit "B") (3) from 1902 to 1963. The beaches in front of the seawall have continued to experience erosion since its beginning in 1903 and completion of the wall in 1963. See Exhibit "B." (3) The most significant loss of sand occurred during the 1915 storm. The beaches never recovered naturally from this loss. Continued erosion after 1915 threatened the seawall foundation and provided justification for the installation of the groin field in the 1980's. Since that time, the groin field has held sufficient sand to protect the toe of the seawall under normal conditions. However, the original design intent has not been achieved. The citizens of Galveston in the 1930's wanted a beach 300 feet wide in front of the seawall. A report to Congress justifying the groins' installation identified a 300-foot wide beach as the design intent. A dredge report in the early 1940's indicated that "experience with the existing groin system appears to have been already sufficiently long to warrant the statement that equilibrium has been reached. Although there is available an ample supply of drift sand, the spacing of the groins equal to three times their length appears excessive under the conditions existing at Galveston to arrest a sufficient portion of this sand for the formation of the desired beach and full protection of the toe of the seawall."(4) Beaches in front of the seawall from 61st Street to the end of the seawall have eroded.

Although there is no danger of saltwater exposure to the concrete piling support within this section, there is concern about long term exposure of the steel sheet pile bulkhead at the toe of the seawall. Damage occurred at the base of the seawall during storms in the past. Substantial damage occurred during Hurricane Carla in 1961 when beaches still existed in front of this section of wall. The lack of beach increases the possibility of continued scouring at the base of the seawall which could expose the steel sheet pile wall along the base of the seawall to the salt water. The original groins were steel bulkheading; however, this material failed after 30 years of continued exposure to salt water.

<u>WEST BEACH</u> has continued to recede at an average of "1.8 to 2.6 feet per year." (8) The movement of the beach and dunes landward has created conflict between the Attorney General's Office and local residents. As dunes move inland and encroach on existing subdivisions, the beaches begin to narrow. Though citizens have tried to maintain and stabilize the dune line in front of their homes, structures have been lost to receding beaches. As a result of this inland movement of beaches and dunes, Highway 3005 is vulnerable to storm damage from Pointe San Luis to Bay Harbour and from Sunbird to Indian Beach. Road damage may also occur at each of the 18 dune cuts which allow vehicular access to the beach. These cuts allow unobstructed storm surges to enter the back beach areas.

III. SAND SOURCES

Prior studies and reports have identified adequate sand sources on both the west and east ends of the Island. See Exhibits C and D.(5) The Corps of Engineers, the Bureau of Economic Geology, and Texas A&M University have all identified sand of significant quantities to re-establish Galveston's beaches. Additional testing will be required to verify quality quantities and specific locations of sand sources.

The Corps of Engineers has an active navigational channel dredging program. Every two to three years, the Corps dredges the Galveston channel. Approximately 1.5 to 4 million cubic yards of material is removed and disposed of in the open gulf. Thus, in a ten year period, 15 to 40 million cubic yards of dredged material is lost in the gulf. The Corps estimates that it would take 1,344,000 cubic yards of material to replenish the beaches within the groin field during initial construction. They are currently studying alternatives for using dredge material to replenish beaches with the hope of implementing a program in the 1993 dredge cycle.

IV. BEACH DESIGN

The beaches in Galveston have a consistent slope. See Exhibit E.(6) Factors which must be considered when designing the beach are: "1) littoral movement; 2) beach sand characteristics; 3) characteristics of sand sources; 4) beach berm evaluation and width; 5) wave adjustment in offshore slope; 6) beach fill transition; and 7) location of feeder beach."(7) The Texas coast has a relatively mild wave tidal curve with variation ranging on the average of two feet. The cycle of re-nourishment is reduced to 10 - 12 years depending primarily on storm cycles. The Corps of Engineers is currently testing sediment within the channel to determine the quality and quantity for beach nourishment. The Corps report of 1985 indicated a typical restored beach section in front of the seawall and on West Beach (see Exhibits E and F) and recommended that the material be transported by truck to the groin field. DEC recommends that a wider backbeach and foreshore be installed and that the material be transported by dredging. The increased backbeach and forebeach will provide additional shoreline flood protection and recreational benefits.

The primary movement of sand is from northeast to southwest. Therefore, the placement of sand within the groin field will result in the movement of this material to the southwest or to West Galveston Island. The groin field will act as a feeder beach until other replenishment phases of the plan can be implemented. Ideally, a feeder beach should be created at the end of the seawall, allowing sediment to move each direction depending on winds and seasonal changes. A feeder beach at this location will protect the end of the seawall from flanking and will feed the West Beach area which relies on a natural system for storm protection.

V. PROJECT PHASING

Dannenbaum Engineering Corporation recommends that the beaches on Galveston Island be renourished in the following five phases: Phase I - in front of the seawall from 10th Street to 61st Street; Phase II - 61st Street to the west end of the Seawall; Phase III - Spanish Grant Subdivision to Galveston Island State Park; Phase IV - Galveston Island State Park to Indian Beach; and Phase V - Sunbird Beach to San Luis Pointe. In addition to beach replenishment, we recommend that dunes be installed on the beach in front of the Seawall and landscaping be planted to soften the hard structures in these three highly visible locations. (See Exhibits F and H.) Dunes should also be rebuilt on the west end of the Island where the dunes have been breached for vehicular access and by prior storms. If vehicular access is necessary to provide public parking, cross over ramps should be installed over the dunes to provide storm surge protection.

VI. CONCLUSION

Unless some replenishment action is taken to better manage the sediment resources within Galveston County, we will continue to see our beaches erode. Better utilization of our sand resources can provide continued storm surge protection for existing structures. A management system will protect existing structures and thereby maintain and strengthen the County's tax base. We hope the city, county, state and federal governments will work actively in the future to protect Galveston County's number one natural resource - its beaches.

BIBLIOGRAPHY

(1) *National Shoreline Study, Texas Coastal Shores Regional Inventory Report* by U.S. Army Corps of Engineers, Galveston District, 1971.

(2) *Gulf Shoreline of Texas: Processes, Characteristics, and Factors in Use*, by J. H. McGowen, L. E. Garner and A. H. Wilkinson, Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas, 1977.

(3) *Rehabilitation of Galveston Groins*, Design Memorandum No. 7, U.S. Army Corps of Engineers, Galveston District, May 1967.

(4) *Report on Galveston Bay, Texas, for the Reduction of Maintenance Dredging*, U.S. Army Corps of Engineers, Galveston District, Vol. 1 of 3, May 15, 1942.

(5) *Galveston County Shore Erosion Study*, U.S. Army Corps of Engineers, Galveston District, 1985.

(6) *Shoreline Changes on Galveston Island*, Bureau of Economic Geology, University of Texas Austin, Texas, 1977.

(7) *Shore Protection Manual*, Department of the Army Coastal Engineering Center, Volume I and Volume II, 1984, Fourth Edition, Second Printing.

(8) *Shoreline and Vegetation - Line Movement*, Texas Gulf Coast, 1974 to 1982, Bureau of Economic Geology, Jeffrey G. Paine and Robert A Morton, University of Texas at Austin, Austin, Texas, 1989.

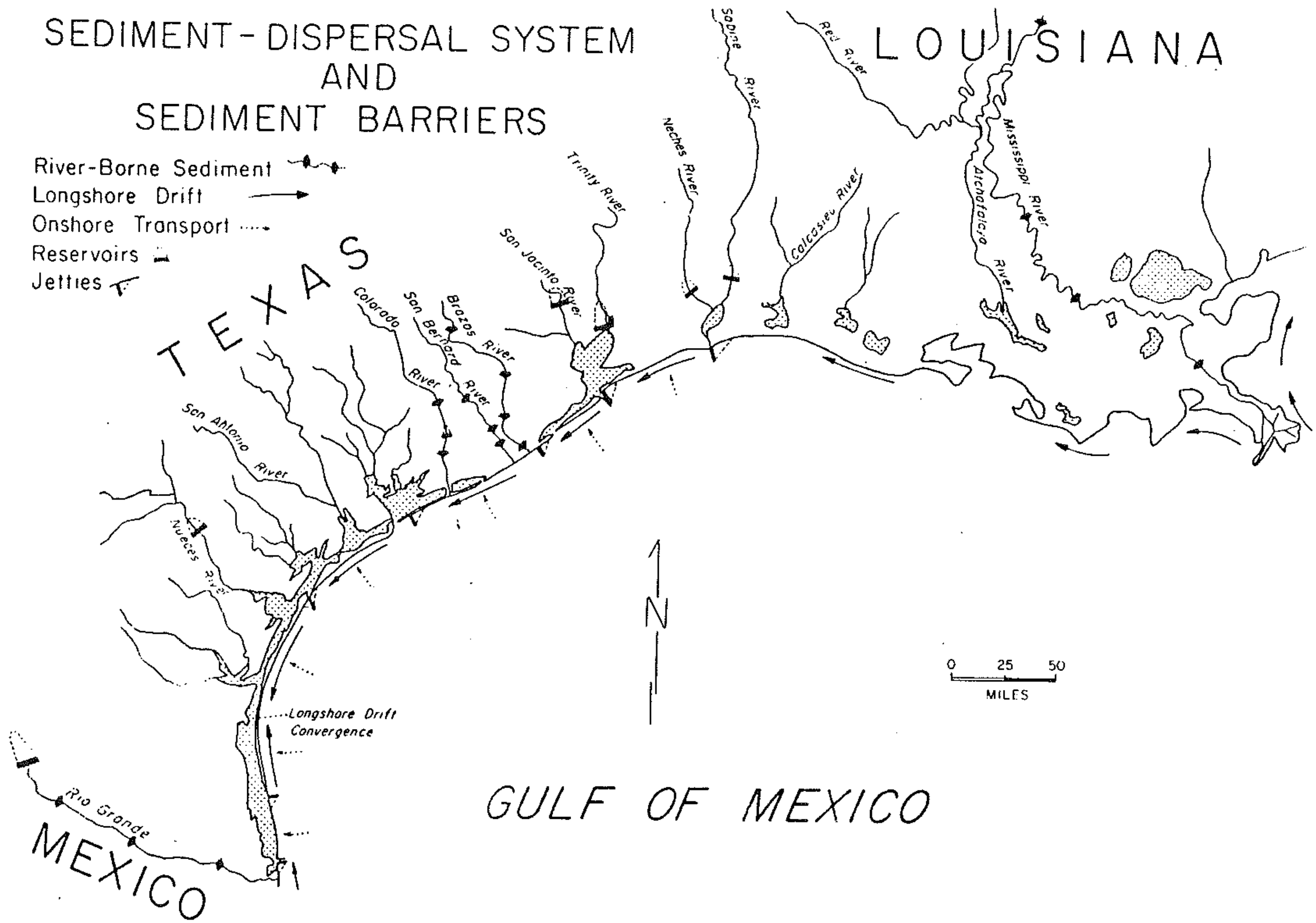


Exhibit "A" - "Sediment Dispersal System and Sediment Barriers"
(Taken from Ref. 2, Fig. 17, Pg. 21)

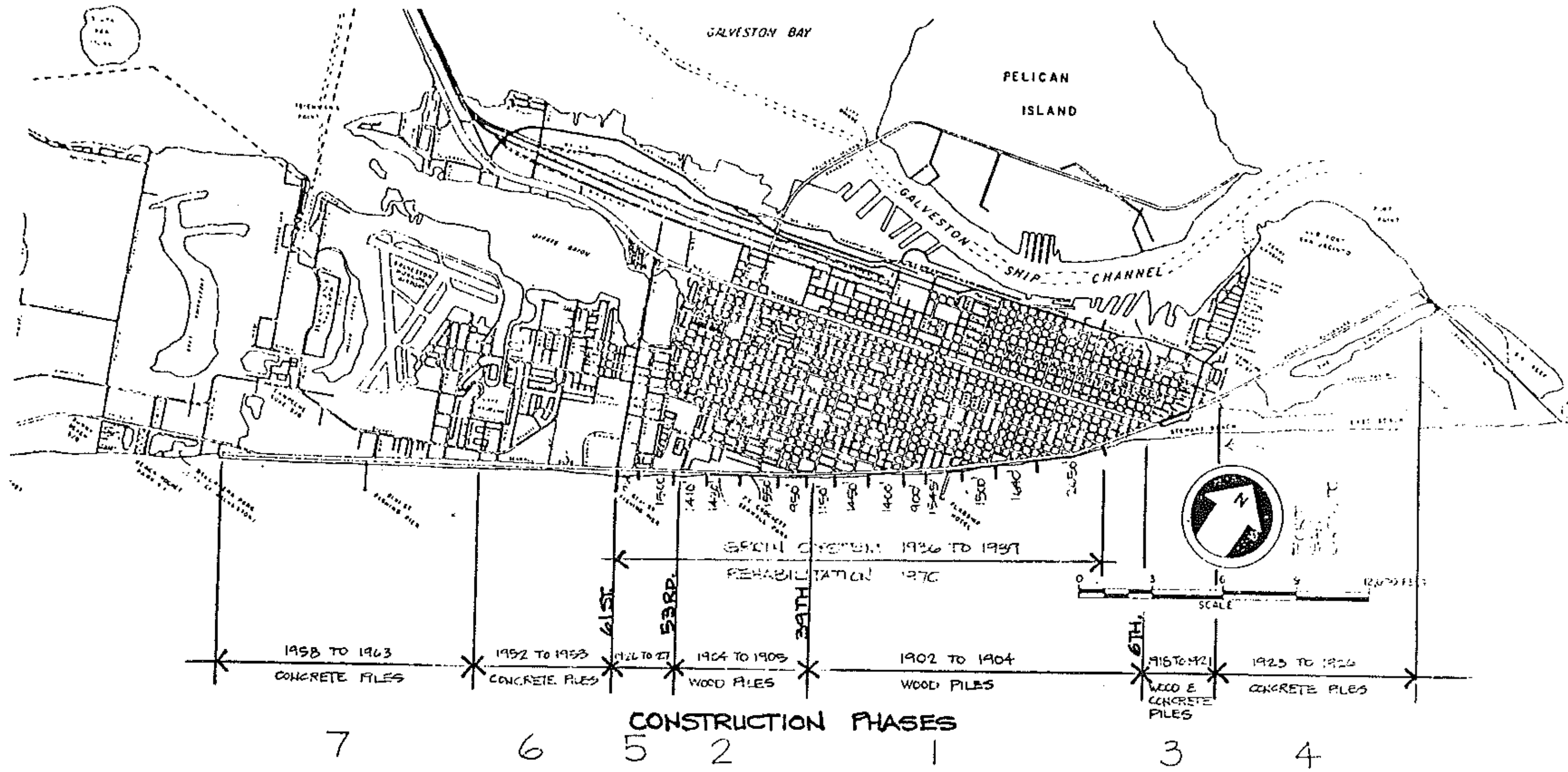
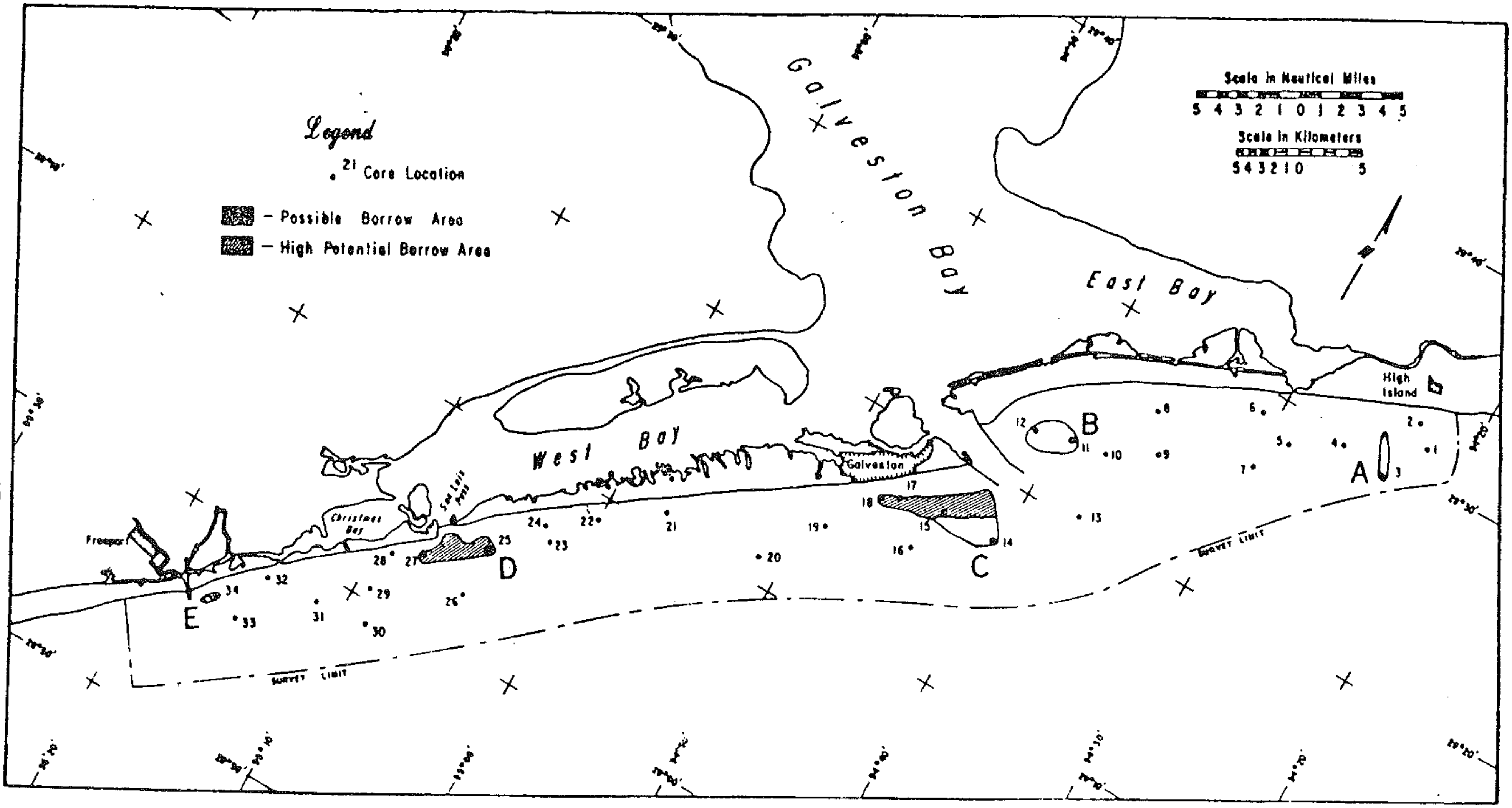


Exhibit "B" - "Seawall and Groin Construction Schedule"



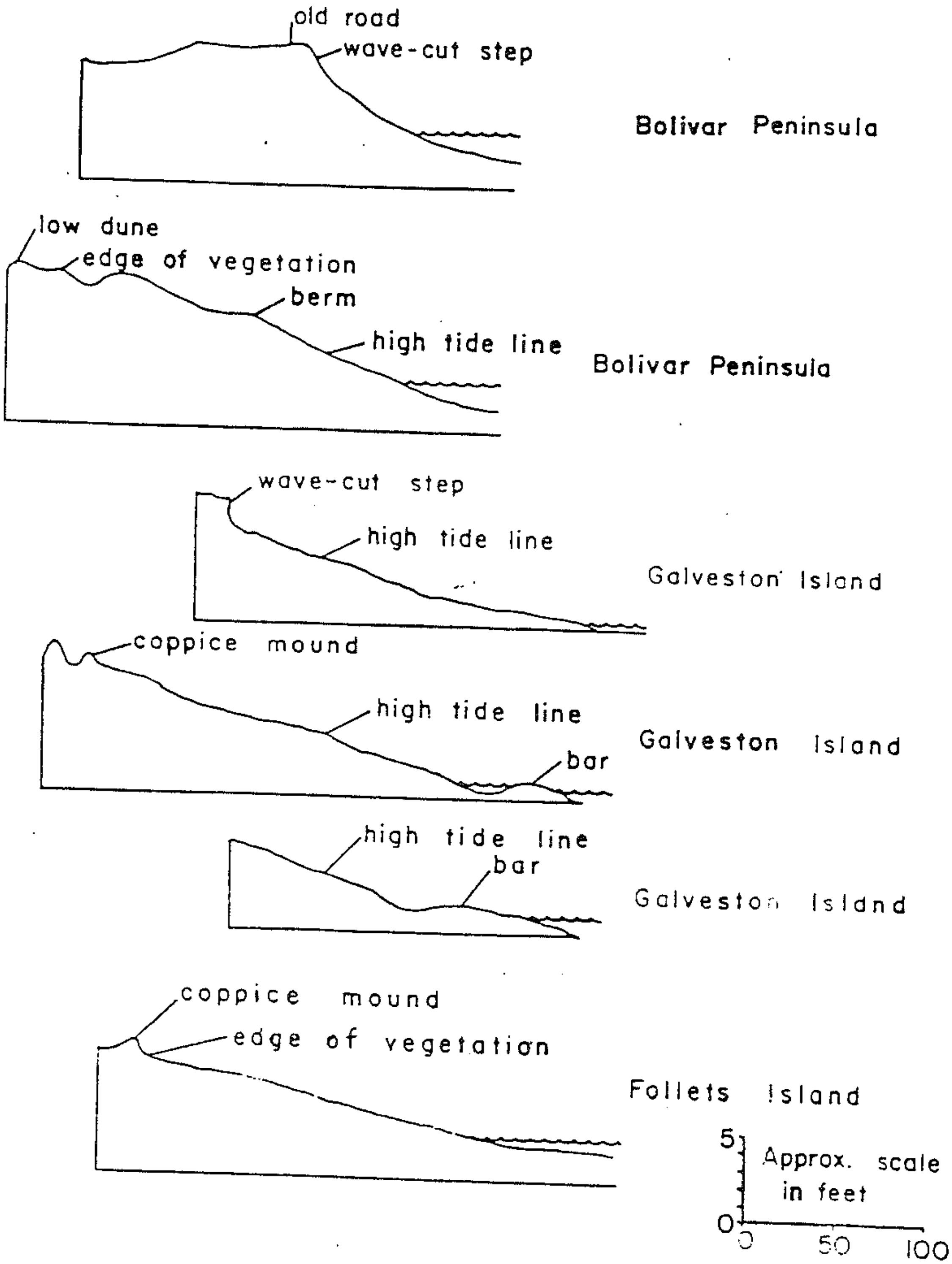
MAP OF FIVE POTENTIAL OFFSHORE BORROW AREAS

Exhibit "C" - "Map of Potential Offshore Borrow Sites"
(Taken from Ref. 5, Fig. 44, Pg. 142)

CHARACTERISTICS OF POSSIBLE OFFSHORE BORROW SITES

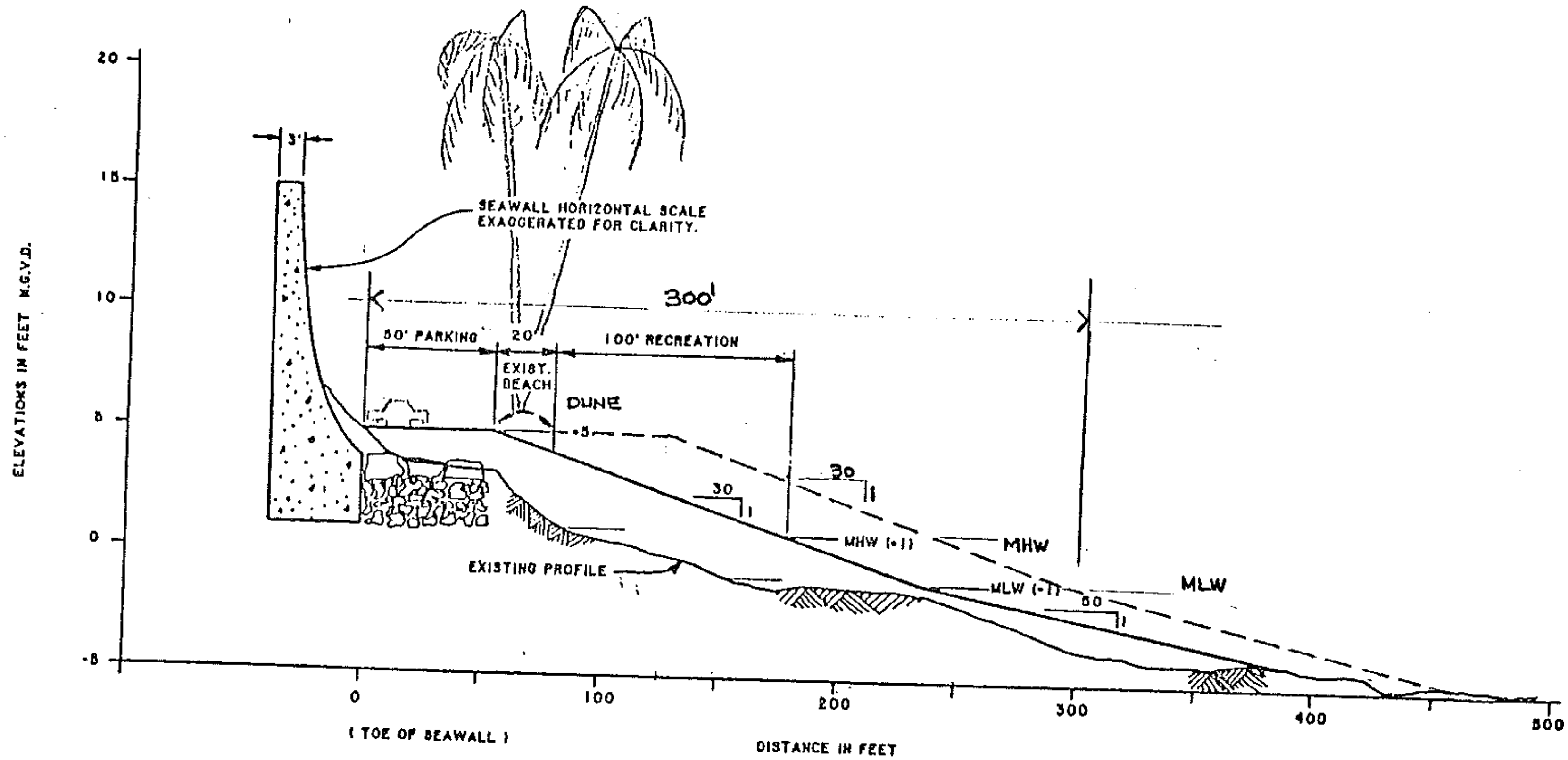
Designation	Core Number	Water Depth (ft)	Thickness (ft)	Mean Grain Diameter (mm)	Standard Deviation (phi units)	Mud Overburden (ft)	Area ($10^6 ft^2$)	Estimated Volume ($10^6 yds^3$)	Remarks
Offshore High Island (Site A)	3	20-33	8-27	0.11 to 0.16	0.5 to 1.0	None	31.2	8.9	Sand is interbedded with mud as channel fill. Buried 20-inch gas line crosses site.
Offshore Bolivar Peninsula (Site B)	11	18-28	6	0.16 to 0.23	0.42 to 1.04	4	106.6	12.9	Sand in core 11 occurs as basal channel fill and Pleistocene erosion surface. Sand in core 12 occurs in two layers separated by 3 feet of mud and sandy mud.
	12		3	0.16 to 0.23	0.50 to 1.39	3			
Offshore South Jetty (Site C)	14	18-32	7	0.12 to 0.19	0.51 to 1.06	None	297.1	26.9	Sand in core 14 is interbedded with muddy sand in dredge disposal area. Sand in core 15 occurs in two layers separated by 5 feet of mud and sandy mud. Sand and cores 17 and 18 is interbedded with muddy sand.
	15		2	0.12 to 0.19	0.53 to 1.02	1			
	17		18-30	0.13 to 0.17	0.40 to 0.81	2			
	18		13	0.10 to 0.16	0.43 to 0.78	None			
San Luis Pass Ebb Tidal Delta (Site D)	25	5-30	5-30	0.13 to 0.24	0.37 to 0.60	None	135.6	30.3	
	27			0.15 to 0.17	0.57 to 1.24	None			
Offshore Freeport (Site E)	34	18-23	8	0.10 to 0.12	0.61 to 0.88	1	8.6	2.7	Muddy sand in core 34 possibly part of the relief Brazos River Delta.

Exhibit "D" - "Characteristics of Possible Borrow Sites"
(Taken from Ref. 5, Table 10, Pg. 143.)



TYPICAL BEACH PROFILES FROM :
MORTON (1974, 75) & MORTON and PIEPER (1975)

Exhibit "E" - "Typical Beach Profiles"
(Taken from Ref. 6)

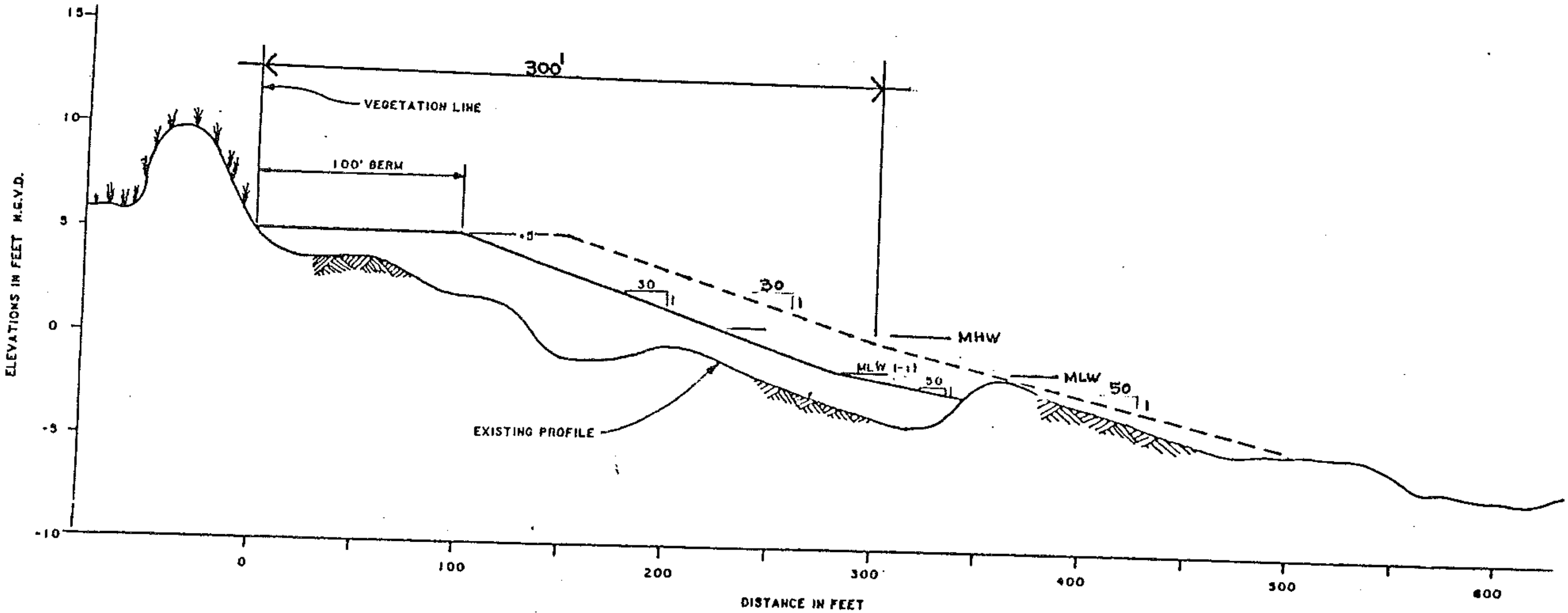


TYPICAL GROIN FIELD PROFILE

GALVESTON COUNTY SHORE EROSION STUDY

GROIN FIELD PROFILE

Exhibit "F" - "Typical Groin Field Profile"
[Taken from Ref. 5, Fig., 53, Pg. 200]
Modified by Dannenbaum Engineering Corporation



TYPICAL WEST BEACH PROFILE

GALVESTON COUNTY SHORE EROSION STUDY

WEST BEACH PROFILE

Exhibit "G" - "Typical West Beach Profile"
[Taken from Ref. 5, Fig., 56, Pg. 204]
Modified by Dannenbaum Engineering Corporation

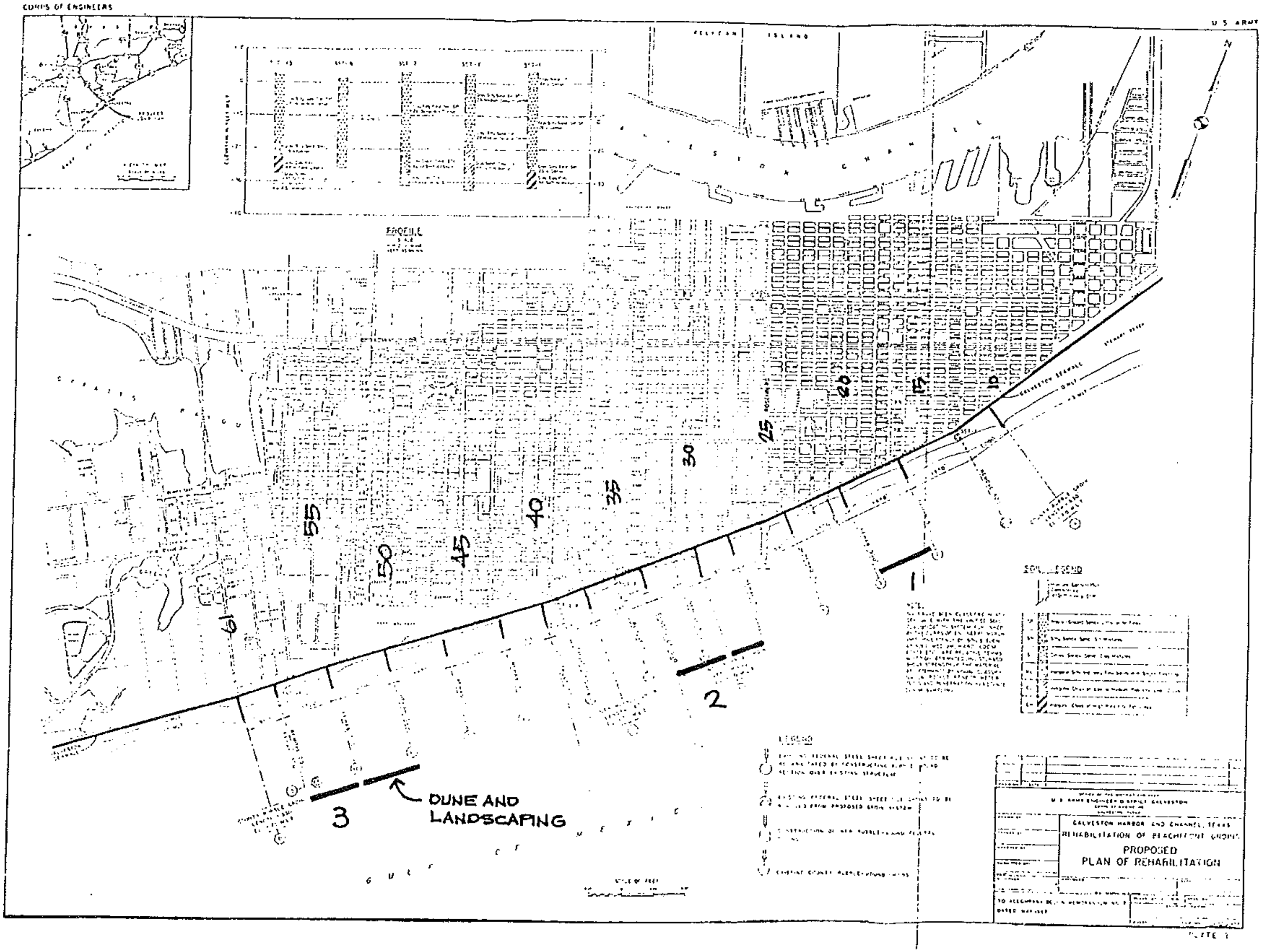


Exhibit "H" - "Dune, Landscaping, and Parking Locations"

ALTERNATIVE SAND SOURCES FOR BEACH NOURISHMENT

by, Mark E. Leadon[1] and Y. H. Wang[2]

ABSTRACT: Beach nourishment has evolved over recent years as the preferred solution to beach erosion problems along developed coastal shorelines. Extensive beach nourishment projects have been conducted in the U.S. and have proven successful, such as at Miami Beach, Florida. Borrow source material for nourishment is generally obtained from offshore sites, tidal inlets and associated shoals, or from inland sand deposits. Selected borrow sites are based on consideration of availability, cost and quality of the borrow material. This paper will focus on these selection considerations with particular reference to Galveston Island. Retrieval of sand resources lost from beaches into inlet-related shoal systems generally provides a high quality sand for beach nourishment. Consideration should be given to the effect of sand excavation from inlet shoals on natural sand bypassing at the inlet to adjacent shorelines.

---

[1]Professional Engineer Administrator, Florida Division of Beaches and Shores, 3900 Commonwealth Boulevard, Tallahassee, Florida 32399

[2]Professor, Department of Maritime Systems Engineering, Texas A&M University at Galveston, P.O.Box 1675, Galveston, Texas 77553-1675

INTRODUCTION

Beach nourishment has been conducted extensively along shorelines of the U.S. and other countries to restore eroded beaches in developed areas to provide storm protection as well as recreational benefits. Beach nourishment consists of the placement of beach compatible sand material from a source outside of the active beach system which is being restored. Such sand placement essentially results in a net gain of sand to the beach system and thus potential for adverse impact to the beach system and adjacent areas is low. The low impact potential exists provided the borrow material for the beach fill does not disrupt another component of the active sand sharing system and provided beach stabilizing structures which may accompany the fill do not disrupt sand transport to areas adjacent to the beach fill project. Successful beach nourishment projects have been constructed in several coastal states in the U.S. such as in Florida. A total of over 50 beach nourishment projects have been constructed in Florida including most of Dade County which contains the Miami Beach project where approximately 15 million cubic yards of sand was initially placed.

A total of about 60 million cubic yards of sand has been placed as nourishment projects in Florida. In addition, about 28 million cubic yards of sand have been placed on beaches as nourishment as a by-product of inlet navigational dredging.

Sand material placed on Florida's beaches has been obtained from various alternative sources. In a couple of cases, it has been economical and feasible to transport sand from inland sand deposits by truck or railcar for beach placement. However, the vast majority of sand has been obtained from offshore sources or, as mentioned, from inlets. In addition to sand obtained from navigational dredging operations, focus has increased in Florida on retrieving sand which has accumulated in inlet shoal systems and become essentially lost from beaches adjacent to the inlets. The quality of sand material contained in inlet shoals is generally found to be of a good quality for beach nourishment. This is understandable since the source of the majority of the shoal material is from adjacent beaches.

The beaches of Galveston, Texas have experienced long-term erosion. Following the devastating hurricane of 1900, the massive Galveston seawall was constructed along the Gulf of Mexico shorefront to protect the city of Galveston from any recurring hurricane assaults. The Galveston beaches experienced some recovery and widening after completion of the seawall. However, in recent years erosion and shoreline recession has occurred along the Galveston shore and throughout other portions of Galveston Island. Erosion control along Galveston Island has become of major importance and beach nourishment through retrieval of lost sand resources is, at least in part, the apparent preferred erosion control solution.

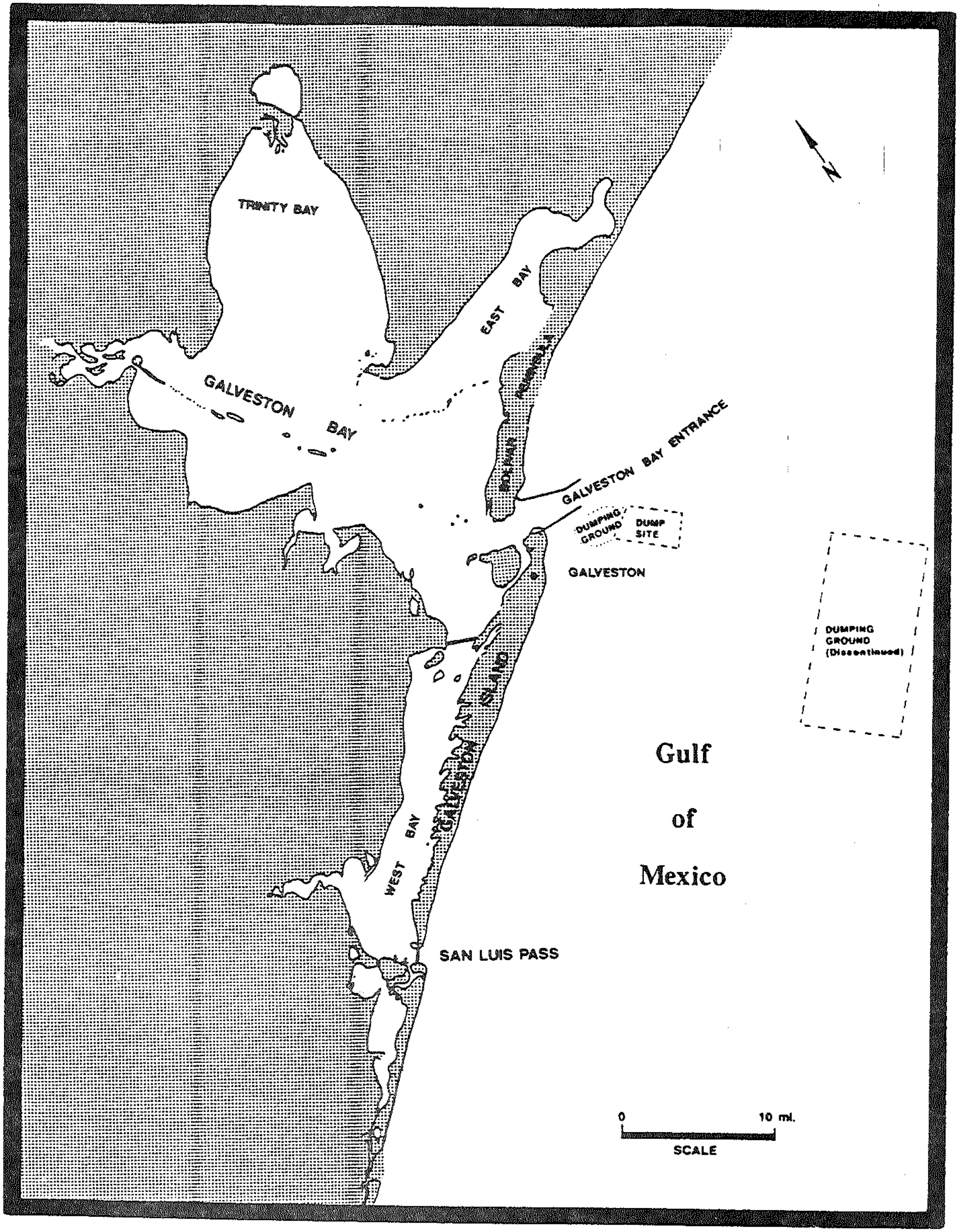


Figure 1. Galveston Island Map Including Nearshore Dump Sites

BEACH EROSION ON GALVESTON ISLAND

Galveston Island is a coastal barrier island of approximately 29 miles in length along the Texas coast and oriented in a northeast-southwest direction. The island is bounded by Galveston Bay and West Bay to the north and west, the Gulf of Mexico to the south and east, and by two tidal inlets at its ends, Galveston Bay Entrance at its northeast terminus and San Luis Pass at its southwest terminus (see Figure 1). The island is extensively developed particularly along its northeasterly end where the City of Galveston is located. The geomorphic behavior of Galveston Island is typical of other barrier islands where erosion losses occur in the middle portions of the island with deposition near ends of the island and into adjacent tidal inlet systems. Erosion problems have been exacerbated by the development along Galveston Island where structures are located in close proximity to eroding shorelines.

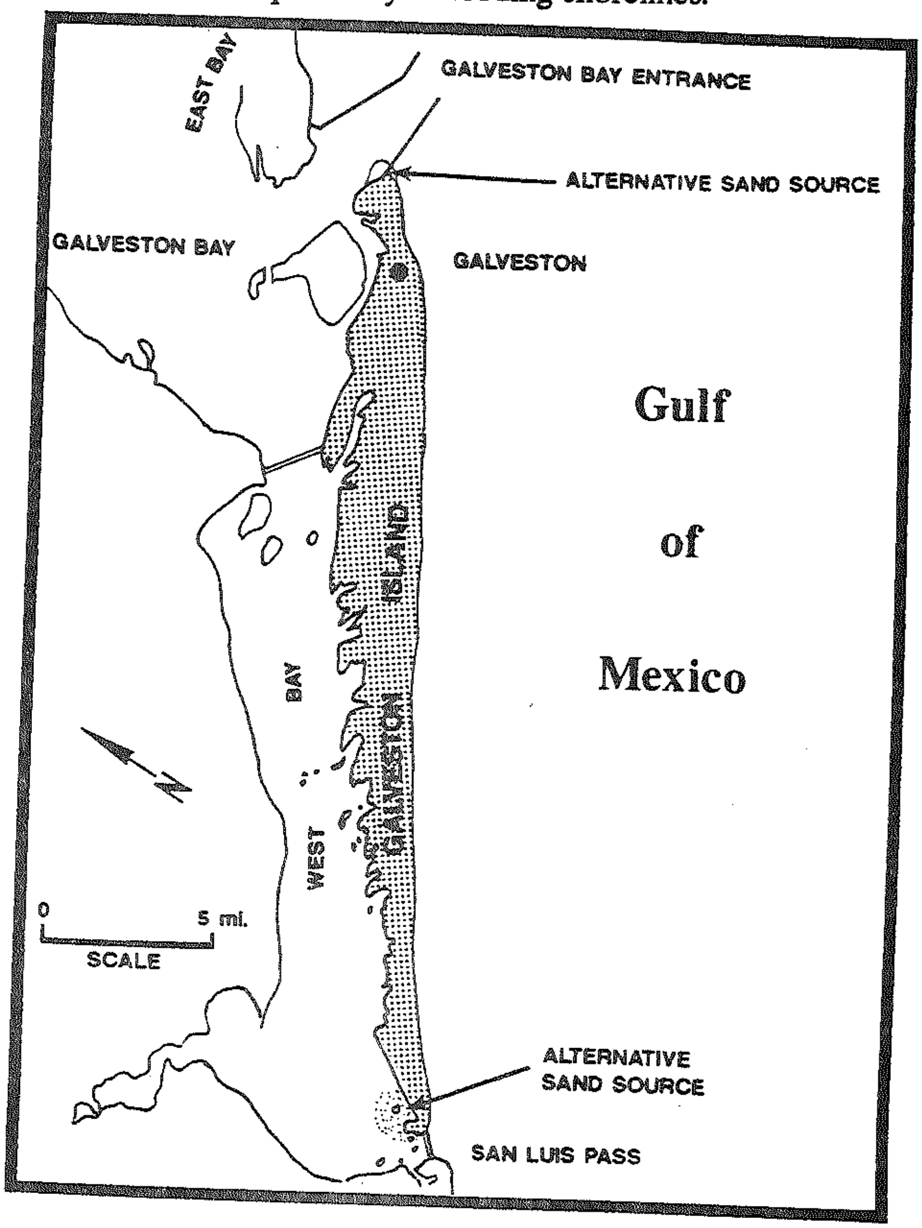


Figure 2. Location Map of Alternative Sand Fill Sources

TIDAL INLET DEPOSITION

In the case of Galveston Island, sand deposition has occurred at the Galveston Bay entrance and at San Luis Pass. Sand deposition at Galveston Bay entrance has occurred adjacent to the northeast tip of the island where sand has transported over and through the rock jetty structure and into the inlet creating a large area of accretion immediately inside the jetty. Sand deposition at San Luis Pass has occurred predominantly into interior flood tidal shoals of West Bay and has created extensive sand deposits over a long time period (see Figure 2).

Galveston Bay entrance is a Federally-authorized navigation channel and has been dredged extensively by the U.S. Army Corps of Engineers. Dredged material from the entrance channel has been dumped into both nearshore and offshore sites. Sand material dumped into these disposal sites by dredging has effectively been lost from the active sand transport system. Although some of the dredged material in the nearshore site may be affected by sand transport mechanisms, the benefit of that material to upland beaches will likely be minimal because of the water depth at which it has been placed. In addition, enlargement of nearshore shoals as a result of the sand dumping may negatively affect adjacent downdrift beaches by altering wave refraction patterns in nearshore areas. Optimum use of the dredged sand would be to return it to neighboring beaches where it will provide the greatest benefit, such as on Galveston Island.

San Luis Pass has not been dredged routinely for navigation. The large deposits of sand contained in the Pass's flood tidal shoals represent sand which has been essentially lost from the active Gulf-fronting beaches of Galveston Island.

FEDERAL DREDGED MATERIAL DISPOSAL REGULATIONS

The Federal dredging regulations require the Corps of Engineers to place dredged material in the least-cost approved disposal site (9). Fortunately, it has often been the case in coastal states, such as Florida, that disposal of dredged sand onto beaches has turned out to be the least-cost alternative. Such cases usually have been in inner channel regions where dredging has been conducted by hydraulic pipeline dredge with direct pumpout capability. Generally, hopper dredges are used in deeper waters which are subject to higher seas. Hopper dredges require additional equipment for pumpout capability which generally increases the cost. Thus, beach disposal from dredging by hopper dredge usually is not the least-cost alternative and necessitates the need for additional funds for beach placement (7,11). Such additional funds for beach placement must be obtained from non-federal sources, such as state and local government.

In Florida, state law provides for state payment of up to 75% of the non-Federal cost of placement of inlet sand onto adjacent beaches (1). The Federal government may provide up to 50% of the added costs for beach placement as a cost sharing effort with the state, provided a favorable report supporting the cost-sharing is obtained from the Corps of Engineers (8,11). It is noted that the Federal government may also consider the adverse impacts that a navigation inlet may have on the beaches of adjacent barrier islands and include an increase in percentage of Federal cost for a shore protection project on an adjacent beach to mitigate the adverse impact (6).

BEACH NOURISHMENT FOR GALVESTON ISLAND

Alternatives to the beach erosion problem on Galveston Island may include a combination of solutions. Such solutions may include increased restrictions on development on the island. However, in locations where the beach has been eroded away and existing upland development provide justification, shore protection projects appear to be necessary. Shore protection projects may involve placement of hardening structures such as seawalls and revetments, or shore stabilization by structures such as offshore breakwaters. Restoration of eroded beaches to provide for increased storm protection and recreational benefits suggest beach nourishment as a preferred alternative.

Beach nourishment in the case of Galveston Island may include a combination of obtaining sand for beach placement from the navigational dredging of the Galveston Bay entrance and the design and implementation of a beach nourishment project for a portion of the island. A major factor in consideration of beach nourishment is the source of material for nourishment. Potential alternative sources of sand for nourishment include offshore sources, some of which have been identified by the Corps of Engineers, and the sand deposits at both the Galveston Bay entrance and San Luis Pass. Consideration must be given in the selection process to the sand quality, cost and environmental impacts of each potential borrow source. Specific studies including these considerations should be conducted for each borrow source in the selection process. The quality of the sand in the inlet deposits is expected to be very similar to and compatible with the native beach sand. In fact, most of this identified inlet sand presumably was derived from the beaches of Galveston Island.

It is generally the case with inlet sand that it is of a coarser grain size and more similar to native beach sand than offshore sand deposits. This is certainly by no means absolute. Offshore sand exploration has resulted in the location of a number of coarse-grained sand deposits in Florida. Likewise some of Florida's coastal inlets have consistently produced finer-grained sand in navigation channels and associated flood tidal shoals. But the trend for inlets to produce the coarser grained sand is apparent. This apparent trend is demonstrated in review of a limited data set depicted in Figure 3 where mean grain size for both inlet and offshore borrow material is compared with that of nearby native beach sands.

The sand contained in the identified deposits at the Galveston Bay entrance and at San Luis Pass should be of a quality very similar to that found on beaches of Galveston Island. It is desirable to obtain a borrow sand material which is the same as, or coarser than, the native beach sand in grain size. The Corps of Engineers has developed methods by which to compare compatibility of alternative borrow sands with the native beach sand (3,9). The overfill of borrow sand vs. beach sand is calculated based on grain size and sorting differences between the native and borrow sands.

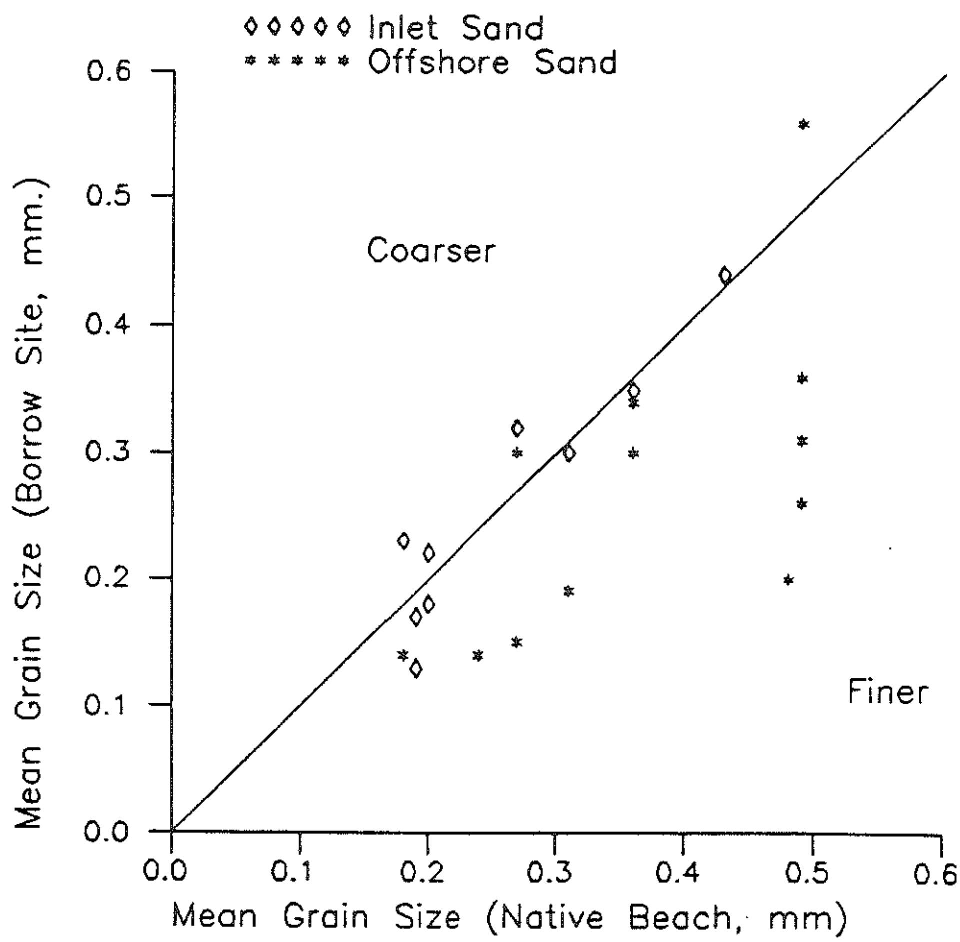


Figure 3. Inlet and Offshore Sand Grain Size Comparison

Dean (2) used the equilibrium beach profile concept as a means of comparing alternative borrow sands with native beach sands. The equilibrium beach profile assumes the form

$$h(y) = Ay^{2/3}$$

where h is elevation, y is distance and A is a scale parameter. The scale parameter decreases with decreasing sediment size. Dean illustrated that a coarser-sized nourishment material produces a greater dry beach width per unit volume of sand. A representation of an illustration from Dean in Figure 4 shows resultant beach widths for varying borrow material grain sizes. The spreading of nourishment fill in the alongshore direction is also affected by sediment size where alongshore losses of fill may be greater with finer size sand.

The cost of use of each alternative sand source must also be specifically studied. There are a number of factors which

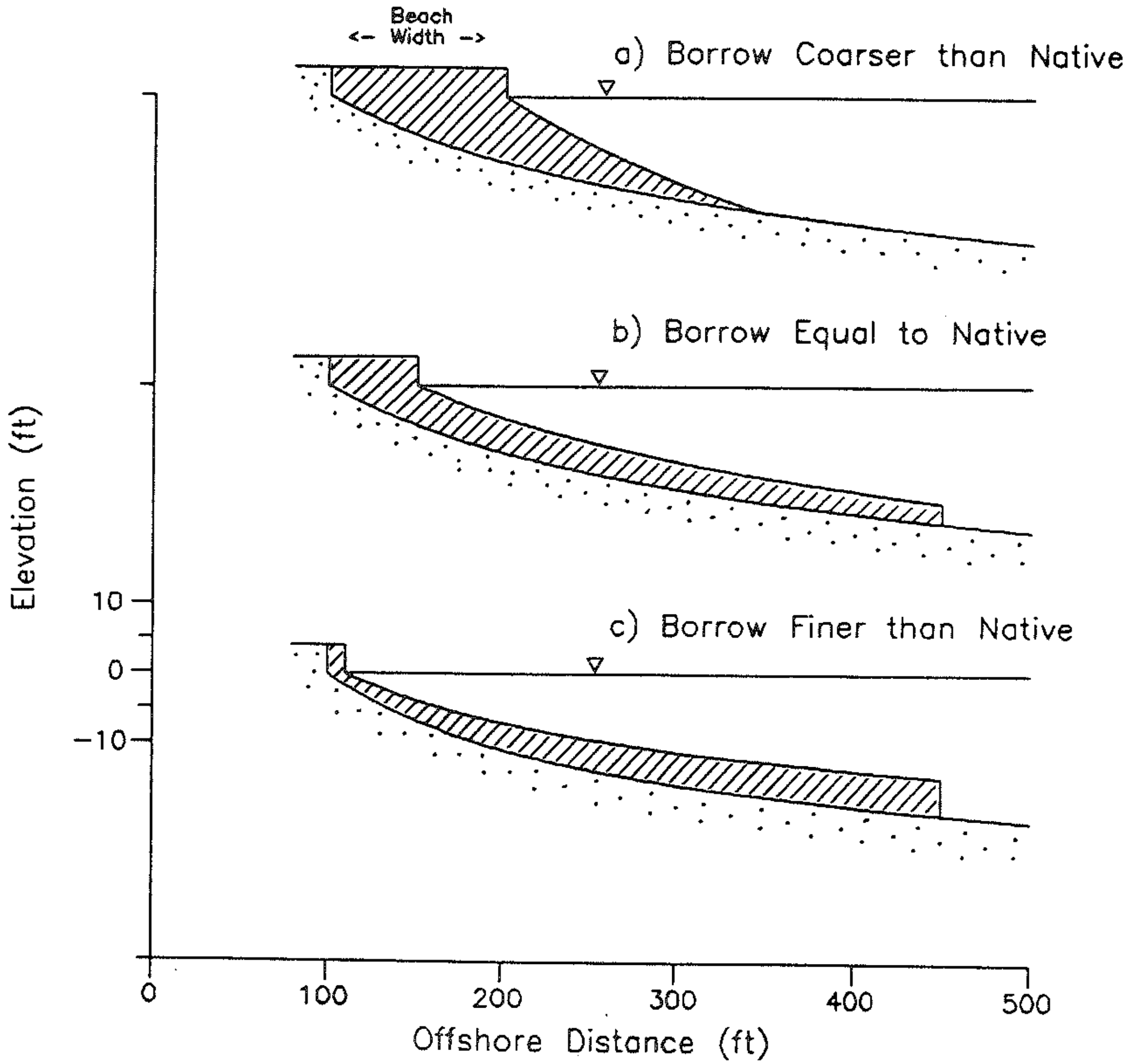


Figure 4. Beach Width Variation with Change in Fill Grain Size (representation after Dean (1988)).

influence the costs of one alternative versus another. Generally, the costs are greatly influenced by the distance from the borrow area to the beach nourishment project site and by requirements for additional dredging equipment, such as booster pumps, etc. A nourishment project may result in a combination of borrow sites, using offshore material from borrow sites which are in reasonably close proximity to the nourishment site and using inlet sand from adjacent tidal inlets. Optimum use of sand dredged from inlet navigational dredging which is in close proximity to a nourishment project site should be incorporated into the project planning and design. Leadon (4) reviewed costs for nourishment from sand obtained from inlet navigational dredging and compared them with costs for nourishment from offshore sources and found the unit cost of nourishment for the inlet sand, in general, to be significantly lower than for the offshore sand. An illustration of such a cost comparison is given in Figure 5. The costs of placement of the inlet sand contained in Figure 5 reflect, in most cases, the added costs for placement of the inlet sand on adjacent beaches instead of in offshore sites. They also do not reflect any Federal 50/50 cost sharing discussed earlier, but only added costs which were provided 100% by non-Federal (State and local) sources.

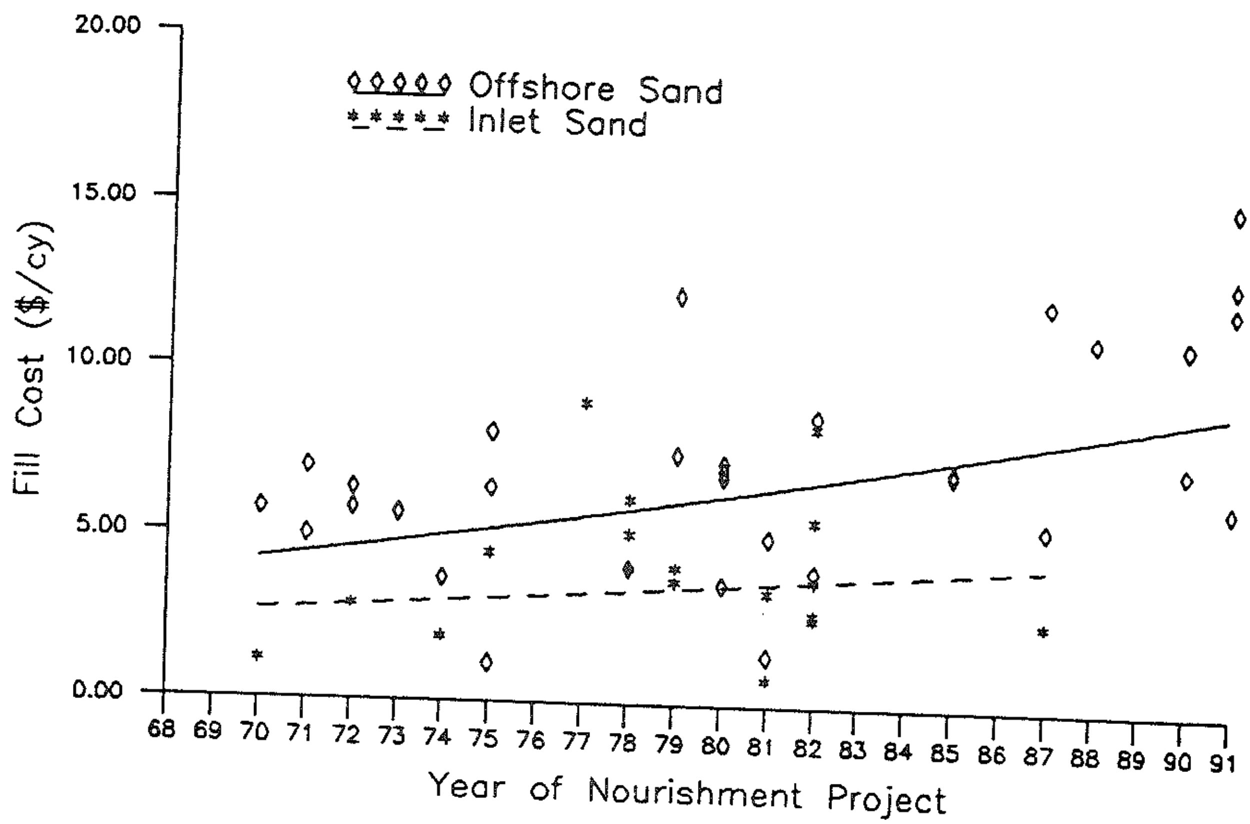


Figure 5. Cost Comparison of Nourishment from Inlet and Offshore Sources

In using inlet sand for beach nourishment, analyses must be conducted to ensure that there is no increased disruption to material sand transport and bypassing processes which may be occurring at the inlet. Such cases have been identified at some of the inlets along Florida's lower east coast, such as Jupiter Inlet, where studies have suggested maximum levels of allowable sand removal from ebb tidal shoals to minimize impact to natural bypassing around the inlets (5).

In both cases of inlet and offshore sand sources, environmental studies must be conducted. Environmental impact considerations may affect viability of use of an identified borrow source for a nourishment project.

CONCLUSIONS AND RECOMMENDATIONS

Beach erosion along portions of Galveston Island have resulted in loss of recreational beach and loss of storm protection to upland development. Beach nourishment would serve to restore lost beach and recover the lost benefits. Review of alternative sand sources for beach nourishment should include analysis of sand deposits at tidal inlets adjacent to Galveston Island, as well as offshore borrow sites. Inlet sand is generally coarse-grained sand which provides good material for beach nourishment. Considerations in the selection of a sand source for nourishment should include availability, cost, quality of the sand and environmental impacts.

Efforts to obtain sand from inlet navigational dredging at Galveston Bay entrance for beach nourishment should be pursued. Cost-sharing with the Federal government for the added cost of placement of the navigational dredging sand on the beach may be available. Overall costs of beach nourishment where sand has been obtained from tidal inlets, including that from navigational dredging, have been lower than for nourishment from other alternative sources. Studies may show this to be the case for Galveston Island.

REFERENCES

1) Chapter 161, Florida Statutes, "Beach Shore Preservation Act."
2) Dean, R.G., "Engineering Design Principles", Short Course on Principles and Applications of Beach Nourishment, Chapter 3, March 22, 1988.
3) Hobson, R.D., "Review of Design Elements for Beach-Fill Evaluation", U.S. Army Corps of Engineers, CERC TP 77-6, June 1977.
4) Leadon, M.E., "Use of Inlet Sand for Beach Nourishment in Florida", ASCE Coastal Zone '83 Conference, Volume III, June 1-4, 1983.
5) Mehta, A.J. and Montague, C.L., "Management of Sandy Inlets: Coastal and Environmental Engineering Imperatives," ASCE Coastal Zone '91, pgs. 628-642, July 1991.
6) PL 90-483, Sect. 111 (Title 33, Sect. 426i, U.S. Code) 1968.
7) PL 94-587, Sect. 145 (Title 33, Sect. 426j, U.S. Code) 1976.
8) PL 99-662, Sect. 933, Water Resources Development Act, Nov. 17, 1986.
9) U.S. Army Corps of Engineers, Shore Protection Manual, 1984.
10) U.S. Army Corps of Engineers, ER 1130-2-307, Oct. 31, 1968.
11) U.S. Army Corps of Engineers, EC 1165-2-142, Dec. 15, 1987.22