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BARRIER ISLAND EROSION AND OVERWASH STUDY - VOLUME 1

By

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16. Abstract

This is the first of a pair of reports documenting the effects of storms on barrier island systems. The present report (Volume 1) investigates storm effects on natural island conditions whereas Volume 2 addresses the effects of seawalls. With the aim of simulating the effects of overwash on barrier islands and characterizing their response, a series of nine experiments was conducted at the Coastal Engineering Laboratory of the University of Florida. The barrier island was simulated by a 400 feet wide (prototype units) horizontal crest and an initially planar (1:19) beach. The effects of various storm surge levels and accompanying overtopping were investigated. Experiments were conducted with both regular and irregular storm waves. Regular waves without overtopping caused the formation of a substantial berm in the swash zone and a prominent longshore bar offshore. Increasing degrees of overtopping resulted in substantial loss of sand from the barrier island system. The longshore bar was considerably more subtle for the highest water level tested (11.5 ft. above mean sea level). Simulation of a storm-surge hydrograph with rising and falling water levels indicated that the presence of the bar tends to occur only during a relatively steady or slowly changing water level. The experiments with irregular waves were conducted with reasonably similar wave heights and carrier periods as those with regular waves. The major difference was in the characteristics of the longshore bar response. In comparison with cases with regular waves, the bar was less distinct without overtopping, subtle with minimal overtopping and absent in cases with substantial overtopping. These experiments seem to indicate that offshore bars are simply break-point bars which require a fairly steady break-point and undertow (return of mass transport) for optimal formation.

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Chapter 1

INTRODUCTION

Barrier islands are long, narrow, low-level offshore islands lying generally parallel to the mainland (Figs. 1.1 and 1.2). Most of the U.S. Atlantic coast south of Long Island and the coast along the Gulf of Mexico is composed of barrier islands. These islands are generally characterized by a beach and dunes on the ocean side, salt marshes and estuaries on the mainland side and are bounded by inlets. Barrier islands are constantly changing their shape, size, elevation and location in response to forces of wind, waves, currents, storms, sea level changes and sediment supply.

1.1 Relevance of study

Gierloff-Emden reported in King (1972) that barrier islands comprise over 13 percent of the world's coastline (see Fig. 1.3). Although they are found in different types of climates and tidal conditions throughout the world, the most extensive barrier island systems occur in the lower latitudes and in coastlines with moderate tidal ranges. The United States has the longest and best developed chain of barrier islands in

Figure 1.1: A view of a barrier island showing sand dunes.

Figure 1.2: A barrier island with vegetation and human habitat.

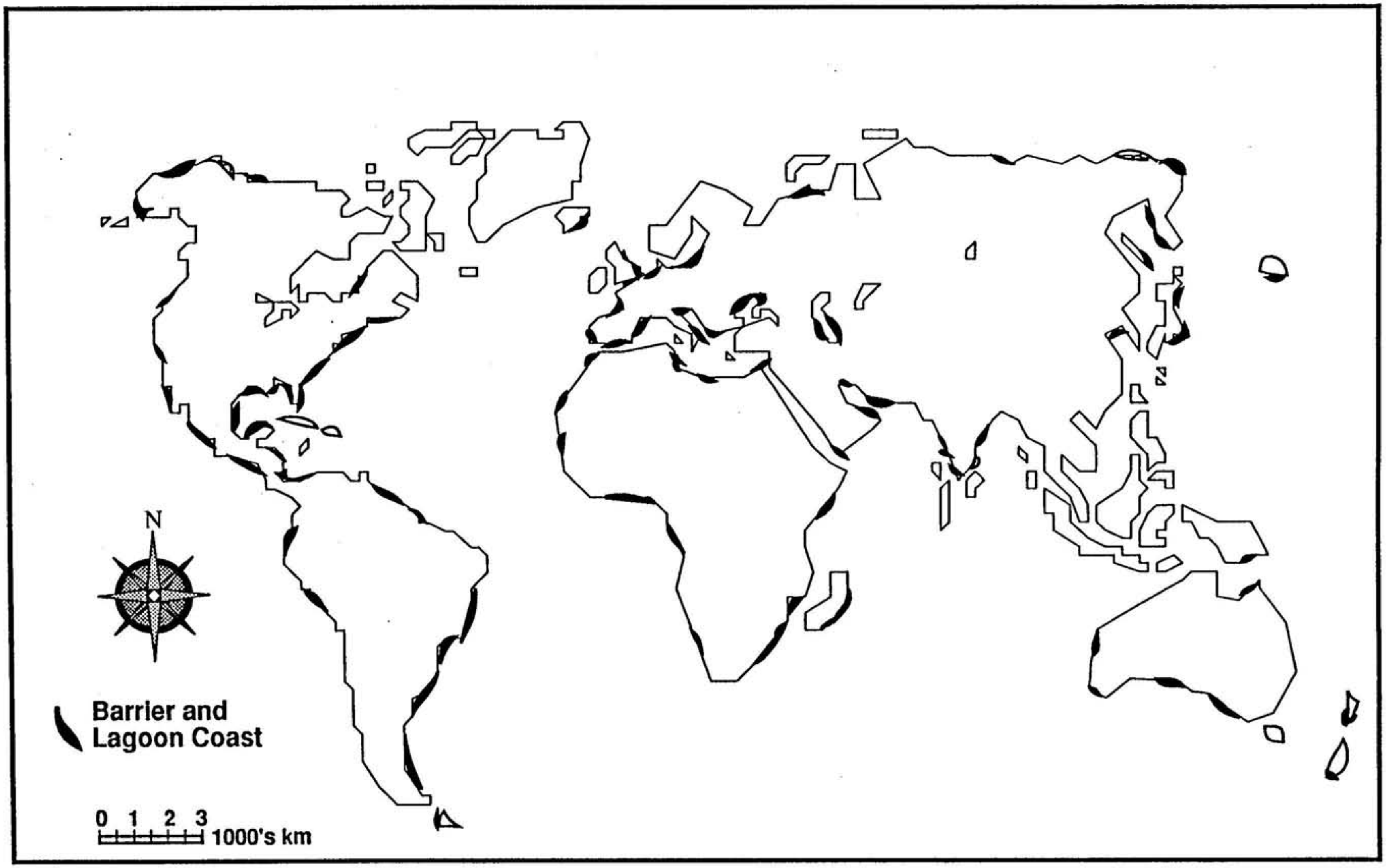


Figure 1.3: Barrier island shorelines of the world (from Gierloff- Emden 1961).

the world. These islands form a major feature of the coastline from New York to Texas. In Florida, barrier islands cover more than 50% of the shoreline. Of all the coastal island types, barrier islands are one of the most unique, dynamic, fragile and vulnerable landforms. During severe storms, barrier islands act as a physical barrier, protecting the mainland and bays behind them by absorbing the brunt of the attack of the waves and storm surges. However, many of the barrier islands themselves are now highly developed human habitats and the protection of their beaches has become a subject of major concern at many locations. For instance, in Louisiana, the barrier island beaches are subsiding at rates exceeding 1 cm per year in some locations. At this rate, some of the existing barrier islands are submerging and becoming ineffective in providing protection to the mainland.

Several field studies have been carried out over the past 50 years to promote the understanding of erosion and overwash processes of barrier islands. However, the relevant coastal processes responsible for the continually changing characteristics of barrier islands are still not fully understood to the extent which would enable making reliable predictions. The work by Williams (1978) is probably the only laboratory study with a focus on "overwash process" as applicable to barrier islands. Additional laboratory studies quantifying the erosion and overwash of barrier islands, including their submergence during storm surge levels, are therefore essential for understanding the basic sedimentation processes involved and for obtaining data on the response of barrier islands to natural and human-related forces. Furthermore, field studies are necessary to validate laboratory results.

Results of laboratory investigations recently carried out at the University of Florida on the erosion and overwash of barrier island are presented in this report. A comprehensive bibliography is given at the end of the report which also includes references to the literature cited in the report. The cases reported here simulate natural barrier islands; a companion report (Volume 2) describes a parallel testing program including the effects of seawalled shorelines. Detailed experimental results are available as separate Appendices.

1.2 Barrier Beaches: Terminology

A barrier beach includes more than just the beach itself. It needs to be considered as a complete system including the beach, dunes, marshes and flats shown in Fig. 1.4. Leatherman (1977a) has suggested a scheme for the classification of barrier islands according to their overall shapes. These categories reflect certain similarities in origin, sea energy, sand supply and tidal range, which affect the geomorphology of barrier islands. Barrier islands are considered as a sub-category of the overall geomorphic category called Barrier Beaches. The three sub-categories are: i) Bay Barriers, ii) Barrier Spits and iii) Barrier Islands. These are shown in Fig. 1.5. This classification mainly describes the geography on the mainland side. Most of the barrier island beaches have characteristics similar to those of the beaches on the mainland. As far as the response of the sea-side beach is concerned, parameters such as sediment size, shell content, vegetation and tidal as well as wave characteristics would be significant for all the barrier beaches.

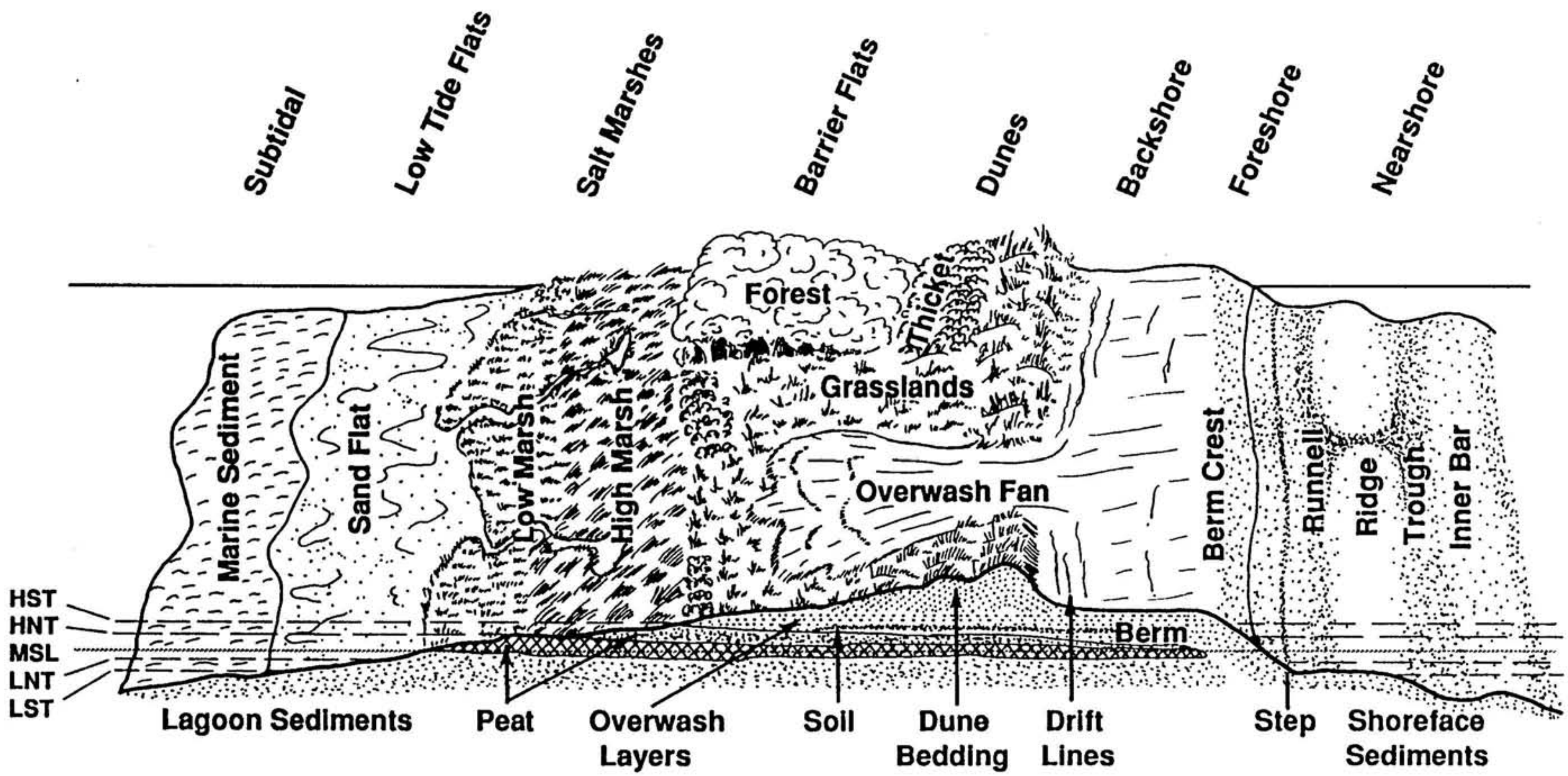


Figure 1.4: **Barrier Beach as a Complete System (Godfrey, 1976).**

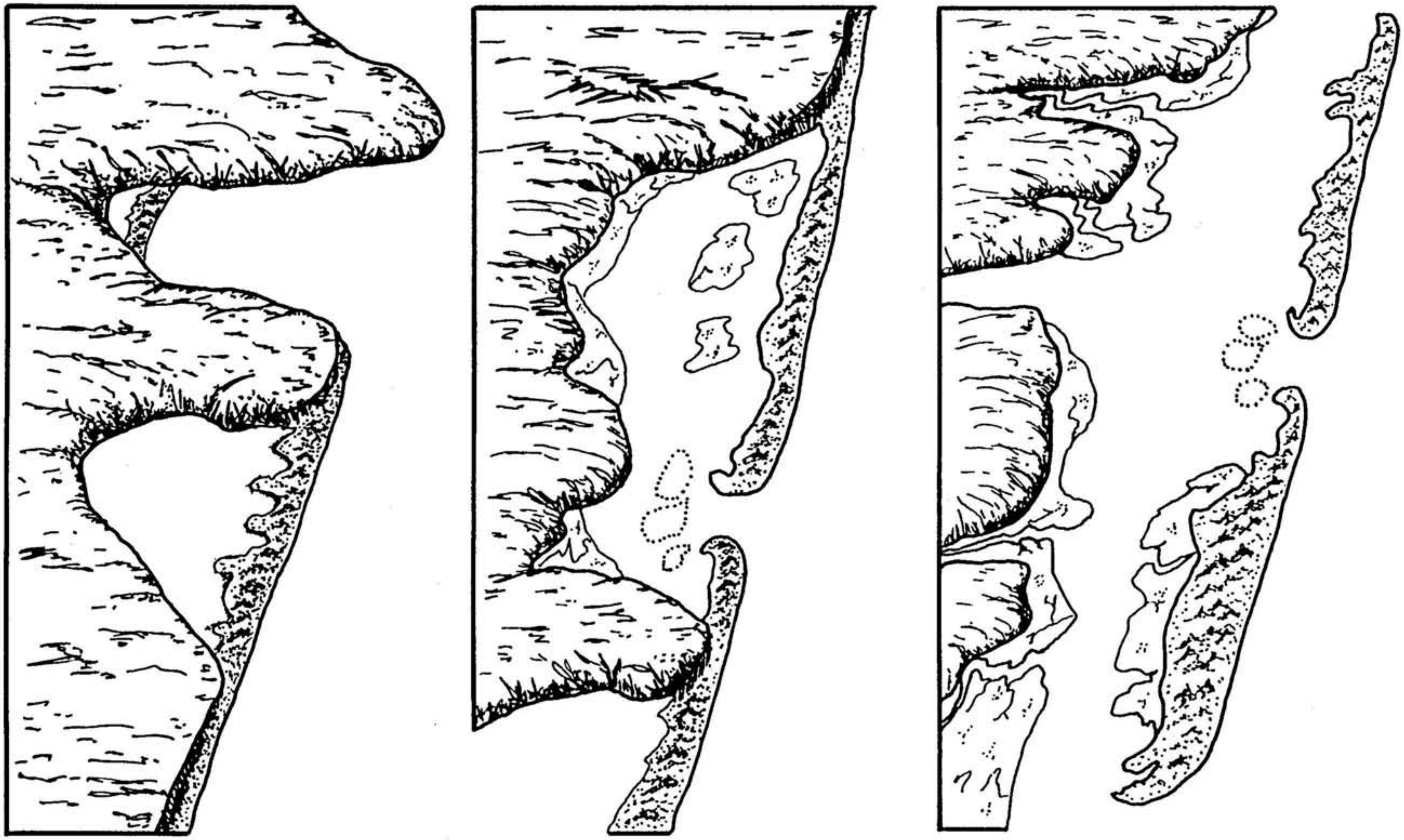


Figure 1.5: **Types of Barrier Beaches: (a) Bay Barriers, (b) Barrier Spits, and (c) Barrier Islands, (Redrawn from Godfrey, 1978).**

1.3 Erosion and Overwash Processes

The National Hurricane Center, Coral Gables, Florida, has estimated the magnitude of the storm surge for Category 5 hurricanes making landfall normal to the shoreline at 20 locations in Florida as shown in Fig 1.6. Hydrographs were predicted with the use of SLOSH model. The estimated peak surge elevation, the rate of rise and the rate of fall of storm surge are presented in Table 1.1. The peak storm surge ranges from 10.5 feet to 26.2 feet. As the maximum crest elevation of most barrier islands typically varies from 5 feet to 15 feet above mean sea level, hence, low-level segments of the islands may frequently get inundated under storm surges whereas beaches with relatively higher crest elevations may experience wave overtopping only under extreme storm conditions.

The continuity of barrier islands is broken by tidal inlets, most of which are creations of nature while some are man-made. Also, natural inlets are sometimes modified for navigation. Barrier islands often form a continuous beach extending, say, 2 miles to 50 miles between the adjacent inlets. The inlets typically have widths varying from 400 feet to 3000 feet. The bay area (i.e., the waterway between the mainland and the barrier islands) is connected to the sea only through these relatively narrow tidal inlets. Hence, there is a substantial phase lag between the bay water level and the rapidly rising sea water level during storms. The differential hydrostatic head could be of the order of 2 to 6 feet depending upon the intensity and duration of storm. If an island is already inundated, this energy gradient alone creates strong currents over the crest of a barrier island from the sea-side towards the bay-side,

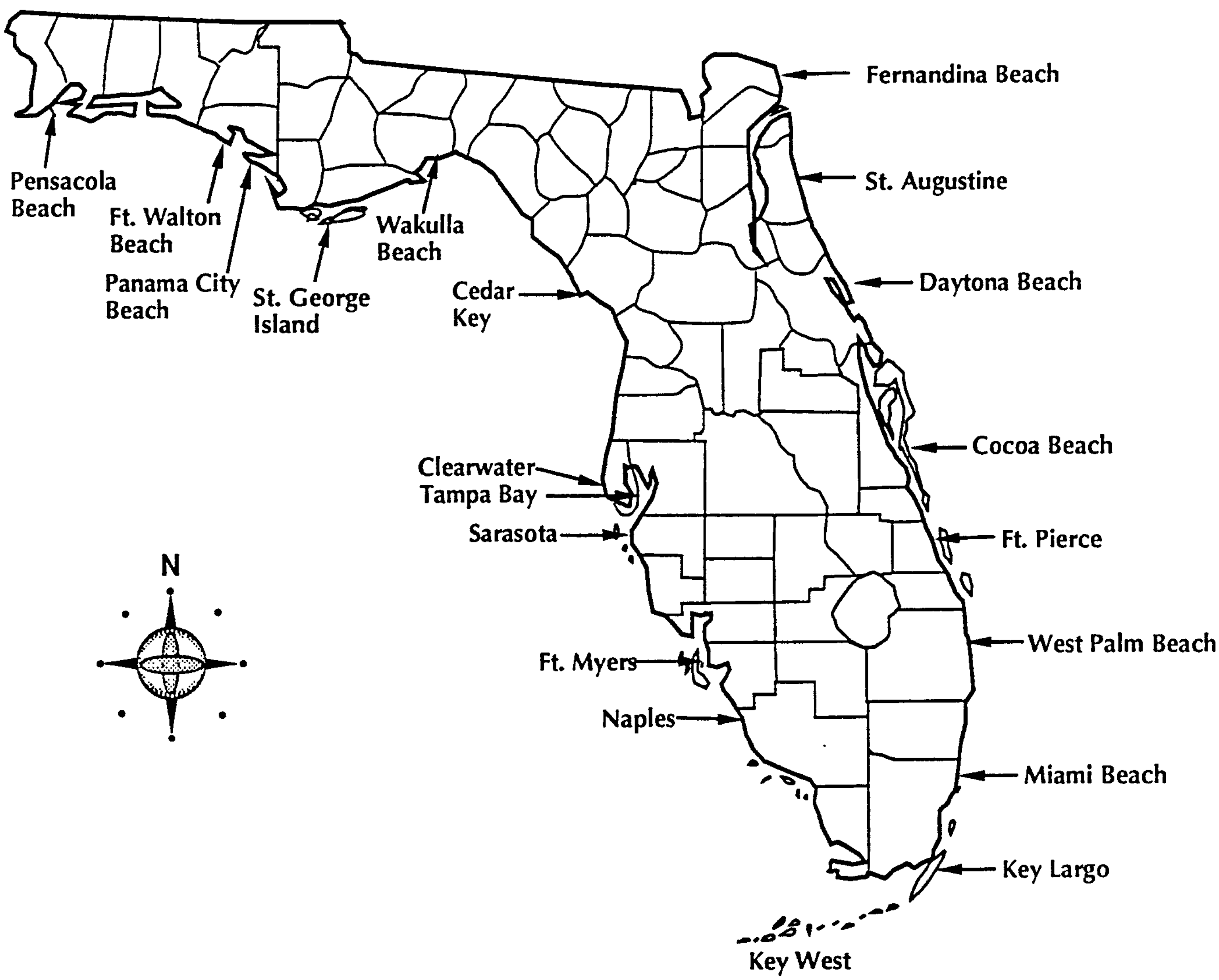


Figure 1.6: Locations in Florida for which the magnitudes of storm surges for a Category 5 storm have been computed.

Location	Peak Surge Elevation Feet above M.S.L.	Rising Rate (ft/hr)	Receding Rate (ft/hr)
Pensacola Beach	12.5	6.0	19.0
Ft. Walton Beach	11.0	4.0	3.5
Panama City Beach	13.0	3.6	3.4
St. George Island	14.2	2.3	2.6
Wakulla Beach	26.2	9.3	4.3
Cedar Key	21.4	5.0	5.7
Clearwater Beach	20.0	5.9	14.3
Tampa Bay	25.5	7.6	4.7
Sarasota	18.8	6.1	7.1
Ft. Myers	22.5	5.7	6.9
Naples	21.5	4.6	7.7
Key West	10.5	2.0	2.0
Key Largo	11.0	3.0	2.4
Miami Beach	10.5	3.0	2.1
Palm Beach	12.0	3.2	2.8
Ft. Pierce	13.5	3.3	5.2
Cocoa Beach	14.5	3.4	3.6
Daytona Beach	13.0	1.9	3.8
St. Augustine	16.8	3.1	4.1

Table 1.1: Magnitude of storm surge for a Category 5 storm at 20 locations in Florida.

resulting in considerable erosion. Waves, in combination with the inundation of a barrier island, further increase the erosion rate.

It is of interest to note that the erosion of the crest of a barrier island can also take place with a current from the bay to the ocean during falling storm tides. Torrential rains accompanying storms pile up large quantities of storm water drainage within the bay area which cannot be quickly drained to the sea through the narrow tidal inlets. A study of Hurricanes Carla (1961) and Cindy (1963) by Hayes (1967) showed that channels were cut in the barrier islands of Texas to a level below the mean sea level. Significant amounts of sediment from the barrier islands were lost offshore by the flow of bay waters to the sea across the barrier island. The currents were driven by the hydrostatic head difference set up between the trapped bay waters and the receding ocean waters.

Transport of sediment in the onshore, offshore and alongshore direction is a function of the magnitude and direction of wave energy and availability of sediment. A beach profile generally tends to adjust to the wave energy in order to achieve "equilibrium" conditions. In general, high waves with short periods cause the beach to erode and the berm sand moves offshore. Low height waves with longer periods move the sediment from the offshore bar and return it to the berm on the shore.

Overwash is one of the principal processes by which sediment is transported across the barrier island. Overwash occurs when storm surges allow waves to overtop the beach and push sand across the island from the beach and dune zones. This results in deposition of sand above the normal high tide mark and the creation of barrier flats.

The frequency of occurrence of overwash depends on the frequency and magnitudes of storms and the barrier island profile. The amount of overwash depends on the exposure and orientation of the barrier island, magnitude of wave energy, tidal range and the ecological response of vegetation to the overwash process. The magnitude of overwash is particularly high when storm waves coincide with high tide levels.

The major natural processes which affect the dynamics of barrier island are tidal inlet migration, aeolian sediment transport, littoral drift, and overwash. The most significant long- term force affecting the stability of barrier islands is the rising sea level. Measurements made by Godfrey (1970) using bench marks established by the Corps of Engineers have shown that the Outer Banks Island have experienced 8.4 cm of sand deposition over a period of ten years during the 1960's. Hicks (1972) has estimated that the rise in the mean sea level over the same period was 8 cm. It may thus be seen that overwash is one process which allows barrier islands to increase their elevation thereby keeping pace with rising sea level.

Overwash does not occur on all barrier islands, and if it does, the rate of overwash varies from site to site. Data presented by Pierce (1968) suggests that for over half the shoreline between Cape Hatteras and Cape Lookout, North Carolina, the short-term loss due to overwash was of the order of 0.6 cubic yards per year per foot of beach front. The most extensive overwash on the East coast occurs at the Delmarva Peninsula and the Outer Banks of North Carolina (Leatherman, 1979a).

Frequent and large quantities of overwash can cause migration of the barrier islands. When large segments of the island are overtopped, sand is deposited inside the bay causing recession of the ocean shoreline and extending the landward limit of the barrier. In this manner, the barrier island retreats while maintaining its width and height relative to the sea-level.

The ecological response to overwash is different for the Northern and Southern beaches. In the South, overwash deposits are quickly colonized by the buried grassland. Almost complete recovery occurred after two years in North Carolina. The vegetative growth reduces wind erosion and helps in retaining the sand. On the North-East coast of the United States, most of the plants die when the salt marsh vegetation gets covered. With overwash deposition into the bay waters, a sloping sediment plane is formed which allows lateral plant growth. This overwash serves to assure growth of highly productive salt marshes which are essential to the estuarine ecosystem.

The beach terminology and coastal processes involved in the formation of barrier islands are briefly described by Parchure et al. (1991).

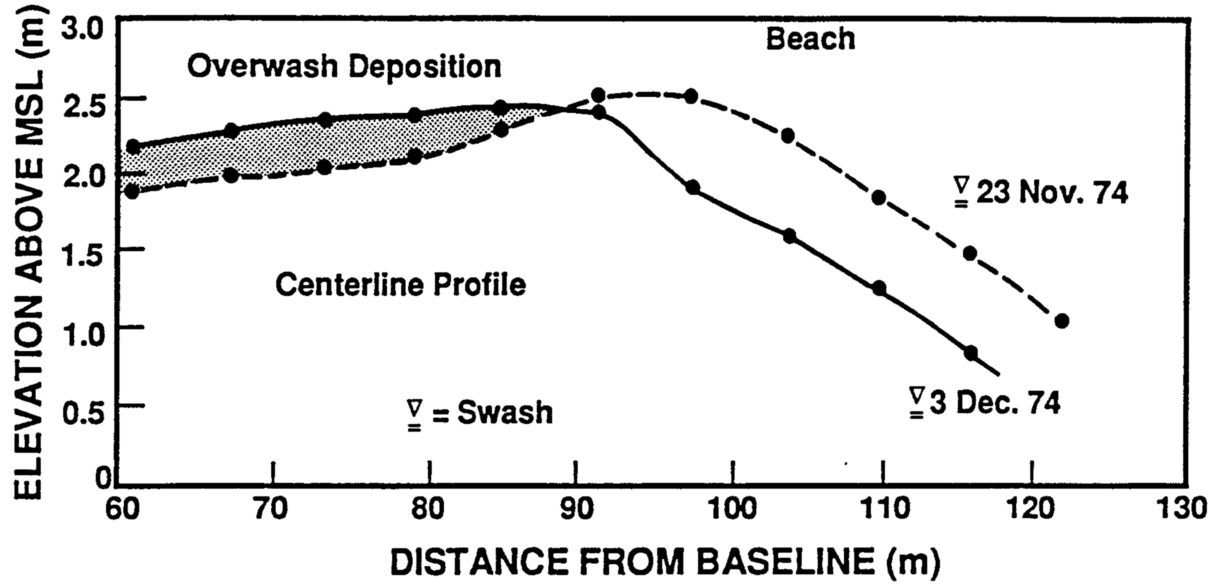
Chapter 2

LITERATURE REVIEW

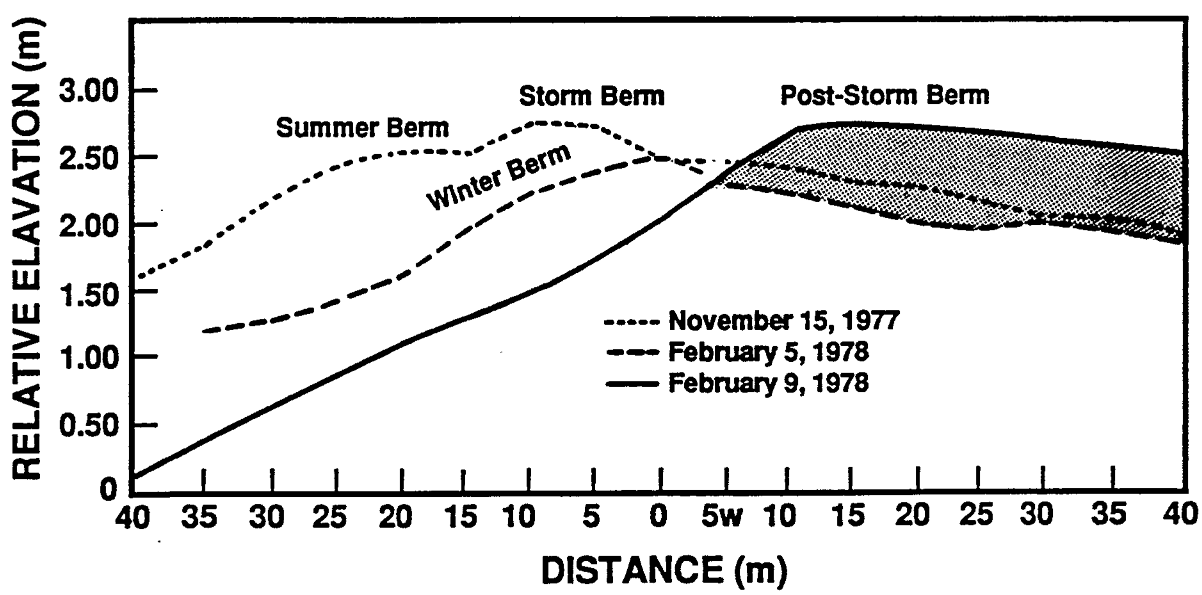
2.1 Field studies

Several field studies have been conducted regarding geological processes, ecological aspects and management plans for barrier islands (Fisher, 1968; Swift, 1975; Godfrey, 1976a, 1976b and 1978; Leatherman, 1977; Davis et al., 1979; Stauble, 1989).

Leatherman (1979b) documented field observations at two sites – (i) Assateague Island, Maryland, along the mid-Atlantic coast for the December 1974 storm and (ii) Coast Guard Beach, Nauset Spit, Cape Cod, Massachusetts, for the February 1978 storm. At Assateague Island, the beach was characterized by medium-sized sand (0.3 mm) and a gentle beach foreshore slope of 5 degrees (1:11). The mean tidal range was 3.6 feet. During the storm of December 1, 1974, breaking waves of about 9 feet were observed from the shore. The calculated significant wave height was 16 feet in deep-water and the storm surge was 2.6 feet. Fig. 2.1 shows the storm-induced changes along the centerline profile. The beach experienced an erosion of 4 cubic yards per foot length of beach. The dune lost 2.8 cubic yards per foot of beach sand and the



Beach erosion and overwash deposition following the 1 December 1974 northeasterly storm at Assateague Island, Md.



6 -7 February 1978 northeasterly storm resulted in severe beach erosion and overwash deposition at Coast Guard Beach, Nauset Spit, Ma.

Figure 2.1: **Field Measurements of Beach Erosion and Overwash (Leatherman, 1979).**

dune face was displaced 15 feet landward. Dune erosion averaged from several profiles was calculated to be 2 cubic yards per foot of beach. An important conclusion drawn from the analysis of sand samples was that there was no evidence of beach sediment coarsening nor steepening of the beach profile as a result of the severe storm.

The sediments at Nauset Spit were medium-sized sand (0.40 mm) and the beach slope was rather steep (1:5). The mean tidal range was 6.6 feet. During the storm of 6-7 February 1978, the significant deep-water wave height was 16 feet. The nearshore breaker heights exceeded 10 feet and the maximum storm surge was about 4 feet. As a result of this storm, the berm crest receded about 66 feet with a loss of 11.8 cubic yards per foot of beach. Large quantities of sediment were moved across the berm by the overwash surges and deposited as an overwash fan. Volumetric determinations revealed that about 40.7 cubic yards per foot of beach was transported as overwash sand during the event. The overwash deposition thickness was up to 5.6 feet above the living marsh (Fig.2.1).

Leatherman (1977) reported that during the storm of March 1975, Assateague Island, Maryland, experienced an overwash deposit of the order of 1.1 cubic yards per foot width of dune.

2.2 Laboratory studies

Several laboratory and analytical studies have been carried out in the past on the equilibrium beach profile, erosion of beaches and formulation of numerical models for the erosion process. Examples of these are the studies reported by Saville (1950), Noda (1972), Dalrymple (1976), van der Meulen (1969), Dean (1973, 1976 and 1991), and Vellinga (1976 and 1982). Dean (1976) has given a detailed review of causes, processes and remedial measures for beach erosion.

Williams (1978) is the only laboratory investigation of overwash. The experiments were conducted in a wave tank approximately 100 feet long, 8 feet wide and 5 feet deep. Only monochromatic waves were generated. The beach was composed of reasonably uniformly sorted sand with a median grain size of 0.21 mm. The barrier island was simulated with an initial profile slope of 1:15 on the seaward side and 1:40 slope landward of the beach crest. Each test comprised three phases. The first phase was the formation of an equilibrium profile. This generally required a period of six to ten hours. After the formation of the equilibrium profile, the water level in the tank was increased gradually in the second phase to a level at which overwashing of the beach crest commenced. In the third phase, the storm surge level was increased further by about 10 to 25 % of the vertical difference between the dune crest-elevation and the water level at which overwash commenced. The tests were then carried out until overwash had occurred to the point that the resulting deposits prevented further overwash. Some washover three- dimensionality occurred in the relatively wide (8 feet) tank. In all, 22 tests were conducted and the results from the best 10 tests were utilized to evaluate two proposed relationships for predicting the washover volumes. It was found that the predictive relationship was better for larger washover volumes. The best fit line agreed with the laboratory data to within approximately 50%.

The first model considered the overwash transport rate, q_s, to be proportional to the excess runup raised to an exponent α, i.e.,

$$q_s = \frac{K_1}{T}(A(t) - A_*)^\alpha \tag{2.1}$$

where q_s was the sediment discharge rate per unit width and K_1 was a dimensional coefficient. $A(t)$ was the excess runup in the elapsed time which was defined as the difference in elevation between the potential runup and the crest of the dune or structure, A_* was the critical excess runup defined as the minimum height which the potential runup must exceed the crest of the dune for sand to be tranported and T was the wave period. The second model expressed the overwash sediment transport rate as a rapidly increasingly function for small values of excess runup and asymptotically approaches zero for larger values of runup:

$$q_s = \frac{K_2}{T}(A(t) - A_*)e^{-K_3(A(t)-A_*)} \tag{2.2}$$

where K_2 and K_3 were dimensional coefficients.

A non-linear least-squares fit was used to determine the coefficients for both the relationships. No attempt was made to apply the predictive relationship to prototype overwash events because the method required data on the time-varying storm surge and assumed that the dune height was constant during the event.

The values of the coefficients were quantified as follows:

Model I	$K_1 = 0.09$	$\alpha = 0.04$	$A_* = 0.4$
Model II	$K_2 = 0.24$	$K_3 = 0.66$	$A_* = 0.32$

Other laboratory studies with particular emphasis on overwash are not available.

2.3 Analytical studies

The results of field investigations and model studies are often used to calibrate and supplement the analytical expressions developed for achieving predictive capabilities. The theoretical development in respect of overwash and beach erosion may be classified in two areas, namely, hydrodynamics of breaking waves and the sediment-wave interaction. The hydrodynamics of wave transformation inside the surf zone has been studied by several researchers such as Horikawa and Kuo (1966), Collins (1970), Battjes and Stive (1985), Dally et al. (1985), Dally and Dean (1986, 1988). Models of sediment-wave interaction have been given by Kemp (1960), Meyer (1972), Swart (1972), Dean (1973), and Hughes (1981) among others.

Chapter 3

SCOPE OF PRESENT STUDY

The objective of the present laboratory study was to measure changes in the profile of a barrier island under storm waves occurring at various sea levels, including those which cause overtopping and inundation.

The laboratory study was not intended to be site-specific. Instead, a hypothetical barrier island with an arbitrary crest width of 400 feet and a mild beach slope of 1:19 was considered for simulation. A geometrically similar scale of 1:16 was adopted for the present study. Similitude considerations in selecting this scale are described in Chapter 4. The laboratory studies were conducted in a wave tank facility which is described in Chapter 5. The wave direction was normal to the beach. Experiments were conducted for different sea water levels and both regular as well as irregular waves were simulated. For each experiment, the initial beach profile was linear from the crest of the barrier island to the toe (as shown in Fig 3.1). This provided a common reference profile for comparison of profiles obtained under different experimental conditions.

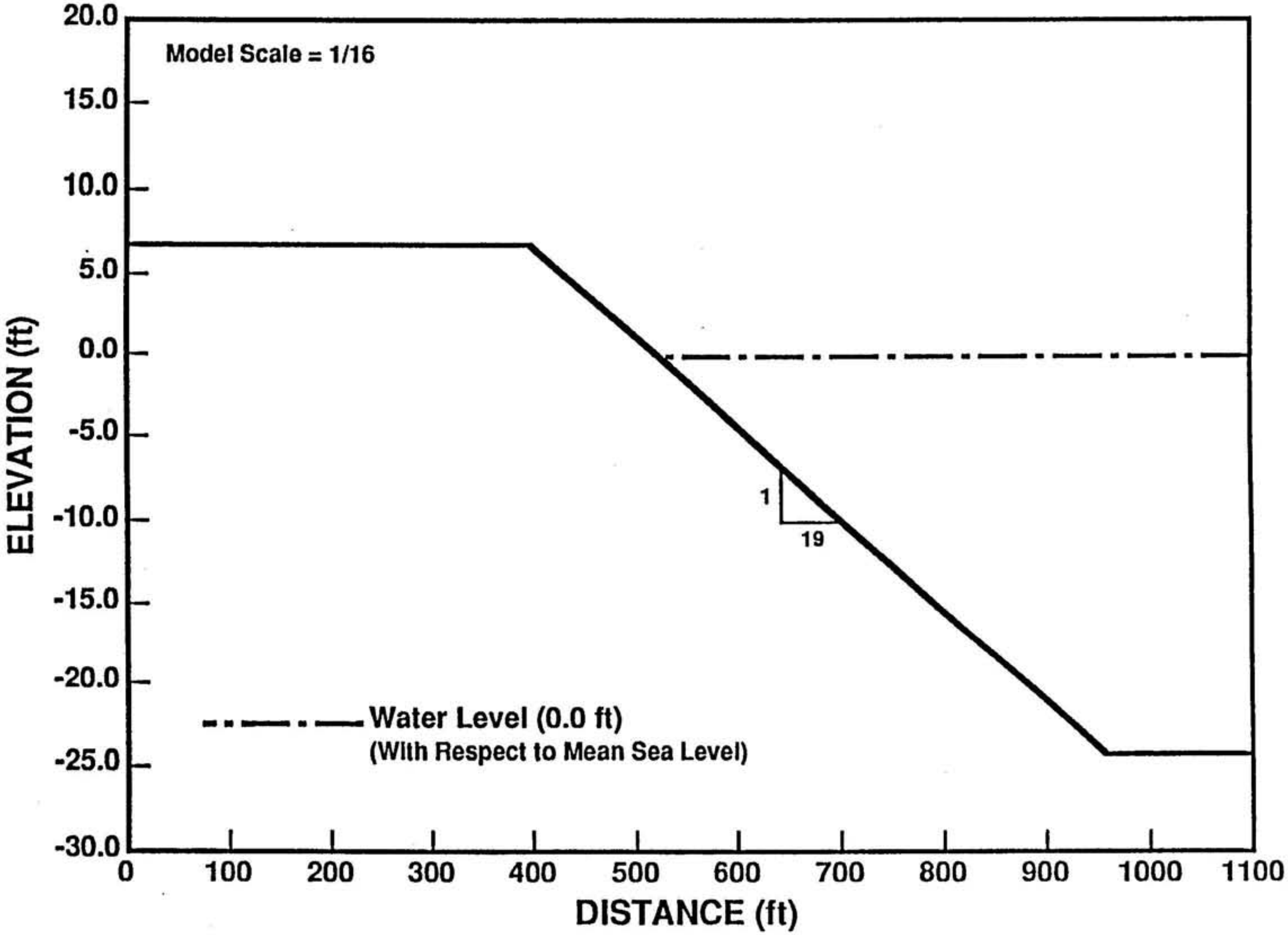


Figure 3.1: Initial beach profile in the wave tank for each experiment.

Vegetation on the barrier island might have a significant effect on the magnitude of erosion and overwash at some of the sites, however, this factor was not taken into account in the present study and all the experiments reported here have been carried out to represent barrier islands with no significant effects of vegetation. Also, ecological aspects related to erosion and deposition have not been considered in the present report. The bay water level was the same as the sea water level in the present study. Experiments incorporating a difference in these two levels have been conducted and the results will be presented in a separate report.

The characteristics of the nine experiments included in this report are described below.

- Initial crest elevation of barrier island - The entire island had an elevation of 6.3 feet above the mean sea level for all the experiments.
- Initial beach profile - Linear with 1:19 slope, constant for all tests.
- Water depth at toe of beach at mean sea level - 24 feet.
- Sediment - Fine sand with a median diameter of 0.2 mm (see Fig 3.2). No shells or protective armor layer were included.
- Still water level - The following four levels were used:
    1. Mean Sea Level (MSL), referred to as zero.
    2. 6.3 feet above MSL (same as the island crest)
    3. 10.0 feet above MSL (causing inundation).

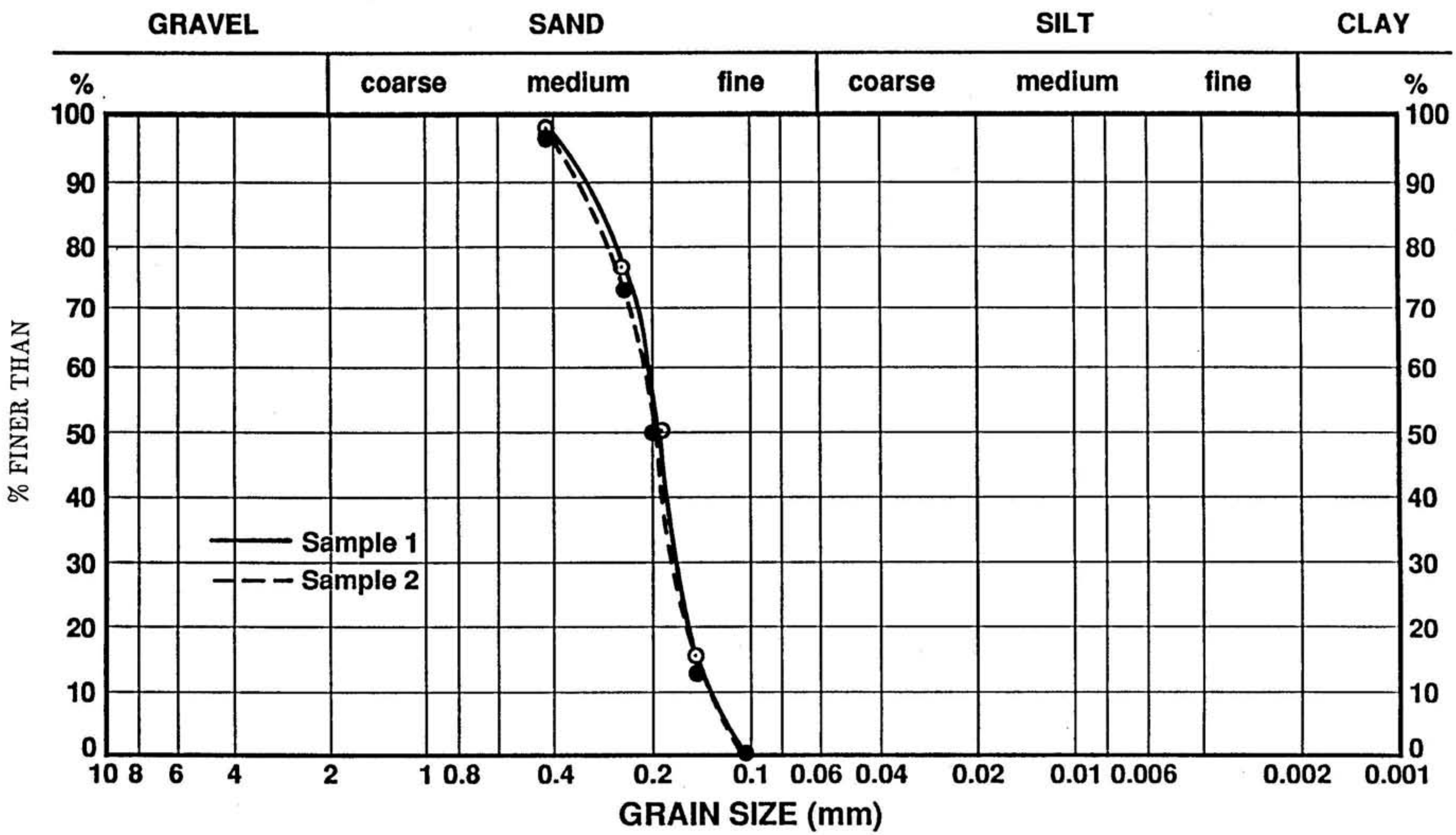


Figure 3.2: **Size Distribution of Sand used for Model Study.**

4. 11.5 feet above MSL (causing inundation).

5. Time-varying water level with peak surge of 11.3 feet.

- Incident waves -

1. Regular waves with a height of 8.5 feet and a period of 8 seconds.

2. Irregular waves with a mean period of 8 seconds and in the range 7.6-8.4 seconds (narrow-banded spectrum).

- Structures - Experiments were conducted without a seawall as well as with a seawall. Two locations of the seawall were examined: (i) the seaward end of the barrier island crest where the beach slope began, and (ii) just landward of the MSL shoreline. Two elevations of the seawall were also tested – (i) 6.3 feet and (ii) 8.3 feet above MSL. These are discussed in the companion to the present report (*Barrier Island Erosion and Overwash Study:Volume 2* Srinivas et al., 1992).

Chapter 4

SIMILITUDE CONSIDERATIONS

In order to achieve similarity between the model and the prototype in beach profile studies, several criteria have been recommended depending upon the principal phenomenon to be studied and the predominant active forces. Often, practical considerations such as the type and size distribution of bed material available for laboratory tests, size and capabilities of the available test facilities, funds and time available for study and the degree of accuracy desired are the governing constraints in laboratory investigations.

Some of the important similitude criteria recommended for scale model studies are based on the following:

1. Froude Number

2. Densimetric Froude Number

3. Reynold's Number

4. Bed Shear Velocity

5. Friction Factor

6. Kinematic Condition (ratio of horizontal to vertical displacement of sediment particles)

7. Fall Velocity

The Coastal Engineering Research Center, U.S. Army Corps of Engineers (1979), conducted a comprehensive review of literature on similitude criteria for beach erosion investigations. A summary is presented in Table 4.1. The main conclusions were as follows - Complete similitude of all dynamic processes involved in the movement of coastal sediment is impractical. Similitude of certain dynamic processes fixes the relation between model and prototype linear dimensions, material characteristics and other factors. Therefore, no particular set of scale model laws for coastal sediment models was recommended. Each of the scale model laws given in Table 4.1 was believed to have its own special area of application, and the selection of the appropriate set of equations for a particular problem largely depends on the experience and expertise gained by the particular group of laboratory personnel performing mobile bed scale model tests. Kemp and Plinston (1968) suggested a distortion relation for beach profile erosion study -

$$\frac{n_l}{n_d} = (n_d)^{\alpha} \tag{4.1}$$

Source	Basic relations	Method of derivation
Goddet and Jaffry (1960)	$n_D = \mu^{17/20}\Omega^{8/5}$ $n_{\gamma\prime} = \mu^{3/20}\Omega^{-3/5}$	Sediment motion due to combined action of waves and currents
Valembois (1960)	$\Omega = n_{\gamma\prime}^{-1}$ $n_{\gamma\prime} n_D^3 = 1$ $\mu = n_{\gamma\prime}^3 n_D \left(\frac{n_H}{\mu}\right)^4$	Kinematic of motion of suspended sediments Similitude of D_* Modified relation of initiation of sediment motion: $D_* = KR_*^{8/9}$
Yalin (1963)	$n_D = \mu^{3/4}\lambda^{1/2}$ $n_{\gamma\prime} n_D^3 = 1$	Dimensional analysis
Bijker (1967)	$n_{\gamma\prime} n_D \Omega^{-1} = \mu n_{\mu r}$ $\Omega \leftarrow$ equilibrium beach profiles	Similitude of F_* SEE NOTE:
Fan and Le Mehaute (1969)	$n_{\gamma\prime} n_D^3 = 1$ $n_{\gamma\prime} = \mu^3\lambda^{-3/2}$ or $n_D = \lambda^{1/2}\mu^{-1}$ $\Omega \leftarrow$ equilibrium beach profiles	Similitude of sediment transport characteristics, i.e., F_* and R_*
Noda (1971)	$n_D n_{\gamma\prime}^{1.84} = \mu^{0.55}$ $\lambda = \mu^{1.32} n_{\gamma\prime}^{-0.386}$ $\Omega \leftarrow$ equilibrium beach profiles	Similitude of sediment transport characteristics, i.e., F_* and R_*

Note: Although this basic relation was noted to be in error, it was not corrected.
Reference: Coastal Hydraulic Models, Coastal Engineering Research Center, U.S. Army Corps of Engineers, Special Report No. 5, May 1979

Table 4.1: Comparison of various approaches for determination of basic scale ratios of coastal movable bed models.

where

$$
\begin{aligned}
n_l &= \frac{\text{model length}}{\text{prototype length}} \\
n_d &= \frac{\text{model depth}}{\text{prototype depth}}
\end{aligned}
$$

and $0.45 < \alpha < 0.65$.

Noda (1972) has given a detailed account of scale model relationships for movable bed models. Data from experiments utilizing a number of materials and grain sizes suggested that the following need to be satisfied for reasonable similitude

$$\lambda = (\mu)^{1.32}(n_\gamma)^{-0.386} \tag{4.2}$$

$$\text{and } n_d(n_\gamma)^{1.85} = \mu^{0.55} \tag{4.3}$$

where

λ = ratio of horizontal scale in model to that in prototype

μ = ratio of vertical scale in model to that in prototype

n_d = ratio of sediment diameter in model to that in prototype

n_γ = ratio of relative specific weight of sediment in model to that in prototype

whereas sand data suggested

$$n_d = \mu^{0.55} \tag{4.4}$$

$$\lambda = \mu^{1.32} \tag{4.5}$$

when $n_\gamma = 1$.

Dean (1973) and Kohler and Galvin (1973) have identified the importance of the dimensionless fall velocity parameter (H/WT) as a criterion for berm-bar formation where H and T are the wave height and period, respectively, and W is the sediment fall velocity. Dean (1973) also noted the relevance of this parameter in modeling beach systems. Dalrymple and Thompson (1976) conducted a series of beach profile experiments in the laboratory and confirmed that similitude occurs if

$$n(\frac{H}{WT}) = 1 \tag{4.6}$$

where n stands for the ratio of model to prototype, as the most promising scale relationship for modeling of beach processes. From earlier tests on dune erosion with two types of sand, van de Graaff (1977) found that the results of different sands compared very well using the (H/TW) concept. The movable bed model tests on dune erosion conducted by Vellinga (1978) at the Delft Hydraulics Laboratory have assumed that equal (H/TW) values in model and prototype lead to geometrically similar beach profile development in the model.

It would be apparent from the above review of various similitude criteria that for the scale model study of beach profiles, dimensionless fall velocity criterion is the most appropriate and hence has been adopted for the present study. Since gravity is the predominant force for free-surface water waves in the ocean and in the laboratory, Froude similarity also needs to be achieved simultaneously, i.e.,

$$\frac{V_m}{\sqrt{gd_m}} = \frac{V_p}{\sqrt{gd_p}} \tag{4.7}$$

where V = velocity and d = depth; m and p denote model and prototype respectively. This leads to the time relationship for geometrically similar scale models as

$$\frac{T_m}{T_p} = \sqrt{\frac{l_m}{l_p}} \tag{4.8}$$

where l denotes the length scale.

According to Stoke's law, fall velocity, W, of a sediment particle is given by

$$W = \frac{1}{18}\frac{D^2 g}{\nu}\frac{(\gamma_s - \gamma_f)}{\gamma_f} \tag{4.9}$$

where

$$\begin{aligned} D &= \text{diameter of sediment particle} \\ g &= \text{gravitational acceleration} \\ \nu &= \text{kinematic viscosity of fluid} \\ \gamma_s &= \text{specific weight of sediment} \\ \gamma_f &= \text{specific weight of fluid} \end{aligned}$$

For the present study it was assumed that the prototype sediment diameter (D_p) was 0.4 mm. This corresponds to medium-sized sand which occurs on several barrier islands. Size gradation analysis of sand available for the model study showed that the median diameter (D_m) was 0.2 mm (Fig. 3.2). Based on the standard relationship for fall velocity, $W_p = 0.51$ ft/sec and $W_m = 0.127$ ft/sec.

The dimensionless fall velocity criterion (Eq. 4.6) specifies that

$$(\frac{H}{WT})_m = (\frac{H}{WT})_p \tag{4.10}$$

whereby

$$\frac{H_m}{H_p}\frac{T_p}{T_m} = \frac{W_m}{W_p} \tag{4.11}$$

Therefore, using Eq. 4.8 and making substitutions for the fall velocities,

$$\frac{l_m}{l_p}\sqrt{\frac{l_p}{l_m}} = \frac{0.127}{0.51} \tag{4.12}$$

whence

$$\frac{l_m}{l_p} = \frac{1}{16} \tag{4.13}$$

Hence, a geometrically similar scale of 1:16 was adopted for the present study. Thus, all length and time scales in the prototype were 16 and 4 times those in the model, respectively. All dimensions in this report are in prototype units unless mentioned otherwise.

Chapter 5

LABORATORY FACILITY

The tank was 120 feet long, 6 feet wide and 6 feet deep (Fig. 5.1). A concrete block wall had been placed along the tank centerline dividing it into two tanks each approximately 3 feet wide. One outer wall was constructed of glass panels and the experiment was conducted in this side of the tank thereby facilitating direct observation. A wave generator was located at one end of the wave tank with hydraulic drive pistons at two elevations allowing piston, flap or a combination of motions to be generated. The wave maker was capable of generating regular or irregular waves. The splitter wall along the tank centerline was separated from the wave maker by approximately 10 feet; at the downwave end of the tank (beyond the beach), the splitter wall was composed of concrete blocks with horizontal openings, thereby allowing circulation around the splitter wall. A sloping frame with permeable nylon bags filled with pebbles was located at the downwave end of the tank which was not used for the experiments. Rails had been provided at the top of the tank and an electrically operated trolley was mounted on the rails for transporting a carriage containing a

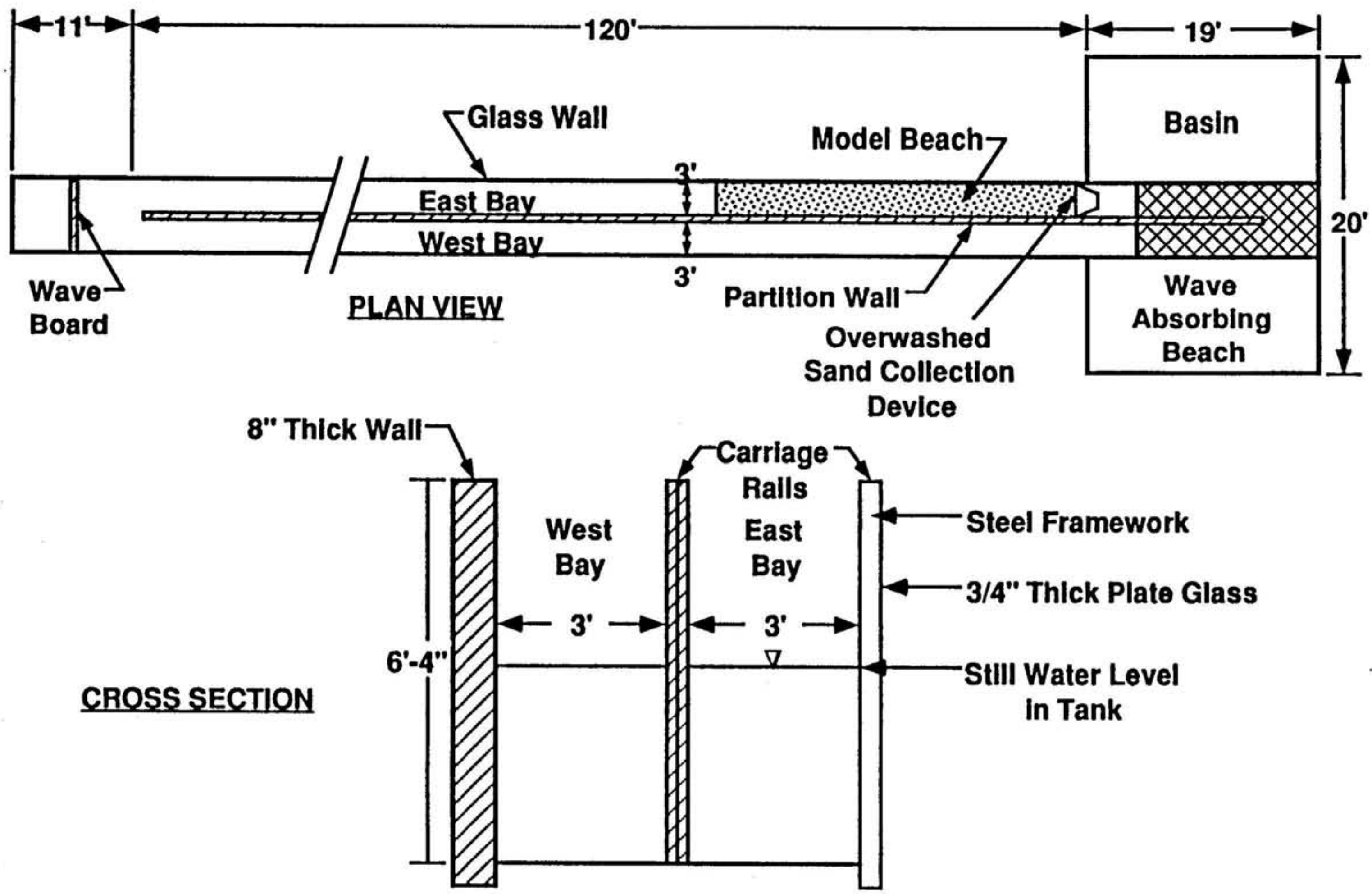


Figure 5.1: Schematic layout and cross-section of wave tank facility.

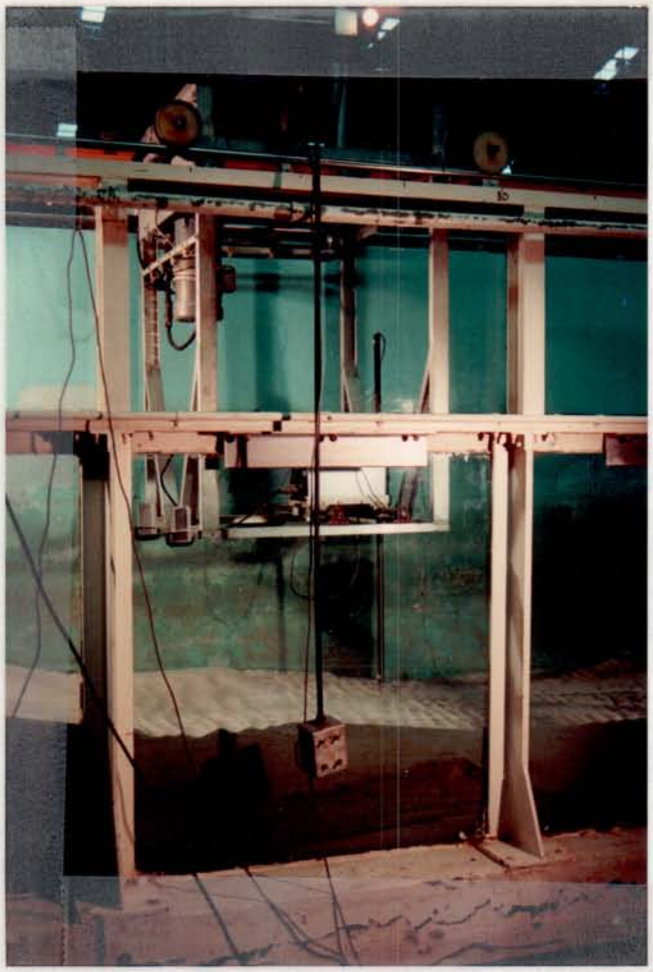


Figure 5.2: Traveling carriage with automatic bed profiler.

measuring equipment package along and across the wave tank.

A capacitance wave gage was used for measuring wave height and period. The gage was mounted on the carriage and it could be moved to any location within the tank for wave measurements. The wave gage was calibrated each time before data acquisition in order to eliminate errors caused by changes in water temperature or other factors.

An electro-magnetic current meter mounted on the carriage was used for current measurements. An automatic bed profiler (Fig. 5.2) mounted on the carriage was used for measuring the beach profiles at various time intervals during the course of an experiment. An electric motor drove the carriage at a constant speed along the length

Figure 5.3: Data acquisition system.

of the wave tank and, simultaneously, the bed sensor automatically moved up or down, closely following the bed profile by maintaining a fixed gap of 0.5 mm between the tip of the sensor and the bed. The direction of travel of the carriage could be reversed and the carriage speed varied to suit the requirements of data acquisition. Data on bed elevation, as a function of distance measured with respect to a pre-defined coordinate system, were stored on magnetic diskettes. Wave data as well as current data were also stored on magnetic diskettes and were subsequently processed and plotted using a VAX 8350 computer and laser plotter. The data acquisition system is shown in Fig. 5.3

Since the effect of storm waves was to be examined for the condition of the barrier island being completely inundated under high storm surges, it was expected that sand from the island would be transported to the leeside of barrier island. Hence, a spout was provided on the leeside and arrangements were made for collection and weighing of the sand washed over the crest of the barrier island.

Chapter 6

METHODOLOGY

In the following description of the experiments, unless noted otherwise, all quantities are presented in prototype units. Thus, all the model data have been converted to equivalent prototype values in all beach profile plots for convenience of interpretation. Experiments were conducted in the wave tank for examining the erosion of an initially planar beach subjected to regular and irregular waves and different water levels. The laboratory measurements included the following:

1. Each experiment was started with a remolded linear profile from the crest of the island to the toe of beach as shown in Fig 3.1. The crest of the barrier island was horizontal and the entire profile was measured at the beginning of each experiment.

2. Under wave action, the initial linear profile was changing with time during the course of an experiment. The resulting beach profiles were measured in the wave tank at every 30 minutes (model units) using a bed profiler which provided data on bed elevation as a function of distance. The number of bed profiles for each

experiment ranged from at least 2 to a maximum of 9, depending upon the reach and the variability of bed forms. Two profiles, designated as B1 and B2, were measured covering the entire length of the barrier island and the beach. In addition, for some of the experiments, where a three-dimensional bed pattern was visually noticed, an additional seven profiles were measured over a smaller area of the tank where the three-dimensional feature was evident.

3. Wave-induced surface currents over the barrier island were measured using weighted floats in those cases where the barrier island was submerged. For a few experiments, the wave- induced current was also measured by means of an electromagnetic current meter.

4. The weight of sand transported over the crest of the island was measured every 30 minutes by collecting it in a bucket and weighing it on a platform balance. These measurements were made only in those tests when the crest of the island was totally submerged with accompanying overwash.

In all, nine experiments were conducted during the course of the study documented in this report. The experimental conditions of these tests are summarized in Table 6.1. These experiments were divided into the following three groups –

Group 1 - Experiments E1 to E4 Under this group, the effect of raising the sea water level from MSL to complete inundation of the barrier island (as can often occur under high storm surges) was studied. These experiments were conducted with the water level at MSL, 6.3 feet above MSL which corresponded to the crest

Expt. No.	Water Level		Wave Characteristics		
	Duration (hrs)	Level (ft)	Type	Height (ft)	Period (sec)
1	0--18	MSL	Regular	7.0	8.0
2	0--18	+6.3	Regular	8.5	8.0
3	0--18	+10.0	Regular	8.5	8.0
4	0-22	+11.5	Regular	8.5	8.0
5	0--6	MSL	Regular	8.5	8.0
	6--8	+0.5			
	8--10	+2.90			
	10--12	+6.82			
	12--14	+10.24			
	14--16	+11.30			
	16--18	+10.24			
	18--20	+6.82			
	20--22	+2.90			
	22--24	+0.50			
6	0--22	MSL	Random	7.0	7.6
7	0--18	6.3	Random	7.0	8.0
8	0--18	+10.0	Random	7.0	8.0
9	0--18	+11.5	Random	7.0	8.0

Table 6.1: Experimental Conditions of all Runs.

Table 6.2: Variation in the magnitude of storm surge parameters.

	Minimum	Maximum
Peak storm surge	10.5 ft	26.2 ft
Rising rate	2.0 ft/hr	9.3 ft/hr
Receding rate	2.0 ft/hr	19.0 ft/hr

level of the barrier island, 10.0 feet above MSL (3.7 feet inundation of island) and 11.5 feet above MSL (5.2 feet inundation of island), respectively. Regular waves of 8.5 feet height and 8 seconds period were allowed to impinge upon the beach and each experiment was conducted over a duration of 18 hours of prototype time which is equivalent to 4.5 hours model time. The duration of test was based on two criteria - 18 hours represent a fairly long duration for a severe storm and the model beach profiles were seen to attain equilibrium profiles and not significantly change beyond this test duration.

Group E2 - Experiment E5 Experiments under Group 1 and Group 3 were conducted under conditions of a steady storm surge level for 18 hours. In nature, the maximum storm surge level may not last longer than one or two hours. Three examples of storm surge estimates made by the National Hurricane Center are shown in Fig 6.1, where zero hours denotes the instant of landfall. At Tampa Bay, the rate of rise of water level is 7 ft/hour and the rate of fall is 4.7 ft/hour. At Pensacola, the rate of rise (6 ft/hour) is slower than the rate of fall (19 ft/hour) whereas the rates are equal for Key West (2 ft/hour). The range of variation in the magnitudes as seen from Fig.6.1 is presented in Table 6.2.

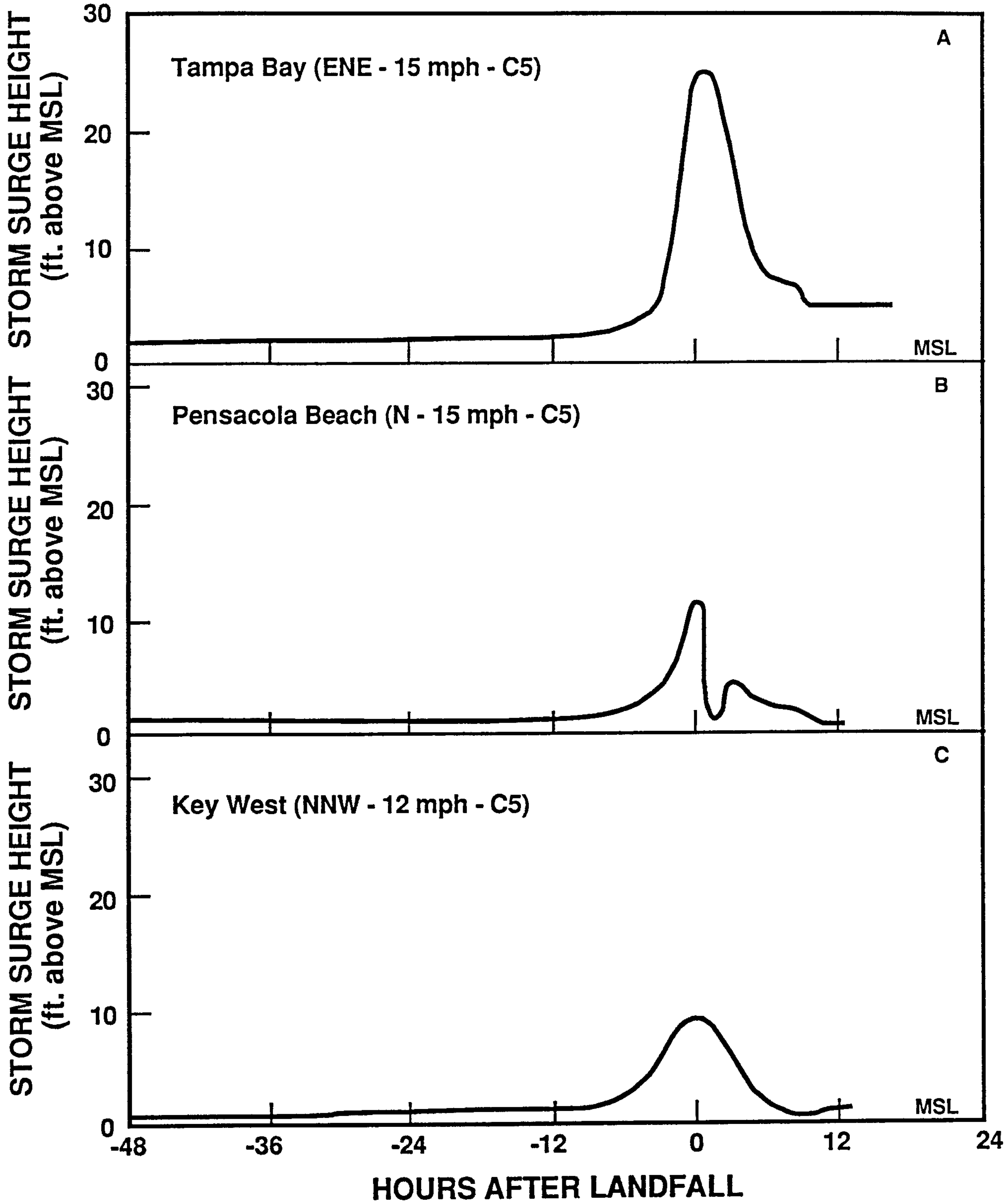


Figure 6.1: Illustration of estimated rising and falling storm surges.

For purposes of preliminary study, equal rising and receding rates of 1.28 ft/hour and a peak storm surge of 11.5 feet above MSL were considered for simulation. Only one experiment was conducted which consisted of simulation of a storm surge hydrograph instead of a steady storm surge level. The effect was simulated by a series of stepped increases and decreases of the water level with each time step lasting two hours. The beach was allowed to reach near- equilibrium by subjecting it to waves at MWL conditions for 6 hours before the onset of the storm. The storm surge simulation (after the aforementioned 6 hours) used in Expt. 5 is shown in Fig. 6.2.

Group 3: Experiments E6 to E9 Under this group, irregular waves were used with significant wave height and mean zero crossing period equivalent to 7 feet and about 8 seconds, respectively, i.e., the wave heights and periods were maintained to be as close as possible to those of Experiments E1 - E4 for comparison of results. The following storm surge levels were simulated - MSL, 6.3 feet above MSL which corresponds to the crest elevation of the barrier island, 10 feet above MSL and 11.5 feet above MSL.

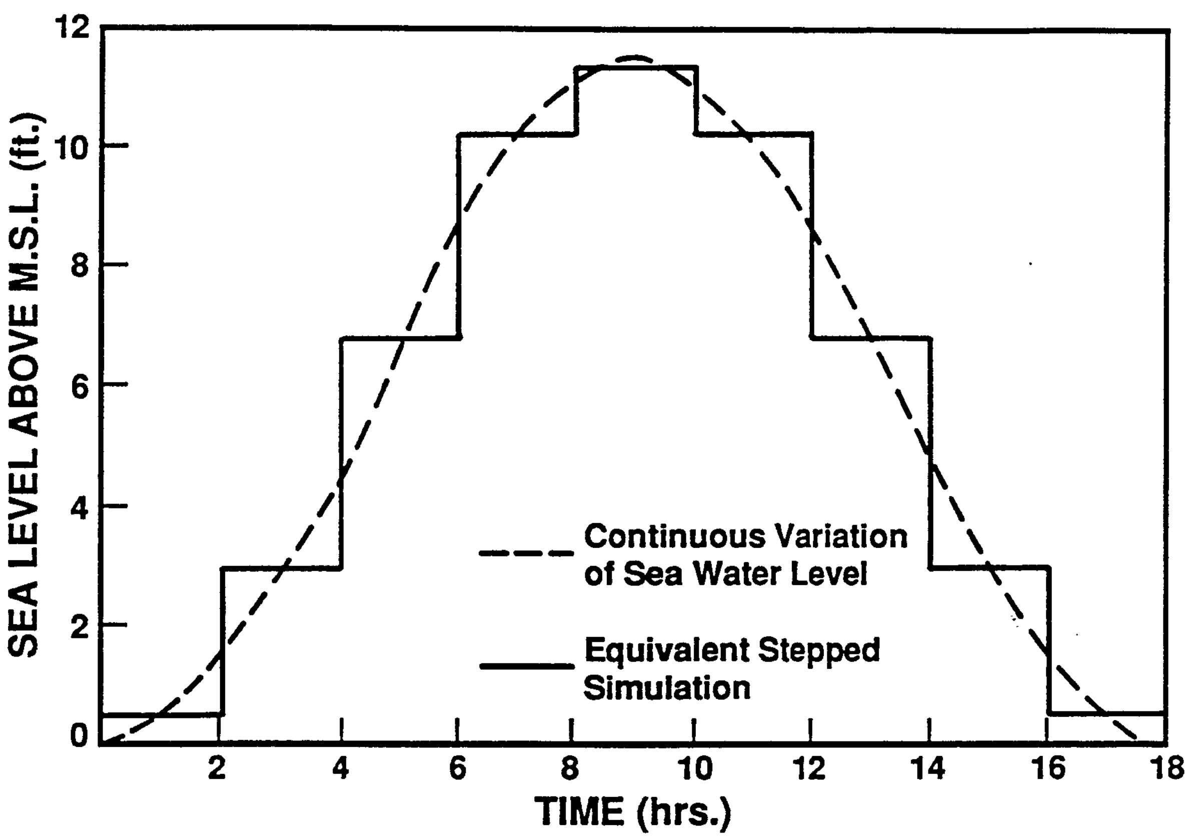


Figure 6.2: Storm surge simulation used in Experiment E5.

Chapter 7

RESULTS

7.1 Wave Data

The height and period of regular waves in the laboratory tank were adjusted to correspond to 8.5 feet and 8 seconds respectively. However, for Experiment 1 the incident wave height was 7 feet. Fig. 7.1 shows an illustration of a regular wave train. The irregular waves were generated in the form of a narrow-banded spectrum with a significant wave height of 7.0 feet while the zero-crossing period was 8 seconds. An example of a wave train for irregular waves is shown in Fig. 7.2 and the associated energy spectrum is presented in Fig 7.3. After breaking,the wave energy decreased from the offshore towards the onshore of the barrier island due to decreasing water depth. The maximum storm surge level during the present series of tests was 11.5 feet above MSL and the following wave measurements are from Experiment 4 with this water level. The landward end of the barrier island crest was taken as the zero reference for measurement of distance. With this reference, the seaward end of the island crest was at 400 feet and the toe of the beach was at 944 feet. Wave

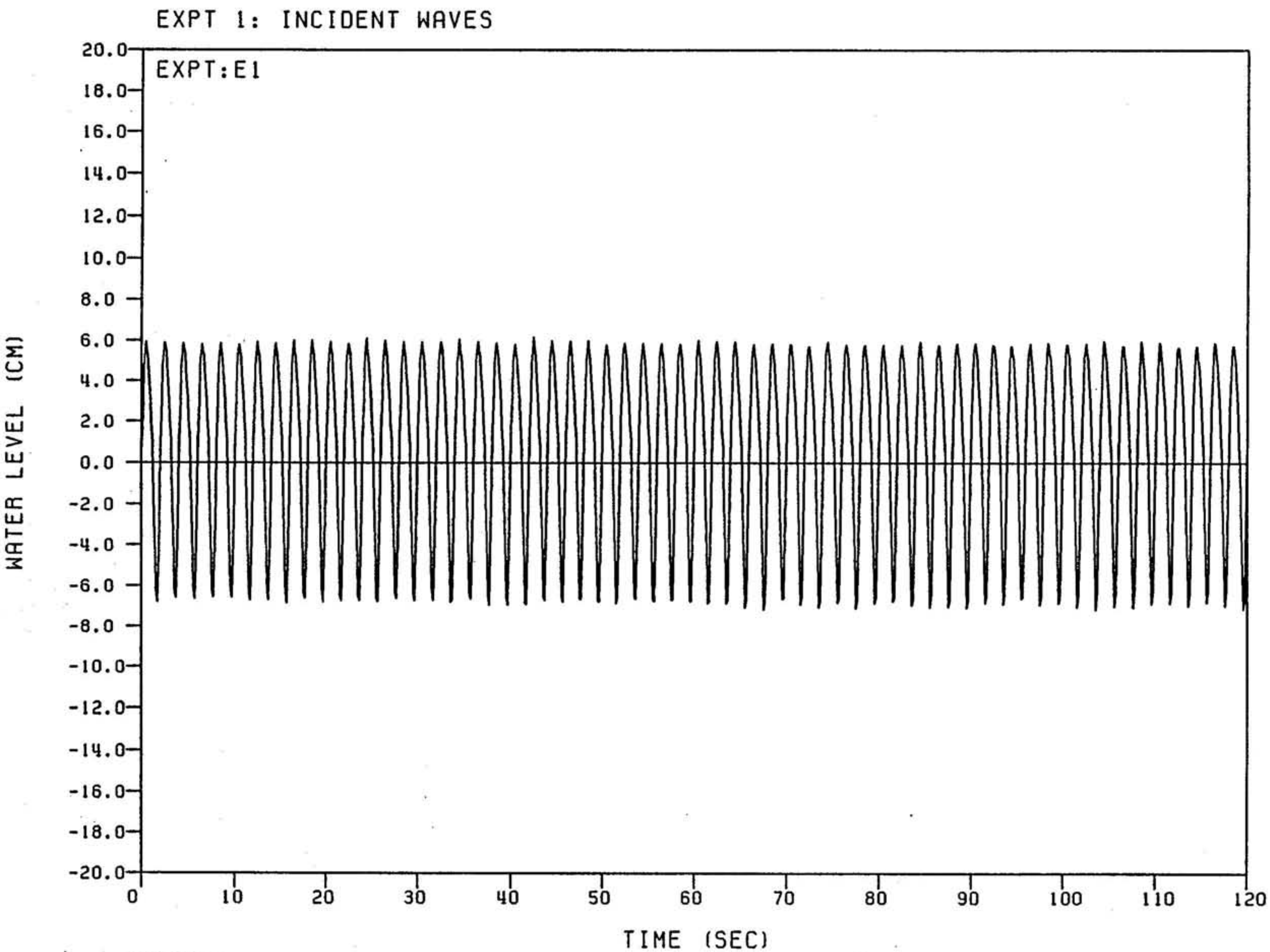


Figure 7.1: An example of regular waves generated in the wave tank.

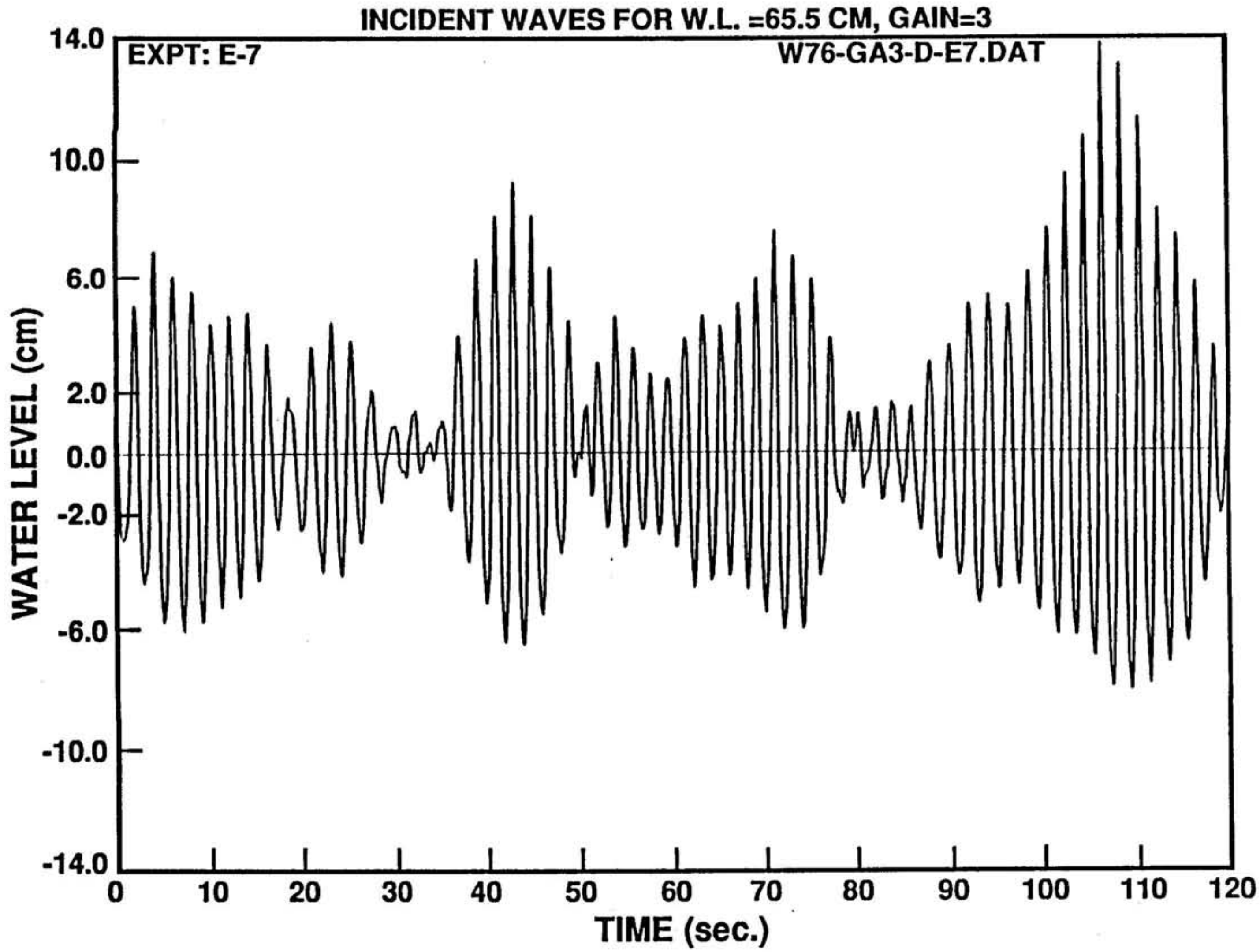


Figure 7.2: An example of irregular waves generated in the wave tank.

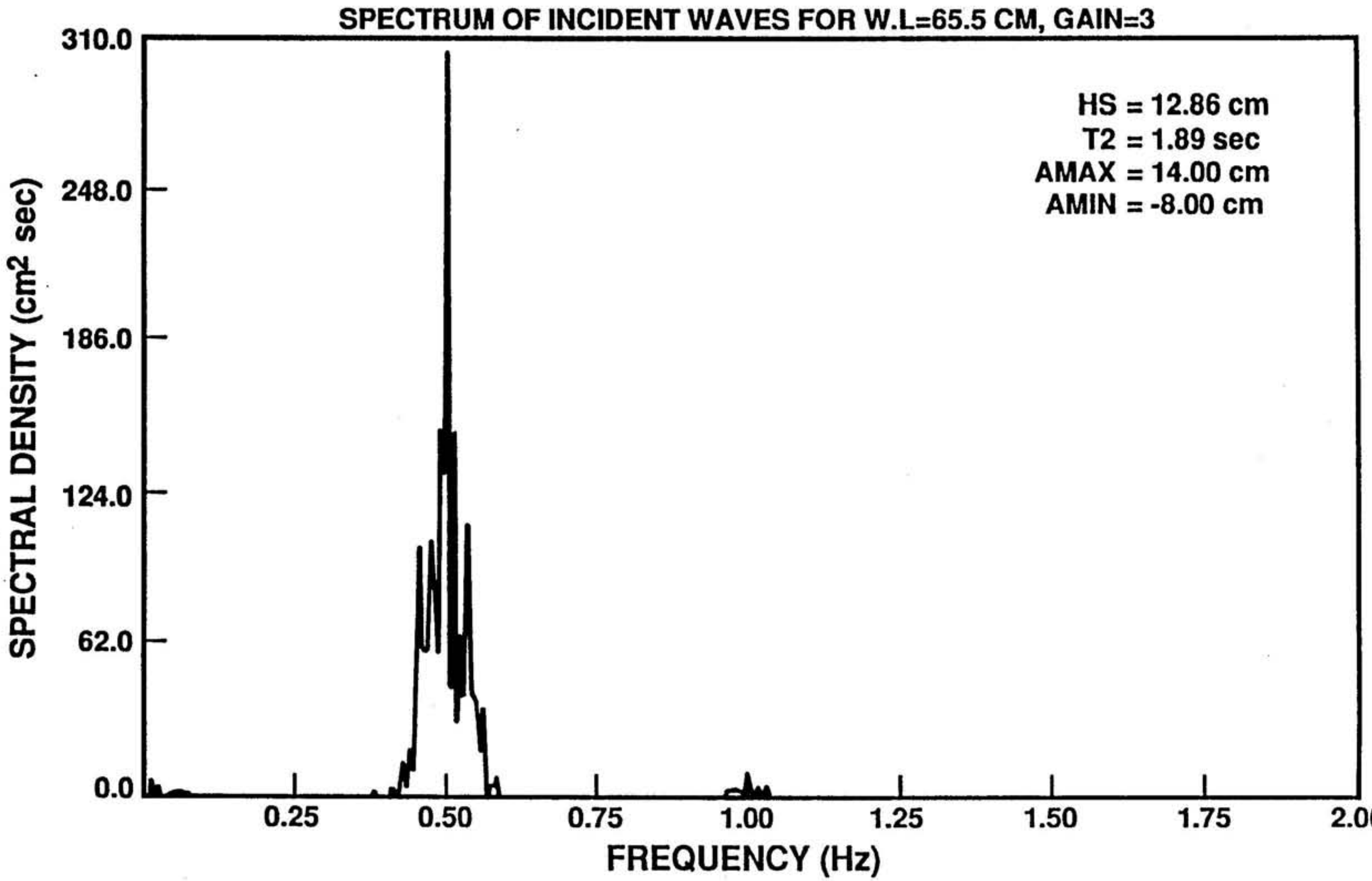


Figure 7.3: **Energy Spectrum for Irregular Waves. (Quantites are in Model Scale)**

Table 7.1: Wave heights at different locations for Experiment E4

Location (ft)	Wave Height (ft)
1120	8.5
800	8.2
576	9.4
448	4.7
320	2.3
160	1.5

measurements were taken in the tank at various locations. Fig. 7.4 presents a sequence of wave measurements at (a)beyond the toe of the beach, 960 feet (b)about two-thirds the length of the beach slope where the waves were breaking over the offshore bar, 576 feet (c)close to the island crest, 448 feet (d)over the crest of the island, 320 feet and (e)further landward over the crest of the island, 160 feet. The asymmetry in the elevations of wave crests and wave troughs as well as the asymmetry of wave form in shallow water are worth noting.

For the incident waves of 8.5 feet in height with a period of 8 seconds, the wave heights decreased as shown in Table 7.1 as the waves propagated landward over the beach and over the crest of the barrier island.

7.2 Current Data

The magnitude of wave-induced surface current over the crest of the barrier island was measured when the island was submerged at water levels of +10 feet and +11.5 feet above the mean sea level. The current velocity was found to be of the order of 2.5 ft/sec to 4.0 ft/sec (prototype values) under regular waves of incident deep water

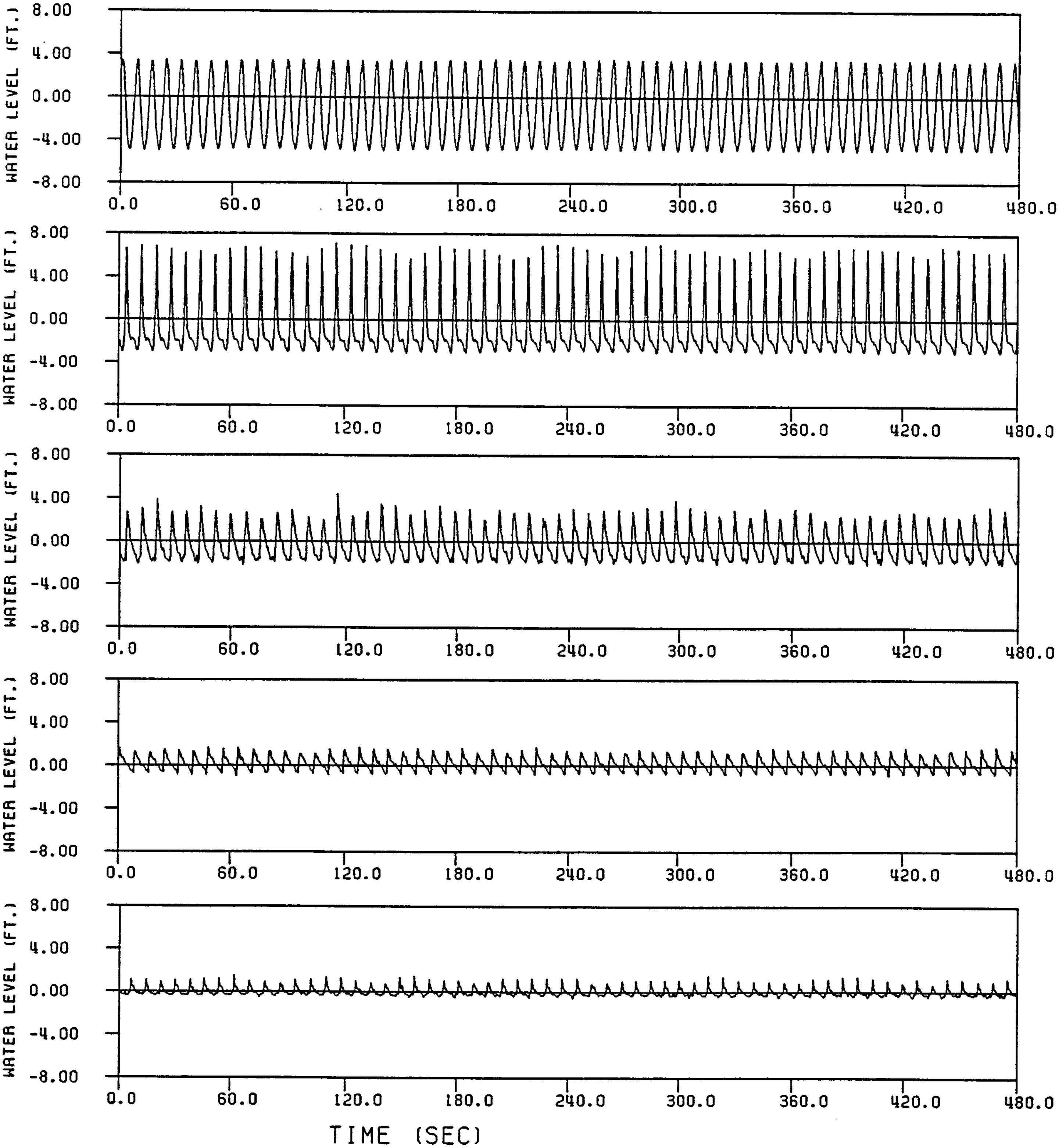


Figure 7.4: Experiment E4, waves recorded at (a)toe of the beach, 960 feet (b)close to the break-point, 576 feet (c)close to the crest of the island, 448 feet (d)over the crest of the island, 320 feet (e)over the crest of the island, 160 feet.

Table 7.2: Observations of wave induced surface current

Experiment Number	Sea Level (feet) W.R.T. MSL	Wave Characteristics	Current Velocity (ft/s)	
			Observed	Average
3	10.0	Regular waves H = 8.5 feet T = 8 sec	2.5 4.0 3.2 3.6	3.3
4	11.5	Regular waves H = 8.5 feet T = 8 sec	4.0 3.6 3.4 3.8	3.7

wave height equivalent to 8.5 feet. The results are given in Table 7.2.

7.3 Sediment Data

The sand transported beyond the barrier island was collected in a bucket every 30 minutes (model time) and weighed. This weight varied from 1 lb to 5 lbs. The data collected during each experiment were to be used to evaluate the total sediment mass balance. However, all the sand eroded from the barrier island was not trapped in the bucket. The reason for the poor trapping efficiency was the fact that all the sediment being transported in the sand trap was not in the form of bed load. A considerable amount of sediment moved as suspended load. The suspended sediment deposited elsewhere outside the bucket and could not be recovered for accurate measurements. Also, it is possible that a part of the "apparent" erosion of beach profile may have been caused by the compaction of sand during the course of the experiment.

Figure 7.5: Ripples on the crest of the barrier island.

7.4 Bedforms

Photographs of typical sediment ripples formed in the wave tank at the end of an experiment are shown in Figs. 7.5 and 7.6. Photographs of a typical offshore bar and the general beach profile resulted from an experiment are shown in Fig. 7.7.

7.5 Beach Profile Data

The beach profile data were analyzed in a variety of ways in order to present data in different formats. It has already been stated that at least two profiles (B1 and B2) were observed each time. These were symmetrically located at one-third the width of the wave tank from both the side walls. The basic data as well as their analysis and plottings are too voluminous for inclusion in this report. All the original laboratory

Figure 7.6: Ripples on the ocean-side beach.

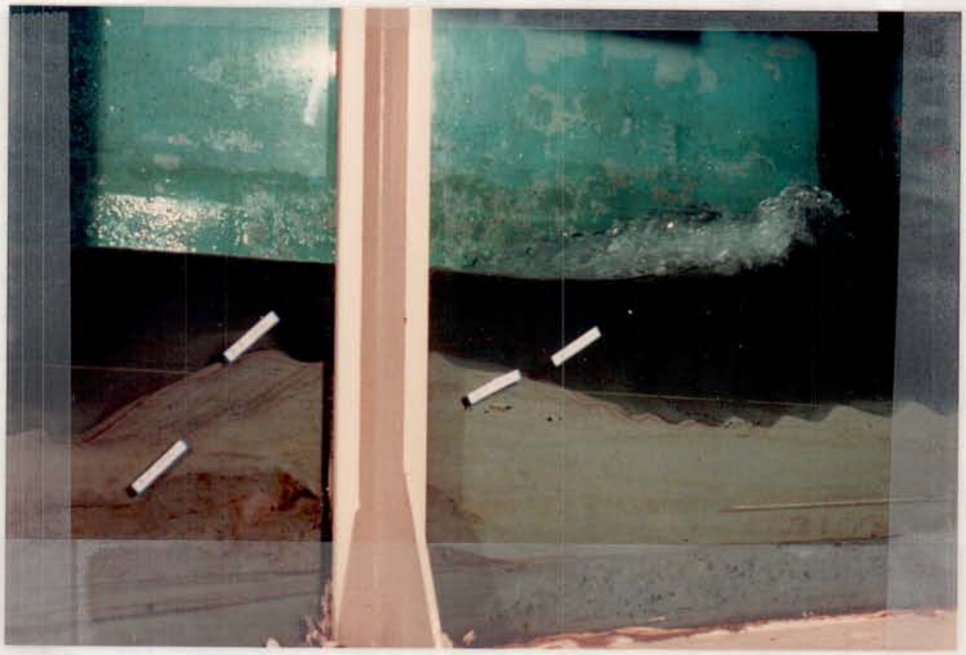


Figure 7.7: Longshore bar and breaking wave during the course of an experiment.

data and their complete analysis and plottings are presented in a separate Appendix and in Parchure et al. (1991) for the experiments without a seawall. Data in the Appendix are in three sections -

1. Each of the beach profiles (B1 and B2) observed every two hours.

2. As mentioned earlier, successive beach profiles for each experiment were measured at two hour intervals. Each pair of consecutive profiles was superposed for comparison of the change in the profile (B1 and B2) as a function of time.

3. The initial and final beach profiles (B1 and B2) for each experiment were superposed for examining the gross change in each profile over the entire experiment

In order to compute the volumes of erosion and accretion, it was essential to obtain an average profile which was representative over the width of tank. Hence, the B1 and B2 profiles observed at the end of each experimental stage (e.g. 2 hours, 4 hours, etc.) were converted into equivalent profiles giving bed elevation at a uniform interval of 0.1 foot (model units) along the length of the tank. This was accomplished by using a suitable interpolation technique. The two transformed B1 and B2 profiles were then merged using an arithmetic average to give a mean profile. Unless otherwise mentioned, this section documents changes discernible in the mean profiles.

7.5.1 A note on beach profiling

The automatic bed profiler needed calibration for each profile and this involved the voltage output corresponding to two "known" elevations which were chosen as those of the water surface and the bed far offshore (at 944 feet) which was considered to be unaffected by the wave action. However, due to leakage, etc., the water level could not be monitored as effectively as desired and, also, the bed level at 944 feet was noticed to change slightly with time. These are two possible sources of error in the bed profiles in terms of elevation. A combination of magnets embedded in the wheels of the trolley and a "Hall-effect" sensor established the horizontal position of the bed sensor. Slippage of the trolley wheels on the rails can cause errors in the prediction of the horizontal position.

7.6 Experiment E1

The initially linear-sloped beach was subjected to 7 feet high monochromatic (8 seconds period) waves for 18 hours with the water level at MSL.

Swash excursions caused some deposition in the range 490-530 feet and prominent deposition ($\sim$ 2.5 feet) up to 560 feet (see Fig. 7.8). The region 570-720 feet experienced erosion (the maximum being $\sim$ 2.5 feet at 720 feet). There was accretion up to a maximum of about 2.5 feet in the range 730-770 feet followed by mild changes in the offshore.

The mean profile exhibited a 5 feet high (defined as the difference in the elevation of the crest and landward-side trough of the bar) and steep-sided longshore bar with its crest at 730 feet and trough at 720 feet. The crest of the bar was just seaward of the breakpoint (confirmed visually). The longshore bar formed within the first 2 hours and its position oscillated slightly before the profile attained equilibrium in

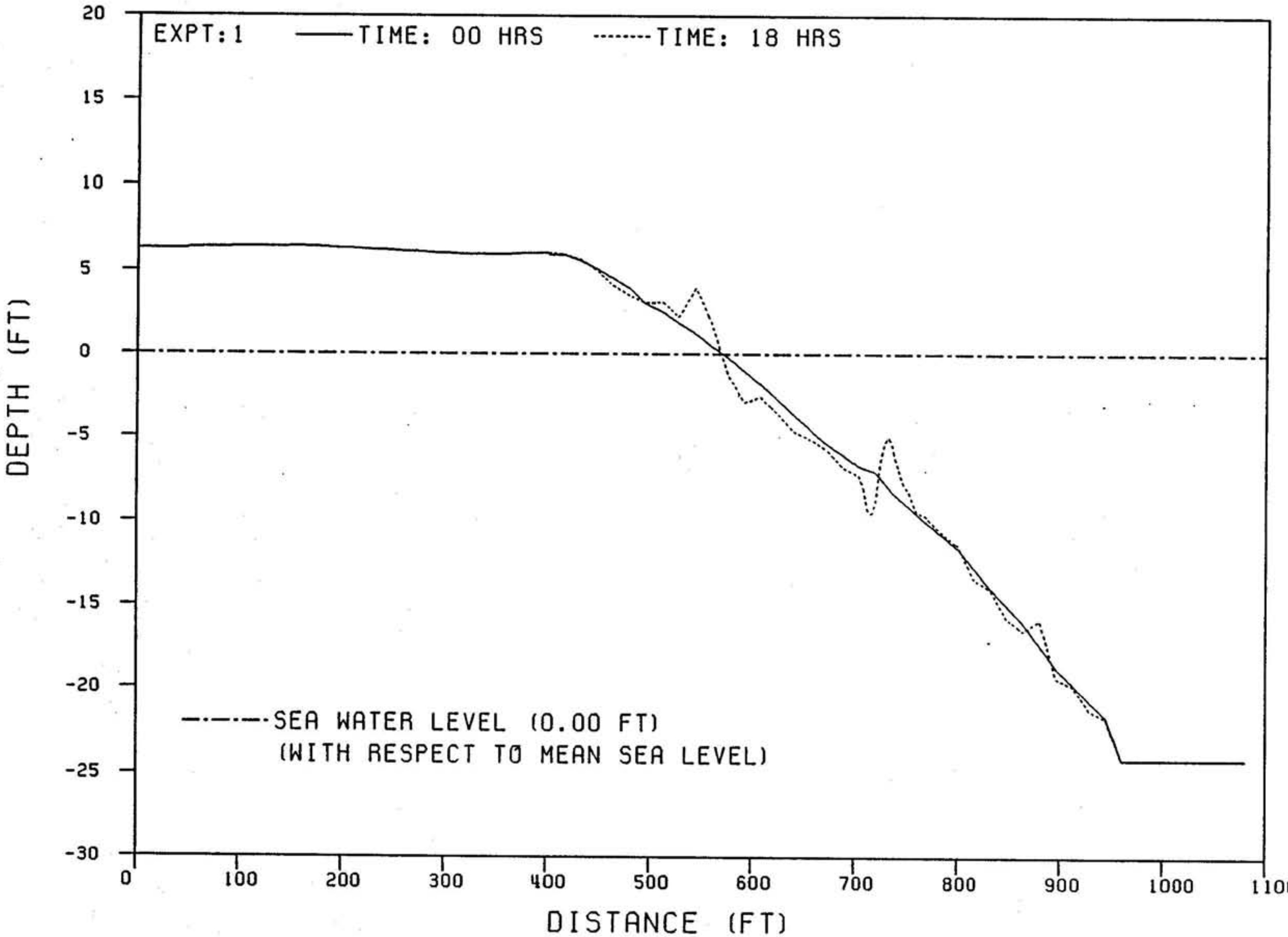


Figure 7.8: Experiment E1, Mean profiles at 00 and 18 hours.

about 12 hours. The MSL shoreline was unchanged (i.e., no retreat or advancement). The net change in the mean profile was -45 ft^3/ft (which is equivalent to 0.003 feet in model units).

7.7 Experiment E2

The initially linear-sloped beach was subjected to 8.5 feet high monochromatic (8 seconds period) waves for 18 hours with the water level at (+)6.3 feet with respect to MSL which corresponded to the crest elevation of the barrier island. Thus, the onset of wave action caused mild overtopping over the crest of the barrier island.

In the mean profile, there was mild washover of sand over the crest of the barrier island in the range 0-300 feet (see Fig. 7.9). The amount of deposition increased (reaching up to $\sim$ 2 feet) in the range 300-450 feet. The region 500-620 feet experienced substantial (up to about 4.5 feet) erosion. The crest of the longshore bar extended from 620-650 feet and this region exhibited accretion. This was followed by some erosion till 750 feet and accretion offshore till 900 feet. The MSL shoreline retreated $\sim$ 30 feet

Again, a prominent longshore bar developed within the first 2 hours. The position of the bar fluctuated by about 30 feet in the next 2 hours. After 6 hours, the position of the bar appeared to approach quasi-equilibrium; however, even after 18 hours the position was still varying slightly, although there was only minimal change in the size and shape of the bar. In the final mean profile, the height of the longshore bar was about 5 feet. The bar had a narrow crest initially, however, it developed a 30 feet

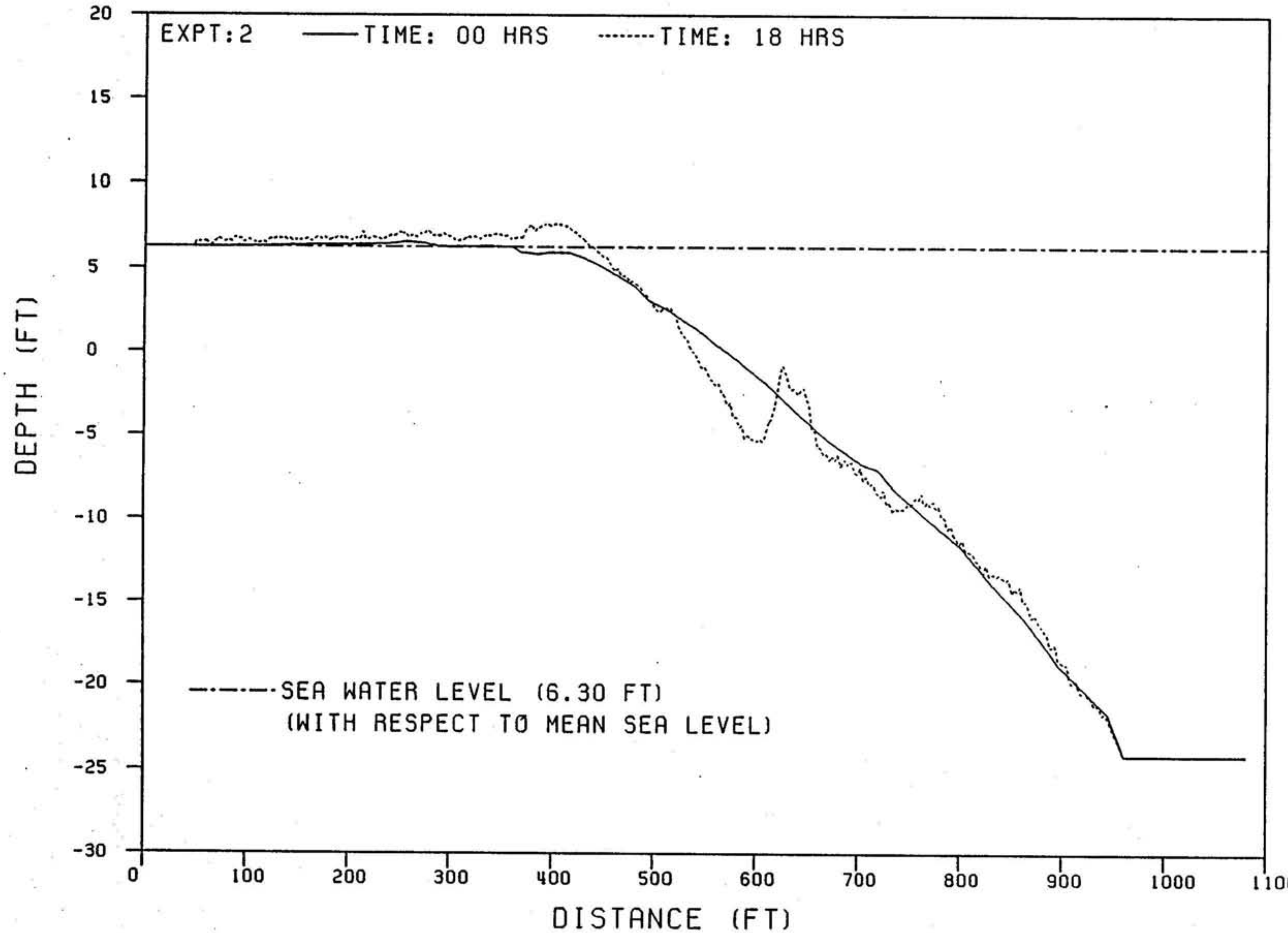


Figure 7.9: Experiment E2, Mean profiles at 00 and 18 hours.

wide crest by about 16 hours. Except for the wider crest and washover of sand over the crest of the barrier island, the patterns of deposition and erosion were similar to those in Expt. E1. The net change in the mean profile in 18 hours was +75 ft^3/ft (which is equivalent to 0.005 feet in model units).

7.8 Experiment E3

The initially linear-sloped beach was subjected to 8.5 feet high monochromatic (8 second period) waves for 18 hours with the water level at (+)10.0 feet with respect to MSL. This resulted in complete inundation of the crest of the barrier island with overtopping of 3.7 feet.

Figs.7.10, 7.11 and 7.12 are samples from the Appendix which document changes in profile B1 over the course of the experiment. Profiles taken every 2 hours are superposed. The longshore bar developed within the first two hours. The size of the bar grew with time and its position oscillated slightly while the crest of the bar seemed to flatten. In the final mean profile, the crest of the bar was at about 560 feet while the trough was at 520 feet.

In the mean profile, there was erosion (up to more than 1 foot) in the range 0-200 feet followed by accretion (up to 1.5 feet) till 350 feet (see Fig.7.13). The entire sloping profile was eroding extensively (up to 4 feet) except in the region of the prominent longshore bar, which was 4 feet high. Fig. 7.14presents the variance calculated using 9 measured profiles at 18 hours. The variance, σ^2, is defined as

$$\sigma^2 = \overline{z^2} - \overline{z}^2 \tag{7.1}$$

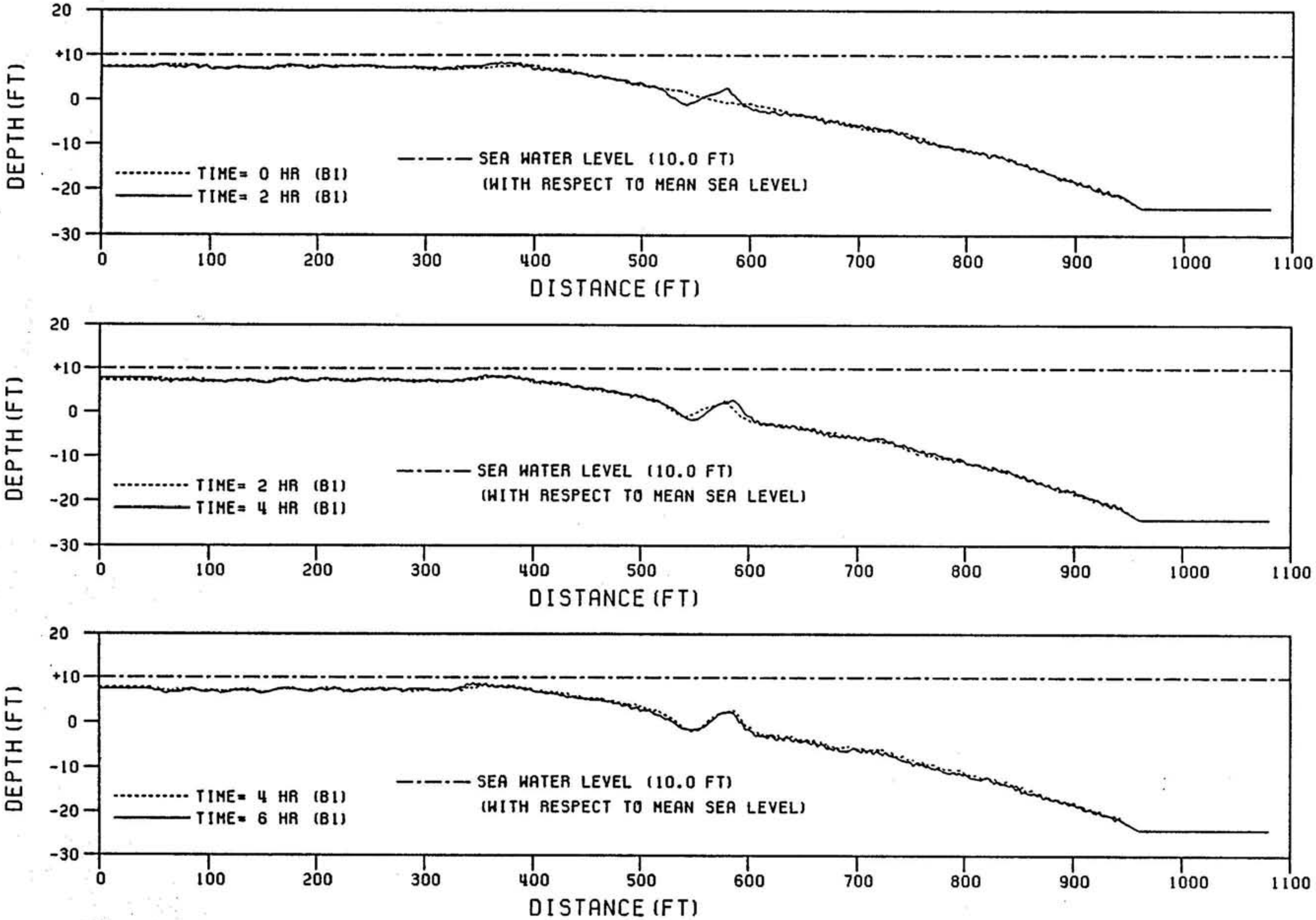


Figure 7.10: Experiment E3, Profile B1, 00-06 hours.

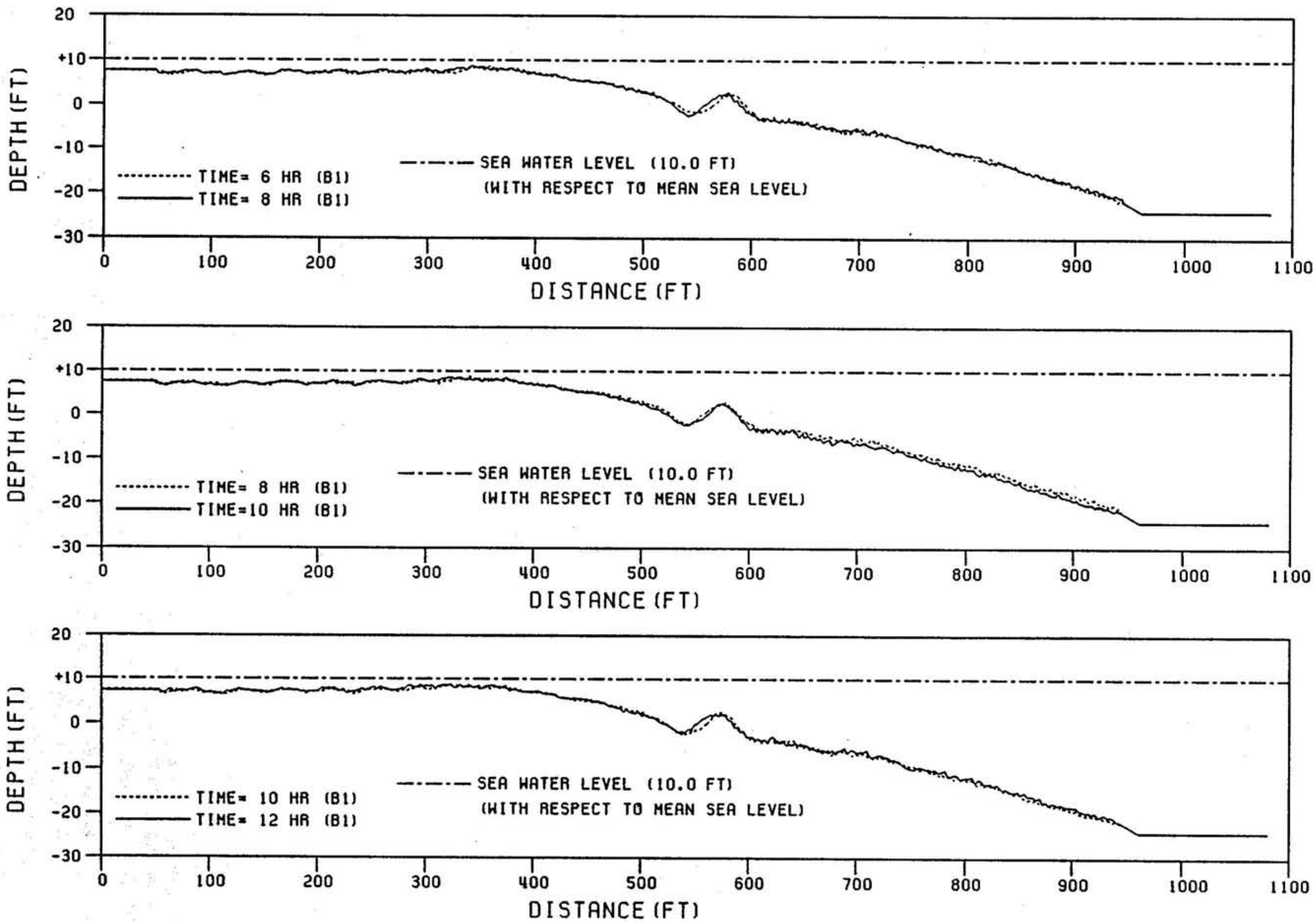


Figure 7.11: Experiment E3, Profile B1, 06-12 hours.

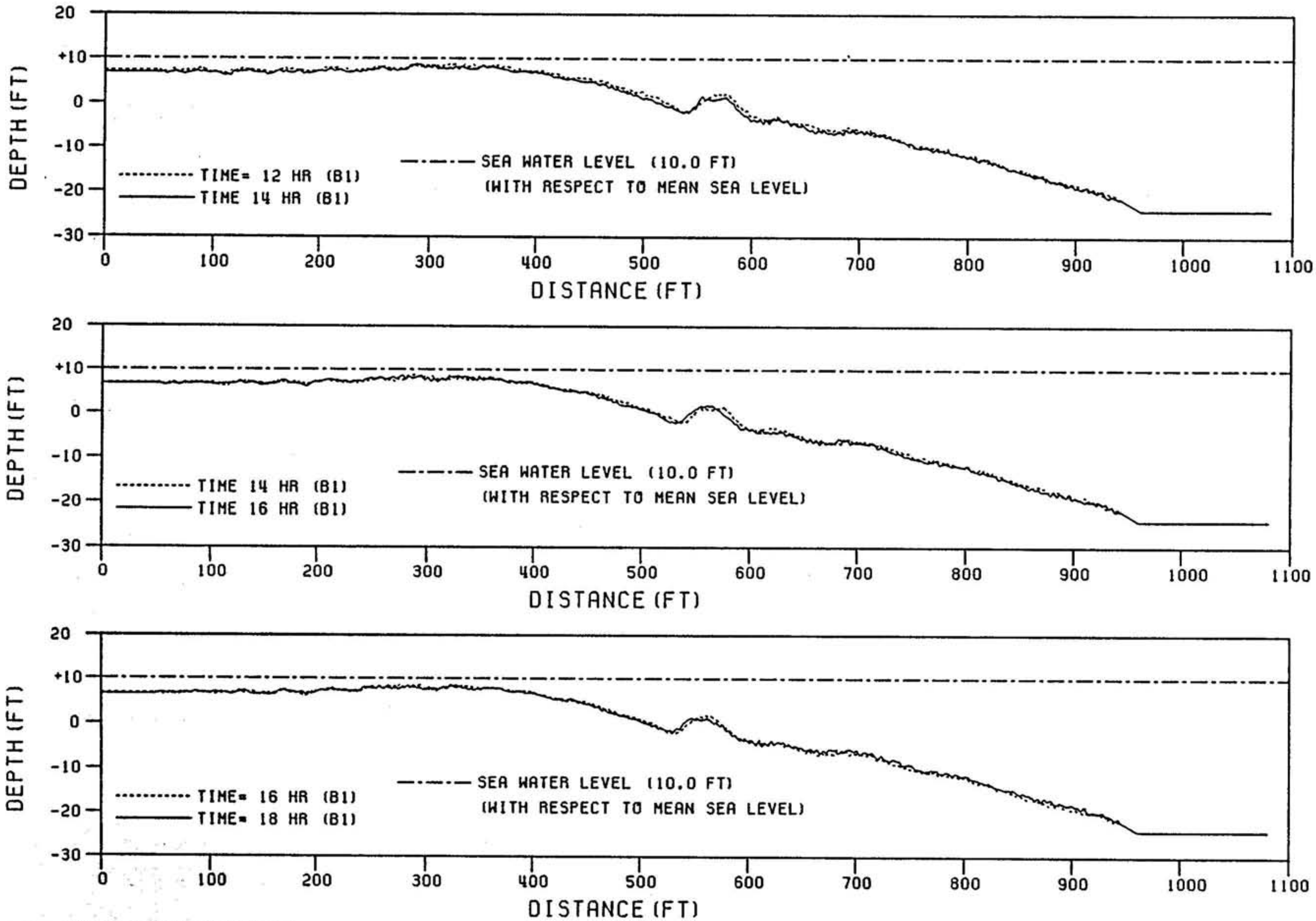


Figure 7.12: Experiment E3, Profile B1, 12-18 hours.

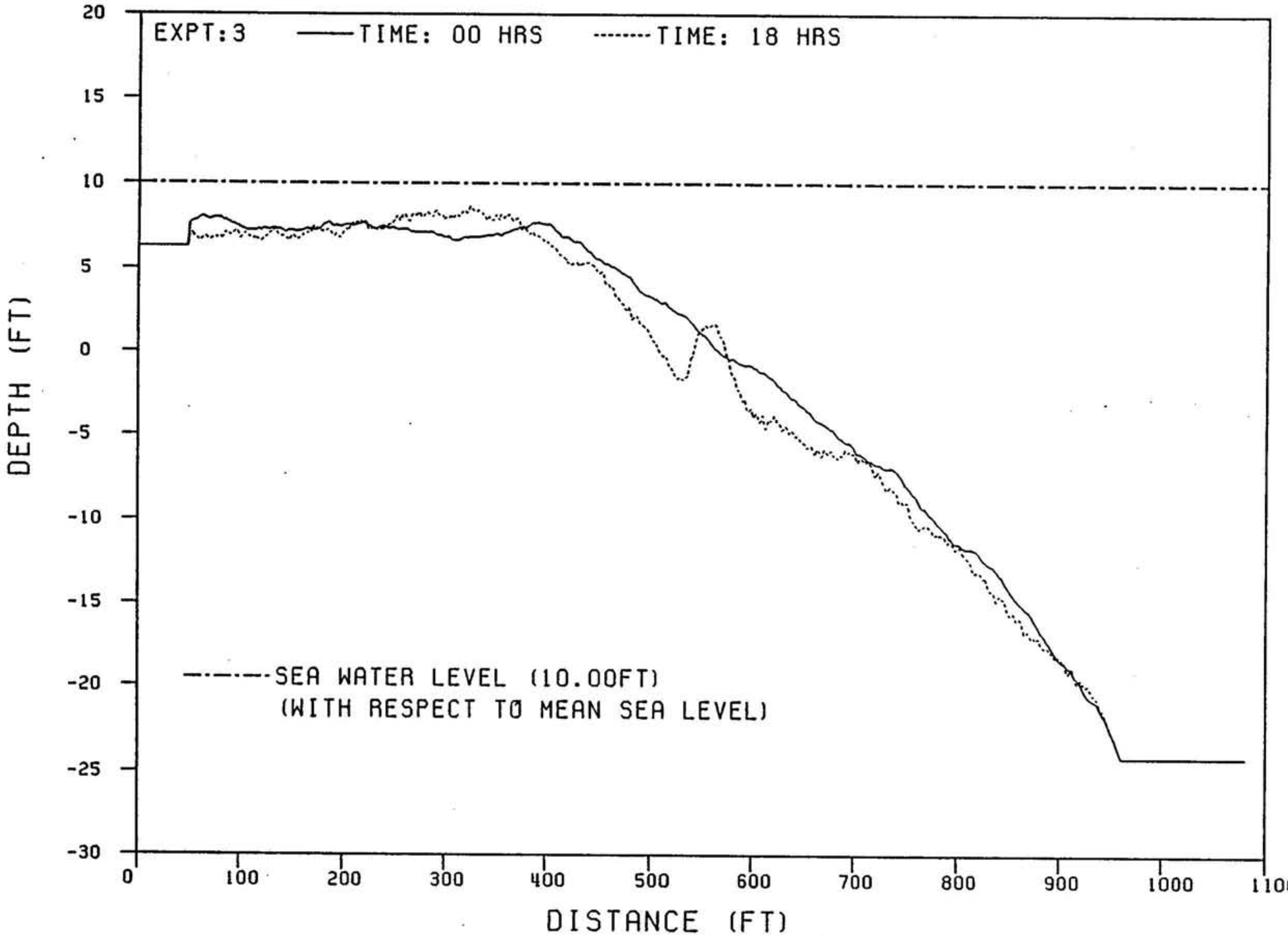


Figure 7.13: Experiment E3, Mean profiles at 00 and 18 hours.

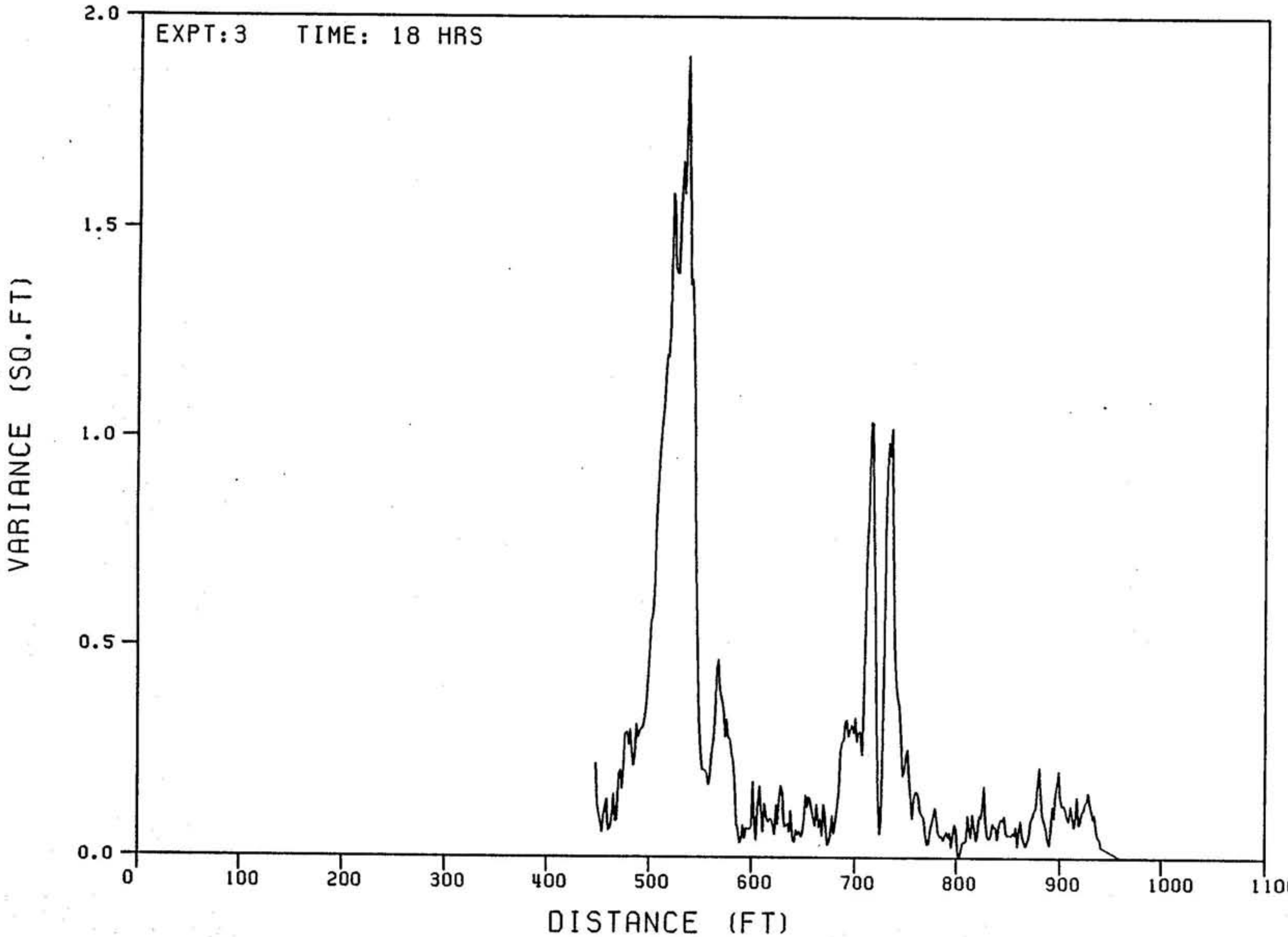


Figure 7.14: Experiment E3, profile variance at 18 hours

where z is the elevation and the overbars denote averaging. It can be observed that the profiles exhibited substantial variations around the position of the longshore bar. Significant erosion extended up to about 700 feet.The MSL shoreline retreated about 60 feet and it was noted that the elevation of the crest of the bar was above that of the MSL. Net change in the mean profile was -615 ft^3/ft (which is equivalent to 0.041 feet in model units). In contrast to Experiment E2, there was both erosion as well as accretion over the crest of the barrier island, extensive erosion of the sloping beach and no accretion far offshore.

7.9 Experiment E4

The experimental conditions were the same as for Expt. E3 except that the storm surge level was raised to 11.5 feet, i.e., the overtopping level was increased to 5.2 feet.

A mild longshore bar developed within 2 hours. The position of the bar oscillated till about 10 hours before flattening out to a more gradual shape.

The final mean profile indicates that there was slight erosion till 100 feet which was followed by deposition (up to 1.5 feet) till 330 feet (see Fig.7.15). The crest of the barrier island eroded in the range 330-400 feet (with erosion levels reaching up to 1 foot). Beyond this, the entire profile was eroding except in the region 700-760 feet which exhibited slight deposition. Extensive erosion (up to 3.5 feet) occurred in the range 500-650 feet. The entire sloping beach became undulatory. The elevation of the crest of the primary bar coincided with that of the initial beach at that position. The final position of the crest of the primary bar was 500 feet (which was landward

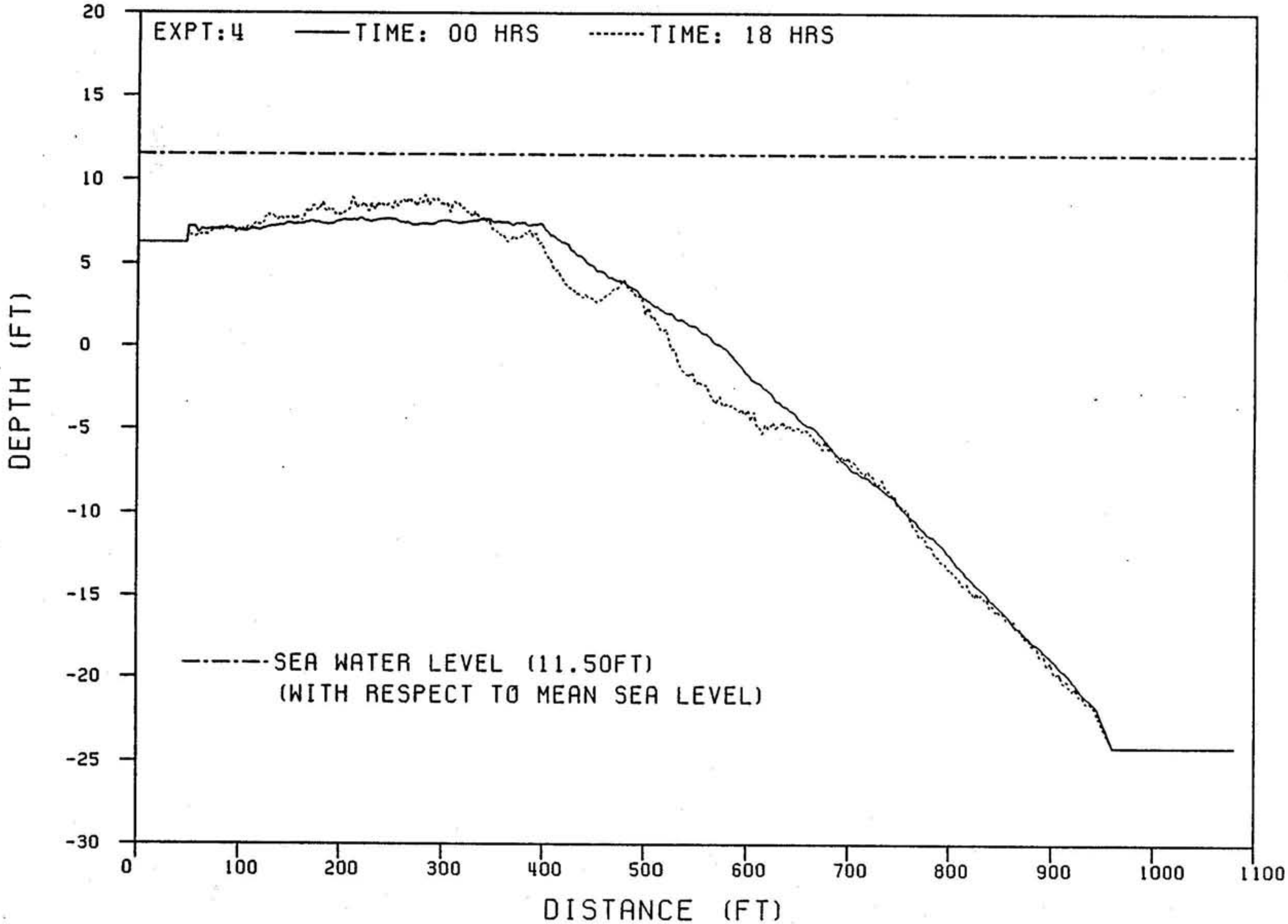


Figure 7.15: Experiment E4, Mean profiles at 00 and 18 hours.

of the MSL shoreline) and the final height was about 2 feet. A secondary bar was discernible landward of the slope break of the initial profile with its trough at $\sim$ 380 feet and its crest at $\sim$ 390 feet. The MSL shoreline retreated about 50 feet. The net change in the mean profile was - 425 ft^3/ft (which is equivalent to 0.03 feet in model units).

The patterns of erosion and deposition were very similar to those of Experiment E3 except that the longshore bar was smaller and gradual.

7.10 Experiment E5

The experiment simulated a storm of 18 hours duration with a peak surge of 11.3 feet. Waves were allowed to mold the initially linear-sloped beach to near-equilibrium by impinging upon the beach for 6 hours at MSL conditions prior to the advent of the storm. The rates of rise and fall of the surge were the same.

The near-equilibrium profile (at 6 hours) prior to the storm exhibited a prominent longshore bar which persisted when the water level was raised to 0.5 feet (6-8 hours). However, the bar disappeared when the water level was raised further (to 2.9 feet) in the next stage of the storm (8-10 hours). No prominent longshore bar was evident as the water level was raised (to 11.3 feet) and lowered (back to 2.9 feet) over the next 12 hours. A prominent longshore bar again developed when the storm surge subsided to 0.5 feet.

Comparison is made here of the mean profiles at 06 hours (just prior to the storm) and at 24 hours (just after the surge had subsided). There was washover of sand over the crest of the barrier island with the amount of deposition increasing up to $\sim$ 2 feet towards the ocean-side of the barrier island (see Fig. 7.16). The region 390-460 feet exhibited slight erosion which was followed by mild deposition till 500 feet. There was substantial erosion (up to 2 feet) in the range 520-680 feet and accretion (up to 1 foot) further offshore except for mild erosion in the range 720-770 feet. A prominent, 4 feet high longshore bar was evident with its crest at about 730 feet. Another small, very mild-sloped, broad-crested bar formed in the region 460-500 feet. The MSL shoreline retreated about 20 feet. The profile subsequent to the storm was quite similar to that prior to the storm especially in terms of the longshore bar position, size and shape. The storm caused washover of sand over the crest of the barrier island. Net change was +60 ft^3/ft (which is equivalent to 0.004 feet in model units).

7.11 Experiment E6

The experimental conditions were the same as E1 except that a narrow-banded spectrum of irregular waves of 7 feet significant wave height and carrier period of 7.6 seconds was allowed to impinge upon the barrier island.

Swash excursions caused deposition landward of the shoreline in the range 410-550 feet, with maximum deposition reaching up to $\sim$ 2 feet (see Fig. 7.17). Seaward of the shoreline, the region 550-700 feet exhibited erosion and this was followed by deposition still offshore. The crest of the 2 feet high longshore bar was at about 750 feet. The formation of the bar was not immediate (as was the case in Experiment E1) and took about 12 hours to develop. There was no change of the MSL shoreline.

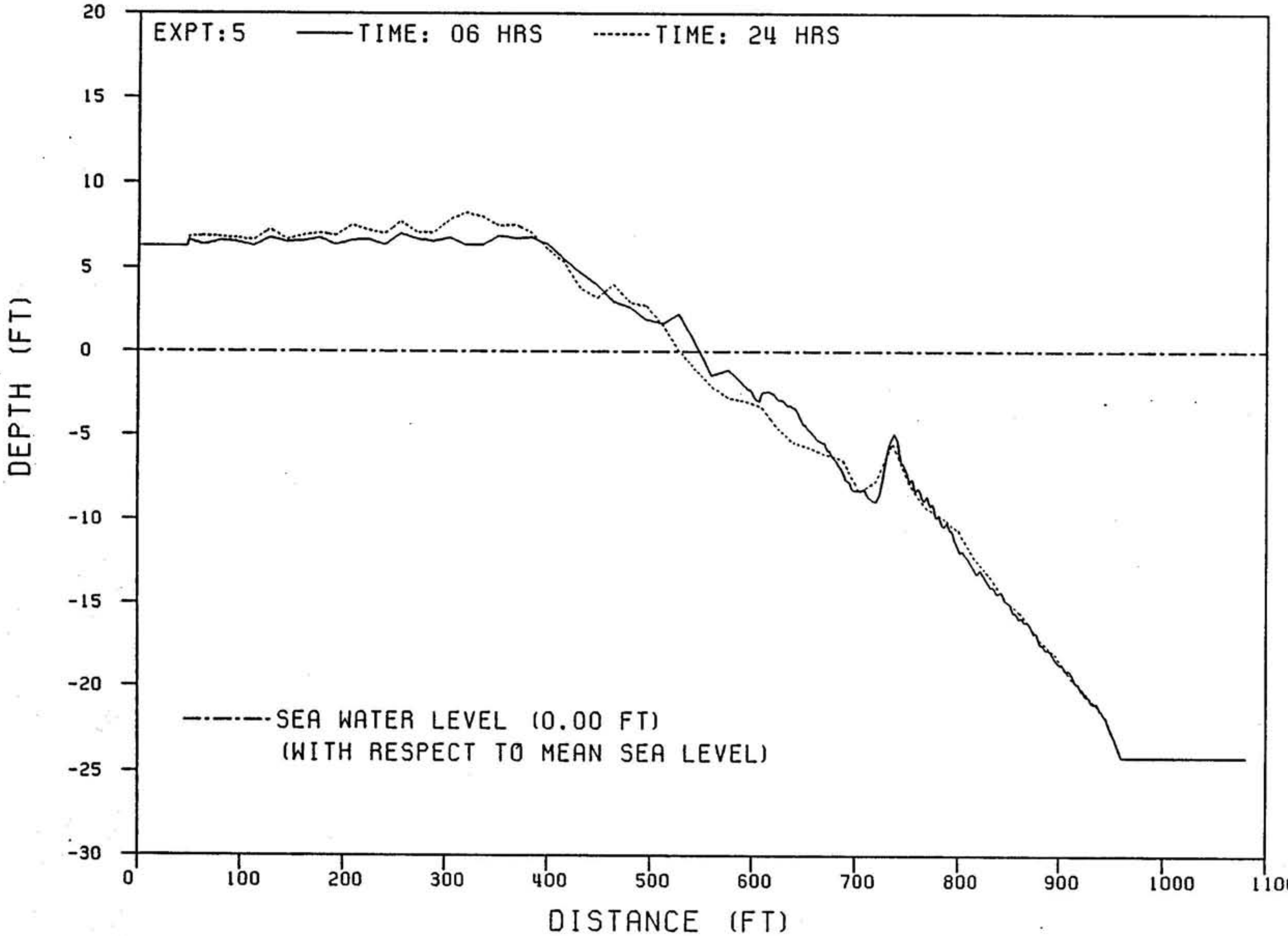


Figure 7.16: Experiment E5, Mean profiles at 06 and 24 hours.

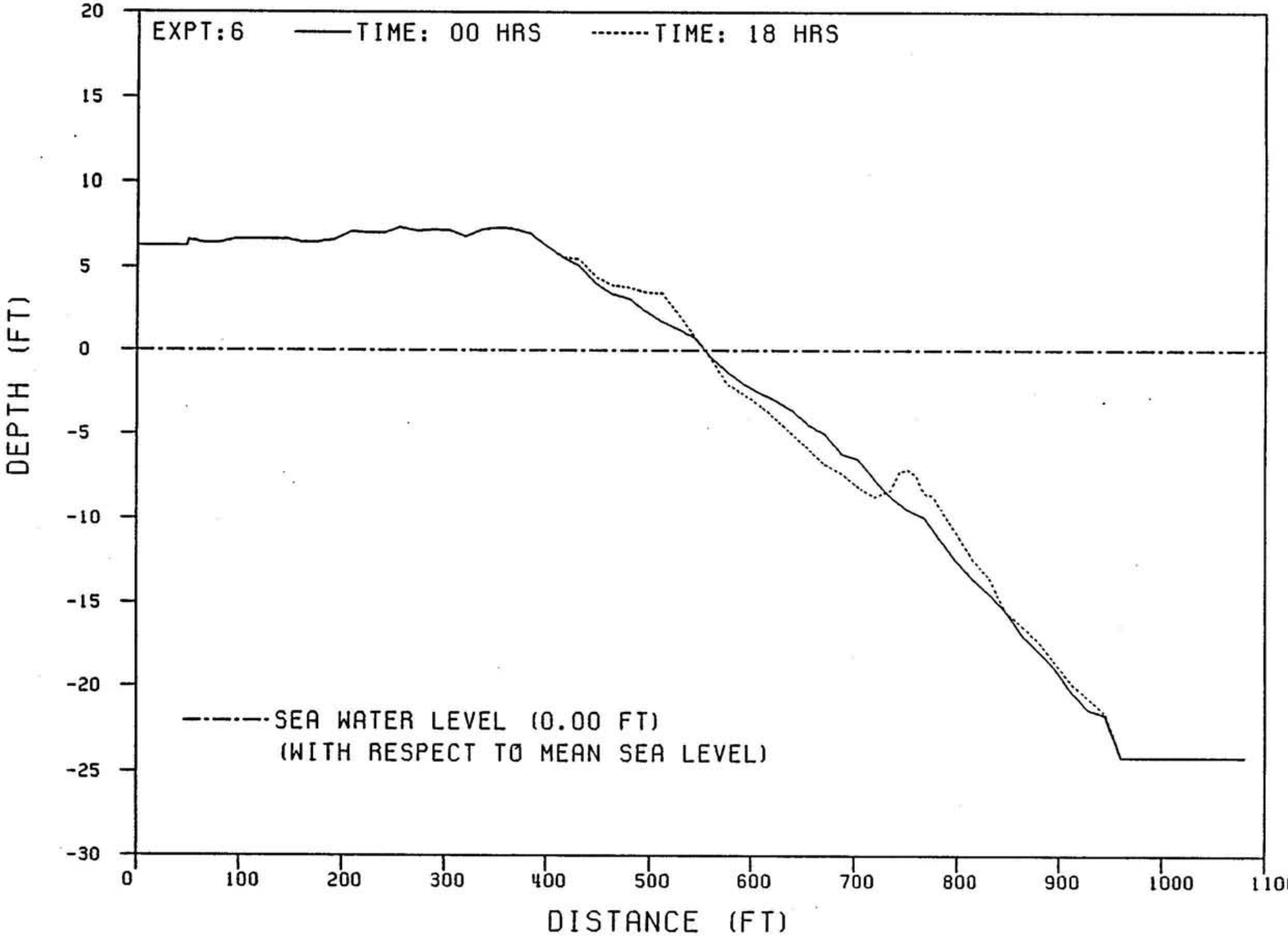


Figure 7.17: Experiment E6, Mean profiles at 00 and 18 hours.

The net change in the mean profile was +115 ft^3/ft (which is equivalent to 0.008 feet in model units).

The patterns of deposition and erosion were similar to Expt. E1 except that the changes were smaller, the longshore bar was much less prominent (and the inflexion of the bed profile was only on the landward side of the bar) and a greater portion of the beach face was affected by swash mechanisms.

7.12 Experiment E7

The experimental conditions were the same as E2 except that irregular waves were used with a carrier period of 8 seconds. Thus, the onset of wave action caused mild overtopping over the crest of the barrier island.

Washover occurred over the crest of the barrier island, with the deposition increasing from the bay-side towards the ocean-side (see Fig. 7.18:). Accretion was more than 1 foot in the region 200-350 feet. Substantial erosion (up to 3 feet) occured from the shoreline (which was now at 400 feet) till about 680 feet. There was deposition of about 2 feet at around 700 feet and this was followed by decreasing amounts of accretion still further offshore. A small and very mild-sloped offshore bar was discernible with its crest at about 720 feet. The formation of the bar was not immediate and took about 16 hours to develop. The MSL retreated about 30 feet. Net change in the mean profile was +80 ft^3/ft.

Again, the patterns of erosion and deposition were similar to those of Experiment E2 except that the changes were more subdued and the longshore bar was much less

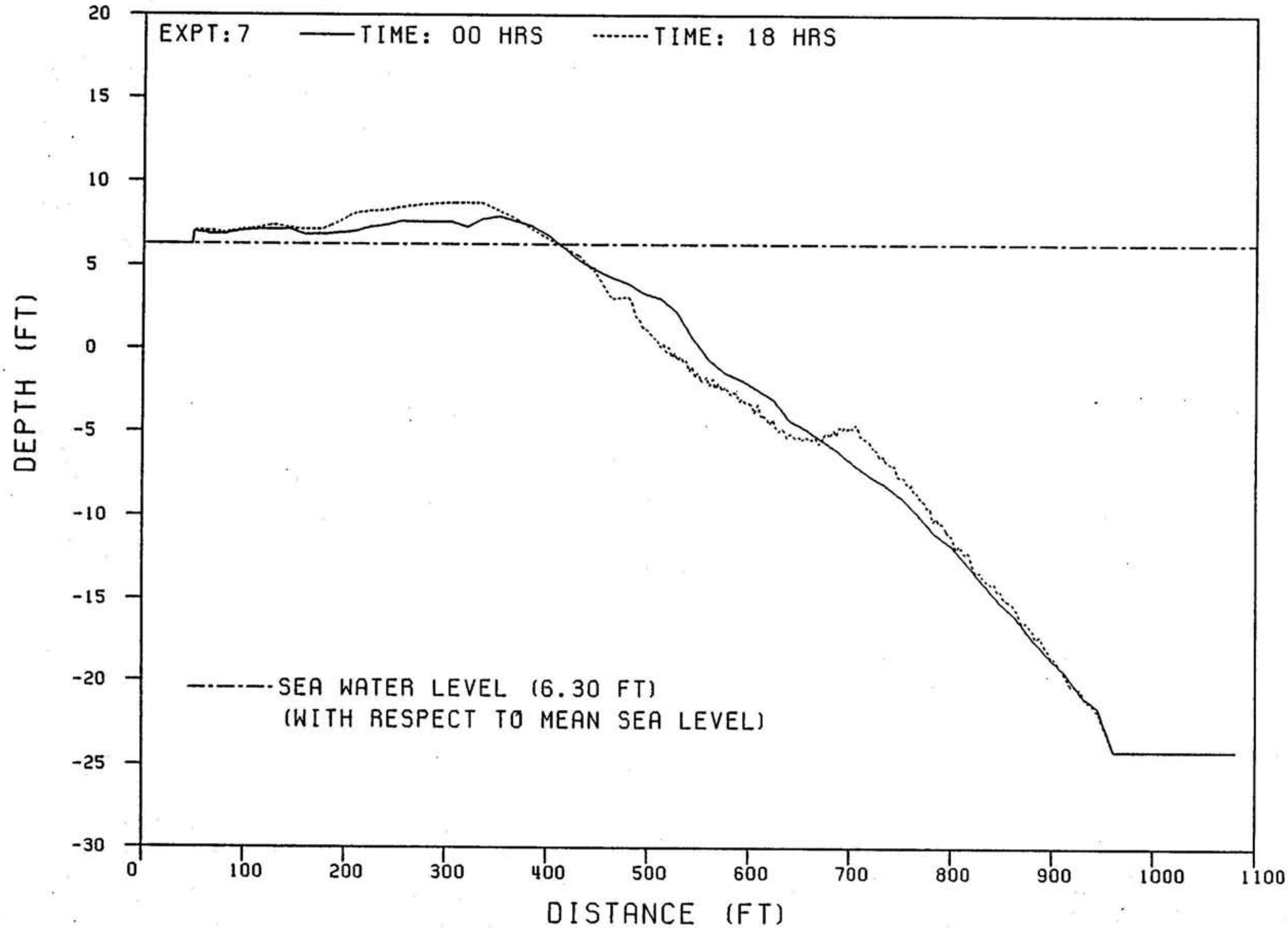


Figure 7.18: Experiment E7, Mean profiles at 00 and 18 hours.

prominent (with the inflexion in the bed profile occurring on the landward side of the bar only).

7.13 Experiment E8

The experimental conditions were the same as E3 except that a narrow-banded spectrum of irregular waves was used with a carrier period of 8 seconds.

The crest of the barrier island exhibited mild uniform accretion (about 0.5 feet) all over (see Fig. 7.19). There was substantial erosion (up to 2.5 feet) from 400 to about 620 feet, followed by decreasing amounts of deposition in the offshore. No longshore bar was evident. The MSL shoreline retreated about 25 feet. Net change was +95 ft^3/ft (which is equivalent to 0.006 feet in model units).

Patterns of deposition over the crest of the barrier island were similar to Experiment E3. However, unlike Experiment E3 where the entire sloping part of the profile was eroding, there was deposition offshore of about 600 feet in this experiment. Also, Experiment E3 had a prominent longshore bar while no longshore bar formed here and changes in the beach profile were much subdued as compared to those in Experiment E3.

7.14 Experiment E9

The experimental conditions were the same as E4 except that a narrow-banded spectrum of irregular waves were generated with a carrier period of 8 seconds.

Overtopping caused washover of sand up to $\sim$ 1.5 feet over the crest of the barrier

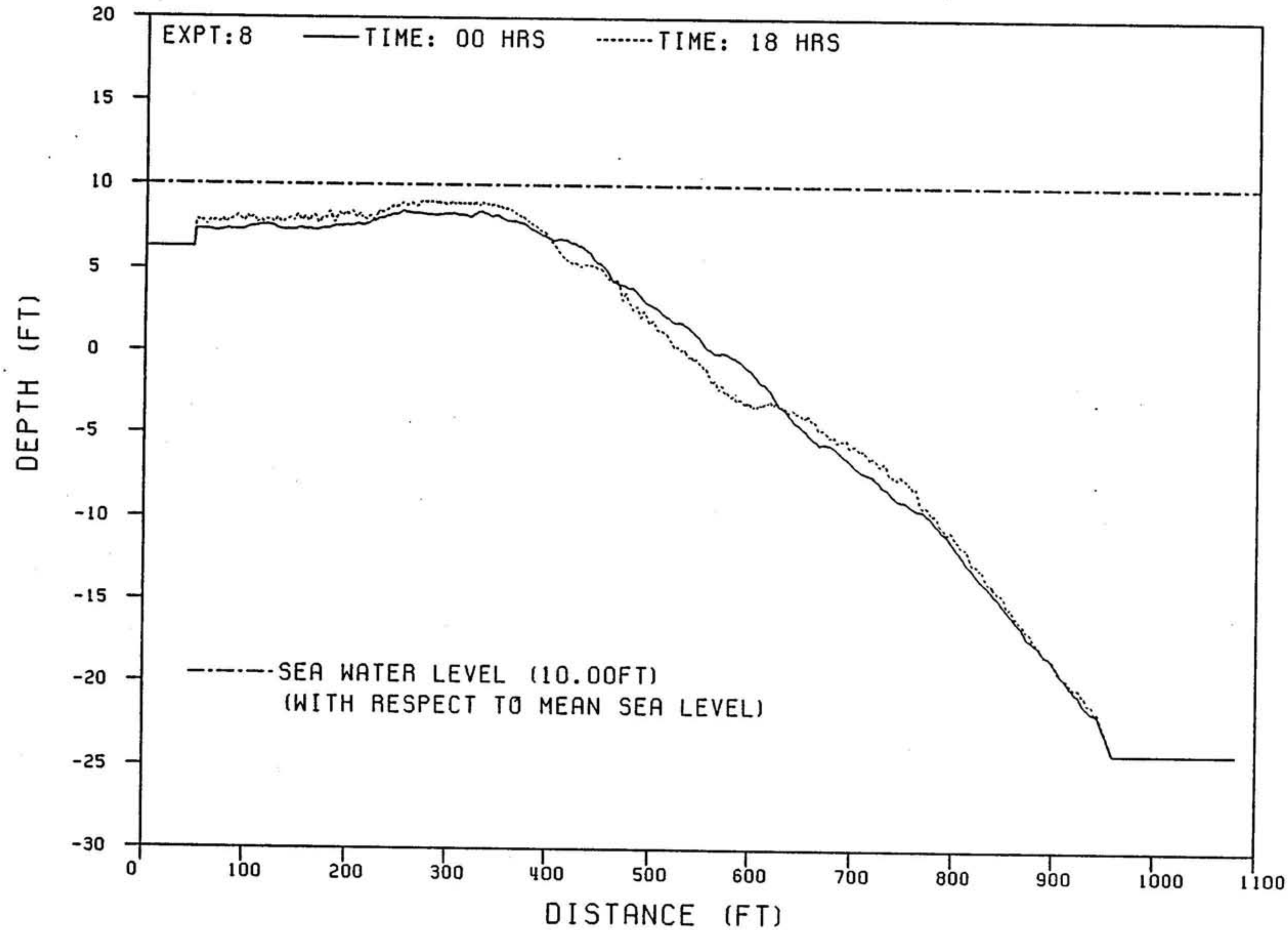


Figure 7.19: Experiment E8, Mean profiles at 00 and 18 hours.

island till 380 feet, with the deposition again increasing from the bay-side to the ocean-side (see Fig. 7.20). This was followed by substantial erosion (up to 2.5 feet) in the range 400-650 feet and mild, decreasing amounts of deposition still further offshore. No longshore bar was evident. The MSL shoreline retreat was $\sim$ 70 feet. The net change was -50 ft^3/ft (which is equivalent to 0.003 feet in model units).

Patterns of deposition over the crest of the barrier island were similar to those of Experimnt E4. However, the bed profile of Experiment E9 was devoid of the presence of a longshore bar and the profile exhibited mild accretion beyond about 650 feet unlike Experiment E4. Changes in Experiment E4 were much more prominent when compared to those in Experiment E9.

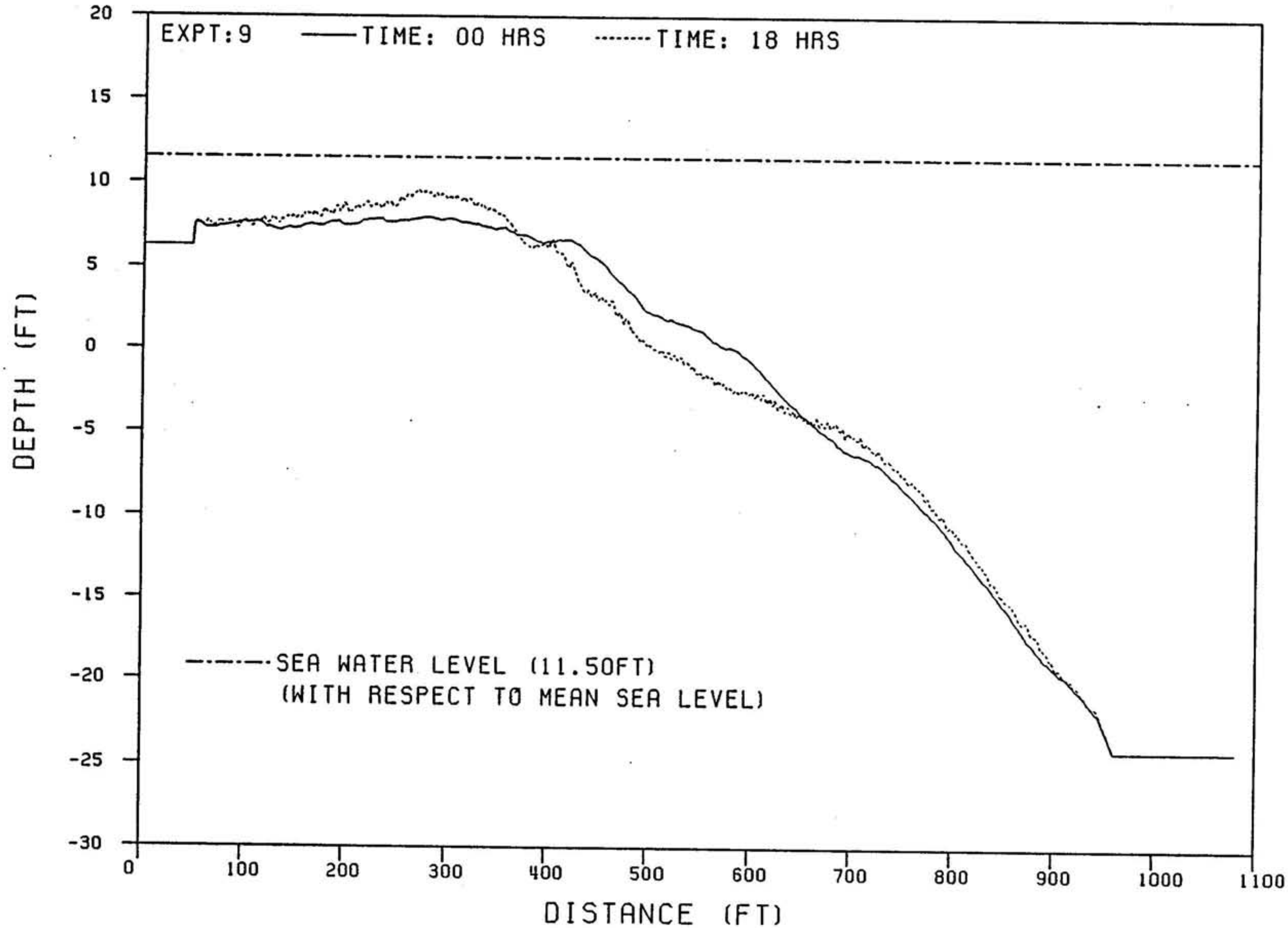


Figure 7.20: Experiment E9, Mean profiles at 00 and 18 hours.

Chapter 8

SUMMARY AND CONCLUSIONS

This report describes the results of a series of nine wave tank tests to investigate the evolution of beach and barrier island profiles under the action of various wave and tide conditions. The range of tests has included steady and time-varying normal and storm water levels and regular and irregular waves. Overtopping of the barrier island occurred for the elevated water levels. Sand with a mean size of approximately 0.2 millimeters was used in all tests. The crest of the model barrier island was 25 ft. wide and a nominal model to prototype scale of 1:16 was considered. The beach for all tests was initially planar with a slope of 1:19. For each test, documentation included the incident waves and beach profiles at intervals of 0.5 hours. In addition, velocities over the barrier island were measured in some of the tests. The detailed beach profile measurements are presented in a separate Appendix.

The first series of four experiments maintained the wave characteristics reasonably constant while increasing the water level from test to test. Water levels tested were, in prototype units, 0 ft., 6.3 ft. (the same as the barrier island crest), 10.0 ft., and 11.3 ft. For Experiment 1 with the normal water level (0 ft.), a prominent bar formed and a fairly substantial triangular berm was established immediately landward of the waterline. The profile evolution for the remaining tests may be interpreted in light of the forces which caused profile evolution in the first test. For the second test with the water level at the barrier island crest, a bar of approximately the same height but of much greater width formed. Since overtopping of the barrier island could occur, the sediment that had formed a triangular berm in the first experiment was deposited over the seaward portions of the barrier island. In Experiment 3 with a water level of 10 ft., the bar was similar to that in Experiment 2; however, sand was transported over the barrier island resulting in substantial losses of sediment to the beach system. Experiment 4, the final test with a steady water level and regular waves, extended the trend established in the preceding two tests with the exception that the offshore bar was considerably more subtle.

Experiment 5 was conducted with regular waves and a time- varying waterlevel which simulated the rising and falling hydrograph associated with a storm. There were similarities and differences between this and previous experiments which contribute to understanding the causes of bar formation. During periods of slow changes in water level, a prominent bar formed on both rising and falling water levels. However, during those portions of the hydrograph when the water level was either rising or falling fairly rapidly, the bar became much more subdued to nonexistent, apparently because the processes of bar formation were not able to keep pace with the changing water level. There was substantial loss of sediment over the barrier island but of course less than for the case of an elevated water level over the entire testing period.

Experiments 6 through 9 replicated approximately the conditions of Experiments 1 through 4 with the exception that the waves were irregular. The following discussion focuses on the similarities and differences between the tests with regular and irregular waves. The processes at the landward end and over the barrier island were substantially the same for regular and irregular waves. Without overtopping (Experiment 6), the berm formed was less distinct than with regular waves. For the remaining experiments in which overtopping occurred, sand was carried over the barrier island where some was deposited and a portion transported beyond the island. The major difference occurred in the characteristics and degree of bar formation. With irregular waves, the bar was less prominent and less distinct for the case of no overtopping as compared to the regular wave case. In those cases in which overtopping occurred, the bar feature was more subtle with the mean water level at the barrier island crest elevation and was not present at all during Experiments 8 and 9 with water elevations of 10.0 and 11.3 ft., respectively.

Dissipation of wave energy acts as an effective sediment- mobilizing agent and in conjunction with other (non wave-driven) currents, which are apt to be present in nature, has a greater transport potential. Under these conditions, overtopping can result in a serious erosive impact to the barrier island system. This hypothesis was tested and validated by conducting additional tests combining the actions of waves and currents. Data from these tests will be presented in a separate report. The data presented here provide a basis for the development and calibration of a numerical model to simulate overwash of barrier islands during storms. In addition to these data, which are presented in much greater detail in the accompanying (separate) Appendix, the principal results from these experiments include further evidence of the mechanisms of bar formation. It appears that contrary to other proposed causes, offshore bars are simply break-point bars and that the return flow of mass transport, sometimes termed "undertow" and the relative constancy of wave breaking location play important roles in bar formation.

Bibliography

[1] Allsop N.W.H., 1986, Sea Walls: A literature review. Hydraulics Research, Wallingford, Report No. EX 1490.

[2] Armon J.W., 1975, The dynamics of a barrier island chain, Prince Edward Island. Canada, Ph. D. Dissertation, McMaster University, Canada.

[3] Battjes, J.A. and Stive, M.J.F., 1985, Calibration and verification of a dissipation model for random breaking waves. J. Geophysical Research, Vol 90, No. C5, pp. 9159-9167.

[4] Bijker, E.W., 1967, Some considerations about scales for coastal models with movable bed. No. 50, Delft Hydrographic Laboratories, Delft, The Netherlands.

[5] Coastal Engineering Research Center, 1979, U.S. Army Corps of Engineers, Coastal Hydraulic Models. Special Report No. 5, Chapter V.

[6] Collins, J.I., 1970, Probabilities of breaking wave characteristics. Proc. 12^{th} Int Conf Coastal Eng., Vol. 1, pp. 399-412.

[7] Dally, W.R. and Dean, R.G., 1986, Transformation of random breaking waves on surf beat. 20^{th} Int Conf Coastal Eng, Vol. 1, pp. 109-123.

[8] Dally, W.R. and Dean, R.G., 1988, Closed-form solutions for the probability density of wave height in the surf zone. Proc 21^{st} Int Conf Coastal Eng., Vol. 1, pp. 807-821.

[9] Dally, W.R., 1990, Random breaking waves: a closed-form solution to planar beaches. Coastal Engineering J., Vol. 14, No.3, pp. 233-263.

[10] Dalrymple, R.A. and Thompson, W.W., 1976, Study of equilibrium beach profile. Proceedings of the 12th Coastal Engineering Conference, Honolulu.

[11] Davis, R.A., Burke, R.B. and Brame, J.W., 1979, Origin and development of barrier island on west central peninsula of Florida. AAPG-SEPM Annual Convention, Abstract, pp.74-75.

[12] Dean, R.G., 1976, Heuristic models of sand transport in the surf zone. Proceedings of the Conference on Engineering Dynamics in the Coastal Zone, Sydney.

[13] Dean, R.G., 1976, Beach erosion: causes, processes, and remedial measures. CRC Critical Reviews in Environmental Control, Vol. 6, pp. 259-296.

[14] Dolan R., 1972, Barrier dune system along the Outer Banks of North Carolina: a reprisal. Science, Vol 176, pp. 286-288.

[15] Fan, L.-N. and Le Mehaute, B., 1069, Coastal movable bed scale model technology. Tetra Tech Report TC-131, Tetra Tech, Inc., Pasadena, Calif.

[16] Fisher, J.J., 1968, Barrier island formation: discussion. Geol. Soc. Amer. Bull. Vol. 79, pp. 1421-1426.

[17] Gierloff-Emden, H.G., 1961, Nehrungen und Lagunen, Petermanns Geog. Mitt., 105(2), pp. 81-92; 105(3), pp 161-176.

[18] Goddet, J. and Jaffry, P., 1960, Similitude laws for sediment transport under the simultaneous action of waves and currents, La Houille Blanche, Grenoble, France. Vol. 15, No. 2, pp. 136-147.

[19] Godfrey P.J. 1970, Oceanic overwash and its ecological implications on the Outer Banks of North Carolina. Office of Natural Science Studies, National Park Service, Washington D.C., 37p

[20] Godfrey, P.J., 1976 a, Comparative ecology of East Coast barrier islands: hydrology, soils, vegetation, in barrier islands and beaches. The Conservation Foundation, Washington, D.C. pp. 5-34.

[21] Godfrey, P.J. and Godfrey, M.M., 1976 b, Barrier island ecology of Cape Lookout National Seashore and vicinity, North Carolina. National Park Service Scientific Monograph Series, No. 9.

[22] Godfrey, P.J., 1978, Management guidelines for parks on barrier beaches. Parks, Vol. 2, pp. 5-10.

[23] Graaff, J. van de, 1977, Dune erosion during a storm surge. Coastal Engineering (Journal), Vol. 1, No. 2.

[24] Hayes M.O. 1967, Hurricanes as geological agents: case studies of Hurricane Carla 1961, and Cindy 1963. Report of Investigations No. 61, Bureau of Economic Geology, University of Texas, Austin (TX).

[25] Herbich J.B., and Ko S.C., 1968, Scour of sand beaches in front of seawalls. Proc. 11th Int Conf Coastal Eng., London, England, pp. 622-643.

[26] Hicks S.D., 1972, On the classification and trends of long period sea level series. Shore & Beach, Vol. 40, pp. 20-23.

[27] Horikawa K. and Kuo C.T., 1966, A study of wave transformation inside surf zone. Proc 10th Int Conf Coastal Eng, Vol. 1, pp. 217-233.

[28] Hughes S.A. and Chiu T.Y., 1981, Beach and dune erosion during severe storms, Coastal and Oceanographic Eng Dept, University of Florida, Tech Report No. UFL/COEL - TR/043

[29] Kadib A., 1963, Beach profile as affected by vertical walls. Tech. Memo. No. 134, Beach Erosion Board, Corps Of Engineers.

[30] Kemp P.H., 1960, The relationship between wave action and beach profile characteristics. Proc 7th Int Conf Coastal Eng., The Hague, Vol. 1, pp. 262-277.

[31] Kemp, P.H. and Plinston, D.T., 1968, Beaches produced by waves of low phase difference. Proceedings of the American Society of Civil Engineers, Journal of the Hydraulics Division.

[32] King C.A.M., 1972, Beaches and Coasts. Second Ed., St. Martins Press, New York, N.Y.

[33] Kohler, R.R. and Galvin, C.J., J., 1973, Berm-bar criterion. Unpublished, CERC Laboratory Report, 70 p.

[34] Leatherman, S.P., 1976, Barrier island dynamics: overwash processes and aeolian transport. Proceedings of the 15th Coastal Engineering Conference, Honolulu, pp. 1958-1974.

[35] Leatherman, S.P., 1977, Overwash hydraulics and sediment transport. Coastal Sediments 77, Fifth Symposium of the Waterway, Port, Coastal and Ocean Division of ASCE, pp. 135-148.

[36] Leatherman, S.P., 1979a, Barrier island handbook. National Park Service, Cooperative Research Unit, The Environmental Institute, University of Massachusetts at Amherst.

[37] Leatherman S.P., 1979 b, Beach and dune interaction during storm conditions. Q. J. Engineering Geology, Vol. 12, pp. 281 - 290.

[38] Meyer R.E., (ED.), 1972, Waves on beaches and resulting sediment transport. Academic Press, New York.

[39] Noda, K.E., 1972, Equilibrium beach profile scale-model relationship. Proceedings of the American Society of Civil Engineers, Journal of the Waterways, Harbors and Coastal Engineering Division, Vol. 98, No. WW4, pp. 511-528.

[40] Parchure T.M., Dean R.G., and Srinivas R., 1991a, Laboratory study of overwash on barrier islands. Progress Report Submitted To Beaches and Shores Resource Center, Tallahassee, Florida, University of Florida, Coastal and Oceanographic Engineering Dept, Report No. UFL/COEL-91/006.

[41] Pierce, J.W., 1968, Sediment budget along a barrier island chain. Sedimentary Geology, Vol. 3, No. 1, pp. 5-16.

[42] Saville, T. Jr., 1950, Model studies of sand transport along an infinitely straight beach. Transactions Geophysical Union, Vol. 31, No. 4.

[43] Schwartz R.K., 1975, Nature and genesis of some washover deposits. CERC Technical Memo. 61.

[44] Srinivas, R., Dean R.G. and Parchure T.M., 1992, Barrier island erosion and overwash study - effect of seawalls, volume 2. University of Florida, Coastal and Oceanographic Engineering Dept, Report No. UFL/COEL - 91/011.

[45] Stauble, D.K., 1989, Barrier islands: progress and management. American Society of Civil Engineers.

[46] Swart D.H., 1976, Predictive equations regarding coastal transports. 15th Int Conf Coastal Eng., Honolulu, Vol. 12, pp. 1113-1132.

[47] Swift, D.J.P., 1975, Barrier island genesis: evidence from the central Atlantic Shelf, Eastern U.S.A. Sedimentary Geology, Vol. 14, pp. 1-43.

[48] Valembois, J., 1960, Etude sur modele du transport littoral conditions de similitude. Proceedings of the 7th Conference on Coastal Engineering, American Society of Civil Engineers, Vol. 1, pp. 307-317. (Translation No. 65-7 available at U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.)

[49] van der Meulen, T. and Gourlay, M.R., 1968, Beach and dune erosion tests. Proc 11th Int Conf Coastal Eng, London, England, pp. 701-707.

[50] van der Meulen, T. and Gourlay, M.R., 1969, Beach and dune erosion test report. Delft Hydraulics Laboratory, Publication 61.

[51] Vellinga, P., 1978a, Movable bed model tests on dune erosion. Delft Hydraulics Laboratory, Publication No. 205.

[52] Vellinga, P., 1978b, Movable bed model tests on dune erosion. Proceedings of 16th Coastal Engineering Conference, Hamburg, pp. 2020-2039.

[53] Vellinga, P., 1982, Beach and dune erosion during storm surges. Delft Hydraulics Laboratory, Publication No. 276.

[54] Williams, P.J., 1978, Laboratory development of a predictive relationship for washover volume on barrier island coastlines. M.E. Thesis submitted to the University of Delaware.

[55] Yalin, S., 1963, Method for selecting scales for nodels with movable bed involving wave motion and tidal currents. Proceedings of the 10th Congress of the International Association for Hydraulic Research, Vol. 1, pp. 221-229.