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BARRIER ISLAND EROSION AND OVERWASH STUDY - EFFECT OF SEAWALLS, VOLUME 2

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16. Abstract This is the second of a pair of reports documenting the effects of storms on beach systems including the presence of seawalls. With the aim of simulating the effects of overwash on barrier islands with seawalls and characterizing their response, a series of eight experiments was conducted at the Coastal Engineering Laboratory of the University of Florida. The barrier island was simulated by a 400 feet wide horizontal crest and an initially uniform mildly-sloped (1:19) beach. The effects of positioning the seawall at two different locations as well as the effects of various storm surge levels and accompanying overtopping were investigated. Experiments were conducted with both regular and irregular storm waves. With the seawall located at the slope break between the crest and the sloping beach of the barrier island, and the crest of the seawall just submerged in sand, the effects on the sediment transport process were found to be minimal. For the same position of the seawall but with the crest of the seawall raised above the surrounding ground level, overtopping caused washover of sand indicating substantial transport in suspension. Increased levels of overtopping tended to accentuate bed profile changes but supress bar formation (as did irregular waves). Positioning the seawall at the Mean Sea Level shoreline caused significant scour both immediately landward as well as immediately seaward of the seawall. A prominent scour trough developed further seaward. The longshore bar was highly three-dimensional. It appears that seawalls need to be located adequately landward of the shoreline to discharge their function effectively without adverse effect to the beach. In addition, concerns for safety warrant the presence of an adequate buffer-zone between the seawall and the upland property.

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Contents

1 BACKGROUND **6**

2 PERTINENT STUDIES: A BRIEF OVERVIEW **12**

3 PRINCIPLES **16**

4 SCOPE OF THE PRESENT STUDY **18**

5 METHODOLOGY **22**

5.1 LABORATORY FACILITY 22

5.1.1 Beach profiling 24

5.2 EXPERIMENTAL CONDITIONS 25

5.3 OBSERVATIONS AND DISCUSSION 25

5.3.1 Experiment S1 26

5.3.2 Experiment S2 35

5.3.3 Experiment S3 37

5.3.4 Experiment S4 39

5.3.5 Experiment S5 41

5.3.6 Experiment S6 41
5.3.7 Experiment S7 43
5.3.8 Experiment S8 45

6 SUMMARY AND CONCLUSIONS **52**

6.1 Summary 52
6.2 Conclusions 53

List of Figures

4.1 Idealized initial beach profile in the wave tank for each experiment. . 19

5.1 Schematic Layout and Cross-Section of Wave Tank 23

5.2 Mean profile, Expt S1, at 00 and 18 hours 28

5.3 Expt S1, change in 18 hours 29

5.4 Expt S1, Profile B1, T=00-06 hr 30

5.5 Expt S1, Profile B1, T=06-12 hr 31

5.6 Expt S1, Profile B1, T=12-18 hr 32

5.7 Expt S1, Longshore variance at 00 hours 33

5.8 Expt S1, Longshore variance at 18 hours 34

5.9 Initial and final mean profiles, Experiment S2 36

5.10 Mean profile, Expt S3, at 00 and 18 hours 38

5.11 Mean profile, Expt S4, at 00 and 18 hours 40

5.12 Mean profile, Expt S5, at 00 and 18 hours 42

5.13 Mean profile, Expt S6, at 00 and 18 hours 44

5.14 Mean profile, Expt S7, at 00 and 20 hours 46

5.15 Mean profile, Expt S8, at 04 and 22 hours 48

5.16 Variance of the mean profile at 22 hours, Experiment S8 50

5.17 Failure of seawall due to improper end sealing 51

List of Tables

1.1 Estimated storm surge along Florida shoreline for Category 5 storms 7

5.1 Experimental Conditions of all Runs 25

Chapter 1

BACKGROUND

As a practical application, seawalls may form a viable option for coastal communities as a method of limiting shoreline recession. Coastal engineers are frequently called upon to establish storm (hurricane) design criteria in promulgating, for example, local/state government policies for beachfront construction. 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 given in Table 1.1. Peak storm surge elevations at these twenty locations range from 10.5 to 26.2 feet. The prospect of augmented, long-term effective sea level rise again prompts the need for effective design of "setback lines" and the need for protection of existing upland property. Due to their low crest elevations (generally in the range 5-15 feet above mean sea level), Florida's barrier islands are especially vulnerable to storm surge effects. Even though seawalls have been used for over a century in several locations, surprisingly, there is no consensus about their effectiveness and impacts on adjacent shorelines. Seawalls are designed to protect the upland, and, in the presence

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: Estimated storm surge along Florida shoreline for Category 5 storms

of a pervasive erosional trend will eventually result in loss of the beach. Communities, while making decisions on whether to permit seawalls for coastal protection, are justifiably confused by the widely- contradictory claims of scientists as consistent and reliable data seem to be lacking. Seawall design considerations should include assessing long-term shoreline trend, coastal geomorphology (e.g., cliffed coastlines of California vis- a-vis beaches with lowlands and dunes of the Gulf coast), aesthetics and the long-term viability of the fronting beach. Considerations should include the prevailing wave climate, typical storm surge levels, sediment size and beach shape to ascertain position with respect to the shoreline. The sediment budget with the presence of the seawall affects the (a)longshore transport which can translate into "end-effects": flanking, updrift accretion and downdrift erosion, and (b)cross-shore transport with associated "frontal effects": scour trough or toe scour, profile deflation and longshore bar formation. The height, length and material of the seawall can then be specified taking into account the required degree of protection and costs.

Effective field monitoring of the effects of seawalls on beaches and the nearshore should optimally encompass pre- and post- construction data. As the time-scales of change in field observations can be very large (up to years), reliable monitoring of existing seawalls can be expensive, laborious and time- consuming. These are generally beyond the scope of most locally- financed projects. As an alternative to the aforementioned field monitoring, a laboratory investigation can provide quantitative predictions for different storm conditions as this offers an almost ideal environment for controlling key forcing parameters to investigate their effects and weigh their importance. Obviously, the forcings are varied and complex. Thus, a limited laboratory program will necessarily be constrained in scope. However, a laboratory study can provide controlled conditions, a verifiable data-base and, in addition, can be site-specific. In any case, it can definitely assist in attaining a higher degree of confidence for making predictive estimates. Ideally, laboratory studies would be coupled with field observations to provide a basis for comparative evaluation.

The effects of seawalls on adjoining beaches, cross-shore and longshore sediment transport rates, steepening of the nearshore, etc. have been well-examined. As protection of the upland is the primary purpose of building a seawall, it is quite surprising to find that cases of overtopping have not been well investigated. Overtopping during storm events may result in significant reconfiguration of low-lying areas as the dynamics of the interaction between waves and the structure will change, for example, the seaward-directed current close to the bottom ("undertow") is not necessitated any more by fluid continuity requirements, wave reflection will be reduced, etc.. Overwash occurs when the storm surges allow water and waves to overtop the beach and transport substantial quantities of sand across the island from the beach and dune zones. This results in the deposition of sand (washover) above the normal high tide levels and creation of back-barrier flats. Leatherman (1979) has documented field events at Assateague Island, Maryland for the December 1974 storm when the beach experienced erosion of 110 ft^3/ft and the dune face was displaced 15 feet landward. Volumetric computations for Coast Guard Beach, Nauset Spit, Cape Cod, Massachusetts after the February 1978 storm (Leatherman 1979) showed that about 1100 ft^3/ft

of beach was transported as overwash sand during the event. Erosion of barrier island crests can also occur in the reverse direction as waters flow from the bay to the ocean. Torrential rain and surges accompanying storms can pile-up large quantities of water in the bays which are not rapidly drained through narrow tidal inlets. Studies of the effect of Hurricanes Carla (1961) and Cindy (1963) by Hayes (1967) showed that significant amounts of sediment were lost to the deep-water offshore by the flow of bay waters across the island into the sea. The currents were driven by the hydrostatic head difference set up between the trapped bay waters and the receeding ebb tide in the ocean.

As overwash processes cause washover deposits over berm levels, this sand is consequently lost from the nearshore sediment budget and may hinder post-storm recovery. This is especially a distinctly probable scenario for barrier islands which are first and often most severely affected by episodic storms; furthermore, this is of acute concern for Florida where barrier islands are well-inhabited and comprise almost 50% of the shoreline.

The first section of the present investigation chronicled cross- shore changes of a model barrier island subject to different surge levels and wave conditions. The same initial configuration was used to investigate further the changes of an armored barrier island configuration with the presence of a seawall. The seawall was positioned at different locations of the the beach profile, and surge levels and wave conditions were varied during the course of the investigation. With this arrangement, "end-effects" of the seawall could not be examined. The reader is referred to Parchure et al. (1991) and the companion to the present report ("Barrier Island Erosion and Overwash Study: Volume 1") for detailed descriptions of associated terminology. Volume 1 describes the first phase of this study in which the beach profile response in the absence of a seawall was modelled.

Chapter 2

PERTINENT STUDIES: A BRIEF OVERVIEW

A variety of field data exists for the West and East coasts of the U.S.. Data provided be Sexton and Moslow (1981) on the effects of Hurricane David, 1979, at Seabrook Island, South Carolina, showed evidence of a scour trough apparently caused by the presence of a seawall. Also, beaches adjacent to armored shorelines exhibited substantial erosion and negligible recovery after four weeks while beaches in a more natural setting showed net deposition and swift recovery. Data presented by Davis and Andronaco (1987) documenting the effects of Hurricane Elena, 1985, at Sand Key, Florida showed the presence of a "ridge and runnel" system irrespective of the position of the seawall. However, the seawalled profile appeared to be scoured about 5 feet deeper close to the seawall relative to the non-seawalled case. Data collected by Kriebel et al. (1986) for Hurricane Elena indicated additional toe scour at the seawall and the presence of a swash bar. In contrast, the data of Griggs and Tait (1988) for Monterey Bay, California, on the Pacific showed no evidence of a scour trough or a bar. Rather, there was evidence of profile deflation, i.e., the beach became flat in front of the seawall while a berm persisted seaward of the wall location at an adjacent beach. Post-storm recovery occurred with deflated profiles. However, the scour-trough profiles persisted. It must be noted that erosion of the Pacific coast beaches are distinct from those of the Atlantic coast. Erosion of the Atlantic and Gulf coasts seems to be significantly influenced by hurricanes and associated storm surges while storm surges on the Pacific coast are relatively small due to the narrow continental shelf. Baba and Thomas (1987) documented the response of a 50 feet wide beach fronting a revetment on the South- West (S.W.) coast of India. The system was in long-term equilibrium with the annual S.W. monsoons. Frontal erosion and end scour were visible during the storms (May-October) and the eroded material was deposited offshore as a longshore "ridge and runnel" system which then aided in the dissipation of wave energy. Post-storm recovery was complete and rapid. This seems to indicate that as long as the seawall is fronted by a sufficiently wide beach, performance can be effective. The reader is also referred to Tait and Griggs (1990) who listed and qualitatively detailed numerous field observations of the response of beaches to the presence of seawalls.

End scour or flanking of seawalls has been well-documented in the literature and generally takes a crescentic shape with the maximum recession immediately adjacent to the seawall. The beach systems next to structures are invariably adversely affected (Chiu 1977, Walton and Sensabaugh 1979, Birkemeier 1980, Sexton and Moslow 1981, etc.). However, Hurricane Elena data for West Florida reveals no such scour

(Kriebel et al. 1986, Kriebel 1987). If a seawall starts protruding like a groin due to shoreline retreat, the updrift side can show accretion with associated downdrift erosion (Birkemeier 1980).

The reader is referred to an extensive review of most literature (lab, field and theoretical models) on the effects of seawalls carried out by Kraus (1988). He concludes that the changes of beaches near seawalls is similar to those without seawalls as long as a sediment supply exists, erosion rates due to storms are similar, as is post-storm recovery. Beach phenomena affected by seawalls and reviewed by Kraus (1988) include scour depths, beach profiles (deflated bars, steepened profiles, undulatory profiles) and planform changes (flanking, impoundment, downdrift erosion) and beach recovery. The reader is further referred to Dean (1986) who discusses some of the common (mis?)perceptions about seawalls and ways to mitigate the adverse impacts based on sediment budget considerations. He states that there is no factual evidence to support contentions of profile steepening, increased longshore transport rates or delayed recovery. He also concludes that in two- dimensional situations in nature with the presence of a longshore bar, the additional erosion in front of the seawall is not more than the volume that would have eroded from the upland had the armoring been absent. Also, Barnett (1987) conducted two- dimensional laboratory experiments which led him to conclude that major transport processes are not significantly affected by the presence of a seawall and that the presence of a seawall does not preclude recovery.

Thus, because of sediment conservation constraints (Dean 1986), it appears that during storms the presence of a seawall results in increased depths near the seawall as the seawall precludes upland erosion which would have occurred otherwise. If the seawall protrudes sufficiently into the surf-zone, it can interrupt longshore transport and function as a groin causing updrift accretion and downdrift erosion. There does not seem to be enough evidence to confirm most other claims (including accelerated erosion and delayed post-storm recovery) attributed to the presence of seawalls on beaches.

Chapter 3

PRINCIPLES

Seawalls are constructed with the intent to protect upland property located on shorelines exhibiting a persistent erosional trend, substantial seasonal swings and/or at sites believed to be susceptible to severe episodic events. The pervasive constraint imposed on the site is that of sand conservation. Sand is neither lost nor added to the *total* sediment system by the seawall, however, the sand transport is reconfigured. A systematic and rational analysis of the sand budget (cross-shore and longshore transport) must always be carried out for the site before any conclusions can be reached.

Thus, if, as in a commonly held perception, a seawall is held to cause erosion and profile steepening in front, then this sand has to be transported and deposited elsewhere, i.e., the sand is not lost to the littoral system. There have been claims that wave reflection due to seawalls causes a steepening of the offshore profile. However, the hydrodynamics associated with wave reflection do not offer any apparent causative mechanism for the required offshore transport. On the basis of momentum flux considerations, it can be shown that increased reflection can actually reduce the total net longshore thrust and the related longshore sediment transport. It appears that the behavior of a beach is governed by the amount of sand in front of the seawall relative to the equilibrium profile. During storms, augmented water levels and high storm waves require sand to be transported seaward along both armored and natural shorelines. For two-dimensional cases as in a wave tank, as the armoring denies upland sand, it is expected that this deficit is made up by aggravated erosion as near as possible to the natural source, i.e., immediately adjacent to the seawall. This situation can be extended to three-dimensional situations where this sediment demand results in an " erosional stress" adjacent to the armoring causing sediment to flow from the offshore of unarmored laterally to the offshore of armored regions. If eroding shorelines cause an isolated seawall to project into the surf zone, it will behave as a groin and interrupt net longshore transport. The sand deficit on the downdrift side is equal to that blocked by the seawall and that not yielded by the upland protected by the armoring. This downdrift deficit increases with the seawall length and with time. Data on post-storm recovery rates for armored beaches are often contradictory.

In summary, adverse impacts to the sand budget essentially include (1) protected upland not yielding material which would have been provided in the absence of of armoring (2) restricting longshore sediment transport in the event that the seawall projects into the surf-zone. Sediment budget analysis can provide quantitative estimates of these "losses" and periodic placements of sand in the vicinity of the armoring will mitigate these adverse impacts. The reader is referred to Dean (1986) for further details.

Chapter 4

SCOPE OF THE PRESENT STUDY

The present study was motivated by the desire to quantify and, later, theoretically analyze the effects of storm conditions on the beach profile of a model barrier island with emphasis on the effects of seawalls. During storms, barrier islands located seaward of the mainland absorb a substantial impact of the storm energy thereby providing shelter to the property and structures on the mainland. Augmented surge levels lead to overtopping. The laboratory studies considered a model to prototype geometric scale ratio of 1:16. In this report, all dimensions are reported in prototype units (unless noted otherwise), i.e., the length and time scales will be 16 and 4 times larger than in the model. The laboratory model was non site-specific; instead, a hypothetical barrier island with a crest width of 400 feet at an elevation of 6.3 feet above mean sea level (MSL) and a mild, initially uniform slope of 1:19 was considered for simulation, see Fig. 4.1. For each experiment, the initial beach profile of the barrier island was linear from the crest to the toe, thereby providing a common reference for

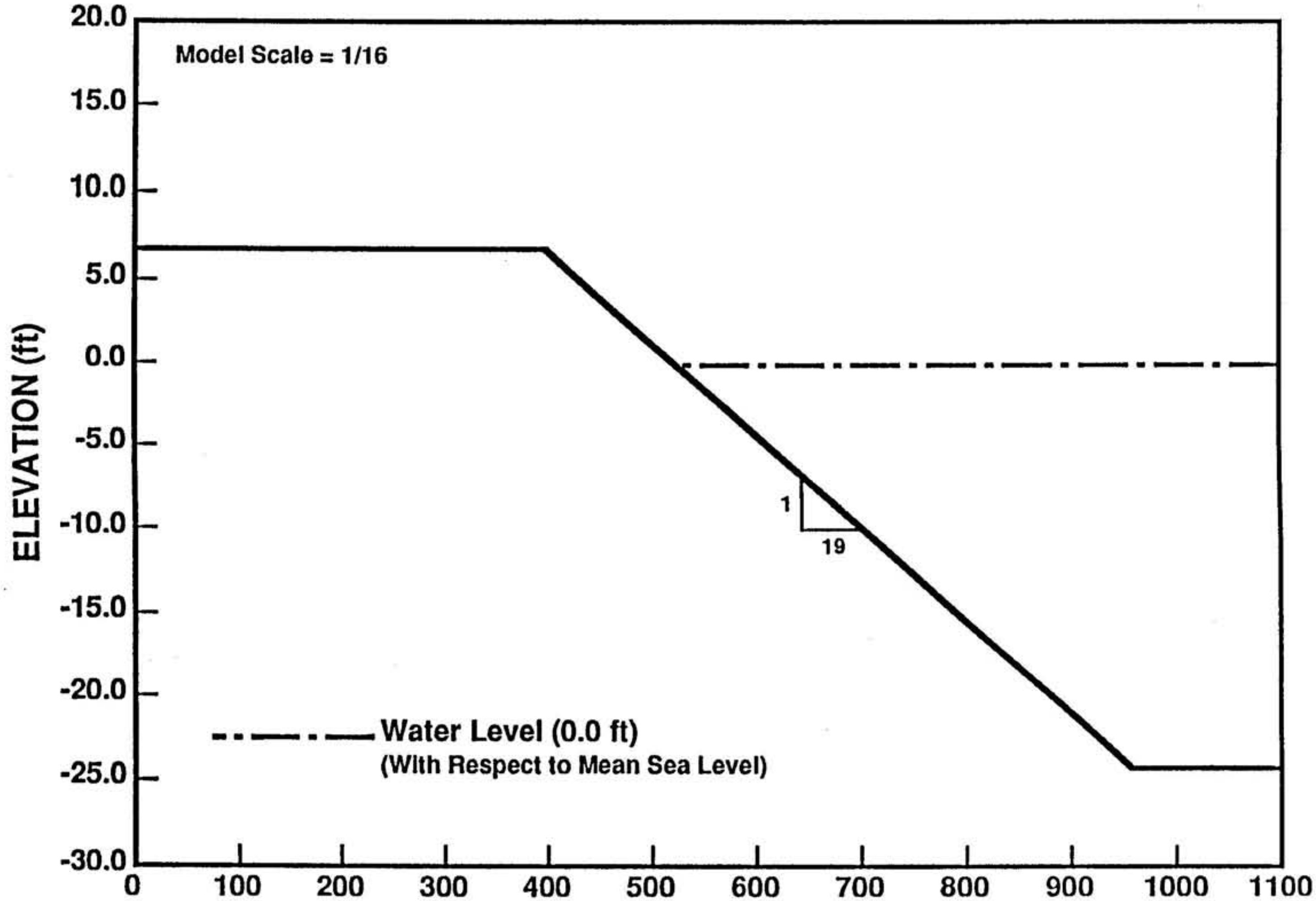

Figure 4.1: Idealized initial beach profile in the wave tank for each experiment.

all the beach profiles. Each simulation was carried out for at least 18 hours by which time near-equilibrium of the beach profiles had occurred. The wave direction was normal to the beach. A detailed description of the laboratory facility and similitude considerations are given in the companion report (Volume 1). It should be recognized that the presence of vegetation could have some effect on sediment transport rates, however, this was not accounted for in the present study, and thus, this study may not be very representative for heavily-vegetated barrier islands. Some experiments were conducted with the additional presence of an imposed current; however, these will be discussed in a forthcoming report.

The forcing parameters varied were the storm surge level (to accomodate overtopping), wave height, wave spectral characteristics (monochromatic and narrow-banded) and position of the seawall. The results of eight experiments are presented in this report and the characteristics of these are described below.

- The crest of the barrier island was horizontal, flat, 400 feet wide and had an elevation of 6.3 feet above MSL for Expts. S1- S7. In Experiment S8, the seawall was positioned at 544 feet with a crest elevation of 6.3 feet. Thus, backfill of the seawall resulted in an effective advance of the crest of the barrier island to 544 feet.

- The water depth at the toe of the beach was 24 feet below MSL.

- Fine sand with an approximate median diameter of 0.2 mm (model scale) was used.

- Still water level: The following levels were used –
  1. 6.3 feet above MSL (same as the island crest elevation)
  2. 10.0 feet above MSL (causing inundation)
  3. 11.5 feet above MSL (causing inundation)
  4. Time-varying water levels ranging from 0.0 to 11.3 feet.
- Incident waves in deep-water –
  1. Regular waves with a height of 8.5 feet and a period of 8 seconds
  2. Irregular waves with mean period of 8 seconds (narrow-banded spectrum in the range 7.6-8.4 seconds) and maximum wave height of 8.5 feet.
- Seawall position –
  1. At 400 feet with crest elevations of 6.3 and 8.3 feet. This was the location of the slope break between the island crest and the sloping beach.
  2. At 544 feet with crest elevation of 6.3 feet. This location was just landward of the shoreline at MSL conditions.
- Three parallel cross-shore profiles, termed B1, B2 and B3, were monitored. B3 was along the wave-tank centerline, and lines B1 and B2 were $\sim$ 0.7 feet (model scale) on either side of B3.

The characteristics of the individual experiments are presented in the next section.

Chapter 5

METHODOLOGY

5.1 LABORATORY FACILITY

The wave-tank was 120 feet long, 6 feet wide and 6 feet deep (Fig. 5.1) A concrete splitter wall placed along the tank centerline divided it into two tanks each approximately 3 feet wide. The tests were conducted in the tank where the outer-wall was made of glass panels thereby facilitating visual observation. The outer-wall of the other tank was made of concrete. A wave-maker 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 both regular as well as irregular wave motion. The splitter wall was separated from the wave-maker by about 10 feet. At the downwave end of the tank, the splitter wall consisted of concrete blocks with horizontal openings which allowed circulation through the splitter wall, i.e., with the advent of overtopping of the crest of the barrier island, any wave- driven currents would cause water to circulate from the test section into the adjacent tank at these downwave openings. A sloping frame with permeable ny-

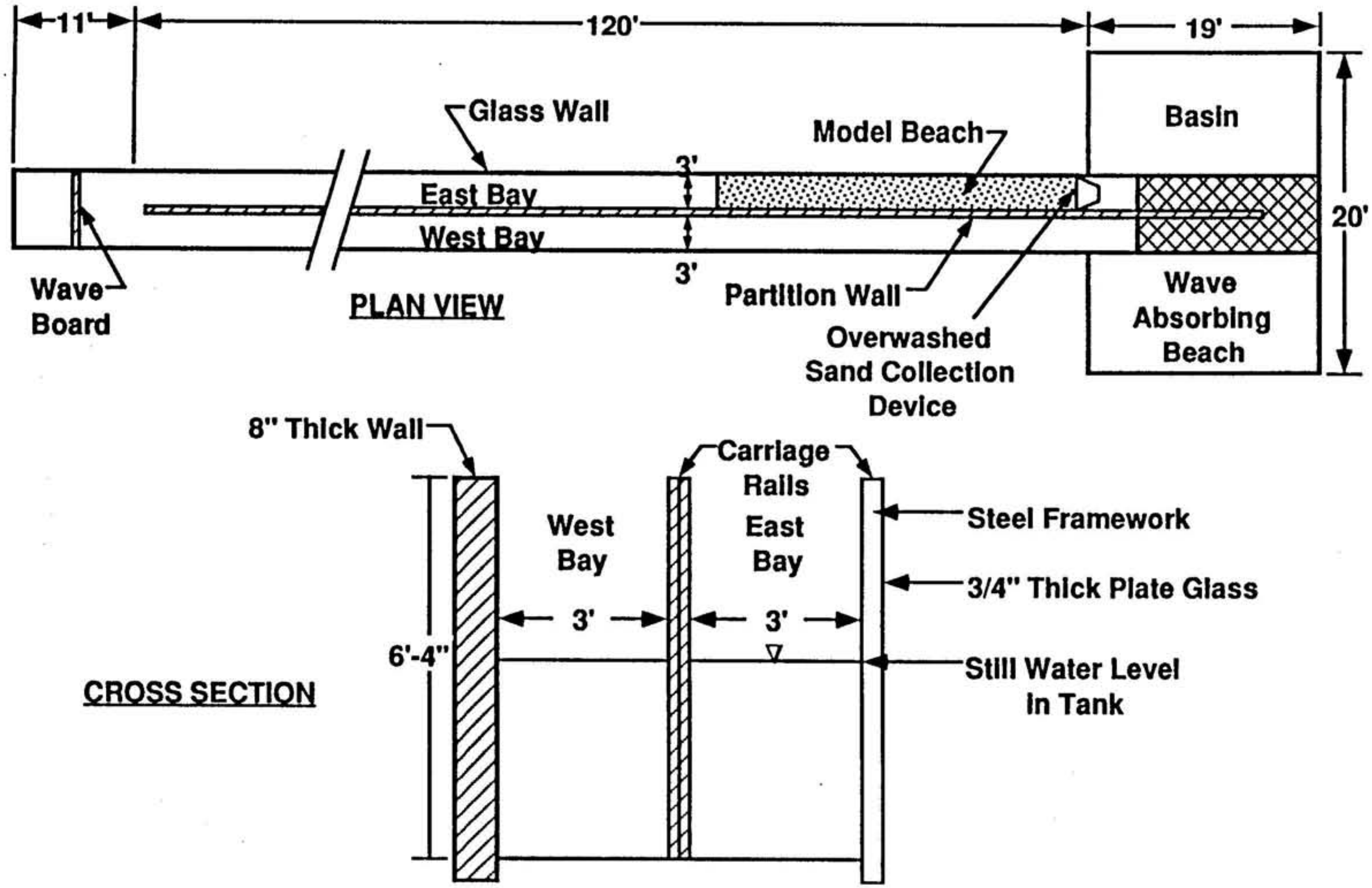

Figure 5.1: Schematic Layout and Cross-Section of Wave Tank

lon 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 measuring equipment package along and across the tank.

5.1.1 Beach profiling

An automatic bed profiler was mounted on a carriage which moved in the on-offshore directions inside the wave tank. The longshore position of the bed profiler could also be adjusted. An electric motor drove the carriage at constant speed along the wave tank and the bed sensor moved up or down simultaneously, maintaining a fixed gap of 0.5 mm between the tip of the sensor and the bed. Periodic calibration of this sensor was required for each experiment and involved establishing the voltage output corresponding to two "known" elevations. These were chosen to be the elevation of the water surface and the level of the bed far offshore at 944 feet (deep-water) which was considered to be unaffected by the wave action. Thus, these are two possible sources of error in the magnitude of the output in terms of model/prototype units for vertical position. A combination of a system 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 wheels of the trolley on the rails can cause an error in the prediction of the horizontal position.

Expt.	Storm Surge		Wave Characteristics			Seawall	
	Duration (hrs)	Level (ft)	Type	Height (ft)	Carrier period (sec)	Position (ft)	Elevation (ft)
S1	00-18	6.3	Regular	8.7	8.0	400	6.3
S2	00-18	10.0	Regular	8.5	8.0	400	6.3
S3	00-18	10.0	Regular	8.5	8.0	400	8.3
S4	00-18	10.0	Irregular	8.5	8.0	400	8.3
S5	00-18	11.5	Regular	8.5	8.0	400	8.3
S6	00-18	11.5	Irregular	8.5	8.0	400	8.3
S7	00-04	0.0	Regular	4.7	8.0	400	8.3
	04-06	0.5	Regular	5.4	8.0	400	8.3
	06-08	2.90	Regular	7.4	8.0	400	8.3
	08-10	6.82	Regular	7.1	8.0	400	8.3
	10-12	10.24	Regular	8.5	8.0	400	8.3
	12-14	11.30	Irregular	8.2	8.0	400	8.3
	14-16	10.24	Irregular	8.0	8.0	400	8.3
	16-18	6.82	Irregular	7.0	8.0	400	8.3
	18-20	2.90	Irregular	5.7	8.0	400	8.3
S8	00-04	0.0	Regular	6.5	8.0	-	-
	04-22	6.3	Regular	8.5	8.0	544	6.3

Table 5.1: Experimental Conditions of all Runs

5.2 EXPERIMENTAL CONDITIONS

Table 5.1 lists the conditions for the 8 experiments (S1-S8) conducted with the presence of the seawall and without any externally-imposed current, i.e., the currents present were solely wave-driven.

5.3 OBSERVATIONS AND DISCUSSION

Unless otherwise mentioned, this section contains discussions of the changes in the *mean* bed profiles due to the imposed surge levels and wave conditions. As mentioned earlier, three parallel, cross-shore profiles (B1, B2 and B3) were monitored at intervals of 2 hours generally and occasionally at intervals of 4 hours. B3 was the centerline profile while B1 and B2 were about 0.7 feet (model dimensions) on either side. The average of the three gives the mean profile. The seawall, positioned at 400 feet in Expts. S1-S7, was built into the beach *before* the beginning of each of these experiments. In Experiment S8, the initially linear-sloped beach profile was allowed to reach quasi-equilibrium by being subjected to 6.5 feet high waves (of 8 seconds period) for 4 hours. *Then*, a seawall of 6.3 feet crest elevation was built at 544 feet and its backside was filled with sand.

Detailed beach profile evolution is documented in a separate Appendix. This Appendix consists of three parts –

- Beach profiles B1 and B2 for each experiment and for every 2 hours are presented.

- Beach profiles for every two hours superposed are presented (for B1 and B2 separately).

- Initial and final beach profiles (B1 and B2) for each experiment are presented superposed.

The figures in the Appendix are self-explanatory. Thus, a brief discussion of these is provided only for Experiment S1.

5.3.1 Experiment S1

The run time was 18 hours with the seawall positioned at 400 feet having a crest elevation of 6.3 feet, whereby the seawall was at the edge of the backshore and just submerged in sand. The surge level was 6.3 feet, thus, the onset of wave action resulted in mild overtopping over the crest of the barrier island (termed the backshore). Monochromatic waves with a period of 8 seconds and 8.5 feet high were allowed to impinge on the the initially linear- sloped (1:19) beach.

A prominent, 9 feet high (defined as the difference in the elevation of the crest and the trough of the longshore bar) longshore bar developed, see Fig 5.2. The crest of the bar was just offshore of the break-point (confirmed visually). The faces of the bar were steep, with the crest of the bar at 660 feet and the trough at 620 feet. The bar resulted in a *ridge and runnel* system being formed with the elevation of the ridge being just below MSL. The MSL shoreline retreat was about 50 feet.

There was minimal washover on the crest of the barrier island. Offshore of the submerged seawall, in the range 480-650 feet, there was substantial erosion and most change (up to 5.5 feet), see Fig 5.3. The region still offshore (650-940 feet) exhibited steadily decreasing accretion. Thus, only the beach in the region 480-650 feet experienced erosion, and the same eroded sand was deposited both onshore and offshore. The net change in the profile over 18 hours was -56 ft^3/ft (which corresponds to 0.0037 feet in model units)

Figs. 5.4, 5.5 and 5.6 are samples from the Appendix of the evolution of profile B1. A primary bar with its crest at $\sim$ 650 feet formed within 2 hours. The position of the bar oscillated slightly till 10 hours and then appeared to be in equilibrium. However, the smaller bar evident landward of the primary bar (at $\sim$ 430 feet) in profile B1 was not apparent in profile B2. Figs. 5.7 and 5.8 show the longshore

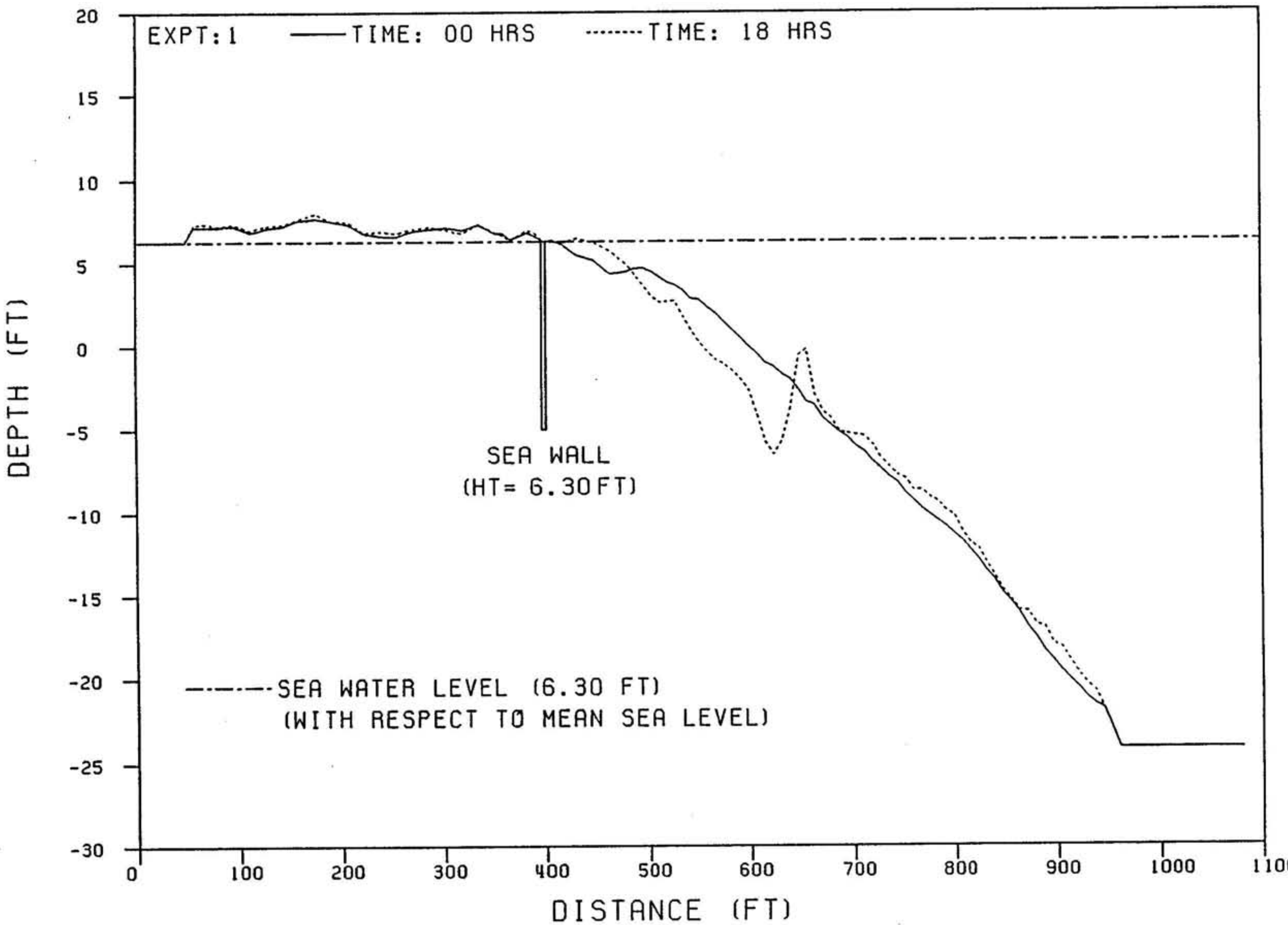

Figure 5.2: Mean profile, Expt S1, at 00 and 18 hours

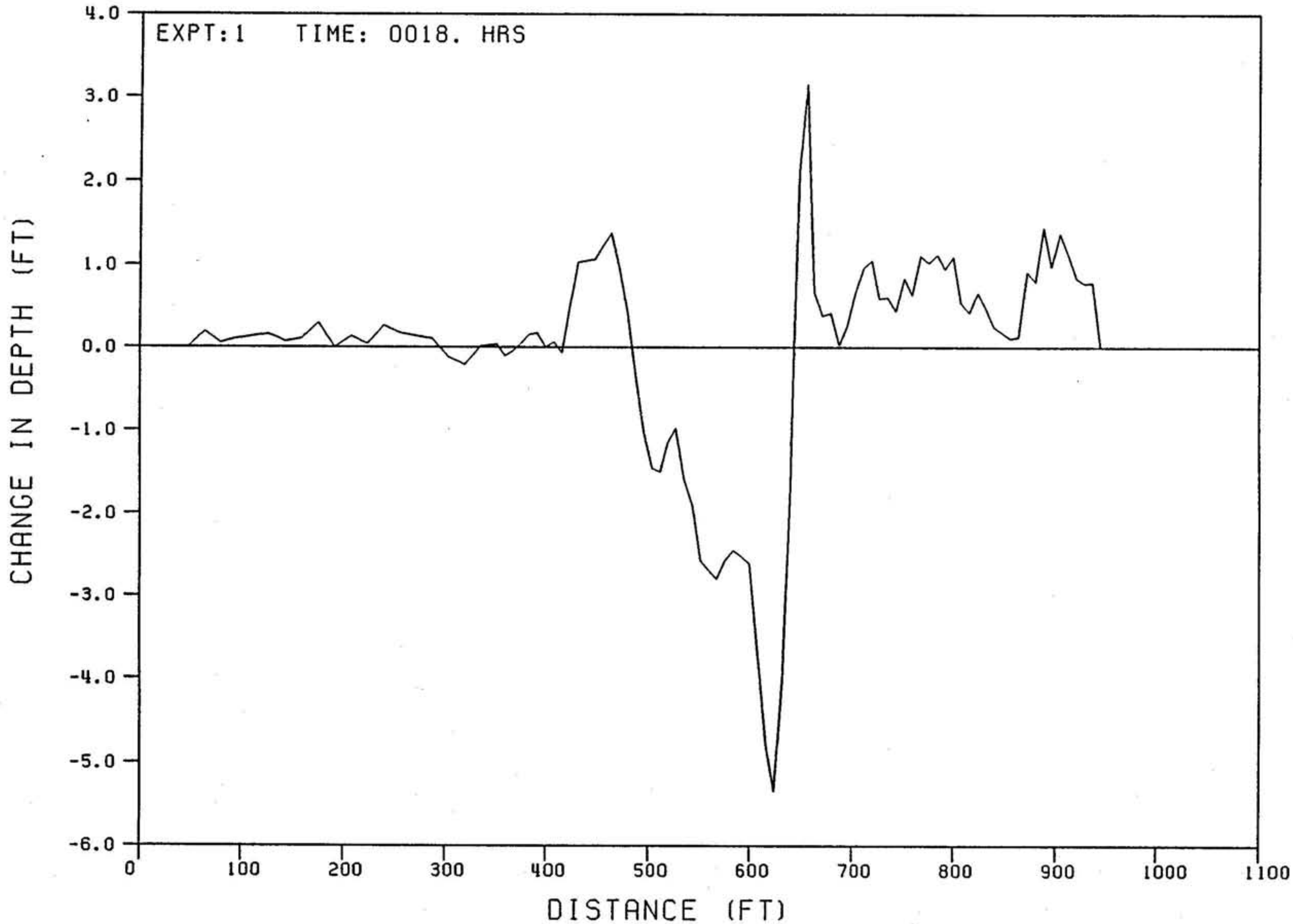

Figure 5.3: Expt S1, change in 18 hours

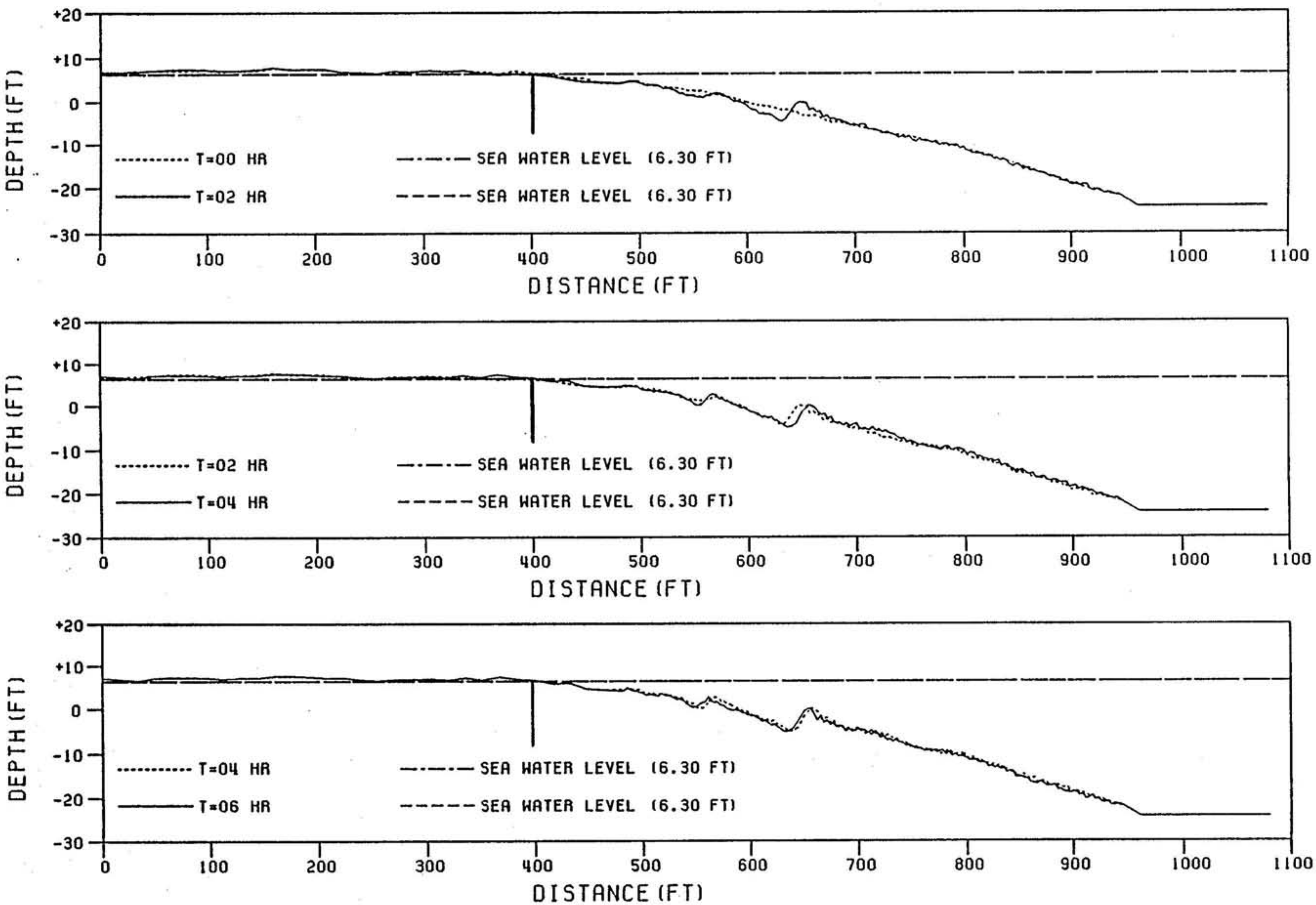

Figure 5.4: Expt S1, Profile B1, T=00-06 hr

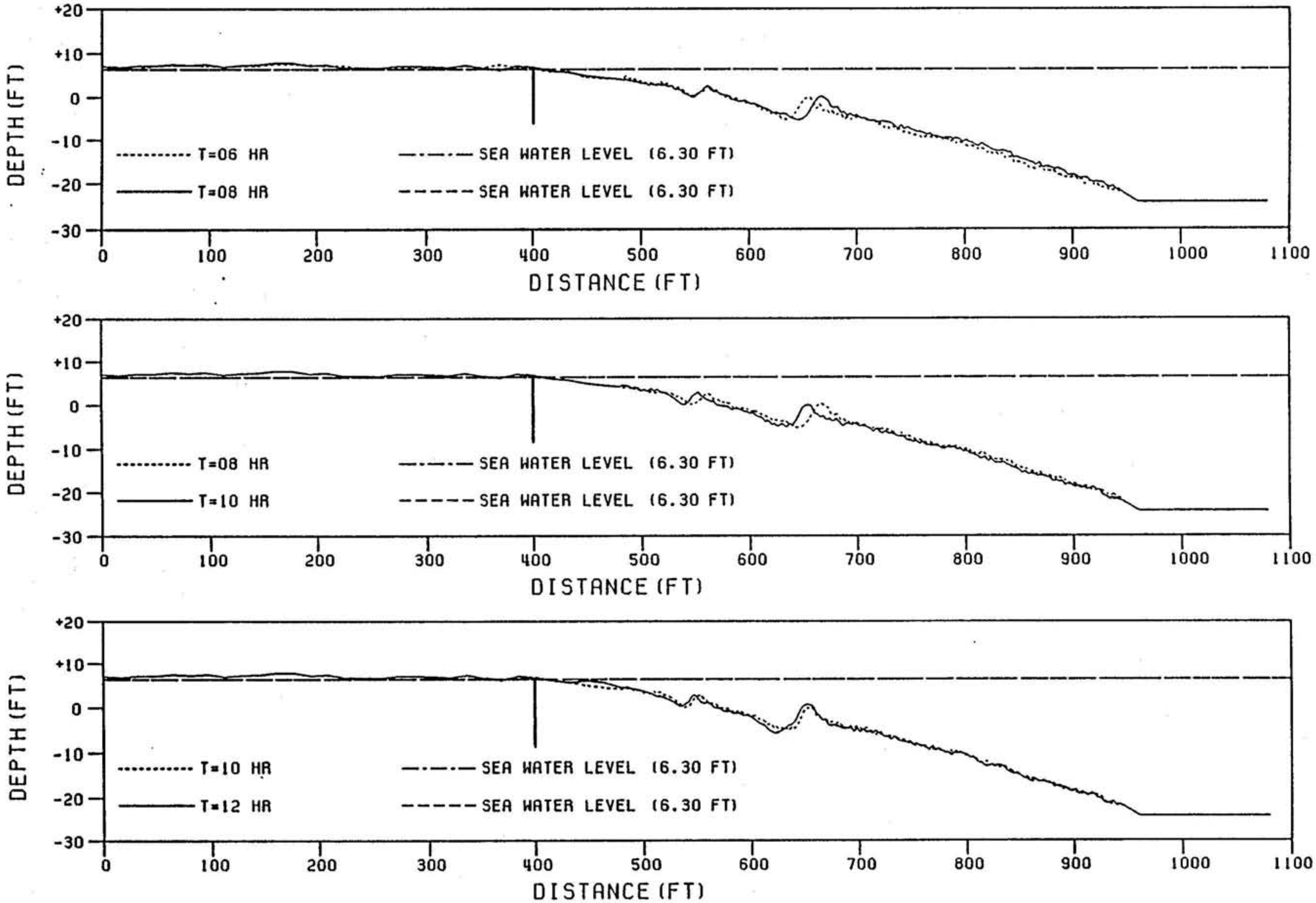

Figure 5.5: Expt S1, Profile B1, T=06-12 hr

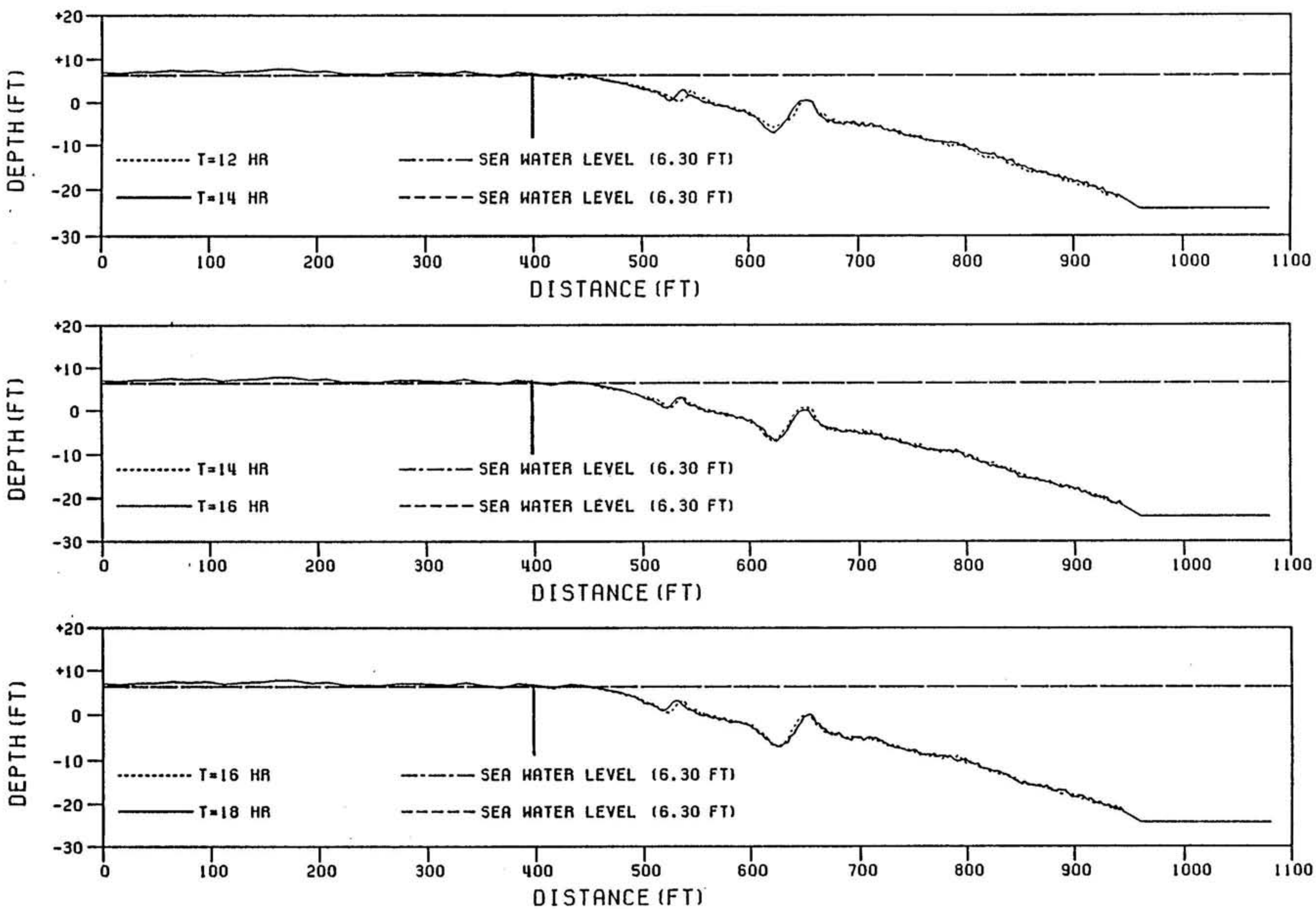

Figure 5.6: Expt S1, Profile B1, T=12-18 hr

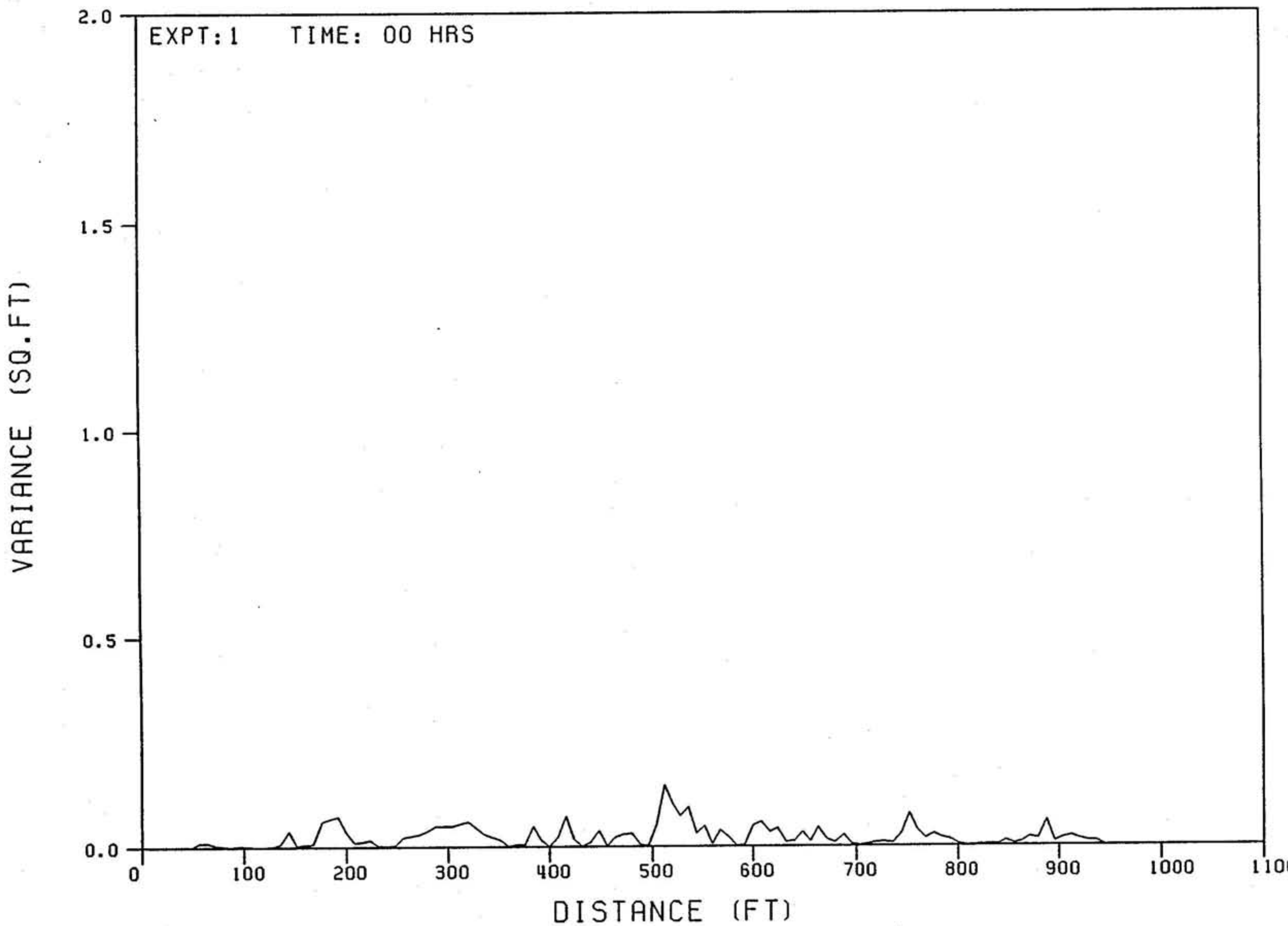

Figure 5.7: Expt S1, Longshore variance at 00 hours

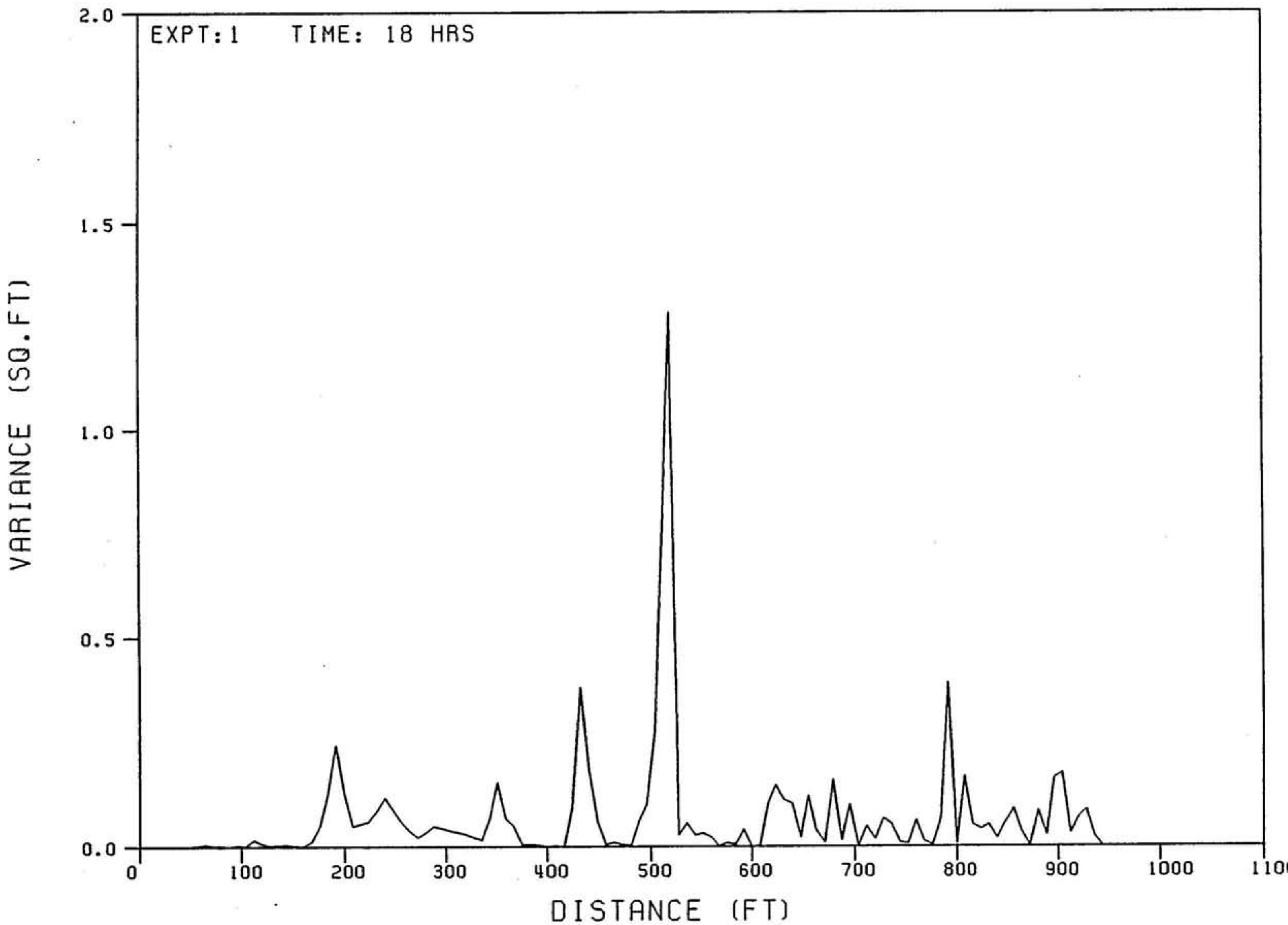

Figure 5.8: Expt S1, Longshore variance at 18 hours

variation exhibited by the measured beach profiles at the beginning and at the end of Experiment S1 respectively. Variance, σ^2, at each cross-shore point is defined as

$$\sigma^2 = \overline{z^2} - \overline{z}^2 \tag{5.1}$$

where z denotes the elevation of the point and the overlines represent averaging. It is noted that longshore symmetry was not maintained in the region around 520 feet which corresponds to the position of the secondary bar of profile B1. Also, it is apparent that the primary bar was very two-dimensional.

In summary, since the crest of the seawall was flush with the top of the barrier island and no erosion occurred just landward of the seawall, the seawall had no significant effect on profile evolution in this experiment.

5.3.2 Experiment S2

The test conditions were the same as for Experiment S1 except that the surge level was increased to 10 feet to allow overtopping of 3.7 feet at still water.

A longshore bar developed within 2 hours and persisted till 12 hours after which it flattened out. Thus, the mean profile exhibited a marked change at the end of 18 hours. In contrast to Experiment S1, there was no prominent offshore bar.

The region 0-200 feet showed marginal washover (see Fig. 5.9), with the deposition steadily increasing to 1 foot in the range 200-410 feet, i.e., up to just in front of the seawall. There was substantial erosion all the way up to 750 feet. It appears that the profile underwent deflation. There was minimal deposition offshore. The MSL shoreline retreat was 50 feet. Net change in the mean profile over 18 hours was about

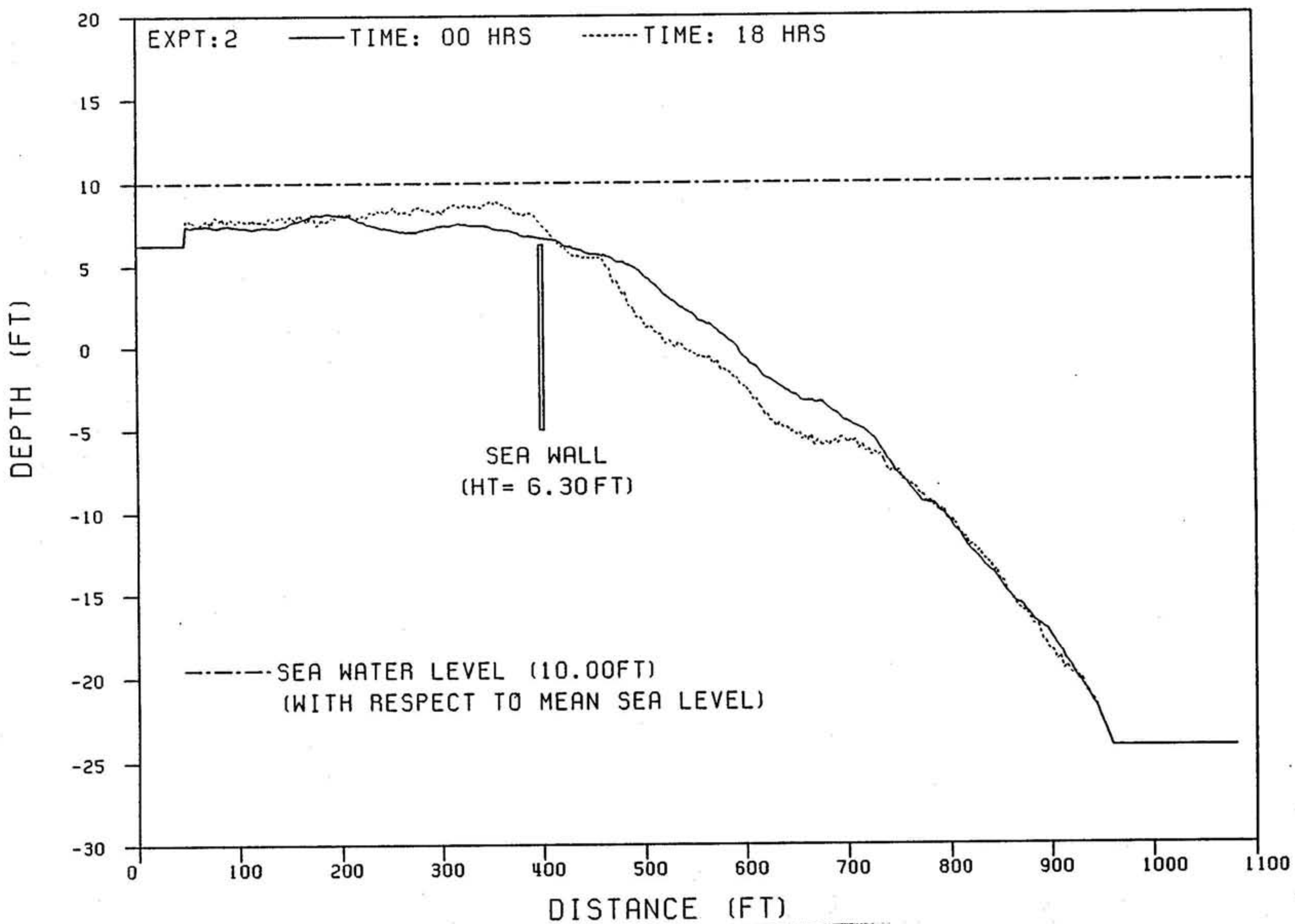

Figure 5.9: Initial and final mean profiles, Expt. S2

-350 ft^3/ft (which corresponds to 0.023 feet in model units).

As was the case in Experiment S1, because the seawall did not protrude above the sand level, there was no significant change in beach profile evolution, even though the extent of overtopping was increased to 3.7 feet. However, it must also be noted that that under the same experimental conditions as Experiment S2 but without the seawall, a prominent longshore bar was present (see Experiment E3 in Volume 1). This difference appears to be counter-intuitive and no rational explanation is evident.

5.3.3 Experiment S3

The test conditions were identical to those of Experiment S2, however, the crest of the seawall was raised 2 feet above the crest of the barrier island, i.e., to 8.3 feet above MSL. With overtopping, as the water level was 10 feet, cross-shore bedload transport was inhibited while transport in suspension could occur over the seawall.

The backshore showed some deposition with the amount increasing slightly towards the seawall, see Fig 5.10. However, there was scour (up to 0.5 feet) just behind the seawall. The offshore profile contained a mild-sloped bar. There was prominent erosion in the foreshore (450-680 feet) and slight deposition offshore. The raising of the seawall retarded the net erosion, and a bar was definitely discernible. The net change was -65 ft^3/ft (which corresponds to 0.0044 feet in model units).

In this experiment, the seawall protruded above the sand level and interacted with the sediment transport process. This caused scour to develop behind the seawall, unlike Experiment S2 where there was deposition of about 1.5 feet at the seawall. It must also be noted that that under the same experimental conditions as Experiment

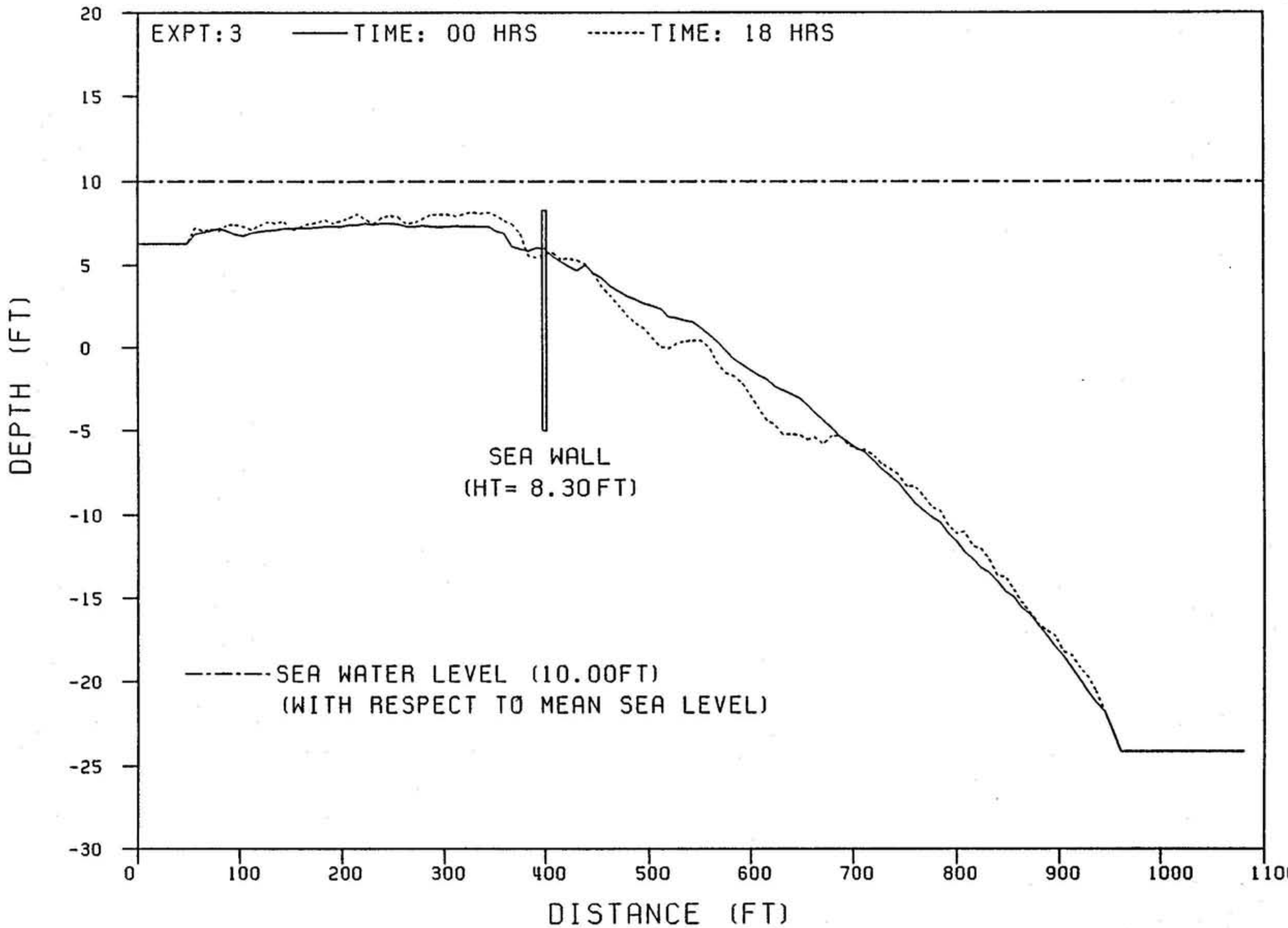

Figure 5.10: Mean profile, Expt S3, at 00 and 18 hours

S3 but without the seawall, a prominent longshore bar was present (see Experiment E3 in Volume 1) and changes in the sloping beach profile were pronounced with the entire sloping beach profile experiencing erosion.

5.3.4 Experiment S4

The seawall, positioned at 400 feet, had a crest elevation of 8.3 feet above MSL. The simulated storm surge was 10 feet. The original intention was to generate bichromatic waves such that the carrier wave period would be 8 sec with individual components at 7.6 and 8.4 seconds. However, this was not possible with the available input signal modulator. Instead, the generated waves had periods spread over 7.6-8.4 seconds (narrow-banded spectrum), but the carrier frequency was still about 8 seconds. The maximum wave height was 8.5 feet.

The backshore showed increasing deposition towards the seawall, see Fig 5.11. However, there was scour immediately behind the seawall. The nearshore up to 670 feet showed aggravated erosion with slight deposition in the region 670-940 feet. There was no longshore bar present and the net change was +55 ft^3/ft (which corresponds to 0.0036 feet in model units).

The overall patterns and scales of deposition/erosion were very similar to those occurring in Experiment S3. Again, there was scour of about 1 foot immediately behind the seawall. The parameters of Experiment E8 which was documented in Volume 1 were identical to those of Experiment S4 except for the absence of the seawall and the patterns of erosion and deposition were similar.

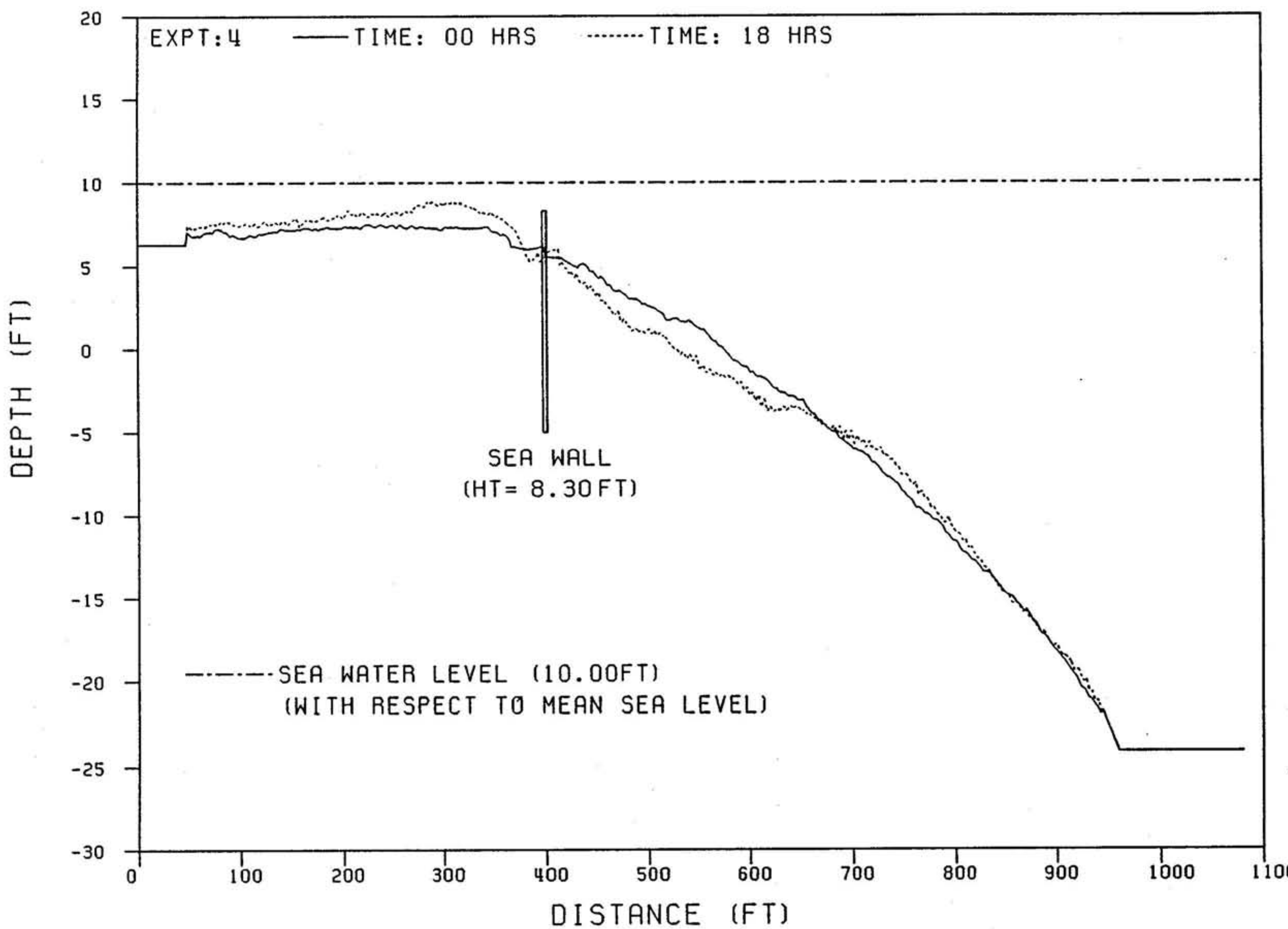

Figure 5.11: Mean profile, Expt S4, at 00 and 18 hours

5.3.5 Experiment S5

The total run time was 18 hours with the storm surge now being 11.5 feet. Regular (monochromatic) waves of 8 sec period and 8.5 feet height were generated. The seawall was again at 400 feet with a crest elevation of 8.3 feet.

The mean profile was devoid of any longshore bar, see Fig 5.12. There was depostion on the backshore (up to 1.5 feet), however, an extent of almost 40 feet behind the seawall showed scour. The region in front of the seawall showed substantial erosion up to 650 feet, followed by decreasing degrees of deposition till 940 feet. The shoreline at MSL appeared to retreat 50 feet. Net change was -205 ft^3/ft (which corresponds to 0.0013 feet in model units).

The scour immediately behind the seawall was about 2 feet. Also, seaward of the seawall, scour started right from the position of the seawall unlike Experiment S4 which showed deposition till about 420 feet. The magnitude of erosion increased in front of the seawall (relative to Experiment S4). The results of Experiment S5 can be compared directly with those of Experiment E4 which was documented in Volume 1. The presence of the seawall precluded the formation of a longshore bar and caused mild deposition offshore of 700 feet unlike Experiment E4 which exhibited mild erosion offshore.

5.3.6 Experiment S6

The conditions are similar to Experiment S5, however, irregular (narrow-banded spectrum) waves with periods in the range 7.6-8.4 sec (mean period of 8 sec) were allowed

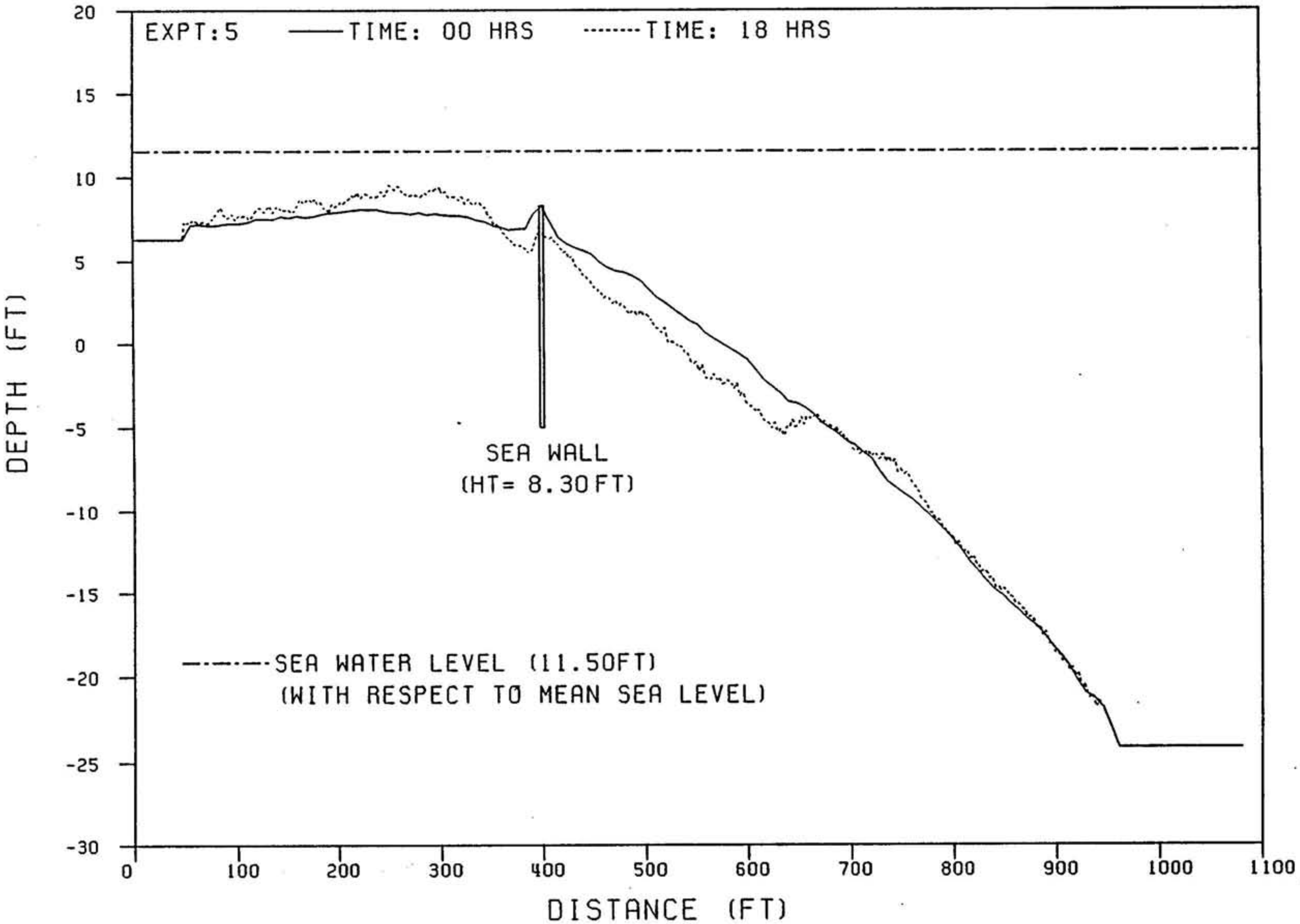

Figure 5.12: Mean profile, Expt S5, at 00 and 18 hours

to impinge on the beach. The maximum resultant wave height was about 8.5 feet.

There was no prominent longshore bar, see Fig 5.13. The backshore showed deposition, however, there was scour for about 40 feet behind the seawall. There was erosion in front of the seawall from 400 to 600 feet. This was followed by decreasing deposition in the offshore direction. Overall, the changes were quite small. The net change was estimated at +96 ft^3/ft (which corresponds to 0.0064 feet in model units).

The mean bed-profile evolution in this experiment was very similar to that of Experiment S5. However, the erosive changes in front of the seawall seemed to be muted as compared to those in Experiment S5. The scour immediately behind the seawall was about 2 feet. The results of the present experiment can be compared with those of Experiment E9 documented in Volume 1 which had similar experimental parameters but was devoid of the presence of the seawall. The presence of the seawall seemed to reduce the seaward erosion and caused scour to develop immediately landward of the seawall, otherwise the changes seemed to be unaffected.

5.3.7 Experiment S7

This experiment was instigated to judge the response of the barrier island to storm conditions with increasing surge levels followed by decreasing ones, and having 8 second regular waves. However, due to some problems, the final 8 hours of the simulation were conducted with irregular waves of mean period 8 seconds and in the range 7.6-8.4 seconds.

The first 4 hours were run with water at MSL and 4.7 feet high monochromatic (8 sec) waves were allowed to mold the initially linear-sloped beach to near-equilibrium.

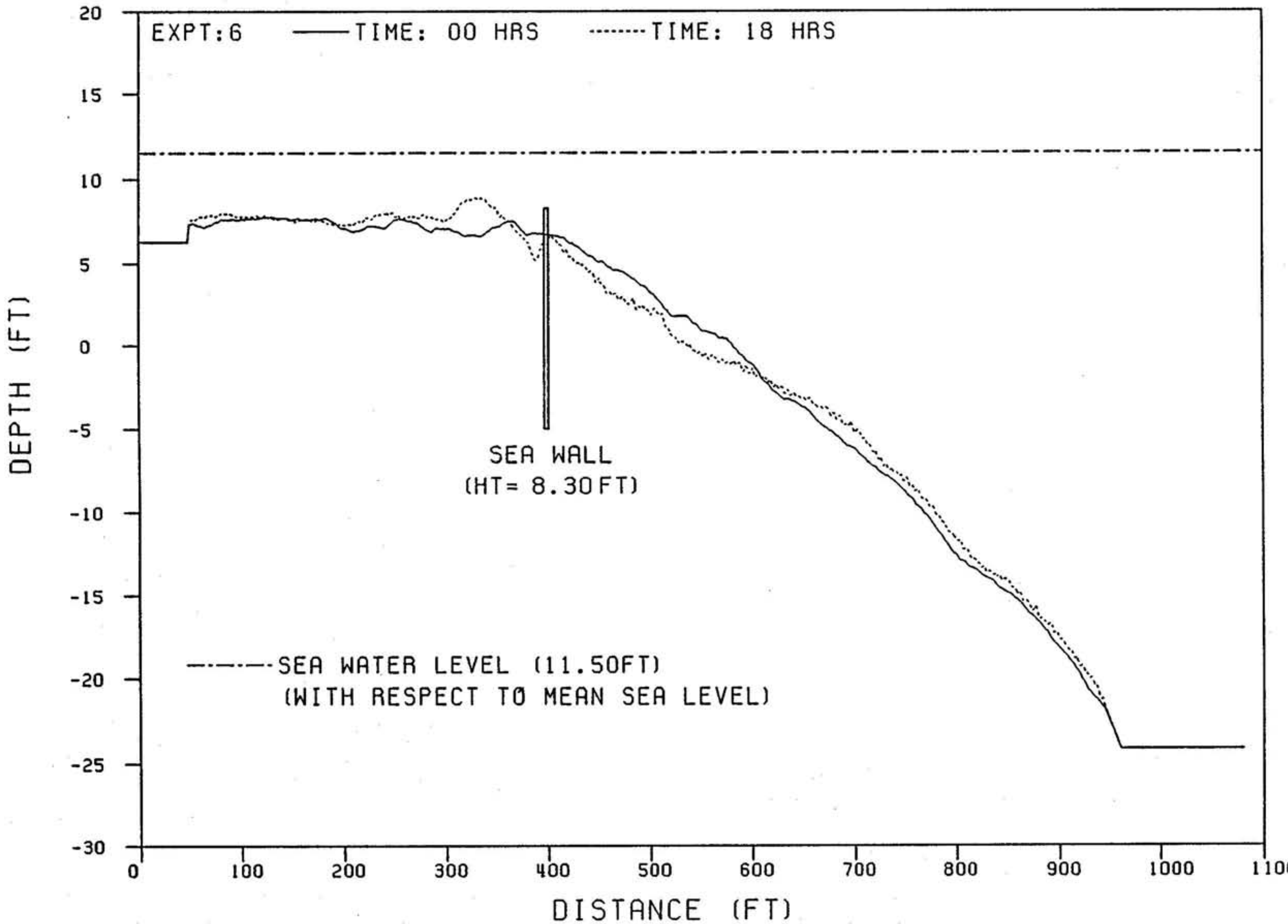

Figure 5.13: Mean profile, Expt S6, at 00 and 18 hours

The storm simulation was carried out by running waves for 2 hours at each succeeding level.

At 20 hours, the backshore showed negligible change (some erosion till 180 feet, followed by some deposition till 320 feet), see Fig 5.14. The foreshore beach seemed to undergo some profile deflation till 700 feet. There was some deposition in the range 700-820 feet, followed by some erosion still further offshore. The MSL shoreline retreat was about 20 feet. Net change was estimated as -210 ft^3/ft (in 20 hours) (which corresponds to 0.014 feet in model units).

The final mean profile for this experiment exhibited some differences from those obtained with constant storm surge levels. There was slight erosion up to 180 feet which was not noticed in any of the earlier experiments. Furthermore, there was deposition immediately behind the seawall ($\sim$ 1 foot) for about 5 feet. Also, there was erosion up to 1.5 feet in the region 820-950 feet unlike in other experiments. The maximum erosion in front of the seawall was about 1.2 feet. On comparing with Experiment E5 of Volume 1, it appears that the presence of the seawall precluded bar formation and erosion was also higher.

5.3.8 Experiment S8

In this experiment, the initially linear-sloped beach profile was allowed to reach quasi-equilibrium by being subjected to 6.5 feet high waves (of 8 seconds period) for 4 hours without any storm surge. Then, a seawall, of 6.3 feet crest elevation, was built at 544 feet and its backside was filled with sand such that the edge of crest of the barrier island advanced from 400 feet to 544 feet, i.e., the region 0-544 feet was at an elevation

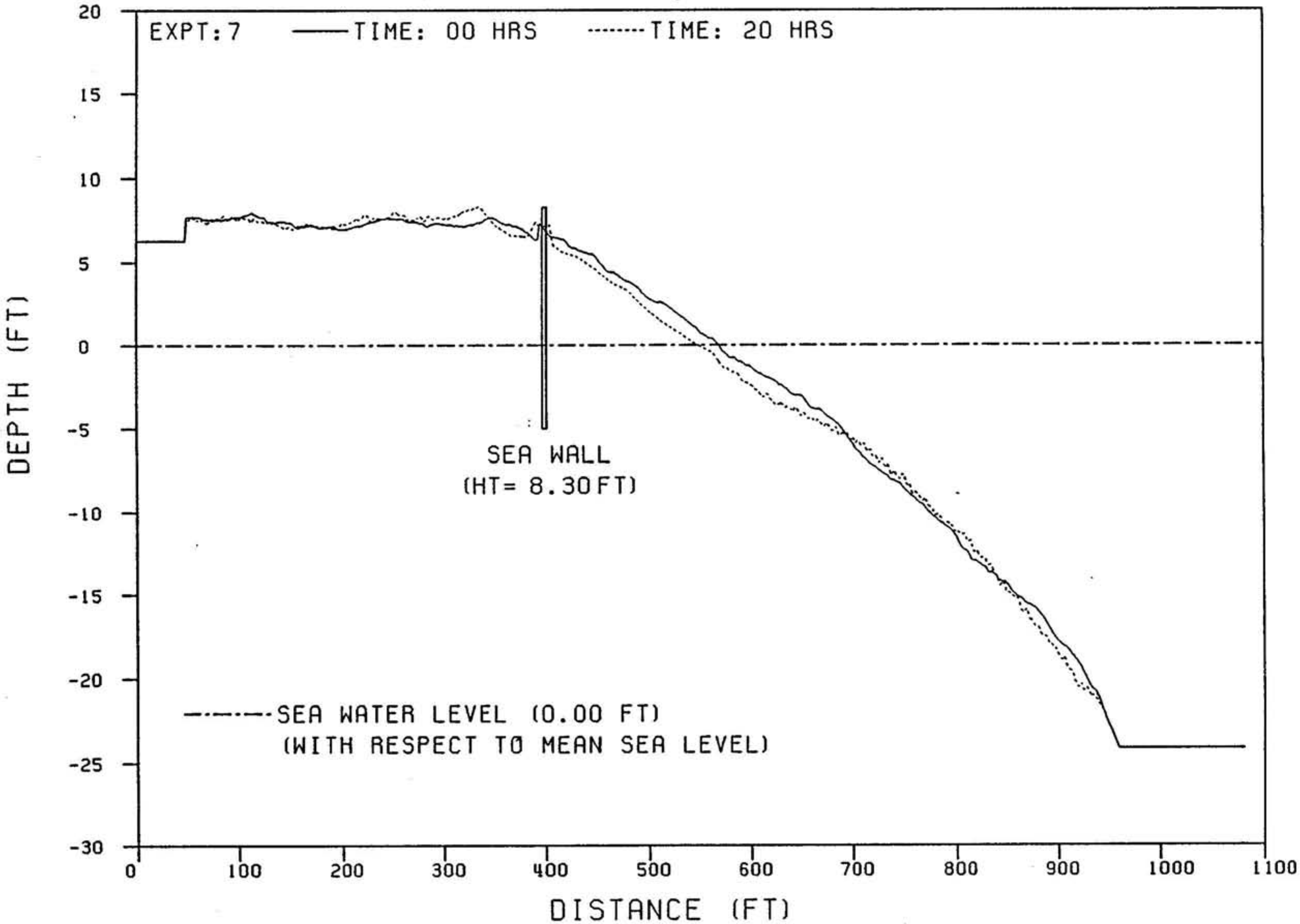

Figure 5.14: Mean profile, Expt S7, at 00 and 20 hours

of 6.3 feet. Regular waves of 8.5 feet height and 8 seconds period were allowed to impinge upon the armored beach for 18 hours with an accompanying storm surge of 6.3 feet.

In 4 hours, the beach approached short-term equilibrium with bar formation in the region 700-750 feet (bar height $\sim$ 5 feet in B1 and $\sim$ 3 feet in B2). The sea bed was heavily rippled in the region close to the bar and offshore.

Between 04-06 hours, the region 400-475 feet was reconfigured by swash into a smooth, almost horizontal bench. A 40 feet wide scour with a maximum depth of $\sim$ 3 feet developed behind the seawall. A system of "multiple-bars" appeared with the crest of the primary bar at $\sim$ 640 feet; the crests of the secondary bars were at $\sim$ 710 and 780 feet respectively. This configuration persisted till 18 hours for both B1 and B2 with the crest of the primary bar moving slightly offshore to $\sim$ 620 feet. The scour around the seawall increased. During 18-22 hours, a strong three-dimensionality appeared in the profiles with more scour and a prominent primary bar in B1 whereas the primary bar was almost non-existent for B2. Around 400 feet, there was upto 3 feet deposition.

Here, comparison is made between mean profiles at 4 hours and at 22 hours, see Fig 5.15. There was negligible change up to 400 feet. The region 400-440 feet showed substantial deposition (up to 3 feet). This was followed by significant erosion (up to 4 feet) till the seawall. There was erosion (up to 3.5 feet) in front of the seawall till 650 feet beyond which there were two cycles each of successive erosion and deposition till 750 feet. This was followed by deposition till 940 feet. The net change was -155

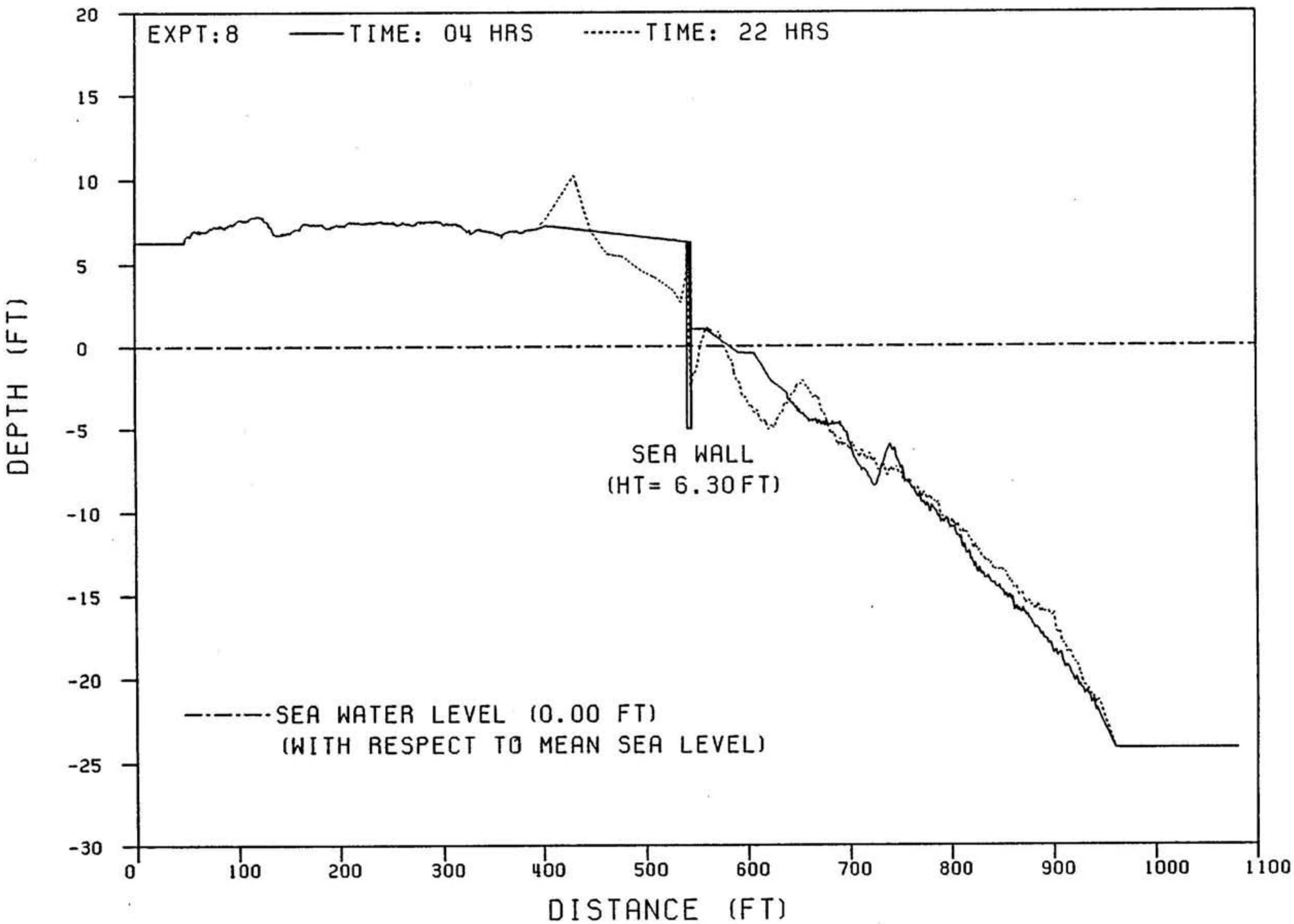

Figure 5.15: Mean profile, Expt S8, at 04 and 22 hours

ft^3/ft (which corresponds to 0.01 feet in model units).

The magnitude of the changes along the beach were accentuated by the positioning of the seawall. There was a prominent scour trough of 100 feet cross-shore extent with a maximum scour of about 4 feet. The mean profile exhibited the presence of two prominent offshore bars, at about 560 and 660 feet respectively. At the end of storm simulation, the bed exhibited significant three- dimensionality. The cross-tank variance, calculated using the three profiles B1, B2 and B3, is presented in Fig. 5.16 for T=22 hours. Regions 630-680 feet and 800-850 feet are especially notable.

An additional experiment was conducted after S7 and before S8. In this experiment, the seawall was at 544 feet with backfill extending up to the crest of the seawall at its back. Sand was packed behind the seawall such that the crest of the barrier island (the + 6.3 contour with respect to MSL) was advanced an additional 144 feet (from 400 feet to 544 feet). Storm surge was set at 6.3 feet, and 8-second regular waves of height $\sim$ 8 feet were allowed to impinge on the armored beach. Though the sides of the seawall were quite flush with the walls of the wave tank, adequate effort had not been made to make these joints "sand-tight" whereby steady seepage occurred with advent of storm waves. Consequently, sand upland of the seawall was transported seaward, a vertical scour of about 7 feet occured immediately behind the seawall, and failure occurred after 17 hours (see Fig 5.17). The results of this experiment are mentioned herein since they are somewhat representative of conditions where three-dimensional flows occur induced by the failure of adjacent seawall sections.

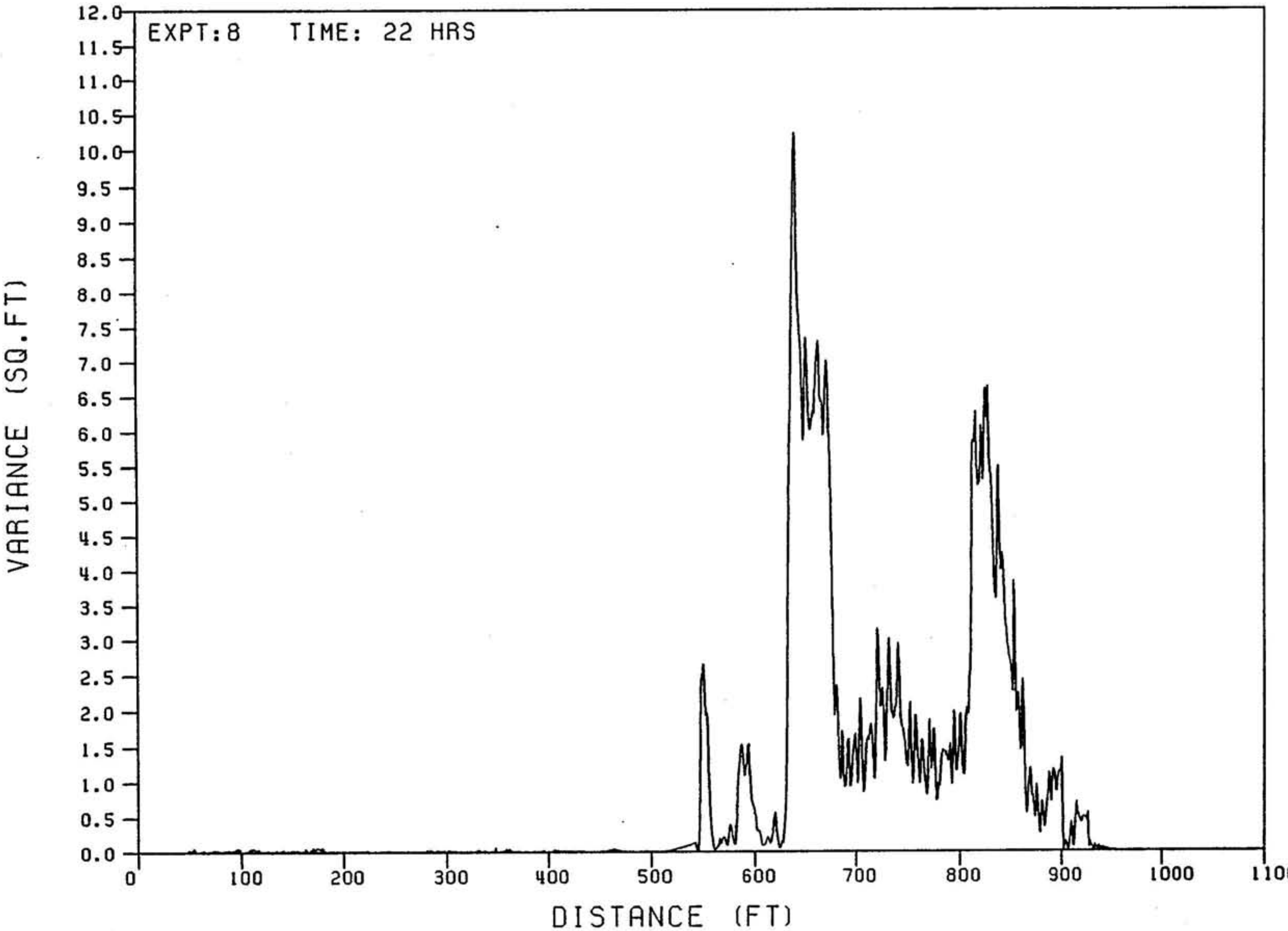

Figure 5.16: Variance of the mean profile at 22 hours, Expt. S8

Figure 5.17: Failure of seawall due to improper end sealing

Chapter 6

SUMMARY AND CONCLUSIONS

6.1 Summary

With the aim of simulating the effects of overwash on barrier islands with seawalls and characterizing their response, a series of eight experiments was conducted at the Coastal Engineering Laboratory of the University of Florida. A barrier island was constructed with a 400 feet long horizontal crest and an initially- uniform mildly sloped (1:19) beach. The effects of positioning the seawall at two different locations and with varying crest elevations as well as the effects of various storm surge levels and accompanying overtopping were investigated. Experiments were conducted with both regular as well as irregular waves.

6.2 Conclusions

For the two experiments conducted with a non-interactive seawall (Expts. S1 and S2), i.e., when the seawall was just submerged in sand, the effect on the sediment transport process appeared to be minimal. A prominent longshore bar developed within 2 hours in both instances. However, for the case with substantial overtopping the longshore bar disappeared after about 14 hours (Experiment S1 vis-a-vis Experiment S2) and the profile appeared to undergo deflation. Also, increasing the amount of overtopping caused significant accretion over the crest of the barrier island.

Four experiments were conducted with the crest of the seawall raised 2 feet above ground level (Expts. S3, S4, S5 and S6). These encompassed two levels of overtopping (3.7 feet for Expts. S3 and S4, and 5.2 feet for Expts. S5 and S6) over the crest of the barrier island. Overtopping resulted in washover deposits indicating substantial transport in suspension. The amount of accretion increased from marginal at the bay-side of the barrier island to prominent towards the ocean-side. Varying degrees of scour were apparent for about 40 feet on the lee-side of the seawall with the maximum scour occurring immediately behind the seawall. There was substantial erosion on the ocean-side of the seawall in all instances, however, aggravated toe scour was not apparent. All the profiles exhibited accretion further offshore. Overtopping appeared to supress longshore bar formation. When there was overtopping of 3.7 feet, a mild longshore bar was evident for the case of regular waves, however, when the level of overtopping was increased to 5.2 feet there was no bar formation. Longshore bars were not present in the experiments conducted with irregular waves. Also, the changes in the bed profiles were milder for the cases with irregular waves as compared to those with regular waves. Changes were greater when the level of overtopping was increased.

An experiment (S7) was conducted to simulate a storm with a peak surge level of 11.3 feet and symmetrical rising and falling storm surge levels. The characteristics of the gross final changes were similar to those with steady storm surge levels except there was mild erosion on the bay-side of the barrier island and there was erosion far offshore which was not evident in the other experiments. Overall, the differences were quite moderate.

Another experiment (S8) was conducted to investigate the effects of the position of the seawall. The seawall was constructed just landward of the shoreline (corresponding to MSL), and the crest elevation of the seawall was level with that of the island and the storm surge level. With the seawall positioned well into the surf-zone and a storm surge of 6.3 feet, the changes in the profiles were quite dramatic. There was substantial erosion of the backfill for about 100 feet which was deposited further landward as a high mound. There was significant scour at the toe of the seawall (on the ocean-side) and a prominent scour trough further seaward. A prominent and highly three-dimensional longshore bar was present indicating lateral movement of sand. The offshore experienced accretion. The scour immediately landward of the seawall has implications pertaining to the seawall integrity during storms as it may jeopardize the "deadman" anchoring system.

Under the conditions examined in the eight experiments, it appears that seawalls can discharge their function of protecting the upland from storm damage due to augmented surge levels quite effectively provided they are placed adequately landward from the shoreline. Concurrently, upland property should not be developed immediately behind the seawall as there can be scour immediately behind the seawall, in fact, scour reaching about 40 feet behind the seawall was documented in this study. When the seawall was placed just landward of the shoreline and only mild overtopping occurred due to wave action, the seawall failed to protect the upland till about 100 feet behind it. The model study indicated aggravated erosion on both sides of the seawall which, in turn, demands detailed and accurate design of seawalls to prevent failure. Also, the failure of one panel of a seawall can have a "snow-ball" effect and cause failure of adjacent panels rapidly. It must be noted that the experimental study precluded analysis of the effects of the seawall on adjacent beaches. Under conditions of overtopping, the seawall will probably be projecting into the surf- zone and pose a hindrance to the longshore sediment transport. This will be detrimental to the downdrift beaches. A seawall placed well landward on a beach with a persistent erosional trend will, with time, be located closer to the shoreline and will interact adversely with the beach system (cf. Experiment S8) and will reduce its own capability to survive storms. Also, seawalls affect the aesthetics of beaches adversely (unless they are submerged).

Finally, although an attempt has been made to apply state of the art sediment modeling principles in this study, interpretation of the results when scaled to prototype should recognize the somewhat immature state of movable bed modeling, the specific range of variables included herein and the fact that when the model sediment is scaled to prototype, the diameter is 0.4 mm which is larger than that of many Florida beaches and thus would tend to underestimate scour. The presence of external currents which were not simulated in the study and the fact that during storms, wave heights are frequently higher than the simulated height of 8.5 feet , would further amplify scour.

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