DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

SHORE EROSION BY STORM WAVES

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BEACH EROSION BOARD
OFFICE OF THE CHIEF OF ENGINEERS

FOREWORD

The data presented in this paper have been assembled with the principal objective of furnishing timely aid to the offices of the Corps of Engineers engaged in the design of hurricane protection measures. Since it is realized that the data presented herein are by no means either a complete or authoritative treatment of the subject, the material is being published at this time as a Miscellaneous Paper for limited distribution only.

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Views and conclusions expressed herein are not necessarily those of the Beach Erosion Board.

SHORE EROSION BY STORM WAVES

by
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1. Introduction. In connection with its mission of developing hurricane protection plans for the Atlantic and Gulf shores of the United States, the Corps of Engineers, Department of the Army, has need to know the magnitude of shore erosion which can be expected from hurricane wave attack. To partially fill this need, the information on storm wave erosion available in the files of the Beach Erosion Board is summarized in this report. This report is not intended to be an exhaustive analysis of the data; in fact, the available data are not in sufficient detail to warrant such an analysis. Rather, the data are presented in a summary form in order to acquaint the interested offices of the Corps of Engineers with the general aspects of shore erosion by storm waves.

2. Erosion data from both frontal storms and hurricanes are included in this report. The wave action in both cases is similar, the main difference being in the magnitude of the surges and the duration of the surges and waves accompanying the two types of storms.

3. It will be noted that the remaining paragraphs of this introductory section are in the nature of a description of hurricane erosion and the elements of protection against such erosion. This description is included as being helpful to an understanding of the subsequent paragraphs.

4. Protective Beaches and Dunes. A wide sand beach backed by a line of sand dunes provides, in many cases, a practical form of protection from hurricane wave attack. In effect, the beach and dune are subjected to erosion by the turbulent action of the waves. A successful design of a protective beach and dune combination involves an estimate of the extent of the erosion which can be expected during the hurricane selected as the basis of design. This paper presents and discusses data bearing on beach and dune design for hurricane protection.

5. First it should be recognized that the erosive attack on the shore face consists of three parts:

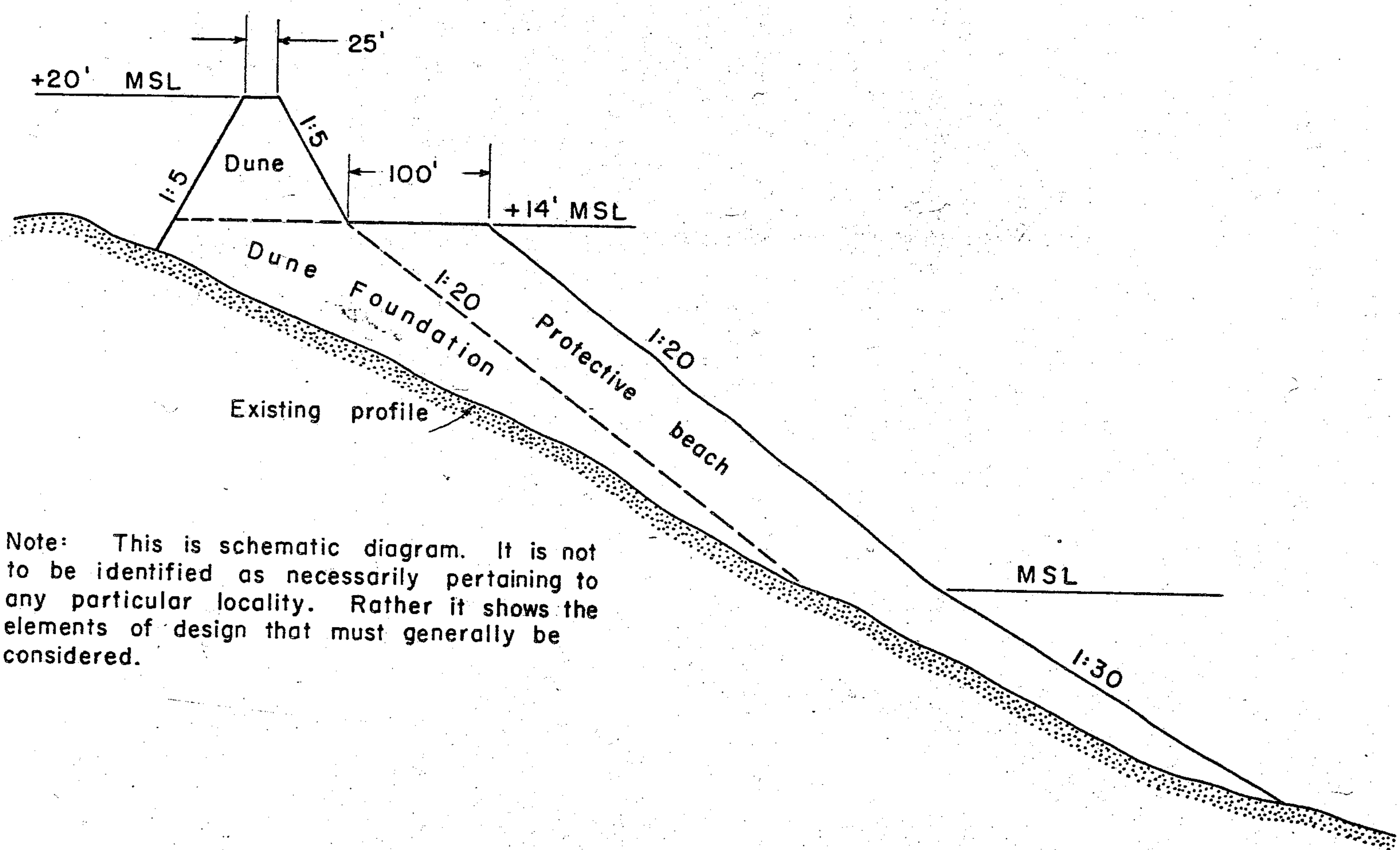
a. The long-term, normal wave attack which, over the years between hurricanes, may reduce the width of the protective beach. The eroded sand may be deposited partly in deeper water and partly moved alongshore out of the study area. The design of this protective beach and the maintenance of the beach against these long-term erosive processes sometimes requires the provision of groins or of periodic replenishment of the beach by adding new sand to the beach.

b. The short-term erosion of the beach face by the storm wave action which reaches the beach during the one to three days preceding the arrival of the hurricane. This erosive action generally is greatest between the mean low water and the elevation of the natural beach berm, usually some 5 or 6 feet above mean high water. The eroded sand is usually pulled offshore into deeper water and may form a temporary offshore bar. Much of this bar sand may be returned to the beach by the normal-weather ocean swells after the hurricane has passed.

c. The erosion of the dunes by violent storm wave action riding in on top of the surge accompanying the arrival of the hurricane over the problem area. This attack is usually of less than six hours duration; however, the erosion can be rapid and severe due to the nature of the wave attack. The erosion becomes particularly severe if the dunes are breached or become overtopped by the combination wave and surge action.

6. From the above it can be seen that there are usually three elements in the design: the design of the dunes, the design of that portion of the beach fill to serve as the foundation of the dunes, and the design of the protective beach face which is the long-term wearing surface that insures that the first two elements are intact when a hurricane approaches the area. In some cases, all or part of the first two elements may be replaced by a seawall, bulkhead, or parapet wall. These three elements are illustrated schematically on Figure 1.

7. The design of the protective beach is the same as would be made in a beach erosion control (BEC) study without a hurricane protection study. The criteria are those generally used in the BEC studies and involve a determination of the most suitable and economical means for meeting the long-term erosive tendencies in the area. It generally provides enough beach width and berm height to insure that the normal winter storm cycle will not erode the beach to the



Note: This is schematic diagram. It is not to be identified as necessarily pertaining to any particular locality. Rather it shows the elements of design that must generally be considered.

EXAMPLE OF ELEMENTS OF HURRICANE PROTECTION

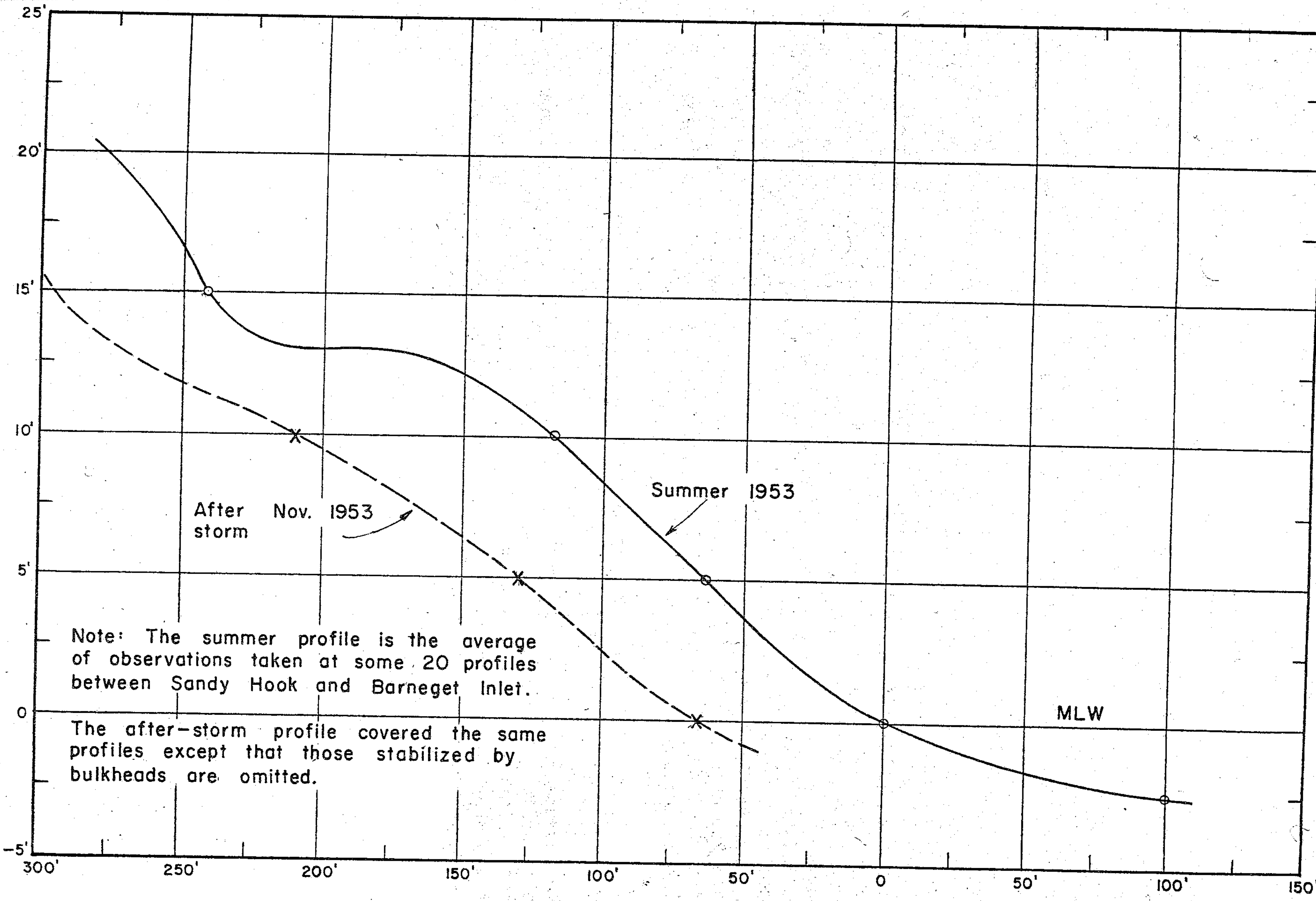
FIGURE I

extent that the purely hurricane protection components are not brought under erosive wave attack until the hurricane arrives. Methods of arriving at the design of this protective beach are discussed in Beach Erosion Board's Technical Report No. 4, "Shore Protection Planning and Design," dated June 1954. Appendix F thereof gives an example of the working out of a beach erosion control plan.

8. In contrast to the fairly well-established principles for designing stabilized protective beaches, as discussed in the preceding paragraph, the criteria for the design of protective dunes and that portion of the beach which serves as the dune foundation are not yet well established. The principal deficiency is the lack of design criteria on the magnitude of beach and dune erosion which can be expected to accompany a given hurricane. The sudden violence of meteorological forces inherent in hurricanes and the chaos usually left in their wake militate against securing beach and dune profiles immediately before and immediately after the passage of the hurricane. There are, however, a few observations which throw some light on this element of design; these observations are discussed in the following paragraphs.

9. The New Jersey Storm of 6 - 7 November 1953. This storm lasted approximately two days and was a northeaster accompanied by gale force winds. The storm winds raised the water level as much as 6 feet above normal during part of the storm. Thus, the entire beach face was brought under wave attack up to and even above the normal berm level of about +10 feet mlw. Fortunately, a survey of the shore between Sandy Hook and Barnegat Inlet had been made in the summer of 1953 by the New York District. The severe erosion resulting from the storm prompted the District to make a survey immediately after the storm, even though available funds permitted only the portion above mean low water to be surveyed. The results of the comparison of the before and after surveys are given in the following table and on Figure 2. A total of 20 profiles spaced over some 40 miles of shore were averaged in the comparison, although all measurements which were believed to be influenced by the presence of a seawall or bulkhead were excluded from these averages.

Contour Elevation (feet above mean low water)	Landward Retreat of Contours (feet) Average	Maximum
0	65	110
5	63	90
10	98	180
15	53	120



STORM EROSION OF BEACHES
OF NORTHERN NEW JERSEY
(Storm of 6-7 Nov. 1953).
FIGURE 2

There were no records to indicate to what extent the shore had eroded - or accreted - between the summer survey and the onslaught of the storm on 6 November, however, it is believed that the greater part of the indicated erosion took place during the storm itself. The recommended beach erosion control plan comprises beach restoration to provide a minimum beach width of 100 feet at elevation 10 feet above mlw.

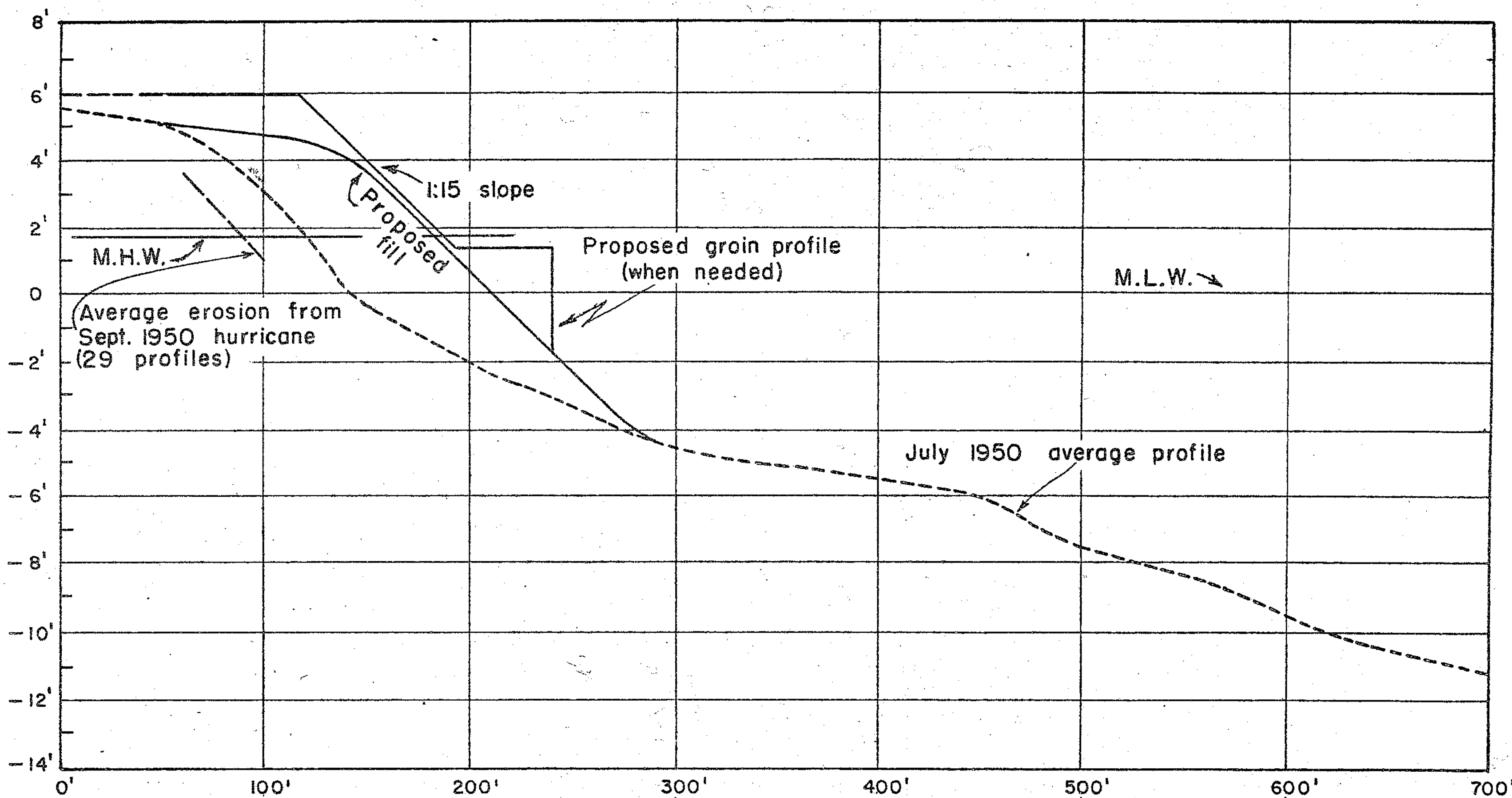
10. Florida West Coast Hurricane of September 1950. This hurricane moved into the Gulf of Mexico and took a northerly path some 30 miles offshore and parallel to the Florida West Coast. The hurricane was of only moderate intensity but became stalled about 75 miles northwest of Clearwater, Florida. The waves from the hurricane subjected the beaches of Pinellas County, Florida, to unusually severe wave action for well over a day. The storm surge rose some 5 feet above normal high tide along the shore for a short while, and deep water waves approaching the shore are computed to have been up to 19 feet in height with a wave period of about 7 seconds. A survey of the beaches of Pinellas County had been made about 2 months before the arrival of the hurricane. A survey of the position of the high-water line was made immediately following the passage of the storm. A comparison of the positions of the high-water contour on the beach showed the following:

Profiles advancing (accreting),	16
Profiles retreating (eroding),	53

The retreat of some of the profiles was obstructed by seawalls and bulkheads; eliminating these from consideration, it was found that 29 representative unobstructed profiles retreated an average of 35 feet at the mean high water line. The distribution of the retreat was as follows:

Number eroding less than 30 feet,	10
Number eroding more than 30 feet,	19
Number eroding more than 40 feet,	9
Number eroding more than 50 feet,	8
Number eroding more than 60 feet,	3
Number eroding more than 75 feet,	2
Number eroding more than 100 feet,	1

In this tabulation, the numbers are cumulative, i. e., the 19 on the second line is cumulative of all profiles eroding more than 30 feet. The solution to the Pinellas County beach erosion problem recommended by the District Engineer, and concurred in by the Beach Erosion Board, involved widening the beach to provide a 60-foot width of beach (at mhw) in front of the shore property needing protection, as shown on Figure 3.



HURRICANE EROSION OF BEACHES
PINELLAS COUNTY, FLORIDA
(Hurricane of September, 1950)

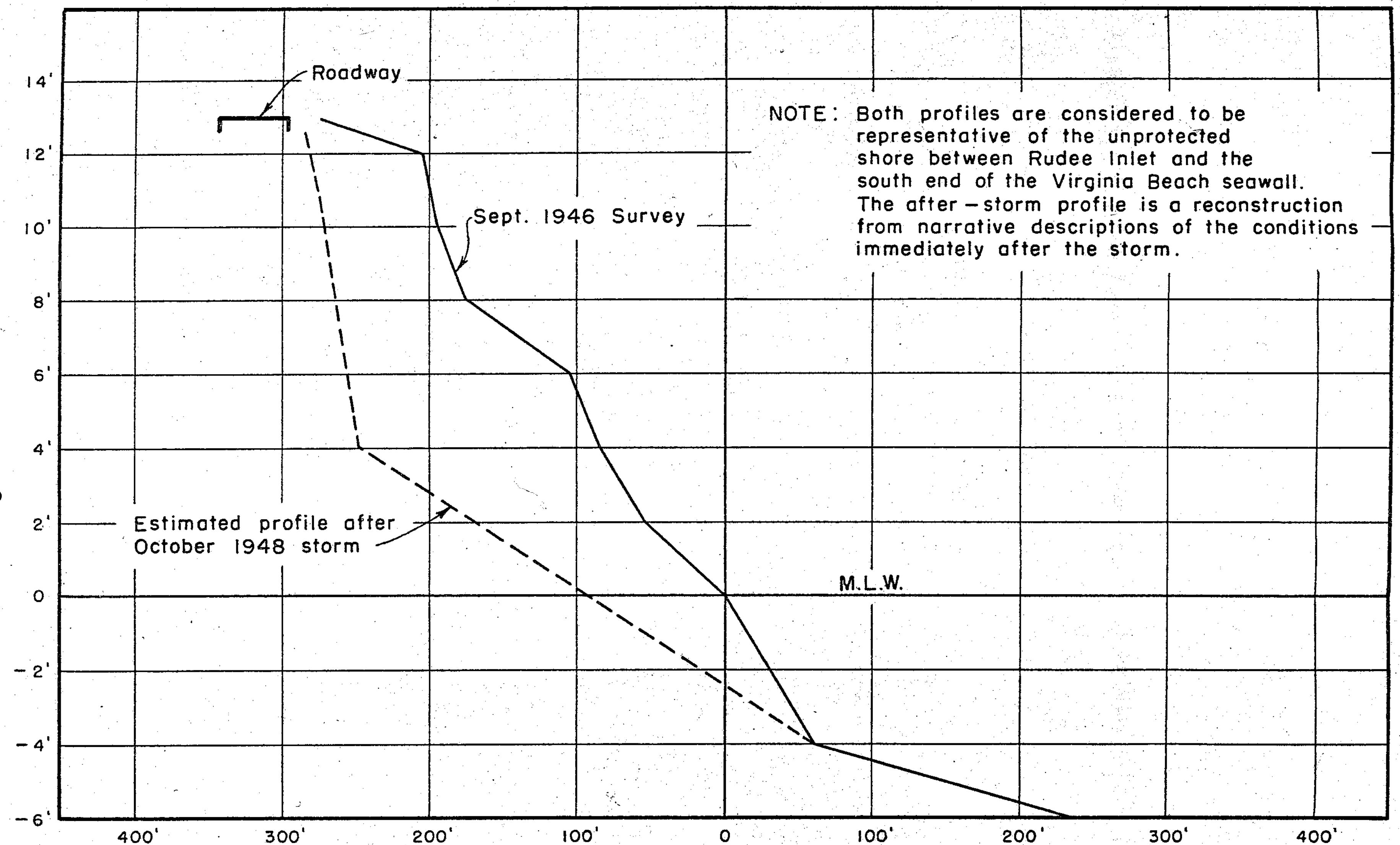
FIGURE 3

11. Virginia Beach Storm of 4 - 5 October 1948. This storm, a northeaster, struck the Virginia coastline on 4 October 1948 and continued for several days thereafter. It reached maximum intensity on 5 October when highest water levels occurred, reaching 6.8 feet above mlw at the tide gage in Norfolk Harbor. Natural berm elevation at Virginia Beach is about 7 feet above mlw. A comprehensive survey of the Virginia Beach area made in September 1946 is the best indicator of beach conditions prior to the October 1948 storm, although some gradual erosion had probably taken place in the 2-year interval just prior to the storm. An inspection of the beach was made on 7 October after the storm had subsided. Observations and photographs taken on that date indicated that in the unprotected section of shore between the end of the concrete seawall at 7th Street and Rudee Inlet, the storm washed away practically all of the backshore to the highway, a few relatively narrow sand hummocks being left immediately east of the highway. At the time of the 1946 survey the mhw shore line was generally 175 feet seaward of the highway, and the 7-foot contour about 110 feet. Backshore elevations seaward of the highway in 1946 ranged up to 14 feet above mlw. The exact elevation of the shore immediately fronting the highway after the 1946 storm is not known, but in general it could have been no more than from 4 to 7 feet above mlw indicating recession during the storm of about at least 100 feet as shown on Figure 4.

12. The Long Island Hurricane of September 1938. This storm was of great violence. The storm surge rise against the beach was in the order of 9 feet. The astronomical tide was at about mean sea level when the peak surge reached the shore; so the peak surge elevation was about +9 feet msl or about +11 feet mlw in the shore area around Jones Beach. Some fourteen shore profiles had been measured in the Jones Beach area in July 1938. These profiles were resurveyed in October 1938 to determine the effect of the September 1938 hurricane. The average erosion picture is illustrated on Figure 5. The results at the +5-foot mlw contour showed that four of the fourteen profiles accreted, two did not change, and eight eroded. The erosion picture at the +5-foot mlw contour for the eight eroding profiles was as follows:

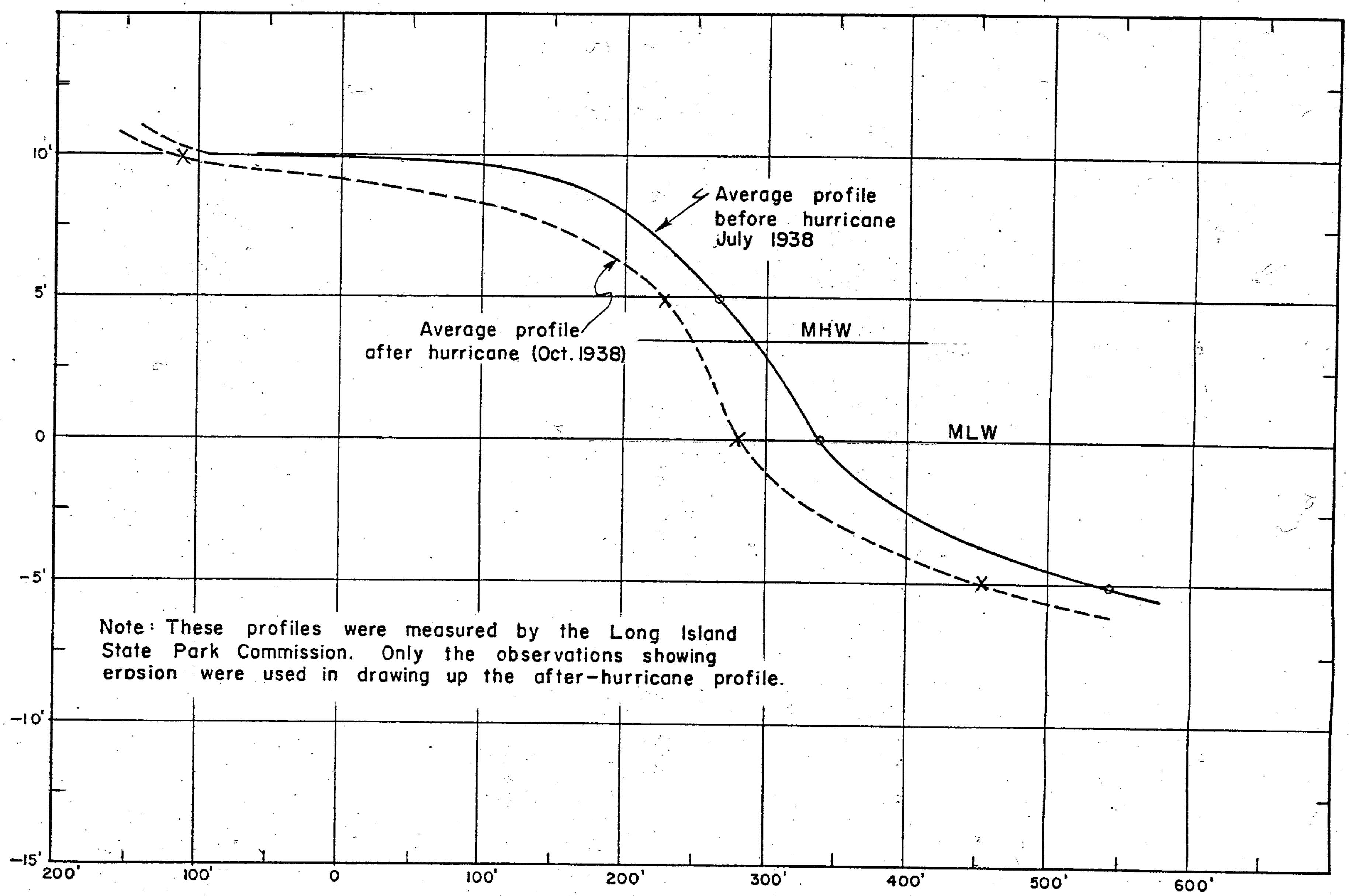
Eroding less than 30 feet,	2
Eroding 30 feet or more,	6
Eroding 40 feet or more,	5
Eroding 50 feet or more,	2

The two profiles that eroded more than 50 feet, showed erosion of 80 feet and 122 feet. It is of some interest to note that while only four profiles showed accretion at the +5-foot msl elevation, a total of nine profiles showed accretion at the mlw contour; this indicates that possibly storm waves pulled material from the higher beach elevations and deposited the material on the lower elevations.



STORM EROSION OF BEACHES
VIRGINIA BEACH, VA.
(Storm of 4-5 October 1948)

FIGURE 4



HURRICANE EROSION OF BEACHES
JONES BEACH, LONG ISLAND, N.Y.

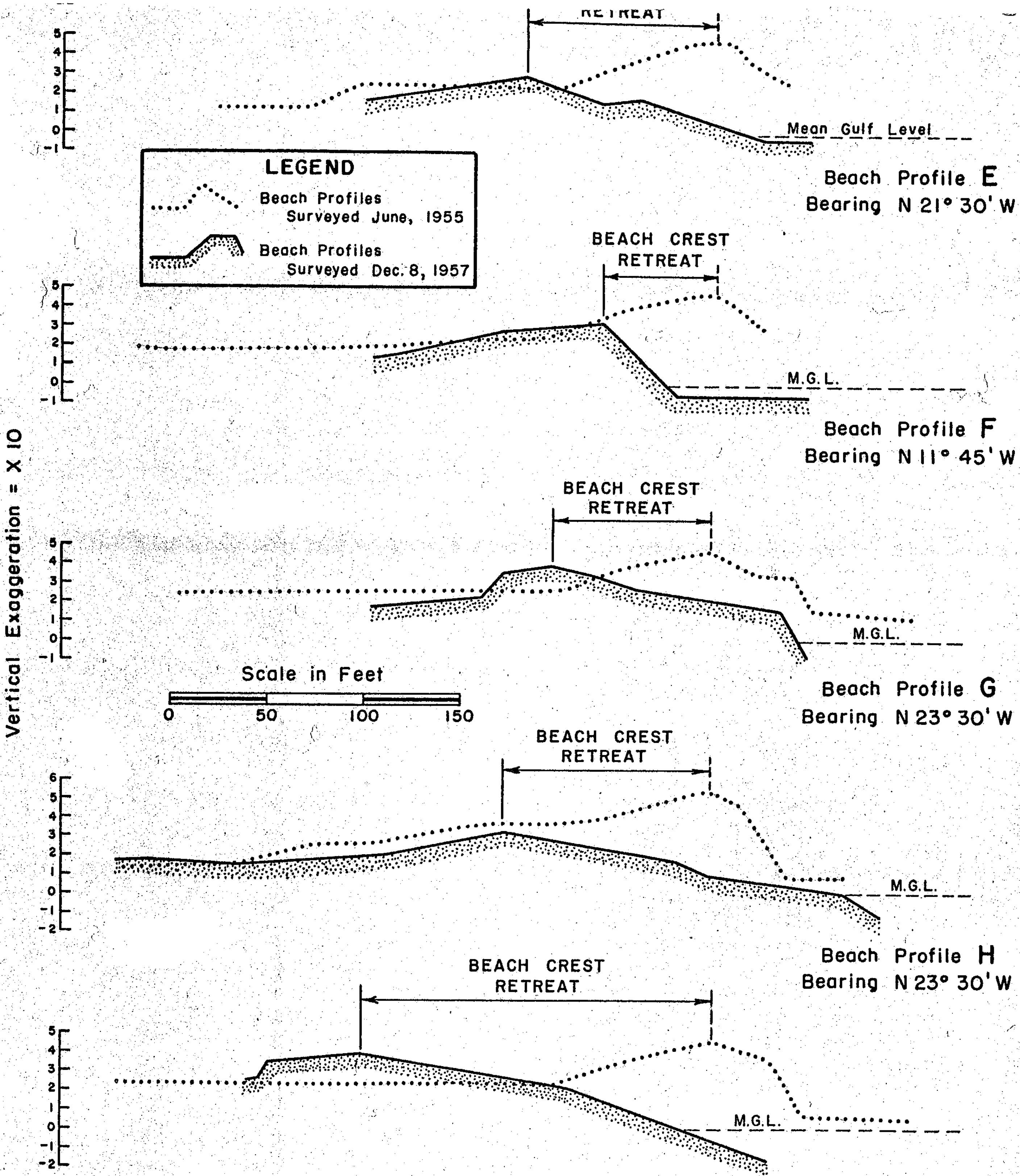
FIGURE 5

13. This 1938 hurricane also breached the dune line in a number of cases. A study of the situation showed that dunes with a crest height of 20 feet mlw or greater were not breached by the hurricane waves while dunes with a crest height less than 20 feet mlw were generally breached or severely damaged by wave overwash.

14. Hurricane Audrey of June 1957. This storm struck the low swampy Louisiana coast south of St. Charles on 27 June 1957. Much of this coast is a thin sand veneer laid over a mud subgrade. A number of profiles were available in the area between Sabine Pass and a point on the shore some 75 miles to the east. The profiles had been established for comparative purposes in the period 1953 - 1955. Nine of these profiles were resurveyed within 5 months after the storm. The hurricane surge rose in the order of 10 feet along most of this shore, and completely submerged the crown of the beach ridge, or dune line, which had an average elevation of about +5 feet mean Gulf level. The resulting changes in the beach profile and character were phenomenal. In many cases the sand veneer was removed and the underlying mud became the beach face for miles along the shore. The action at the +3-foot mean Gulf level contour was an average retreat of 125 feet. The action is described in considerable detail in Technical Report No. 10 of the Coastal Studies Institute of Louisiana State University, entitled "Morphological Effects of Hurricane Audrey on the Louisiana Coast," dated June 1958; Figure 6 was extracted from that report.

15. Lake Okeechobee Hurricane Data. Data on levee erosion for several hurricane passages at Lake Okeechobee, Florida have been obtained by the Jacksonville District. These are summarized in Table 1. The levee material was generally a sand and marl, or rock and marl mixture, occasionally protected to some extend by vegetation, rather than loose unconsolidated sand as with beaches and dunes. However, some idea of erosion rates for other materials may be obtained from these. The worst damage occurred from the hurricane on 26 - 27 August 1949. Gusts up to 120 - 125 miles per hour were recorded during its passage over the Lake. The portion of the north shore where the worst damage occurred, was subjected to waves and wind set-up resulting from a southerly wind with a maximum velocity of 65 miles per hour and a fetch of about 36 miles. The section was subjected to a maximum wind set-up of 6.8 feet with maximum significant waves of 6.3 feet. The waves had a duration of about 2.6 hours above a 4.5-foot height. Damage started about 0.7 foot below the maximum significant wave trough and extended about 4.1 feet above the maximum significant wave crest. The wave erosion resulted in about a 60-foot cut at the wind set-up level, leaving a vertical scarp of about 8 feet as shown on Figure 7. The original levee slope was 1 on 8.

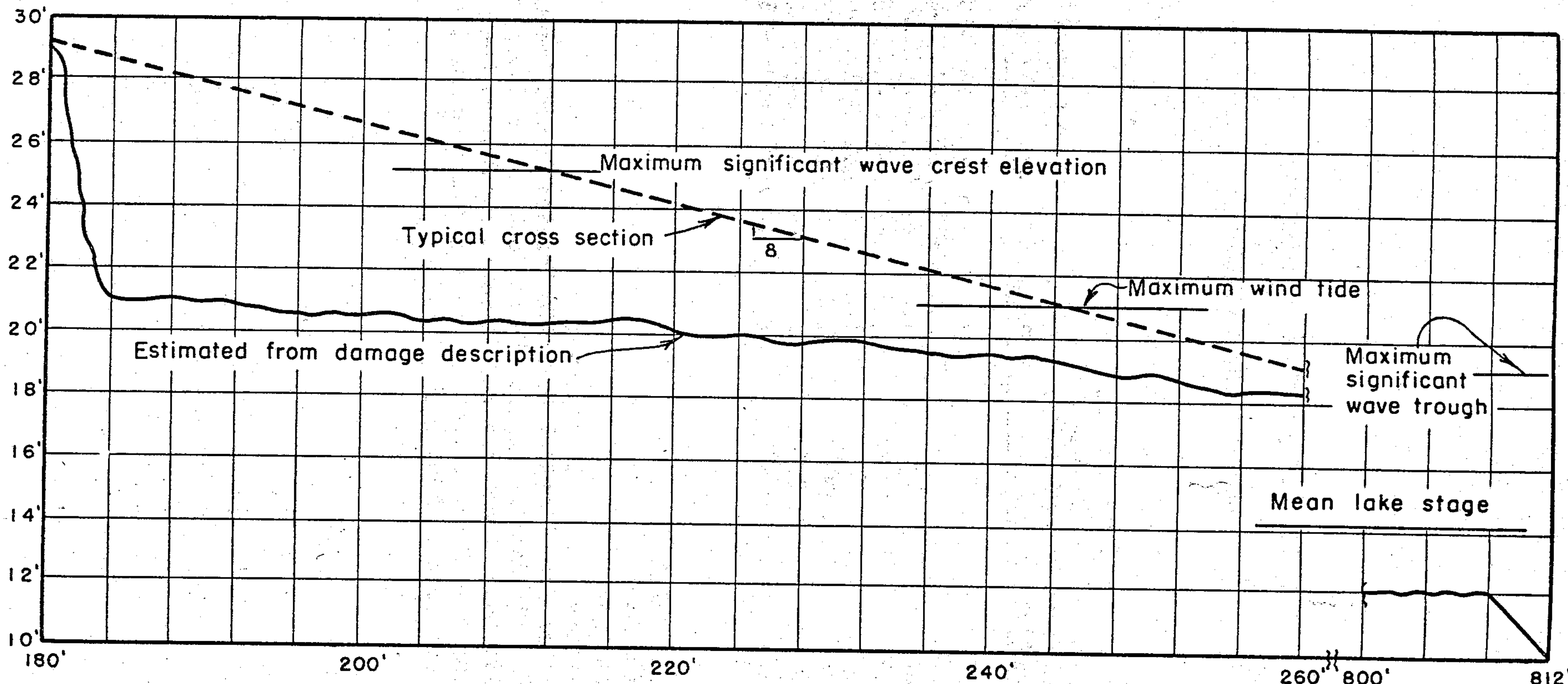
16. Wave Tank Tests. Tests of profile changes resulting from wave attack have been made in the large wave tank at the Beach Erosion Board. Table 2 attached gives the results of the eight tests



From Technical Report No. 10
Coastal Studies Institute
Louisiana State University

VARIATIONS IN HURRICANE INDUCED BEACH RETREAT

FIGURE 6



Taken from Part IV of 13 Aug. 54 report on Central and Southern Florida Flood Control Project. Jacksonville District, Corps of Engineers.

HURRICANE EROSION OF LEVEES

Lake Okeechobee Storm of August 1949

FIGURE 7

TABLE 1-HURRICANE WAVE EROSION OF
LAKE OKEECHOBEE LEVEES(5)

Year	Maximum Significant Wave (feet)	Duration of Waves Greater than 4.5 ft. (hours)	Levee Slope	Erosion (ft.) at -2'	-1'	0(4)	+1'	+2'	Material
1945	4.9	6	1:8	0	-12	-20	-20	-13	(1)
1947	5.8	7	1:5	-11	-10	-7	-4	-1	(2)
	6.0	8	1:6	+2	0	-5	-7	-8	(2)
	5.7	6.5	1:6	+1	-1	-4	-6	-7	(2)
	5.7	6	1:6	0	-12	-11	-6	0	(3)
1948	6.6	13	1:5	0	-10	-6	-4	-1	(3)
1949	5.5	1.3	1:5	-9	-6	-3	-1	-1	(3)
	6.3	2.6	1:8	-16	-32	-60	-53	-45	(1)

(1) Sand and shell
(2) Sand and marl
(3) Rock and marl
(4) Still water (wind set-up) level
(5) Data taken from "Partial Definite Project Report, Central and Southern Florida Project for Flood Control and Other Purposes, Part IV, Lake Okeechobee and Outlets, Supplement 2--Hydrology and Hydraulic Design, Section 6--Design Memorandum Resistance of Levees to Wave Erosion."

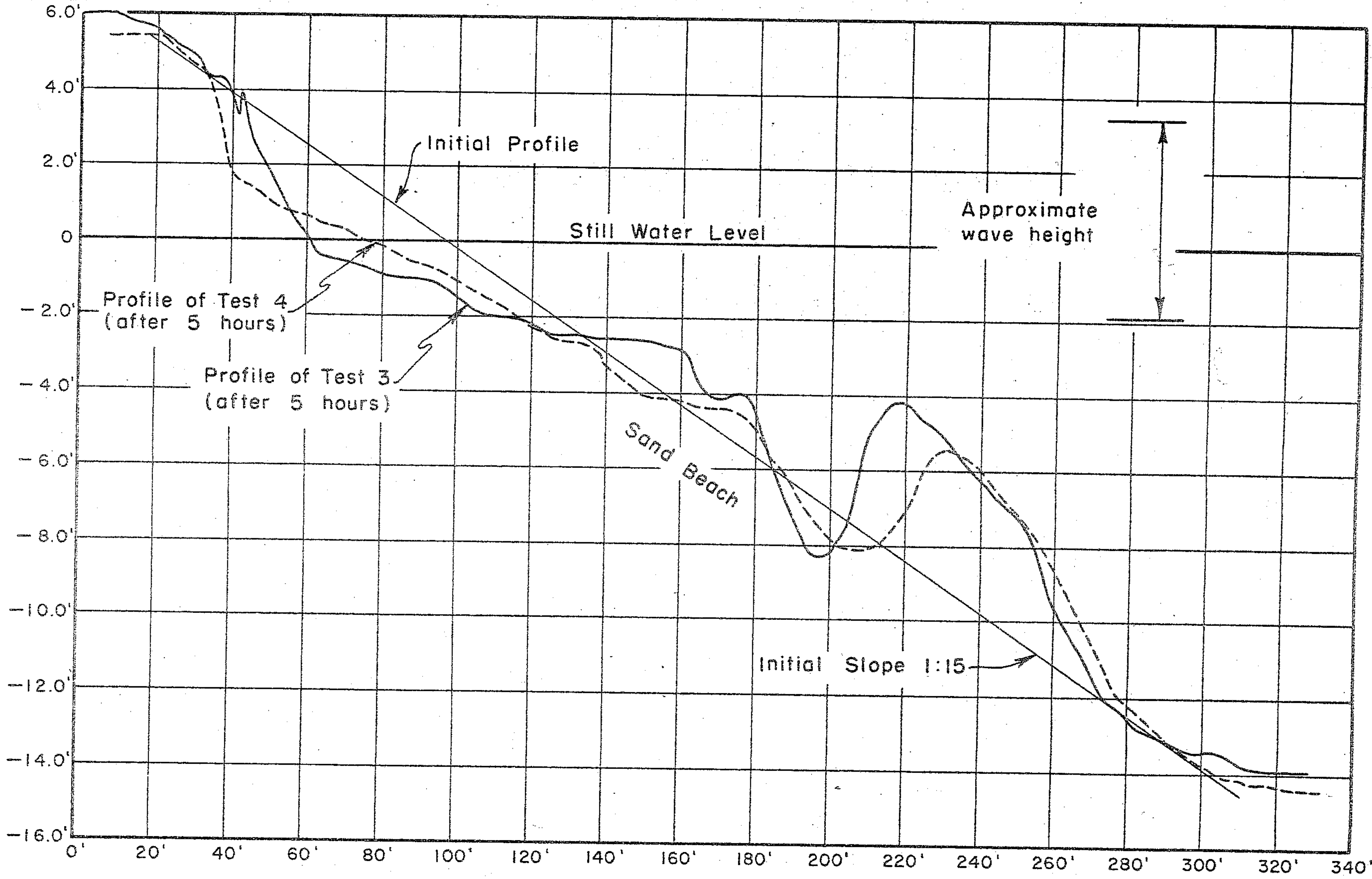
TABLE 2-RATE OF BEACH RECESSION

Results of Tests in Prototype Wave Tank
at Beach Erosion Board

Run No. Date & Initial Slope	Wave Period (sec)	Wave Height (ft)	Time of Profile (hr)	Retreat (-) or Advance (+) of Profile (feet) at Indicated Level Referred to SWL							
				-3'	-2'	-1'	0'	+1'	+2'	+3'	+4'
#1	11.3	4.2	1	+13	-3	-14	-16	-17	-9	0	0
Mar.			5	-14	-12	-26	-28	-26	-21	-12	-1
1956			12	-16	-24	-38	-43	-40	-35	-27	-16
1/15			19	-4	-27	-46	-57	-50	-42	-34*	--*
#1	11.3	4.2	1	-4	-3	-4	-4	-2	-1	0	+1
(repeat)			5 1/2	-32	-26	-24	-23	-19	-13	-5	+1
Mar. 1956			19 3/4	-6	-25	-32	-40	-33	-31	-26*	--*
1/15											
#2	11.3	1.8	2	-3	-3	-8	-6	+2	+10	0	-1
May 1956			6	-1	+6	-7	-9	0	+7	0	0
1/15			9	+2	+8	-7	-10	-2	+7	+2	0
			19 1/2	+8	+3	-7	-18	-6	+4	+6	0
#3	11.3	5.5	1	+2	-6	-15	-17	-12	-8	-2	0
Nov. 1956			5	+18	-18	-31	-36	-28	-19	-9	+2
1/15			10	-6	-30	-43	-48	-40	-30	-21	-6
			20	-4	-35	-51	-59	-49	-38	-25	-11
#4	5.6	5.3	1	-6	-8	-11	-15	-10	-2	0	0
Dec. 1956			5	-6	-13	-16	-24	-32	-25	-16	-6
1/15			10	-15	-20	-28	-35	-30	-24	-19	-6
			20	-23	-34	-39	-46	-41	-29	-17	-5
#5	3.75	5.0	1	-8	-6	-3	-2	-1	0	0	0
Mar. 1957			5	-8	-12	-15	-17	-14	-5	0	0
1/15			10	-9	-17	-23	-23	-16	-8	0	0
			20	-4	-15	-27	-30	-23	-7	0	0
#6	16.0	2.0	1	-4	-9	-4	+1	+7	+13	+1	0
Jun. 1957			5	-7	-9	-4	0	+3	+2	+15	0
1/15			10	-5	-14	-6	+1	+11	+17	+20	0
			20	-2	-10	-3	+3	+11	+19	+23	0
#7	16.0	5.3	1	-2	-8	-8	-5	-7	0	+2	0
Jun 1957			5	-13	-17	-18	-12	-10	-6	-2	+6
1/15			10	-18	-30	-29	-22	-15	-9	-3	+6
			20	-24	-37	-39	-34	-30	-20	-13	-4

NOTE: Median diameter of sand = 0.22 mm.
Still water depth = 15 feet
All dimensions are as measured

* Measurement affected by fact that beach had eroded sufficiently to expose concrete wall at end of tank.



NOTE: The waves for these tests were as follows.

Test	Height (ft.)	Period (sec.)
3	5.5	11.3
4	5.3	5.6

STUDY OF PROFILE CHANGES FROM WAVE ATTACK

Tests in Large Wave Tank at Beach Erosion Board

FIGURE

which have been made to date. The tabulation shows the readjustment of the profiles when compared to the position of the contour on the initial 1:15 smooth slope. Of the eight tests, Tests 3 and 4 are considered to most nearly represent hurricane wave characteristics; the erosion of the slope after 5 hours for these tests is shown on Figure 8. In fact, both tests might be taken to represent a storm wave that has broken when crossing the flooded berm and impinges against the dune line. The retreat is found to be greatest near still water level, being about 35 feet after 5 hours of attack in both cases.

17. In connection with the effect of beach berm width and elevation in reducing wave action against a dune line, a few tests were made in the Beach Erosion Board laboratory. The results of this study are presented in the July 1957 edition of the Bulletin of the Beach Erosion Board (Vol. 11, No. 1.). This was a small-scale, fixed bed study and, of course, does not furnish erosion data. It does, however, show the character of wave attack which can be expected against the face of the dunes for various conditions of berm width, berm height, surge level, and wave characteristics. Copies of this Bulletin were furnished all District and Division offices at the time of publication.

18. The relative inadequacy of the data discussed in the preceding paragraphs is recognized. However, as stated earlier, it summarizes all the reliable data on this subject now in the files of the Beach Erosion Board. Within the next year, additional data may become available from a beach profile observation program under consideration by the Hurricane Survey Coordinating Committee of the Corps of Engineers; if this program materializes, it should add greatly to the knowledge of the rate of storm wave erosion.