P2

SQT

ENGINEERING AND INDUSTRIAL EXPERIMENT STATION

College of Engineering

University of Florida

Gainesville

KENNEDY SPACE CENTER

OCEAN BEACH EROSION

SPONSORED BY:

National Aeronautics and Space Administration

Kennedy Space Center

SUBMITTED BY:

Coastal and Oceanographic Engineering Laboratory
Engineering and Industrial Experiment Station
University of Florida
Gainesville, Florida

June, 1973

ACKNOWLEDGEMENT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

A_c = Throat cross-sectional area of assumed breakthrough inlet

D_{50} = Mean sand grain diameter

Q = Tide induced flow rate

Q_{max} = Maximum tidal flow rate through the breakthrough inlet

S_o = Sorting coefficient for sand size distribution

T = Semi-diurnal tidal period

V_{max} = Maximum tidal current velocity through the breakthrough inlet

Greek Letters:

n = Tidal elevation with respect to mean water level

ABSTRACT

The present investigation concerns the problem of dune barrier erosion and possible breakthrough due to storm and hurricane wave activity near Mosquito Lagoon, in Kennedy Space Center property, and the consequent danger to KSC facilities. The results of a geological as well as hydrodynamic appraisal of the problem area indicate that no inlet has existed across the dune barrier since 500 A.D., and that there is little likelihood of a possible breakthrough inlet remaining open permanently, primarily because the relatively shallow lagoon does not contain enough volume of water to maintain an inlet between the ocean and the lagoon.

It is therefore recommended that only minimal measures, such as closing up the man-made passes across the dunes, be carried out to ensure continuation of the action of natural beach maintaining processes. Appraisal of the need for hurricane protection to the KSC facilities is beyond the scope of this study.

1. INTRODUCTION

1.1 Scope of Study

The present study was carried out at the request of Kennedy Space Center to investigate ocean beach erosion in KSC property at Cape Kennedy. The work statement called for (1) a review of the problem of dune erosion at Kennedy Space Center, (2) identification of the risk to KSC facilities and the impact on the Intracoastal Waterway and Mosquito Lagoon should the dune barrier fail in a storm or otherwise, and (3) recommendation of the most economical method(s) of achieving reasonable protection to KSC facilities and Mosquito Lagoon through preservation of the dune system, if such is required. The dune area to be studied was expected to include all of the KSC ocean boundary of approximately 25½ miles.

1.2 Study Location

Fig. 1 shows the study area, including Mosquito Lagoon and the dune barrier between the lagoon and Atlantic ocean. The lagoon, which is approximately 33 miles long, is rather shallow and marshy (Photo 2(a)), and is connected to the ocean through Indian River North and Ponce de Leon Inlet. The Intracoastal Waterway is close to the western boundary of the lagoon and runs into Indian River through the cut at Haulover Canal (Photo 1(b)). Tides entering Ponce de Leon Inlet are dissipated in the northern portion of the lagoon, so the tidal range near Haulover Canal is very small indeed. The dune barrier (Photo 1(a)) along the KSC property is in a more or less natural state, and the dune line, although varying in elevation, is unbroken, except for a few man-made low spots parti-

1
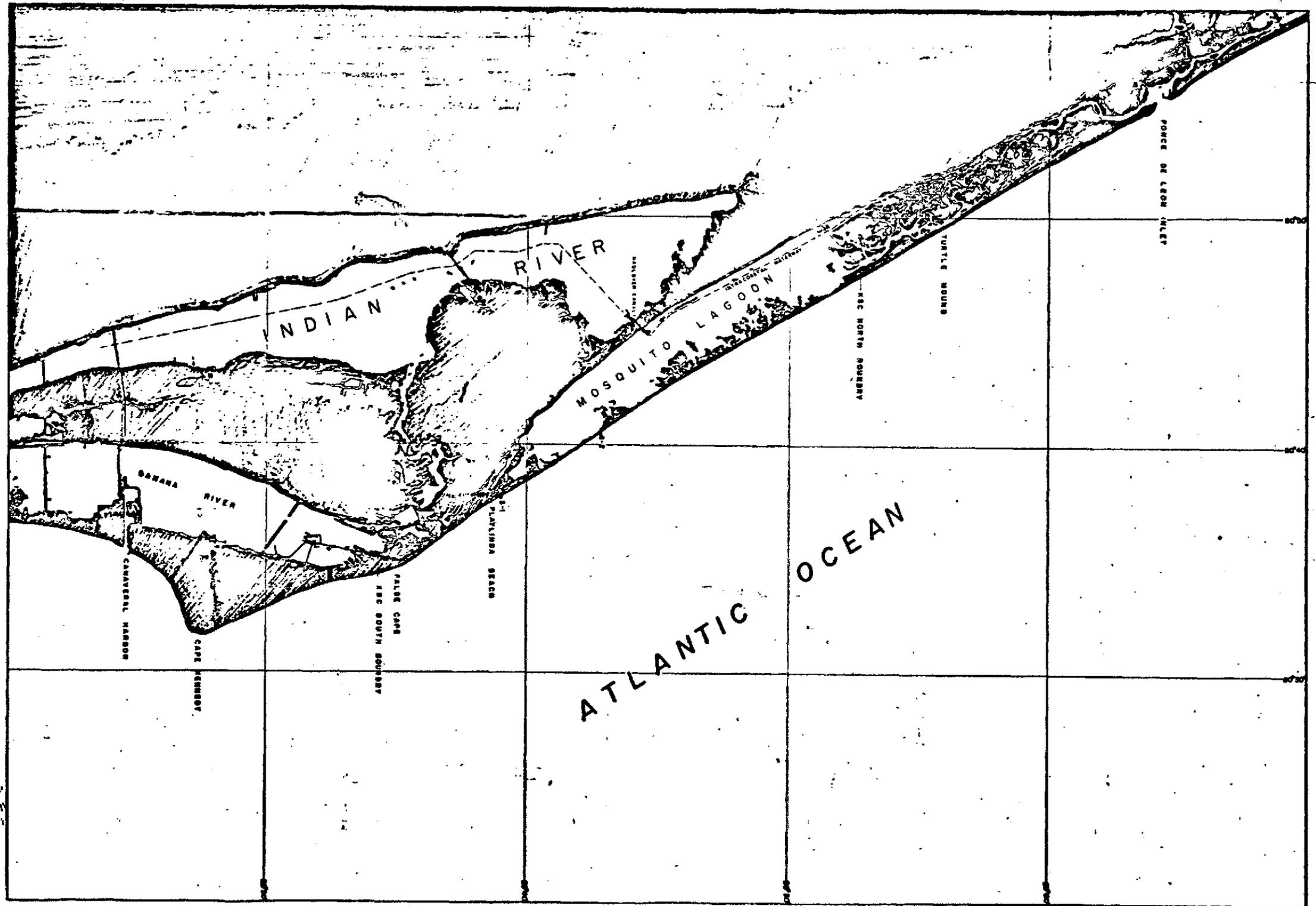
Fig. 1.2.1   Study Area Including Mosquito Lagoon
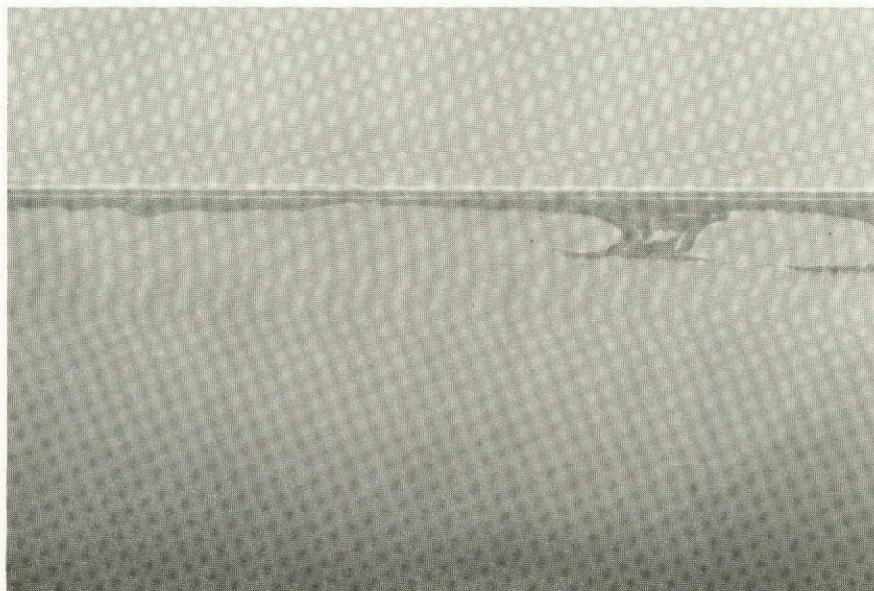
(a)

(b)

Photo 1
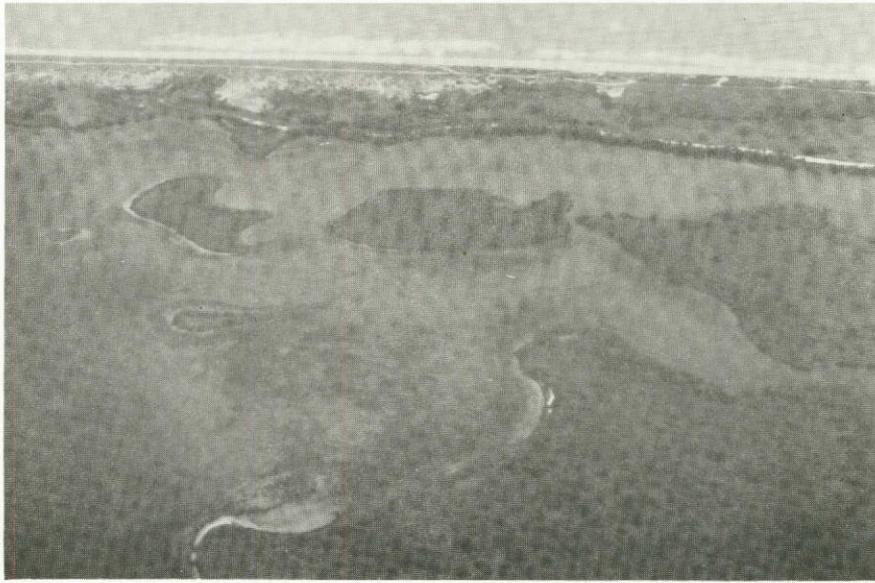
(a)

(b)

Photo 2

cularly near Playlinda Beach. Major KSC installations are located south of the lagoon (Photo 2(b)).

1.3 Approach to Problem

In accordance with the objectives set in the work statement, it was decided to approach the problem broadly in the following manner.

1. Carry out an aerial survey of the problem area, and photograph locations of particular interest.

2. Survey the beach and the dunes along the KSC property.

3. Geologically appraise the KSC shoreline, with a view to determine the likelihood of the land barrier between the lagoon and the ocean breaking through, and consequently forming an inlet.

4. Hydrodynamically investigate the possibility of a breakthrough inlet remaining open.

5. Study the possibility of breakthrough due to storm winds piling up water in the lagoon itself.

6. Appraise existing studies on hurricane effects in the KSC area, in the light of findings from the above.

2. FIELD INVESTIGATION

2.1 Scope of Field Study

In order to appraise the state of the study area, the following specific items were included in the field study.

1. Aerial photographs of the beach, the dunes, the land barrier, lagoon, Haulover Canal and some of the KSC installations.

2. Sand samples at various points on the beach.

3. Soil borings at various sites.

4. Salinity measurements in the lagoon.

5. Beach slope measurements and sand samples.

6. Measurement of the heights of some of the low spots along the dunes.

7. Survey of beach and dune erosion, and the nature of washover at low spots.

The above field measurements were carried out during various periods between early April to early June, 1973.

2.2 Beach Face Characteristics

The beach face along the KSC property exhibits interesting features. Near KSC South boundary, a very regular cusp formation was observed on June 1. These cusps had an average wavelength of about 90 ft. Approximately one mile north of the south boundary, two sets of cusps were found. The lower ones, which were more recent and closer to the waterline had an average wavelength of 60 ft., where as the second set, which was somewhat higher up on the beach face, was probably formed during the February 9-13, 1973 storm, and had a mean wavelength of 123 ft. The lower cusps had average slopes of 10° (1:5.6) at the ridge and 6° (1:9.5) at the trough. At about two miles from the south boundary, the cusps became extremely faint, and disappeared completely northward of this point until about 4 miles from the south boundary, when the two sets

reappeared. Here, the upper older set had a wavelength of 44 ft., and the lower set had a wavelength of about 23 ft. For the lower set, the slope at the ridge was about 11° (1:5.1) and the trough slope was 8° (1:7.1). It is interesting to note that where two sets of cusps were observed, the upper set had close to twice the wavelength of the lower set.

North of Playlinda Beach, the cusps became faint once again. About 7 miles north of Playlinda beach an old ship wreck lies just offshore. In this region of the shoreline, although no cusps were observed, there was a distinct spit formation, and the crest of the spits were approximately 1300 ft. apart. The beach (photo 3(a)) here is relatively more steep as compared to that near Playlinda beach.

2.3 Dune Survey

The dune height varies (photo 3(b)), but almost nowhere, except at a few man made low spots near Playlinda Beach (photo 4(a)), are they less than about 9 ft. above mean sea level. Figs. 2.3.1 shows dune heights measured from Canaveral Harbor (Corps of Engineers, 1970). At some locations, the heights are observed to be as much as 27-28 ft. The low spots are too narrow to be recorded on this plot, except the one near location P-6, which is a wide opening near Playlinda Beach.

Figs. 2.3.2 through 2.3.6 show cross-sectional dune and beach profiles (selected from Brevard County Beach Erosion Study, 1965), corresponding to locations P-1 through P-16 indicated in Figs. 2.3.1. A careful look at these profiles reveals that in many, the beach has two different slopes, one relatively flat slope between the mean low water and mean high water lines, and a second steeper slope above the mean high water line (the mean tidal range at Cape Kennedy is 3.5 ft.). These slopes are plotted in Figs. 2.3.1. It is seen

7

(a)

(b)

Photo 3

8
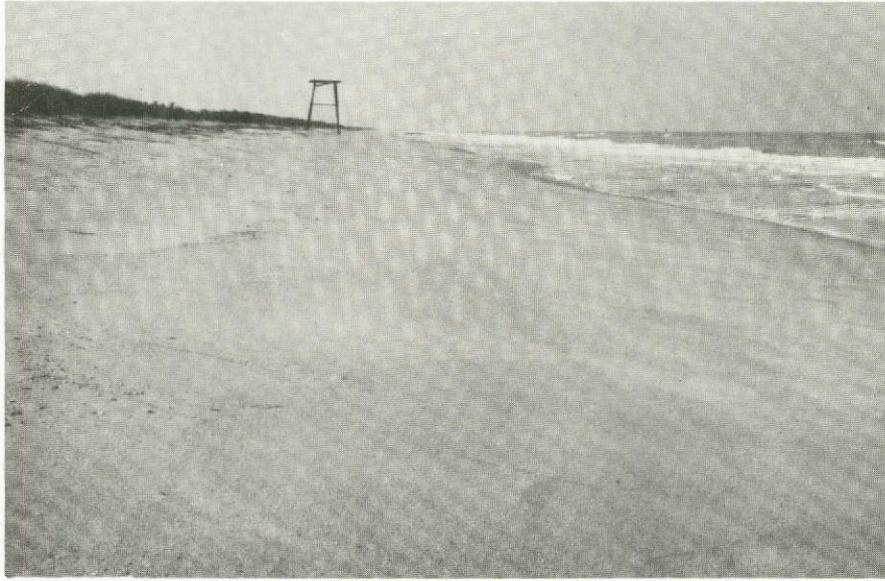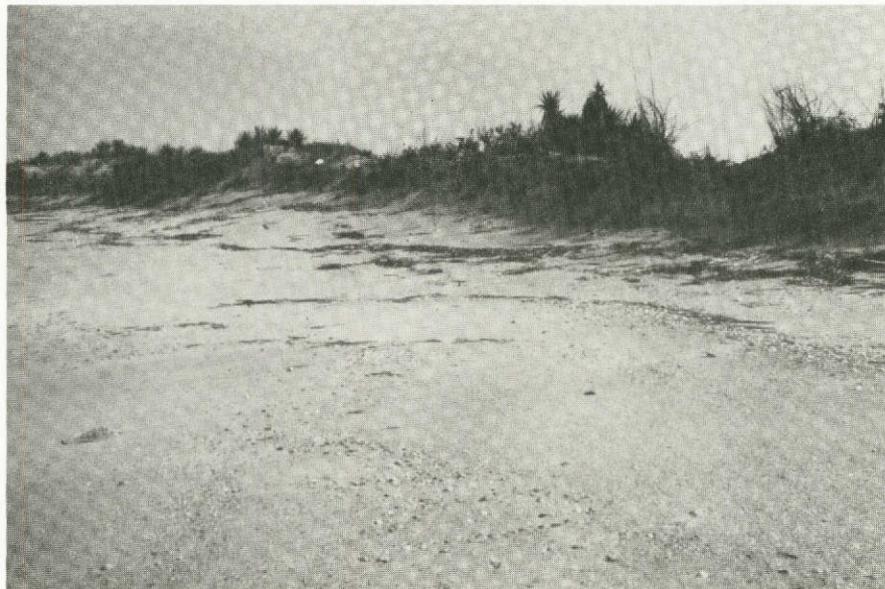
(a)

(b)

Photo 4
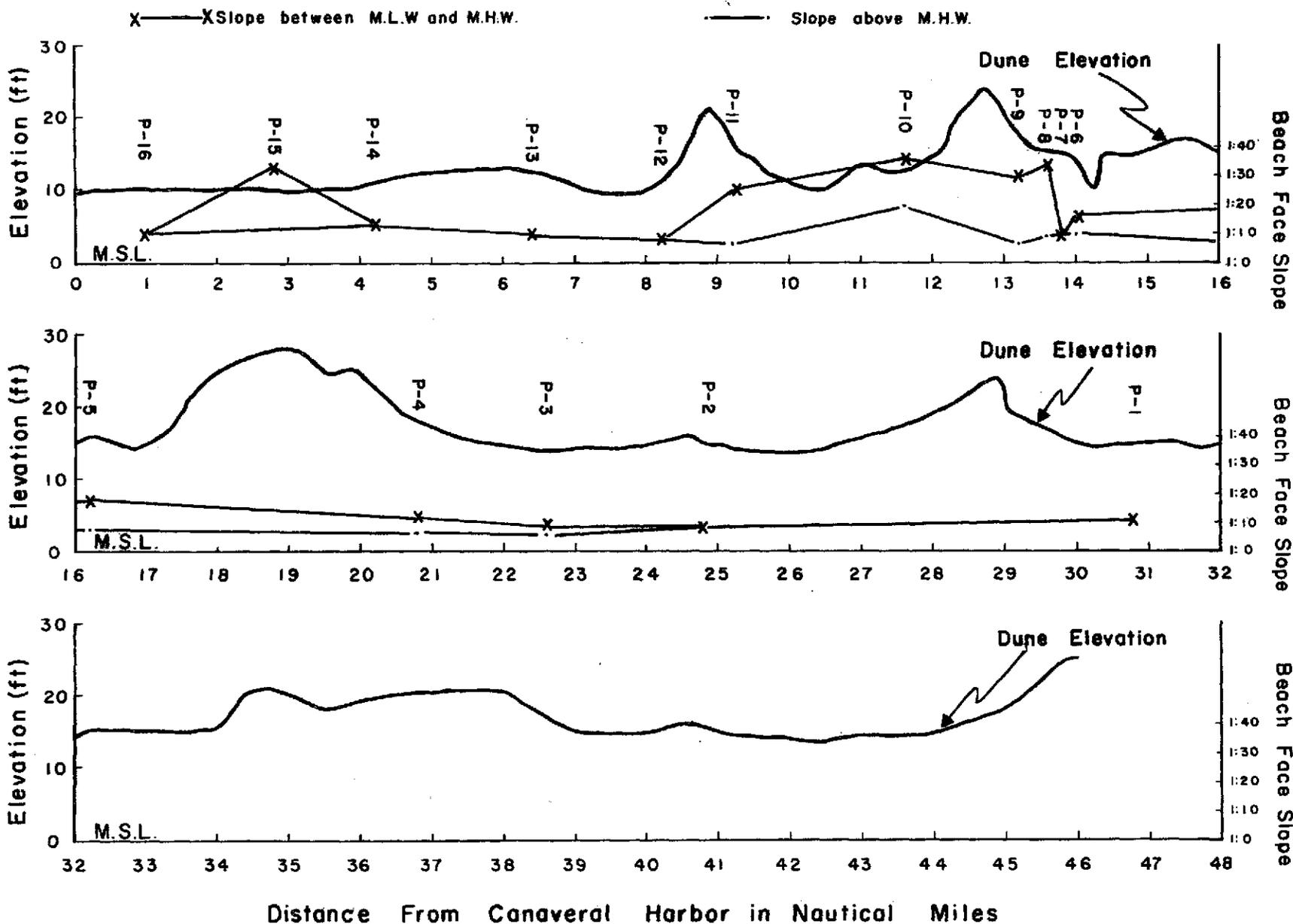
Fig. 2.3.1. Dune Height and Beach Slope as a Function of Distance North From Canaveral Harbor.
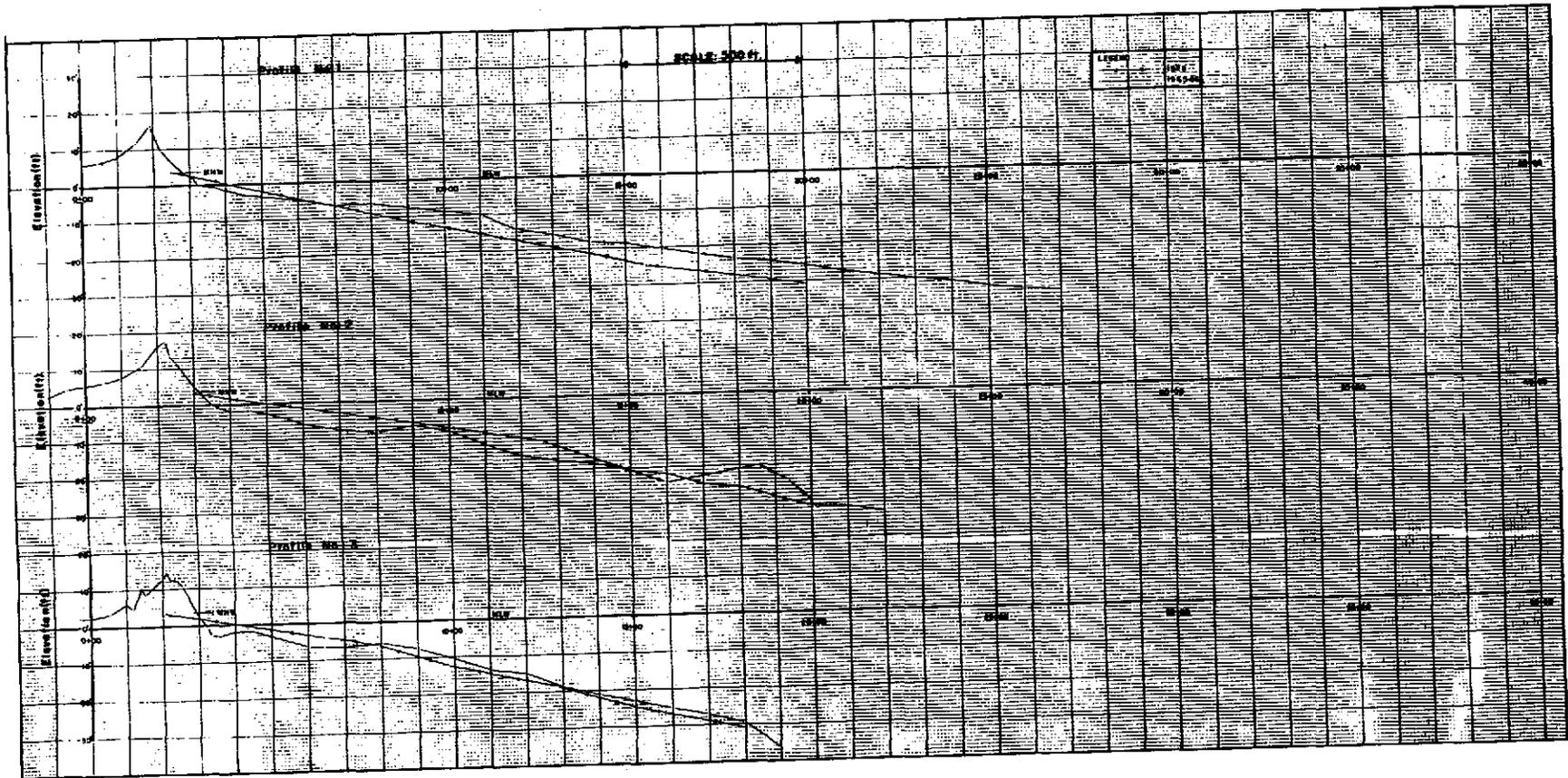
Fig. 2.3.2. Beach Profiles P-1, P-2 and P-3.
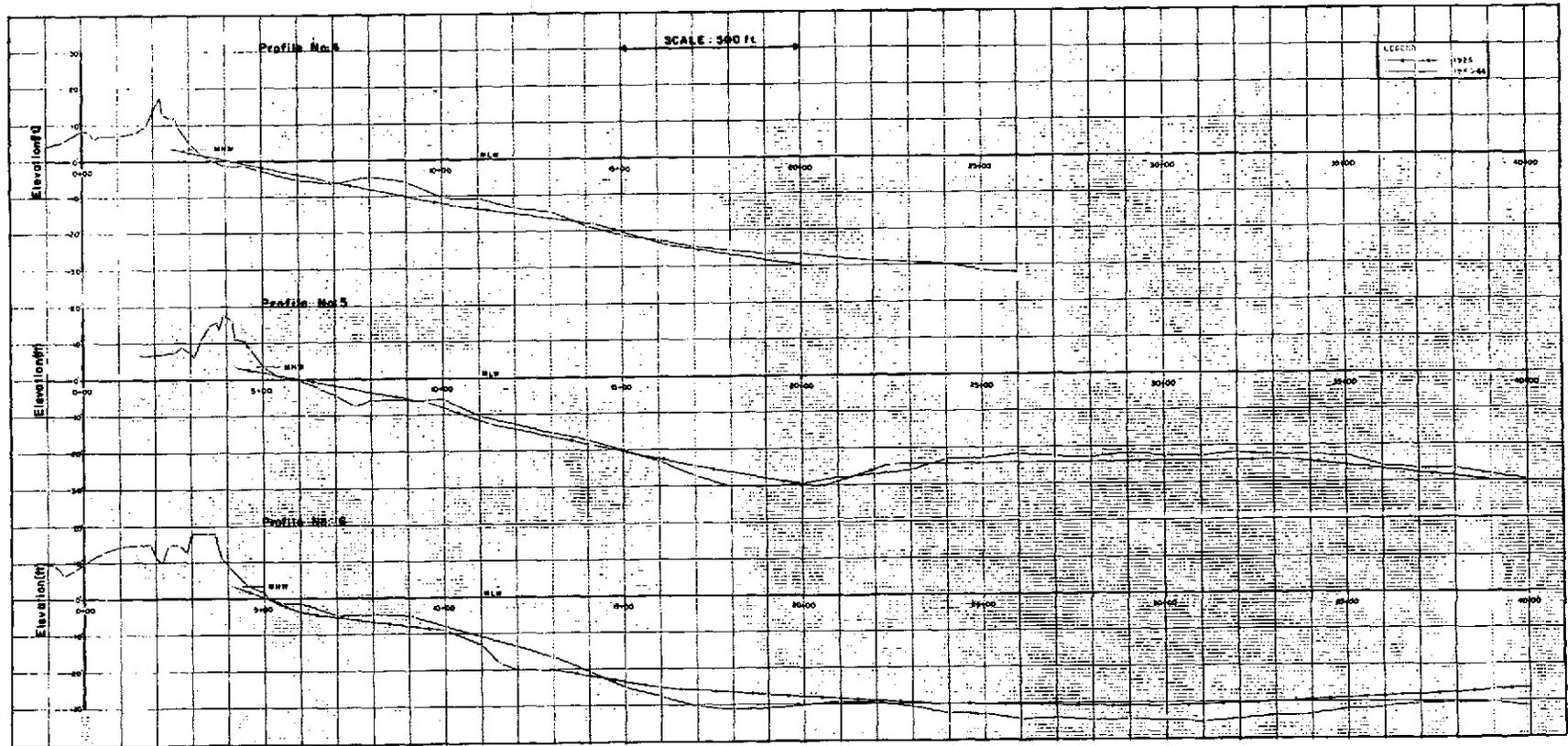
Fig. 2.3.3. Beach Profiles P-4, P-5 and P-6.
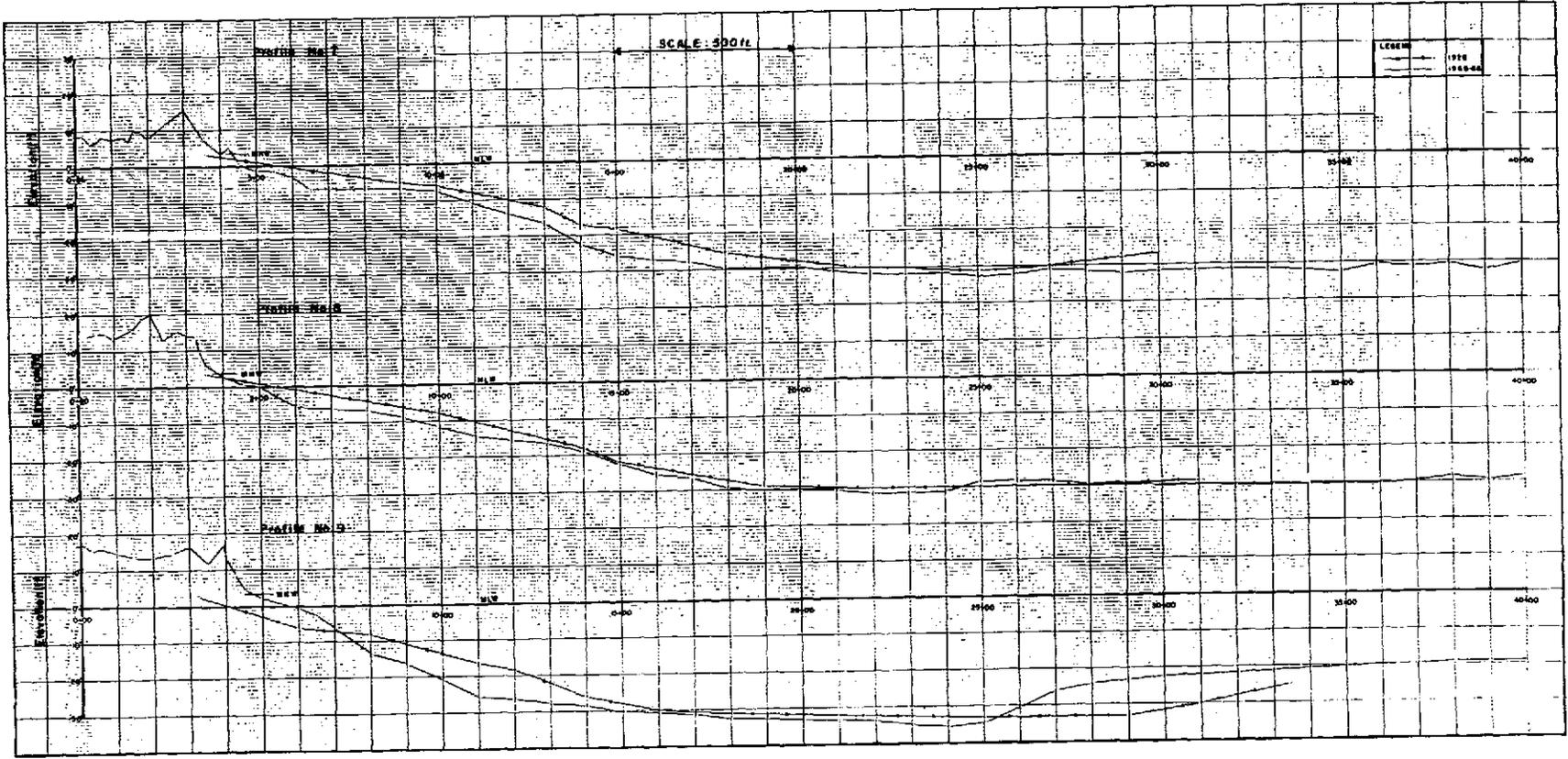
Fig. 2.3.4. Beach Profiles P-7, P-8 and P-9.

13
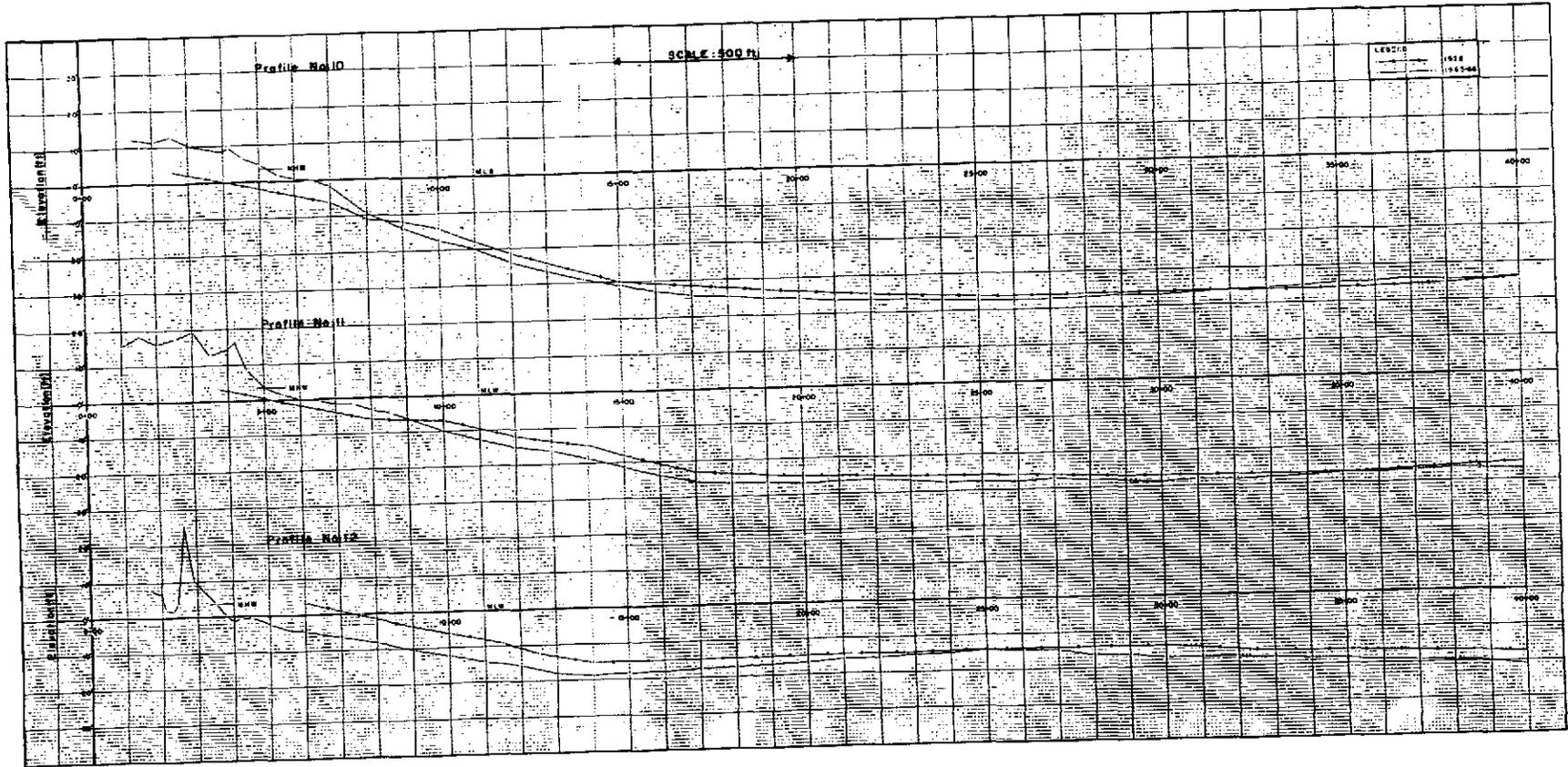
Fig. 2.3.5. Beach Profiles P-10, P-11 and P-12.

14
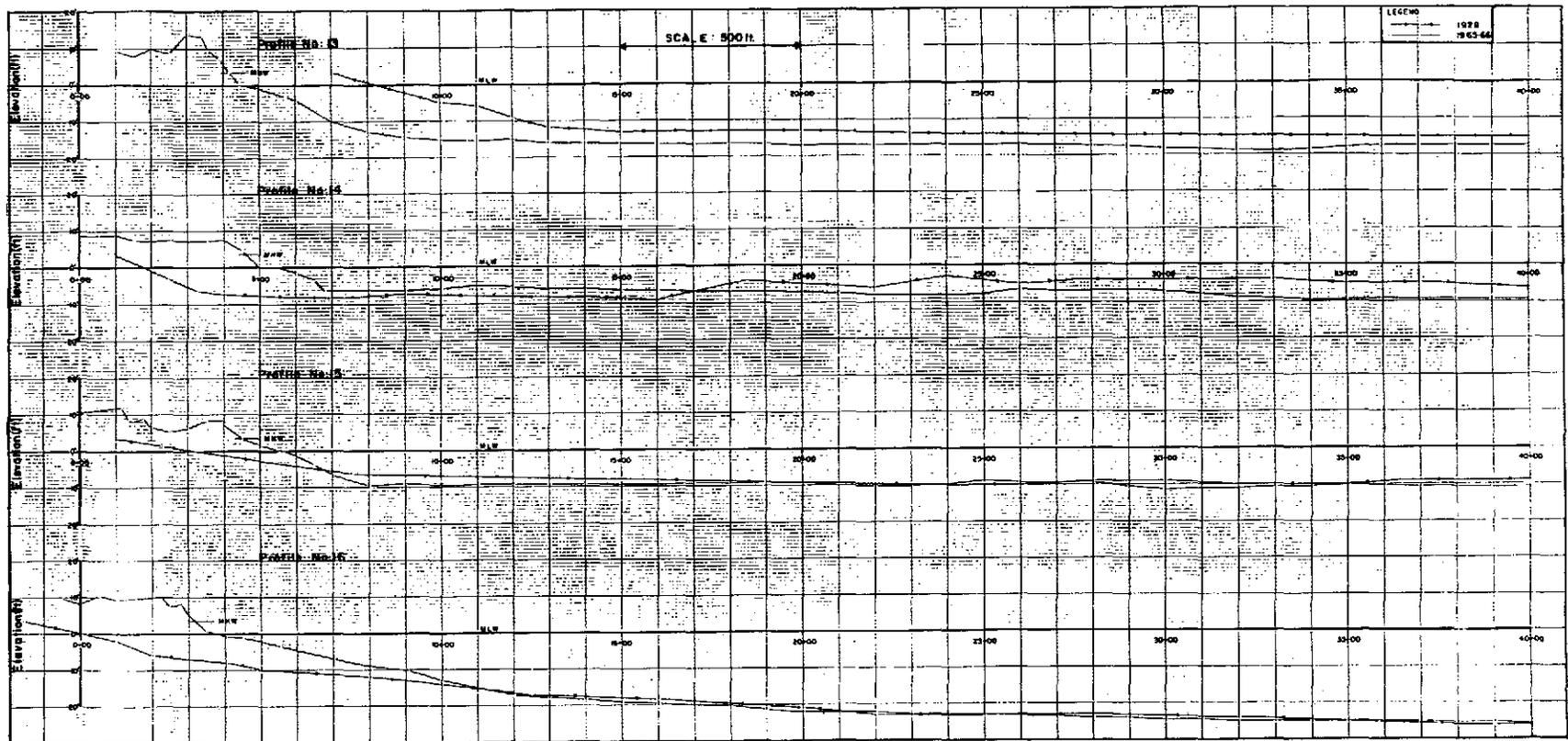
Fig. 2.3.6. Beach Profiles P-13, P-14, P-15 and P-16.

that while the flatter slope varies from 1:9 to 1:33, the steeper slope is on the average close to 1:10.

The dunes showed varying degrees of erosion. The most significant erosion, caused by the February 9-13 storm was about 2-1/2 miles north of the KSC south boundary. Here, the scarp was observed to be nearly 10 ft. high. It should be noted however that in this region, several older dune lines are observed behind the first line and some of the older lines are taller. This for example is clearly observed from Profile No. 11 in Figs. 2.3.5. However KSC installations here are sufficiently in the rear of the first dune line, and do not appear to be in any danger from normal storm wave action.

In general, the dune line along the KSC property is in its natural state of preservation, with a vegetative cover on the top, and though eroding in some places, is regressing landward due to the action of oceanic overwash, particularly during storm wave climate. In places along the dune barrier north of Playlinda Beach, where the dune height is relatively low, or where there are low spots, the debris carried over to the backside of the dunes by the February storm was observed (photo 4(b)).

2.4 Sand Analysis

Sand size distributions of samples taken at locations S-1 and S-2 (Fig. 1.2.1) are given in Fig 2.4.1 through 2.4.4. At each location, four samples were collected approximately at points A,B,C, and D along the beach, as shown in Fig. 2.4.1. This was done in order to obtain a representation for the entire selected beach profile. The size distributions were measured for the samples as they were (original sample) and also for samples from which shells were dissolved by treatment with hydrochloric acid (treated sample). Table 2-1 gives the mean diameter D_{50}, the sorting coefficient S_o and the shell content in percent, for each sample. It is observed from the table that the samples at S-1

16

TABLE 2-1

BEACH SAND CHARACTERISTICS

Original Sample	Location: S-1				Location: S-2			
	A	B	C	D	A	B	C	D
D_{50}(mm)	0.42	0.34	0.37	0.28	0.45	0.33	0.45	0.53
S_o	1.25	1.26	1.47	1.50	1.20	1.24	1.20	1.20
Shell %	23	23	26	24	32	22	30	50

Treated Sample	Location: S-1				Location: S-2			
	A	B	C	D	A	B	C	D
D_{50}(mm)	0.34	0.34	0.28	0.27	0.45	0.33	0.45	0.52
S_o	1.25	1.28	1.45	1.45	1.21	1.24	1.21	1.20

Fig. 2.4.1. Sand Size Distributions at S-1 (Original Sample).
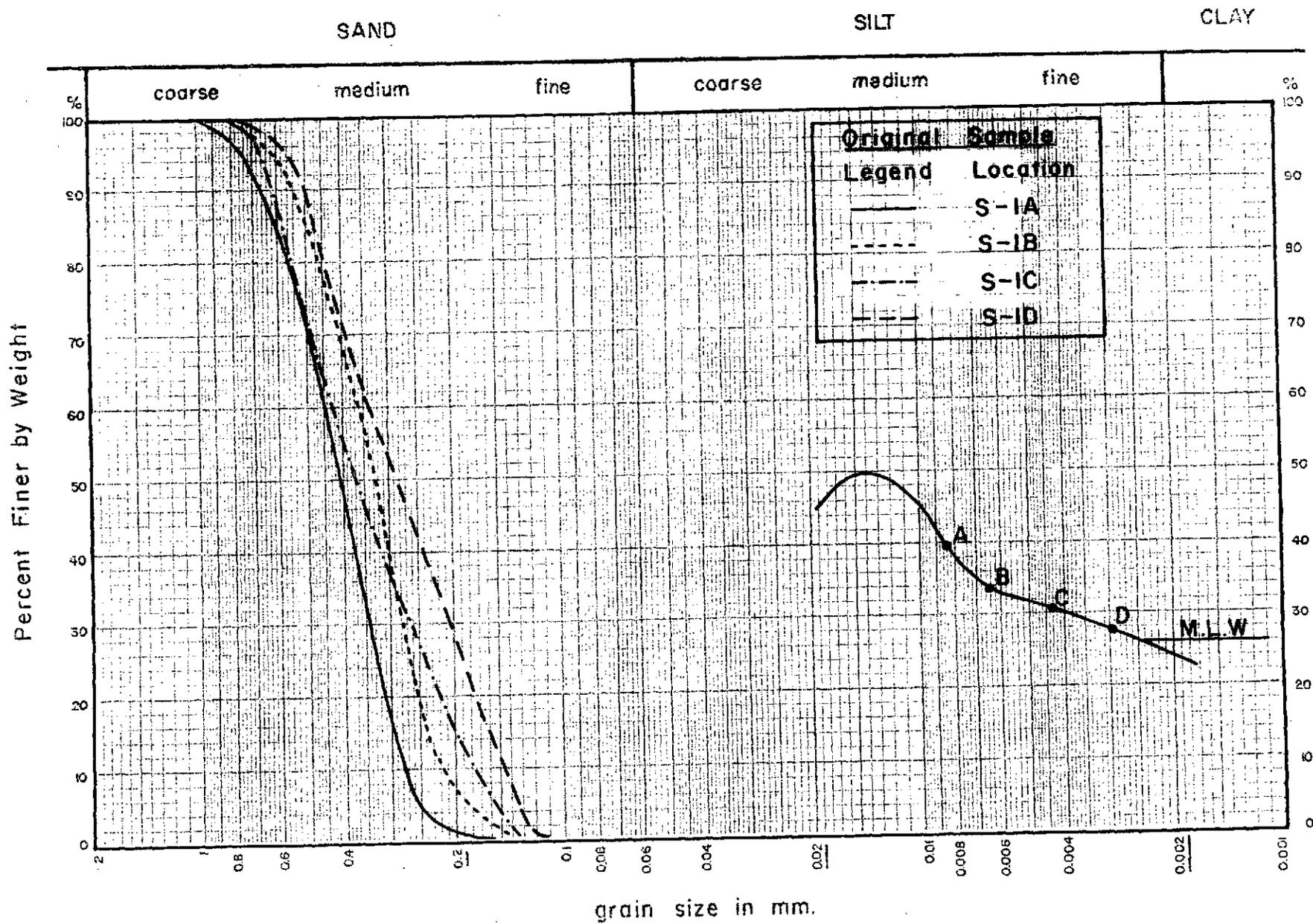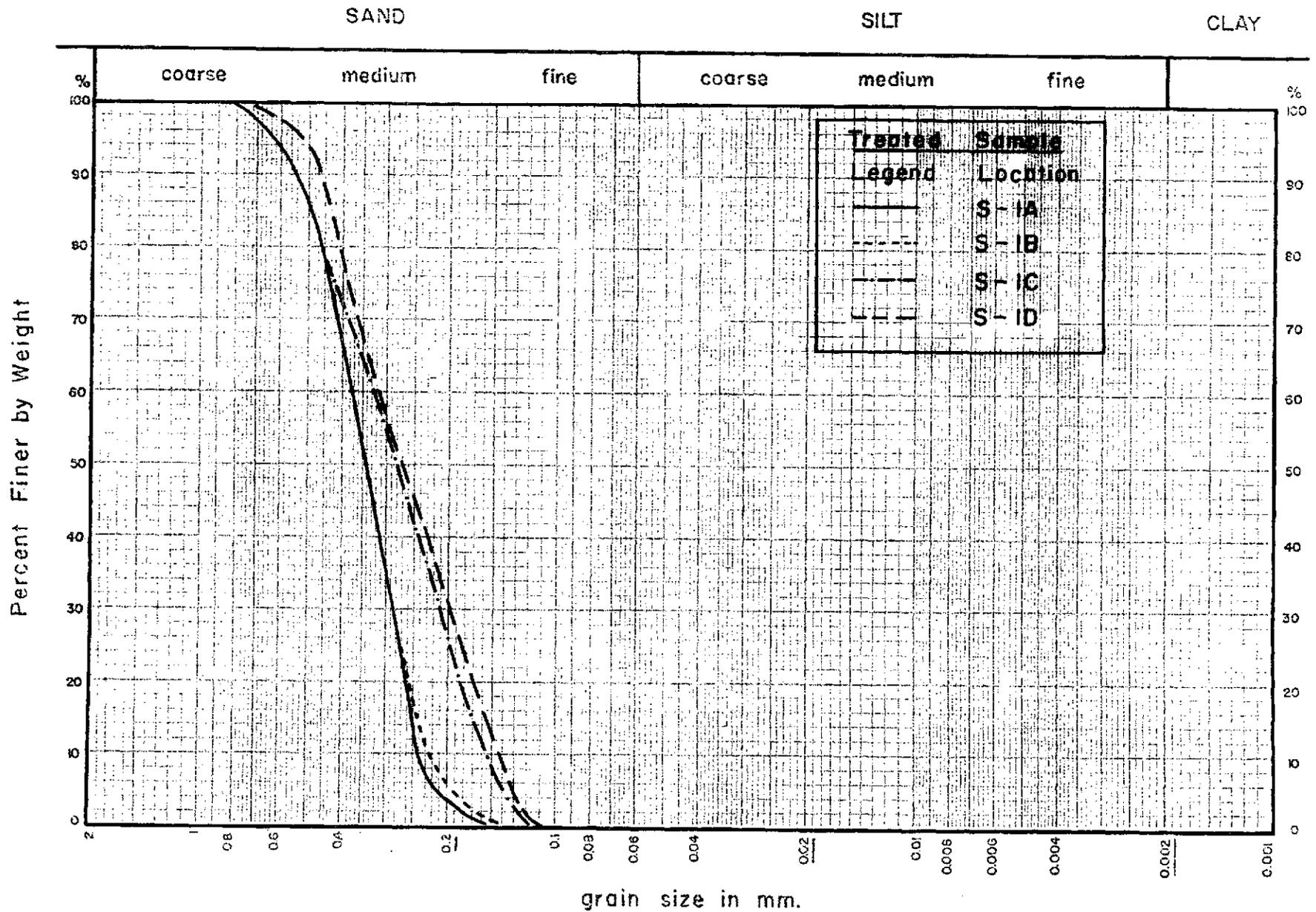
Fig. 2.4.2. Sand Size Distributions at S-1 (Treated Sample).
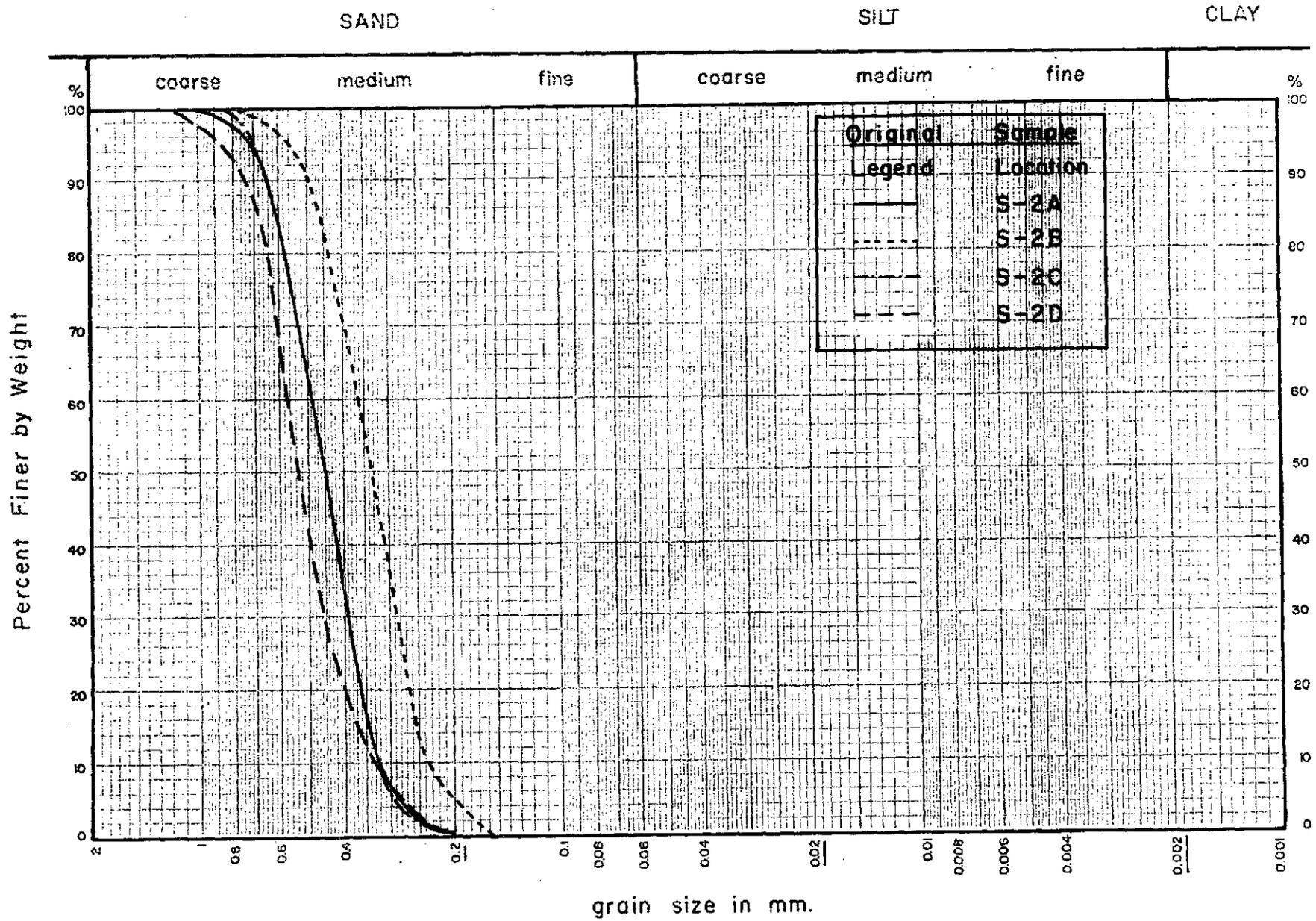
Fig. 2.4.3. Sand Size Distributions at S-2 (Original Sample) .
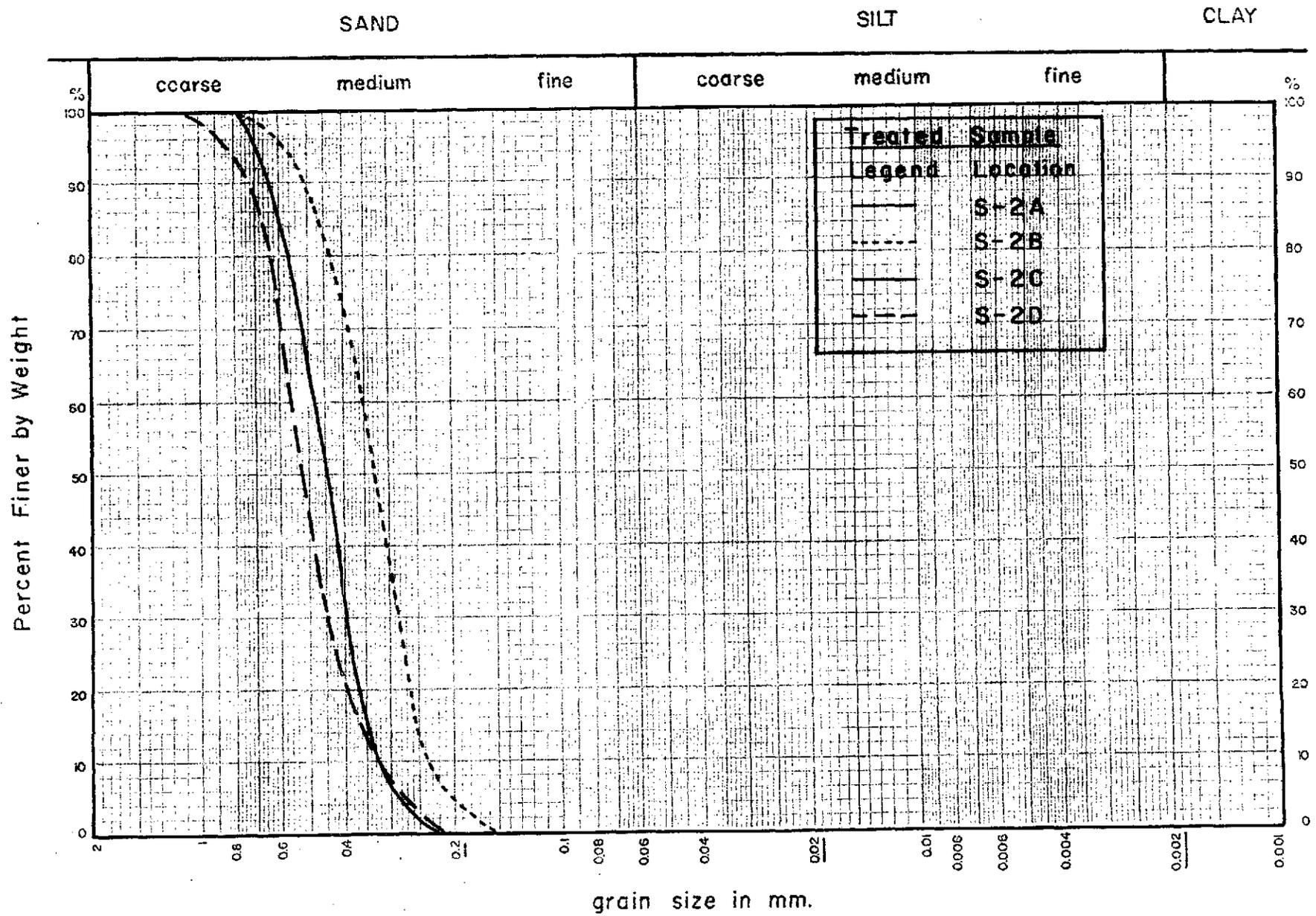
Fig. 2.4.4. Sand Size Distributions at S-2 (Treated Sample).

21

have a somewhat lower shell content than the samples at S-2. S-1 also has a somewhat finer sand (average D_{50} = 0.35 mm) than S-2 (average D_{50} = 0.44 mm). Further, the sand at S-1 exhibits a wider size distribution (average S_o = 1.37) than S-2 (average S_o = 1.21). It is interesting to note that the shell free samples have characteristics that are closely similar to the original sample. This implies that the shell in the sand is very much like the sand itself in its particle size distribtuion, which indicates a fairly ancient origin of the shell, since the similar size distributions imply that both the sand and the shell must have been reworked by the same physical processes over a long period of time.

The average D_{50} values at S-1 and S-2 are plotted against the corresponding beach face slopes in Fig. 2.4.5. The two points do suggest the general trend of the curves described by Wiegel (1964), and indicate a moderately protected beach. It should be noted that the points are somewhat below the curve, but this is expected, since the curves are based on measurements along the West Coast of the United States, where the wave steepness is generally greater than along the Eastern Coastline, giving rise to relatively steeper beach slopes for a given sand grain diameter.

Sand samples between the south boundary and Playlinda Beach indicated D_{50} varying from 0.25 to 0.30, and S_o varying from 1.23 to 1.40. The S_o values appear to be similar to these given in Table 2-1, but the mean grain diameters are smaller. This is compatible with the relatively flatter beach face slopes, as observed from Fig. 2.3.1.

22

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

D_{50} (mm)

Average slope of exposed beaches

Average slope of moderately protected beaches

Average slope of protected beaches

1:5 1:6 1:7 1:8 1:9 1:10 1:12 1:15 1:20 1:30 1:40 1:50 1:60 1:70 1:80 1:90 1:100
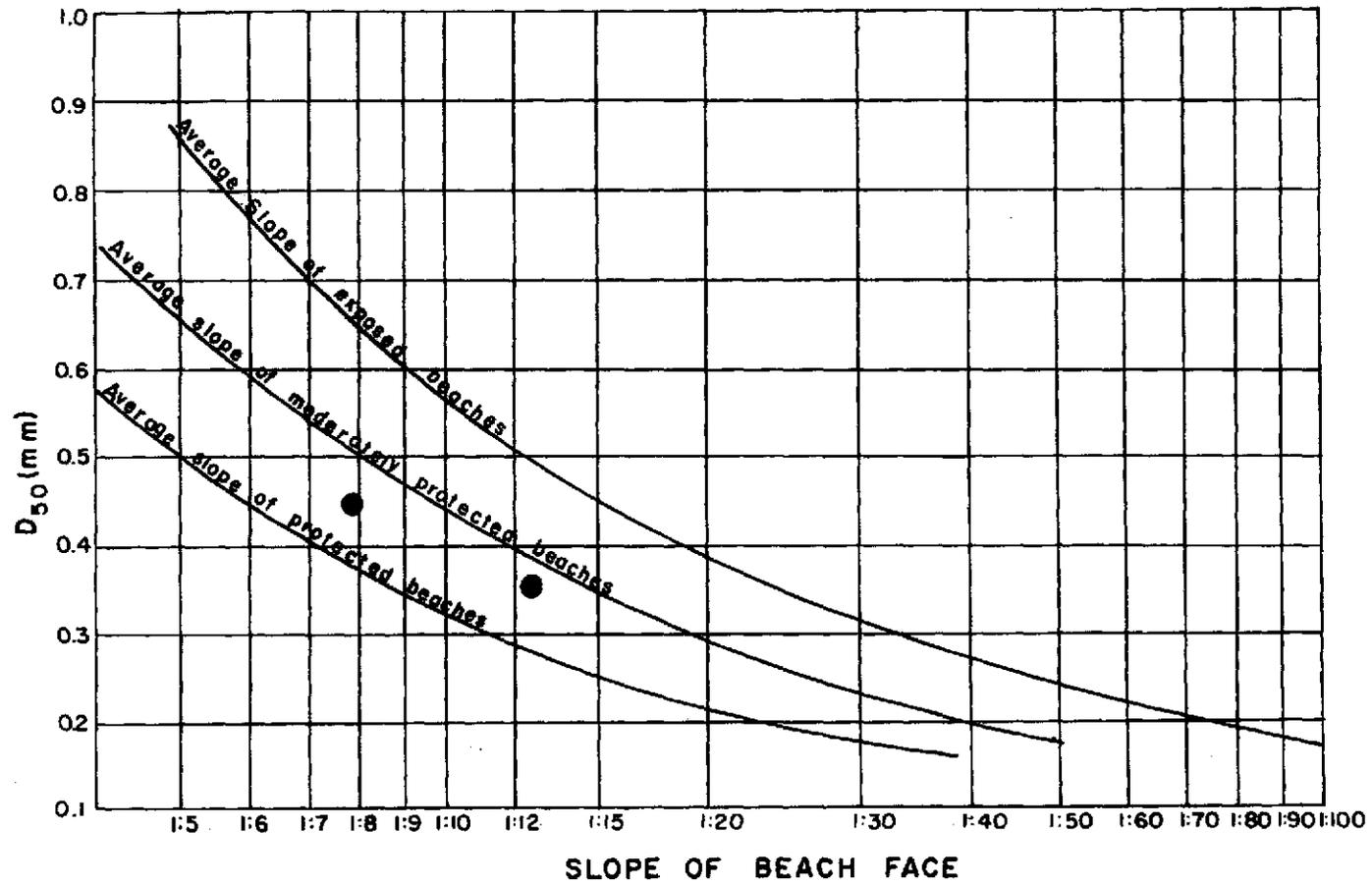
SLOPE OF BEACH FACE

Fig. 2.4.5. Relationship Between Slope of Beach Face
and Mean Sand Grain Diameter D_{50}.

3. GEOLOGY OF MOSQUITO LAGOON

3.1 Introductory Remarks

Any plans for protecting or modifying Mosquito Lagoon and its associated barrier island should take into consideration their origin and history. Evidences of the past are preserved in the deposits of the lagoon and the barrier. Geomorphic expresion from study of aerial photographs and maps provide clues in the search for ground truths. These principles have been employed in this study.

The field data presented below will show that Mosquito Lagoon is in the final stages of silting. There have been at least five separate inlets opening directly into the lagoon from the Atlantic Ocean during the past 6,000 to 7,000 years. The most recent inlet was in the vicinity of Turtle Mound (See Fig. 1.2.1). From archaeological information, this inlet closed before 500 A.D. Though the barrier is being badly eroded and overwash or overtopping during storms occurs, there appears to be no possibility of a new inlet being permanently established at the present time.

Mosquito Lagoon occurs in the northern portion of the cuspate foreland known as Cape Canaveral. The lagoon and seaward barrier have formed by the same depositional processes that have resulted in the great accumulation of coquina and sand constituting Merritt Island and the Cape. It is not a simple pregradational feature developed during recent time as interpreted by Kofoed (1963). The Cape's history is complex; the older portion of Merritt Island consists of beach deposits that are $240,000^{\pm}$ years old (Brooks, 1972). Changes of sea level resulting from glacial eustatic icewater volume (Brooks, 1972; Field and Duane, in press) have occurred, and the Cape has grown by successive increments.

The land portion of the Cape proper consists of older cape relics that form Merritt Island the Recent island complexes to the north and south of False Cape. False Cape is a promontory because of resistant older beach deposits outcropping in the surf zone. Paleontological (Brooks, 1972) and radiometric dating (Osmond, et al, 1970) of the deposits underlying Merritt Island show this coastal feature to be related to "Ice Age" stands of sea level. Canaveral Peninsula seaward of Banana River (a lagoon) is a progradational series of beach deposits protected "up drift" by False Cape. Accretion southeastward during the last 7,000 years (Brooks, 1972) is clearly recorded in the increments of beach ridges. Though the barrier seaward of Mosquito Lagoon appears to have initiated about the same time, its history has been associated with prevailing erosion, overwash and landward migration.

At the present time Mosquito Lagoon has no direct connection to the ocean. Some interchange via Ponce de Leon Inlet does occur northward through the maze of mangrove islands. Clams and oysters thrive in this area of subdued tides where the salinity is near normal (34.7 p.p.t.). During May of 1973 the southern, open, shallow portion of Mosquito Lagoon had a salinity of 38 p.p.t. Here only euryhaline organisms exist; the shell fish fauna is dominated by a hardy, small clam, Anomalocardia cuneimeris. As noted in section 4.3, interchange with Indian River through the artificial cut at Haulover Canal is minor. There is negligible tidal interchange in the main portion of Mosquito Lagoon. Thus no new clastic quartz sediment has been carried into the lagoon since the "Turtle Mound Inlet" closed about 1,500 years ago.

3.2 Field Evidence

Eight days were spent in the field making a reconnaisance and sampling. Wash borings were widely made. Six core borings were taken to obtain subsurface samples.

The ridge separating Mosquito Lagoon from Indian River that extends from the mainland southeastwardly from Oak Hill to Merritt Island is composed of coquina shell, the upper portion of which is lithified. Solution pipes filled with residual terra rosa soil are common. These older interglacial "Ice Age" beach deposits are clearly exposed in the ditches along old U. S. A1A and in the cut at Haulover Canal. The same regressional humate sand sequence that occurs eastward of this same coquina belt on Merritt Island extends under Mosquito Lagoon. All deep probings and cores in Mosquito Lagoon encountered humate cemented sand at 12 to 14 ft. below sea level.

In contrast to the beautiful, broad, gently sloping forebeach consisting of fine to very fine sand at New Smyrna Beach, the ocean beach on the barrier island of Mosquito Lagoon becomes very steep, narrow and the berm is extraordinarily high as indicated by the profiles in Figs. 2.3.2 and 2.3.3. The sediment consists of 20 to 70% reworked coquina shell. Back of the beach, in most places, a single "dune ridge" exists. The ridge is covered by thick scrub vegetation as observed in Photos 4(a) and 4(b). The ridge is noteworthy because the back slope typically is gentle. Evidence suggests that this ridge is not due solely to normal wind action. The gentle back slope appears to be due to blow over and occasional overwash during severe storms.

Proof that the barrier is migrating landward by erosion on the seaward side and deposition of washover on the lagoonal side, as postulated in the above paragraph, is supported by the fact that occasionally lagoonal deposits with mangrove stumps are exposed on the lower beach face.

It is interesting to compare the steep, narrow beach on the Mosquito Lagoon barrier with what has occurred on Cape Hatteras, North Carolina, where comparable beach conditions have inadvertently been produced. Artificial dunes were established to retard oceanic overwash (Dolan, Godfrey and Odum, 1973).

This resulted in beach narrowing and "has created a situation in which high wave energy is concentrated in an increasingly restricted run-up area, resulting in a steeper beach profile, increased turbulence, and a tendency for the beach sand to be broken into finer pieces and washed away". If recreation and beach conservation are of foremost concern, it may be in our best interest to encourage overtopping on the Mosquito Lagoon Barrier.

Inspection of aerial photographs and topographic maps show a clustering of lagoonal marshes and mangrove islands back of the barrier island. There are five clusters. Their centers are:

28° 40.5' N, 80° 39.5' W
28° 43.0' N, 80° 41.5' W
28° 46.0' N, 80° 44.0' W
28° 49.0' N, 80° 45.5' W
28° 56.0' N, 80° 50.0' W

The last area is the maze of mangrove islands in the northern portion of Mosquito Lagoon near Turtle Mound.

Field evidence shows these islands are marshes developed on sand shoals (tidal deltas). Typically two to three feet of clay, muck and calcareous marl rests upon quartz sand and shell. The present topographic expression as islands is due to build-up by fine sediment entrapped by the roots and pneumatophores of red and black mangroves. Supersalinity exists on the interior salt flats. It is possible that some of the carbonate marl is chemically precipitated under these conditions. It may be of significance that each of the five clusters are evidently of successively younger age northward.

The clusters of island built upon delta bars have indicated the position of former inlets through which sand was carried into the lagoon from the ocean. The antiquity of these inlets is proven by the fact that Turtle Mound is built upon materials closing the most recent inlet. Archaeological evidence indicates this mound dates from about 500 A.D. (Ripley Bullen, personal communication).

Shells from core boring into the inlet fill are being dated by the radio carbon method. If the archaeological data is correct, there has been no new quartz sand swept into the lagoon directly from the ocean in the last 1500 years.

Corroborating the above interpretation is the sediment sequence in Mosquito Lagoon. There is generally one to three feet of mud with about 30% Anomalocardia shells overlying a clean, fine sand to grey silty sand with normal lagoonal shell lenses and shell beds. The mud-sand sequence is consistent throughout the lagoon. The lower sand, eight to eleven feet thick, contains a typical lagoonal shellfish fauna. One can only conclude that the upper mud represents the final isolation of the lagoon with the closing of the "Turtle Mound Inlet".

3.3 Concluding Note

Much remains to be done in interpreting and proving the actual chronology of events in the evolution of Mosquito Lagoon. Evidence obtained in this preliminary study suggests that the lagoon has shoaled by silting to the point that it can no longer maintain an inlet. The last inlet closed about 1500 years ago. Overwash occurs in relation to landward regression of the barrier. There is no evidence to prove that this is harmful; in fact experience from Cape Hatteras has proven the contrary.

4. DUNES AND BREAKTHROUGH INLET STABILITY

4.1 Wave Refraction and Dune Heights

In the Cape area, the winds are generally moderate. The direction varies but often there is a predominance of easterly wind. Wind action over the dunes therefore is rather mild, which is attested by the fact that the dune heights, although varying over relatively long stretches, are surprisingly constant over relatively significant lengths along the shoreline. The dunes in such a situation must be maintained by the sand transported by wave uprush. Uprush is stronger for relatively long period waves with correspondingly low steepness (ratio of wave height to wave length), and stronger uprush is likely to build higher dunes, due to its greater capacity to transport sand up-slope. This strong uprush due to long waves will yet be higher at those spots where the wave energy is concentrated as a result of wave refraction. It is therefore reasonable to expect a correlation between wave energy concentration and dune height.

Fig. 4.1.1, is a directional and percent frequency breakdown of wave periods for the Cape area (Walton, 1973). It is called a wave period "rose" and shows waves moving onshore as well as some moving offshore. This is so because the data are collected from ship observations at distances considerably offshore, where waves are found to approach from all directions. It is however observed that the predominant wave direction is nearly perpendicular to the shoreline near Mosquito Lagoon and also from about S80°E. The same is observed from the deep water wave height rose in Fig. 4.1.2. The roses indicate that most of the time, the waves have 7.5 sec. or less period and with deep water wave heights less than 9 ft.

In Figs. 4.1.3 through 4.1.7, refraction of wave rays (normals to wave

29
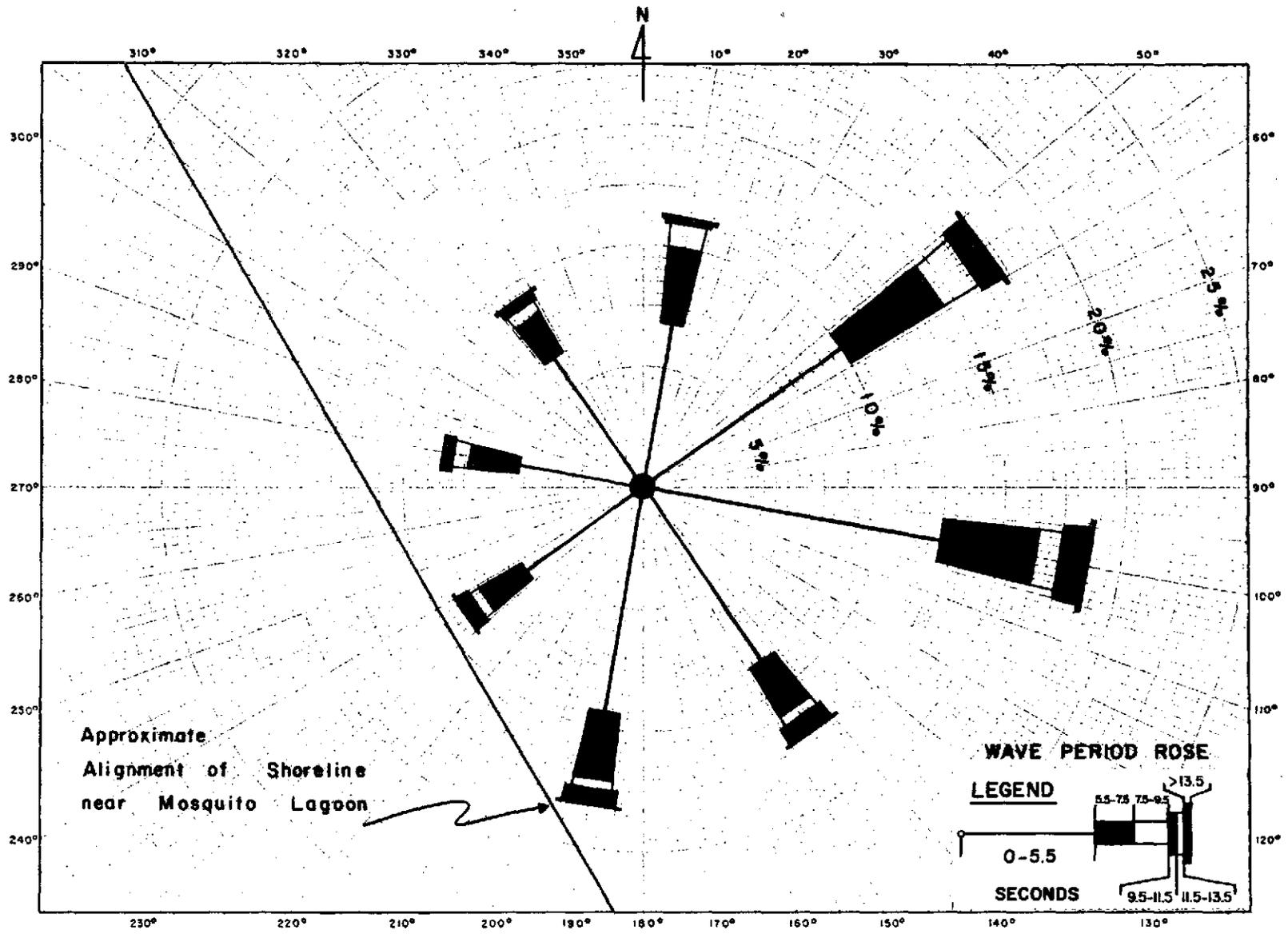
Fig. 4.1.1. Wave Period Rose for Cape Kennedy.
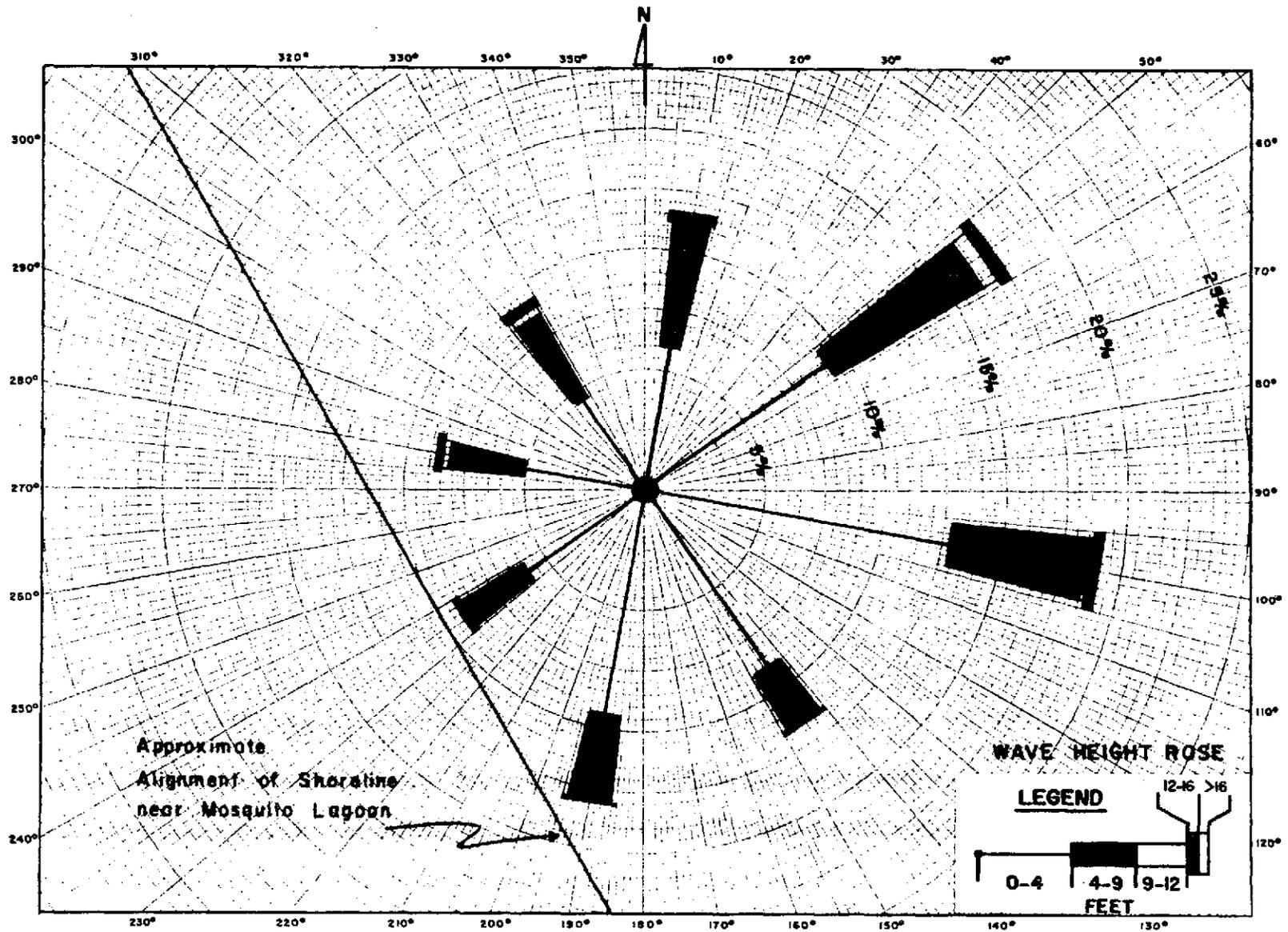
Fig. 4.1.2. Wave Height Rose for Cape Kennedy.
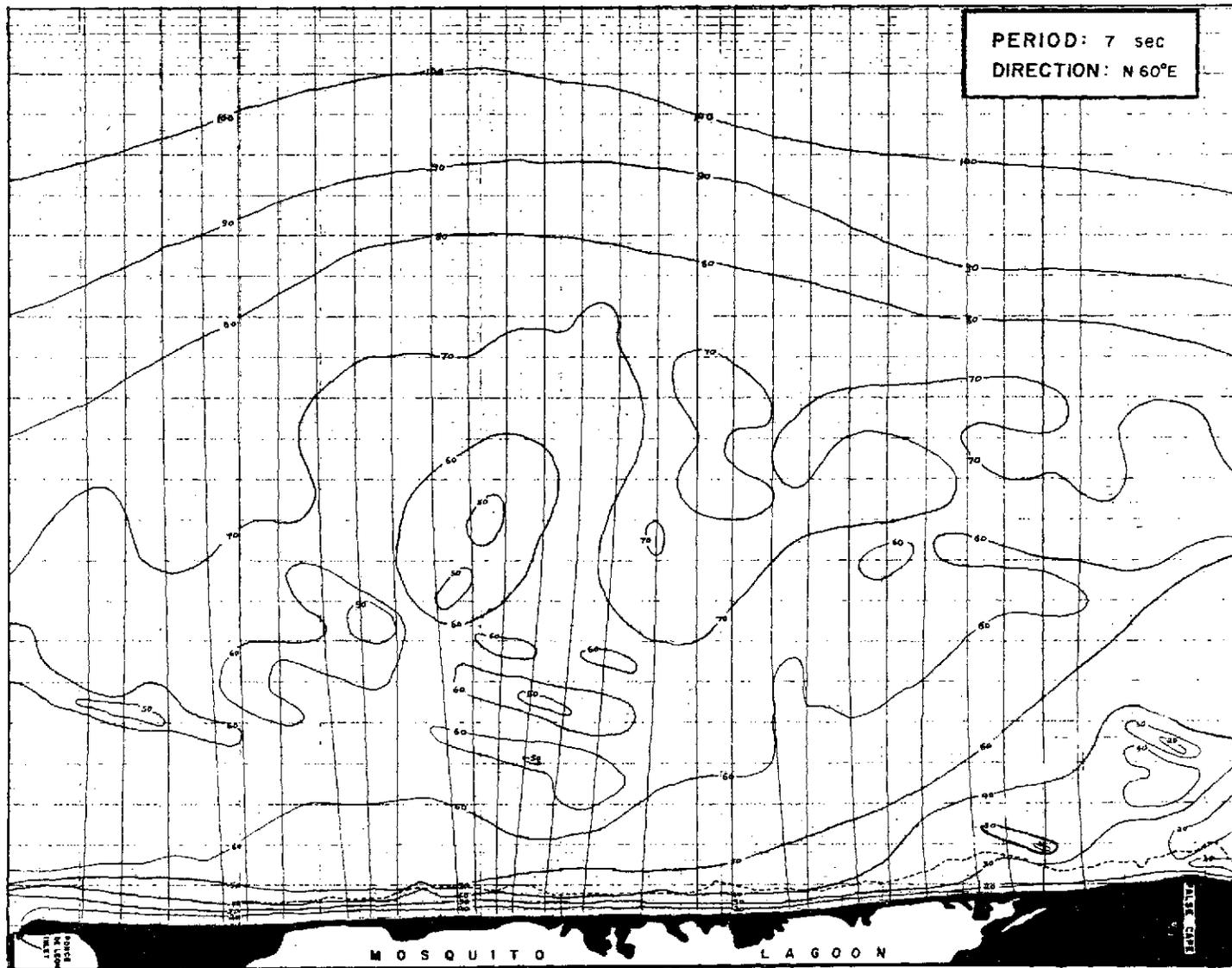
Fig. 4.1.3. Refraction of 7 Sec. Waves With N60°E Direction.
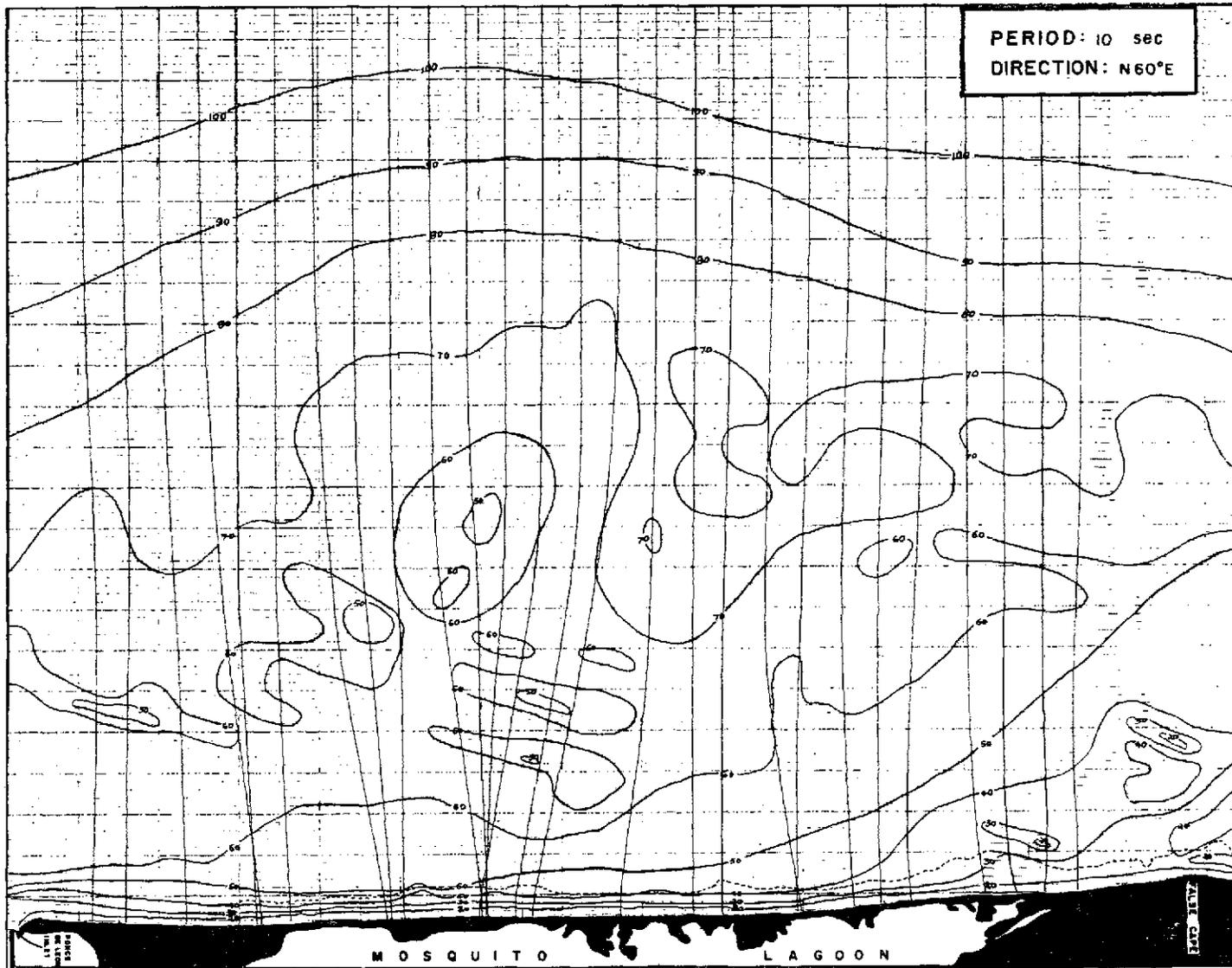
Fig. 4.1.4. Refraction of 10 Sec. Waves With N60°E Direction.
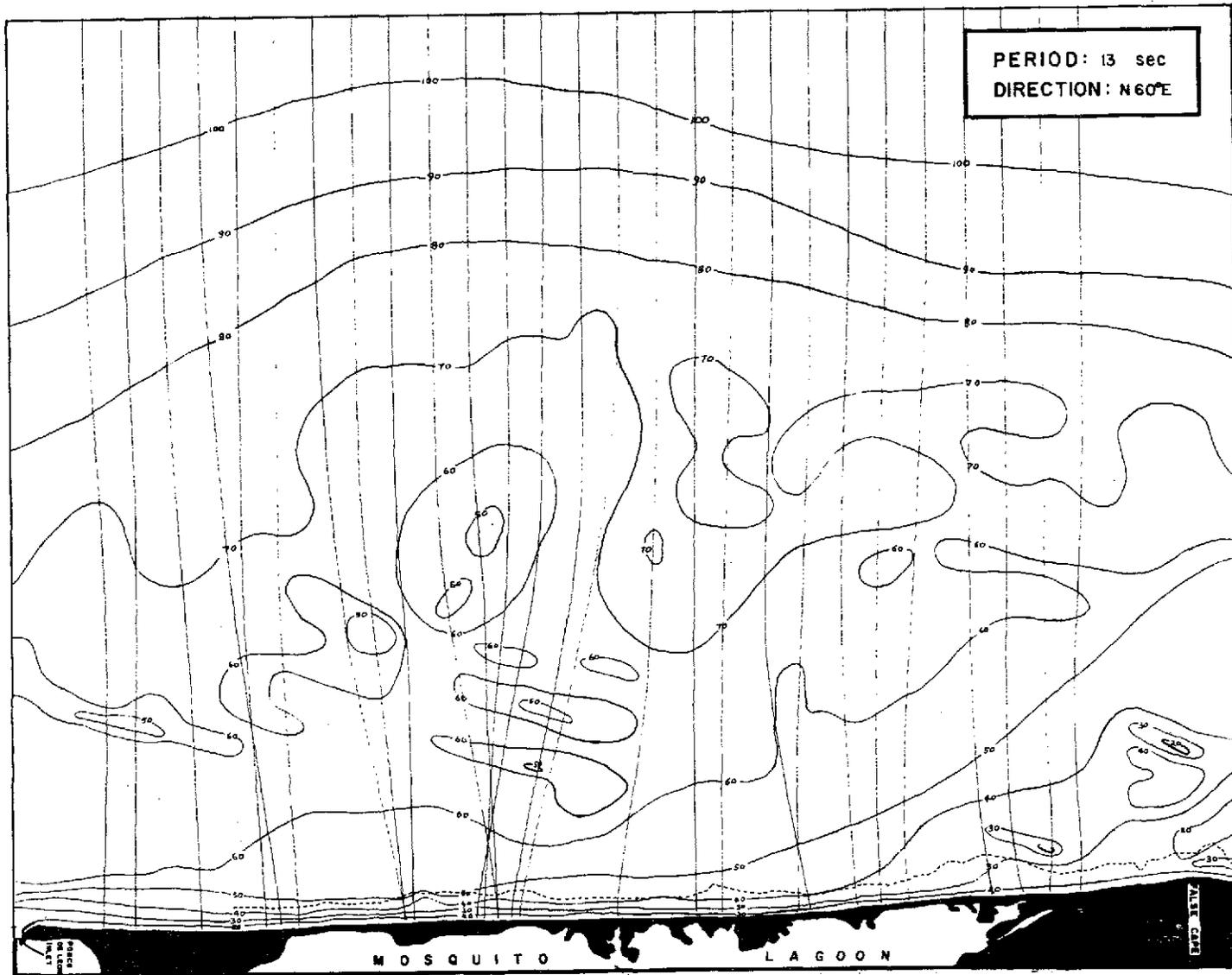
Fig. 4.1.5.   Refraction of 13 Sec. Waves With N60°E Direction.

PERIOD: 10 sec
DIRECTION: S75°E

MOSQUITO   LAGOON
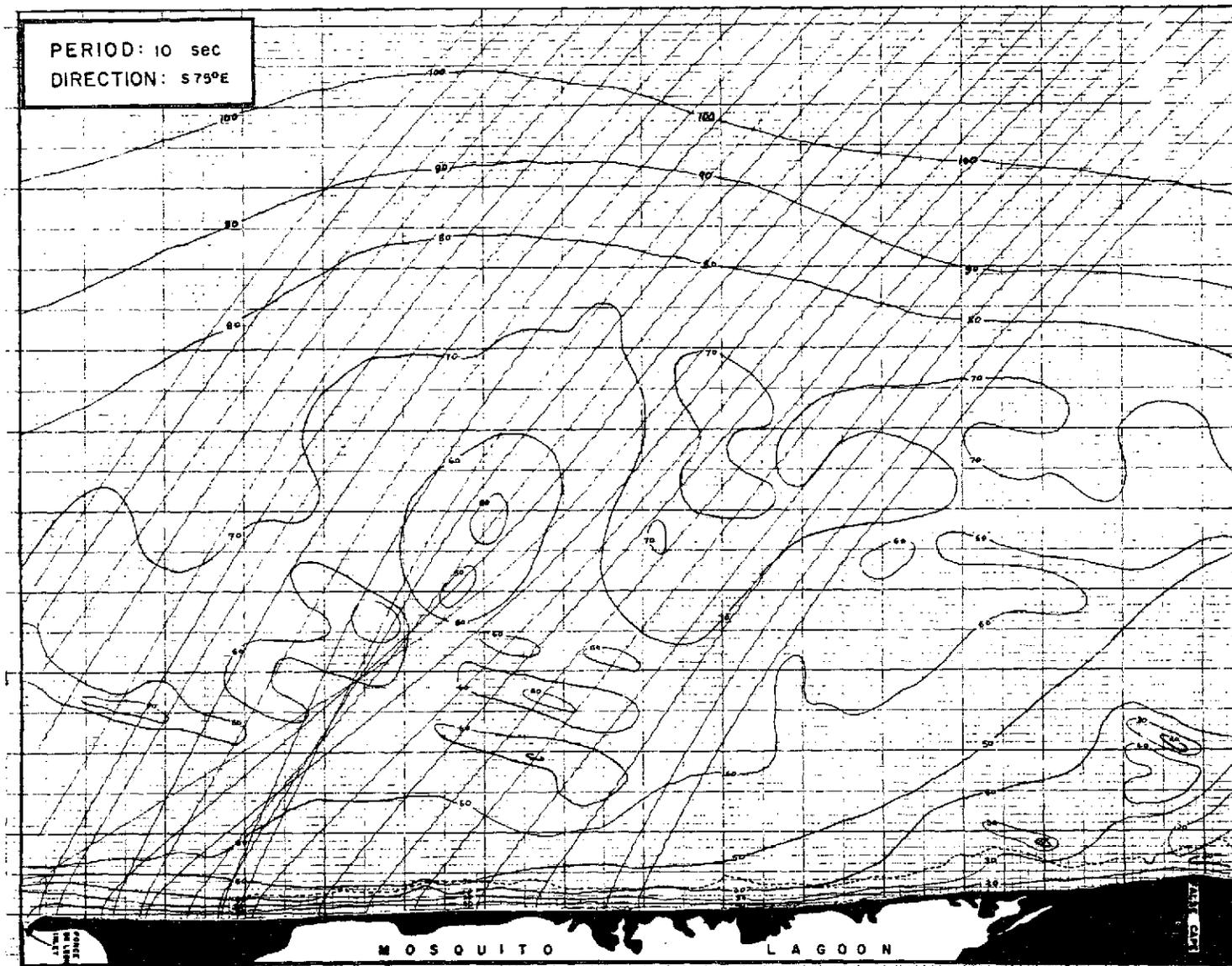
Fig. 4.1.6. Refraction of 10 Sec. Waves With S75°E Direction.
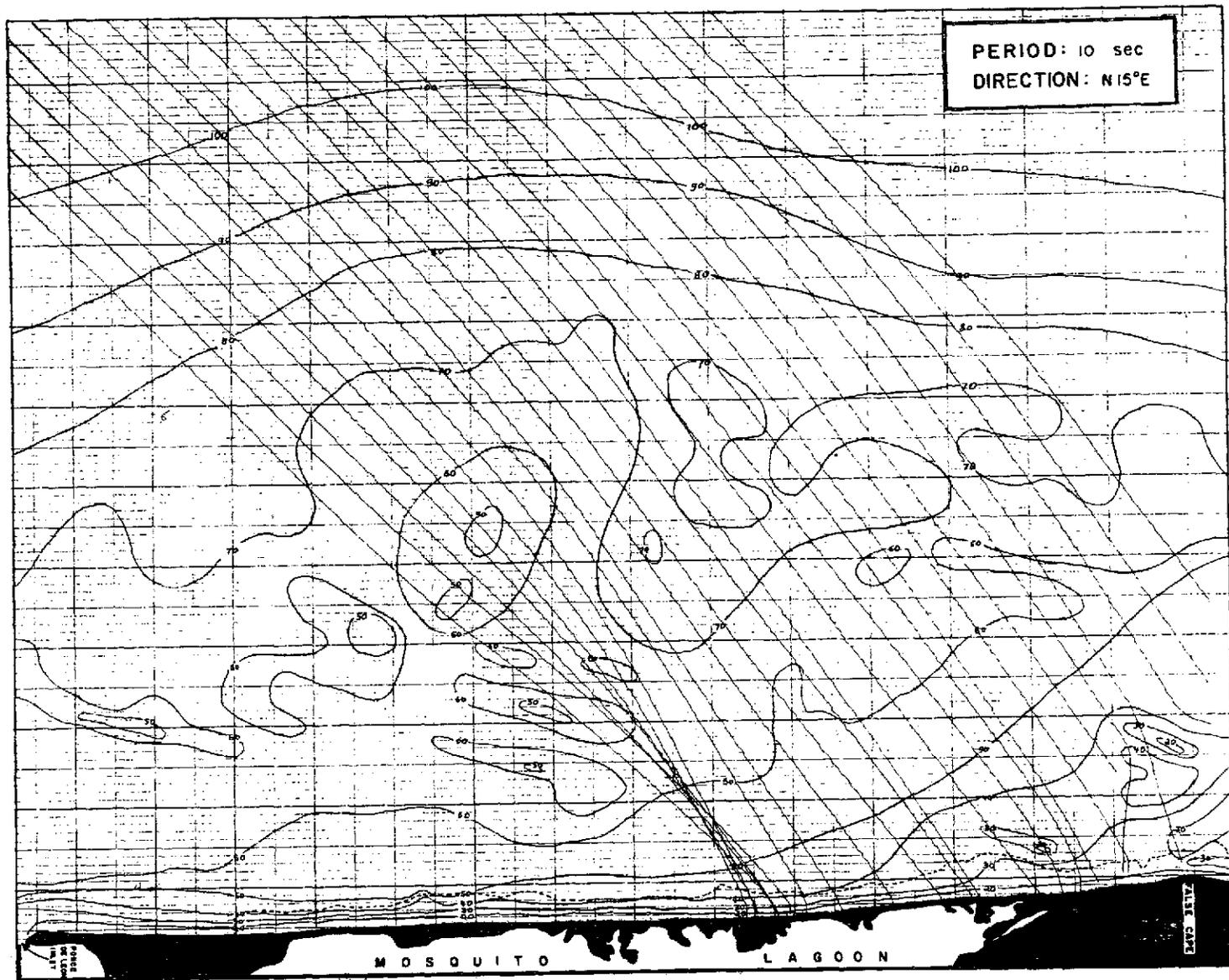
Fig. 4.1.7.   Refraction of 10 Sec. Waves With N15°E Direction.

crests) are considered for 7, 10 and 13 sec. waves, with directions perpendicular and at 45° angles with the shoreline. Wave heights are not involved in these computer calculations (Wilson, 1966), since the linear wave theory is used. While 7 sec. waves may be considered as those corresponding to a normal wave climate (as indicated by the wave period rose), the 10 and 13 sec. waves are generally produced under storm conditions.

Figs. 4.1.3, 4.1.4 and 4.1.5 show the manner in which wave refraction increases (increasing deviation of wave rays) with increasing wave period. Thus storm waves are observed to cause a greater concentration of energy at certain spots along the shoreline than normal waves, as observed by the greater concentration of wave rays at these spots. Also shown in these Figures is a dotted line indicating the dune height. An observation, particularly of Figs. 4.1.4 and 4.1.5 indicates that there does appear to be a correlation between increased wave energy at a given spot and a higher dune height there, and correspondingly, low wave energy and low dune height.

Fig. 4.1.6, which also is a predominant wave direction according to the wave rose shows a concentration of energy occuring at locations north of KSC property, where dune heights were not measured. However, the observed correlation tends to indicate that high dunes must occur just north of KSC property. Finally, Fig. 4.1.7 is for a wave direction which is not predominant, and therefore expectedly does not indicate any significant correlation between wave energy and dune height.

In Fig. 4.1.8, wave energy distributions obtained from the refraction diagrams are plotted on a relative basis. The shoreline is a zero line that indicates unrefracted deep water wave energy, whereas a level above the shoreline indicates energy concentrated by refraction, and a level below indicates a deep water wave energy reduced due to spreading out of wave rays. As discussed,
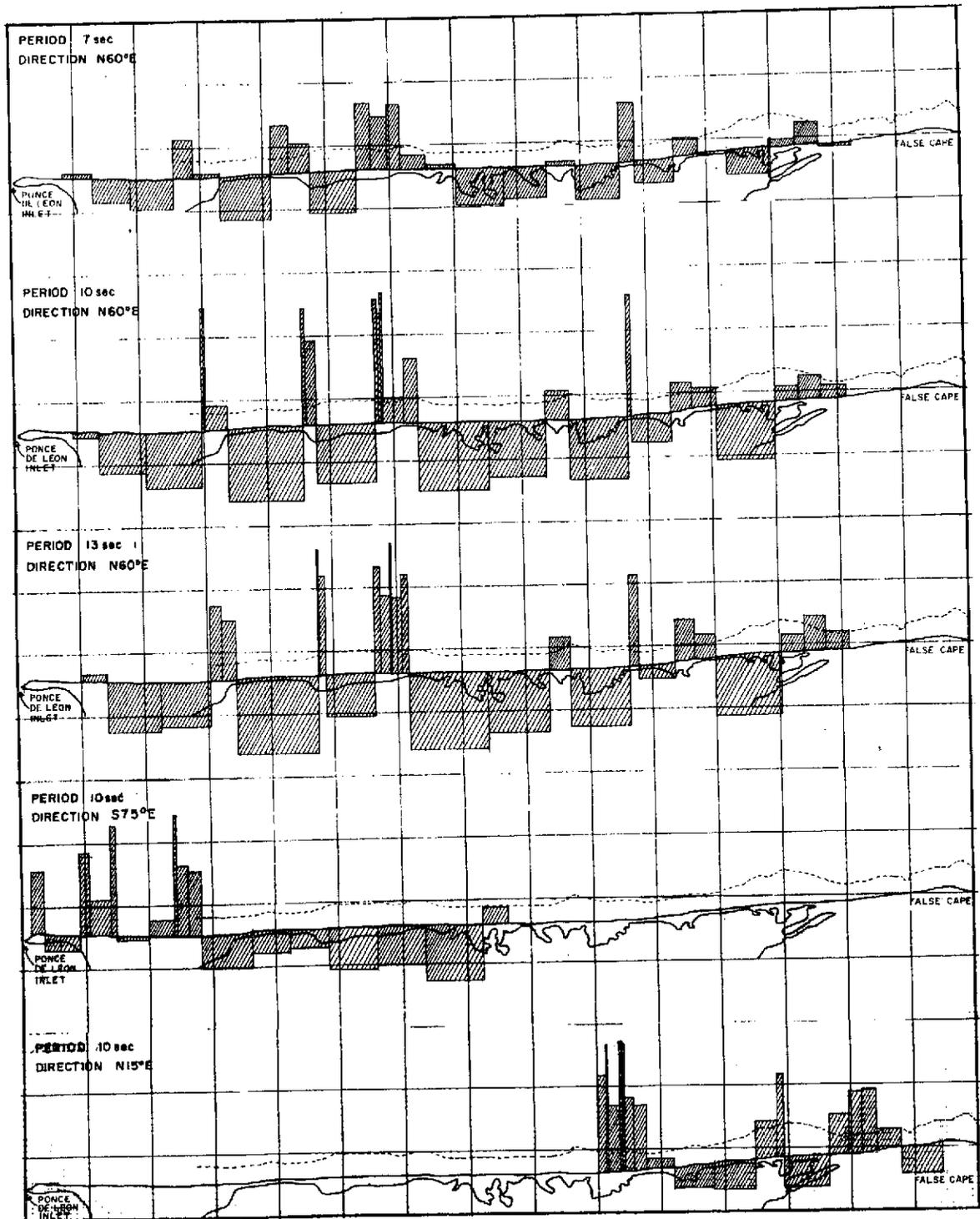
Fig. 4.1.8. Wave Energy Distributions on Shoreline.

the first three plots indicate a correlation between dune heights and wave energy. The fourth plot shows a concentration of energy north of KSC property, whereas the fifth shows a poor correlation, as noted before.

4.2 Effect of Storm Conditions

Storm wave climate is particularly significant in dune development, since waves with relatively low heights and large steepness under normal conditions tend to dissipate their energy by breaking at offshore distances that are too large to have any significant runup. On the other hand, storm waves tend to have relatively low steepness and high breaker heights with the result that they break close to the shore. The strong uprush from such waves, particularly at high tides, contributes significantly to dune development and migration.

Evidence of storm wave effects on the KSC shoreline were evident everywhere, during the field survey, as noted previously. This was the February 9-13, 1973 storm (Lincoln's Birthday Storm) which was "the second most intense extra-tropical storm to occur along the mid-Atlantic Coast in last 30 years", as noted by Dolan, Hayden and Vincent (1973). Based on storm center movement from Northern Hemisphere Surface Charts (1973), it was determined that a fetch of about 1100 miles was developed. This fetch was the longest observed in last three decades. As a result of the long fetch, waves of long periods (and long wave lengths) with relatively low steepness caused a significant damage along the Florida Coastline. Dolan, Hayden and Vincent (1973) note that this storm was exceeded in magnitude only by the Ash Wednesday Storm of March, 1972 (Lazarus and Nowlin, 1966), and "in intensity and structure, this recent storm is a member of a class of storms of which only six others have occurred since 1899".

Fig. 4.2.1 shows the buildup of significant wave height and period of
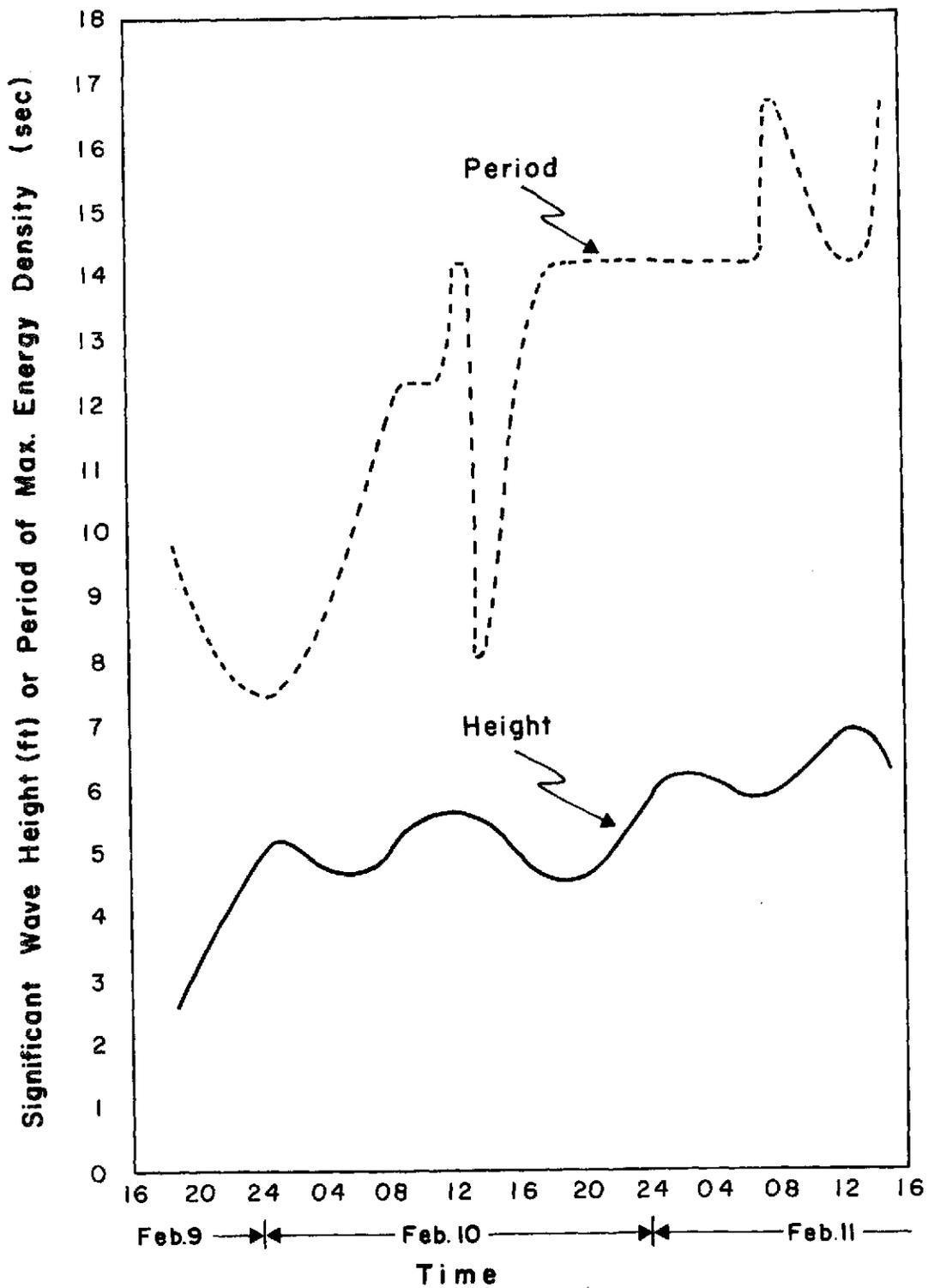
Fig. 4.2.1. Wave Height and Period Buildup at Daytona
Beach During February 9-13, 1973 Storm.

maximum wave energy from 1900 hrs. on February 9 up to 1521 hrs. on February 13 (Coastal Engineering Research Center, 1973). The buildup was probably greater on February 12 and 13, but at the time of writing of this report, information for the time period covered in Fig. 4.2.1 was available only. The record shown was registered at Sunglow Fishing Pier at Daytona Beach, which is close to the area of study. Water depth at the location of these measurements is 13 ft. below mean sea level. Based on this record, Table 4-1 gives the value of maximum wave runup (vertical height above mean water level to which water will rise on the beach), for waves at 1900 hrs. on February 9 and 1521 hrs. on February 11. These calculations are based on results presented in Shore Planning Protection and Design (1966) for impermeable structures, with the assumption that the beach behaves similarly. Actual runup values for the beach will be somewhat lower than those noted here, due to the semipermeable nature of the beach face. As noted earlier, the deep water wave steepness appears to decrease considerably (from 0.011 to o.0056) with the development of the storm, with a consequent increase in runup. It should be noted that along the dunes, many spots are lower than 12.4 ft. below the mean sea level, but except for some of the man made passes, no spot is as low as 4.6 ft. In other words, whereas the Feb. 9 wave climate, which is closer to normal condition, is not capable of building or eroding dunes, the storm climate of Feb. 11 represents a state in which washovers at low spots are expected. Indeed, field observations indicated washovers at many spots caused by the storm, as noted earlier. It should be pointed out however that despite the serverity of the storm, no significant breaches or breakthroughs along the dunes were observed.

TABLE 4-1

WAVE RUNUP CALCULATION

Date	Time	Deep Water Wave Steepness	Runup (ft)
Feb. 9	1900	0.011	4.6
Feb. 11	1521	0.0056	12.4

4.3 Breakthrough Inlet

In order to investigate the possibility of occurrence of a permanent breakthrough inlet between the ocean and the lagoon along some location on the barrier, a computer model developed by Professor R. G. Dean (Coastal Engineering Study of Proposed Navarre Pass, 1973) was modified and utilized for (a) simulation of existing conditions in the lagoon, with Indian River north and Haulover Canal and (b) prediction of expected conditions in the lagoon with the presence of a breakthrough inlet.

Fig. 4.3.1 shows assumed geometry of Mosquito Lagoon. For simulating the tides and flow rates under existing condition, tidal inputs were provided as boundary conditions at two locations, namely, at a point just inside Ponce de Leon Inlet (Coastal Engineering Study at Port Orange, Florida, 1972) and at the Indian River end of Haulover Canal. Since Indian River at this point has almost negligible tide, a zero tidal range was assumed there.

Fig. 4.3.2 shows curves for typical tidal elevation η and corresponding tide induced flow rate Q variations along the length of the lagoon, for a tidal range of 1.2 ft. inside Ponce de Leon Inlet. The four plots for time $t = o$, $T/4$, $T/2$ and $3T/4$ correspond to quarter phases in the semi-diurnal tidal cycle with period T (=12.4 hrs.). It is observed that throughout the tidal cycle, the tidal range and flow rates in the lagoon near Haulover Canal are rather small.

42
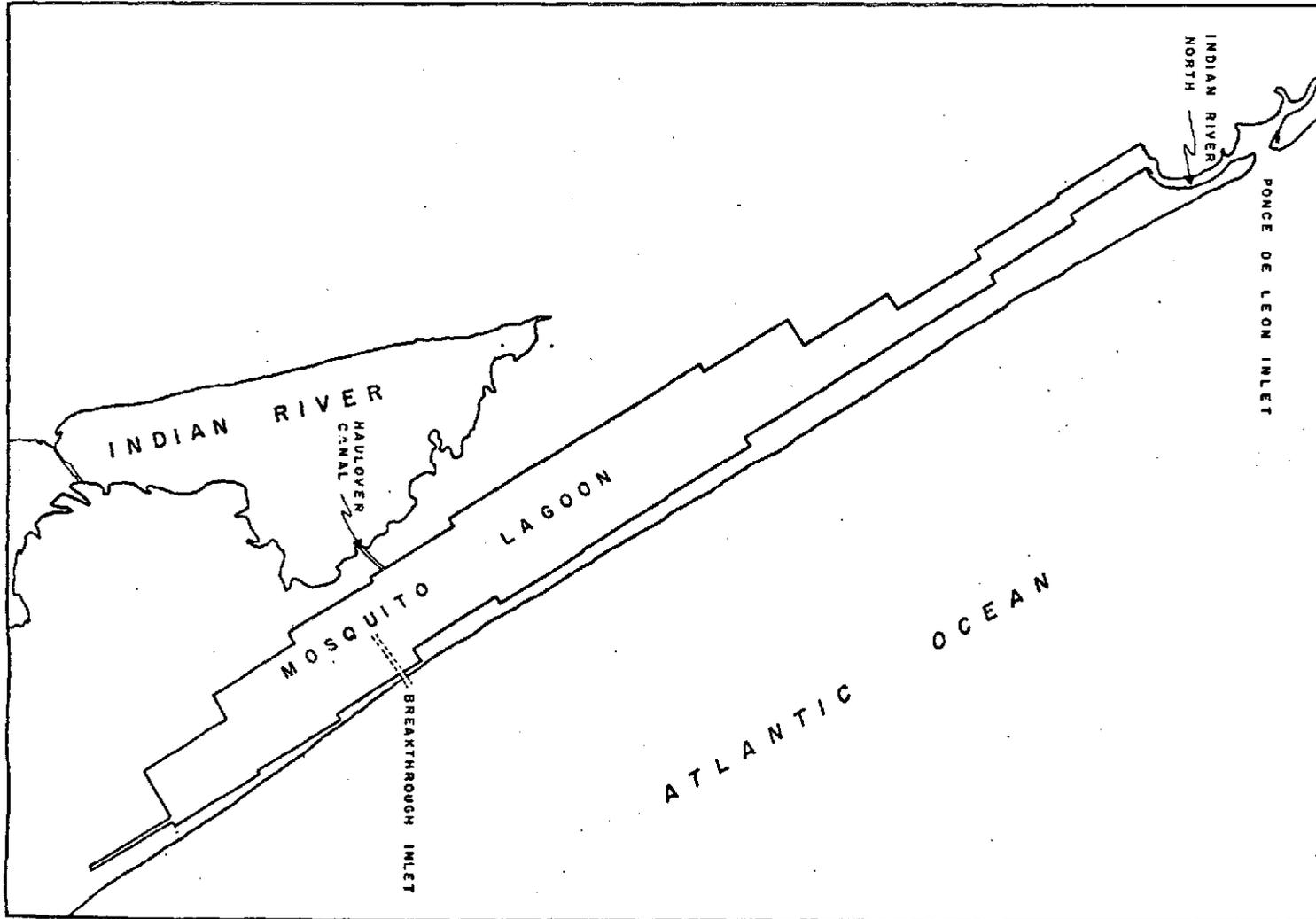
Fig. 4.3.1. Simulated Lagoon and Assumed Breakthrough Inlet Location.
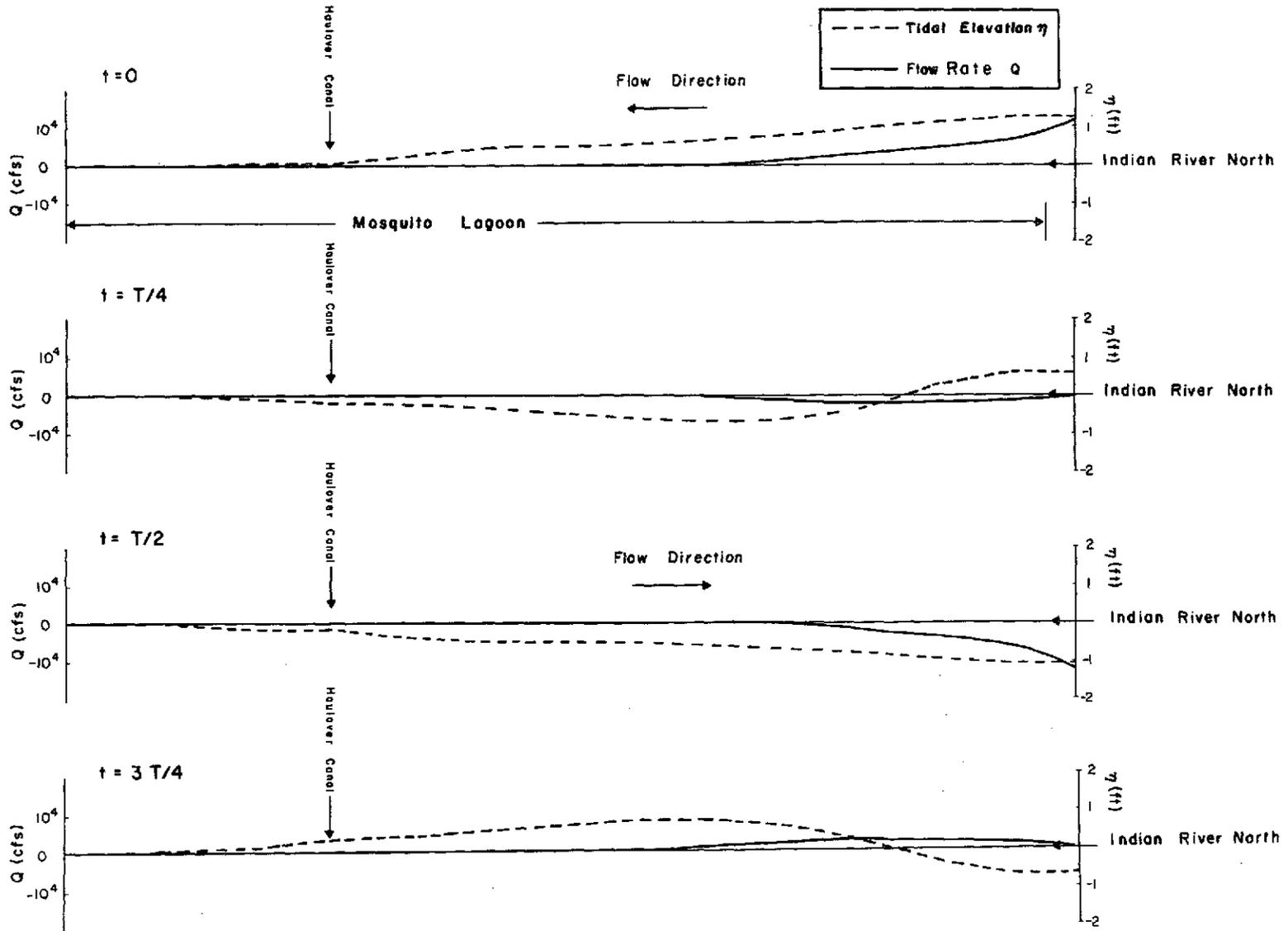
Fig. 4.3.2. Simulated Existing Tides and Flow Rates in Mosquito Lagoon.

Fig. 4.3.3 shows current velocity variations in Indian River North, near Ponce de Leon Inlet, and in Haulover Canal. These are based on data given in the previous figure (Fig. 4.3.2) and correspond to typical existing conditions. On May 10, at 1100 hrs., a current of 0.77 fps was measured in the canal, flowing toward Indian River. Tide Tables (1973) indicate that this time corresponds to a time of about 4 hrs. in Fig. 4.3.3, at which the indicated flow velocity in the canal is 0.57 fps, which may be considered to be in reasonable agreement with the measured value, notwithstanding the possible effect of wind in the measured current, and of the simplifying assumptions in the model.

To the simulated model for existing conditions, an inlet was added with a possible breakthrough location indicated in Fig. 4.3.1, where the land barrier is rather narrow and has a location close to KSC facilities. Also, at this location, the lagoon has its maximum depth of 9 ft. In order to consider a range of inlets, two extremes were selected. It was assumed that bottom friction in these inlets would be the same as that in Hatteras Inlet in North Carolina, which connects Atlantic ocean to Pamlico Sound (Tide Current Tables, 1973). The relatively deep Inlet A was assumed to have a length of 9000 ft., extending from the 25 ft. (below mean sea level) depth contour on the ocean side to the maximum depth of 9 ft. in the lagoon with a mean depth of 17 ft. Inlet B was assumed to be 8000 ft. long, with a constant depth of 9 ft.

Fig. 4.3.4 shows the relationship between the maximum current velocity, V_{max}, in the inlet and the throat cross-sectional area A_c of the inlet. The calculations are based on an annual mean tidal range of 3.5 ft. in the ocean (Tide Tables, 1973). Curve for each inlet exhibits a maximum corresponding to a peak V_{max} value, V_{max}^*, at a given A_c^*. As described in detail by Dean and O'Brien (1972), in the portion of the curve to the left of V_{max}^*, any
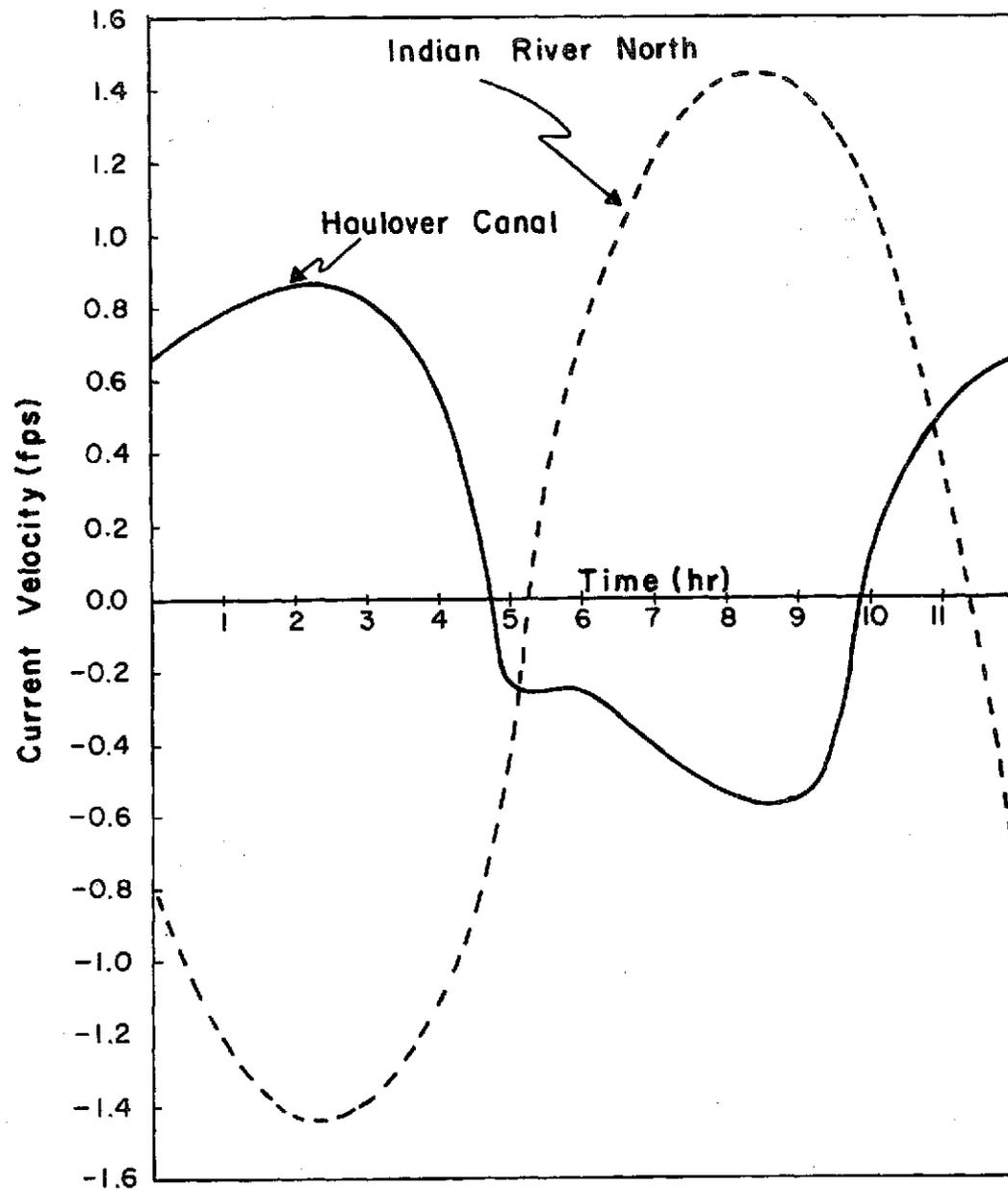
Fig. 4.3.3. Simulated Existing Current Velocities in
Indian River North and in Haulover Canal.
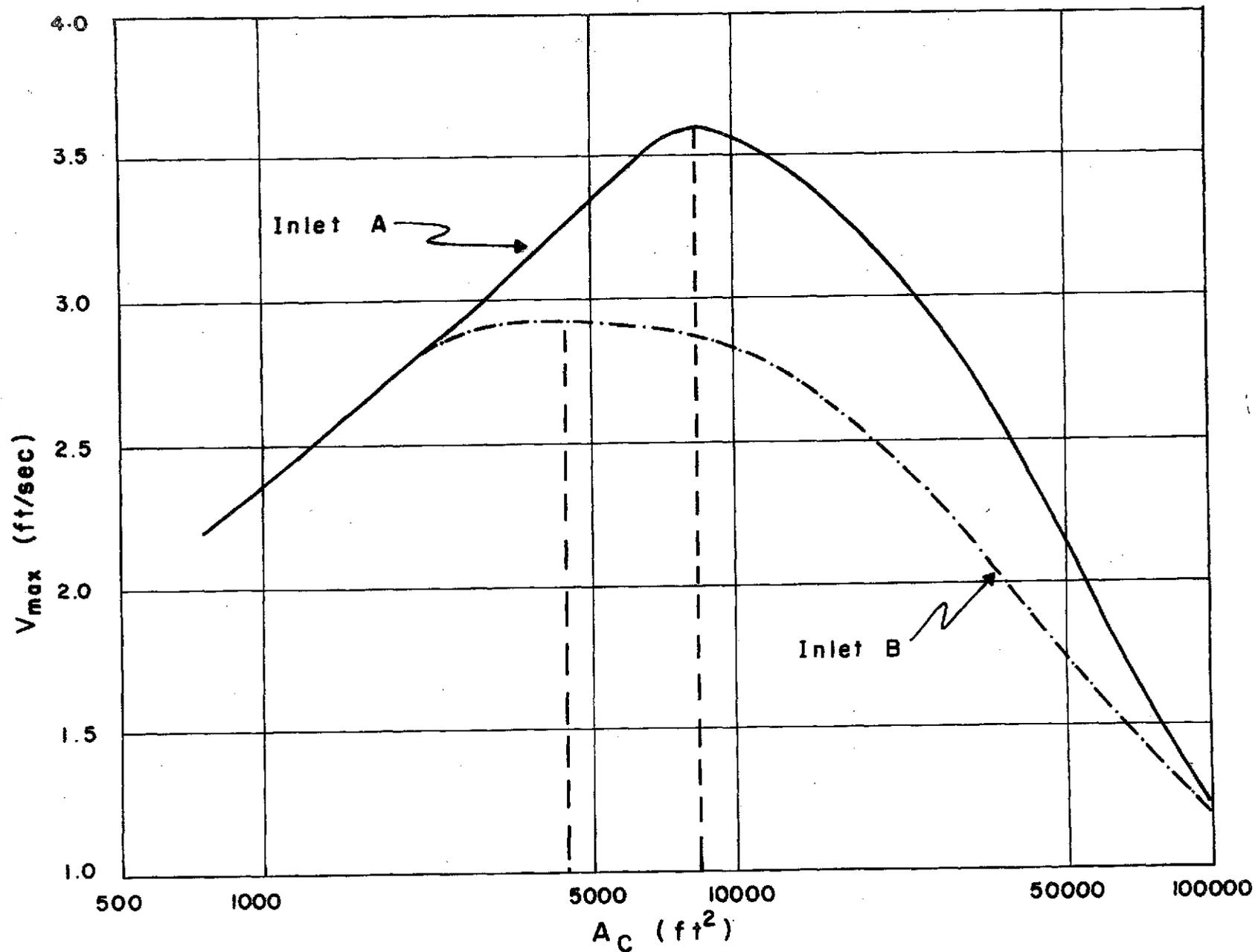
Fig. 4.3.4. Maximum Velocity V_{max} Versus Throat Cross-sectional Area A_c
For Breakthrough Inlets.

decrease in A_c, say be sediment deposition, is accompanied by a corresponding decrease in V_{max}. This in turn will cause more sedimentation due to lower current velocities, and thus the process will continue until the inlet closes. For the curve to the right of V^*_{max}, a decrease in A_c is counter-balanced by an increase in V_{max}, so that the inlet remains stable and open. The magnitude of the cross-sectional area in such a case of a stable inlet will be a function of the tidal prism through the inlet (O'Brien, 1969).

Fig. 4.3.4 shows that for Inlet A to remain open, it must have a minimum cross-sectional area of 8300 ft.^{2}, with a width of 490 ft. and a depth of 17 ft. Similarly, Inlet B would have to have a minimum cross-sectional area of 4400 ft.^{2}, with a width of 490 ft. and a depth of 9 ft. Breaches as large as these have not occurred, as the geological evidence shows, and therefore the lagoon is not likely to be able to maintain a stable inlet, since it does not have sufficient storage of water within its body.

Another way of looking at the stability criterion for inlets is to observe the relationship between the maximum flow rate Q_{max} ($= V_{max} \cdot A_c$) and A_c. Fig. 4.3.5 shows that the characteristic curves for inlets A and B appear to reach maxima beyond $A_c = 100,000$ ft.^{2}, indicating almost no possibility of a stable inlet formation. It should be noted that the curves for the two inlets tend to merge on the left hand side, in Fig. 4.3.4 as well as 4.3.5. This is so because on the average, natural inlets tend to maintain a width to depth ratio of 30:1 (O'Brien, Private communication). Thus, as A_c decreases below the point where the inlets with the chosen depths of 17 and 9 ft. have 30:1 ratios, the depths must correspondingly decrease to maintain this ratio. Ultimately therefore, the two inlets have the same dimensions, with consequent merging of the V_{max} and Q_{max} versus A_c curves.
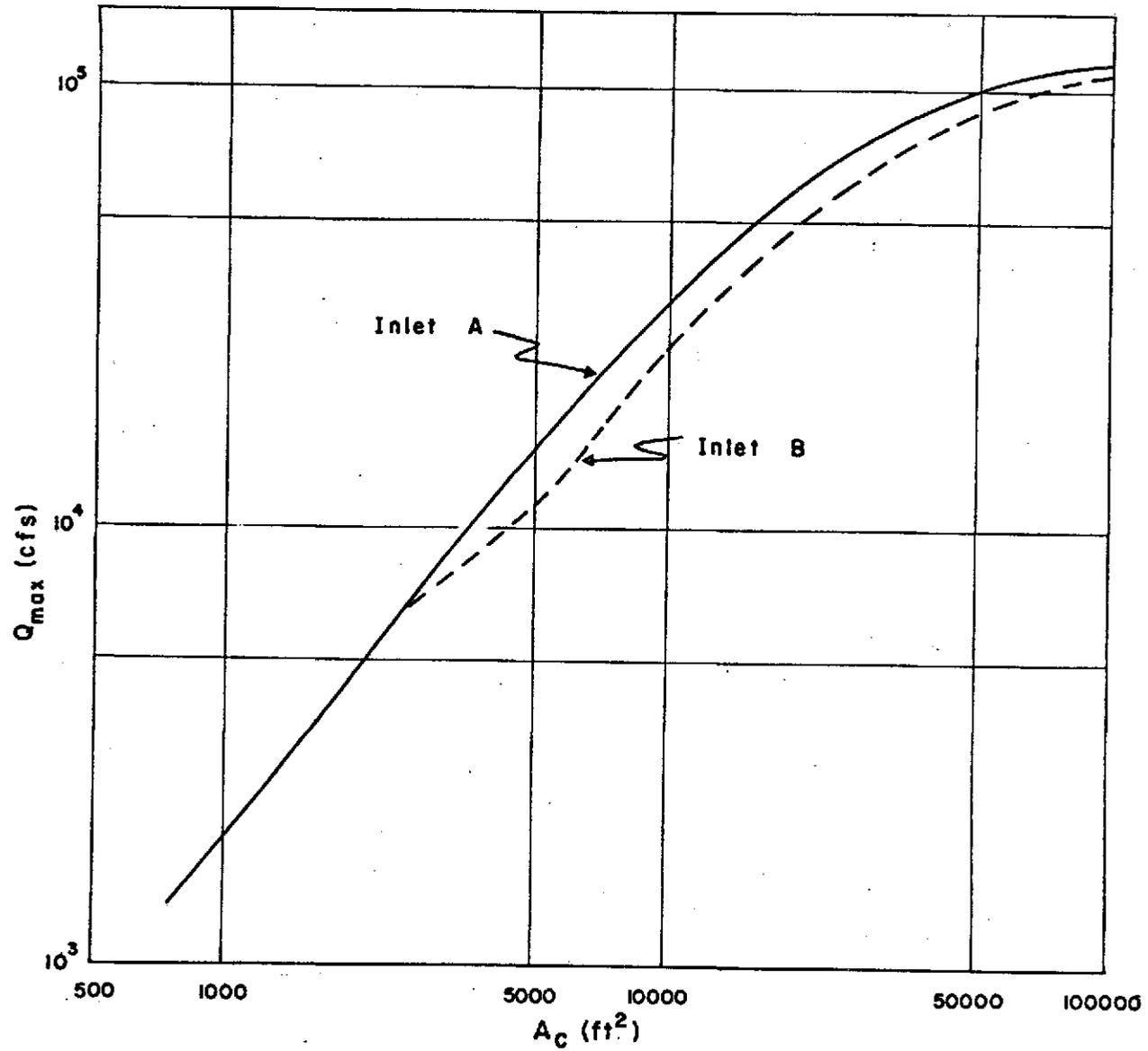
Fig. 4.3.5. Maximum Flow Rate Q_{max} Versus Throat Cross-sectional Area A_c For Breakthrough Inlets.

4.4 Wind Setup in Lagoon

Although the predominant wind direction in the Cape area is easterly, under storm or hurricane conditions, a strong wind from the north-northwesterly direction could blow for a sustained period of time along the axis of Mosquito Lagoon, and pile up water at its southern end. Such a situation has occurred, for example, in Pamlico Sound, N. C., where northeast storms have piled the water up against the barrier islands (Dolan, Godfrey and Odum, 1973). It is interesting to note that before the dunes there were stabilized by sand fences, the surge waters used to "simply flow out between the dunes and over the beach to the sea, but now the water can not drain off readily and vast areas of land are at times submerged."

Calculations (Shore Protection, Planning and Design, 1966) for Mosquito Lagoon show that the lagoon simply does not have enough water to pile up and overflow, or cause a breakthrough. Fig. 4.4.1 shows that at a 50 mph wind, the maximum setup is less than 7 ft. and a 60 mph wind has one less than 8 ft. Further the setup shows that at 50 mph, more than 23 miles of the lagoon (total length 33 miles) from the north end will run dry, and at 60 mph, the dry portion increases to about 25 miles.

4.5 Hurricane Considerations

Hurricane effects at the Cape and vicinity have been evaluated by Corps of Engineers (1962, 1970) and by Deese at KSC (1973). These studies, which estimate critical wind and surge conditions near KSC, are based on statistical predictions of hurricane path, intensity and frequently, using data from past hurricane records. There is a significant degree of uncertainity involved in these computations, especially in view of the difficulty in determining the frequency of a hurricane of a given magnitude striking the KSC facilities.
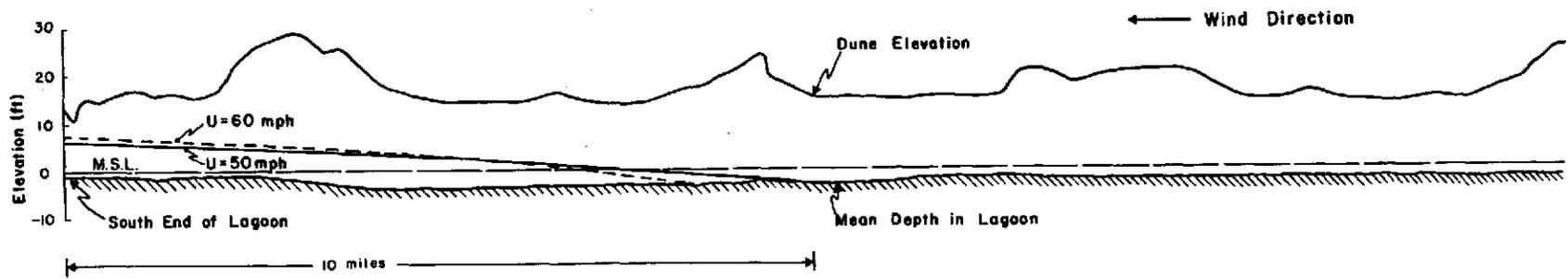
Fig. 4.4.1. Wind Setup in Lagoon.

As the Corps of Engineers report (1962) notes, "owing to the wide disparity in occurrence frequency and the absence of any predictable pattern of occurrence, it is difficult to predict future hurricane frequency for the Cape area."

The study of Deese is a commendable one, and is a realistic and comprehensive analysis of the probability of exposure to KSC facilities. It is based on a detailed analysis of past records and describes results that are plausible, if indeed the predicted hurricanes therein do occur, as described. However, any appraisal of the need for hurrican protection to KSC facilities is beyond the scope of this study.

5. SUMMARY AND CONCLUSIONS

The objectives of the present investigation were (1) a review of the problem of beach erosion in KSC property (2) identification of the risk to KSC facilities and the impact on Intracoastal Waterway and Mosquito Lagoon in the event of dune barrier failure in a storm or otherwise and (3) recommendation of the most economical method(s) of achieving reasonable protection to KSC facilities and Mosquito Lagoon through preservation of the dune system, if necessary.

The study was carried out by field and aerial survey of the location, a geological appraisal of the Lagoon-barrier system and finally, a hydrodynamic investigation of the possibility of the occurrence of a breakthrough inlet at the barrier.

The following are the main conclusions:

1. The beach along the Kennedy Space Center property is in a geologically natural state, wherein the characteristics of dune, berm and beach face profiles are determined primarily by wave action and the available beach material. A study of wave refraction along the shoreline appears to indicate that in those sections of the shoreline where refraction causes a concentration of wave energy, relatively higher dunes are formed, due to higher wave uprush. Uprush due to relatively long and high swells at high tide transports sand which is deposited on the berm, the first dune line or on the gently sloping backside of the dunes. The latter action is generally caused by oceanic overwash during extreme wave conditions due to storms and hurricanes, and serves to stabilize the dunes by maintaining their heights. Winds in the region are generally moderate and play only a secondary role in dune development.

2. The land barrier near Mosquito Lagoon is slowly regressing landward, by

53

erosion on the seaward side, and deposition of washover material on the lagoonal side. In order for the regression to continue, without significantly altering the dune heights and beach profiles, it is essential that washovers continue to transport the necessary amount of beach material, as at present.

3. Mosquito Lagoon, which on the average is only 4 ft. deep, is in the final stages of silting. There have been at least five separate inlets opening directly into the lagoon from the ocean during the past 6,000 to 7,000 years. The most recent inlet was in the vicinity of Turtle Mound, which was closed more than 1,500 years ago. Geological evidence indicates that though the barrier is being badly eroded and overwash or overtopping during storms occurs, there appears to be no possibility of a new inlet being permanently established at the present time.

4. Hydrodynamic considerations of a possible breakthrough inlet indicate that the lagoon does not contain sufficient volume of water to maintain any such inlet. Thus in the event that hurricane storm surge and related waves may breakthrough the barrier beach, the opening formed will soon be closed by subsequent normal wave action.

5. Major installations at Kennedy Space Center are far enough from the shore-line, such that they are in no danger from storm wave action.

6. Even under an extreme storm wind condition wherein a wind of 60 mph blows for a sustained period of time from the northwest along the length of the lagoon, the amount of water piled up at the southern end of the lagoon will be less than 8 ft., with more than two thirds of the northern portion of the lagoon running dry. The 8 ft. wind setup is significantly lower than the dune heights along the barrier, and will not be sufficient to cause a breakthrough from the lagoonal side.

7. The study of hurricane conditions made by KSC is a realistic and compre-

hensive analysis of the probability of exposure of KSC facilities. Appraisal of the need for hurricane protection to the facilities is beyond the scope of this study.

6. RECOMMENDATIONS

Based on the conclusions presented in the preceeding section, the following recommendations are in order:

1. Since the entire beach along the KSC property is in a state maintained by natural processes, it should not be manipulated by any means that would alter the action of these processes.

2. Low spots in the dunes, particularly those caused by beach vehicles and human traffic should be covered up , where possible, by sand and overgrown by vegetation from adjacent areas.

3. A limited number of convenient access passes over the dunes may be maintained for human traffic.

4. Since plant life growing on the dunes is a part of the dune system, it should be retained, where possible, in its natural state.

BIBLIOGRAPHY

"Brevard County Beach Erosion Study", Survey by Corps of Engineers, Jacksonville District, 1965.

Brooks, H. K., "Geology of Cape Canaveral", in "Space-Age Geology", Edited by T. E. Garner, Southeastern Geology Society, Tallahassee, P. 35-44, 1972.

Coastal Engineering Research Center, Private Communication to R. G. Dean, February, 1973.

"Coastal Engineering Study at Port Orange, Florida", Report Submitted to Department of Transportation, by Coastal and Oceanographic Engineering Laboratory, University of Florida, 1972.

"Coastal Engineering Study of Proposed Navarre Pass", Report Submitted to Santa Rosa County Beach Administration, by Coastal and Oceanographic Engineering Laboratory, University of Florida, February, 1973.

Corps of Engineers, "Evaluation of Oceanographic, Hydrographic and Hydrologic Effects - Cape Canaveral Area, Florida", Jacksonville District, June, 1962.

Corps of Engineers, "A Study of the Cape Canaveral Area, Florida, Standard Project and Maximum Probable Hurricane Tide Levels", Jacksonville District, March, 1970.

Deese, J. H., Unpublished Report, Kennedy Space Center, NASA, 1973.

Dolan, R., Godfrey, P. J. and Odum, W. E., "Man's Impact on the Barrier Islands of North Carolina", American Scientist, Vol. 61, No. 2, p. 152-162, March-April, 1973.

Dolan, R., Hayden B., Vincent, L. and Riddel, P., "The Ninth February Mid-Atlantic Storm", Unpublished Report, National Park Service, 1973.

Field, M. E. and Duane, D. B., "Geomorphology and Sediments of the Inner Continental Shelf, Cape", in Press.

Kofoed, J. W., "Coastal Development in Volusia and Brevard Counties", Florida Bull, Marine Sciences of the Gulf and Carribbean, Vol. 13, p. 1-10, 1963.

Lazarus, M. and Nowlin, C. L., "Effect of Wave Action on Tidal Stages Along the Coast of Florida, March 1962", CERC Bulletin and Summary Report of Research Progress For Fiscal Years 1965-1966, 1966.

Northern Hemisphere Surface Charts, Published by National Oceanic and Atmospheric Administration, Environmental Data Service, February, 1973.

O'Brien, M. P., "Equilibrium Flow Areas of Inlets on Sandy Coasts", J. Waterways and Harbors Division, ASCE, WW1, Proc. Paper 6405, pp. 43-52, February, 1969.

O'Brien, M. P., and Dean, R. G., "Hydraulics and Sedimentary Stability of Coastal Inlets", Proc. 13th Coastal Engineering Conf., Vancouver, B. C., Canada, p. 761-780, July, 1972.

Osmond, J. K., May, J. P. and Tanner, W. F., "Age of Cape Kennedy Barrier and Lagoon Complex, J. Geophys. Res., Vol. 75, p. 469-479, 1970.

"Shore Protection, Planning and Design", Tech. Rep. No. 4, 3rd Ed., Published by U. S. Army Coastal Engineering Research Center, 1966.

Tide Current Tables, Published by National Oceanic and Atmospheric Administration, National Ocean Survey, 1973.

Tide Tables, Published by National Oceanic and Atmospheric Administration, National Ocean Survey, 1973.

Walton, T. L., "Littoral Drift Computations Along the Coast of Florida by Means of Ship Wave Observation", Tech. Rep. No. 15, Coastal and Oceanographic Engineering Laboratory, University of Florida, February, 1973.

Wiegel, R. L., "Oceanographic Engineering", Prentice-Hall, Inc., 1964.

Wilson, W. S., "A Method for Calculation and Plotting Surface Wave Rays", Tech. Memo. No. 17, U. S. Army Coastal Engineering Research Center, February, 1966.