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INLET HYDRAULICS AT GREEN HARBOR MARSHFIELD, MASSACHUSETTS

by

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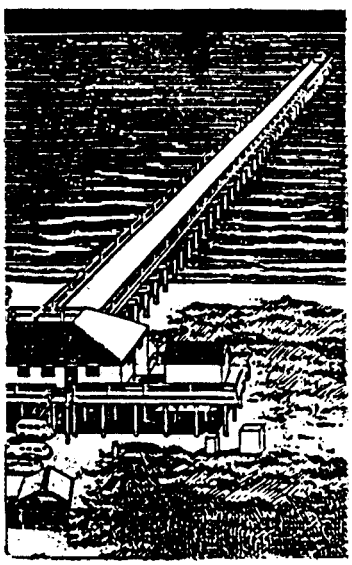

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A combination office study, field data collection, and numerical model study was used to determine the principal causes of shoaling at Green Harbor, MA. Results of a year-long data collection effort which obtained directional wave information offshore of the harbor entrance revealed that the harbor is subjected to waves of over 12-sec periods. Results of the wave refraction study and sediment transport calculation formed the basis of the sediment budget which identified the major sediment sources for each of the shoals within the tidal inlet system. The conclusion of the study recommends several methods for decreasing the dredge return frequency at Green Harbor.

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EXECUTIVE SUMMARY

Project History and Background

There is little documentation of how often or to what extent the mouth of Green Harbor has migrated. A map depicting the 1794 and 1897 shorelines (Report of the Joint Board of Land Commissioners et al. 1898) shows that the mouth of Green Harbor River has migrated to the south in recent (Geologic) times (Figure 6). Migration of the inlet to the north is limited by the bedrock outcrops at Blackman's and Green Harbor Points. Modification of the inlet back-bay system began in 1633 with the construction of a channel, now known as the Cut River, linking Green Harbor River to Duxbury Bay.

In 1806 the inlet was sealed by a storm, and in 1807 a petition was granted by the State House of Representatives to construct a canal in the previous location of the inlet to drain stagnant water from the marsh. The draining operation was marginally successful; in 1811 another storm breached the beach that had formed since 1806. The dike was constructed in 1872 in the present location of Route 139 (Dike Road). After construction of the dike, the entrance to Green Harbor, never very deep or wide, became shallower and more sinuous, hindering navigation. The area behind the dike settled approximately 3.5 ft* because it was no longer subject to the tides.

In 1897 the conflict between agricultural and navigation interests led to establishment of the Joint Board of Harbor and Land Commissioners who were charged with evaluating the condition of the harbor and deciding what action, if any, should be taken with respect to removal of the dike. The Board of Commissioners found that the dike had worsened navigation conditions in Green Harbor; however, they stated that the value of the agricultural land gained by dike construction outweighed the navigation loss. They recommended that the dike remain and the State construct two jetties to increase the effect of tidal flow through the channel and that the channel be dredged periodically.

Stone jetties were constructed by the State in 1899, extending seaward from shore to the 6-ft contour at mean low water (mlw). At about this same time, the timber pile structure at the mouth of the Cut River was also

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* A table of factors for converting non-SI units of measurement to SI (metric) units is given on page 10.

constructed. In 1900, a survey indicated that the entrance channel had deepened from 1.5 ft above mlw to 0.2 ft below mlw. A channel 60 ft wide and 5 ft deep at mlw was dredged later that year. Within 2 years the controlling depth was 1 ft below mlw.

Dredging and jetty repair were undertaken periodically by the State through 1964. In 1968 the Corps of Engineers modified the structures originally built by the State. The east jetty was rebuilt with a sand-tight core, and a 200-ft-long extension was added to the seaward end of the structure. The entrance channel was dredged, as were anchorages and a turning basin upstream of the throat, or "Narrows."

Channel shoaling has continued to the extent that the effects of dredging have been generally short-lived. The principal shoals consist of a bar at the outer ends of the jetties and a mound at the throat of the entrance channel. Based on available information, about 9,000 cu yd of material has accumulated in the outer portion of the entrance channel annually, and about 11,000 cu yd of material has accumulated in The Narrows.

Study Summary

The need for frequent maintenance of the entrance channel led to a reevaluation study of the Federal project starting in September 1981. The study has had two primary objectives: (1) to accurately describe how the existing project at Green Harbor behaves in a physical sense and (2) to develop economically viable and environmentally sensitive alternatives that would produce a more stable entrance channel for the harbor. This report documents work on the first objective and introduces measures aimed at meeting the second objective. Refinement of structural options is under way.

The initial effort included three areas of investigation. First, a thorough review of historic data--including prior reports, aerial photography, surveys, and recollections of people who have lived in the Green Harbor area--was done. Secondly, nearly a year's directional wave data were collected to determine the predominant wave climate of the harbor. Analysis of bottom and subbottom sediment offshore was a part of this work as was analysis of refraction patterns in the vicinity of the project and reflection patterns within the entrance area. These data made it possible to quantify sand movement offshore of the project and then determine the potential for sand movement by

reflected waves within the project. Thirdly, a computer-based tidal inlet hydraulic model was developed for the harbor. This model simulated flow patterns within the channel and harbor during the tidal cycle and was used to predict how those patterns would be modified if structural changes were made. Work on the first area was a joint effort between Drs. David G. Aubrey and Lee L. Weishar. Work on the second area of investigation was conducted primarily by Dr. Aubrey of the Woods Hole Oceanographic Institution in Woods Hole, MA. Work on the third area was conducted primarily by Dr. Weishar of the US Army Engineer Waterways Experiment Station (WES) in Vicksburg, MS.

Findings

Wave studies

Wave studies offshore of Green Harbor show that virtually all the waves generated enter the harbor inlet from an angle of about 260 deg from true north. This occurrence is due in part to refraction of waves approaching from various directions. These waves vary in height and power during the year. The highest, most powerful waves are concentrated in the late winter and early spring and have the capability to move large quantities of material from offshore if material is available there to be moved.

Investigations of areas offshore of Green Harbor indicate that limited quantities of sand are available to be moved into the harbor. There is very little sand-sized material offshore from the harbor mouth to the north. A band of shallow sand deposits underlain by glacial till extends south from the mouth of the harbor along Green Harbor Beach; the width of this deposit averages 2,100 ft, although it is narrowest in the vicinity of the harbor entrance. A narrow strip of glacial till interspersed with streamers of sand lies seaward of the shallow sand band; beyond this area, the bottom is composed of glacial till that has not been worked by the ocean. This information was obtained by a combination of physical sampling, side-scan sonar surveys, and subbottom profiling.

The foregoing work was combined with hydrographic surveys to describe offshore bathymetry. The results show highly irregular contours with apparent rock outcrops north of the harbor and regular contours to the south. The line of demarcation between the two areas coincides with the harbor entrance.

An effort has been made to quantify longshore sediment transport in the

entrance area. Directional wave data and (small scale) refraction analysis were applied to an empirical equation linking sediment transport at and adjacent to the entrance to breaking wave conditions. Results indicate average estimated potential transport quantities as follows:

Direction	Quantity, cu yd/year
To the north	8,500
To the south	26,150
Net transport	17,650*

* To the south.

Since very little sediment is available to the north, the potential for southward transport is not realized at the harbor entrance.

Green Harbor has a very small tidal prism, i.e., the volume of water available in the harbor to flush out accumulated sediment is limited. Hydraulic analysis indicates that entrance channel currents are slow. The maximum flood current in the inlet during spring tides is only about 1.5 ft/sec (0.89 knots). Consequently, currents in the entrance channel are able to move sediment in or out of the entrance channel only during a short period of time in each tidal cycle, so there is little flushing of material either into or out of the harbor entrance. Any sand, silt, or cobbles which get into the project are unlikely to be moved out by the flushing action of tidal currents. Current and tide measurements were used to develop a computer model (Inlet III) of the back-bay and inlet regions.

Evaluation of suggested harbor modifications

The "inlet" model, once calibrated, was used to estimate the hydraulic impact of specific system modifications proposed prior to the study. Results are as follows:

a. A half-tide training structure between The Narrows and the seaward end of the east jetty would not increase channel current velocity enough to materially improve the flushing capacity of the inlet.

b. Rebuilding a pile jetty at the mouth of the Cut River would have a negligible effect on entrance channel shoaling because it would have little impact on current velocity.

Wave refraction-diffraction analysis

Wave conditions based on field data were analyzed with a

refraction-diffraction model developed at WES. Results indicate that most waves approaching the entrance from various angles are refracted toward the entrance such that sediment transport is directed toward the inlet from both the northeast and the southwest sides. Waves either directly enter the entrance channel or are reflected off the inside of the west jetty. Large waves generated by northeast storms overtop the northeast jetty.

Conclusions

Based on wave climate observations, littoral drift estimates, currents in the inlet area, sediment distribution, inlet configuration, and shoaling history, the following sources of shoaling have been identified:

Potential Source	(× 1,000 cu yd/year)	(× 1,000 cu yd/year)
Direct wave action	8	--
Sand transport around SW jetty	2	--
Wave reflections off inside SW jetty	--	13
Windblown from Green Harbor Beach	--	1
Wave overtopping of NE jetty	--	undetermined

The above listing reflects an extremely limited source of sand-sized material directly offshore and to the north of Green Harbor. Of the average 8,500 cu yd of sediment transported annually from the south toward the inlet, 90 percent is being transported around the west jetty (source 1). The amount will increase as the shoal expands (due to wave refraction at Green Harbor Beach). Approximately 8,000 cu yd of material are transported directly into the inlet from offshore. The mechanism for transporting the sand-sized material is the refraction of waves at the entrance mouth. The refraction analysis showed that long-period waves approaching the harbor entrance from the north are refracted by the offshore bathymetry until they can either directly enter the entrance channel or are reflected off the west jetty. These waves transport sand-sized and a limited amount of cobble-sized material into the entrance channel.

The potential source of material resulting from wave reflection off the west jetty is a combination of sand being transported toward The Narrows by

reflected mach stem waves and erosion of the inner beach region landward of the east jetty.

The last two potential sources of sand (windblown and wave overtopping) are difficult to quantify. Sand transported by aeolian process is a definite factor in this region. Clouds of sand have been observed being transported off the wetted intertidal beach toward the harbor. However, this source is believed to be relatively small.

During large northeast storms, waves overtop the east jetty and break directly on the inner beach region, transporting some cobbles and sand from the seaward side of the jetty in addition to eroding sand and cobbles from the inner beach directly into the channel. The condition arises only during the largest storms but has the potential for transporting significant quantities of sand and cobbles in a relatively short period of time.

In summary, sediment transport within the Green Harbor inlet/back-bay system at present is a wave-dominated process. Wave energy is transmitted into the inner jetty region by direct propagation, wave reflection, and wave refraction. This combination of wave forces is the primary process responsible for the shoaling at Green Harbor. Wave energy is also transmitted into the interjetty region during storm conditions by overtopping of the east jetty. Wave reflection and refraction are responsible for transporting sediment around the west jetty and for redistributing sediment within the interjetty region. Tidal currents combine with wave processes to redistribute sediment within the interjetty region. There is no evidence of sediment being transported through The Narrows and forming a flood-tidal shoal. Peak tidal flows are of sufficient strength to initiate sediment motion and to transport sediment; however, these velocities are maintained only during a small portion of the tidal cycle. Reduced tidal flows are due primarily to the limited storage area in the back-bay region.

Lengthening of the west jetty increased wave reflection and wave diffraction within this region. At the same time, regional refraction has been increasing the fillet on the west side of the west jetty. Sand has been continually transported into the lee of the west jetty by refracted waves and has been trapped there. Offshore sediment transport at Green Harbor is geomorphically controlled. North of the harbor entrance little if any sand is available for transport. South of the harbor entrance there is sand in the offshore and nearshore regions, but the majority of this sediment is not

transported due to the fetch-limited conditions which occur within Massachusetts Bay.

Recommendations

The following recommendations are made:

a. Reduce the west jetty lee side fillet which is partially responsible for building the entrance shoal.

b. Raise and sand tighten the east jetty to minimize wave overtopping during storms.

c. Eliminate or reduce the length differential between the east and west jetties. This will accomplish the following:

   (1) Eliminate or minimize mach stem reflected waves which build the entrance shoal.

   (2) Reduce erosion on the east side of The Narrows, thus reducing the quantities of sediment available to the shoal at The Narrows.

   (3) Reduce overall reflected wave energy during storms, thus providing safer boating conditions.

   (4) Reduce storm damage to the west jetty.

d. Riprap the east Narrows in the interjetty region to reduce erosion and sediment transport in the interjetty region.

e. Implement a beach grass planting program for the dune region adjacent to Green Harbor Beach to minimize sand transport into the interjetty region by aeolian processes.

This report identifies the dominant physical processes responsible for shoaling in the entrance channel at Green Harbor and identifies sources of sediment and the mechanisms responsible for building the entrance and interjetty shoals. Measures to minimize shoaling within the Green Harbor interjetty region are identified. The design details of these measures are being refined for inclusion in a subsequent report along with an evaluation of their likely effectiveness.

It is clear that the basic problem remains and will continue. With limited tidal prism, the natural tendency will be toward an entrance channel with a small cross-sectional area. As long as sources of shoal material are available, nature will work in that direction. The objective of efforts described herein is to extend the period of time between dredging operations by reducing the rate of shoaling.

PREFACE

The study presented herein was authorized by US Army Engineer Division, New England, Navigation Branch, under the direction of Mr. Carl G. Boutlier. This report was prepared by Dr. Lee L. Weishar, Coastal Processes Branch, Research Division, of the Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES), and Dr. David G. Aubrey, Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Falmouth, MA.

The work was performed under direct supervision of Dr. Steven A. Hughes, Chief, Coastal Processes Branch, and Mr. H. Lee Butler, Chief, Research Division; and under general supervision of Mr. Charles C. Calhoun, Jr., Assistant Chief, and Dr. James R. Houston, Chief, CERC. This report was edited by Ms. Shirley A. J. Hanshaw, Information Products Division, Information Technology Laboratory, WES.

COL Dwayne G. Lee, CE, was Commander and Director of WES during the preparation of this report. Dr. Robert W. Whalin was Techincal Director.

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CONVERSION FACTORS, NON-SI to SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
knots (international)	0.514444	metres per second
miles (US statute)	1.609347	kilometres
pounds (force)	4.448222	newtons
tons (2,000 pounds mass)	907.1847	kilograms
yards	0.9144	metres

INLET HYDRAULICS AT GREEN HARBOR
MARSHFIELD, MASSACHUSETTS

PART I: INTRODUCTION

Background

1. Green Harbor is a small tidal estuary located on the east side of Massahusetts (Figure 1) approximately 35 miles* southeast of Boston, MA, located within the town of Marshfield in Plymouth county. The inlet back-bay harbor system is located at the terminus of the Green Harbor River. The study area (Figure 1) consists of the Green Harbor inlet back-bay system and adjacent offshore region. Protected by two stone jetties, the entrance to Green Harbor has an arrowhead configuration with a navigation opening of approximately 250 to 300 ft at the outer ends. The project design depth of the harbor entrance channel is 8 ft mean low water (mlw),** while that of the channel located between the harbor jetties and in the harbor is 6 ft mlw.

2. Mean tide level (mtl) in Cape Cod Bay near Green Harbor (reported at Gurnet Point) is 4.6 ft mlw with a spring tide range of 9.2 ft mlw. Green Harbor River flows into the inlet back-bay system, draining a small freshwater marsh system located to the northwest of the harbor entrance. River discharge into the harbor system is highly irregular, depending upon the amount of rainfall in the immediate vicinity of Green Harbor. River and marsh systems are separated from the harbor by a dike that contains a flood gate with a one-way discharge culvert which permits freshwater discharge but prevents saltwater intrusion.

Purpose

3. The purpose of this report is to summarize the results of an

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* A table for converting non-SI units of measurement used in this report to SI (metric) units is found on page 10.

** All elevations (el) cited herein are in feet referenced to National Geodetic Vertical Datum (NGVD) of 1929.

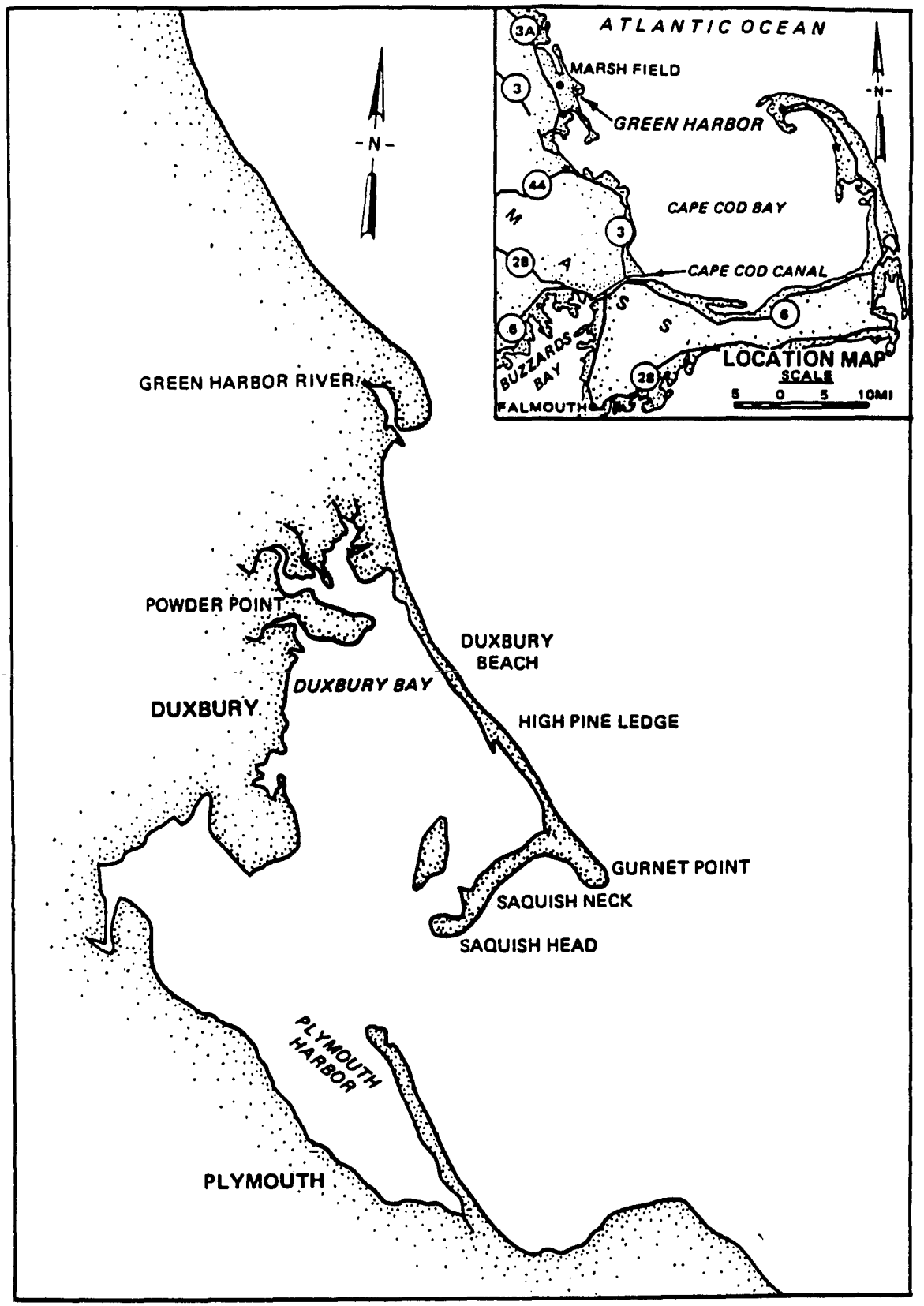

Figure 1. Location map

investigation to determine the causes of shoaling at the entrance to Green Harbor, MA. The Green Harbor back-bay system has undergone a series of man-made changes which have produced a series of complex responses, resulting in increased rates of shoaling in and near the inlet mouth. Examples of these changes include the opening of a canal between Duxbury Bay and Green Harbor (the Cut River) and diking of the back-bay area, the latter reducing tidal flow. In addition, the harbor entrance itself has undergone a series of inlet stabilization steps primarily designed to reduce shoaling at the mouth of the Green Harbor River and maintain navigation in the interjetty region during moderate wave conditions. Typical shoaled depths at the inlet throat (The Narrows) are relatively shallow (3 to 4 ft at mlw), with shoals accumulating in the entrance channel on the seaward side of the inlet throat and near the end of the entrance jetties.

Scope

4. This report describes a combined field and office study designed to define the causes of the shoaling problem and to recommend potential solutions to mitigate shoaling at Green Harbor. The office study consisted of (a) the history of inlet development compiled from existing reports and aerial photographs, (b) available wind data analysis, (c) available wave and current data analysis, (d) refraction-diffraction analysis, and (e) inlet stability analysis. The inlet stability analysis was performed using a two-dimensional numerical model designed to evaluate inlet stability by mathematically introducing changes in inlet geometry into the numerical model. In addition, the numerical model was used to predict the effectiveness of adding various stabilizing structures and/or modifying the existing ones.

5. The field study was divided into three phases. The first phase was performed by personnel of the Coastal Engineering Research Center (CERC) of the US Army Engineer Waterways Experiment Station (WES) and US Army Engineer Division, New England (NED). Measurements of tides, currents, and sediment distribution were obtained over a 48-hr period in September 1981. The second phase was performed by the Woods Hole Oceanographic Institution (WHOI). WHOI installed and maintained an offshore wave sensor near the mouth of Green Harbor River to obtain directional wave information over a 12-month period from June 1983 through June 1984. The third phase was performed by personnel

of WHOI with the assistance of personnel from CERC and NED. Subbottom seismic profiles and high-resolution side-scan sonar profiles were simultaneously collected in the offshore region near the entrance to Green Harbor.

PART II: LITERATURE REVIEW

6. The following review of literature is not intended to be exhaustive. Only literature which has pertinent information has been chosen for discussion. The 1898 "Report of the Joint Board consisting of the Harbor and Land Commissioners and the State Board of Health upon the Restoration of Green Harbor in the Town of Marshfield, Massachusetts,"* was prepared as required by Chapter 495 of the Acts of 1896. The purpose of the report was an

> ...examination of Green Harbor in the town of Marshfield, and of the Green Harbor marshes and the dam and dike constructed across Green Harbor River under the provisions of Chapter 371, to be made by competent engineers, who shall report to said joint board the result of their examination; and if upon receiving such report said joint board shall determine that a substantial improvement in and benefit to Green Harbor shall result from the removal of said dam and dike....

The report contains excellent descriptions of the historical modification of Green Harbor as well as analysis of the changes made in the harbor as a result of the diking.

7. A cooperative beach erosion control report covering Pemberton Point to Cape Cod Canal was published by NED in the fifties (US Army Engineer Division, New England 1957). The study did not address the hydraulics of the navigable inlets in the area but did include an analysis of shoreline utilization. This report emphasized that the entire region (with the exception of Duxbury Beach) is extensively protected by stone revetment, groins, jetties, and seawalls. These shoreline structures have effectively protected the shoreline for many years. However, these structures have eliminated the major source of material from the littoral system. Along with shoreline stabilization has come extensive shoreline development. The majority of the shore is heavily populated, and while the building of protective beaches is recommended, the report concludes that it is imperative to maintain integrity of the shore protection structures to protect the adjoining property from storm damage.

8. In 1958, the town of Marshfield and the Green Harbor Basin Committee commissioned Fay, Spofford, and Thorndyke (1959) to investigate the siltation problem occurring in the entrance to Green Harbor. The report identified the harbor facility (docking and mooring areas) as one of the town's greatest potential revenue sources. The investigation conducted by Fay, Spofford, and

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* Hereafter referred to as Report of the Joint Board.

Thorndyke (1959), completed over a 1-year period, consisted primarily of a sequential historical account of the harbor and addressed various specific questions raised by the Commission. Physical data collection consisted of a bathymetric and topographic survey of the Green Harbor inlet back-bay regions. In addition to the surveys, limited sand samples were collected. Based upon the data collected and interviews with various Federal agencies, the report stated the following conclusions:

a. There is an apparent southerly drift of material (sand) in the 30-mile stretch of coastline from Pemberton Point to Gurnet.

b. Construction of the jetties at Green Harbor has caused a heavy accretion of sand on the southwest side of the west breakwater. The report speculates that southeasterly storms are responsible for causing the accumulation.

c. Siltation occurs in the form of a berm which deposits along the east side of the west jetty, seaward of The Narrows. The berm is continuous from The Narrows to the seaward end of the jetty, its maximum width occurring approximately 300 ft shoreward of the outer end of the west jetty.

d. Hypothesized sediment sources are Green Harbor Beach, Green Harbor inner basin, and the ocean.

9. The report recommends an extensive study be conducted to determine the sources of the sediment. In addition, immediate mitigation measures are discussed which include the following: (a) periodic dredging, (b) sand bypassing, and (c) jetty construction. None of the above mitigation measures were found to be acceptable for either economic reasons or lack of adequate information. Fay, Spofford, and Thorndyke (1959) recommended the construction of a concrete core wall within the body of the west jetty. Along with the core wall, they recommended that a cutoff groin be constructed at the eastern end of the existing timber bulkhead.

10. The "Small Navigation Project, Green Harbor, Marshfield, Massachusetts, Detailed Project Report" (NED 1965) provided the basis for the authorization of Green Harbor as a Federal navigation project. The report focused on the benefit-to-cost ratio of the proposed harbor. Very little information appears in the report about the geomorphology of the harbor or its wave climate. Rather, it mentions the beach erosion report cited in paragraph 6; however, apparently little data on conditions at the harbor were collected during report preparation. The report recommended that the west jetty be extended to reduce sand transport around the end of the structure from Green Harbor Beach.

11. The Town of Marshfield commissioned a tidal circulation study to determine the feasibility of locating a sewage outfall in the vicinity of Brant Rock (O'Hagan 1976). During the course of this study, three point dye sources were deployed to obtain a three-dimensional Lagrangian description of the offshore tidal currents. Surface dye releases were tracked using aerial photography. The maximum surface current determined from the aerial photographs was less than 0.1 knot. The experiment was unsuccessful at tracing the dye that was released at depths of 30, 40, and 60 ft of water. In addition to a description of the study, this report contains a biological assessment of the Brant Rock region which was completed using diver observations. Subaqueous observations by divers revealed cobble and coarse gravel in depths of 55 to 60 ft directly offshore of Brant Rock as well as outcrops of bedrock and boulders with a maximum diameter of 4 ft in the vicinity of Farnham Bank. The bedrock outcroppings and boulders decreased in size and frequency in the offshore direction until the bottom was entirely covered by coarse cobble.

12. Brenninkmeyer, Huidoboro, and Wood (1979) evaluated and compiled a report of storm damage to specific shore structures along the Massachusetts shoreline in response to a series of severe storms culminated by the Blizzard of 1978 (6-8 February). The performance of the groins at Brant Rock was evaluated by comparing two sets of beach profiles. The first set of beach profiles consisting of preconstruction surveys (obtained in 1932) was compared to a set of beach profiles obtained during the summer of 1979. Brenninkmeyer, Huidoboro, and Wood (1979) concluded that the groins at Brant Rock were ineffective because of a lack of available sediment. They classified the area as a sediment starved region in which little active sediment transport was occurring.

13. A small-harbor operation and maintenance reconnaissance report on Green Harbor (NED 1979) gives cursory details on the location and setting for the Green Harbor navigation project, the area served, physical conditions, and a preliminary economic evaluation. In addition, the report provides a limited time-history of previous dredging at Green Harbor which has been expanded to include updated information in Table 1.

14. The report (NED 1979) recommends that "funding of maintenance work at Green Harbor be continued at a level that will assure full access to and utilization of available harbor facilities." The report also recommends an

Table 1

Green Harbor Dredge History

Year	Description	Quantity, cu yd	Cost
1970	Dredged the 6-ft channel and anchorage	35,894	$109,388
1973	Dredged the 8- and 6-ft entrance channels	65,700	$121,753
1977	Dredged the 8- and 6-ft entrance channels	24,000	$118,840
1980-1981	Dredged the 8- and 6-ft entrance channels and the 6-ft inner channel and anchorage	-- --	$375,971
1983	Dredged the 8- and 6-ft entrance channels	--	$342,868
1985	Dredged the 8- and 6-ft entrance channels (as of 30 September 1985)	--	$209,386

in-depth study to determine if project modifications could reduce the frequency and quantity of maintenance dredging.

15. A report to the Marshfield Planning Board prepared by Tippetts et al. (1980) reidentifies the major geographic problem areas associated with Green Harbor as the shallow anchorage within the harbor area and the narrow entrance channel resulting from the accretion of sediment in the entrance channel. Tippetts et al. performed a hypothetical study evaluating the Green Harbor inlet entrance and nearshore hydrodynamic regimes. A sand budget analysis was performed along with calculations of gross sediment transport (Shore Protection Manual (SPM) (1984) method) and existing tidal hydraulics (Keulegan's method). The study showed a gross potential rate of sediment transport of 200,000 cu yd from the north (around Brant Rock). The authors realized that this quantity was excessive when viewed in conjunction with historical aerial photographs which show little or no source of littoral material in this region. However, an adjusted longshore transport rate was not given. The tidal inlet hydraulic regime was computed using a modified Keulegan method. Repletion coefficients, tidal current velocities, anchorage tidal stages, and tidal phase differences were computed. The authors understood that without verification of the calculated velocities, the results were only a "first cut" approximation. In addition to the inlet regime calculations, volumetric calculations were performed from hydrographic surveys to develop a sand budget for the region near the Green Harbor entrance. The sand budget analysis was performed to identify potential sand sources and transport

mechanisms. In Table 2 are the results from the sand budget analysis performed by Tippetts et al. (1980).

Table 2

Net Sedimentation Rates Within Regions

Region	Location	Net Sedimentation Rate, cu yd/year
I	Outer harbor (ocean shoal)	9,300
II	Throat or Narrows (inlet)	10,800
III	Anchorage (bay shoal)	5,300

16. Tippetts et al. (1980) ascertained from the sand budget analysis that there are two primary sources of sediment forming the shoals in the entrance to Green Harbor. The first source resulted from sand being transported (by combination of aeolian and hydrodynamic processes) from the beach directly into the inlet throat. The second source of sediment is derived from sand transported directly into Green Harbor from Massachusetts Bay. They surmised that the first source of sediment must be marginal and therefore concluded that all sediment forming the shoals must be transported from Massachusetts Bay directly into Green Harbor inlet.

17. One of the objectives of the Tippetts et al. (1980) report was to develop a set of preliminary solutions to the problem of inlet sedimentation and maintenance. The mitigating solutions posed anticipated further studies being conducted to evaluate their relative merits. Tippetts et al. speculated that a training structure should be constructed parallel to the west jetty and that it would maintain a parallel channel 150 ft wide from The Narrows through the interjetty region. They anticipated that this structure would eliminate the detrimental effects of the arrowhead jetties. Furthermore, they recommended that this training structure have an elevation such that it would be totally submerged at midtide. The rationale for this submergence was to channelize the ebb velocity, thus maintaining a sustained maximum or near maximum ebb flow while allowing the flood flow to diffuse over a larger area (thus permitting lower velocities) once the water level submerged the training structure. Tippetts et al. (1980) considered a plan proposed by the Harbor and Land Commission to install sluice gates in the region above the dike. The intended purpose of the sluice gates would be to impound water and then

selectively release it into the harbor at the most advantageous time; however, the report gave no recommendation concerning the practicality of these sluice gates.

PART III: HISTORIC SETTING AND DYNAMIC CONDITIONS

Study Area

18. Green Harbor is located on the eastern shore of Massachusetts, approximately at the northern boundary of Cape Cod Bay and the southern boundary of Massachusetts Bay. The field site is situated on a northeast-southwest trending shoreline. The inlet at Green Harbor is bounded on the north by rocky headlands (Blackman's Point and Green Harbor Point) and to the south by Gurnet Point and Saquish Head (Figures 1 and 2). The nearshore region surrounding Green Harbor consists of highly contrasting morphology. The region immediately to the north may be characterized as a series of bedrock outcrops

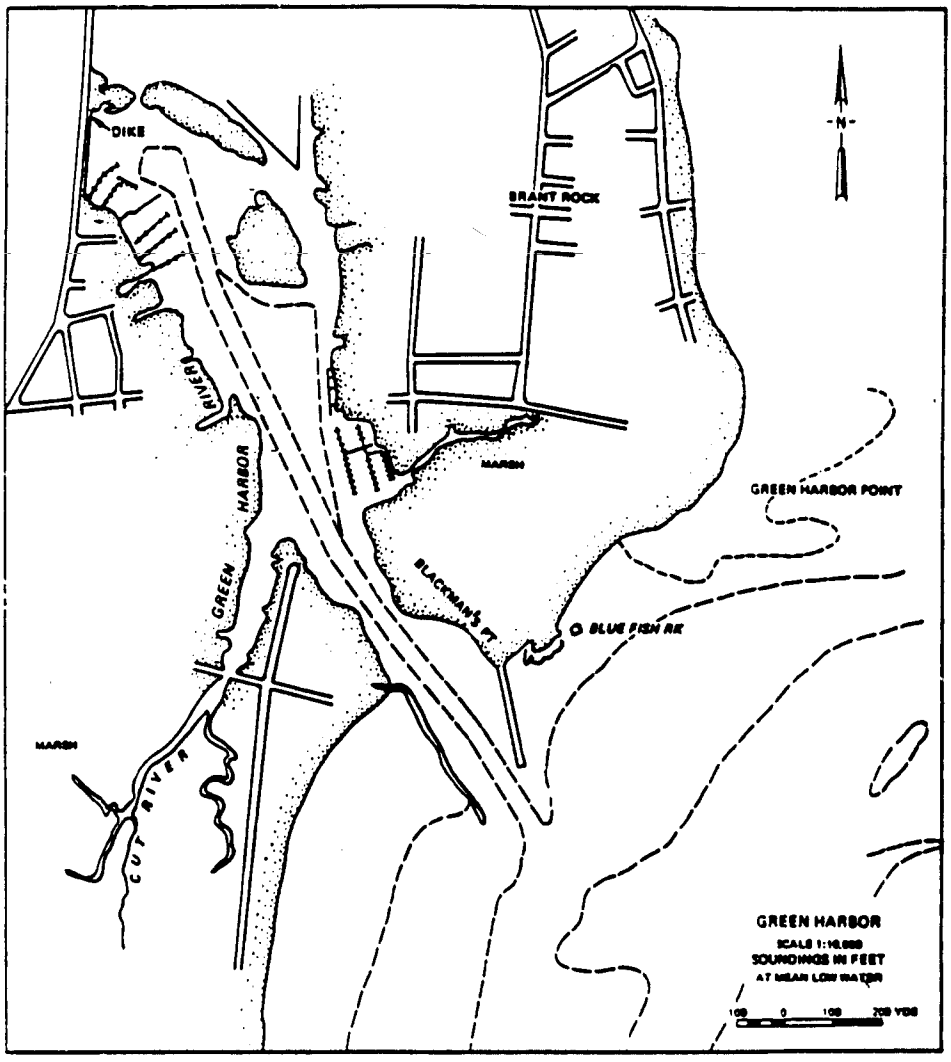


Figure 2. Green Harbor entrance and back-bay region

which effectively anchor the shoreline. These outcrops are most prevalent beginning at Green Harbor Point. Inspection of Figure 2 reveals a series of rocky headlands and bedrock outcrops along the northern shoreline in the immediate vicinity of Green Harbor Point. To the southwest are Green Harbor Beach and Duxbury Beach located immediately adjacent to the harbor-jetty complex. These beaches are characterized by large deposits of well-sorted fine sand. While this shoreline reach has beaches and flanking dunes which vary widely in width and position relative to the shoreline, exposed bedrock outcrops are largely absent.

19. The inner shore region surrounding Green Harbor also reflects the contrasting morphology prevalent along this section of open coast. The marshlands flanking Green Harbor are segregated into saltwater and freshwater marsh communities by a dike which was constructed in 1872 across the Green Harbor River (Figure 2). The marshlands on the seaward side of the dike are populated with normal salt marsh vegetative communities. Immediately upstream of the dike are freshwater marsh communities. The elevation of the marshlands behind the dike has been lowered because of a consolidation of the peat and silt caused by lowering of the water table behind the dike. Green Harbor and Duxbury salt marshes are connected by the Cut River (Figure 2) which provides limited communication between the back-bay region but only during periods of super elevation of the free surface (storm tides).

Geologic History

20. Cape Cod and its immediate shoreline are recent landforms which were formed in the late Pleistocene epoch during the final stages of the Wisconsinan stage, approximately 15,000 years ago (Strahler 1966). Most of the sediments in the area represent outwash materials from the Cape Cod Bay glacial lobe. These materials formed part of the Mashpee Pitted Plain outwash deposits. It is uncertain how far south and east this plain extended. Evidence indicates that during the periods of maximum glaciation so much of the earth's water was contained within the glaciers that the local shoreline was on the order of 100 miles seaward of its present position (Strahler 1966). With a warming climate and melting of the ice cap, sea level rose gradually until it approached its present elevation approximately 5,000 years ago. As the kettle holes and furrows left in front of the receding glacier were

flooded, loose, unconsolidated sediment of the outwash plain was reworked by the encroaching waves and currents (Figure 3), forming bay-mouth bars which were built into barriers such as Duxbury Beach (Strahler 1966).

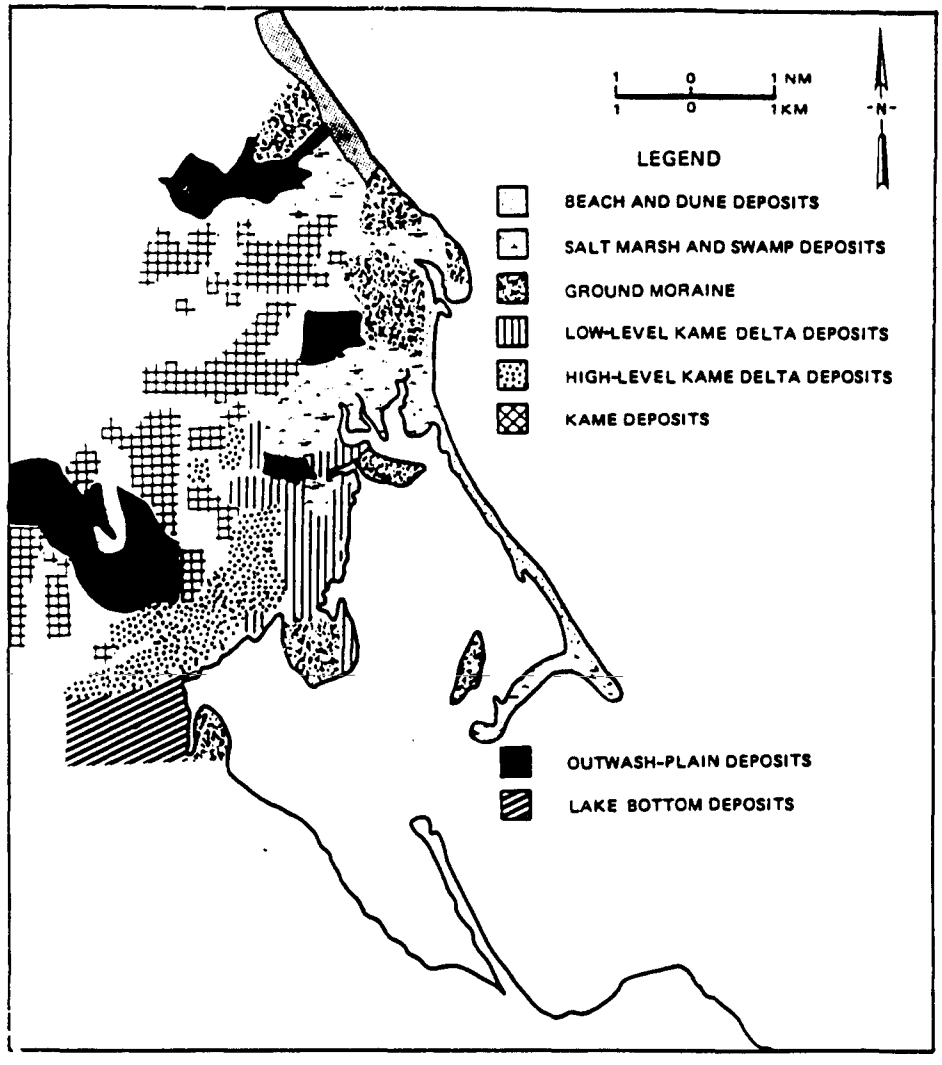


Figure 3. Depositional environment for the Duxbury-Plymouth-Green Harbor area (after Chute 1965)

21. Green Harbor and Duxbury Beaches are composed of Pleistocene and Holocene deposits. The geologic map of this region (Figure 3) indicates that the greater part of the beach is composed of Holocene beach, dune, swamp, and marsh deposits which connect several Pleistocene deposits described as ground moraine and kame deposits (Chute 1965). Although no exposures of bedrock appear on Green Harbor and Duxbury Beaches, outcrops occur to the north at Green Harbor Point (Downes 1981) (Figures 1 and 2) and offshore (High Pine Ledge). The bedrock outcrops located in the vicinity of the beach are in most places

only thinly veneered with glacial and/or marine sediments.*

22. The Wisconsinan Glaciation, which was responsible for many of the topographic features around the Duxbury area, attained its maximum advance approximately 15,000 years before present (BP). A major recession of the ice sheet occurred between 15,000 to 14,000 years BP. The average direction of ice movement through the Boston area is considered to have been toward the south and southeast. It is thought that localized ice flow directions may have varied as much as 135 deg. The maximum variance in flow direction would be expected to occur near the periphery of the ice lobes because of a general spreading from the center of the flow. Long axis orientation of features such as ground moraine deposits at Brant Rock suggests that the dominant flow direction, in the vicinity of Green Harbor, was toward the southwest (Downes 1981). The Green Harbor and Duxbury back-bay regions are thought to be a result of ice stagnation and wastage rather than remnants resulting from glacial advance or steady recession of the ice front through that area (Flint 1971).

23. Glacial outwash material was deposited along the ancient shoreline as the glacier retreated. As sea level rose, waves had the opportunity to rework these glacial outwash deposits. In many areas of Massachusetts and Cape Cod Bay, the presence of linear sand and gravel deposits parallel to the bottom contours suggests the existence of stranded beach and dune deposits (Figures 4 and 5).

Shoaling History

24. Green Harbor has a long and varied history of natural and man-made modifications to the inlet back-bay systems. Most of the changes introduced by man have been an attempt to improve the inlet back-bay system and/or reduce shoaling at the inlet entrance. Improvements often take the form of channel deepening or inlet stabilization. The following history has been compiled from personal interviews and reports such as Tippetts et al. (1980), Downes (1981), and various unpublished documents compiled by NED.

25. Early accounts of Green Harbor are recorded mainly in accounts and/or ship logs centering on Plymouth Harbor, located to the south. One of

* R. Oldale and C. O'Hara, 1974 (unpublished), "Preliminary Report on the Geology and Sand and Gravel Resources of Cape Cod Bay, Massachusetts," Open File Report, US Geological Survey, Reston, VA.

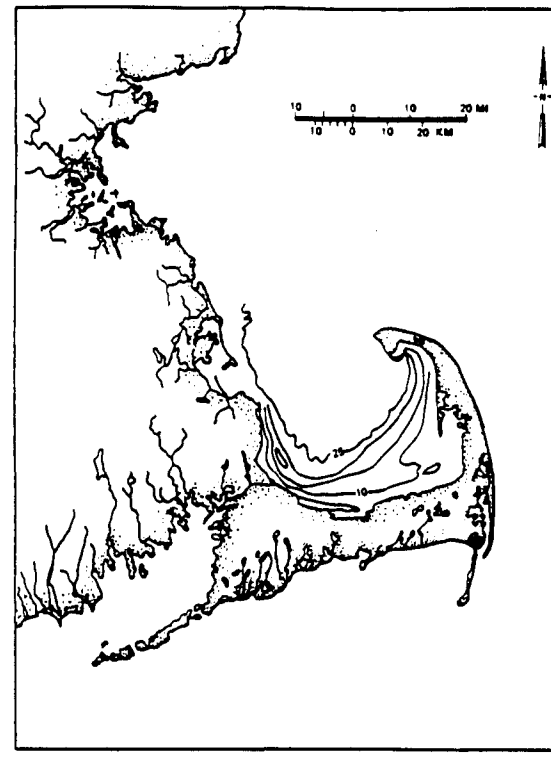


Figure 4. Offshore bathymetry contours (in meters) (after Schlee, Folger, and O'Hara 1973)

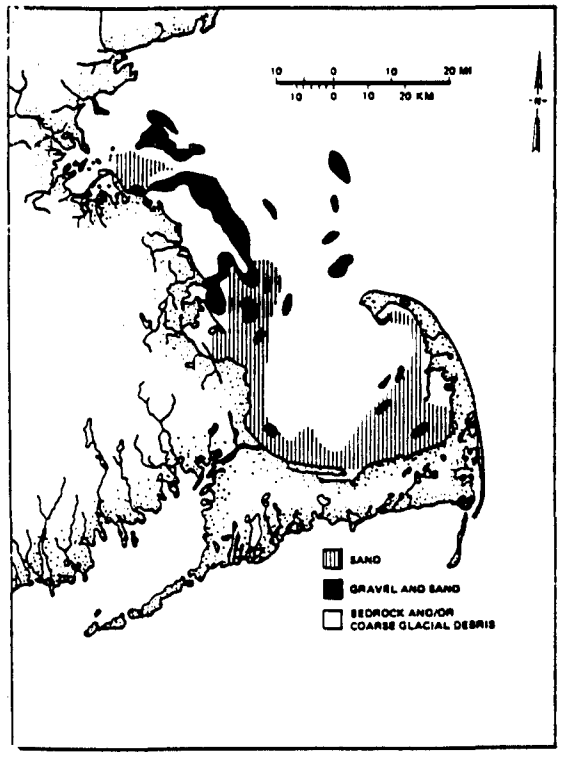


Figure 5. Offshore sand and gravel deposits in Massachusetts Bay (after Schlee, Folger, and O'Hara 1973)

the first recorded maps showing Green Harbor was completed in the accounts of the explorer Champlain in 1605 (Downes 1981). These accounts and his sketches were completed after Captain De Monte ran his ship aground in Plymouth Harbor on Browns Bank. Maps containing greater detail were completed in the ensuing years. Maps such as the one completed by Captain John Smith in 1614 were more complete and showed greater detail. From 1633 to 1872, the harbor entrance was unstable and shifted up and down the coast. The harbor entrance channel was shallow and had a meandering form. One of the early coastal surveys completed in Massachusetts was conducted by Joseph Des Barres in 1769 (Downes 1981). In his log he recounts the condition of the ebb shoal at the mouth of Green Harbor and describes the ebb bar at the mouth of Green Harbor River as being exposed and dry at midtide.

26. There is little documentation of how often or to what extent the mouth of Green Harbor has migrated. A map depicting the 1794 and 1897 shorelines (Report of the Joint Board 1898) shows that the mouth of Green Harbor River has migrated to the south in recent (geologic) times (Figure 6). Migration of the inlet to the north is limited by the bedrock outcrops at Blackman's and Green Harbor Points. Modification of the inlet back-bay system began in 1633 with the construction of a channel, now known as the Cut River, linking Green Harbor River to Duxbury Bay. In 1806, the inlet was sealed by a storm, and in 1807 a petition was granted by the State House of Representatives to construct a canal in the previous location of the inlet to drain stagnant water from the marsh. The draining operation was marginally successful and in 1811 another storm breached the beach that had formed since 1806. The beach was prone to overtopping after the breach occurred; and several petitions were presented requesting permission to construct hedge fences, seawalls, and palisades to prevent beach erosion and damage to the salt hay meadows behind the beach.

27. In 1871, construction of a dike across the Green Harbor River was authorized to allow reclamation of upstream salt marshes for farming. The dike was constructed in 1872 in the location of present-day Highway 139 (Dike Road). After construction of the dike, the entrance to Green Harbor, never very deep or wide, became shallower and more sinuous, hindering navigation. The area behind the dike was rapidly converted to productive agricultural land; it also settled about 3.5 ft because it was no longer subject to the tides.

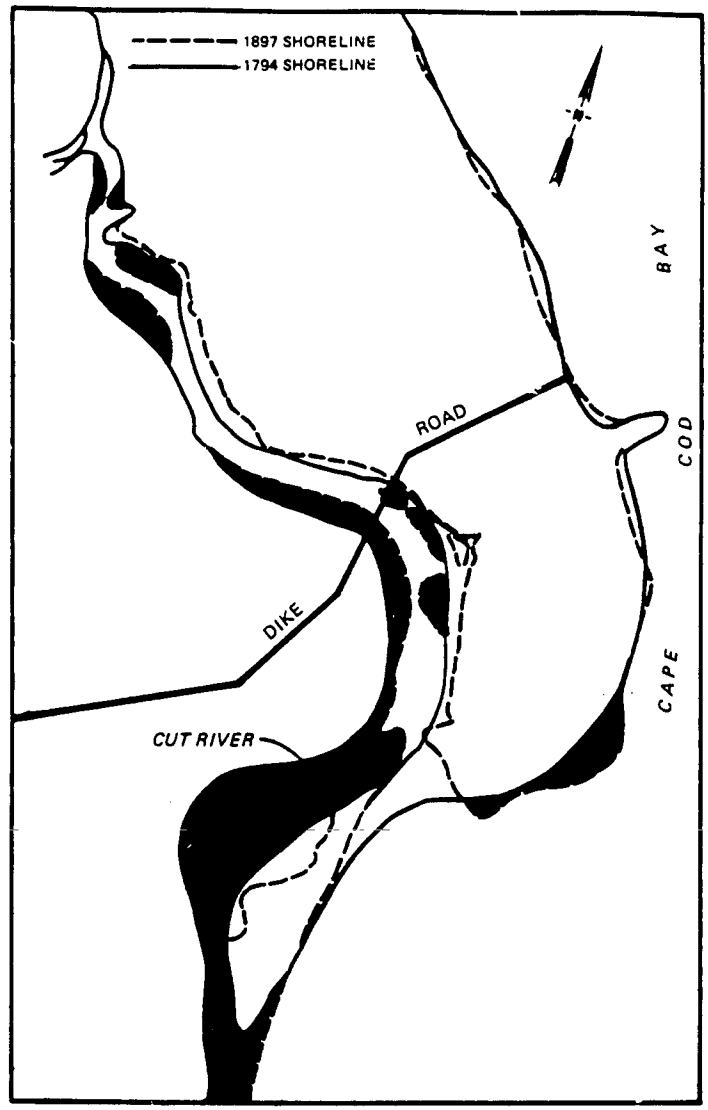


Figure 6. Green Harbor inlet and shoreline migration between 1794 and 1897

28. In 1897 the conflict between agricultural and navigational interests led to the establishment of the Joint Board of Harbor and Land Commissioners who were charged with evaluating the condition of the harbor and deciding what action, if any, should be taken with respect to removal of the dike. The Board of Commissioners declared that even though construction of the dike had worsened navigation conditions in Green Harbor, the value of the agricultural land gained by dike construction outweighed the navigation loss. The Board recommended that the dike remain, that the State construct two jetties to increase the effect of tidal flow through the channel, and that the channel be dredged periodically.

29. Stone jetties were constructed by the State in 1899 extending seaward from shore to the 6-ft contour at mlw. At about this same time, the timber pile structure at the mouth of the Cut River was also constructed. A year after construction of the jetties, a survey of the entrance channel indicated that the depth in the entrance channel had deepened from 1.5 ft above mlw to 0.2 ft below mlw. A channel 60 ft wide and 5 ft deep at mlw was dredged later that year. The channel shoaled following dredging, and within 2 years the controlling depth was 1 ft below mlw. Dredging and jetty repair were undertaken periodically by the State through 1964.

30. In 1968 the US Army Corps of Engineers constructed the present project at Green Harbor. Construction included modification of the structures originally built by the State. The east jetty was raised to an elevation of 14 ft above mlw. The west jetty was rebuilt with a sand-tight core, and a 200-ft-long extension was added to the seaward end of the structure. The entrance channel was dredged, as were anchorages and a turning basin upstream of The Narrows. Initial dredging removed 140,000 cu yd from the entrance channel and anchorages. In 1969, 35,894 cu yd were removed from the channel and anchorages. In the fall of 1970 the east jetty was repaired, and revetment was added to the inner beach area to reduce erosion occurring in that area since the construction of the west jetty extension. Channel shoaling continued, and the channel was dredged in 1973, 1977, 1980, 1982, 1984, and 1985. Dredging was not always performed when needed because of budgetary considerations; generally, the entrance channel needed dredging after each winter season. These events are depicted in Figures 7 and 8.

31. Man-made modifications to the Green Harbor system have a long history. Major events are listed in Table A1 (Appendix A). As can be seen from this table, alteration of the harbor system has occurred more or less continuously from the mid-1800's to the present. Modifications of the harbor system have increased in frequency as the harbor has experienced increased growth and usage.

Longshore Sediment Transport

32. Several longshore transport studies have been conducted in the Green Harbor region to quantify the volume and direction of sediment transport. Because of a lack of directional wave data, these studies have used

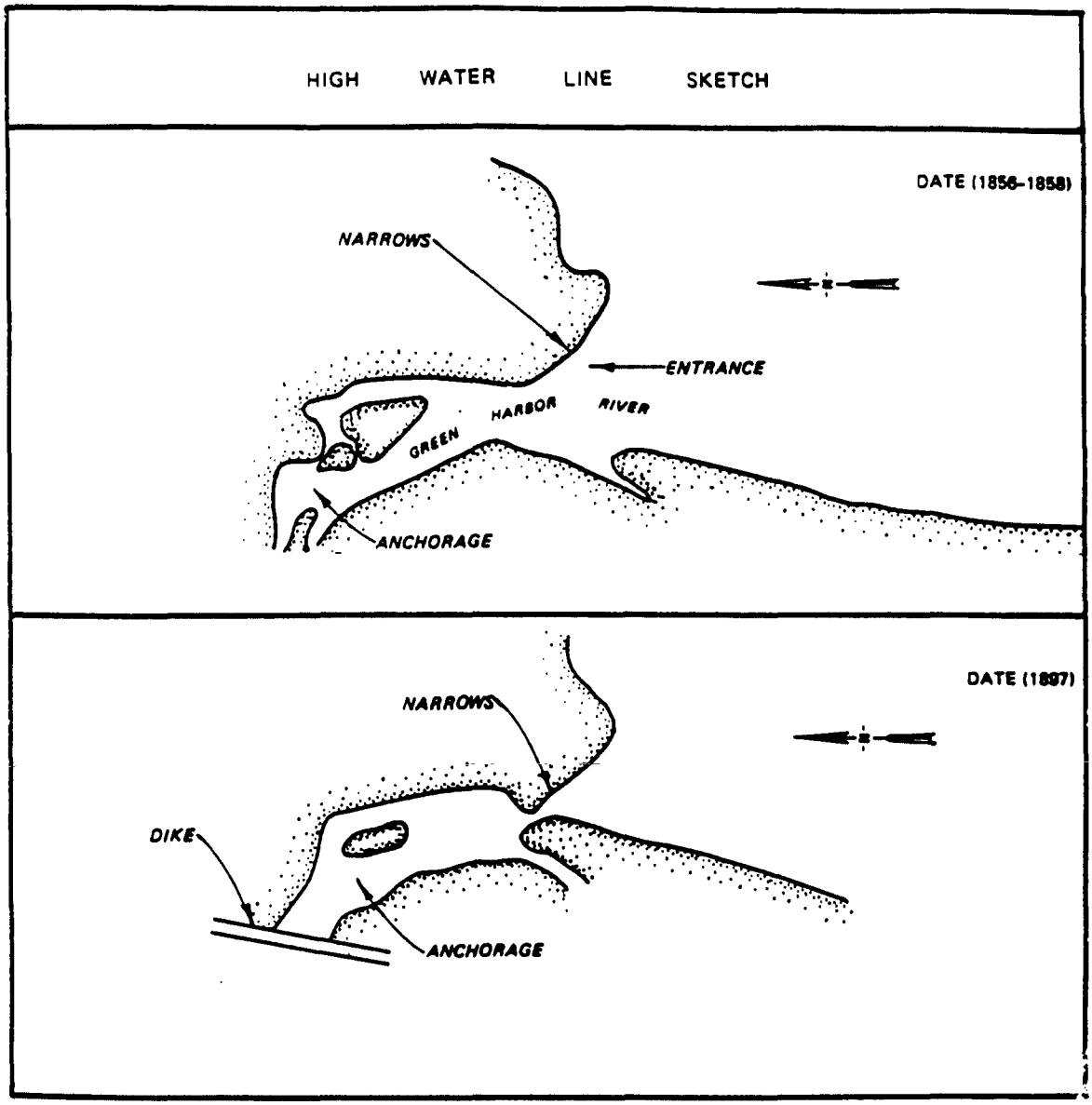


Figure 7. Narrowing of Green Harbor after construction of the dike (after Tippetts et al. 1980)

hindcasted wave statistics to characterize the incident wave field. While these studies provide useful insight to the question of sediment transport, hindcast wave characterizations are extremely difficult to obtain in this region because of the fetch-limited conditions of Cape Cod Bay (Figure 9) which provide a sheltering influence from waves generated in the North Atlantic. From 75 to 150 deg, Cape Cod effectively blocks waves generated in the North Atlantic from propagating into Cape Cod Bay. Incident waves generated within Cape Cod Bay originating from the above referenced directions will be fetch-limited. Green Harbor is exposed to waves generated in the open ocean

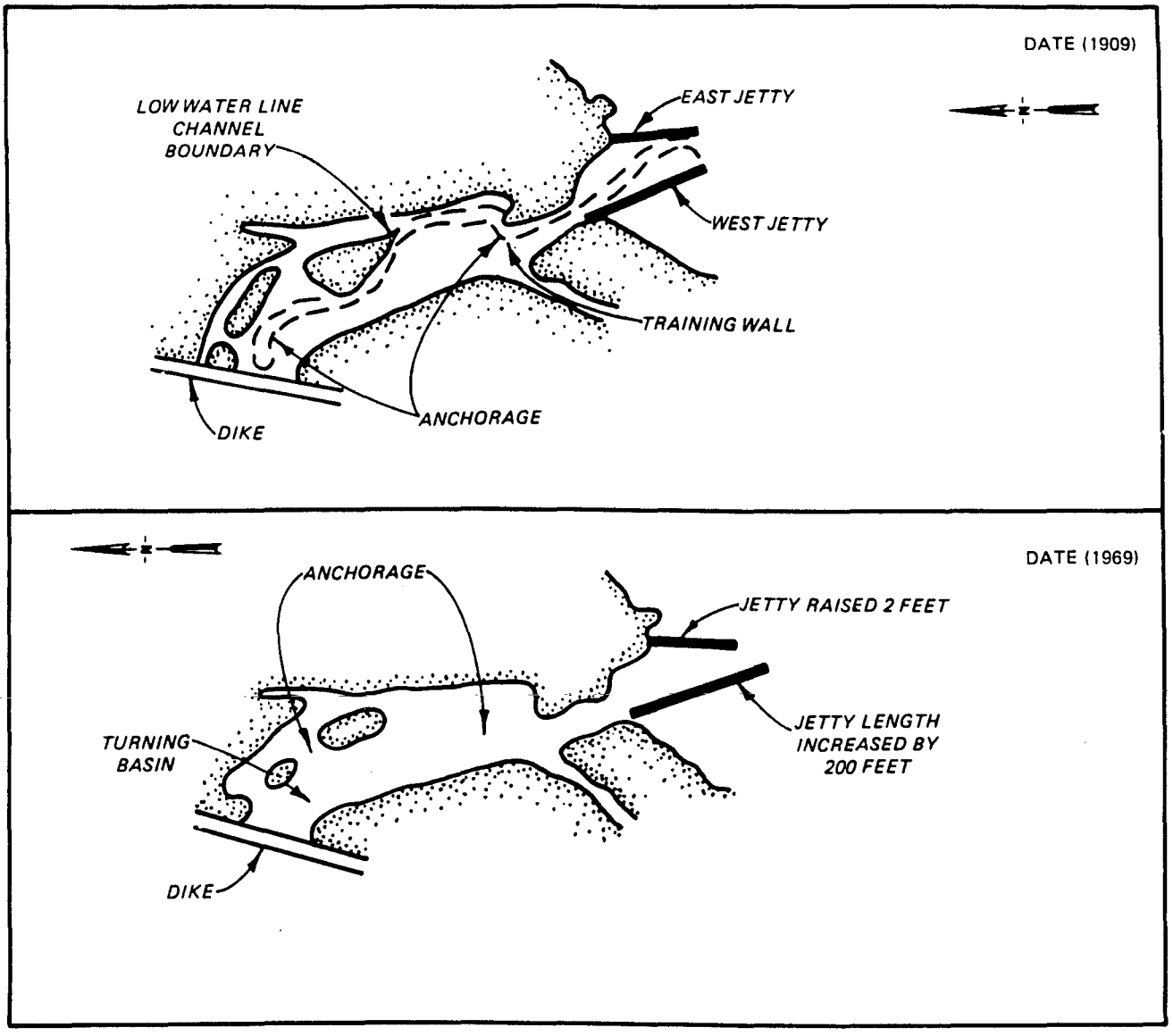


Figure 8. Construction of jetties and training wall at Green Harbor (after Tippetts et al. 1980)

originating only from 10 to 75 deg. The extensive shoals (Stellwagen Bank) existing off the tip of Cape Cod, combined with the extreme irregular topography which exists within Massachusetts Bay, make wave hindcasts extremely unreliable.

33. Littoral drift for the Green Harbor to Duxbury Beach regions has been characterized in a beach erosion report (NED 1957) covering the shoreline located between Pemberton Point and Cape Cod Canal. This report concludes that the littoral drift is in a southerly direction. As a result of this southerly littoral drift, a continuous series of barrier bars has been formed.

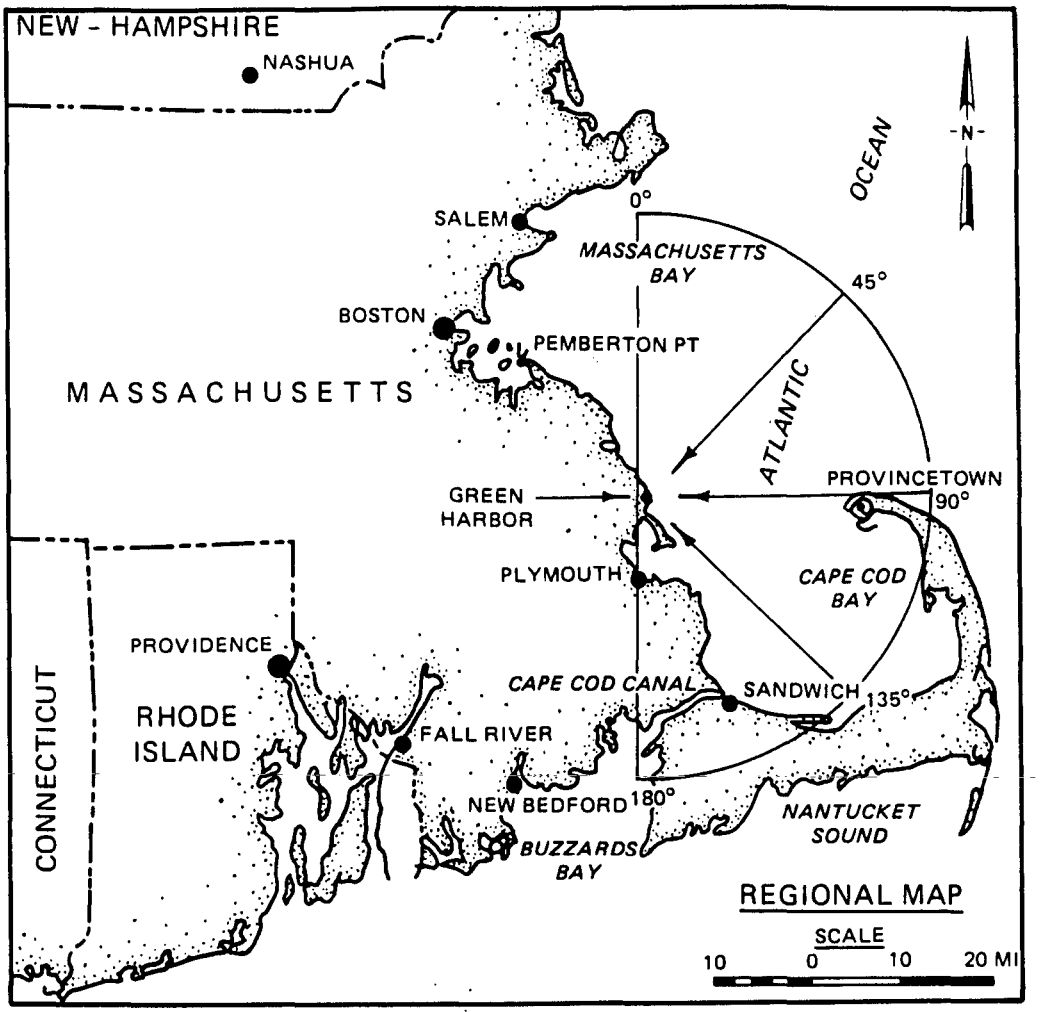


Figure 9. Dominant fetch angles for the entrance to Green Harbor

These barrier bars are reported to extend as far south as Brant Rock. At Brant Rock littoral materials are reported to "take to sea" (move offshore) and continue south until they are returned to shore (presumably as a function of waves and tides) as part of the Duxbury Beach tombolos. The reference to the barrier bars is unclear as to the position of the bar on the profile. It therefore is assumed that the bar is in the littoral zone and refers to a nearshore subaqueous bar. Brenninkmeyer, Huidoboro, and Wood (1979) evaluated the effectiveness of the groins located at Brant Rock. After examining beach profiles obtained in 1932 and 1979, they found that while the groins were trapping sand on the updrift (northerly) side the overall beach was deflating, a finding which suggests limited sediment supply to the region.

34. The above descriptions of this region reflect shoreline development

and removal of sediment sources. The occurrence of eroding beaches in conjunction with groins which are trapping minimal quantities of sand is common in sediment-starved regions. In addition, the predominant sediment sources in the region north of Brant Rock have been almost completely eliminated as a result of the construction of a series of seawalls, rubble riprap, and other shore protection measures. This occurrence is supported by the existence of cobble/gravel beaches immediately north of Brant Rock and thin sand veneer beaches immediately adjacent to these shore protection structures. At present, the region provides little, if any, material to the littoral system, even though it may have in the past (Figure 6). An extensive seawall and large outcrops of bedrock located north of Brant Rock at the shoreline effectively armor the foreshore.

35. The net southerly littoral drift is briefly interrupted in the immediate vicinity southwest of Green Harbor. This region has continually experienced growth in the width of the beach and accretion of the nearshore area as a result of a local net littoral drift reversal. The cause of this net reversal is not discussed in the literature but is merely speculated as causing the growth of the beach region immediately to the southwest of the southwest harbor jetty. The approximate location of this region is shown in Figure 2.

Winds

36. Dominant fetch angles for the study region are shown in Figure 9. The winds in the Cape Cod Bay and Boston vicinity are most easily obtained from Nantucket Island Airport or Boston's Logan Airport. A comparison of wind roses for the two regions over similar time frames shows that the strongest winds are primarily from east-northeast and west-northwest quadrants (Figures 10 and 11). An analysis of a 10-year wind record (1960-1969) which was obtained from the Nantucket Island Airport and analyzed by CERC shows a prevailing wind from the southwest (Figure 12). The most frequent (prevailing) wind is generally of low velocity; hence, it does not influence the graphs of dominant (strongest) winds. Figure 12 appears to underestimate strength of northeasters for some unknown reason.

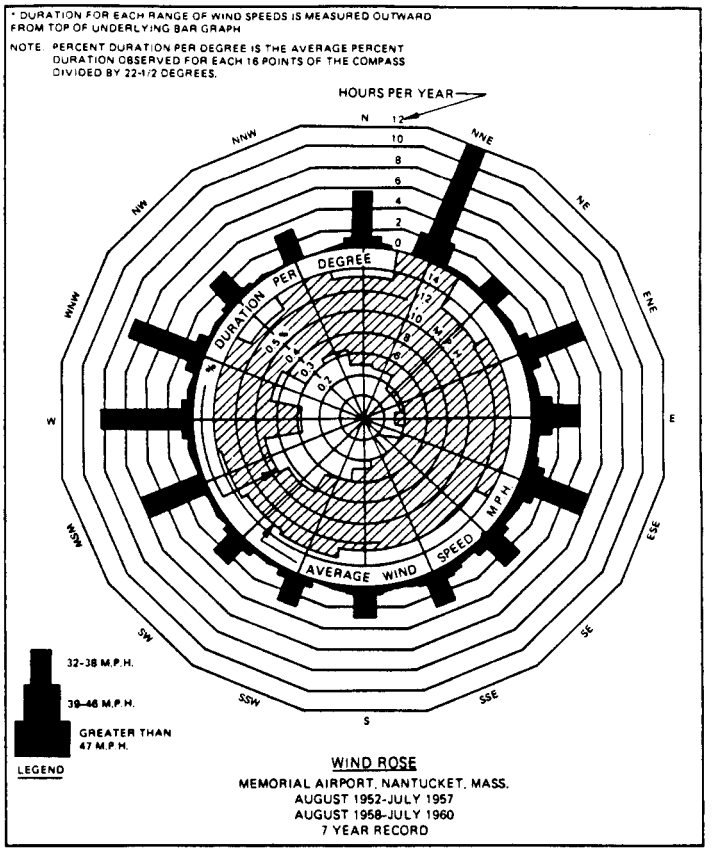


Figure 10. Wind rose obtained from Memorial Airport, Nantucket Island, MA, from August 1952 to July 1960

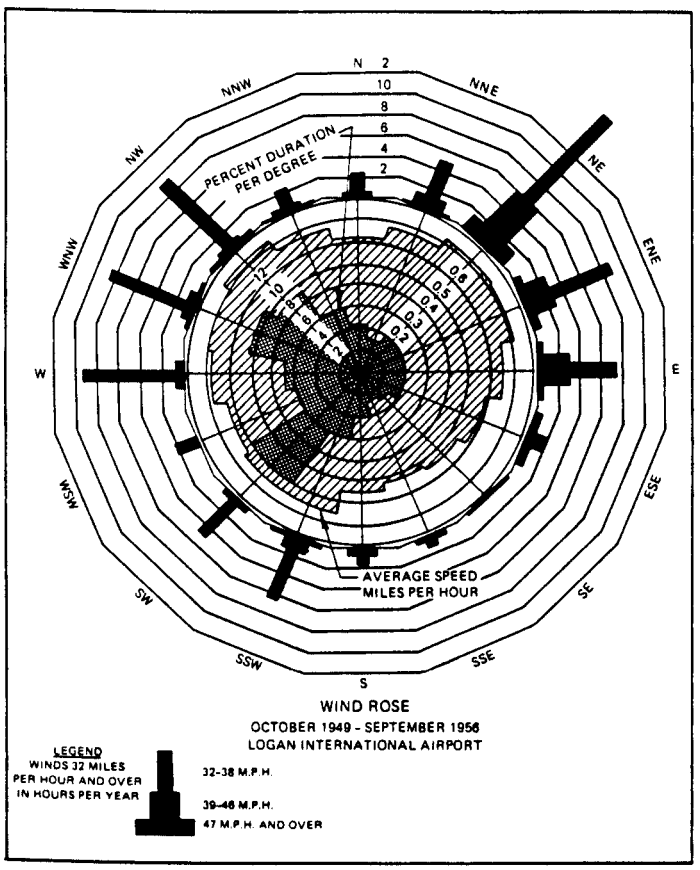


Figure 11. Wind rose obtained from Boston's Logan International Airport, October 1949 to September 1956

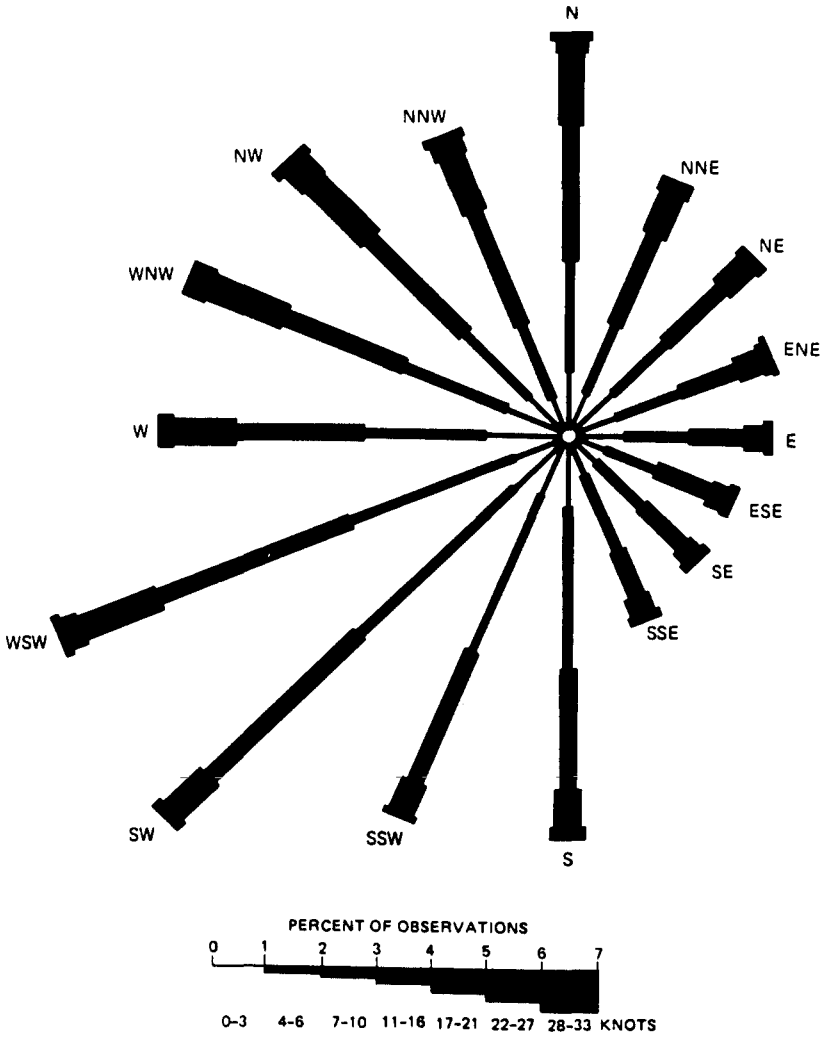


Figure 12. Wind rose obtained from Memorial Airport, Nantucket Island, MA, 1960 to 1969

Waves

37. The shoreline at Green Harbor is protected by Cape Cod from ocean swells generated from most all directions. As a result, it was assumed prior to this study that most waves were fetch-limited, locally generated by winds blowing across Cape Cod Bay. Direct measurements of wave height, period, and direction are not available in the literature. Previous works erroneously have used wave hindcasts produced for Nauset Beach (US Army Beach Erosion Board 1954). However, Nauset Beach is located on the Atlantic (east) side of Cape Cod, unprotected from deep ocean swells generated in the Atlantic. These open coast wave data clearly are inappropriate for Green Harbor. (See Aubrey, Twichell, and Pfirman (1982) for a discussion of the Nauset Beach wave data.)

PART IV: FIELD STUDIES

38. The study at Green Harbor began as a straightforward tidal inlet analysis designed to provide NED estimates of shoaling rates, potential sediment sources, and mitigating engineering solutions. Engineering solutions to these types of problems are not intended to eliminate shoaling problems because they seldom can occur in nature. However, they are intended to improve the situation by reducing dredge return frequency and structure maintenance, thereby reducing operation and maintenance costs. As the study progressed, it quickly became evident that the Green Harbor region is not a simple inlet environment. The inlet is situated on a geomorphologic demarcation separating a region of rocky outcrops (to the northeast) and sandy barrier beaches (to the southwest). Initial sediment transport calculations produced results which could not be supported by field and historical observations. The reason for this inaccuracy is that this is a region in which geomorphologic parameters control dynamic responses such as sediment transport.

39. For these reasons, the initial data set collected proved to be an inadequate data base from which sound engineering solutions to the Green Harbor shoaling problem could be generated. Additional data were required on the incident directional wave climatology and on the sedimentary environments of the nearshore and near-inlet regions. These data were most easily obtained by using local expertise and equipment such as boats, side-scan sonars, and subbottom profilers. For this reason, a joint project between the US Army Corps of Engineers (CERC and NED) and WHOI was initiated. The joint field effort used local expertise and locally based equipment which provided high quality data at a reasonable cost.

Current Measurements

40. Currents near the entrance to Green Harbor jetties were measured by CERC using an Endeco 105, self-recording current meter (Appendix B, Table B1). This current sensor was installed approximately 100 yd southeast of the harbor entrance, 100 ft southwest of the navigation buoy marking the entrance to Green Harbor in approximately 10 ft mlw of water. The current meter tether was attached 3 ft above the ocean bottom. The Endeco 105 mooring system (Figure 13) is designed to allow the current sensor to move freely, independent of

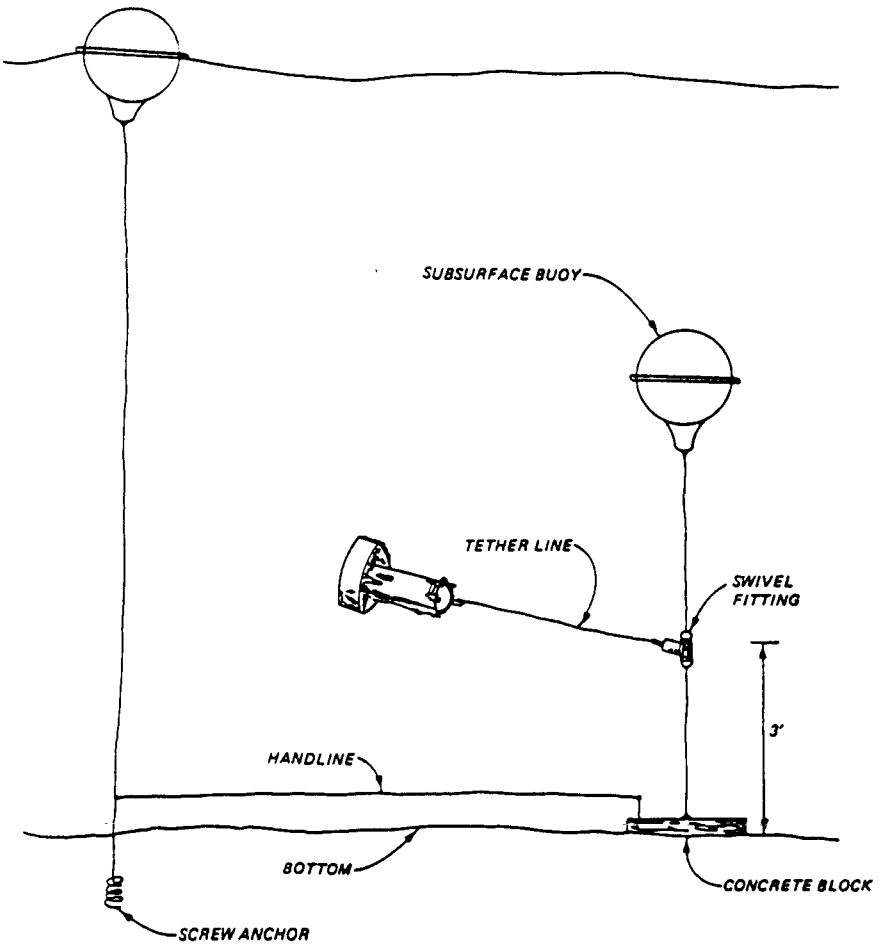


Figure 13. Mooring system used for Endeco 105 current meter

any oscillatory wave motion, so that only current net speed and direction at 30-min intervals are recorded. Although the Endeco 105 current meter is not designed for wave-dominated environments, it yields adequate results in areas with small waves. Current velocity and direction were obtained from 21 September 1981 through 24 September 1981. Velocity data, tabulated in Appendix B are presented as polar vector diagrams in Figures 14 through 17. These data show a flood current directed toward the southwest and a strong ebb current directed toward the northeast. Peak velocities occur during ebb tide (0.76 fps maximum), while peak flood tide velocities are reduced in magnitude (0.28 fps).

41. These data suggest that the flows near the entrance to Green Harbor are directed to the northeast approximately 72 percent of the survey period. Depth-averaged and peak velocities in the dredged channel approaching the harbor channel entrance are relatively weak for both flood and ebb flow conditions. The low velocities measured suggest that the tidal currents within

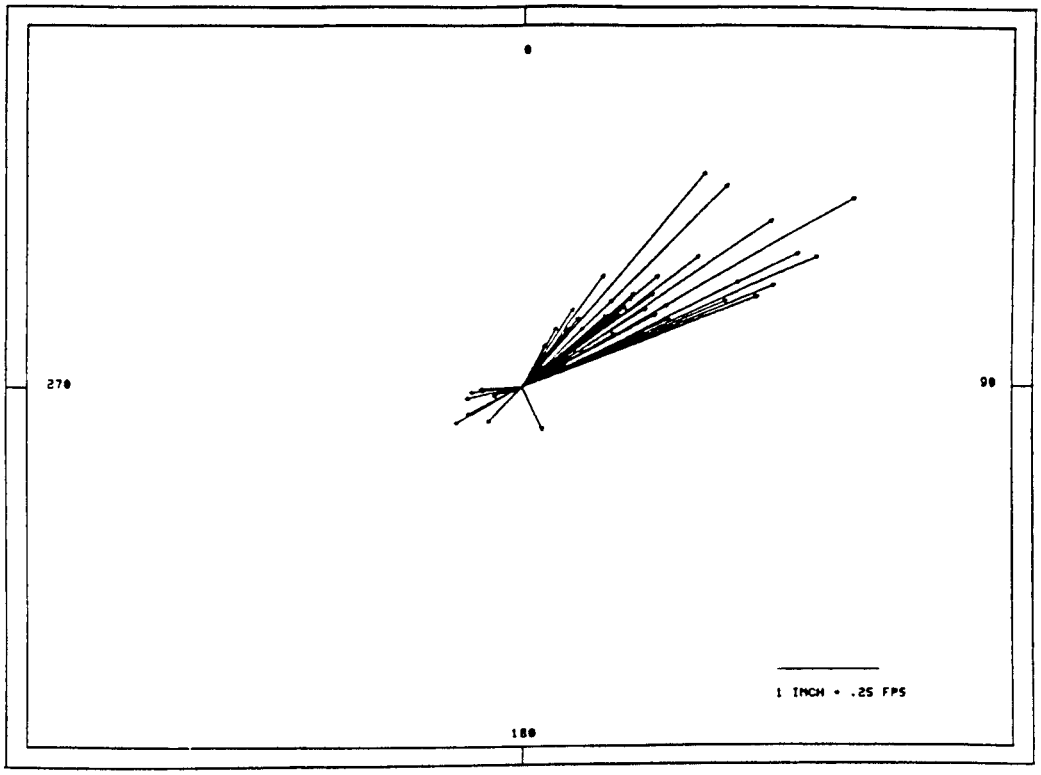


Figure 14. Velocities obtained at the entrance to Green Harbor 21-22 September 1981 from 1630 to 1600 hours

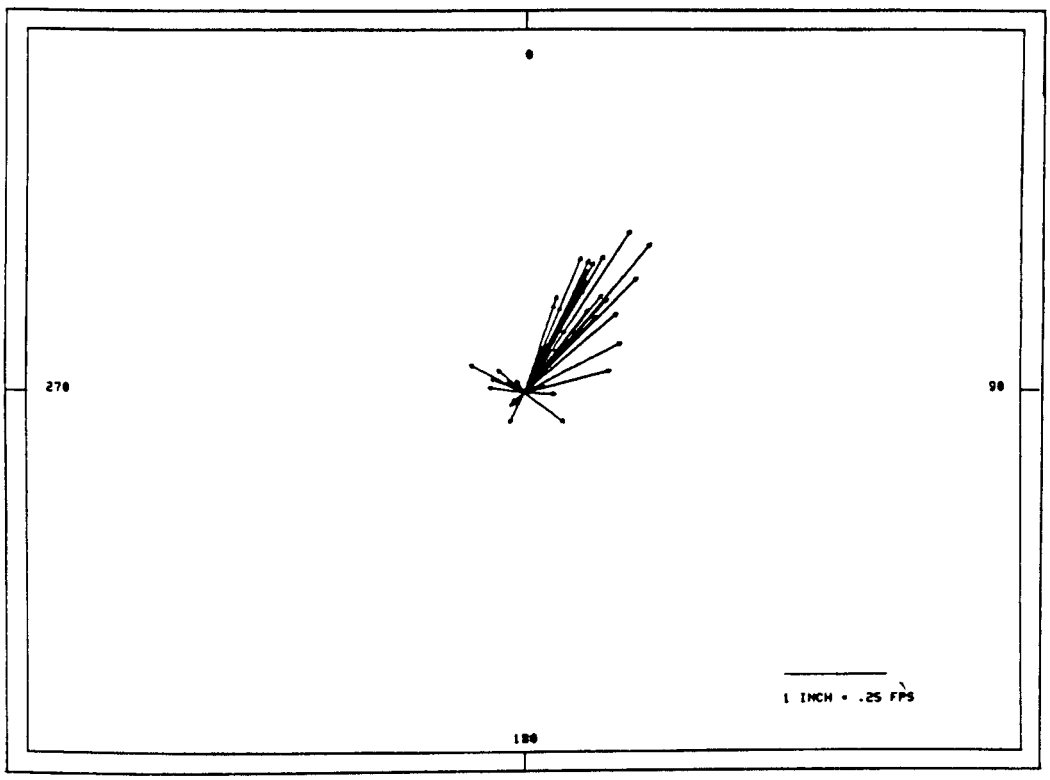


Figure 15. Velocities obtained at the entrance to Green Harbor 22-23 September 1981 from 1630 to 1600 hours

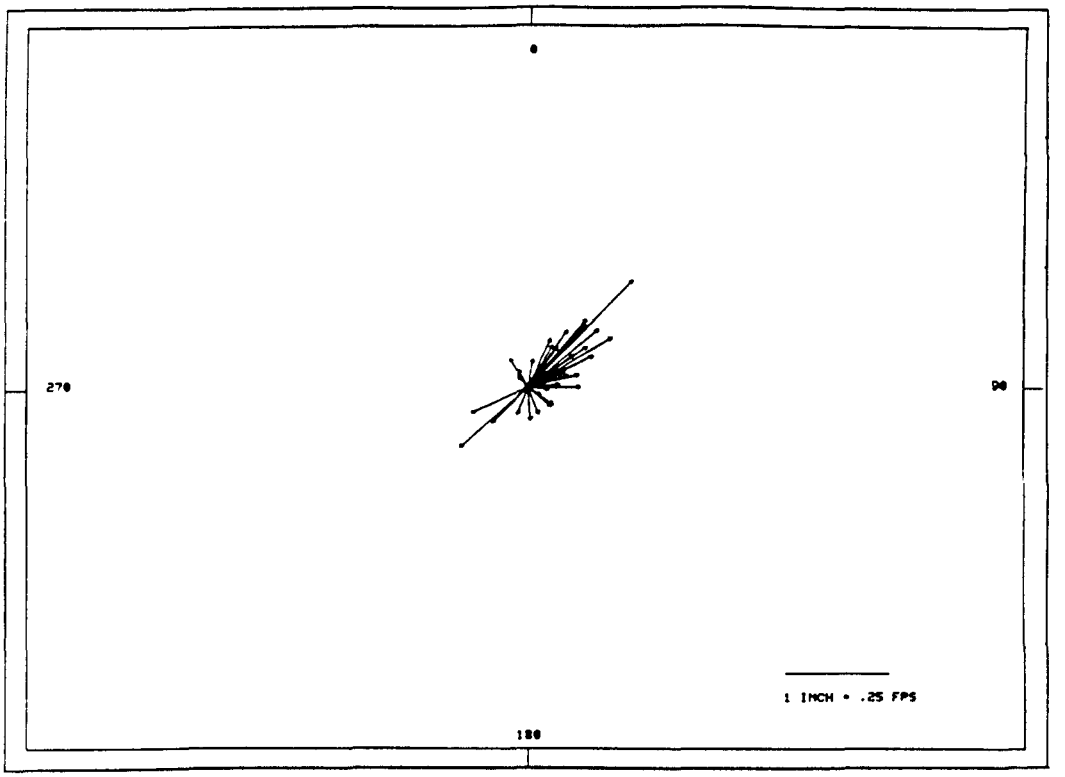


Figure 16. Velocities obtained at the entrance to Green Harbor 23-24 September 1981 from 1630 to 1600 hours

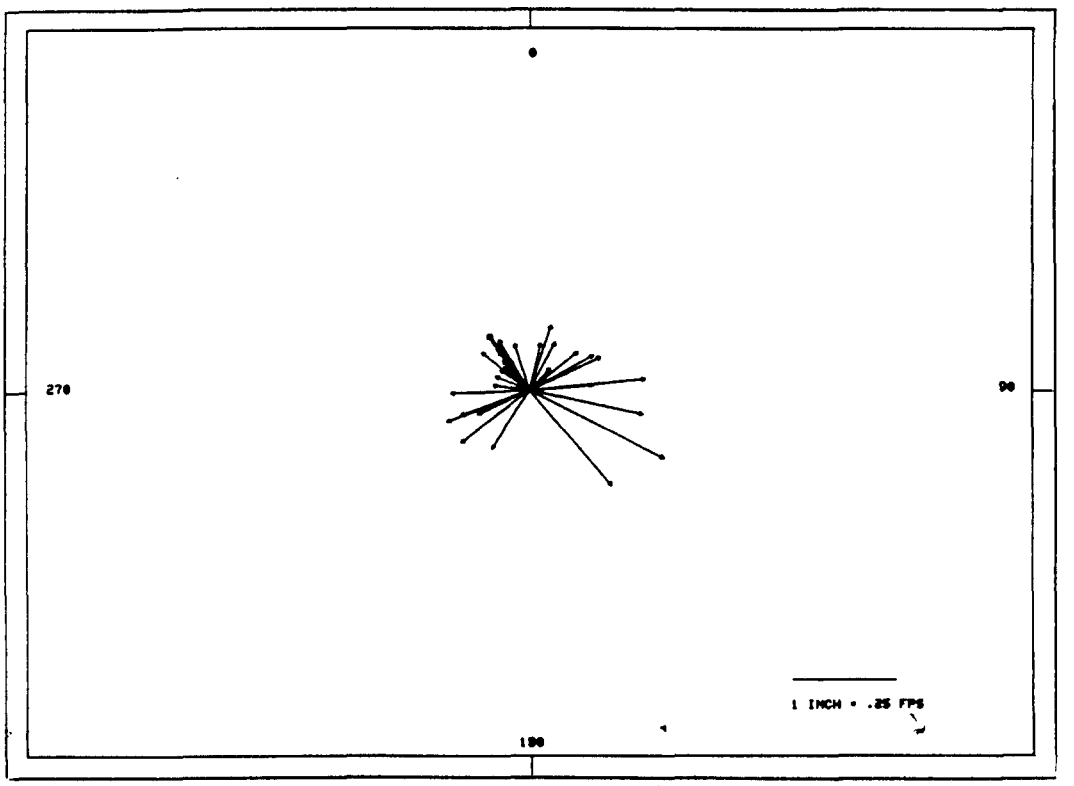


Figure 17. Velocities obtained at the entrance to Green Harbor 24-25 September 1981 from 1630 to 1600 hours

Massachusetts Bay do not play an important role in sediment transport in the nearshore entrance region of Green Harbor. The Endeco 105 meter was located within the path of the expected ebb-oriented "jet" flow in the channel and close to the inlet entrance. The expected direction of ebb flow jet emanating from the harbor would be oriented toward 210 deg true north (TN); however, no such flow was recorded during the measuring period. The data record is of insufficient length to quantitatively determine an explanation. However, it was noted that the northward deflection of the ebb flow correlated with a mild southeast wind of 10-15 mph which began on 22 September and persisted through 23 September 1981.

42. These results suggest that the Endeco 105 meter was seaward of the inlet jet. These observations are consistent with normal shore-parallel tidal flows in the absence of an inlet.

43. Beginning at 1030 hours EST on 23 September 1981 and continuing through 1100 hours EST on 24 September 1981, current velocity profiles were measured at hourly intervals across the inlet throat (The Narrows). Current speed was measured using a Price 667 current meter suspended from the bow of a survey boat (Figure 18). Speeds were measured at three depths at each of

Figure 18. Survey equipment used to obtain velocities in the inlet throat

three stations across the inlet throat. Direction was noted as either "ebb" or "flood." Positioning was accomplished using a premarked cable stretched across the inlet throat.

44. The cable was weighted and dropped to the bottom between measurement sets to allow passage of boat traffic. The measurement technique restricted the inlet for approximately one-half hour each hour. Pretest publicity and concurrent Coast Guard broadcasts over marine radio minimized traffic conflicts. In addition, the survey boat and cable were marked with flashing lights during hours of darkness. The three survey positions relative to the depth profile are shown in Figure 19.

45. Measurement procedures were as follows: At each hour, the cable was pulled taut using an electric power winch. The survey boat would approach the cable from the downcurrent side (unless conditions were such that it was necessary to approach from the downwind side to maintain position). The bow line was secured to a block on the cable; a separate block was securely positioned at each of the three station locations to minimize boat hook-up time. The current meter was then lowered to the bottom using a bow-mounted davit equipped with a winch. Total depth was recorded from the premarked current meter wire. A depth reading was also recorded from the boat-mounted fathometer. The current meter was then positioned at depths equal to 0.2, 0.6, and 0.8 times the total water depth. The actual measurement consisted of reading the number of rotations made by the current meter rotor during a 1-min interval at each depth. This number was later converted to a speed value, in feet per second, using a calibration curve derived for the instrument in the laboratory. This procedure was repeated at each of the three stations each hour.

46. Results of the inlet velocity measurements are plotted in Figure 20 and listed in Table 3. Individual measurements of current speed and direction are shown in Table B2. The maximum velocity measured at a point in the center of the channel on the ebb was 1.35 fps which occurred approximately 4 hr after observed high water. The maximum flood velocity was 1.35 fps which was observed to occur approximately 2 hr before high water was recorded at the town dock.

47. Slack water was observed to occur simultaneously with low water and approximately 45 to 60 min prior to high water. The recorded maximum ebb and flood velocities were equivalent for the period of record. Figure 20 shows

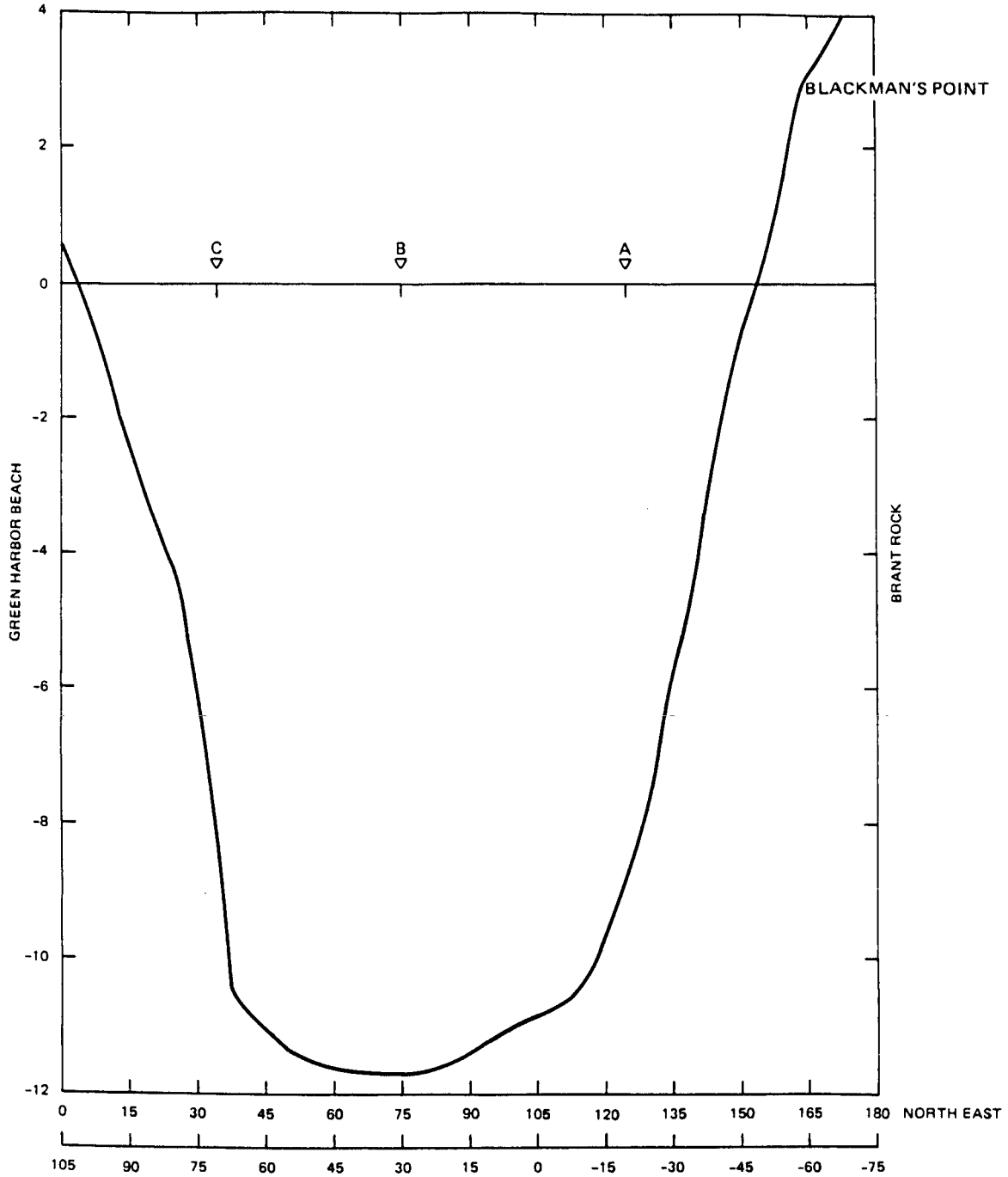


Figure 19. Inlet throat cross section (scale in feet)

the linear depth-averaged flood and ebb velocities recorded during the study. The maximum flood velocity increased from 23 September 1981 to 24 September 1981. There was only one complete ebb tidal cycle recorded, so it was not possible to determine if the maximum ebb velocity underwent a corresponding diurnal increase.

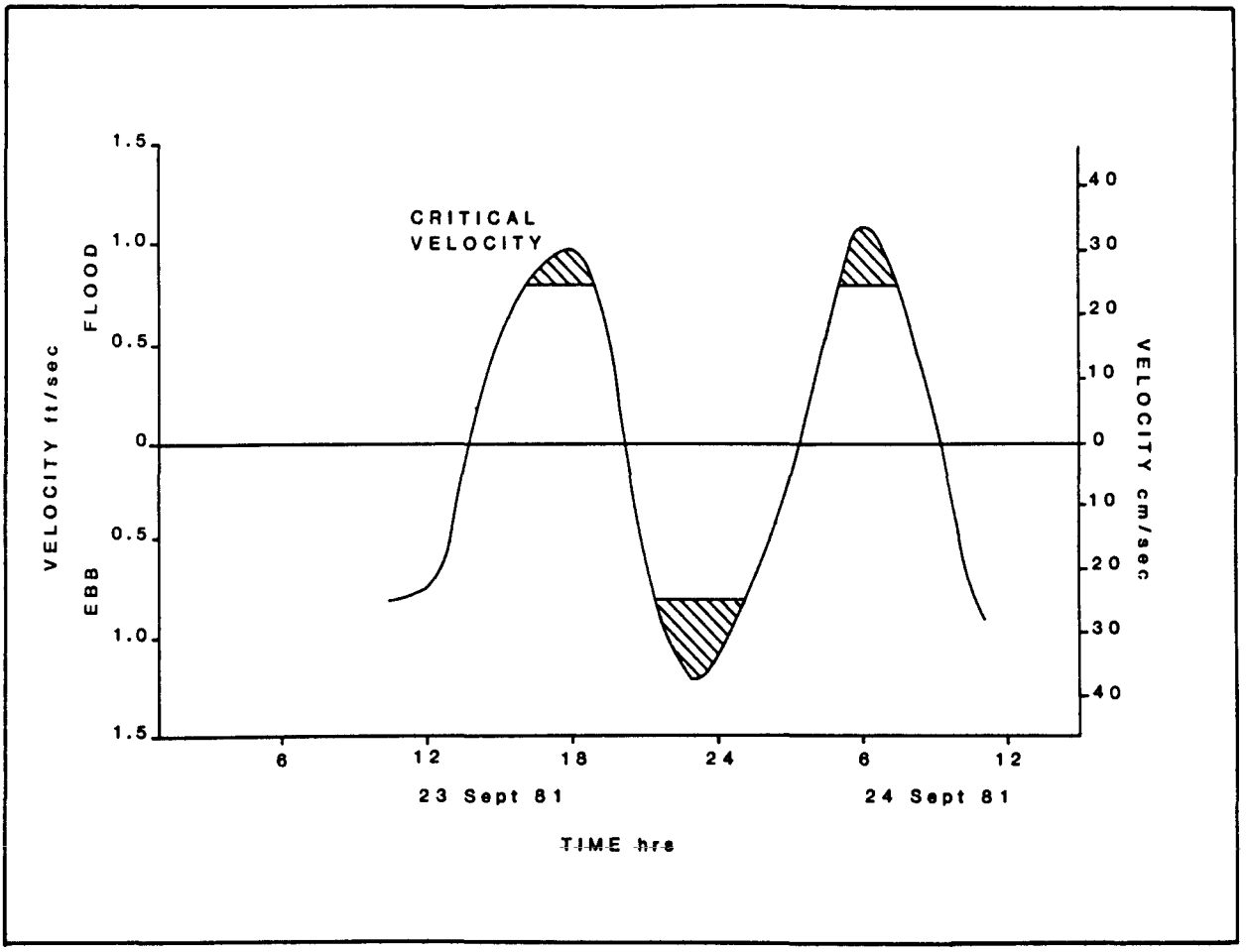


Figure 20. Tidal velocities obtained in the inlet throat

Wave Analysis

Littoral Environment
Observation (LEO) wave analysis

48. The shoreline in Green Harbor region is dominated at the northwest by rocky headlands. The northeast offshore region is characterized by rocky outcrops and irregular bathymetry. The offshore region to the southeast (offshore of Duxbury Beach) is characterized by a sandy bottom with more regular contours. A LEO site was established at Brant Rock because of the irregular shoreline and the highly diverse offshore region. Direct measurements of wave height, period, and direction were not available for Green Harbor prior to this study.

49. Observations were made at Brant Rock by volunteers from the local community from October 1981 through January 1983. A total of 1,400 near daily

Table 3

Green Harbor Current Data*

Date	Time, EDT	Speed, fps
23 Sep 81	1030	0.83 ebb
	1200	0.77 ebb
	1300	0.49 ebb
	1400	0.54 flood
	1500	0.34 flood
	1600	0.77 flood
	1700	0.95 flood
	1800	0.97 flood
	1900	0.79 flood
	2000	0.22 ebb
	2100	0.72 ebb
	2200	0.90 ebb
	2300	1.18 ebb
	2400	1.14 ebb
24 Sep 81	0100	0.62 ebb
	0200	0.41 ebb
	0300	0.23 ebb
	0400	0.43 flood
	0500	0.64 flood
	0600	1.11 flood
	0700	0.71 flood
	0800	0.43 flood
	0900	0.29 ebb
	1000	0.44 ebb
	1100	0.90 ebb

* Each value represents an average of 9 measurements over an approximate 15-min interval along a linear profile line across The Narrows at Green Harbor.

observations of wave breaker height, period, and direction was made as part of CERC's LEO Program. A summary of the wave height and period is presented in Figure 21. This figure shows that the monthly mean wave heights for the

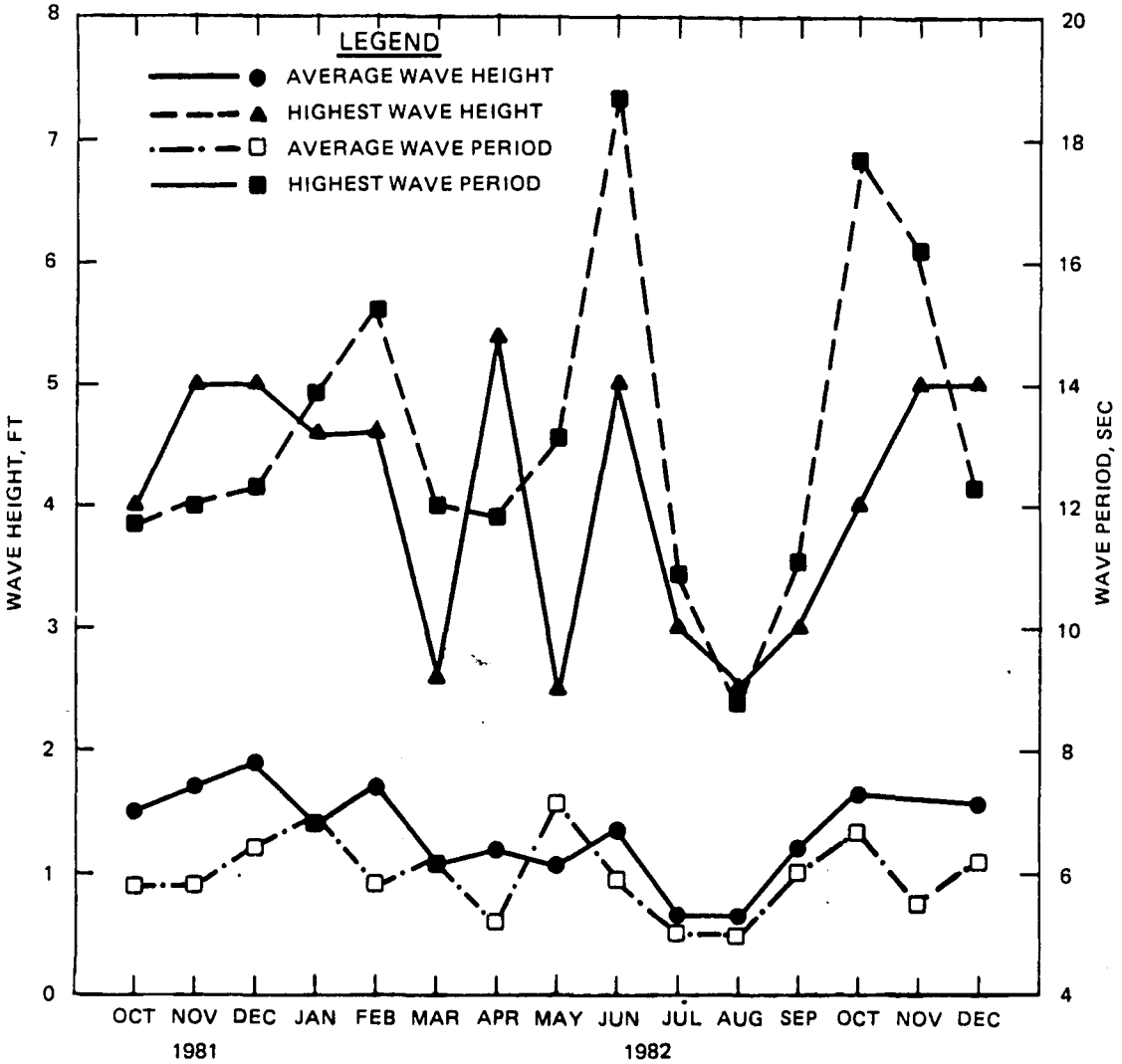


Figure 21. Average conditions during the LEO period

observational periods are highly variable. The highest mean wave height (1.9 ft) occurred during December 1981. The trend of the curve depicting the highest observed wave height and the average wave height follow quite closely except for that of March 1982. During this month, the mean wave height continually increased while the highest wave height observed decreased. This trend is not uncommon in regions in which the background incident wave energy (mean wave height) is not dominated by episodic events. There is not a good correlation between the average wave height and the average wave period.

However, it is not possible to derive this relationship between wave height and period directly from the LEO data because the wave height and wave period tabulations are made independently; that is, individual values of each parameter (e.g. wave height) are scanned for maximum values which occur over the monthly recording period independent of any other parameter (e.g. definition of wave period). These data do not provide a good quantification of the incident energy conditions that occur at Green Harbor.

Directional wave analysis

50. Directional wave measurements were acquired off Green Harbor for nearly a full year, from 15 June 1983 through 1 June 1984. Data collection was essentially continuous except for several missed sampling intervals because of sensor retrieval and deployment and the first two months of 1984 which were lost because of equipment failure. After these equipment problems were corrected, data acquisition was continuous through 1 June 1984. Wave measurements were acquired using Sea Data directional wave sensors. During the year's deployment, both Sea Data 635-9 and Sea Data 635-12 directional wave sensors were used. (The location of the directional wave gage is shown by the solid square in Figure 27.)

51. Wave climate summaries are provided in tabular form in Appendix C (Tables C1 to C4). A synopsis of the four deployment periods is provided below.

52. Deployment period one: 15 June to 14 August 1983. The Sea Data 635-12 was deployed with the pressure sensor 1.48 m above the bottom and the current meter 2.06 m above the bottom, above and slightly (<30 cm) to one side of the pressure sensor. The bottom within approximately 50 m of the installation is flat and sandy with medium sized sand grains and widely scattered 1- to 2-ft-high boulders. Attempts to fluidize the bed with a 1-in.-ID pipe and visual inspections indicated that the sand cover is about 6 to 12 in. deep and overlies a cobble bottom.

53. Over the 61-day deployment, wave energy was low, averaging only 25 cm^2 in variance (Table C1 and Plates 1 through 7). Variance $\langle \eta^2 \rangle$ is defined by

$$E = \rho g \langle \eta^2 \rangle$$

where

E = total energy

ρ = density of water

g = gravitational acceleration

Variance, therefore, is a direct function of the wave energy. Besides variance, another useful parameter representing wave energy is the significant wave height $H_{1/3}$ where

$$H_{1/3} \simeq 4 \sqrt{\langle \eta^2 \rangle}$$

This wave height is close to that which would be estimated visually from a random wave field.

54. For the period of measurement, the mean significant wave height was only 0.12 m. The mean peak wave period was 10 sec. Because the analysis was cut off at 4.0 sec due to depth limitations, periods less than this are not reported. Wave propagation for the most part was toward the west (≈260 deg TN) with an occasional shift toward the northeast or southwest during locally generated events. Mean current flow for the period was toward the northeast (030 deg TN), suggesting a clockwise general mean circulation in Cape Cod Bay.

55. Deployment period two: 26 August to 27 October 1983. The Sea Data 635-12 was deployed with the pressure sensor 0.18 m above the bottom and the current meter 1.98 m above the bottom and slightly (<30 cm) to one side of the pressure sensor.

56. For the second instrument deployment period, the mean significant wave height was 0.32 m. The mean peak wave period was just under 9 sec. Variances, as calculated from pressure, agreed with those calculated from velocity in the first month of the data set (approximately 26 August to 26 September). Throughout the rest of the data set, a gradual degradation of the relationship between the two variances occurred with the velocity variance consistently lower than that of the pressure. This degradation was attributed to the occurrence of soft, filamentous algal fouling found on the electromagnetic current meter (EMCM) ball at the time of retrieval. While this fouling should not have affected directionality as hard fouling would have, the EMCM response and absolute measurement would certainly be affected. The continuing degradation of the relationship between pressure and velocity variance seems to

support this theory because the fouling would have been light at first (soon after initial deployment) and then accumulated throughout the deployment period. This occurrence emphasizes the need for frequent cleaning of current sensors over any long deployment interval.

57. Wave propagation for the most part was toward the west (260 deg TN) with an occasional shift toward the northwest or southwest during locally generated events. Mean current flow for the period was toward the northeast (050 deg TN), again suggesting a clockwise general mean circulation in Cape Cod Bay.

58. A storm during 24 to 25 October 1983 provided the most energetic data recorded up to this time. Preceded by a fairly active period from 20 to 23 October, this storm produced a peak significant wave height of 1.86 m and a peak total energy variance of 2,160 cm^2 during 25 October 1983. Winds for the storm were forecast E/NE 30-35 mph by the National Oceanic and Atmospheric Administration (NOAA) weather radio, which agrees with the directions of wave propagation of 239 to 277 deg TN and wave periods of 7.1 to 12.8 sec. These data are included in Appendix C (Table C2) and Plates 8 through 17.

59. For the measurement period, wave energy was low except for the storm event during 24 to 25 October 1983. The data from this storm, as well as onsite observations of large amounts of suspended material in the water column two days later on 27 October when the instrument was retrieved, indicate that significant sand transport occurs in this area during storm conditions. However, sand cover in the vicinity of the tripod did not appear to have changed, and small-scale sand ripples (<15 cm) were still observed. In comparison with wave data from June to August 1983 that was collected at this same site, the present data show higher energy overall, with one major storm event and several more minor events. The largest waves uniformly approach from the east-northeast, with a minor higher frequency mode from the southeast.

60. Deployment period three: 10 November to 14 December 1983. The deployment was prematurely terminated on 14 December when divers discovered that the EMCM attachment hardware had failed, allowing the EMCM to rotate around the tripod axis approximately 30 deg in the horizontal to either side of its original location. When the hardware failed is not known, but inconsistent directional estimates present for most of the period indicate failure occurred following the first storm during 10 to 11 November 1983. Rather than

a continuous "waving" effect (as some force was required to initiate movement and push the EMCM past various snags (cable ties, etc.) in its path) this probe movement was more of an episodic and unpredictable shift which occurred through most of the deployment. The EMCM may have been stable in one position for a length of time as long as wave energies and directions did not change drastically.

61. An attempt to reconstruct directional information was made by analyzing and comparing wind velocity, wave periods, and wave directions for similar events during the first and second deployments and applying these results to similar events during the third deployment. Corrected wave directional estimates derived from this method are included in Appendix C (Table C3), and Plates 18 through 25 and are marked accordingly. No attempt was made to correct mean flow directions.

62. Corrections were obtained by correlating the mean directional estimates for waves with periods of 9.1, 10.6, and 12.8 sec in the previous data sets with hourly wind velocity data gathered at the Otis Air National Guard Weather Station, Otis Air Force Base, Cape Cod, MA. Mean directional estimates for waves of these periods were 260 deg TN for 9.1-sec waves (direction of propagation) with standard deviations of 35, 31, and 38 deg, respectively. The wind data for these waves correlated as well, giving a general wind pattern coming out of E/NE. Subsequently, directional estimates for waves of the same periods and/or with similar wind conditions were examined in this third deployment, and it was possible in some cases that a correction within the standard deviation of 38 deg could be made to bring the mean directions to approximately 260-265 deg TN.

63. For this period of measurement, the mean significant wave height was 0.47 m. The mean peak wave period was just over 8.5 sec. Because the analysis was cut off at 4.0 sec due to depth limitations, periods less than this are not reported.

64. This data set was more energetic than that from the previous two deployments with three major events and two or three minor ones recorded. The three major events occurred on the following dates: 10 to 11 November, 15 to 16 November, and 4 to 5 December, the latter two producing peak significant wave heights exceeding 2.0 m and total variances exceeding 2,500 cm^2 for the first time since the measurement period began in June.

65. Deployment period four: 23 February to June 1984. Wave propagation for the most part was toward the west (~269 deg TN) which is consistent with previous data sets. Mean current flow for the period was toward the northwest (≈340 deg TN). This direction is not consistent with the mean flow noted in two previous deployments which was to the northeast (030 and 050 deg TN, respectively).

66. This data set is the most energetic, with seven major events and other more minor events recorded. The seven major events occurred on 28 to 29 February, 9 to 10 March, 13 to 15 March, 18 to 20 March, 29 to 31 March, 5 April, and 8 to 12 April. These events produced significant wave heights exceeding 1.0 m and peak total variances exceeding 1,000 cm^2. The storm on 29 to 31 March produced significant wave heights exceeding 3.0 m. Total variance exceeded 6,900 cm^2 for the first time since the measurement period began in June 1983. These data are plotted and included in Appendix C (Table C4) and Plates 26 through 75.

Sediment Samples

67. A representative set of beach, back-bay, and ocean bottom sediment samples was obtained during the field investigation conducted during the period 21 to 25 April 1981. Beach sediment was collected as surface grab samples, while bottom samples obtained in the back-bay, inlet channel, and offshore regions were obtained using a short (24-in.) piston-coring device. The position of each sample was determined by using a sextant and triangulating the sample location from three known points (three "fixes"). This method is accurate when the boat or other platform is stationary. The boat was anchored with a short scope on the anchor line at each position for deployment of the divers. Once the divers were deployed, the boat position was determined by the triangulation method described above. Locations of samples are shown in Figure 22.

68. The sediment samples were brought back to the laboratory and analyzed for grain size distribution. Sample splits with an obvious silt fraction were initially wet-sieved to determine the percentage finer than 62 microns (4ϕ). The remainder was then dry-sieved at quarter-phi intervals. The sample mean grain size and standard deviation were computed using the Method of Moments technique (Folk 1965). These data are listed in Table 4. The mean

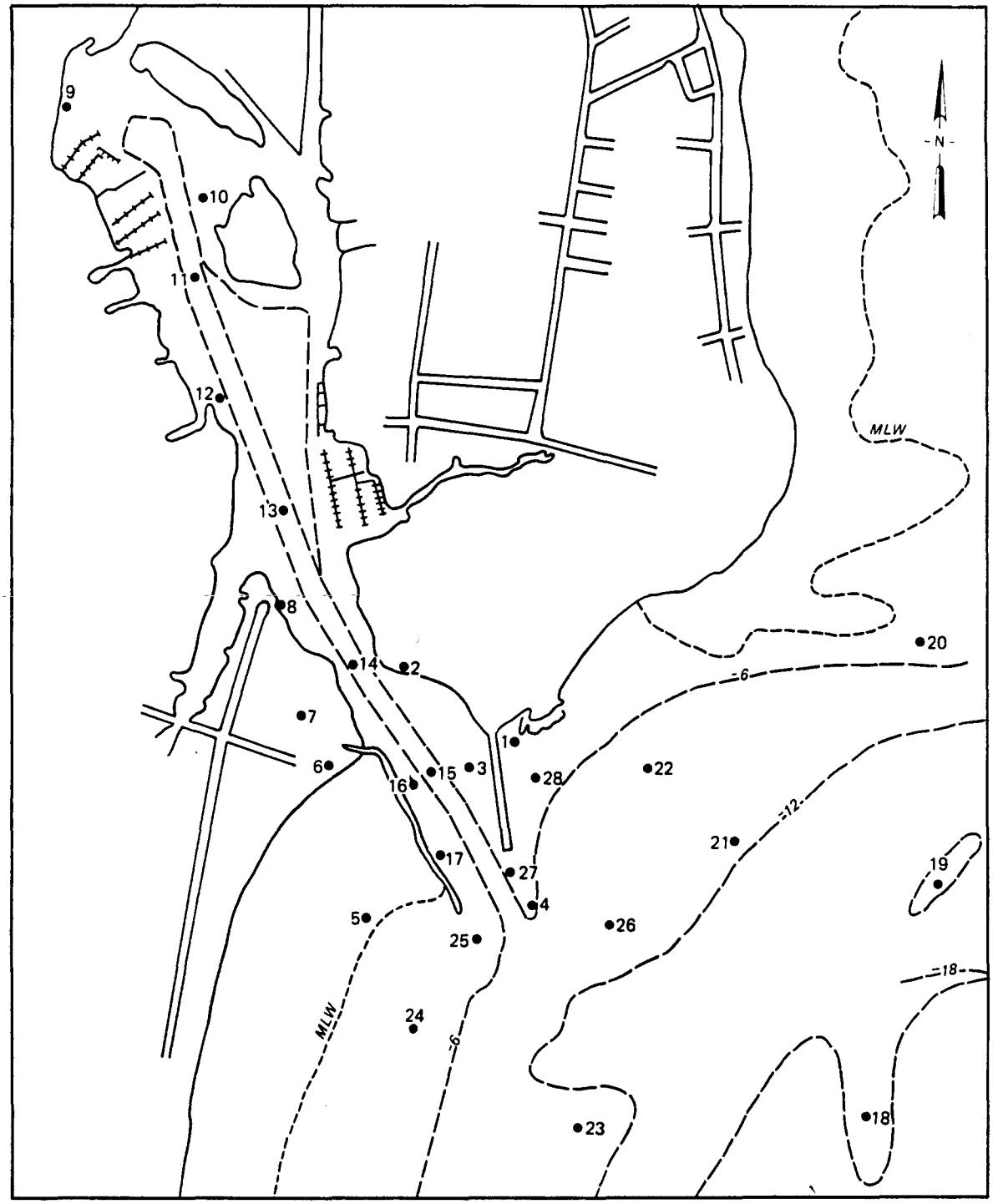


Figure 22. Sediment sample locations

Table 4

Green Harbor Sediment Sample Analysis, 21-25 April 1981

Sample No.	Location	Mean Grain Size mm	Mean Grain Size φ	φ Deviation	Remarks*
GH-1	Beach face	0.17	2.54	0.43	Between jetty and Bluefish Point
GH-2	Dune	0.43	1.18	3.71	Northeast Shore; Blackman's Point
GH-3	Interjetty	0.16	2.64	0.59	Shoal inside of northeast jetty
GH-4	Offshore	0.16	2.64	0.38	Offshore of northeast jetty near channel
GH-5	Beach face	0.23	2.11	0.53	Low tide terrace; south of jetty
GH-6	Dune	0.18	2.41	0.44	Base of sand dune; north end of southwest jetty
GH-7	Dune	0.22	2.20	0.44	North of sample GH-6
GH-8	Back bay	19.18	-4.26	3.45	North end wood retaining wall of southwest jetty; surface covered with small cobbles
GH-9	Back bay	9.34	-3.22	1.72	By tide gage at a depth of -6 ft; boulders and cobbles covering bottom
GH-10	Back bay (-10 ft)	0.18	2.41	0.47	East flank of channel; algal mat covering surface
GH-11	Back bay (-10 ft)	0.13	2.92	-0.17	In channel
GH-12	Back bay (-10 ft)	0.09	3.46	-0.17	North of launching ramp in channel; silt-covered bottom

(Continued)

* For ripple descriptions α = magnetic azimuth parallel to the crest

λ = crest-to-crest wavelength

h = crest-to-trough height

See Figure 22 for sample locations. Sample locations are denoted by number only.

Table 4 (Continued)

Sample No.	Location	Mean Grain Size mm	Mean Grain Size ϕ	ϕ Deviation	Remarks
GH-13	Back bay (-8 ft)	0.13	2.92	0.34	South of town pier in channel; silt-covered bottom
GH-14	Inlet throat (-7 ft)	0.19	2.37	0.50	In channel; ebb-oriented ripples α = 210 deg; λ = 10.2 cm; h = 2.5 cm; large pebbles
GH-15	Interjetty (-5 ft)	0.21	2.27	0.45	Center of channel; ripples ebb-oriented: α = 210 deg; λ = 10.1 cm; h = 2.5 cm; kelp bed directly east
GH-16	Interjetty	0.19	2.37	0.44	West side of channel on shoal
GH-17	Interjetty	0.19	2.37	0.46	West side of channel on shoal
GH-18	Offshore (-30 ft)	6.35	-2.67	2.64	Northeast of harbor; cobbles 6-12 in.; boulders 1 ft diameter; kelp patches
GH-19	Offshore (-21 ft)	6.90	-2.79	2.85	Northeast of harbor; cobbles and boulder with gravel filling in spaces; kelp growing in small thick patches
GH-20	Offshore (-12 ft)	11.32	-3.50	2.92	Northeast of harbor; large boulders with cobbles, gravel, and sand in between; kelp growing
GH-21	Offshore (-20 ft)	4.95	-2.31	2.51	Northeast of harbor; rock, cobbles, and small boulders; no kelp
GH-22	Offshore (-17 ft)	2.26	-1.18	2.80	Northeast of harbor; cobbles, sand and small boulders; kelp growing
GH-23	Offshore (-19 ft)	0.15	2.76	0.41	Offshore of jetties; symmetrical ripples; α = 90 deg; λ = 14 cm; h = 2.5 cm

(Continued)

Table 4 (Concluded)

Sample No.	Location	Mean Grain Size mm	Mean Grain Size φ	φ Deviation	Remarks
GH-24	Offshore (-14 ft)	0.17	2.54	0.46	South of jetties, symmetrical ripples-fine sand; α = 285 deg; λ = 7.6 cm; h = 2.5 cm
GH-25	Offshore (-14 ft)	0.16	2.66	0.44	South of jetties, symmetrical ripples; α = 285 deg; λ = 7.6 cm; h = 2.5 cm
GH-26	Offshore (-22 ft)	0.21	2.2	0.56	North of jetties; some gravel and pebbles on surface; α = 105 deg; λ = 7.6 cm; h = 2.5 cm
GH-27	Offshore (-13 ft)	sample contaminated			Directly off end of northeast jetty; rippled sand with boulders; α = 90 deg; λ = 10.2 cm; h = 3.2 cm
GH-28	Offshore (-9 ft)	sample contaminated			East of northeast jetty; rippled sand; α = 100 deg; λ = 7.6 cm; h = 1.9 cm

grain size is highly variable, which is a reflection of the varying dynamic regions from which the samples were obtained and of the wide range of sizes available from local till deposits. Samples obtained in the back-bay region away from the shore and the dike characterized by samples 12 and 13 (Figure 22 and Table 4), are classified as very fine sand and are well sorted. However, there was a thick (order of 0.12 to 0.5 in.) algal mat covering the floor of the back-bay area. A core was obtained through the algal mat which was carefully removed after extruding the core. It is unknown whether the algal mat is a seasonal or a permanent feature in the back-bay area. This mat provides an effective barrier to sediment transport; however, it was absent from the channel and the dredged regions in the back-bay area.

69. Samples obtained in the channel can be classified as fine sand (samples 13, 14, and 15; Table 4 and Figure 22). The grain size coarsens from the back-bay region through The Narrows into the interjetty region. The beach face and dune samples 1, 5, 6, and 7 (Figure 22 and Table 4) are classified as well-sorted fine sand. Because the sediment is so fine in this region, textural indicators cannot conclusively identify sources of sediment. One dune sample (sample 2) of particular interest is not a typical dune deposit. Closer investigation reveals that this region is related to a glacial outwash deposit with coarse gravels and cobble interlaced with sand finer than is normally found in dunes. Therefore, caution is advised when comparing samples 2, 6, and 7.

70. Offshore samples can be divided into two classes: well-sorted, fine sands, which include samples in the immediate vicinity of the inlet entrance and extending to the south, versus poorly sorted samples characterized by boulders and large cobbles which extend immediately offshore and to the north of the inlet entrance. The well-sorted samples to the south of the inlet entrance had few, if any, exposed cobbles. It was therefore assumed that these deposits were fairly thick (order of 1 to 2 m).

71. A synopsis of the sample, bed form type, and bed form orientation, if present, is contained in Table 4. While the sampling scheme was not designed to be comprehensive, the samples obtained provide a good identification of the geomorphic sedimentary environments within the Green Harbor region. Additional sediment samples obtained in the region offshore of Green Harbor were collected during a joint NED, CERC, and WHOI field investigation. These were required to obtain a more detailed characterization of the offshore

sedimentary environments. Seventeen surface grab samples were obtained from the field area during the data collection period 5 to 6 June 1984 (see Figure 28 for locations). Sample locations were determined using the Del Norte 540 trisponder microwave navigation system. The results of the sediment analysis are presented in Table 5. Six of the samples (Table 5) consisted solely of or had a large number of cobbles. In brief, the sediment data confirm the high resolution side-scan sonar interpretations of bottom sediment distribution and texture. Bedrock was encountered in the northern part of the study area. Rock (cobbles and gravel) was encountered in this same region, particularly in samples GH-84-1, 2, 3, 4, 5, 9, and 12. This occurrence can be indicative of bedrock outcrops but has been interpreted here (with the aid of the side-scan records) as outcrops of unworked glacial till. Several sampling attempts were required to obtain sand in sample 1 because of the presence of coarse cobbles which prevented the jaws of the sediment sampler from closing. Mean grain size of the sand fraction of the samples ranged from 1.0 to 3.0 phi. The standard deviation ranged from 0.4 to 1.1 phi. The nearshore sand zones consisted of fine sand with small standard deviations. The intermediate zones consist of sand with mean grain size near 2.0 phi with a wide range of standard deviations. The offshore rocky zone consists of coarse sand with cobbles, the sand fraction of the samples having a standard deviation close to 0.7 phi.

Tide Measurements

72. Two self-recording tide gages were installed during the September 1981 data collection effort, as indicated in Figure 23. A stilling well tide gage located inside the back-bay region was strapped to a pile located on Town Dock with a tide staff nailed to an adjacent pile (Figure 24). Water elevation data were recorded via a float/cable system which was connected to a Leupold-Stevens strip chart recorder. Tide staff readings were made twice daily and annotated along with the time and date on the strip charts for gage calibration/verification. The ocean-side tide measuring instrument was a Bristol bubbler gage. The sensor (orifice) was secured to a 1/2-in. pipe approximately 1.5 ft above the bottom in a water depth of approximately 6 ft mlw. The strip chart recorder was installed in a weatherproof box on top of the sand-cobble dune east of the northeast jetty (Figure 25). Installation of the

Table 5

Green Harbor Sediment Sample Analysis, 5-6 June 1984

Sample No.	Location*	Mean Grain Size		ϕ Deviation	Ship Log Remarks
		ϕ	mm		
GH-84-1	Northern offshore region	1.197	0.44	0.650	Fine-to-medium sand with pebbles and shell
GH-84-2	Northern offshore region				Small pebbles only
GH-84-3	Northern nearshore region				Cobbles, no sand
GH-84-4	Northern region near inlet				Cobbles, no sand
GH-84-5	Close to shore north of inlet				Rocks, no sand
GH-84-6	Close to shore north of inlet	2.42	0.19	0.60	Fine sand with a few pebbles
GH-84-7	In inlet channel	2.51	0.17	0.57	Fine sand with shrimp
GH-84-8	South of inlet near jetties	2.79	0.14	0.56	Fine sand with a few shell fragments
GH-84-9	Near channel offshore of inlet				Cobbles with no sand
GH-84-10	Near channel offshore of inlet	2.06	0.24	0.96	Fine-to-medium sand with a few cobbles
GH-84-11	Offshore of inlet central region	1.86	0.28	0.71	Fine-to-medium sand
GH-84-12	Offshore of inlet				Cobbles

(Continued)

* See Figure 28 for sample locations.

Table 5 (Concluded)

Sample No.	Location	Mean Grain Size		ϕ Deviation	Ship Log Remarks
		ϕ	mm		
GH-84-13	South of inlet offshore	3.00	0.12	0.39	Fine sand with a few shell fragments
GH-84-14	South of inlet nearshore	2.48	0.19	0.55	Fine sand with scattered cobbles
GH-84-15	Central region near channel	1.01	0.49	0.65	Small quantity of fine sand
GH-84-16	Directly offshore of inlet	2.81	0.14	0.46	Fine sand with worms
GH-84-17	Southern region nearshore	2.80	0.14	0.64	Fine sand

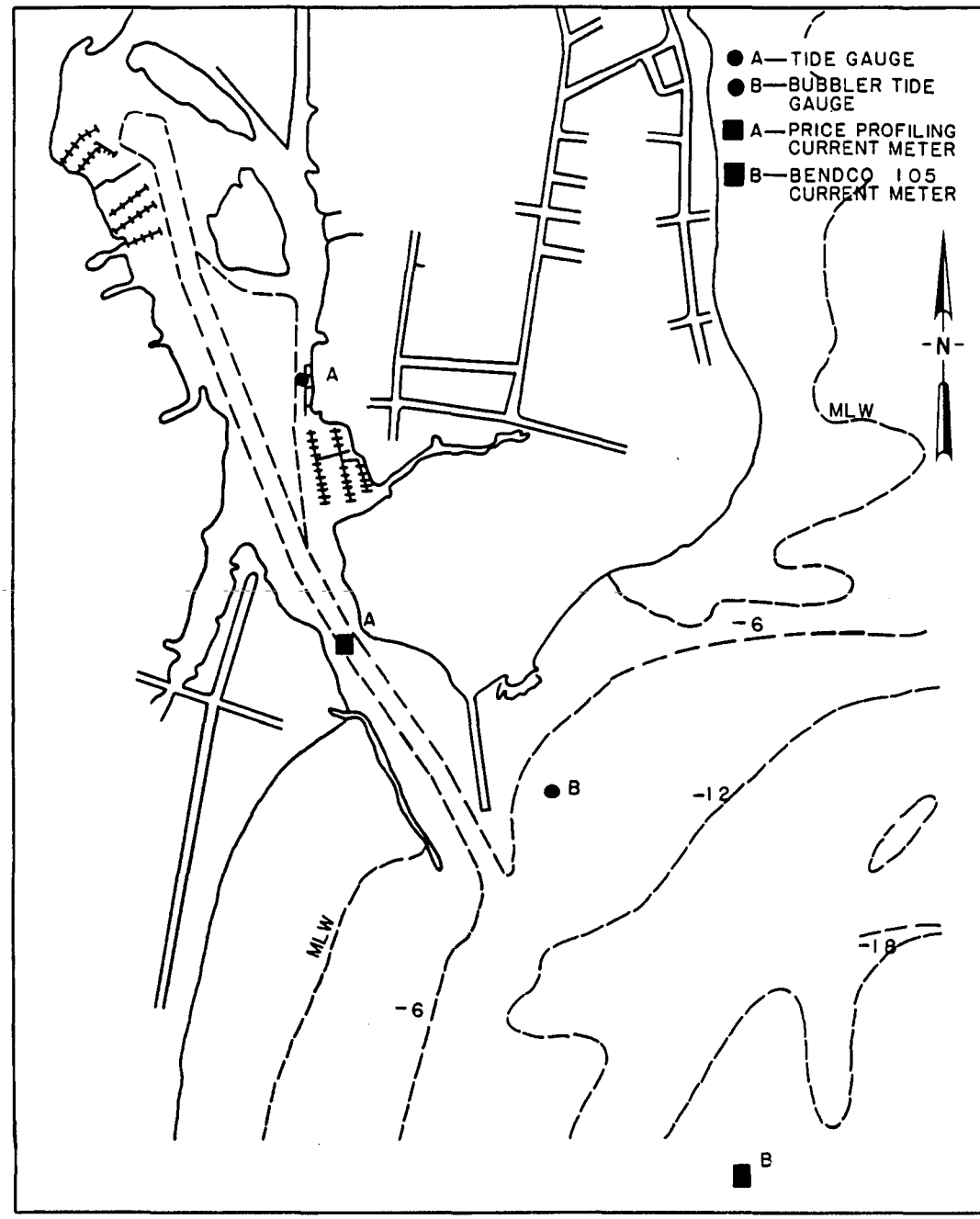


Figure 23. Location of tide and current measuring instrumentation

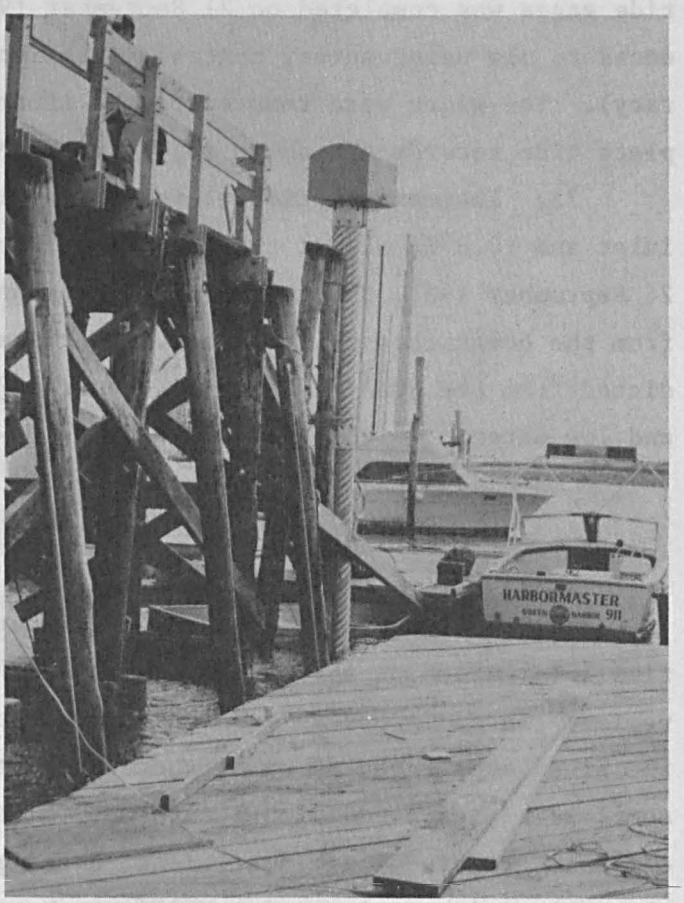


Figure 24. Installation of stilling well tidal elevation recorder at Town Dock

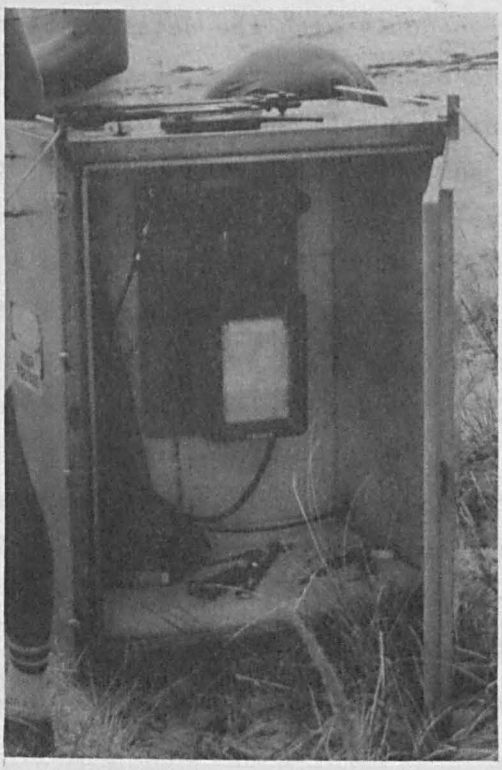


Figure 25. Strip chart recorder used to record tidal elevations

tide gages was completed on 21 September 1981. Gage elevations were referenced to mlw using survey control established by NED (third order of accuracy). The gages were removed on the afternoon of 24 September 1981. Complete tide records are shown in Figure 26.*

73. The maximum tide elevation was 10.5 ft mlw on the ocean side of the inlet and 10.8 ft mlw at the Town Dock. For the record obtained from 21 to 24 September 1981, there were no significant lags between high and low water from the ocean through the inlet. On the average, high and low water predicted from the NOAA tide tables occurred 20 min later than the observed high and low water.

Offshore Bathymetry and Side-Scan Sonar

74. A review of the historical literature (Part II) produced no definitive information on the offshore bottom environment in the Green Harbor Inlet region. In addition, an examination of the available bathymetric charts for the study area revealed an offshore bathymetric structure that is extremely complex. To gain additional information on both the local bathymetry and offshore geomorphologic conditions, detailed bathymetric data were obtained through a joint project with WHOI. High resolution side-scan sonar and subbottom seismic data were obtained simultaneously with the detailed bathymetric data. This data collection provided fine scale resolution of the complex bathymetry and defined specific geomorphic depositional environments.

75. On 4 June 1984, personnel of NED, CERC, and WHOI obtained detailed bathymetric data in conjunction with simultaneous high resolution side-scan sonar and subbottom seismic profiles. These data were obtained from a WHOI research vessel, the R. N. Edwards. Navigational considerations are critical when attempting to obtain shipborne high resolution data. A Del Norte 540 trisponder microwave navigation system provided near continuous, precise ship location data. These data were logged on a Sea Data 1250 data logger. Three remote transmitting units obtained increased positional accuracy precisely located on the beach. These three remote transponders were placed at NED's local benchmark locations (D-South, GH-3, and D-North; see Figure 27). Post-processing of the positional data included reading the cassette tape

* MSL = mean sea level.

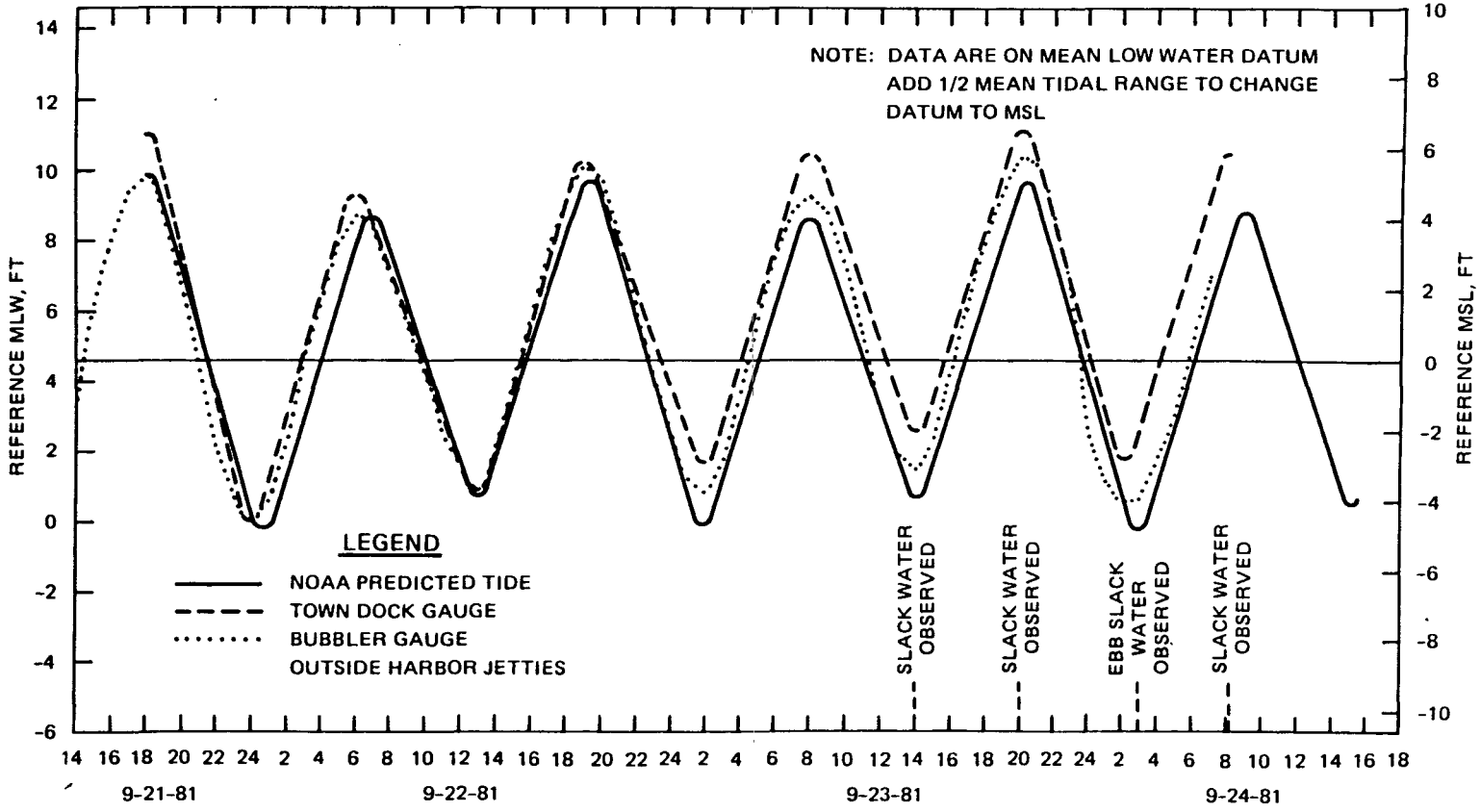


Figure 26. Tidal elevations for the period 21 to 24 September 1985

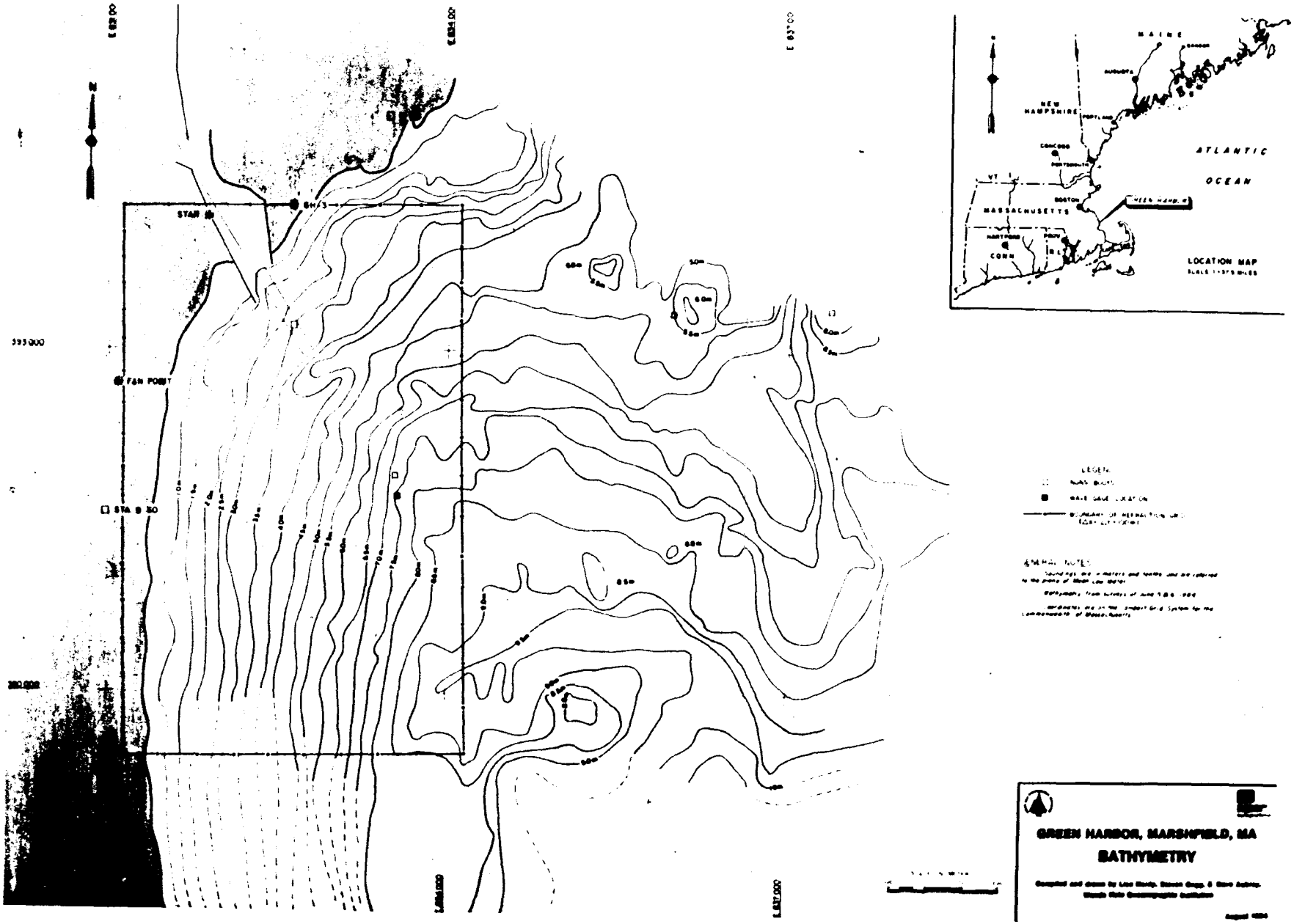


Figure 27. Detailed bathymetry and location of local wave refraction grid

containing the digital data, converting the location and time data to ship tracks, and finally producing a plot of the ship tracks. These data were then stored for later use in reducing the high resolution side-scan sonar and bathymetric data as well as sediment textural analysis.

76. Bathymetric data were obtained using a Raytheon DE-719 C fathometer, equipped with an analog recorder, operating at 200 kHz. In the field, frequent bar checks verified the calibration of these data. Water level elevation was tied to a Sea Data micrologger temperature depth recorder (TDR) installed on the ocean side of the harbor entrance (on the northeast side of the northeast jetty) and referenced to a nearby US Geological Survey benchmark for vertical control. The Sea Data TDR gage provided 5-min averages of water level which were used to correct the fathometer readings for tidal effects and to relate the bathymetric data to a rational datum. Once these data were returned to the laboratory, the fathometer analog record was converted into digital format using a microprocessor controlled digitizer. The digital fathometer data were then merged with the navigational records and corrected for tide and draft, resulting in a highly accurate bathymetric data set. Final results of this analysis (Figure 27) show the contrasting bathymetric zones which exist to the east and south of the inlet. To the south of the inlet bathymetric contours are smooth and shore parallel. Absent are any of the rocky outcrops and convoluted contours that are apparent to the east of the inlet. An examination of Figure 27 shows a fairly well-defined line of demarcation separating the irregular and regular bathymetric contours extending directly from the mouth of the inlet and having a northwest to southeast trend. To the northeast of the inlet the bathymetry becomes highly irregular, with regions which appear to be rocky outcrops.

77. High resolution subbottom and side-scan profile records were obtained simultaneously with the bathymetric data. Two days of subbottom profiling were carried out using a Ferrante/O.R.E. Geopulse System. The Geopulse was selected because it represents a new generation of subbottom profilers capable of higher resolution and better signal-to-noise ratio than past subbottom profilers. Because the geology of the Green Harbor region is characterized by bedrock and glacial till close to the water-sediment interface, a versatile system was needed which was capable of shallow penetration with high resolution. However, the system must also be capable of deeper penetration in the southerly areas of the study region where unconsolidated material was

expected to be thicker. The Geopulse System was chosen because it satisfied all of the above requirements.

78. Subbottom reflectors, which were generally strong at shallow depths, with limited horizontal continuity, revealed three well-defined geomorphic units that were difficult to map. First, the surface layer was composed of fine-to-medium sand which was thin offshore and thick onshore (up to several metres). This material is likely reworked glacial till and forms the beaches of the Green Harbor region. The second well-defined layer has been identified as a compact glacial till most likely deposited during the most recent period of glaciation. This layer was characterized by a strong acoustic impedance of contrast with the overlying reworked glacial till. The high impedance of this layer often made deeper penetration impossible. The third unit was bedrock which underlay the till in places. In several places (particularly to the north of the inlet region) (Figure 28) this unit cropped out at the ocean bottom and was totally exposed. As stated earlier, the contacts among these units were not continuous; therefore, construction of a structural or an isopach map was not possible. An abundance of subbottom relief in this area prevents definitive mapping of these units.

79. Side-scan sonar records were obtained simultaneously with the bathymetric and subbottom profile data. Varying strengths of reflections delineate various bottom types relative to sediment grain size or degree of bottom stiffness. Off Green Harbor, three major zones mapped and verified by sediment sampling and diver observations were (a) the inner shelf deposit zone consisting of fine sand with scattered rocks in an offshore portion of the zone, (b) the intermediate zone consisting of fine sand streamers on a poorly sorted cobble horizon (which may be a glacial till surface), and (c) the outer zone consisting possibly of till outcrop with minimal reworking and little or no sand. Bedrock crops out in a few locations. The fine sand zone is parallel to shore and occurs adjacent to the shore except north of the jetties where the till and bedrock occur. Side-scan sonar analysis (Figure 28) shows the textural surfaces in the study region and the ship tracks used to obtain these data.

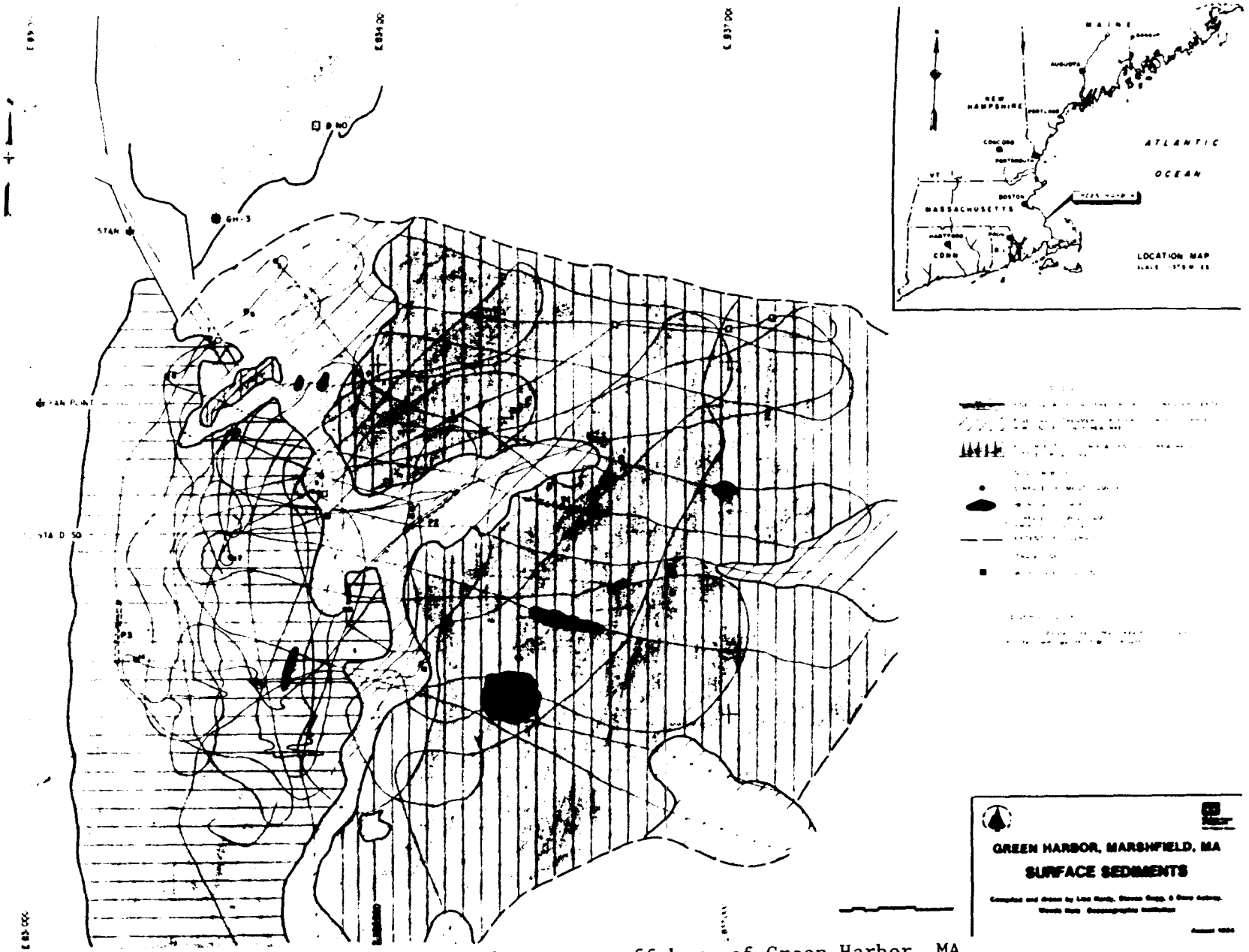


Figure 28. Surface sediment map offshore of Green Harbor, MA

PART V: ANALYSIS AND MODELING

Aerial Photograph Interpretation

80. Aerial photographs of the Green Harbor region were acquired for this study. Several of these photographs have been taken at an oblique angle and at widely varying altitudes. While the photographs obtained at an oblique angle can be compared with the other photographs using advanced computer enhancement techniques, the task is beyond the scope of this project. Because of the intermittent nature of aerial vertical photographic temporal series, the following few representative examples have been selected to show the dominant historical patterns of accretion that occur within the inlet region:

a. 12 April 1966 (Figure 29). This photograph dramatically shows the pattern of accretion that occurs within the interjetty and harbor regions. To date, the turning basin has not been dredged. The limited number of boats at anchor in the dredged portion of the river illustrates the difficulty that arose prior to the excavation of the anchorage and turning basin. Boats were required to anchor in the dredged regions of the back bay because there was not enough depth at low tide outside of these small areas. Thus, navigation became extremely hazardous for boats attempting to traverse the channel. The interjetty region shows the effects of shoaling resulting from sediment transport. The channel is depicted as a darker region angling diagonally from the tip of the northeast jetty to the west side of The Narrows. The navigable portion of the channel is confined to the region between the jetties. This aerial photograph documents the dangerous shoal that rapidly builds between the two entrance jetties. The majority of the accretion within the interjetty region occurs in the north side of The Narrows (between the northeast jetty and The Narrows).

b. 31 October 1968 (Figure 30). This photograph was taken immediately after completion of the 1968 harbor improvement project. The channel in the interjetty region has been dredged to project depth (-8 ft mlw) and relocated to a centralized position between the jetties. This photograph shows the condition of the shoreline in the Brant Rock region (to the north of the inlet). The majority of the vessels are now anchored on flanks of the navigational channel, permitting unimpeded navigation through the inlet and up Green Harbor River.

c. 10 November 1974 (Figure 31). This photograph shows the effects of shoaling on the inlet entrance. The inlet was dredged in late 1973, removing 65,700 cu yd of sand from the inlet region. The inlet has shoaled significantly by this time some 12 months later. Wave conditions at the time of this photograph were minimal. However, the increased breaking which

Figure 29. Aerial photograph, 12 April 1966

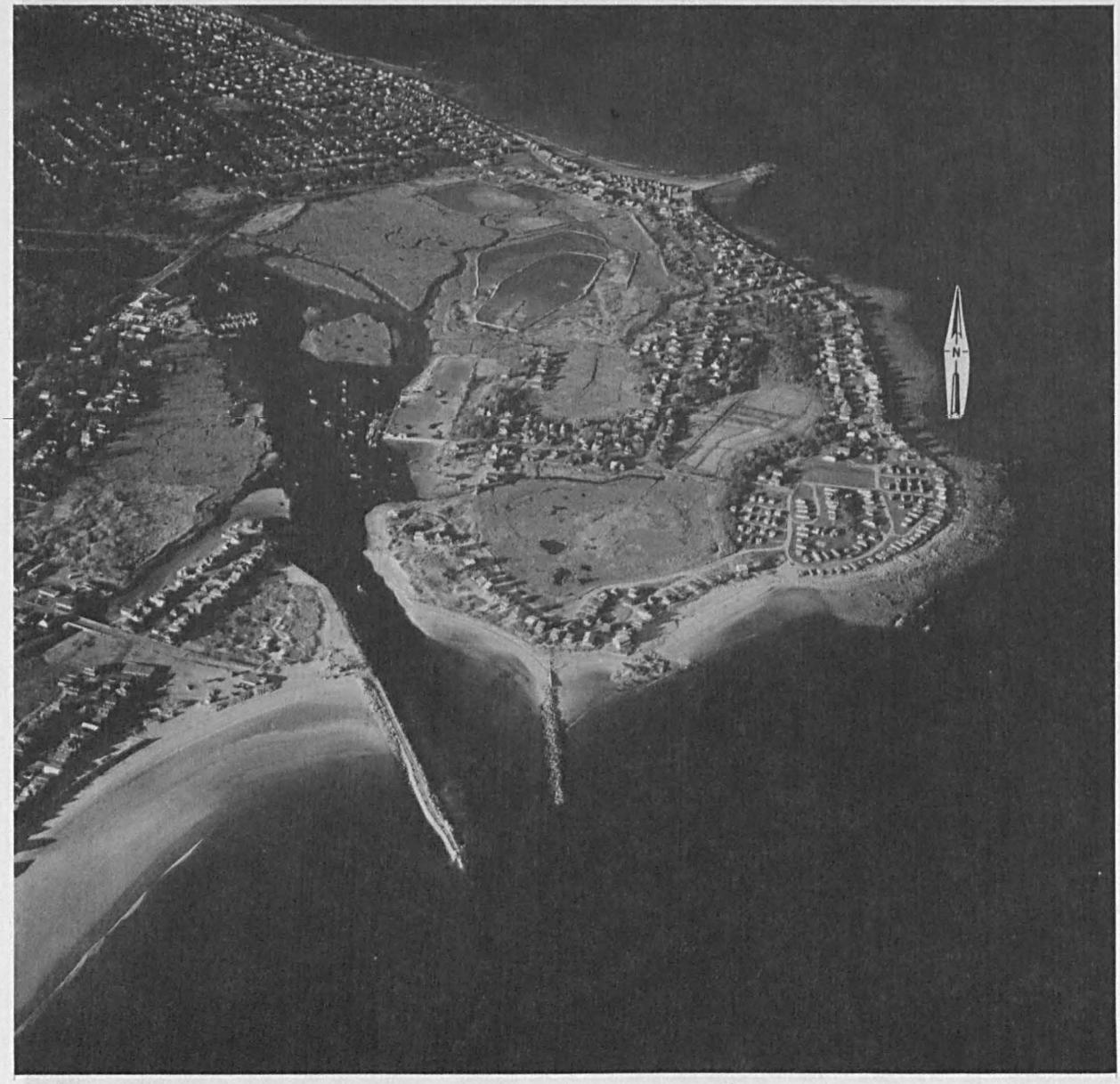


Figure 30. Aerial photograph, 31 October 1968

Figure 31. Aerial photograph, 10 November 1974

occurs at the inlet entrance because of the entrance shoal should be noticed. The effects of direct exposure of the left jetty to wave attack and subsequent reflections are evident. The breaking of the reflected wave on the inner beach can easily be seen. This photograph illustrates a mach-stem wave, a reflected wave having maximum height adjacent to the structure, which becomes trapped on a linear structure. A shoal is beginning to form midway down the southwest jetty, and the effects of aeolian transport are evident in this photograph. A ramp is forming along the southwest jetty from winds blowing from the southwest. Aeolian transport of an unknown magnitude is undoubtedly contributing to the shoal inside the southwest jetty.

d. October 1979 (Figure 32). This photograph was obtained prior to redredging Green Harbor. The inlet has returned to its former shoaled condition. The channel has shoaled and migrated across the inlet, adjacent to the northeast jetty. The

Figure 32. Aerial photograph, October 1979

bulkhead on the inside of the southwest jetty has been reinforced and raised several feet (1976). Because of the effects of aeolian transport (ramping), sand is actively being transported over the southwest jetty. Also depicted in this photograph is the dramatic increase in the subaerial portion of Green Harbor beach. The dune adjacent to the southwest jetty has experienced dramatic accretion. This dune has completely stabilized through vegetation. Growth of the shoals in the interjetty on the inner beach are easily distinguishable.

e. 26 March 1983 (Figure 33). This photograph has been included to show the dramatic effects of reflected waves. Direct reflection of waves and the mach-stem reflection are prominent in this photograph which was taken prior to inlet maintenance dredging operations. It reveals an increase in the inner beach and the shoals occurring at The Narrows. Since interpolating changes in shoreline and channel orientation is difficult from aerial photographs, schematic diagrams were constructed using a zoom transfer scope to facilitate a semiquantitative comparison of the vertical aerial photographs. This analysis technique reduces the aerial photographs to the same scale through a series of prismatic lenses. In the interjetty region, the tendency of the channel to migrate under the influence of incident and reflected waves is apparent. The channel does not migrate back and forth across the inlet naturally; rather, it is reoriented into the center of the jettied region through inlet maintenance activities then migrates eastward naturally. Of interest in these schematic diagrams is the shoreline movement at Green Harbor Beach. The migration of the high waterline at Green Harbor Beach was toward the dune during the period 1940 through 1968. While the high waterline exhibits an erosional tendency, the adjacent dune region is expanding and vegetating. In addition, the subaqueous beach region has accreted, particularly in the region of the southwest jetty. In early 1969 the west jetty was extended 200 ft. After this time the dune, shoreline, and subaqueous beach experienced rapid accretion.

Wave Refraction Analysis

81. Wave refraction-diffraction occurring within the study region was examined on two spatial scales. The first spatial scale examined regional wave refraction-diffraction within the Green Harbor/Western Cape Code Bay region. The second refraction analysis was performed on a smaller scale concentrated in the inlet and the beach region immediately to the south. This study was performed in direct support of a revised series of sediment transport calculations using the directional wave data for input.

Figure 33. Aerial photograph, 26 March 1983

Regional wave
refraction-diffraction analysis

82. A wave refraction-diffraction analysis was performed on a regional scale to determine the potential effects of the harbor entrance and complex bathymetry on the refraction and diffraction of the incident wave field. Typical wave conditions determined from the directional wave data were chosen for these computer runs. The input wave conditions were chosen from the directional wave summaries (Table C1-C4, Appendix C). The wave refraction-diffraction model was developed at WES. The model input was a stretched grid containing 6,300 nodes approximately 8.5 miles in the longshore direction and 8.5 miles in the offshore direction. The grid was generated to ensure that maximum resolution was obtained in the inlet region (Figure 34).

83. Discussion of the results obtained in the wave refraction-diffraction analysis will concentrate on that portion of the grid centered on the inlet and the region immediately adjacent to the south. The northern region of the grid was included in the overall analysis to ensure that the northern boundary conditions were considered and to ensure no adverse propagation occurred because of boundary effects in the highly complex bathymetry which extends offshore well into Massachusetts Bay. Because there is no detailed bathymetry for this region, the grid was generated with large grid intervals. This technique allowed waves to propagate through the grid from the northeast with minimum bathymetric effects in the region offshore of Green Harbor. Typical results of this analysis are shown as Plates 76-85. These plates represent typical wave refraction-diffraction runs. A matrix of input wave period and approach angle conditions was generated from the prototype directional wave input conditions.

84. The interior of the matrix was then filled with typical wave heights. A broad range of wave heights was used, ranging from 1.5 to 8.0 ft. An examination of Plates 76-85 shows that for all input wave periods and approach angles, the input waves are refracted into the inlet at an angle which permits either direct wave transmission into the inlet entrance (inter-jetty region) or reflection off the southwest jetty.

85. The results of the wave refraction-diffraction model in the inter-jetty and inlet entrance regions must be viewed with a degree of caution. An examination of Figure 34 shows only 17 grid cells defining this region. While this grid is adequate to give a qualitative look at waves approaching the

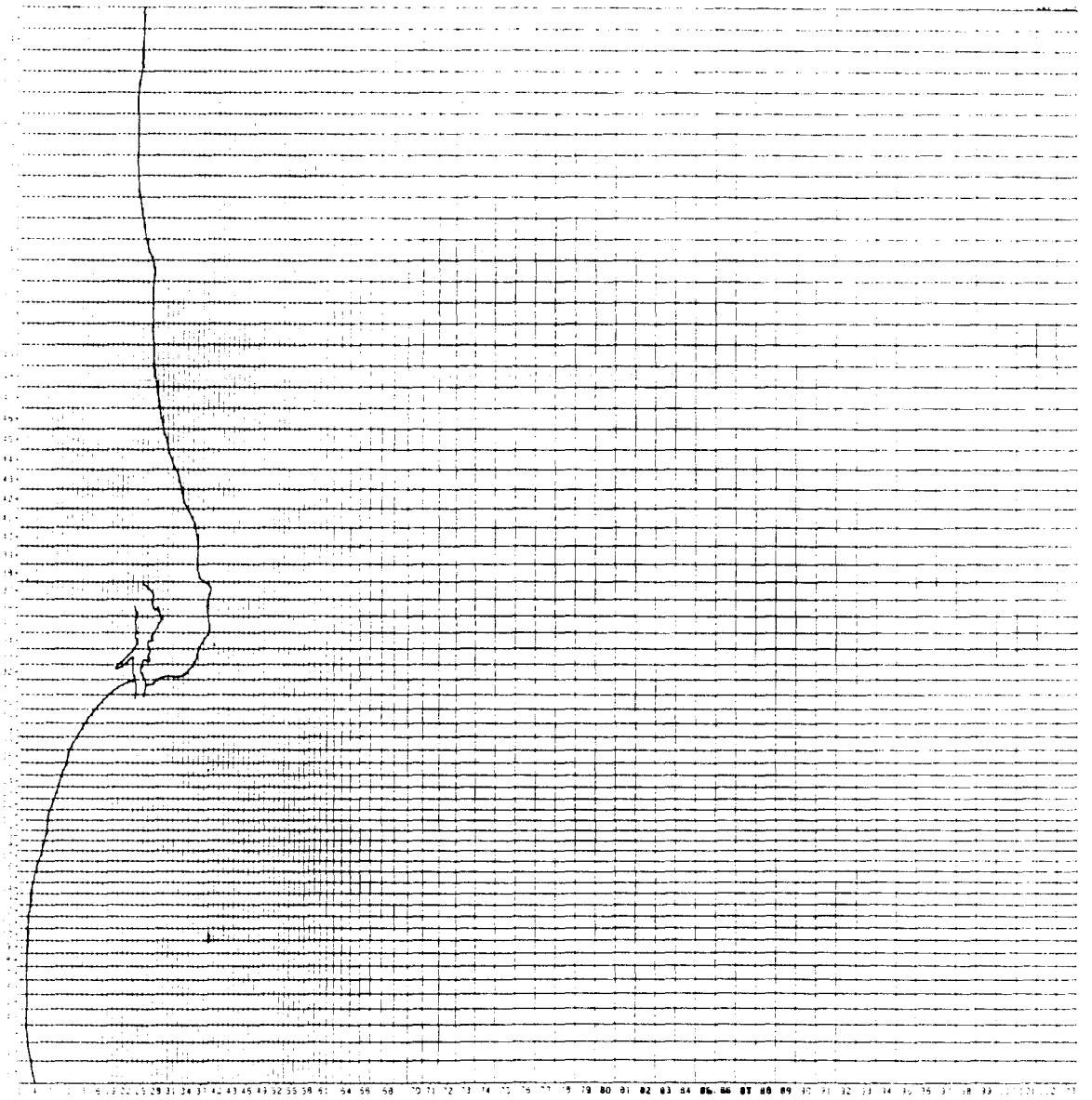


Figure 34. Regional wave refraction grid

inlet, it is not adequate to provide quantitative results. The wave refraction in the region immediately offshore of the inlet can be viewed with a greater degree of confidence, since detailed bathymetric data were provided by NED for this analysis. These results confirm the suspected local bathymetric effect on the refraction-diffraction of the waves. Waves approaching the inlet entrance at oblique angles are turned toward the entrance because of refraction. This local refraction effect is common on most tidal inlets. Refraction effectively focuses wave energy toward the inlet. As a result of wave refraction, sediment transport will be directed toward the inlet entrance from both the northeast and southwest sides of the inlet.

Small-scale wave refraction analysis

86. A separate wave refraction analysis was performed using a smaller (higher resolution) grid. Results from the second wave refraction model were used as direct input for longshore sediment transport calculations. In order to use the detailed bathymetric information that had been collected for this region, a rectangular grid of 6,000 nodes was generated (Figure 27). The longshore grid length was approximately 5,000 ft (100 grid units at 15.2-m (50-ft) spacing). The on-/offshore grid length was approximately 3,000 ft (60 grid units at 15.2-m (50-ft) spacing). This grid was input into a linear refraction program. Representative wave information used as input for the refraction analysis was obtained from observed directional wave information (Tables C1-C4). Computer runs were made with the mean water level at midtide.

87. The result of the small-scale refraction analysis is represented by a matrix of refraction parameters at specific points along the shoreline (Table 6). For any shoreline location, the effects of the refraction can be

Table 6

Refraction Analysis Summary

T, sec	$Q = K_r^2 \left[\frac{1}{2} \sin(\alpha + \alpha_s)\right]$						
θ, deg	6.1	6.7	7.5	8.5	9.8	11.6	14.2
240	0.170	0.131	0.150	0.097	0.117	0.106	0.099
250	0.143	0.145	0.145	0.148	0.152	0.158	0.147
260	0.074	0.072	0.069	0.067	0.065	0.087	0.061
270	0.006	0.004	0.007	0.009	0.008	0.008	0.009
280	-0.029	-0.030	-0.029	-0.028	-0.028	-0.025	-0.027
290	-0.055	-0.053	-0.055	-0.050	-0.051	-0.048	-0.050

represented as the product of refraction coefficient and an angular dependence $\left[K_r^2 \times \frac{1}{2} \sin (\alpha + \alpha_s)\right]$. This quantity is presented as a function of incident wave period (varied from 6.1 to 14.2 sec) and incident wave direction (varied from 240 to 290 deg TN). This table yields a sense of how waves of varying directions and periods are refracted by the offshore bathymetry. Ultimately, the bending of the wave orthogonal may be directly related to the direction of sediment transport. In addition, directions of local convergences and divergences can be depicted. For instance, waves approaching toward 250 deg TN will reach the beach at midgrid nearly shore parallel. Waves propagating toward 250 deg will have the most effect on longshore sediment transport for all periods representing convergence on the beach.

Longshore Sediment Transport Rates

88. Longshore sediment transport rates were calculated using two different analytical methods and one numerical method. The reason for using more than one method was to check the reliability of the estimates obtained within the study area. Green Harbor has a limited sediment supply to the north of Brant Rock. The area adjacent to Brant Rock shows no evidence of large quantities of sand being transported around the rocky outcrop toward Green Harbor. There is a supply of sediment immediately to the west of the inlet along Green Harbor Beach. However, there is little direct evidence of large quantities of sediment being transported into the entrance channel. Two different engineering methods were used to calculate rates of sediment transport because of the complex sediment transport regime in this area. Both techniques used a similar analytic scheme for calculating sediment transport. They differ by the input wave data that was used to calculate the rates of sediment transport. The LEO and the Sea State Engineering Analysis System (SEAS) techniques were used and reported here because they are commonly used along eastern coastlines of the United States. However, it is obvious that the results obtained by each of these techniques produced estimates of sediment transport that are very large. Therefore, the study actually used the sediment transport rates that were calculated using directional wave data obtained over a 12-month period (June 1983 to June 1984) offshore of Green Harbor. This numerical technique provided the most reasonable estimates of rates of sediment transport which occur at Green Harbor.

89. Longshore sediment transport rates at Green Harbor were initially calculated using two different methods because of the complex bathymetry and convoluted shoreline which is immediately adjacent to the entrance to Green Harbor. Each method for estimating sediment transport has been formulated using several inherently simplifying assumptions. Because of either poor historical data and/or Green Harbor's complex geomorphology, one or more of the simplifying assumptions contained within each of the techniques used were violated. This fact necessitated making several longshore sediment transport estimates. The two initial methods used in calculating longshore sediment transport rates are contained in the SPM (1984) and will be discussed briefly in the ensuing paragraphs.

Longshore Sediment Transport Calculations

90. The following calculations are presented for engineering interest. Actual values of sediment transport used in this engineering study are referenced in paragraph 97. In October 1981 a LEO site was established at Brant Rock, MA, immediately to the northwest of the entrance to Green Harbor. LEO observers provided daily observations of the littoral environment, including data such as wave height, wave direction, wave type, windspeed, wind direction, shore slope, surf width, and longshore current direction and speed. While the LEO program provides valuable data in areas where little or no data exist, these data are primarily derived from observations and do not use advanced measuring instruments. Because it is extremely difficult to make accurate estimates of wave heights and distances from shore, caution is advised when using data derived from the LEO program. The LEO data obtained in this study provided valuable estimates of the incident energy conditions. Primarily through the voluntary efforts of the LEO observers, the necessity to obtain more accurate wave height data became apparent.

91. LEO observations were made at Brant Rock for approximately a 16-month period from October 1981 through January 1983. Initial calculations of longshore sediment transport were made using data obtained from the LEO observer. Rates of longshore sediment transport were calculated using SPM Equation 4-38 (SPM 1984) as follows:

$$P_{\theta b} = \frac{\rho g}{16} H_b^2 C_b \sin 2\alpha_b \quad (1)$$

where

$P_{\ell b}$ = longshore energy flux resulting from breaking waves

ρ = density (slugs/cu ft)

g = gravitational constant (ft/sec-sec)

H_b = breaking wave height (ft)

C_b = breaking wave celerity (ft/sec)

α_b = breaking wave angle

The quantity $P_{\ell b}$ is the energy flux in the longshore direction which results from a monochromatic wave train with a breaking wave height H_b traveling with speed C_b and approaching the shore at angle α_b.

92. The longshore energy flux $P_{\ell s}$ can be related to the following longshore sediment transport rate:

$$Q = \frac{K}{(\rho_s - \rho)ga'} P_{\ell s} \quad (2)$$

where

Q = rate of sediment transport (cu yd/year)

K = dimensionless coefficient

ρ_s = density of ambient sediment (slugs/cu ft)

ρ = density of seawater (slugs/cu ft)

Equation 2 has been reduced further, using field data from various locations around the United States, to

$$Q = 7{,}500 * P_{\ell s} \quad (3)$$

where the value of 7,500 is a dimensional number derived from the previously cited field data. The longshore sediment transport rate derived from Equation 3 is in cubic yards per year.

93. LEO data were used to give representative values for breaking wave height and breaking wave direction for each month. A value of Q (Equation 3) was calculated for each month. However, the longshore sediment transport rate calculated is in cubic yards per year. Therefore, the values of Q were summed and divided by 365 to give daily quantities of longshore sediment

transport and the direction in which the sand will be transported. The results of these calculations are shown in Figures 35 and 36. Figure 35 shows the summed raw monthly calculation of sediment transport. In this diagram, the LEO convention of transport to the left and to the right has been maintained. Transport to the right (from left to right) for an observer at Green Harbor facing offshore (looking across the water) is equated to transport from the northeast to the southwest. Conversely, transport to left can be equated to transport from the southwest to the northeast. Figure 36 shows the net transport. This figure is the result of the algebraic summation of the monthly subtotals of sediment transport. Results of the LEO sediment transport calculations are recapitulated in Table 7.

SEAS calculations

94. The following calculations are presented for engineering interest. Actual values of sediment transport used in this engineering study are referenced in paragraph 97. Longshore sediment transport was calculated using wave height information from SEAS. The SEAS data base is designed to provide estimates of wave height (among other information) from hindcast values. Hindcast wave data were obtained for the 6-year period 1970 through 1975. Values of net longshore sediment transport for each month were calculated, summed, and then averaged to provide a mean longshore sediment transport rate in both the positive (northeast to southwest) and negative directions. Longshore sediment transport rates are presented in this manner to give a representative mean condition so that the longshore sediment transport rates calculated from both techniques can be directly compared.

95. The average longshore sediment transport rate (Q_{Right} and Q_{Left}) calculated from the SEAS data are shown in Table 8.

96. The rates of longshore sediment transport obtained using the SEAS wave height information are more than an order of magnitude larger than the rates of longshore sediment transport obtained using the LEO data. This result is partially attributed to wave heights being obtained through the SEAS information system for deepwater conditions. In addition, there has been no attempt to resolve the wave height and direction of propagation across the complex bathymetry existing to the north of Cape Cod. After these initial calculations were performed, it was readily apparent that to obtain accurate sediment transport estimates some of these difficulties needed to be addressed. Both estimates of longshore sediment transport obtained from the

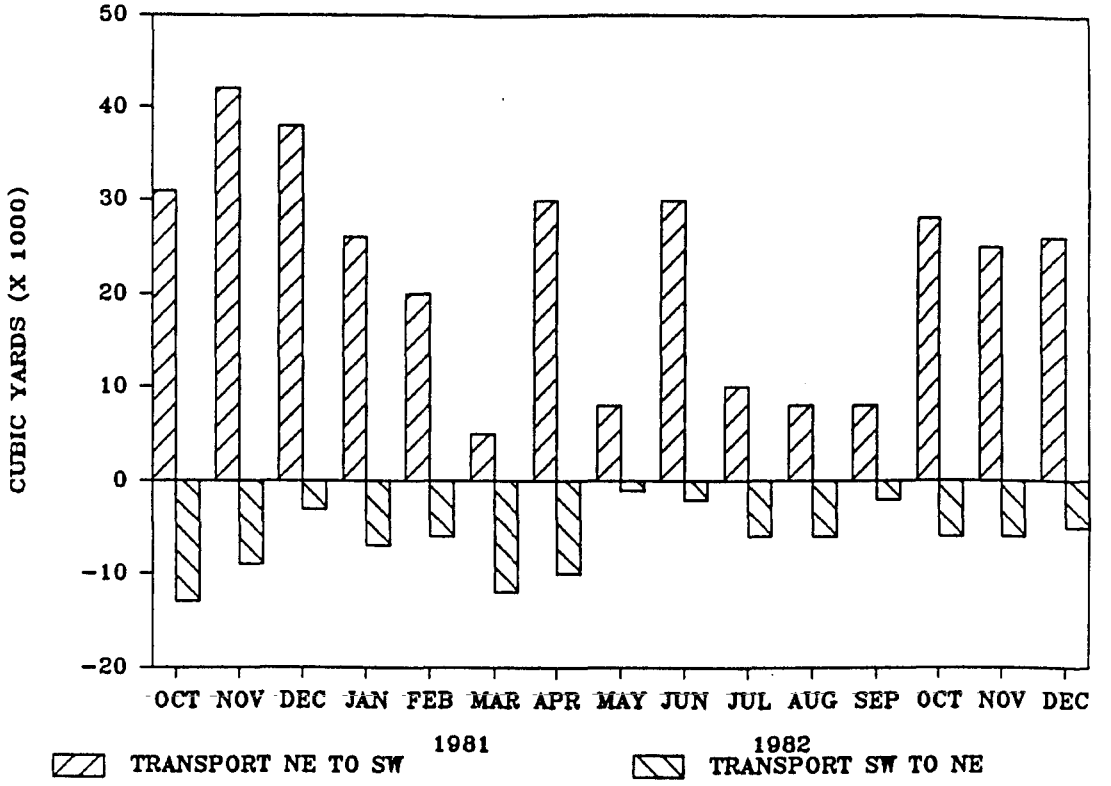


Figure 35. Longshore sediment transport calculated using the SPM method and LEO wave data

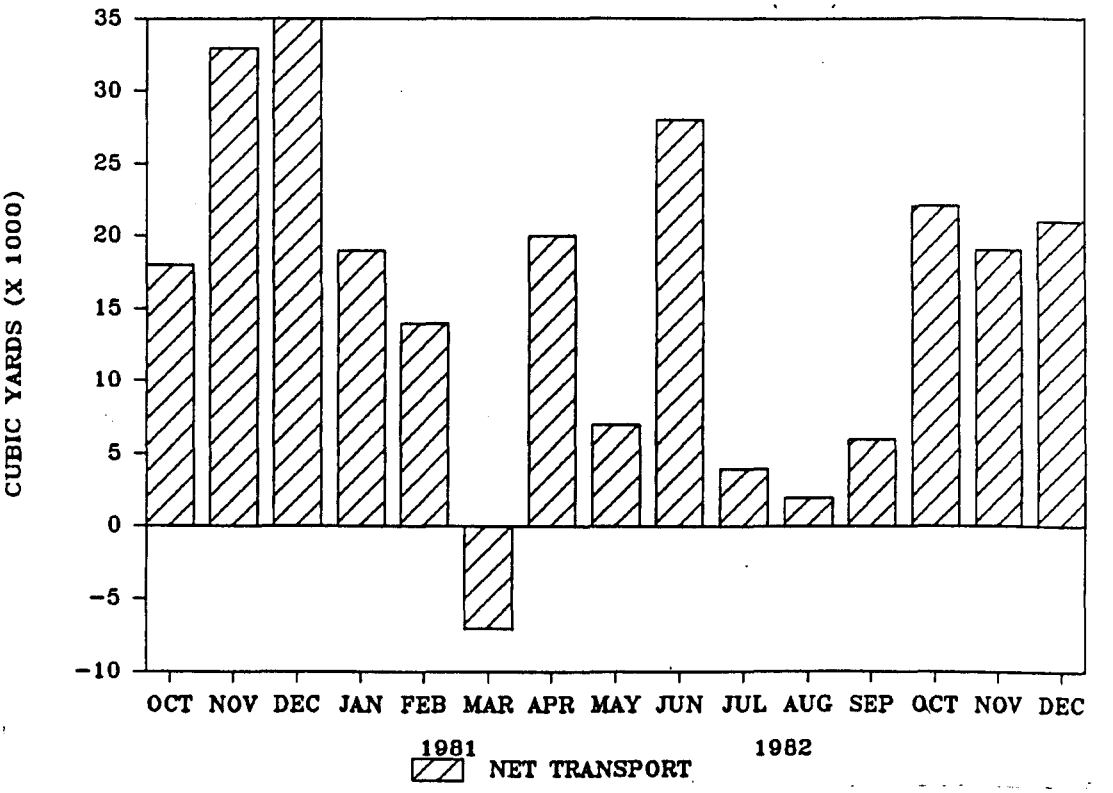


Figure 36. Net longshore transport calculated using the SPM method and LEO wave data

Table 7

Longshore Sediment Transport, LEO

	cu yd/month (× 1,000)	cu yd/year (× 1,000)
Q_{Right}	22.2	266.4
Q_{Left}	-6.2	-74.0
Q_{Net}	16.0	192.0

Table 8

Longshore Sediment Transport, SEAS

	cu yd/month (× 1,000)	cu yd/year (× 1,000)
Q_{Right}	4,000.0	60,000.0
Q_{Left}	-53.0	-636.0
Q_{Net}	3,947.0	59,364.0

LEO and the SEAS data result in large estimates of sediment transport. Because these estimates appear to be large, a different technique was used to obtain estimates which use directional wave information.

Directional wave data calculations

97. Estimates of longshore sediment transport rates were calculated using the results of the directional wave data and small-scale refraction analysis. The directional wave data reported in Part III were used to estimate longshore sand transport rates for the Green Harbor region. To calculate accurate rates of longshore sand transport, the incident wave conditions must be well characterized and the bathymetry accurately known. An empirical equation linking longshore sand transport to breaking wave conditions is also required. There are a large number of these equations available, but because of a lack of overwhelming arguments supporting one method over others, the Komar and Inman (1970) longshore transport formula was applied.

98. Wave data must be simplified for use in computations of longshore transport rates. These simplifications were obtained from summaries of significant wave height and modal periods. Using these data, monthly contours of percent of total monthly energy for various period and direction classes were generated. An example of this technique is shown in Figure 37. For instance,

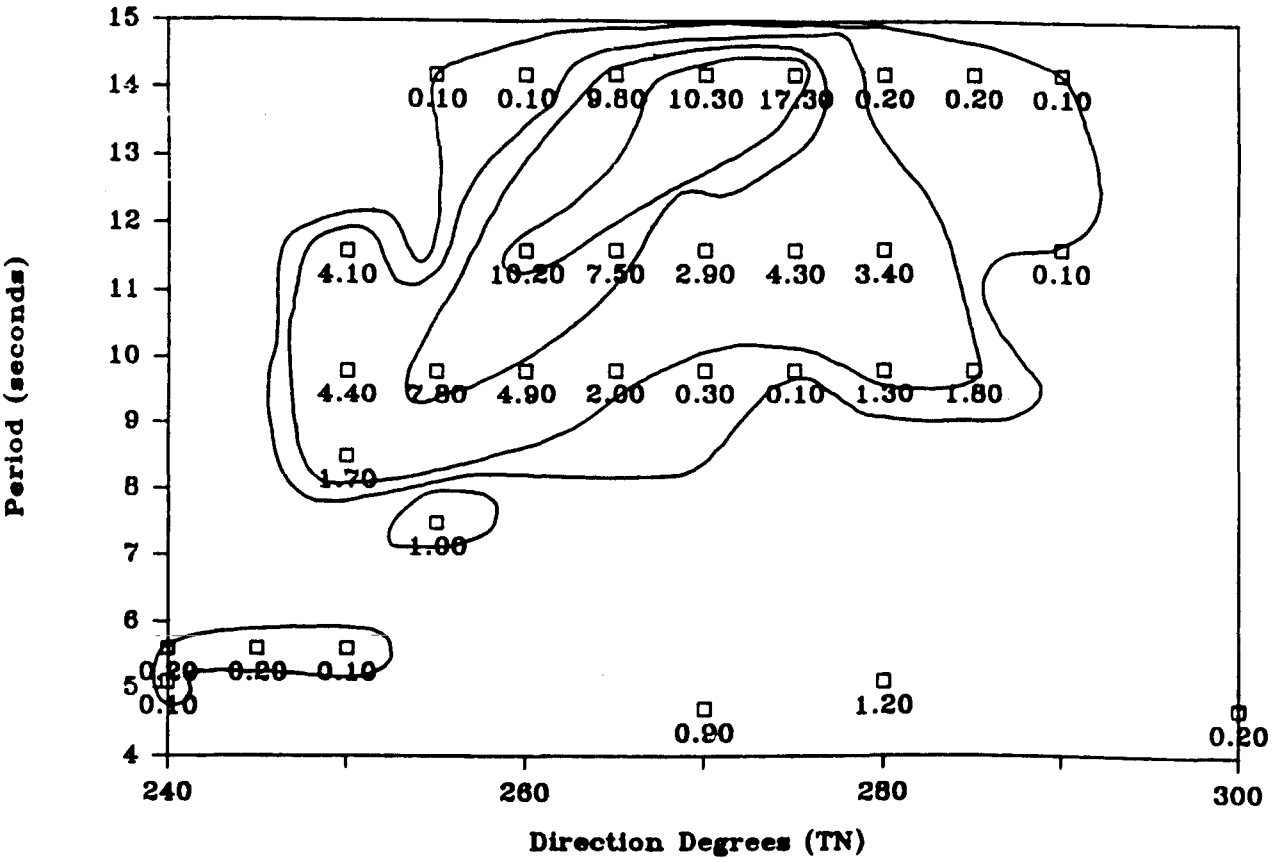


Figure 37. Average values of mean sea surface variance $\langle \eta^2 \rangle = 788$ cm^2 , March 1984

the March 1984 summary shows an average value for the mean sea surface variance $\langle \eta^2 \rangle$ of 788 cm^2. Most of this energy was at low frequency (periods of 10 to 14.2 sec) with direction of propagation of 260 to 280 deg TN. Energy propagation at the lower frequencies is more important than was initially anticipated before obtaining the directional wave data. The direction of wave propagation and time of occurrence coincide with the occurrence of northeast storms which generate the largest waves in the region. Wave data in this form were input into the longshore sediment transport computation. Data for the missing months of January and February were set to the average conditions and to the maximum conditions of March to provide a representative range of sediment transport values and to maintain the continuity of the transport calculations. Even though this technique is based on an empirical algorithm which calculates sediment transport rates, it provides a more accurate estimate because it uses the refracted wave heights and directions as input. Summaries

of recorded directional wave data were used as input to make the sediment transport calculations. Wave input for the sediment transport calculations was not just an averaged condition. Monthly estimates of sediment transport were calculated using incident wave conditions to include storm conditions that occurred during the monitoring period. The location of the refraction grid and the position of the directional wave gage are shown in Figure 27.

99. Using the parameters as input into the longshore transport calculations, values of longshore transport were obtained at the beach (midpoint on the grid) (Figure 27). Because of the position of the grid (on Green Harbor Beach), estimates of sediment transport were obtained for both northeast and southwest directions. These estimates obtained are relevant because sediment is transported back toward the harbor entrance because of wave refraction. These results are summarized in Table 9.

Table 9

Longshore Sediment Transport (Directional Wave Data)

Direction of Transport	Amount of Transport cu yd/year (× 1,000)
Q_{Right} (NE-SW)	19.6 - 32.7
Q_{Left} (SW-NE)	(-5.2) - (-11.8)
Q_{Net} (NE-SW)	14.4 - 20.9

100. Gross longshore transport to the south was calculated to be between 19,600 and 32,700 cu yd/year to the south. Gross northward transport is approximately 30 percent of the gross southerly transport. These estimates are one to three orders of magnitude less than the estimates obtained by the two previous methods. The implications of these calculations will be addressed in the discussion section of this report (Part VI).

Numerical Hydraulic Simulation

101. The hydraulics of the Green Harbor back-bay system were simulated using a numerical model to provide a cost-effective method to evaluate suggested design alternatives. The numerical model, which requires a collection

of tidal current data, is first calibrated to simulate existing conditions. These conditions are then simulated in the model. Once the model accurately simulates the desired hydraulic conditions, the boundary conditions can then be modified to estimate what the hydraulic impact of modifying the system will be. The following steps were used in the numerical simulation:

a. Tidal hydraulic data were collected.

b. Numerical model was calibrated.

c. Existing conditions were simulated.

d. Design alternatives were simulated.

102. The hydraulics of the Green Harbor back-bay and inlet regions were numerically modeled using the "Inlet III" computer model which is a lumped parameter model using spatially integrated equations of motion producing simulations of inlet velocities, discharge rates, and changes in water level elevation. Input for the model includes:

a. Geometry of the inlet region including inlet depths, side slopes, and surface area of the bays.

b. Water level fluctuation (as a function of time) of the sea.

c. Estimates of bottom friction.

The numerical model has provisions for time varying freshwater inflow into each adjoining back bay, thus permitting the simulation of runoff or river inflow. Fluctuation in water level (normally tidal variation) of the sea is the primary forcing process. Water level variation may be input as either a sinusoidal function in which the amplitude and period are specified or as a time-series of water level derived from instantaneous prototype measurements. Model outputs include tables and plots of water levels, velocities, and discharge rates. Specific details concerning the model "Inlet III" can be found in Seelig, Harris, and Herchenroder 1977.

Model Calibration

103. The numerical model was calibrated using one channel and seven cross sections across the inlet. The simple model configuration was used because of the relatively uncomplicated geometry of the Green Harbor inlet back-bay system. An ocean tidal range of 5.35 ft with a period of 12.4 hr was used as a sinusoidal forcing function in the model. Bay surface areas were determined by digitizing topographic maps obtained from the Marshfield town

engineer. Bathymetry in the back bay, the Cut River, the inlet, interjetty region, and the region immediately offshore were obtained from NED's pre- and postdredging bathymetric surveys. Inlet geometry was measured during the initial tidal data collection effort.

104. The numerical model was calibrated using data obtained during the 1981 field data collection effort. Simulated and prototype water level elevations and average and maximum velocities are plotted in Figures 38, 39, and 40. The data plotted in Figure 38 are recapitulated in Table 10. As shown in Table 10, the prototype data are closely simulated by the sinusoidal input. Figure 38 shows that there is a progressive phase difference between the prototype and simulated water elevations because the high and low water at Green Harbor do not repeat every 12.4 hr but incrementally progress forward in time because of the difference between solar and lunar days. The progressive phase difference is not a major modeling consideration because maximum ebb- and flood-tide velocities over relatively short time periods (2-3 tide cycles) are simulated by the model runs.

105. The simulated depth-averaged velocities are compared to the depth-averaged prototype data in Figure 39. Simulated velocities in Figure 39 have been depth-averaged within The Narrows. This simulation does not provide the best indication of maximum velocities that occur within the inlet throat. However, it does provide a good indication that the overall hydraulics of the inlet are being simulated. These data are presented in Figure 39 and Table 11. The model closely simulates the spatially averaged velocities. It was concluded from this comparison that the overall hydraulics of the Green Harbor interjetty region were being adequately simulated (Table 11 and Figure 39). The model verification procedure also compared the prototype and simulated maximum velocities obtained within The Narrows. This comparison is shown in Table 12. The maximum prototype velocities shown in Table 12 are the maximum bottom velocities that were measured hourly during the 1981 field data collection effort. The hourly prototype and simulated maximum values are plotted in Figure 40. A comparison of the data contained within Table 12 and Figure 40 shows that the simulated maximum bottom velocities produced by the model are slightly underpredicted. This underprediction is to be expected because the model calculates a depth-averaged velocity, while the prototype velocities are maximum bottom velocities measured in the deepest portion of The Narrows.

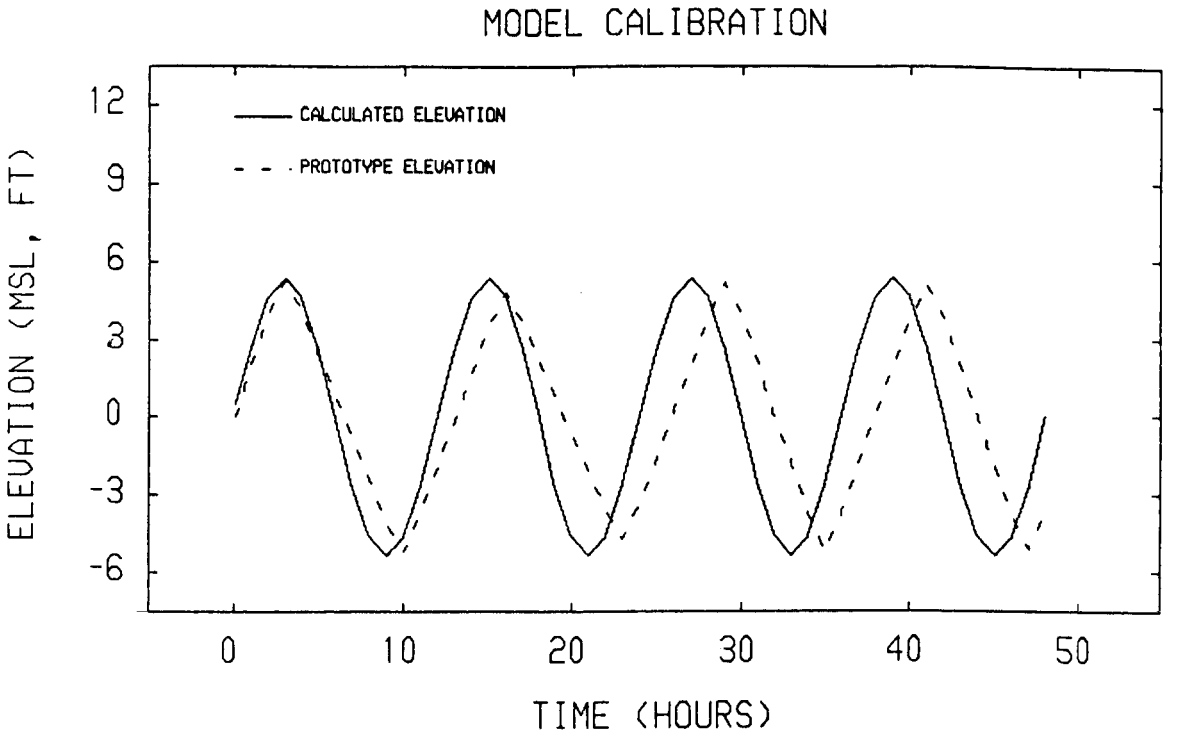


Figure 38. Prototype and simulated tidal elevation comparison

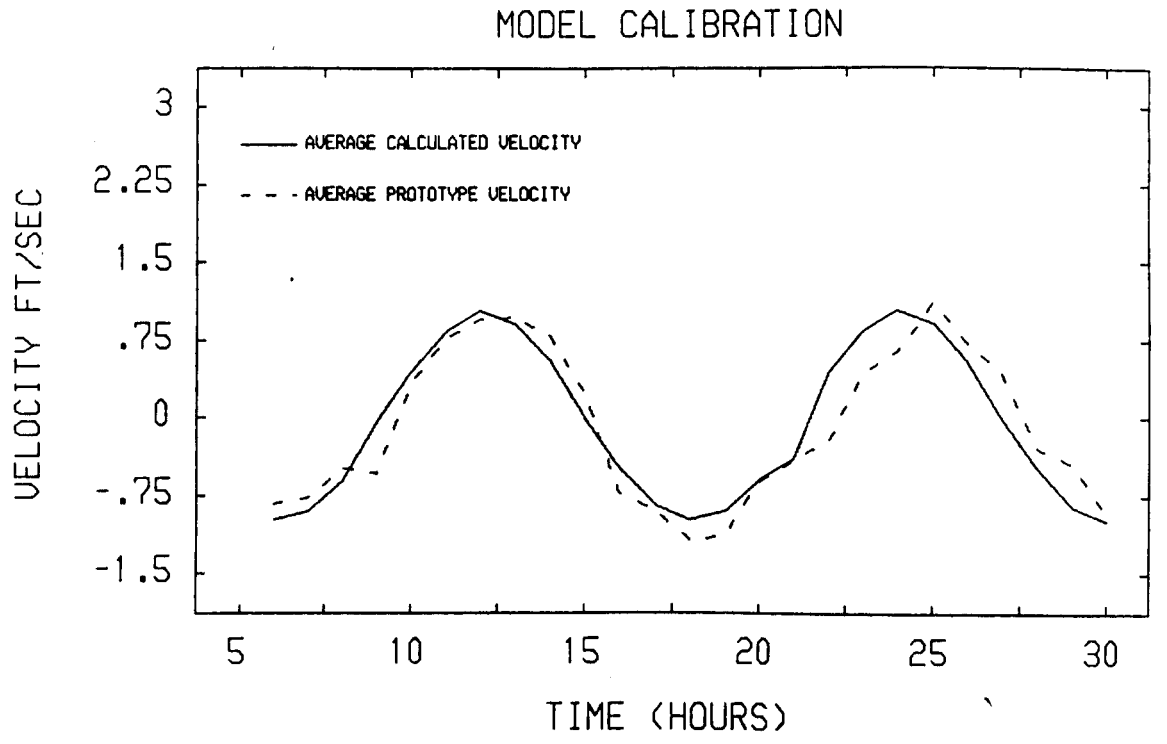


Figure 39. Prototype and simulated depth-averaged velocity comparison at the inlet throat

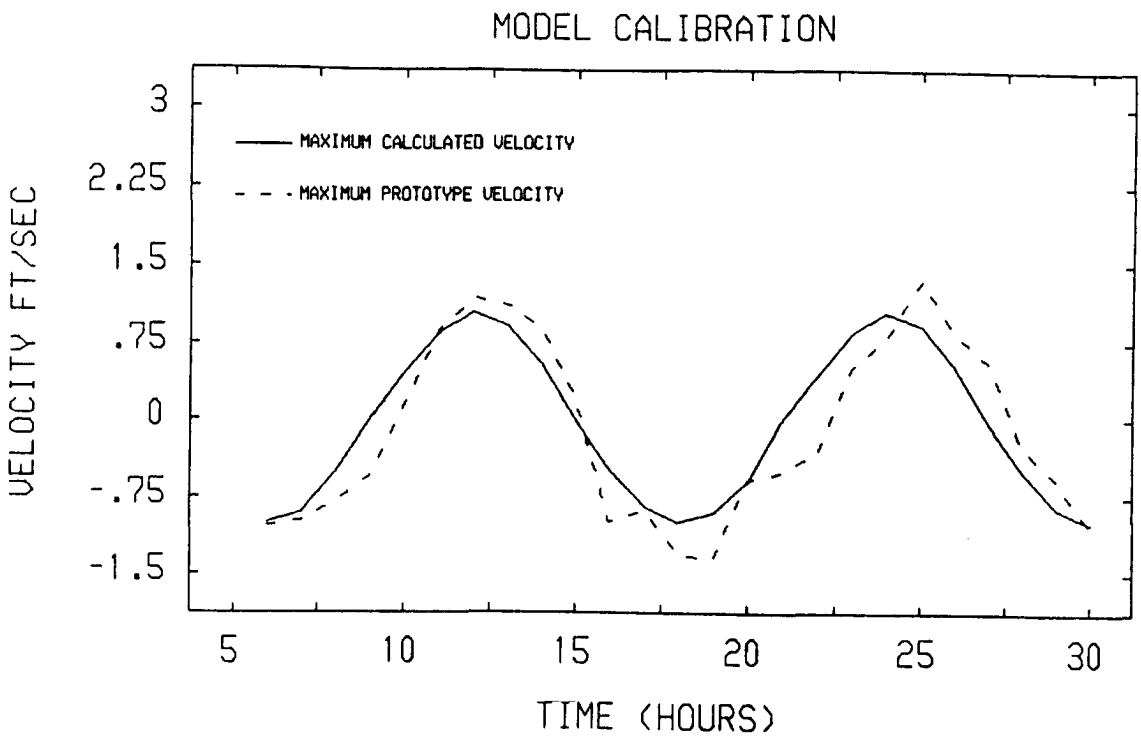


Figure 40. Simulated and prototype maximum velocity comparison at the inlet throat

Table 10

Model Calibration*

Model				Prototype			
Time hr	Maximum Elevation ft	Time hr	Minimum Elevation ft	Time hr**	Maximum Elevation ft	Time hr	Minimum Elevation ft
3.0	5.3	9.0	-5.3	3.05.3	10.0	-5.2	
15.0	5.3	21.0	-5.3	16.0	4.8	23.0	-4.7
27.0	5.3	33.0	-5.3	29.0	5.2	35.0	-5.2
39.0	5.3			41.0	5.1		

* Elevations referenced to msl.
** Prototype time adjusted to model time base.

Table 11

Model Calibration Spatially Averaged Velocities*

Model				Prototype			
Time hr	Maximum Velocity	Time hr	Minimum Velocity	Time hr**	Maximum Velocity	Time hr	Minimum Velocity
--	--	6.0	-0.98	--	6.0	-0.83	--
12.0	1.03	18.0	-0.98	13.0	0.97	18.0	-1.18
24.0	1.03	30.0	-0.98	25.0	1.11	30.0	-0.90

* Velocities in feet per second.
** Prototype time adjusted to model time base.

Table 12

Model Calibration Maximum Velocities*

Model				Prototype			
Time hr	Maximum Velocity	Time hr	Minimum Velocity	Time hr**	Maximum Velocity	Time hr	Minimum Velocity
--	--	6.0	-0.99	--	6.0	-1.02	--
12.0	1.03	18.0	-0.98	12.0	1.17	19.0	-1.35
24.0	1.03	30.0	-0.99	24.0	1.35	30.0	-1.02

* Velocities in feet per second.
** Prototype time adjusted to model time base.

106. Model calibration shows that the magnitude of the depth-averaged current regions is closely simulated by the Inlet III model. A detailed description of the operation and model calibration procedures are given in a report by Seelig, Harris, and Herchernroder (1977).

Numerical Simulation

Training structure evaluation

107. The Inlet III model was used to simulate the hydraulic conditions that would exist if modifications were made to the interjetty region. Several

specific design alternatives were evaluated. The first modification evaluated was the hydraulic effect of adding a training structure, proposed by Tippetts et al. (1980), to be constructed within the interjetty region extending from The Narrows to the terminus of the west jetty (Figure 41). It would have a variable elevation and be located on the east side of the entrance channel inside the existing east jetty. The training structure would parallel the west jetty, forming a linear entrance structure exposed at mlw, but would be largely submerged at mean high water (mhw) having an el of 0.0 at mlw extending to the end of the west jetty. The outer portion of the structure would taper up from mlw to equal the height of the existing east jetty and extend past the end of the east jetty until the training structure and the west jetty were the same length. Essentially, the structure would be a submerged (at high water) jetty parallel to the west jetty constructed within the existing jetty region. The seaward end of the training structure would have an elevation equal to that of the west jetty, thereby eliminating the length differential between the existing stone east and west jetties. Tippetts et al. (1980) concluded that the maximum ebb velocity would be increased by the training of the ebb tidal flow between the structures. At the same time, the maximum flood flow would be decreased by permitting the total interjetty region to become flooded once the training structure was submerged.

108. The numerical model was modified to simulate the hydraulic conditions of the interjetty region modified by construction of the training structure. Results of the numerical simulation are shown in Figure 42. The maximum simulated depth-averaged flood velocity was 1.27 ft/sec, while the maximum depth-averaged ebb velocity was 1.24 ft/sec representing an increase in velocity of approximately 17 percent.

Cut River jetty evaluation

109. The rebuilding of an inlet pile jetty at the Cut River mouth had also been suggested as a means of reducing shoaling in the entrance channel. At present only the piles of the old jetty remain. The model was modified to accept the Cut River as a second inlet. The back-bay surface area contained within the Cut River basin was subtracted from the total surface area and then portioned to the Cut River inlet system. The model velocity simulation was compared to the prototype velocity measurements taken at the Cut River. Maximum flood velocity was simulated at 0.26 ft/sec, while minimum velocity was -0.33 ft/sec. Maximum measured velocities at the mouth of the Cut River were

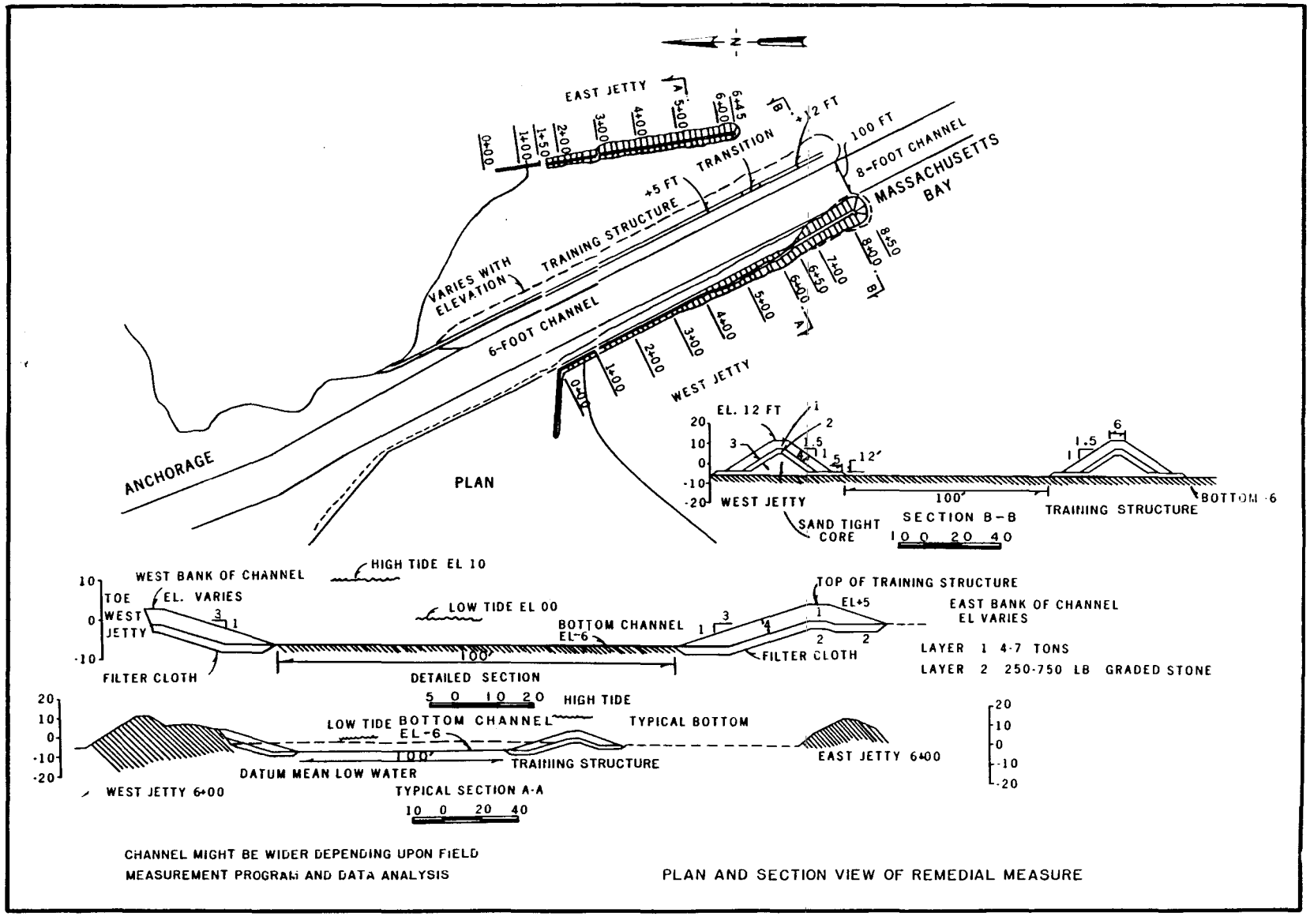


Figure 41. Proposed training structure suggested by Tippetts et al. (1980)

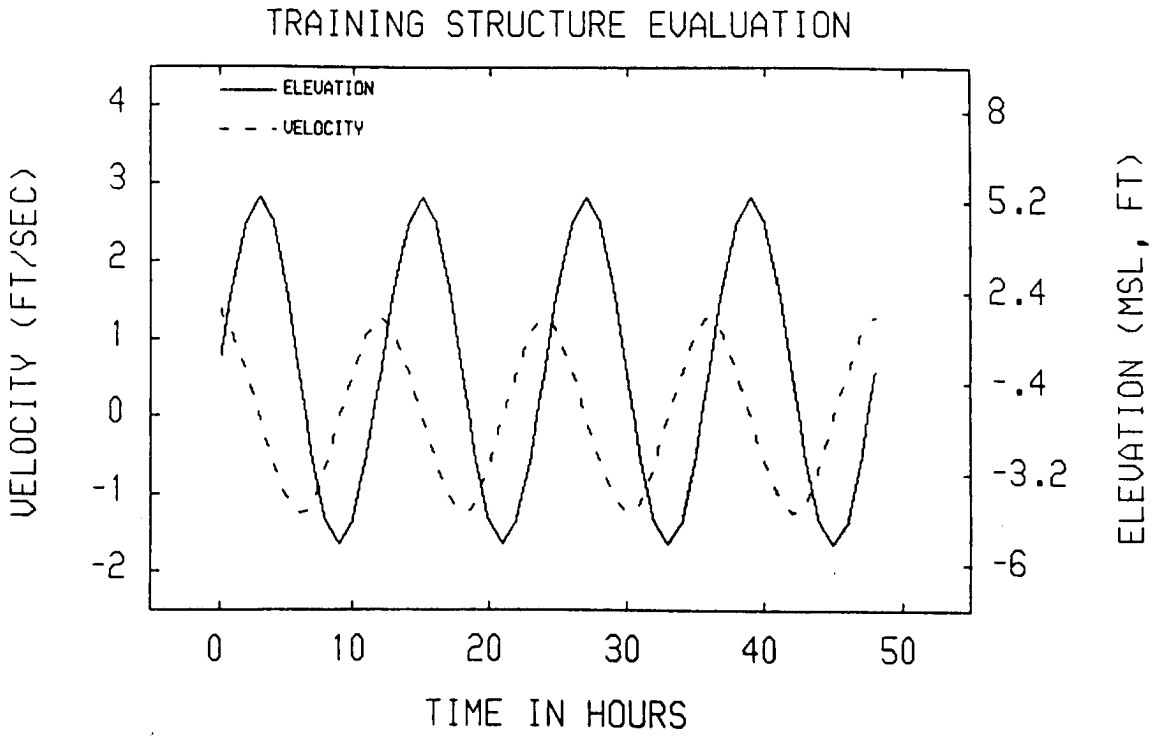


Figure 42. Numerical simulation showing changes in velocity and discharge resulting from proposed training structure

under 0.2 ft/sec (below the threshold of the sensor) and were recorded as zero. The numerical simulation overpredicts the velocity in the Cut River; however, these velocities are not sufficient to transport sediment.

110. The initial simulation was completed using a spring tidal range. In order to evaluate what the effects of an overtide (northeaster) would have on the velocities at the mouth of the Cut River, the model inputs were modified to simulate overtide conditions. The back-bay area was redigitized using the +5 ft (above mhw) contour simulating the increase in water elevation that might occur during northeasters. The results of the simulated model run for the Cut River are shown in Figure 43. The maximum and minimum velocities in the Cut River for these overtide conditions are 0.61 (18.6 cm/sec and -1.01 ft/sec (-30.8 cm/sec), respectively. Threshold unidirectional velocities required to transport ambient sediment in the channel range from 25 to 30 cm/sec. As shown, velocities increase to the threshold condition only during a peak event and for only a brief period of time. The corresponding hydraulic conditions occurring in The Narrows are shown in Figure 44. The maximum and minimum simulated velocities are 3.99 and -4.26 ft/sec, respectively.

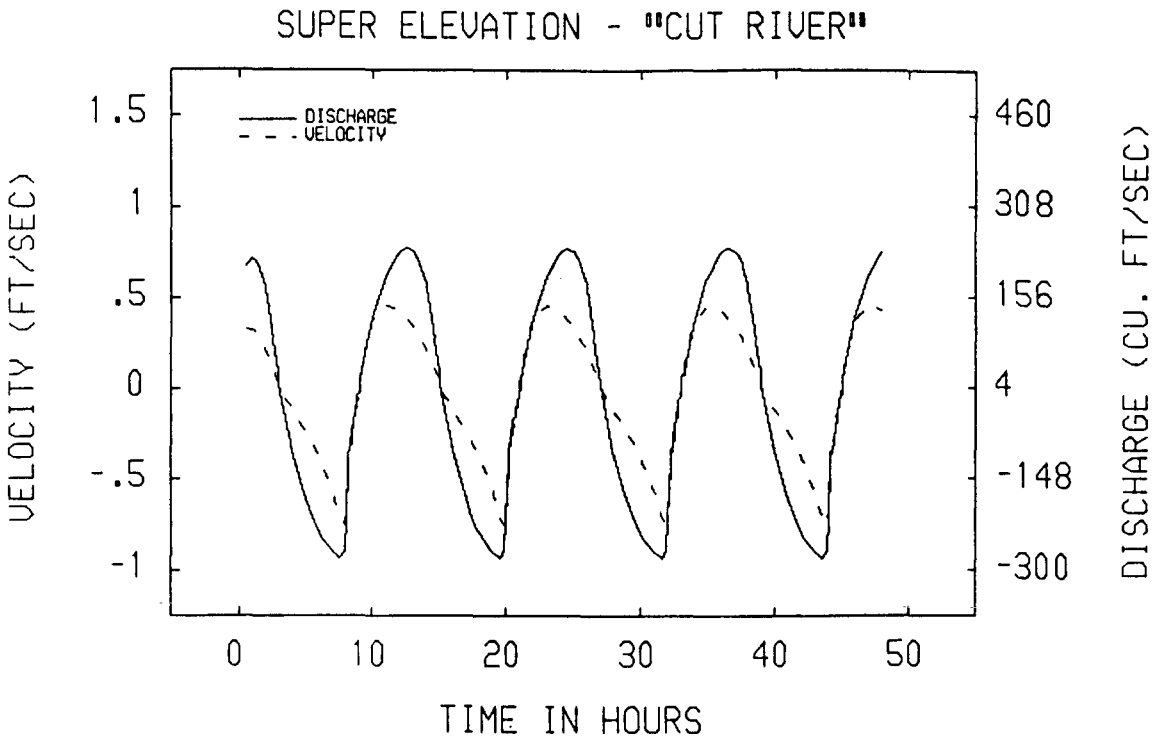


Figure 43. Numerical simulation showing the effects of super elevation at the mouth of the Cut River

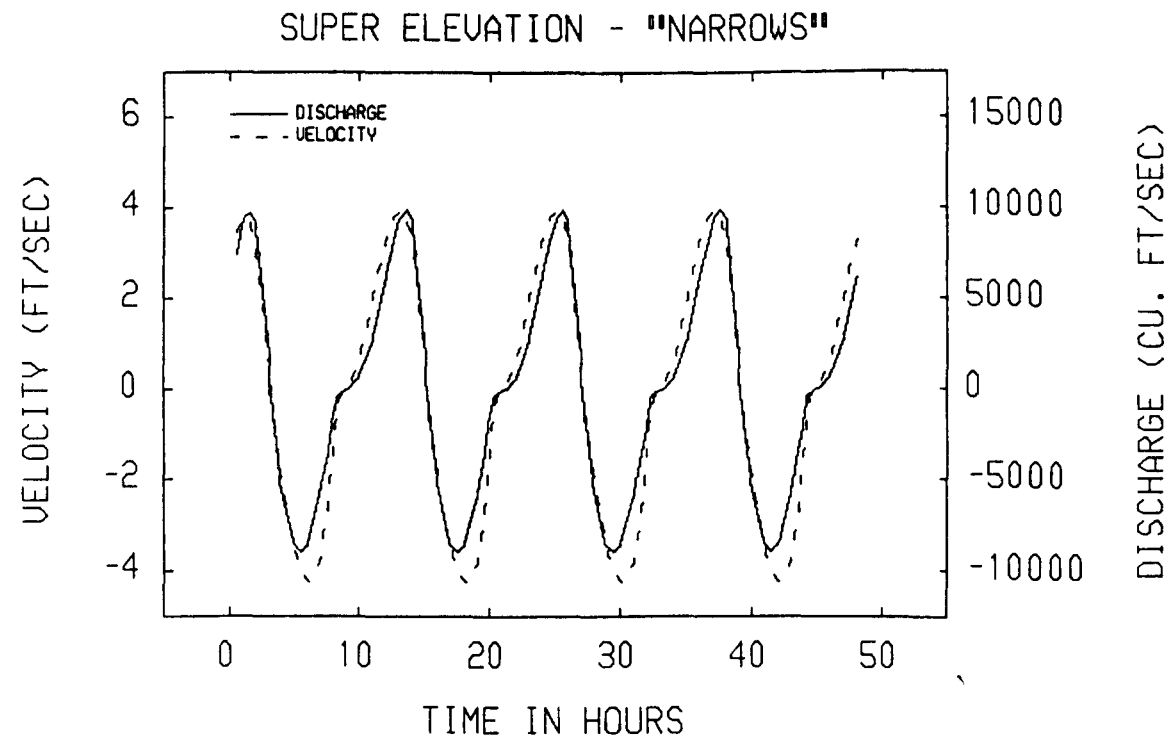


Figure 44. Numerical simulation showing effects of a super elevation at The Narrows (with Cut River jetty)

111. Simulated velocities in the Cut River and The Narrows show increased velocity for northeaster conditions. In addition, the numerical simulation showed no increased flushing because of the half training wall. This structure had little effect on the overall system during the maximum conditions simulated in the numerical model. It should be noted that even though a sinusoidal forcing function was used, the ebb velocities are stronger than the flood velocities in both the Cut River and The Narrows. Hypothetically, then, the Green Harbor system is ebb dominated. However, even though this hypothesis cannot be verified without additional data, it does not adversely affect the results of the present study.

PART VI: DISCUSSION

112. This multifaceted study was begun as an engineering evaluation of a small New England inlet. CERC was asked to provide recommendations for mitigating the inlet entrance shoaling problem. The study approach was to measure and model existing conditions and then evaluate possible design alternatives. Three specific tasks had to be accomplished to perform the requested engineering evaluation. The first task was to obtain a characterization of the currents in the interjetty and inlet entrance regions. The tidal current data obtained outside the jetty entrance provided insights into the magnitude and direction of tidal currents which occur in this region. These data also provided calibration input for the numerical model. This model was used to provide a diagnostic evaluation of proposed inlet modifications. The second task was to determine or characterize the wave climatology of the study area. These data were obtained to provide information about the average (background) and storm wave conditions within this region. The third and most difficult task was to estimate the rates of longshore sediment transport which occur within the study area.

113. Green Harbor is a geomorphically complex region with three dominant offshore sedimentary environments. The innershelf deposit consists of fine sand with scattered rocks in the offshore region. The intermediate region consists of fine sand "streamers" on a poorly sorted cobble horizon which may consist of glacial till surfaces. The third region is a glacial till outcrop with minimal reworking and little or no sand. Close to shore, the bottom is characterized by two distinct environments north and south of the inlet. North of the inlet bedrock crops out in a few locations. These outcrops occur between glacial till horizons which are intermixed with occasional streamers of fine sand. South of the inlet, the bottom is covered with fine sand. This zone of fine sand is shore parallel and extends from Green Harbor jetties to Gurnet Point.

114. Tidal elevations and currents were measured at The Narrows over a 2-day period, 23-24 September 1981. Measurements were obtained during a spring tidal cycle in order to determine the range of maximum current velocities that occur and to obtain data for model calibration. Maximum bottom ebb and flood velocities measured were -1.35 and +1.35 ft/sec, respectively. Tidal elevations were measured outside the Green Harbor jetty region and at

the town dock. Maximum elevations were 5.35 and -5.20 ft (referenced to NGVD) for flood and ebb conditions. No phase lag was measured between the two sampling locations.

115. Directional wave spectra were measured over a 1-year period beginning 15 June 1983 and ending 1 June 1984. Three northeasters were monitored, including the one on 29-31 March 1984 which produced significant wave heights exceeding 3 m. The dominant wave period during these large storms was in the 10- to 12-sec range. Table 13 briefly summarizes each of the deployment periods. A synopsis of the most energetic events is presented in Table 14. The dominant storms propagate from 250 to 277 deg TN with a significant wave period exceeding 12 sec.

116. Mach-stem wave reflection was detected through an examination of aerial photographs. A trapped wave which travels along a structure with its maximum height at the structure, the mach-stem wave resulted from wave

Table 13

Summary of Directional Wave Measurements

Deployment Period	$\overline{H}_{1/3}$, m	$\overline{T}$, sec	Dominant Direction, deg TN
15 Jun to 14 Aug 1983	0.12	10.0	260
26 Aug to 27 Oct 1983	0.32	9.0	260
10 Nov to 14 Dec 1983	0.47	9.1	260
23 Feb to 1 Jun 1984	1.0	10.0	269

Table 14

Summary of Storm Data

Deployment Period	Date	$\overline{H}_{1/3}$, m	$\overline{T}$, sec	Dominant Direction, deg TN	$\langle\eta^2\rangle$, cm^2
1	24-25 Oct 83	1.86	12.8	239-227	2,160
2	15-16 Nov 83	2.00	12.8	--	2,500
3	4-5 Dec 83	2.00	12.8	--	2,500
4	29-31 Mar 83	3.34	12.8	268	6,900

scattering on the long west jetty. The existence of mach-stem waves was confirmed through a simple numerical calculation using the dominant wave angle of approach determined from the directional wave data and the jetty orientation.

117. Longshore sediment transport calculations were initially evaluated using LEO and SEAS data. The results of these estimates were then compared to the volumes of material that had been dredged from the entrance channel at Green Harbor. The quantities of sand dredged from Green Harbor are shown in Table 15. These values have been averaged over a 16-year period beginning in 1968. Values shown in Table 15 do not represent the total sediment transport which occurs within the region. However, the quantities of sediment obtained from dredging records that have been averaged compare favorably with the rates of sediment transport which were calculated using the directional wave data (Table 9).

Table 15

Average Yearly Dredged Quantities

Location	Quantities, cu yd/year
Outer shoals	9,300
The Narrows	10,800
	Total 20,100

118. This magnitude of shoaling is large enough to cause an annual shoaling problem for boating traffic; it is fairly small when compared to the longshore sediment transport estimates obtained using LEO and SEAS wave data.

119. Two major simplifications involved in the longshore transport calculations are the assumption of a monochromatic wave field approaching a shoreline with straight, parallel contours and an adequate source of sediment. The first condition was not satisfied in this region, nor was it possible to obtain a better definition of the directional wave climate from the LEO data. Therefore, a directional wave gage was installed to provide the necessary data. The assumption of a uniform sediment source was clearly not true in this region. An examination of Figure 30 clearly shows a lack of sediment along the shore available for transport north of Brant Rock. Diver observations of the bottom offshore revealed conflicting results. In some regions there appeared to be sand, but attempts to obtain short cores were

unsuccessful because of resistance in the substrate. This occurrence was consistent with information obtained in the literature review which suggested that there are two widely divergent bottom regions: one to the north of the inlet where the bottom is characterized by rocky outcrops and little sand and one to the south that could be characterized by wide sandy deposits with few, if any, rocky outcrops. Two questions that remained unanswered to this point were the location of the zone of demarcation and the extent of sand deposits to the north of the inlet. While the initial analysis was being performed, NED was reporting an increase in cobbles of all sizes in the Green Harbor entrance channel. In order to answer the questions posed above, detailed bathymetry, side-scan sonar, and high-resolution subbottom profiles were obtained. These data were used to generate bottom contour and surficial sediment maps (Figures 27 and 28). Results confirmed that there were two widely divergent bottom regions. The region to the north of the inlet entrance is characterized by rocky outcrops and little sand, while the region to the south is characterized by wide sandy deposits with few, if any, outcrops of rock.

120. The results obtained from the three sediment transport calculations were widely divergent, differing by four orders of magnitude. The SEAS data were used for comparative purposes only, since wave height values generated are for the open North Atlantic coast. Several reports have used these data as input for studies within Massachusetts Bay. The sediment transport calculations obtained using SEAS data clearly demonstrate a misapplication of these data. The longshore sediment transport calculations derived from directional wave data represent the most accurate estimate of the yearly sediment transport that occurs in the region of the inlet. The average estimated sediment transport calculated using directional wave data reported in Table 9 is Q_{SW-NE} = 8,500 cu yd/year, while Q_{NE-SW} = 26,150 cu yd/year, resulting in a net transport to the south of 17,650 cu yd/year.

121. Numerical model Inlet III was used to model the hydraulic response of the Green Harbor back-bay inlet system with field measurements of current velocity and tidal elevation. It was used not only to test two suggested alternatives to reduce shoaling at Green Harbor but also to evaluate the hydraulic effects of the inlet. The model was first used to simulate velocities that would occur if a training structure were built to reduce the adverse effects of the arrowhead jetty configuration and those that would occur during an overtide condition frequently occurring during northeasters. Introduction

of the training structure would increase the maximum depth-averaged ebb tidal velocity from -0.99 to 1.24 ft/sec in the inlet throat. The maximum depth-averaged flood velocity would increase from 1.03 to 1.27 ft/sec. It was determined that the increase in channel flushing is not sufficient to justify the construction of a structure that would be submerged at high tide and exposed at low tide.

122. The reconstruction of the jetty in the mouth of the Cut River will not significantly increase or decrease ebb or flood velocities in The Narrows. This structure does not redirect or rechannel the flow from the Cut River toward The Narrows as was initially reported. The jetty most likely provides bank protection by preventing the channel from actively cutting the bank on its back side. However, there is little flow to divert during a normal tidal cycle. During the overtide simulations, the model simulated velocities on the order of 1.0 ft/sec; in the Cut River the velocities in The Narrows are on the order of 4.3 ft/sec. The model showed no increase in velocity with the introduction of the jetty. Therefore, it was concluded that neither does the jetty provide increased flushing during northeasters nor does it have any positive hydrodynamic effect during storm conditions.

123. Sediment size analysis identified several interesting trends. The mean grain size increased along a traverse line from the back-bay region to the mouth of the jetties. The sediment size ranged from a fine sand (0.09 mm) in the back bay to 0.21 mm in the interjetty region. The remaining sediment samples were either in the cobble or fine sand range. Offshore and to the north of the inlet entrance cobbles were normally found. No cobbles were found in the interjetty region even though there has been a reported increase in the number of cobbles dredged from this region.

124. Calculated rates of sediment transport and the averaged volumes of material dredged from Green Harbor are extremely close. It is unreasonable to assume that 100 percent of the net sediment transported in the region adjacent to the harbor is trapped inside the harbor entrance. Therefore, potential sources of sediment were identified for each of the two major shoal regions inside the jetty entrance. These estimates incorporate sediment that is transported into the harbor (part of the longshore sediment transport) and sources within the jetty region, such as erosion of the exposed bank landward of the northeast jetty. Potential sources of shoaling material for the inner and outer shoal regions were defined using the directional wave data and

estimated dredged volumes obtained from NED. Potential sources for both the inner and outer shoal regions are listed in Table 16.

Table 16

Potential Shoaling Sediment Sources

Potential Source	Outer Shoal cu yd/yr (× 1,000)	Inner Shoal cu yd/yr (× 1,000)
Direct wave action from offshore sources	8	--
Sand transport around southwest jetty	2	--
Wave reflection off southwest jetty (transport from outer to inner shoal and off inner beach)	--	13
Windblown	--	1
Wave overtopping of northeast jetty	--	Undefined

125. The results listed in Table 16 are estimates which reflect an extremely limited source of sand-sized material directly offshore and to the north of Green Harbor. Of the average 8,500 cu yd of sediment transported from the south toward the inlet, 90 percent is being transported around the southwest jetty to the outer shoal. However, the amount of material will increase as the shoal expands (because of wave refraction) at Green Harbor Beach. Approximately 8,000 cu yd of material are transported directly into the inlet from offshore sources. The mechanism for transporting the sand-sized material is the refraction of waves at the entrance mouth. Refraction analysis showed that long period waves approaching the harbor entrance from the north are refracted by offshore bathymetry. Refraction turns the waves until they either can directly enter the entrance channel or are reflected off the west jetty. These waves transport sand-sized and a limited amount of cobble-sized material into the entrance channel. It is indeed fortunate that there is relatively little material available for transport directly offshore and to the north of the inlet.

126. The potential source of material resulting from wave reflection off the west jetty is a combination of sand being transported toward

The Narrows by reflected mach-stem waves and by erosion of the inner beach region by the breaking of the reflected waves directly onto the "inner-beach region" located landward of the interjetty region on the northeast side of the inlet. It must be realized, however, that the majority of the sediment is made available for transport into Green Harbor by storm events. Although wave attack in this region (even during relatively low energy conditions) is a direct result of the 1969 extension of the west jetty, significant shoaling occurs only during storm conditions. During extreme storms wave setup increases water levels such that the jetties are completely submerged. Therefore, during times of high sediment transport, reflection off the jetties is minimal. The situation is further aggravated by wave refraction over the local bathymetry.

127. The last two potential sources of sand (wind and waves) have been defined but are difficult to quantify. Sand transported by aeolian process is a definite factor in this region. On the beach and low tide beach regions sand is well sorted and when dry can easily be transported. In addition, sand on the wetted intertidal beach is readily available for aeolian transport under the following sequence of events. The wind blows dry the uppermost grain surface layer and removes the dried surface grain exposing another wetted grain to be dried and transported. Normally, this process is hindered by grain interlocking because of the interaction of large and small grains which is totally absent in this region because of the size composition of the sand. Clouds of sand have been observed being transported off the wetted intertidal beach toward the harbor. This source is relatively small and is easily controlled through artificial and natural barriers such as sand fencing and the planting of dune grass.

128. The second source is from waves overtopping the northeast jetty. During large northeast storms, waves overtop the east jetty and break onto the inner beach region. The breaking waves transport cobbles and sand from the small sand and cobble beach on the seaward side of the jetty into the channel. In addition, the breaking waves erode and transport material (sand and cobbles) from the inner beach banks into the channel. This condition arises only during the largest storms but has the potential for transporting significant quantities of sand and cobbles in a relatively short period of time.

PART VII: CONCLUSIONS AND RECOMMENDATIONS

129. Sediment transport within Green Harbor inlet/back-bay system at present is a wave dominated process. Wave energy is transmitted into the interjetty region by direct propagation, wave reflection, and wave refraction. This combination of wave forces is the primary process responsible for the shoaling at Green Harbor. Direct transmission of wave energy occurs as waves enter the interjetty region from offshore. Wave energy is also transmitted into the interjetty region during storm conditions by overtopping of the east jetty. Wave reflection and refraction are responsible for transporting sediment around the west jetty and for redistributing sediment within the interjetty region. Tidal currents combine to interact with the wave processes to redistribute sediment within the interjetty region. There is no evidence of sediment being transported through The Narrows and forming a flood-tidal shoal. Peak tidal flows are of sufficient strength to initiate sediment motion and to transport sediment; however, these velocities are maintained only during a small portion of the tidal cycle. Reduced tidal flows result primarily from the limited storage area in the back-bay region.

130. Historically, Green Harbor has maintained an actively migrating entrance channel with a controlling depth of approximately 3 ft mlw. Construction of the entrance jetties stabilized the inlet location. Construction of the dike reduced the back-bay storage area, thus reducing the maximum velocities which occur within The Narrows. The lengthening of the southwest jetty is responsible for increased wave reflection and wave diffraction within this region. However, regional refraction has been increasing the fillet on the west side of the west jetty. Sand has been continually transported into the lee of the west jetty by refracted waves and has subsequently been trapped there resulting in the accretion of the lee side fillet and a decrease in depth along the entire length of the west side of the west jetty. Offshore sediment transport at Green Harbor is geomorphically controlled. To the north of the harbor entrance little, if any, sand is available for transport. Brant Rock forms an effective sediment transport barrier to the north. To the south of the harbor entrance there is sand in the offshore and nearshore regions, but the majority of this sediment is not transported because of the fetch-limited conditions which occur within Massachusetts Bay.

131. Considering the facts presented herein, the following recommendations are made:

a. Reduce the west jetty lee side fillet which is partially responsible for building of the entrance shoal through dredging.

b. Raise the elevation and tighten the east jetty to minimize wave overtopping during storms.

c. Eliminate or reduce the length differential between the east and west jetties to accomplish the following:

(1) Elimination or minimization of mach-stem reflected waves which build the entrance shoal.

(2) Minimization of erosion on the east side of The Narrows, thus reducing the quantities of sediment available to shoal at The Narrows.

(3) Reduction of overall reflected wave energy during storms, thus providing safer boating conditions.

(4) Reduction of storm damage to the west jetty.

d. Riprap the east Narrows in the interjetty region to reduce erosion and sediment transport in the interjetty region.

e. Implement a beach grass planting program, augmented with sand fencing, for the dune region adjacent to Green Harbor Beach. The combination of beach grass and sand fencing should minimize the quantities of sand transported into the interjetty region by aeolian processes.

132. It is recommended that these solutions be applied through a time phased implementation plan that will minimize costs by permitting evaluation of each mitigating recommendation as it is implemented. The implementation of these recommendations will require an engineering analysis to determine specific design parameters. When the implementation plan is completed, shoaling of the entrance and within the interjetty region at Green Harbor will be greatly reduced. However, the basic problem of shoaling will always occur in order to maintain a small channel cross-sectional area.

REFERENCES

Aubrey, D. G., Twichell, D. C., and Pfirman, S. L. 1982. "Holocene Sedimentation in the Shallow Nearshore Zone Off Nauset Inlet, Cape Cod, Massachusetts," Marine Geology, Vol 47, pp 243-259.

Brenninkmeyer, B. P., Huidoboro, P., and Wood, L. 1979. "Evaluation of Specific Coastal Structures in Marshfield, Plymouth, and Oak Bluffs, Massachusetts," Technical Report No. 79-1, Department of Geology, Boston College, Boston, MA.

Chute, N. 1965. "Geologic Maps of the Duxbury Quadrangle, Plymouth County, Massachusetts," US Geological Survey, Quadrangle Map GQ-466, US Geological Survey, Washington, DC.

Downes, T. 1981. "Growth of a Complex Tombolo: Duxbury Beach and Saquish Neck, Massachusetts," Masters Thesis, Boston College, Department of Geology and Geophysics, Boston, MA.

Fay, Spofford, and Thorndyke, Inc. 1959 (Nov). "Report on Silting of Navigation Entrance, Green Harbor, Marshfield, Massachusetts," prepared for Town of Marshfield and Green Harbor Basin Committee, Boston, MA.

Flint, R. 1971. Glacial and Quaternary Geology, John Wiley and Sons, Inc., New York.

Folk, R. L. 1965. Petrology of Sedimentary Rocks, Hemphill Press, Austin, TX.

Komar, P., and Inman, D. 1970. "Longshore Sand Transport on Beaches," Journal of Geophysical Research, Vol 75, No. 30, pp 5914-5927.

O'Hagan, R. M. 1974. "Comprehensive Waste Water Report for the Town of Marshfield, Massachusetts," Coffin and Richardson, Inc., Boston, MA.

O'Hagan, R. 1976 (May). "Comprehensive Drainage Report for the Town of Marshfield, Massachusetts," Coffin and Richardson, Inc., Marshfield, MA.

Report of the Joint Board Consisting of the Harbor and Land Commissioners and the State Board of Health, Upon the Restoration of Green Harbor in the Town of Marshfield, Massachusetts. 1898 (Jan). Chapter 495, Acts of 1896, Chapter 98, Resolves of 1897, Wright & Potter Printing Co., Boston, MA.

Schlee, J., Folger, D., and O'Hara, C. 1973. "Bottom Sediments of the Continental Shelf of the Northeast United States Coast, Cape Cod to Cape Anne, Massachusetts," Miscellaneous Investigation, Map I-746, US Geological Survey, Reston, VA.

Seelig, W., Harris, D., Herchenroder, B. 1977. "Spatially Integrated Numerical Model on Inlet Hydraulics," US Army Engineer General Investigation of Tidal Hydraulics, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Shore Protection Manual. 1984. 4th ed., 2 Vols, US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, US Government Printing Office, Washington, DC.

Strahler, A. 1966. A Geologist's View of Cape Cod, The Natural History Press, Garden City, NY.

Tippetts, Abbett, McCarthy, and Stratton, Consulting Engineers. 1980. "Coastal Zone Management Feasibility Studies Related to Channel Shoaling, Town Pier Facilities and Town Pier Access," Report to the Marshfield Planning Board, Tippetts, Abbett, McCarthy, and Stratton Engineers, Boston, MA.

US Army Beach Erosion Board. 1954. "North Atlantic Coast Wave Statistics Hindcasts by Bretschneider-revised Sverdrup-Munk Method," Technical Memorandum No. 55, Coastal Engineering Research Center, Vicksburg, MS.

US Army Engineer Division, New England. 1957. "Beach Erosion Control Report on Cooperative Study, Pemberton Point to Cape Cod Canal, Boston, Massachusetts," Waltham, MA.

_____. 1965 (Dec). "Small Navigation Project, Green Harbor, Marshfield, Massachusetts, Detailed Project Report," Waltham, MA.

_____. 1979 (Aug). "Reconnaissance Report Operations and Maintenance, Green Harbor, Massachusetts," Waltham, MA.

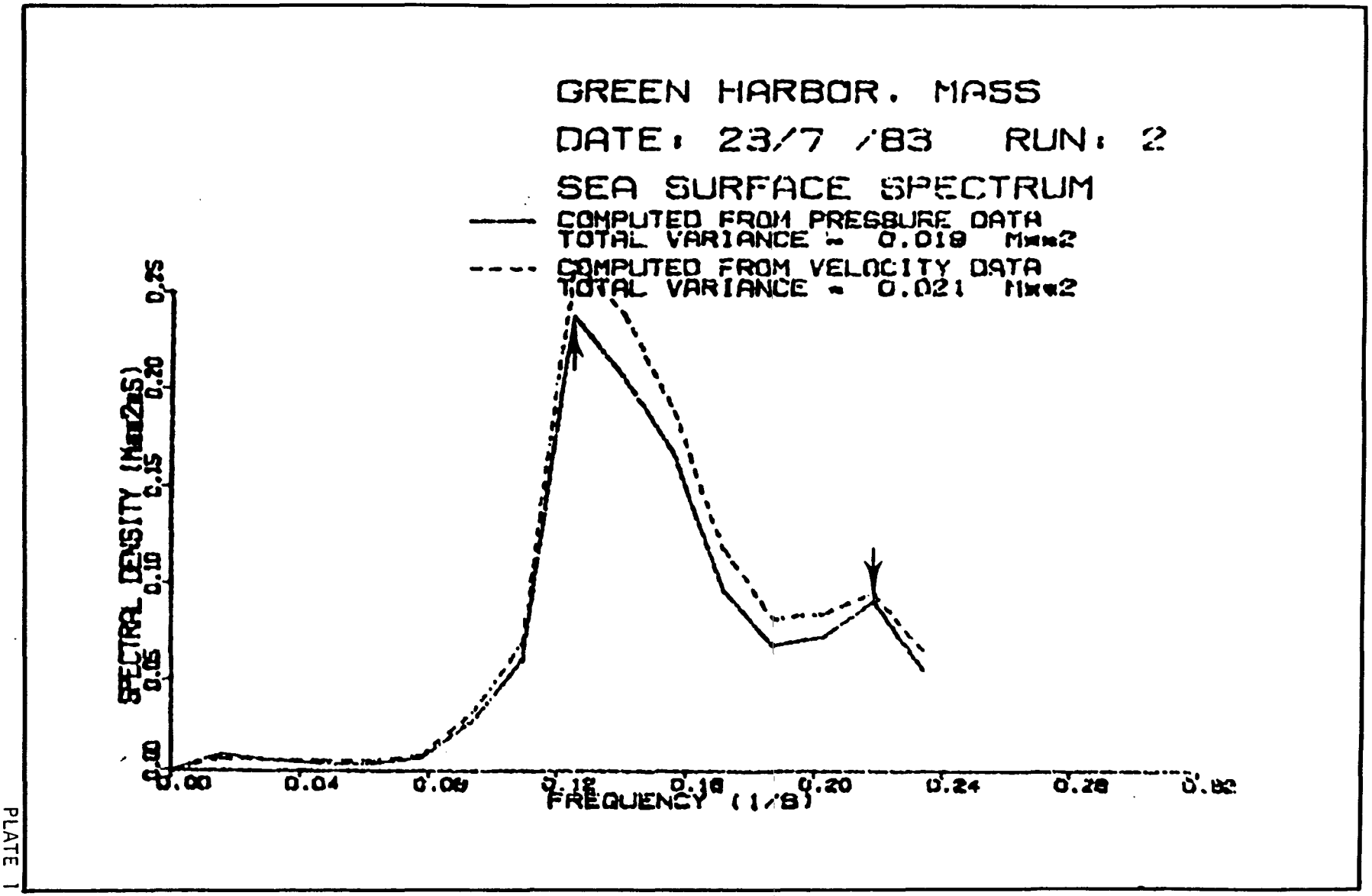
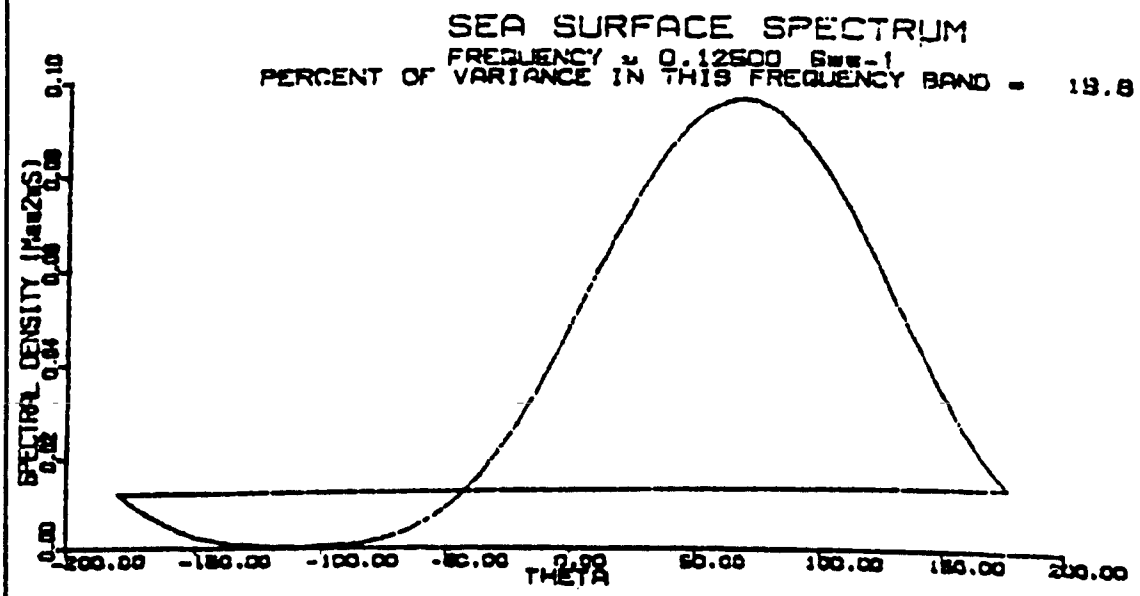

GREEN HARBOR. MASS
DATE: 23/7 /83 RUN: 2
SEA SURFACE SPECTRUM
COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.019 M**2
COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.021 M**2
SPECTRAL DENSITY (M**2/S)
0.00
0.05
0.10
0.15
0.20
0.25
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
FREQUENCY (1/S)

PLATE 1

GREEN HARBOR, MASS

DATE: 23/7 /83 RUN: 2



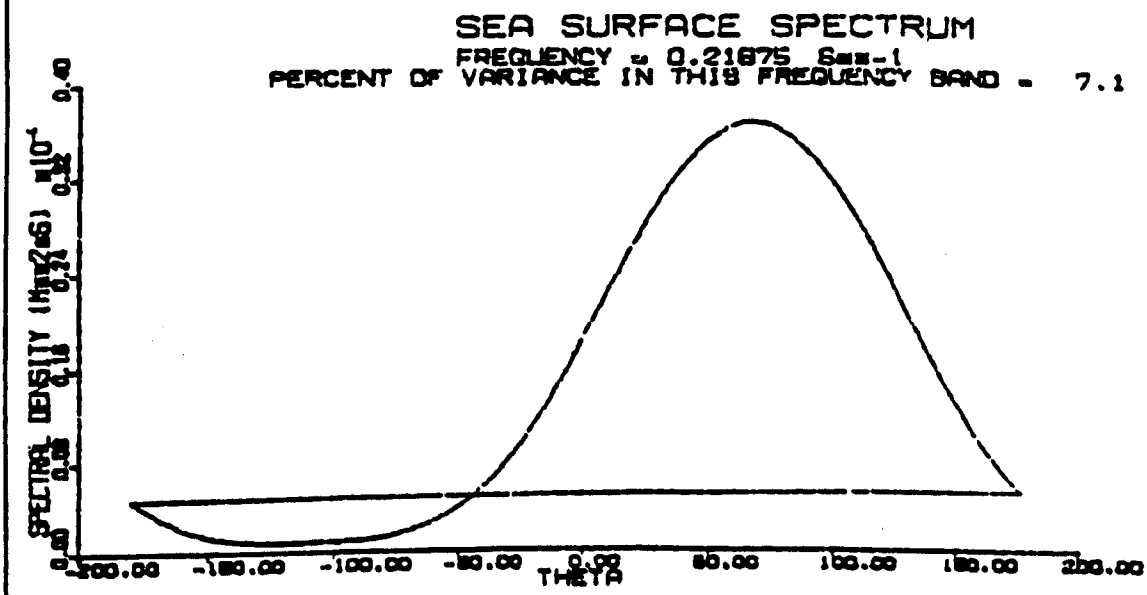
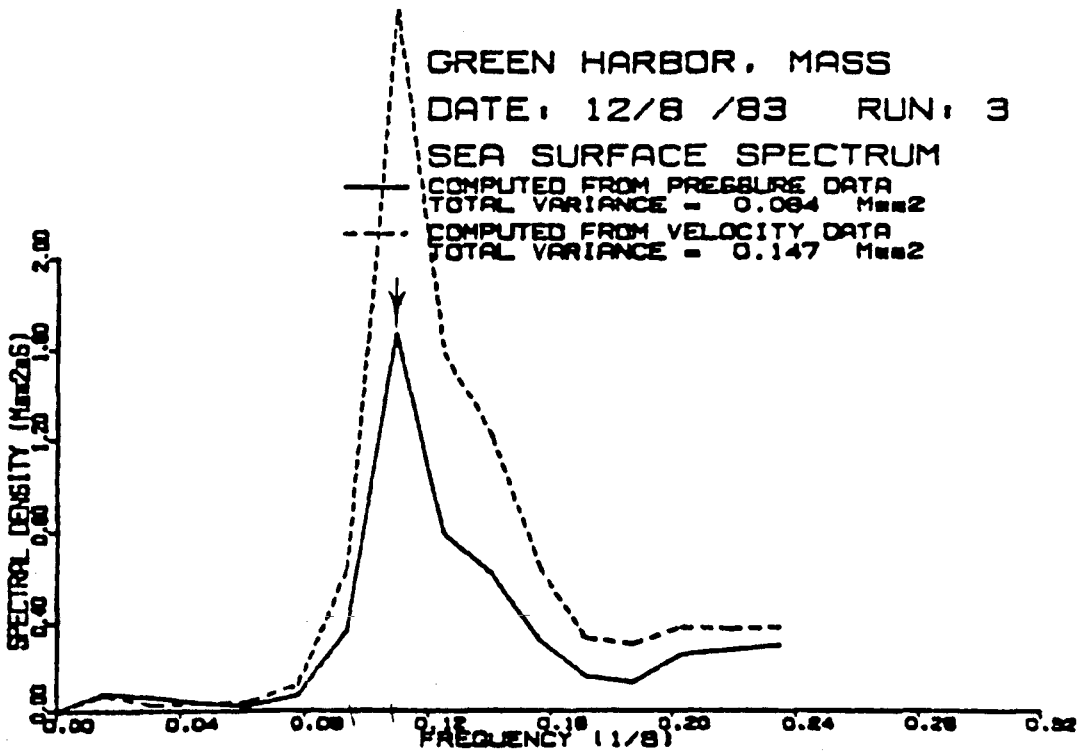


PLATE 2


GREEN HARBOR, MASS
DATE: 12/8 /83 RUN: 3
SEA SURFACE SPECTRUM
COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.084 M**2
COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.147 M**2
SPECTRAL DENSITY (M**2/S)
FREQUENCY (1/S)

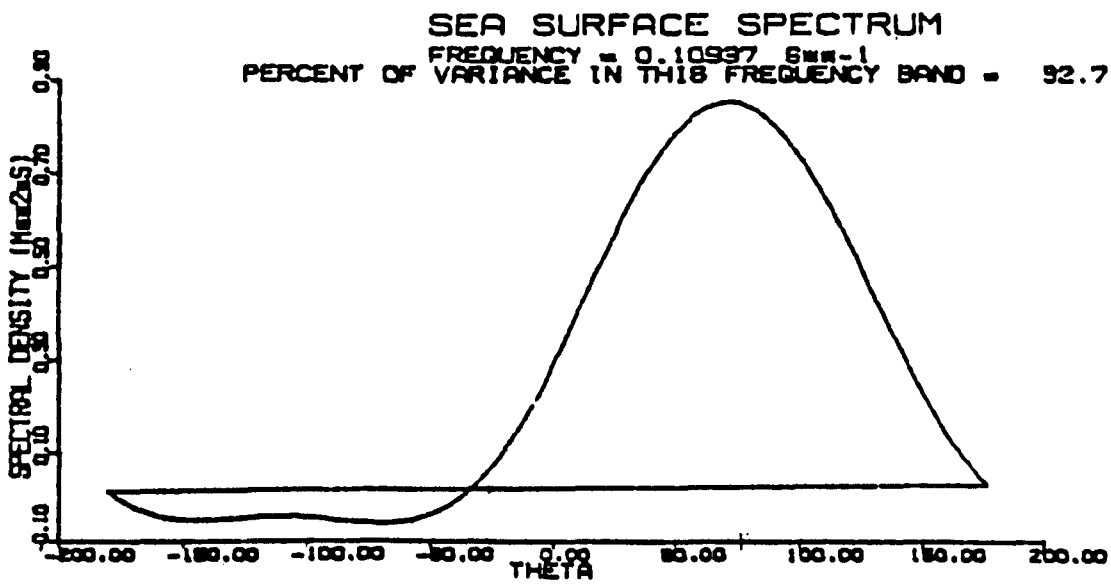
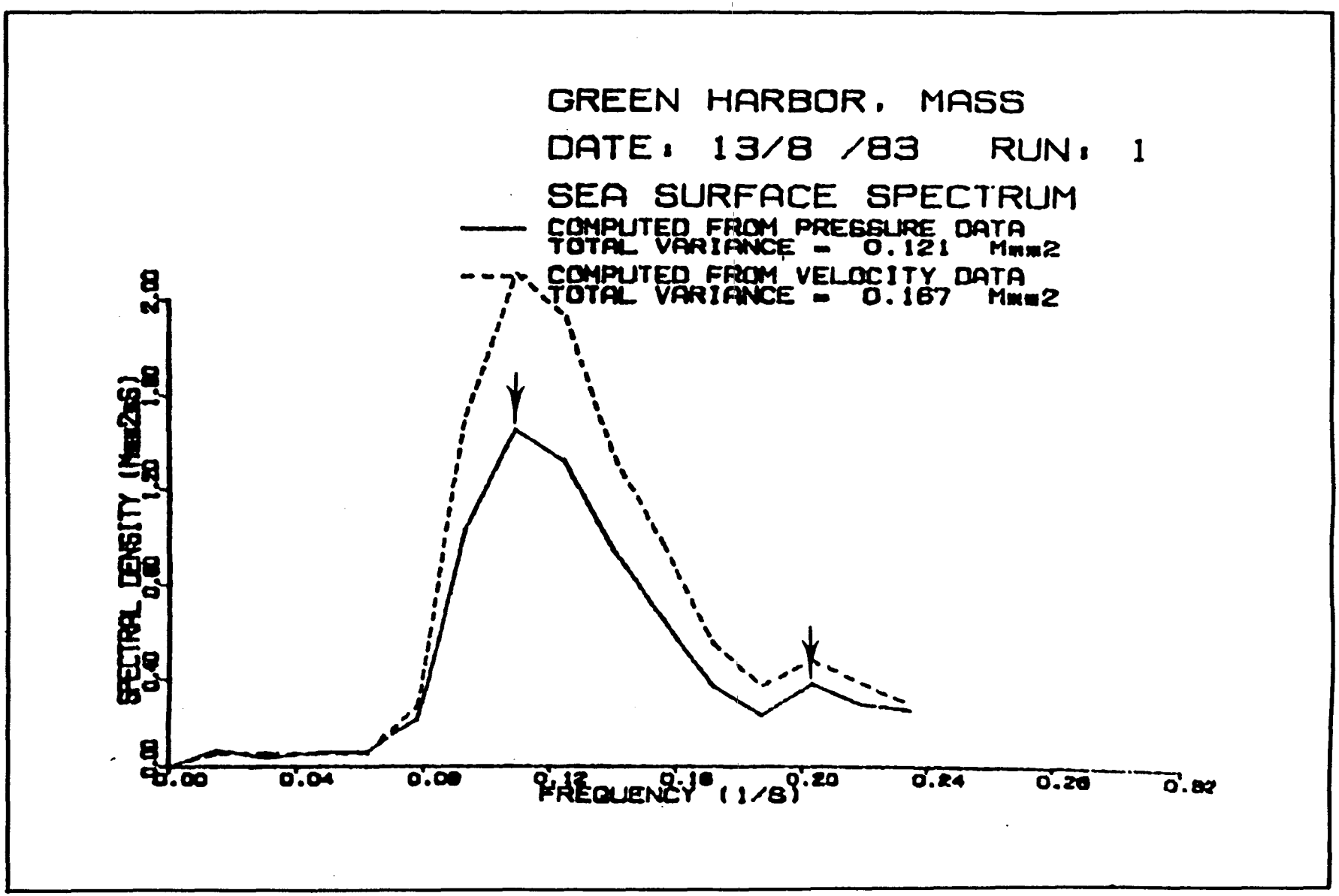

SEA SURFACE SPECTRUM
FREQUENCY = 0.10937 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 92.7
SPECTRAL DENSITY (M**2/S)
THETA

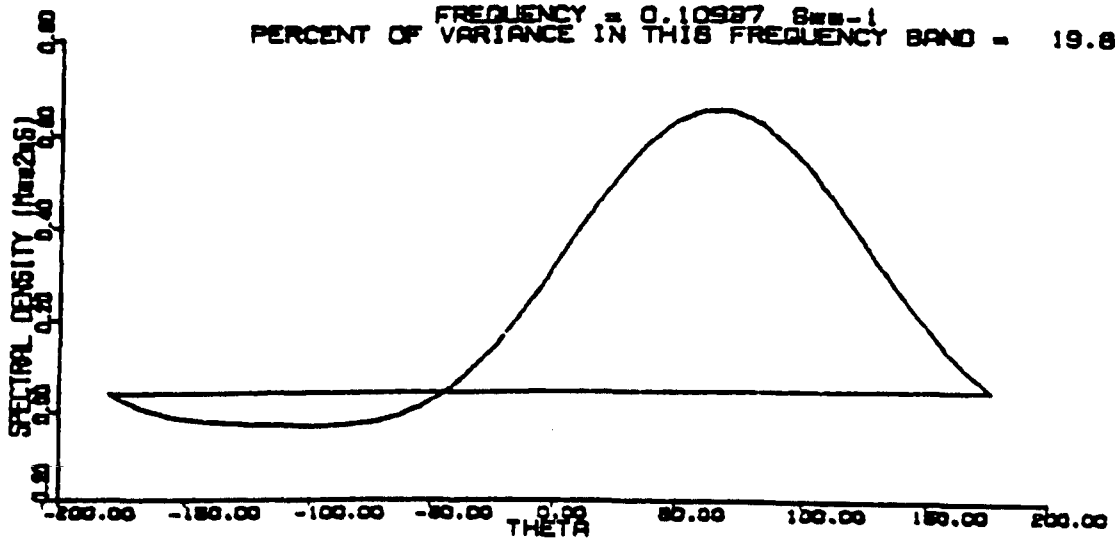
PLATE 3

PLATE 4


GREEN HARBOR, MASS
DATE: 13/8 /83 RUN: 1
SEA SURFACE SPECTRUM
COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.121 M**2
COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.167 M**2
SPECTRAL DENSITY (M**2/S)
0.00
0.40
0.80
1.20
1.60
2.00
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
0.32
FREQUENCY (1/S)

GREEN HARBOR, MASS
DATE: 13/8 /83 RUN: 1

SEA SURFACE SPECTRUM
FREQUENCY = 0.10937 Sec-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 19.8



SEA SURFACE SPECTRUM
FREQUENCY = 0.20313 Sec-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 4.5

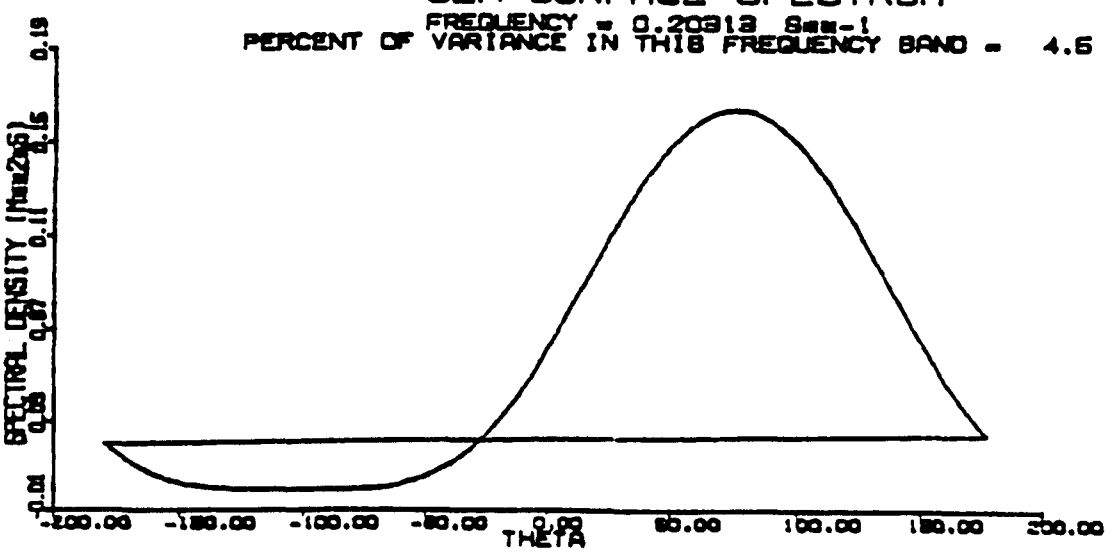
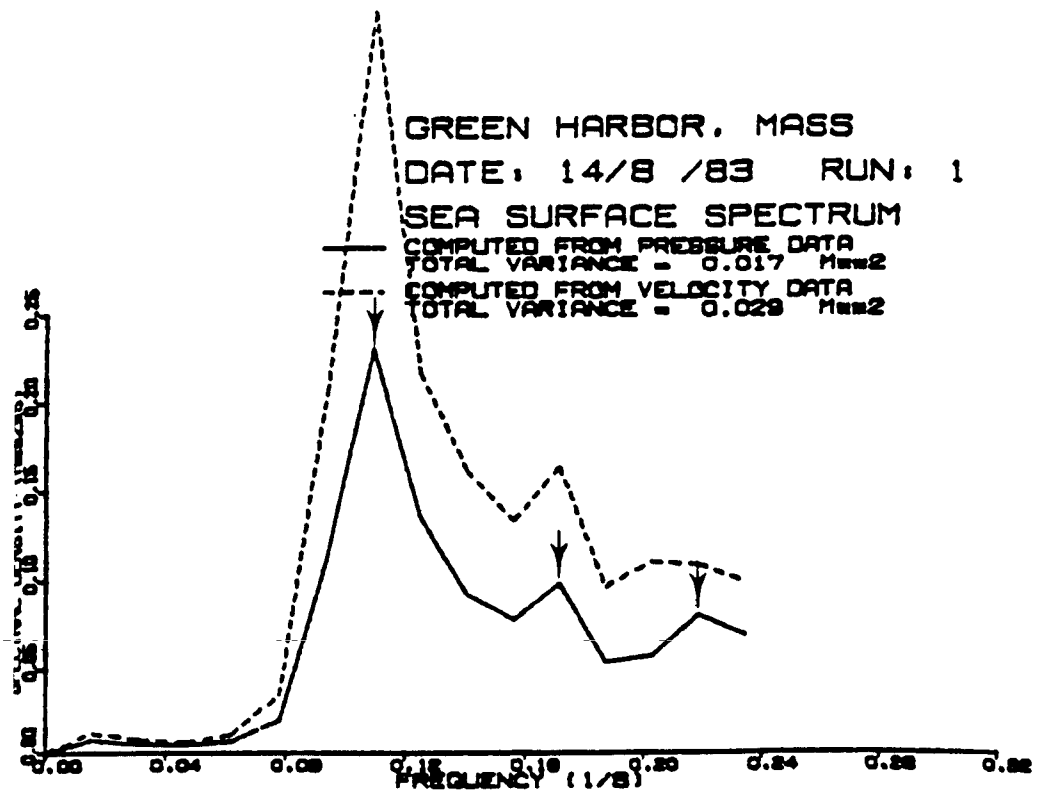


PLATE 5


GREEN HARBOR, MASS
DATE: 14/8 /83 RUN: 1
SEA SURFACE SPECTRUM
COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.017 M**2
COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.029 M**2
FREQUENCY (1/S)

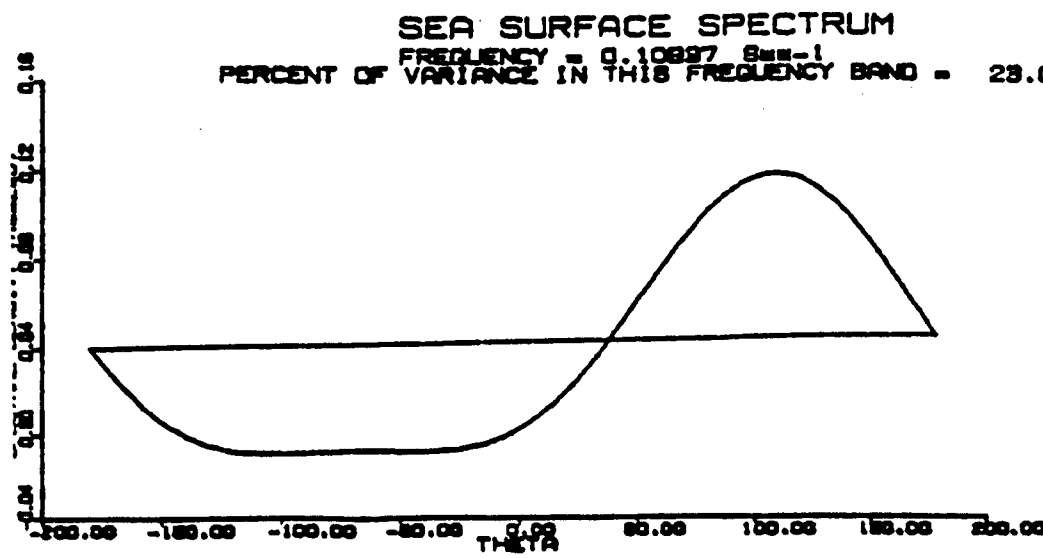
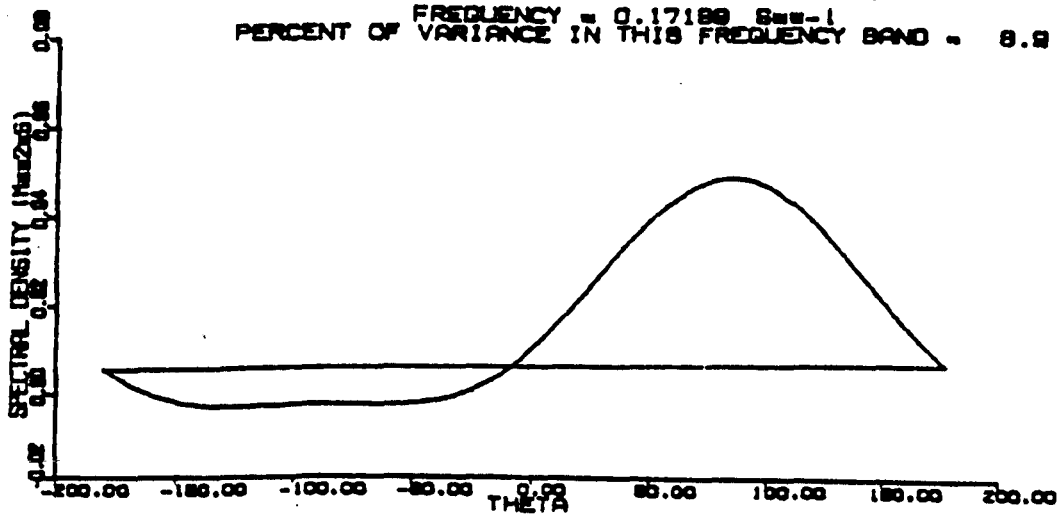

SEA SURFACE SPECTRUM
FREQUENCY = 0.10937 SEC-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 23.0
THETA

PLATE 6

GREEN HARBOR, MASS
DATE: 14/8 /83 RUN: 1

SEA SURFACE SPECTRUM
FREQUENCY = 0.17188 Sec-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 8.8



SEA SURFACE SPECTRUM
FREQUENCY = 0.21875 Sec-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 5.9

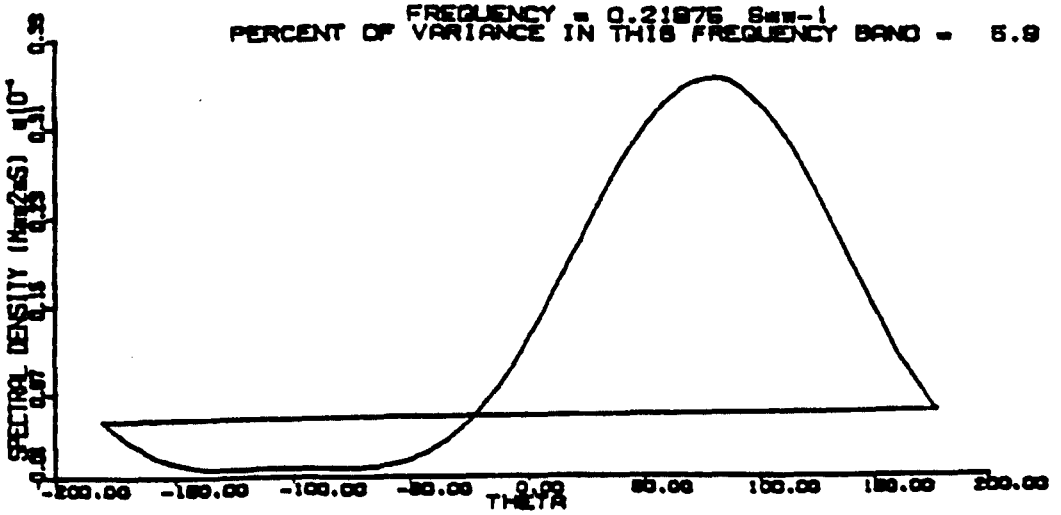


PLATE 7

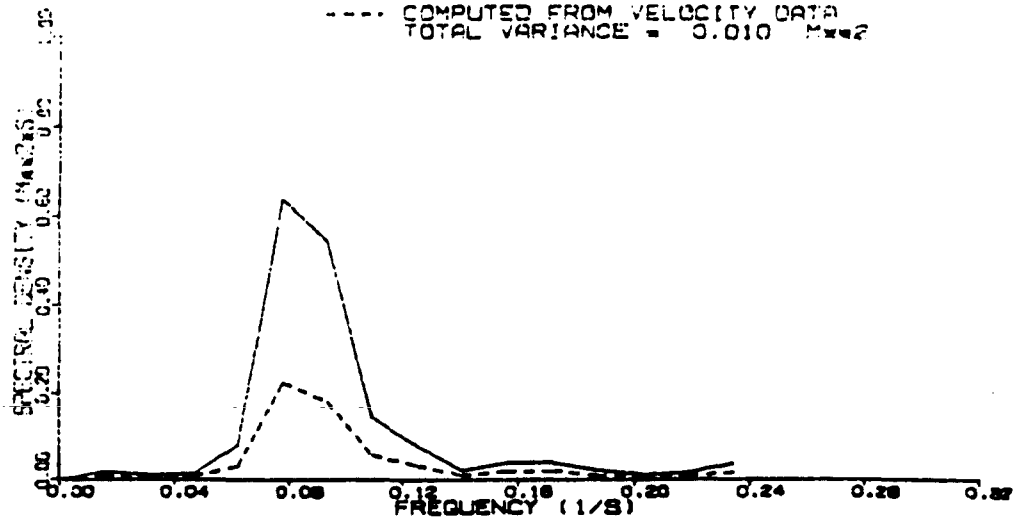
GREEN HARBOR, MASS.

DATE: 24/10/83 RUN: 632

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.027 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.010 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 34.6

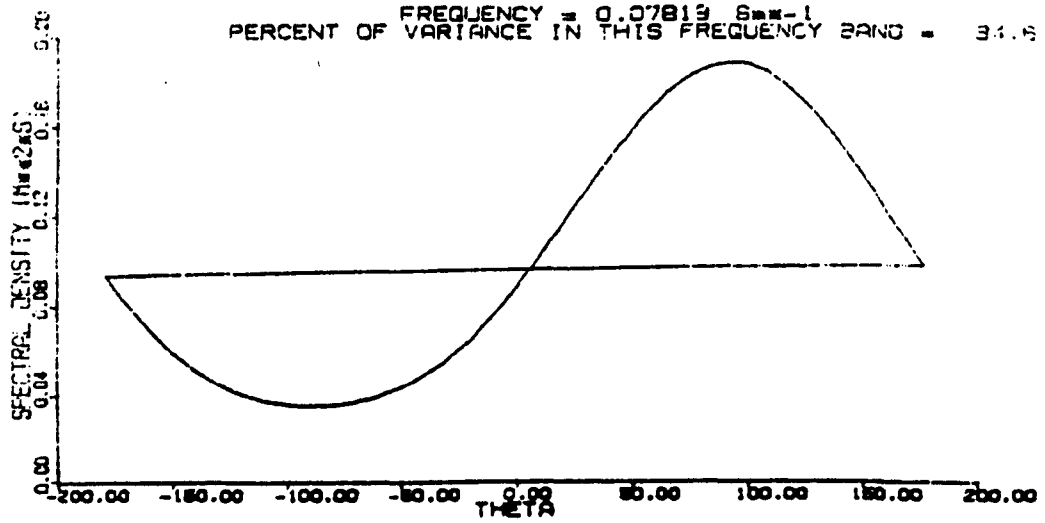
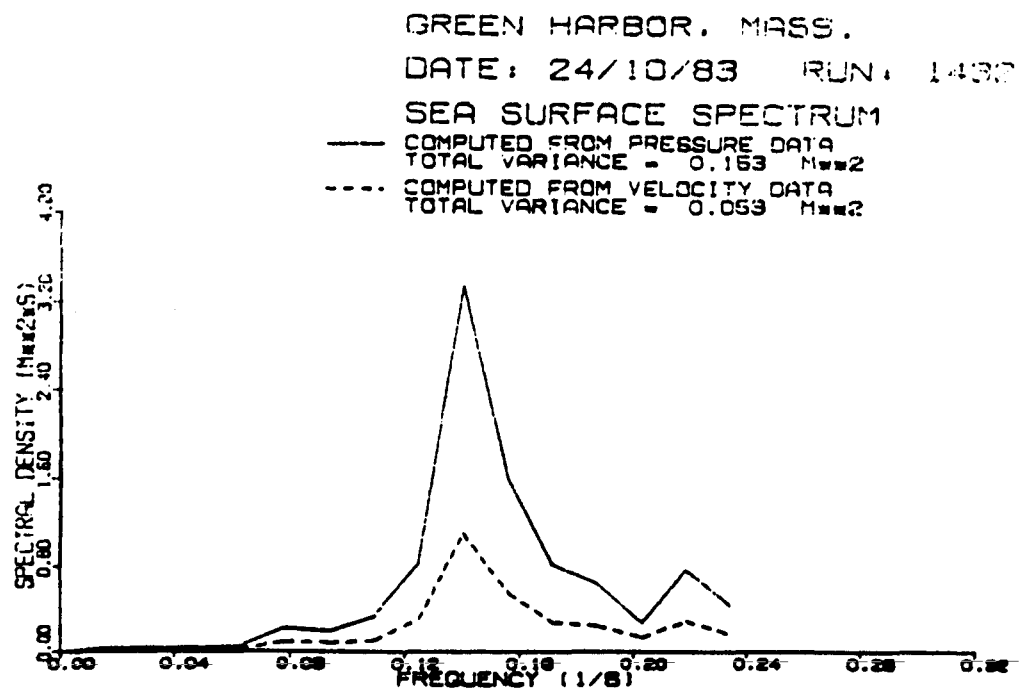


PLATE 8


GREEN HARBOR, MASS.
DATE: 24/10/83 RUN: 1430
SEA SURFACE SPECTRUM
COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.153 M**2
COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.053 M**2
SPECTRAL DENSITY (M**2/S)
FREQUENCY (1/S)

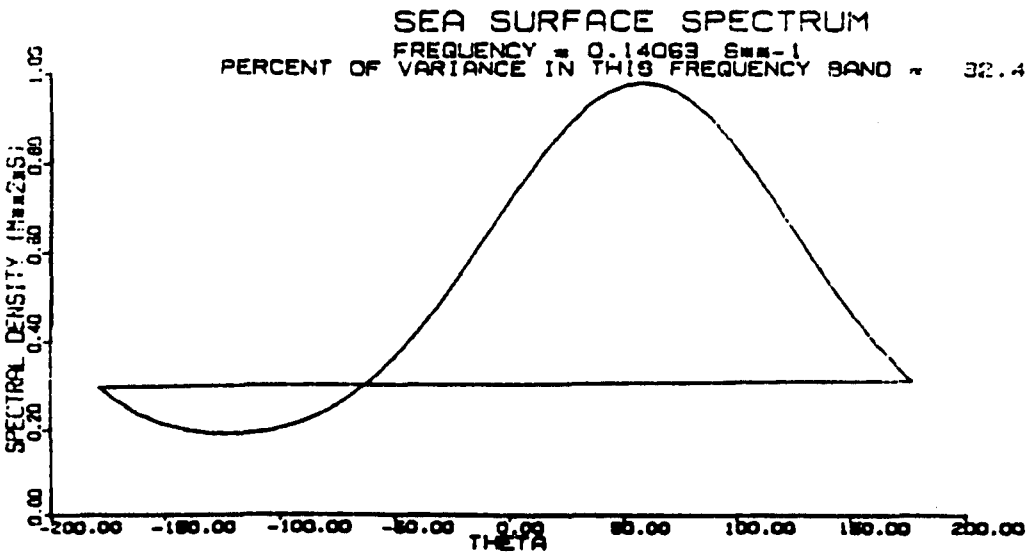
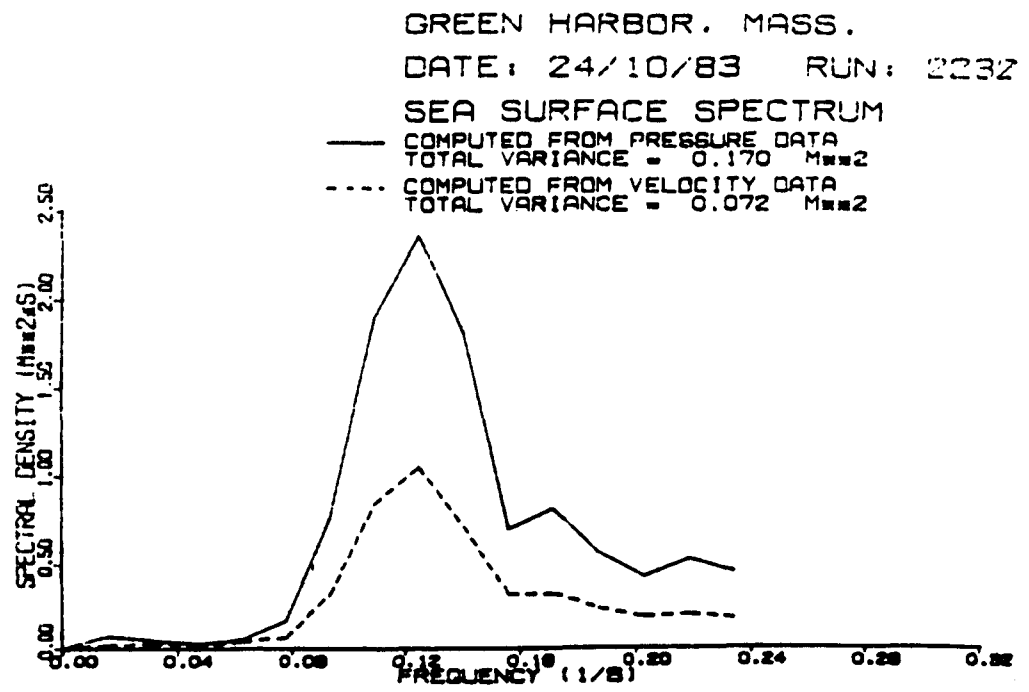

SEA SURFACE SPECTRUM
FREQUENCY = 0.14063 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 32.4
SPECTRAL DENSITY (M**2/S)
THETA

PLATE 9


GREEN HARBOR. MASS.
DATE: 24/10/83 RUN: 2232
SEA SURFACE SPECTRUM
COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.170 M**2
COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.072 M**2
SPECTRAL DENSITY (M**2/S)
0.00
0.50
1.00
1.50
2.00
2.50
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
0.32
FREQUENCY (1/S)

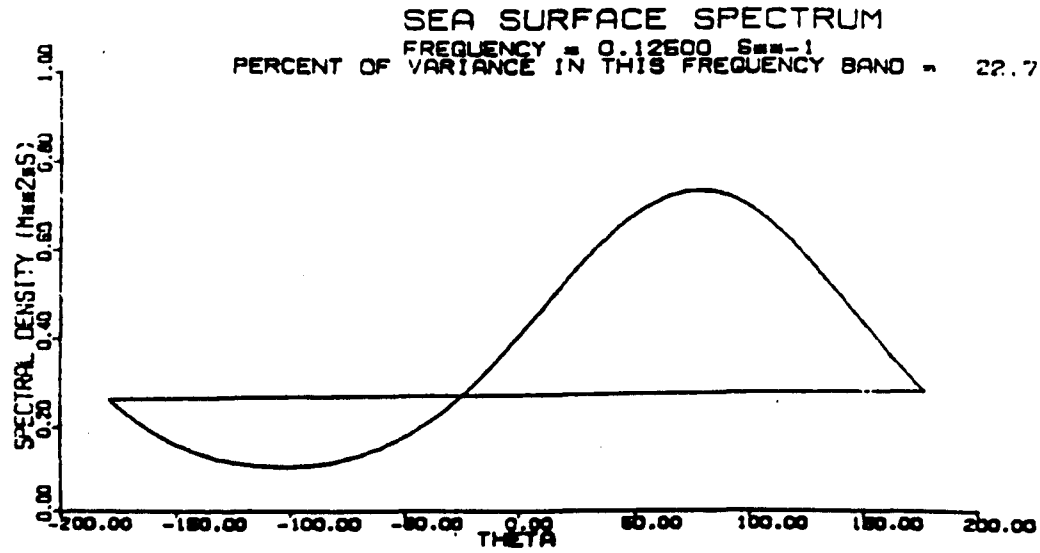
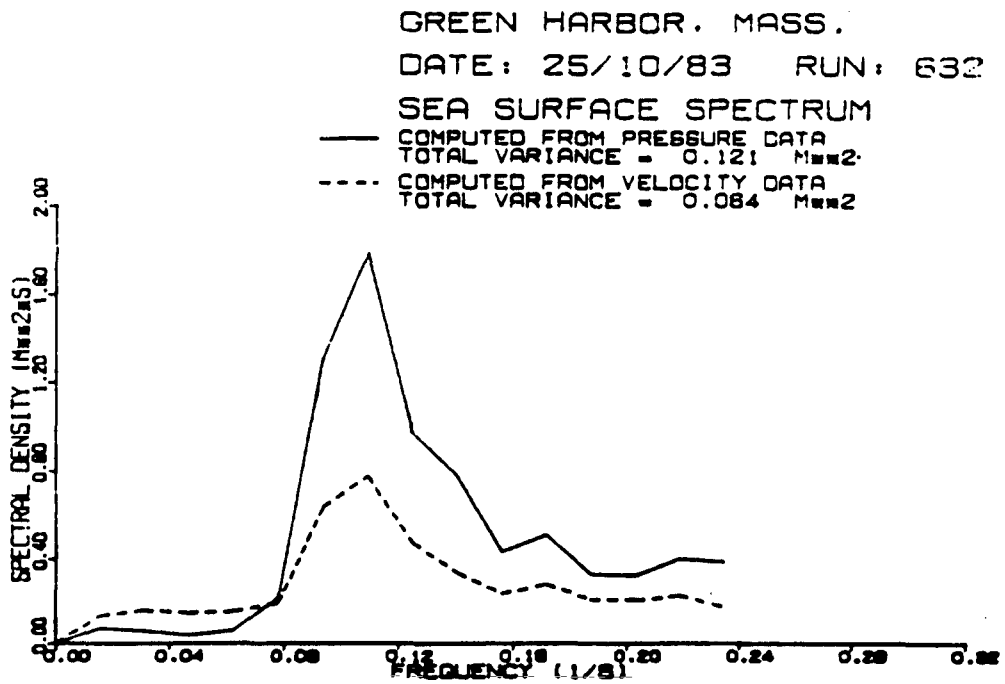

SEA SURFACE SPECTRUM
FREQUENCY = 0.12500 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 22.7
SPECTRAL DENSITY (M**2/S)
0.00
0.20
0.40
0.60
0.80
1.00
-200.00
-150.00
-100.00
-50.00
0.00
50.00
100.00
150.00
200.00
THETA

PLATE 10


GREEN HARBOR. MASS.
DATE: 25/10/83 RUN: 632
SEA SURFACE SPECTRUM
COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.121 M**2
COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.084 M**2
SPECTRAL DENSITY (M**2/S)
FREQUENCY (1/S)

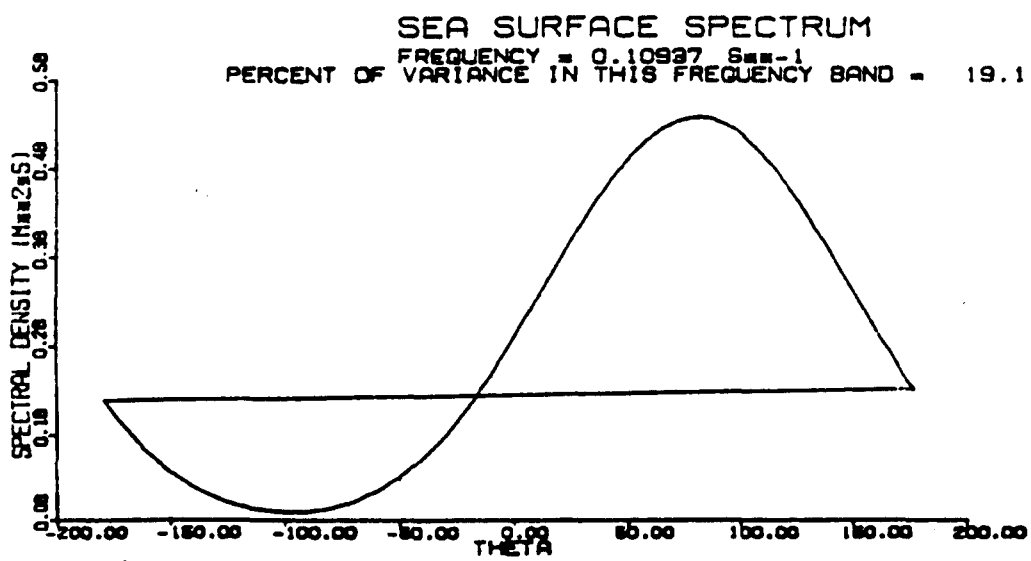

SEA SURFACE SPECTRUM
FREQUENCY = 0.10937 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 19.1
SPECTRAL DENSITY (M**2/S)
THETA

PLATE 11

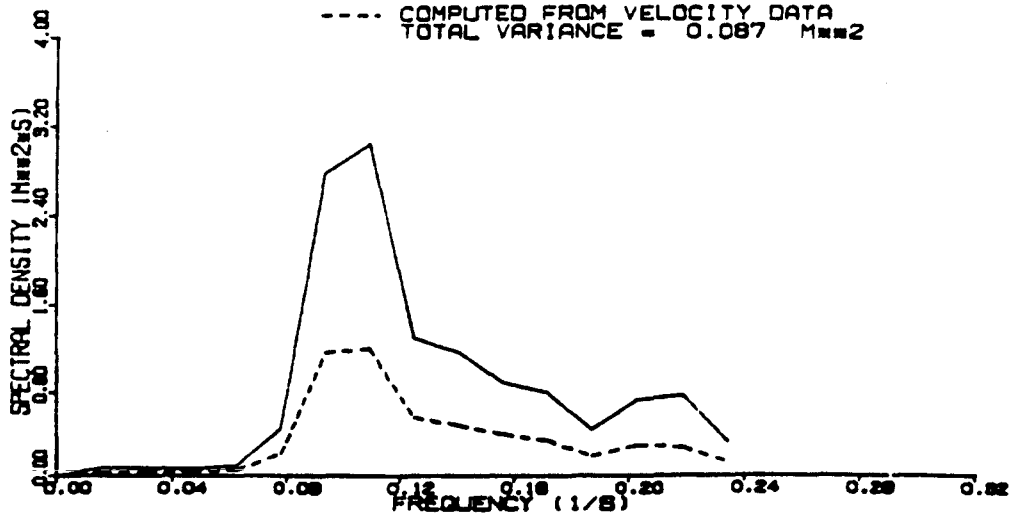
GREEN HARBOR, MASS.

DATE: 25/10/83 RUN: 1432

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.216 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.087 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.10937 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 21.7

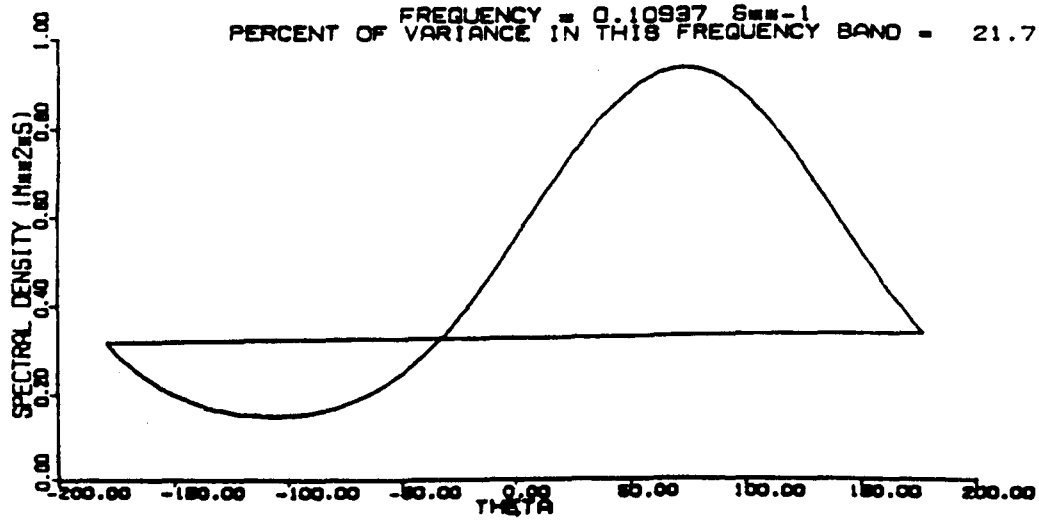
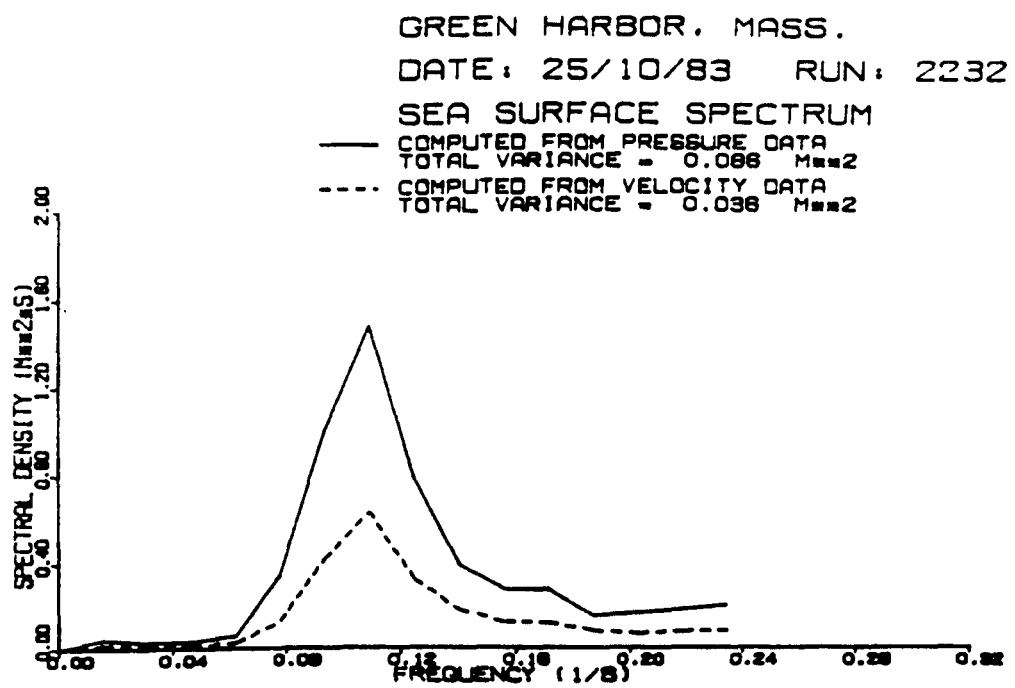


PLATE 12


GREEN HARBOR, MASS.
DATE: 25/10/83 RUN: 2232
SEA SURFACE SPECTRUM
COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.086 M**2
COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.038 M**2
SPECTRAL DENSITY (M**2/S)
0.00
0.40
0.80
1.20
1.60
2.00
0.00
0.04
0.08
0.20
0.24
FREQUENCY (1/S)

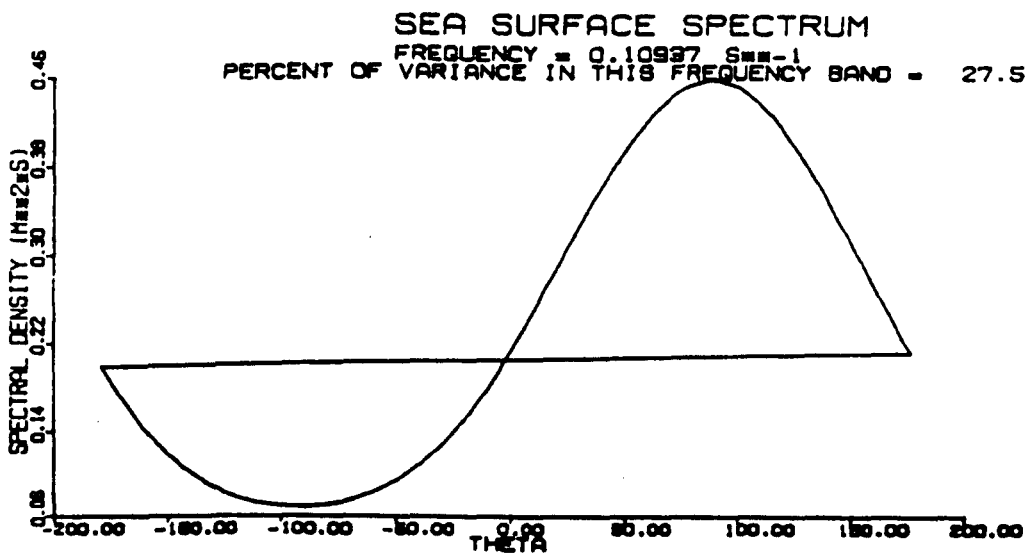
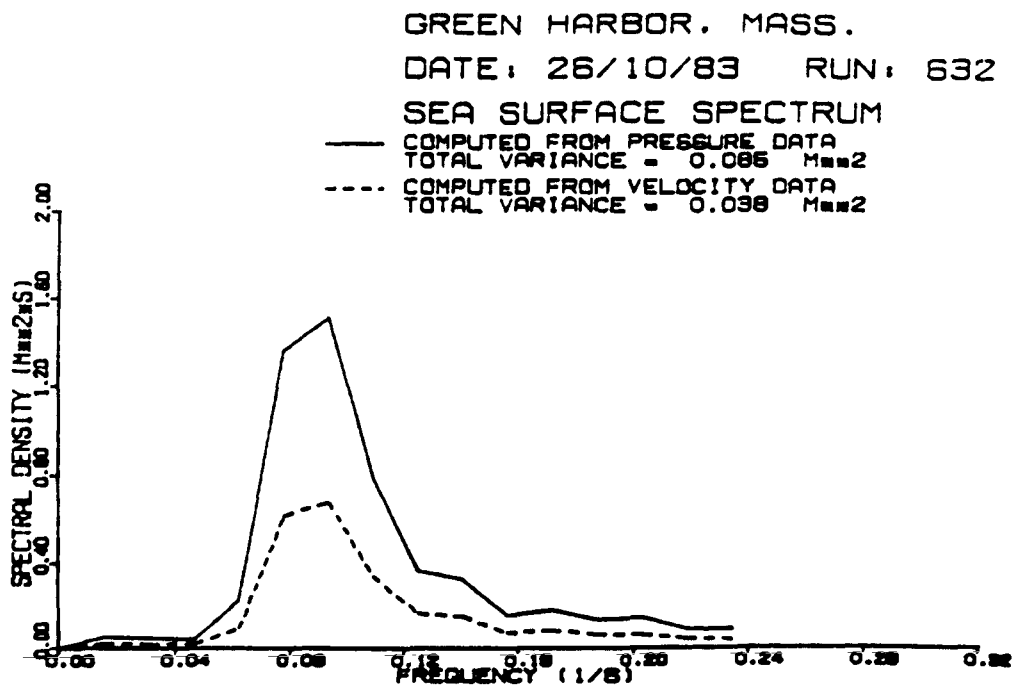

SEA SURFACE SPECTRUM
FREQUENCY = 0.10937 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 27.5
SPECTRAL DENSITY (M**2/S)
0.08
0.14
0.22
0.30
0.38
0.46
-200.00
-150.00
-100.00
-50.00
0.00
50.00
100.00
150.00
200.00
THETA

PLATE 13


GREEN HARBOR. MASS.
DATE: 26/10/83 RUN: 632
SEA SURFACE SPECTRUM
COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.085 M**2
COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.038 M**2
SPECTRAL DENSITY (M**2/S)
FREQUENCY (1/S)

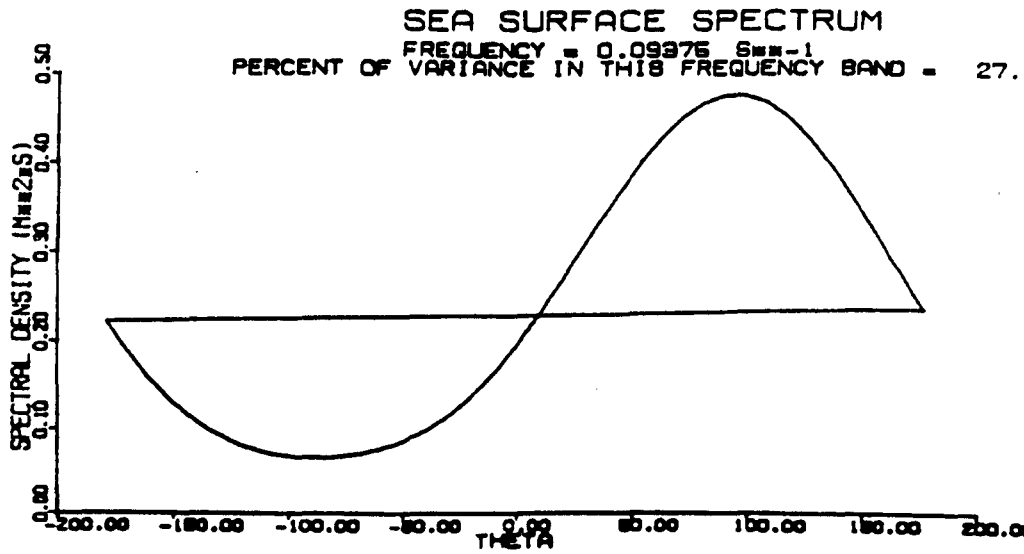

SEA SURFACE SPECTRUM
FREQUENCY = 0.09375 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 27.9
SPECTRAL DENSITY (M**2/S)
THETA

PLATE 14

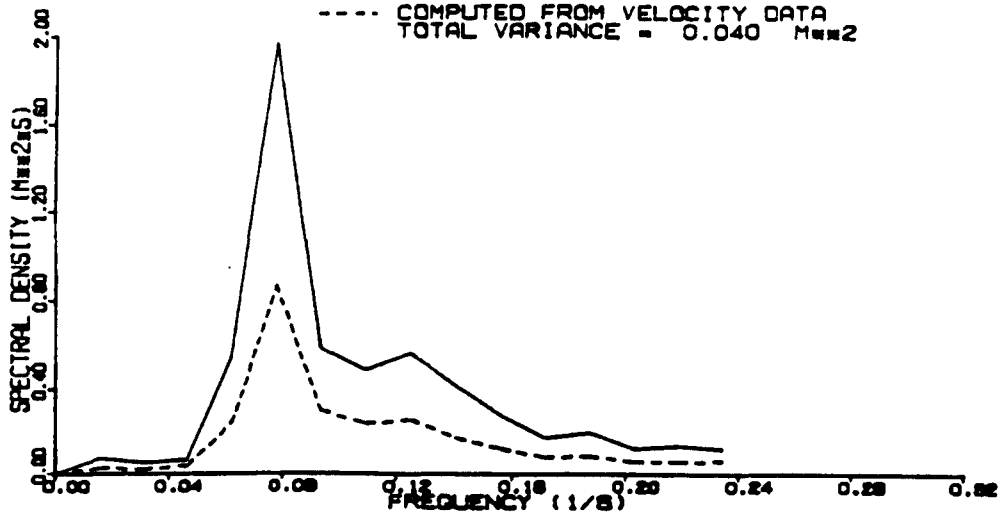
GREEN HARBOR. MASS.

DATE: 26/10/83 RUN: 1432

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.089 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.040 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 33.9

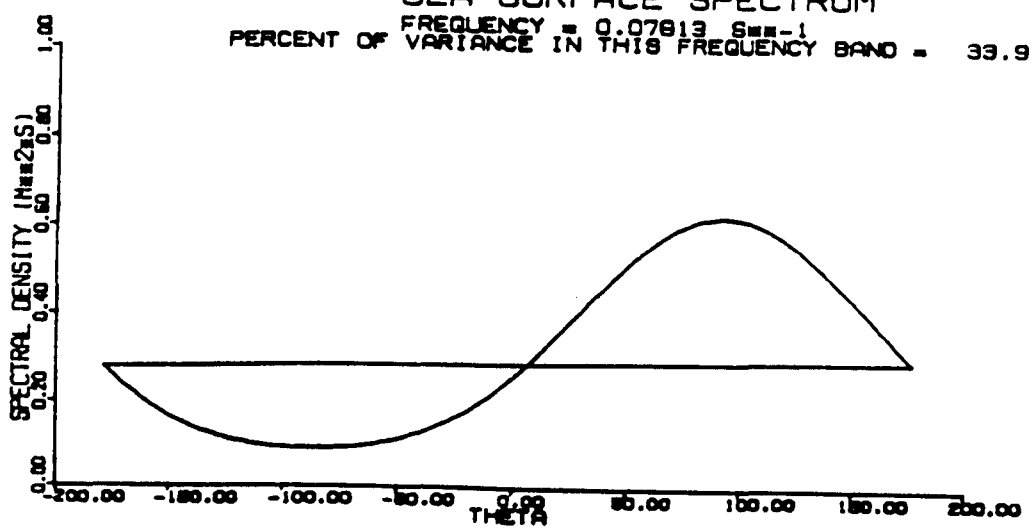
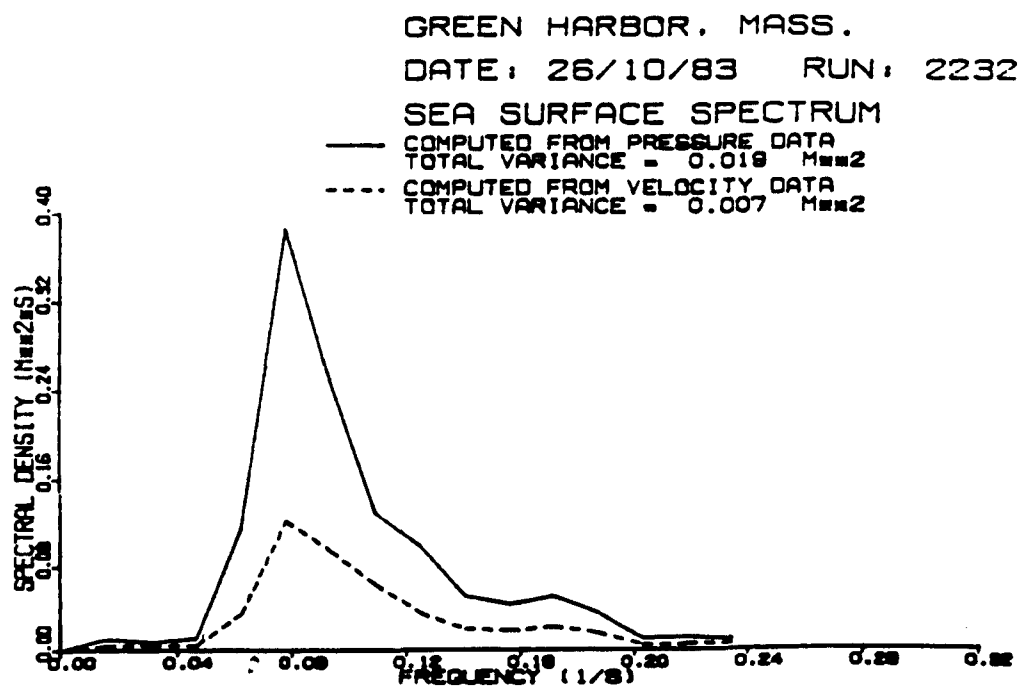


PLATE 15


GREEN HARBOR. MASS.
DATE: 26/10/83 RUN: 2232
SEA SURFACE SPECTRUM
COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.018 M**2
COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.007 M**2
SPECTRAL DENSITY (M**2/S)
0.40
0.32
0.24
0.16
0.08
0.00
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
0.32
FREQUENCY (1/S)

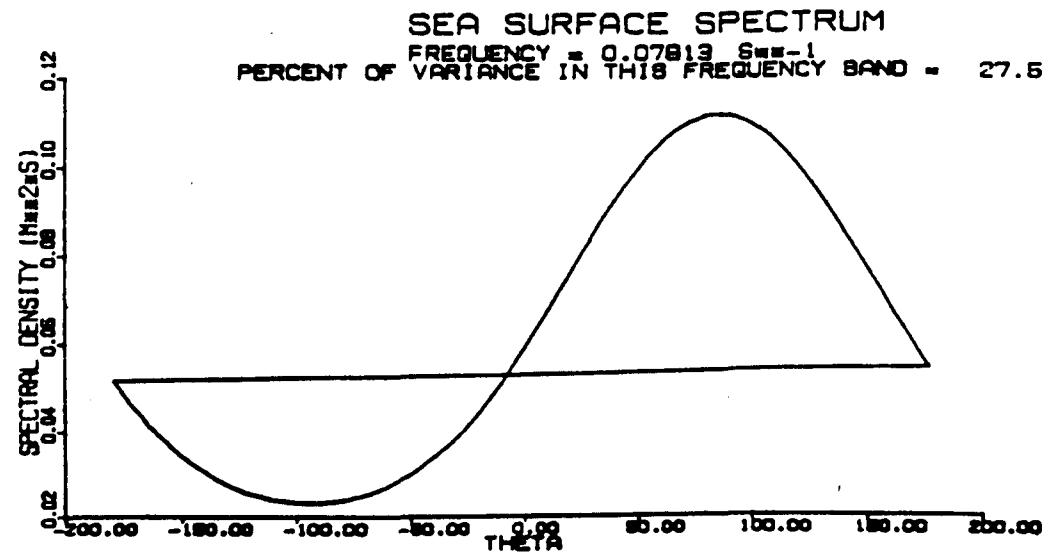

SEA SURFACE SPECTRUM
FREQUENCY = 0.07813 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 27.5
SPECTRAL DENSITY (M**2/S)
0.12
0.10
0.08
0.06
0.04
0.02
-200.00
-150.00
-100.00
-50.00
0.00
50.00
100.00
150.00
200.00
THETA

PLATE 16

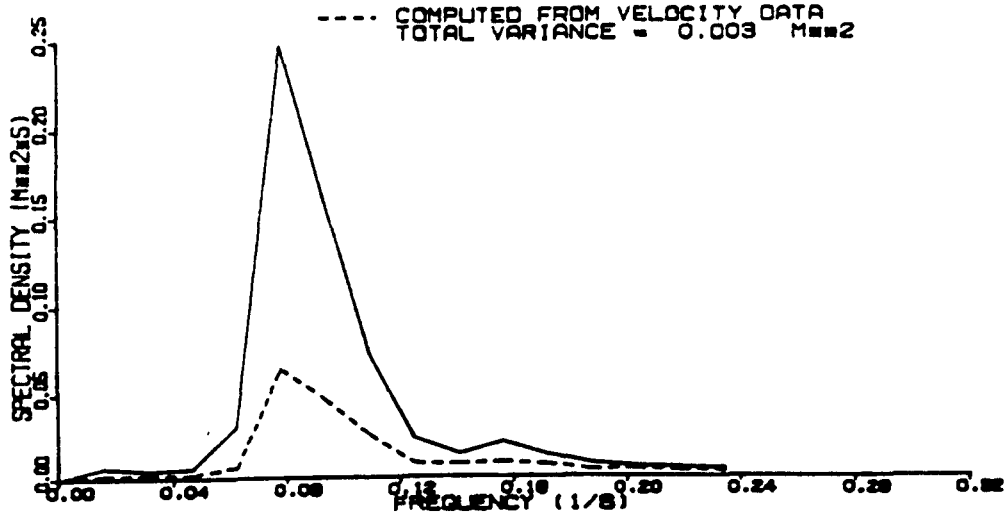
GREEN HARBOR. MASS.

DATE: 27/10/83 RUN: 632

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.010 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.003 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 39.6

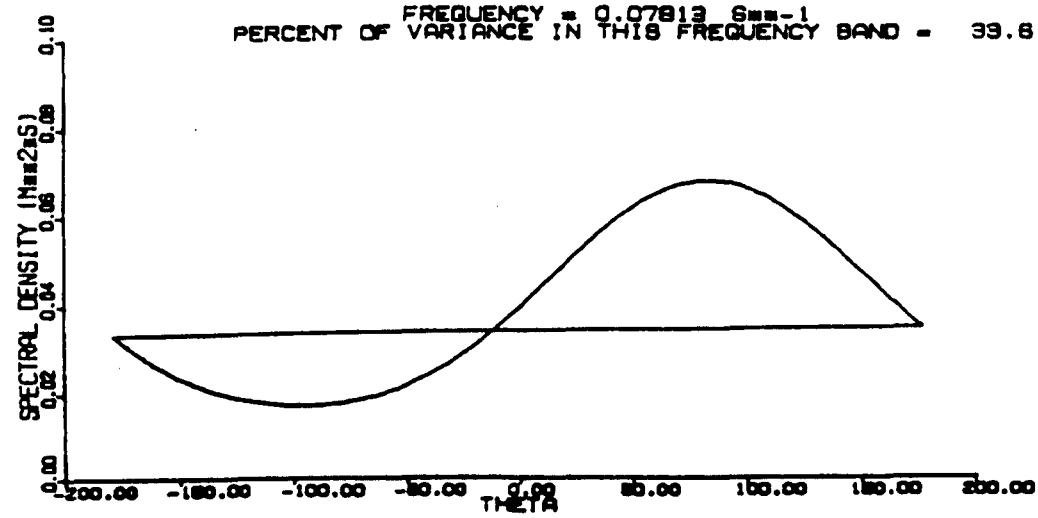


PLATE 17

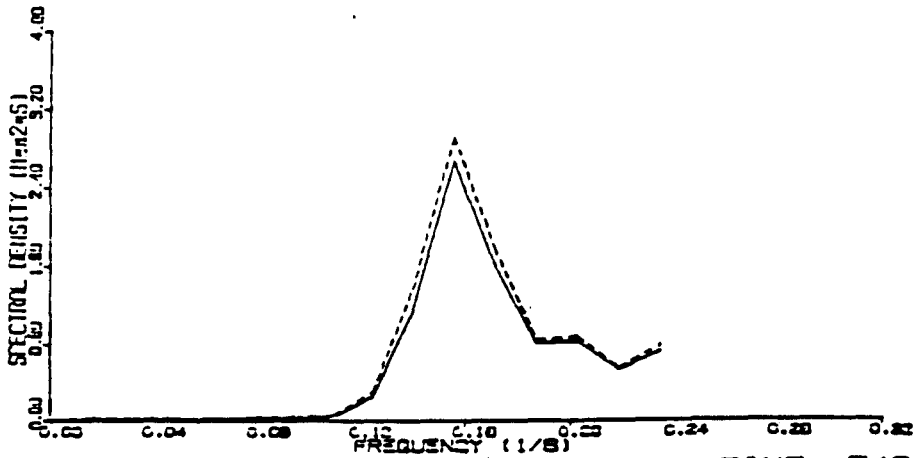
GREEN HARBOR, MASS

DATE: 10/11/83 TIME: 2345

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.143 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.158 M**2



DATE: 11/11/83 TIME: 745

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.048 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.052 M**2

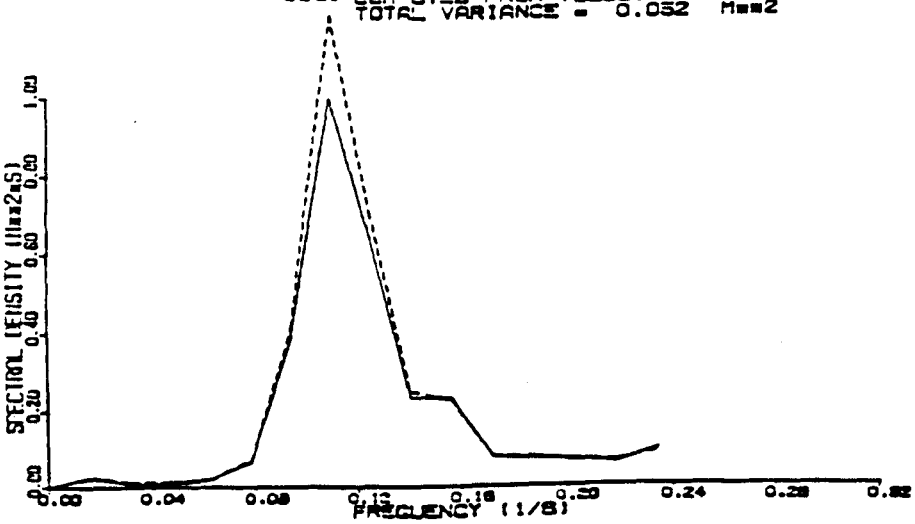


PLATE 18

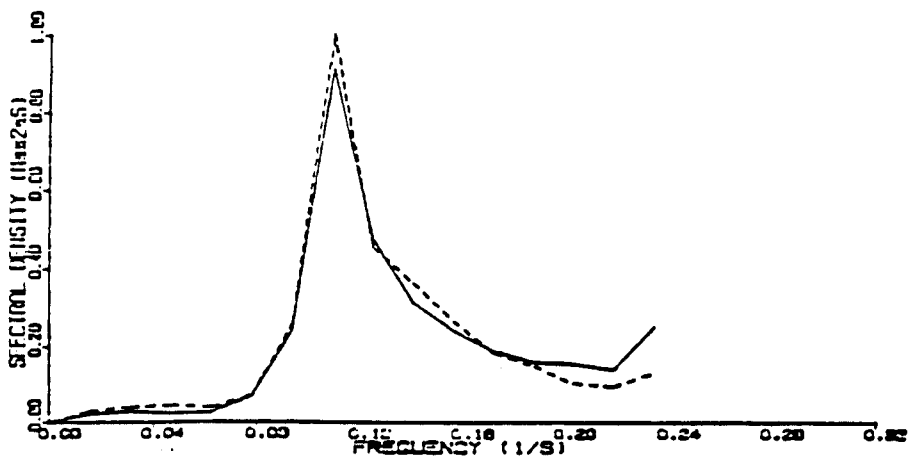
GREEN HARBOR, MASS

DATE: 11/11/83 TIME: 1546

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.058 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.050 M**2



DATE: 11/11/83 TIME: 2346

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.018 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.018 M**2

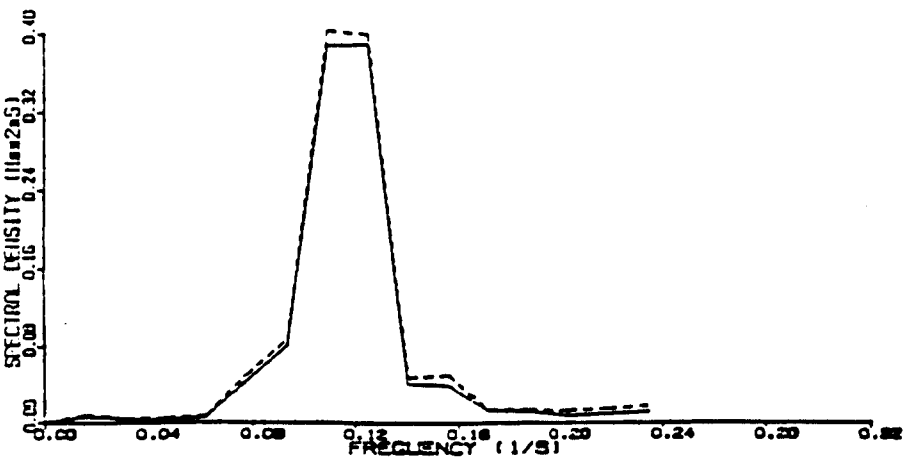


PLATE 19

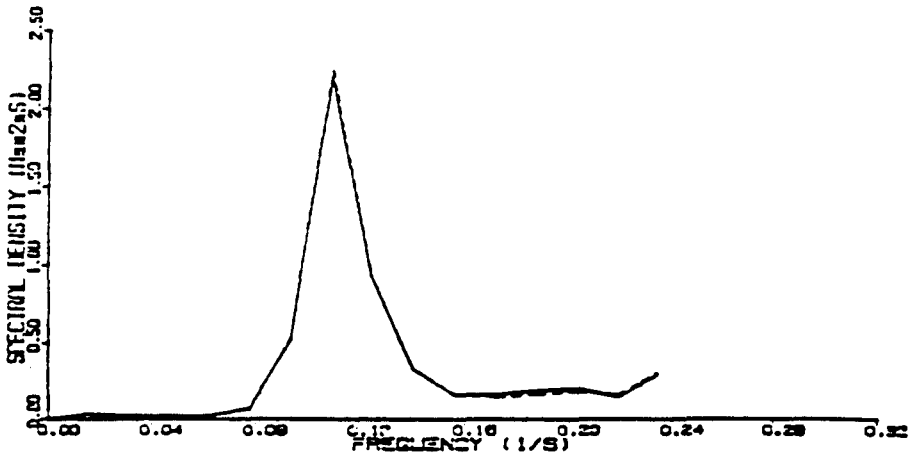
GREEN HARBOR, MASS

DATE: 16/11/83 TIME: 1546

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.084 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.085 M**2



DATE: 16/11/83 TIME: 2345

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.057 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.039 M**2

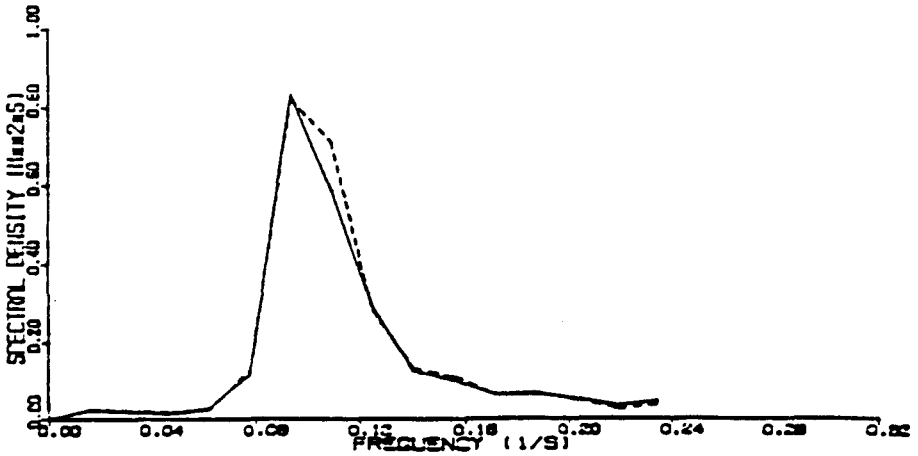


PLATE 20

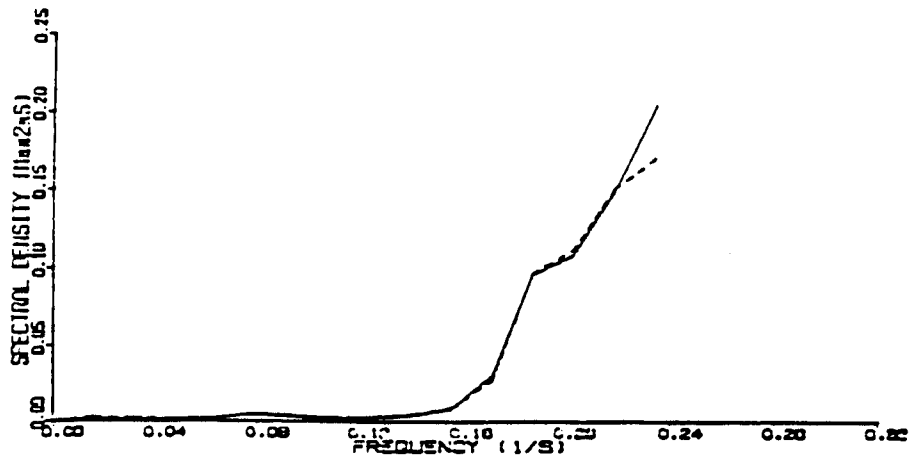
GREEN HARBOR, MASS

DATE: 4 /12/83 TIME: 746

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.014 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.013 M**2



DATE: 4 /12/83 TIME: 1545

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.119 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.078 M**2

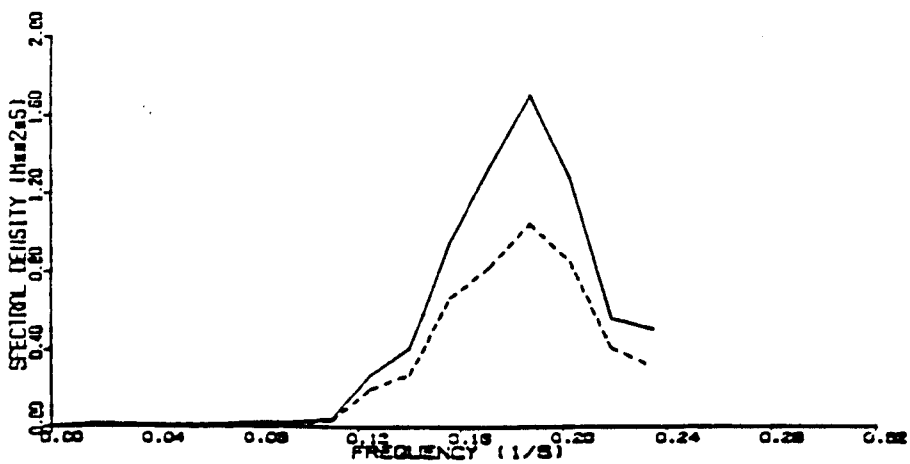


PLATE 21

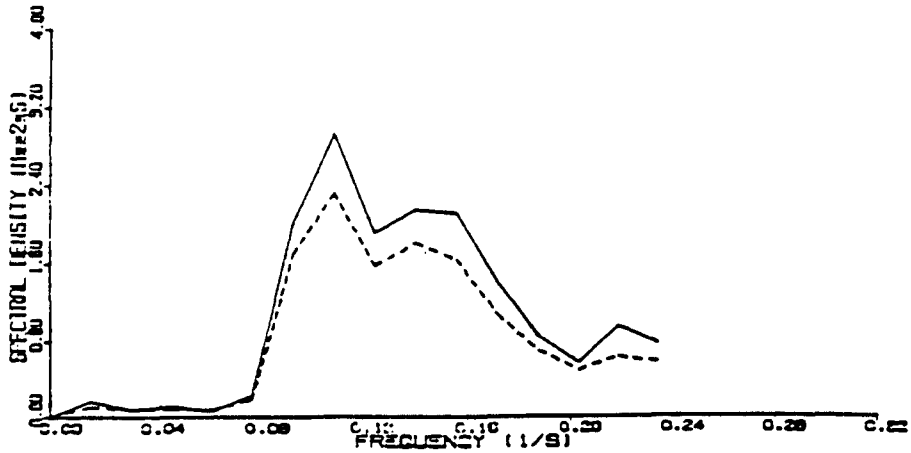
GREEN HARBOR, MASS

DATE: 4 /12/83 TIME: 2345

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.284 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.210 M**2



DATE: 5 /12/83 TIME: 745

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.177 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.148 M**2

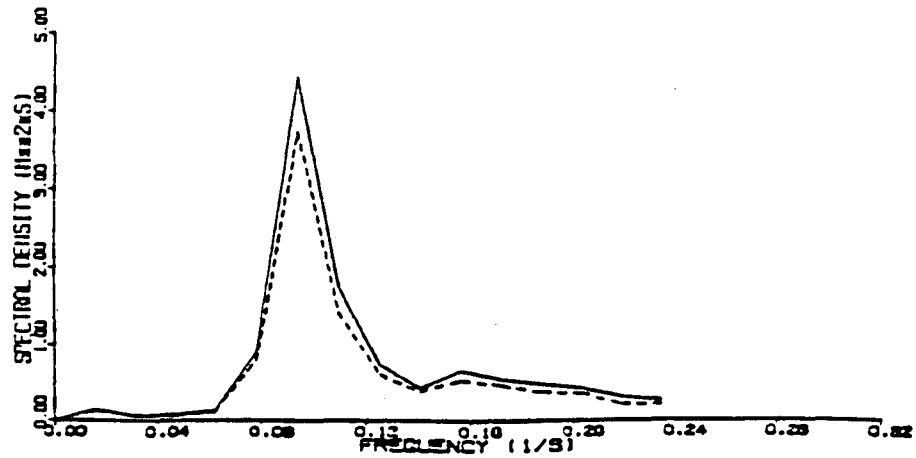


PLATE 22

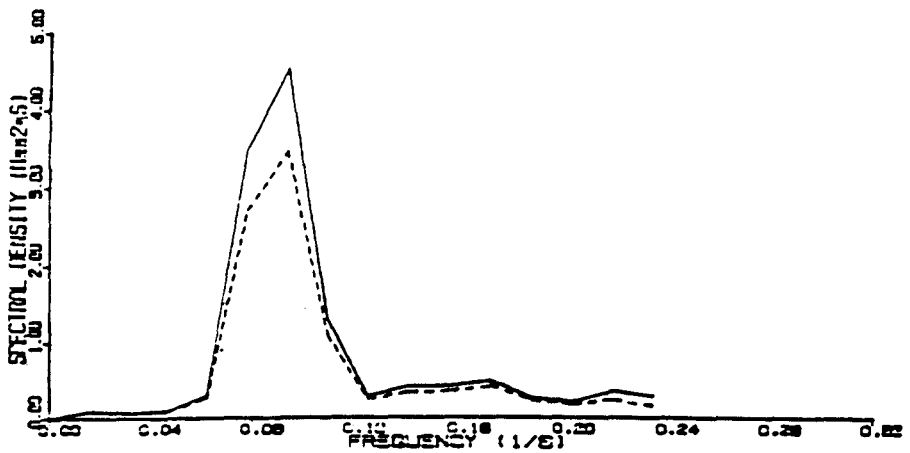
GREEN HARBOR, MASS

DATE: 5 /12/83 TIME: 1546

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.198 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.163 M**2



DATE: 5 /12/83 TIME: 2346

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.089 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.071 M**2

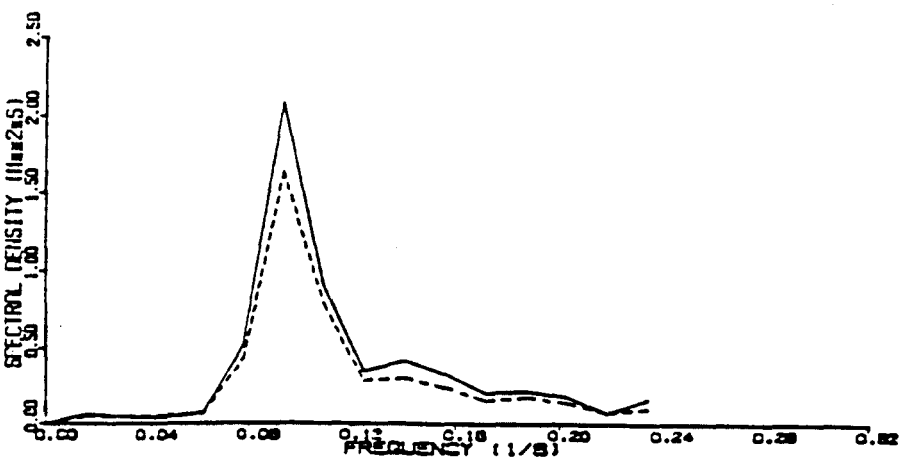


PLATE 23

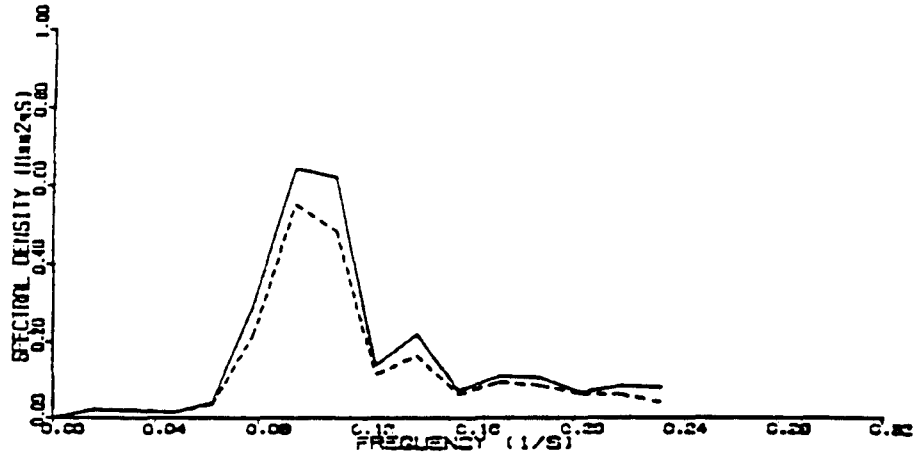
GREEN HARBOR, MASS

DATE: 6 /12/83 TIME: 745

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.039 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.031 M**2



DATE: 6 /12/83 TIME: 1545

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.048 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.032 M**2

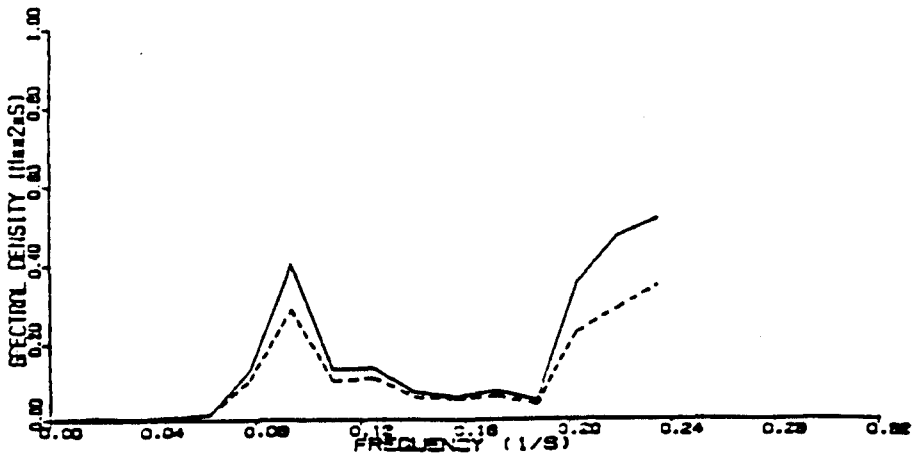


PLATE 24

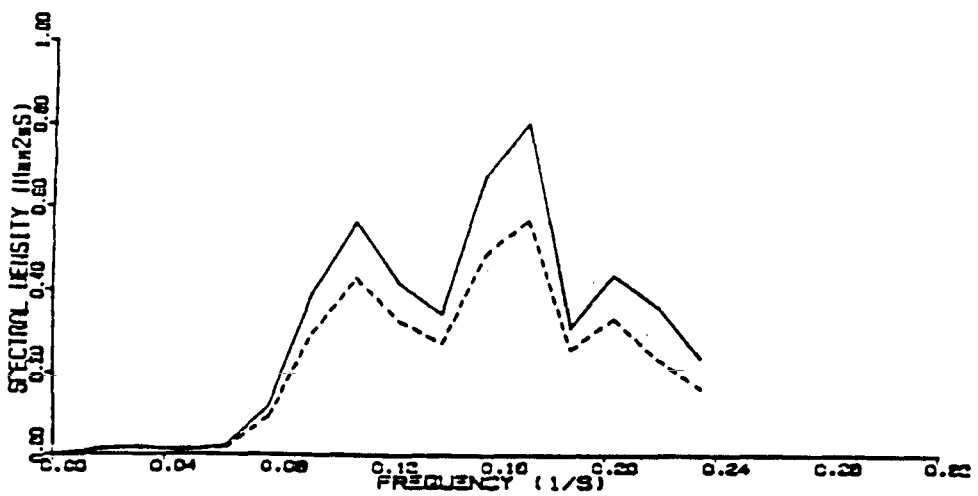
GREEN HARBOR, MASS

DATE: 6 /12/83 TIME: 2345

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.078 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.067 M**2



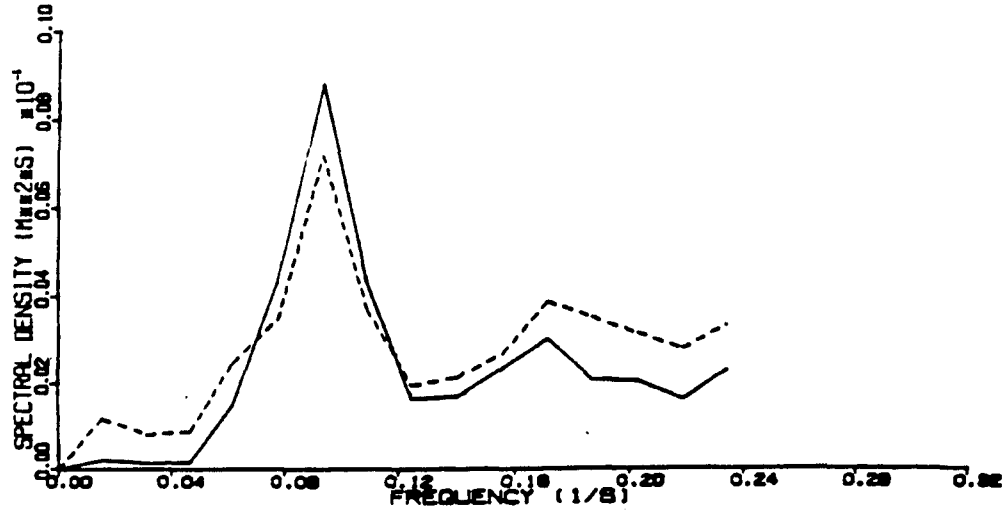
GREEN HARBOR, MASS

DATE: 28/2 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.001 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.001 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 15.4

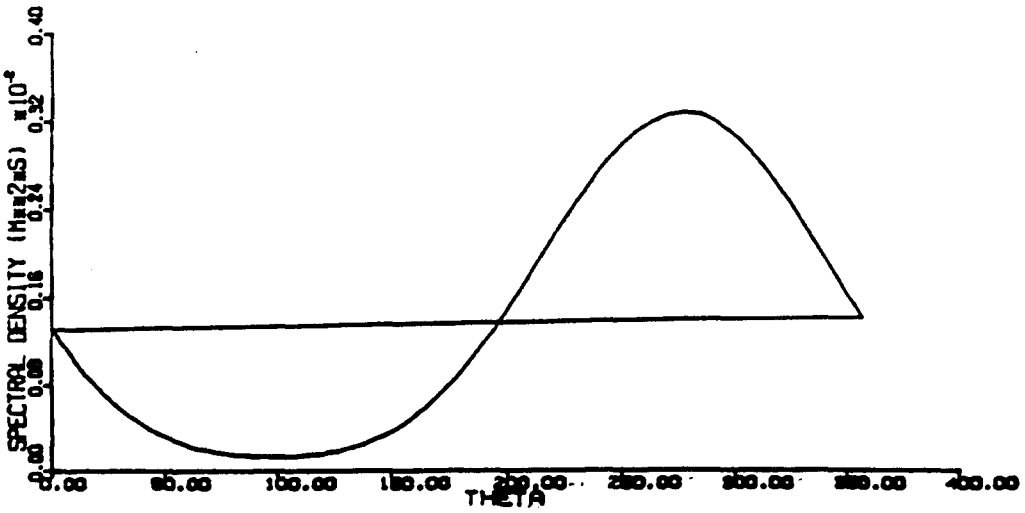


PLATE 26

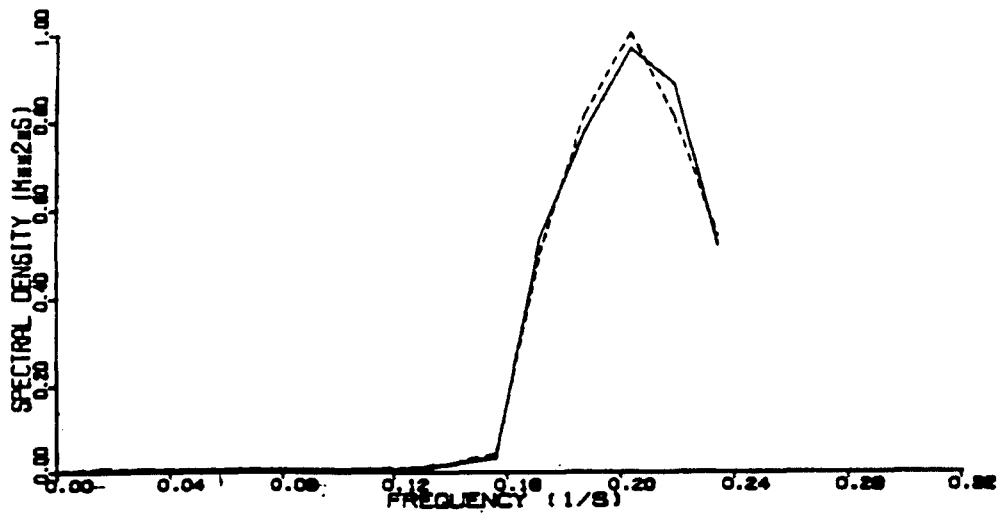
GREEN HARBOR, MASS

DATE: 28/2 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.071 M**2

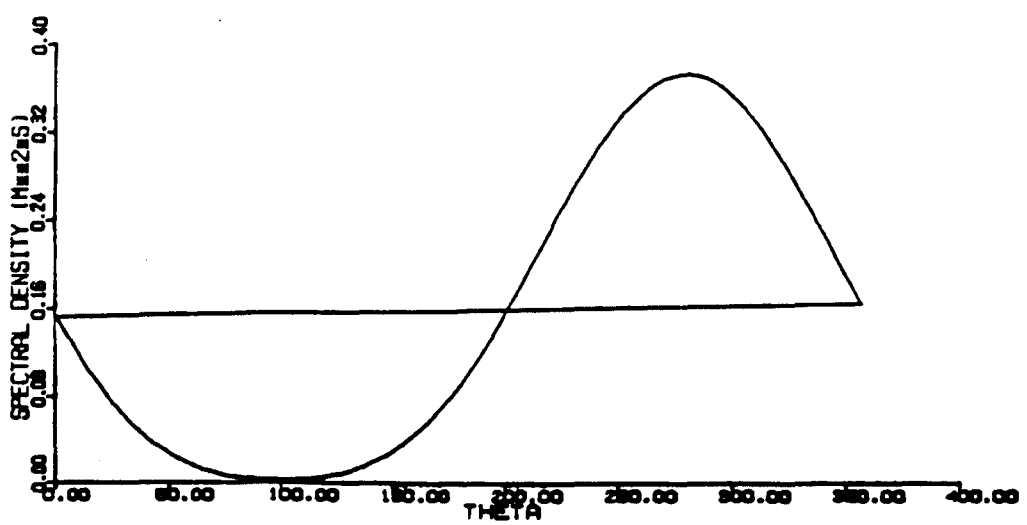
---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.069 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.20313 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 22.8



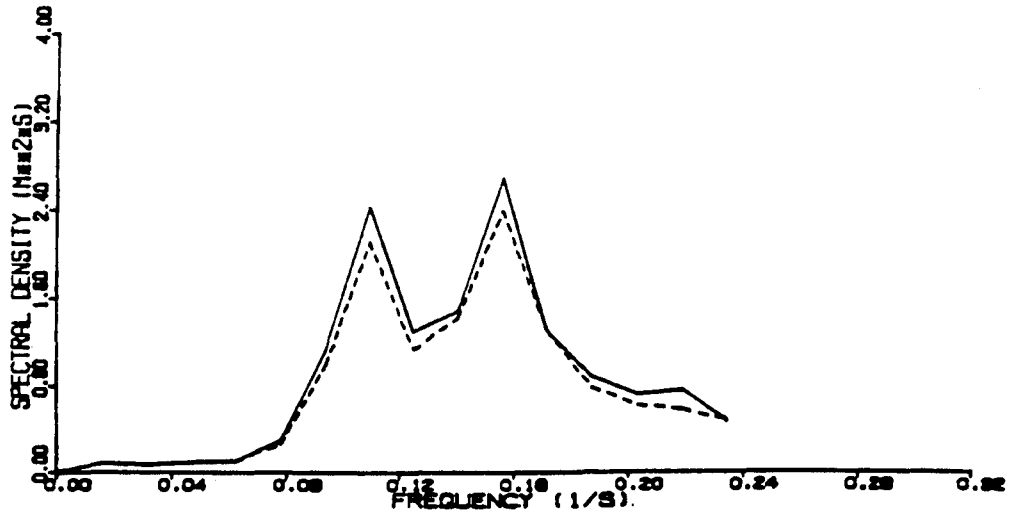
GREEN HARBOR, MASS

DATE: 28/2 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.222 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.198 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.15625 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 18.9

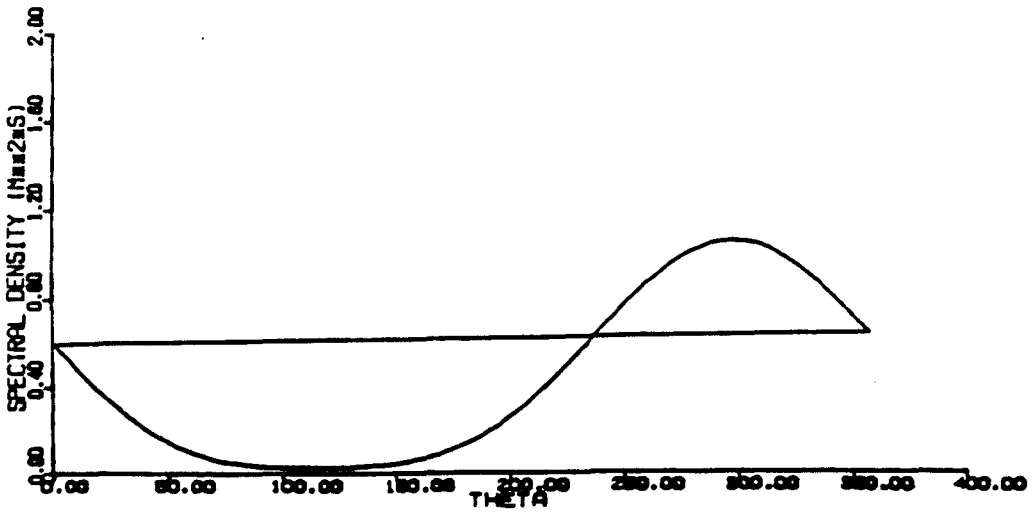


PLATE 28

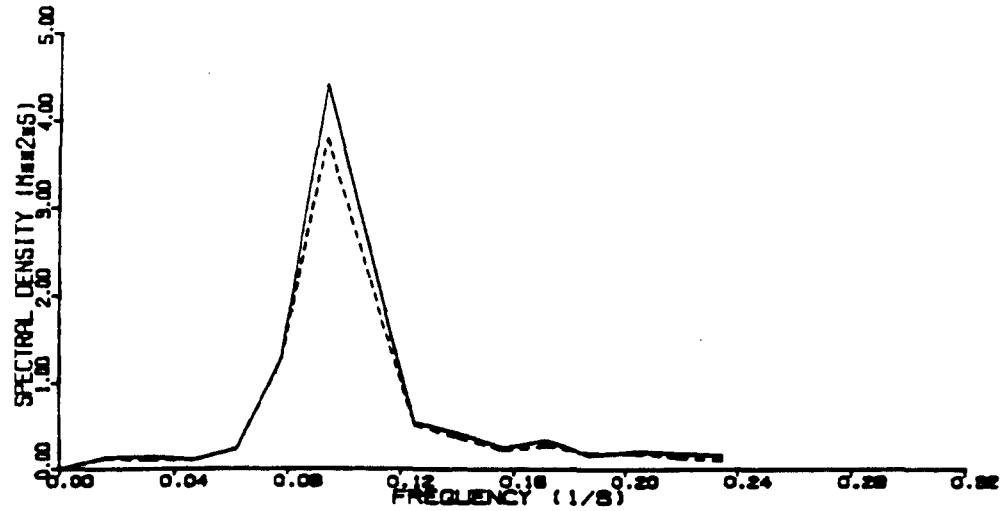
GREEN HARBOR, MASS

DATE: 29/2 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.170 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.148 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 39.8

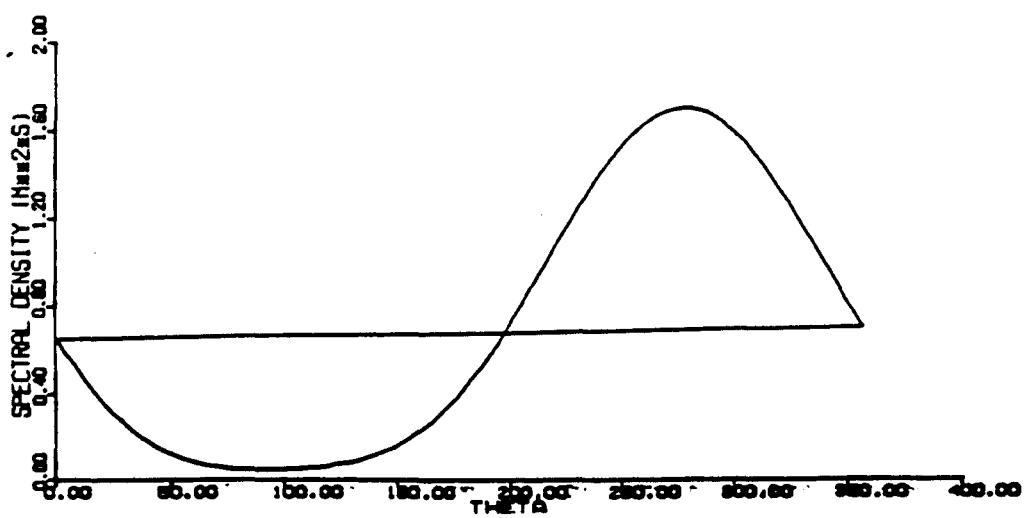


PLATE 29

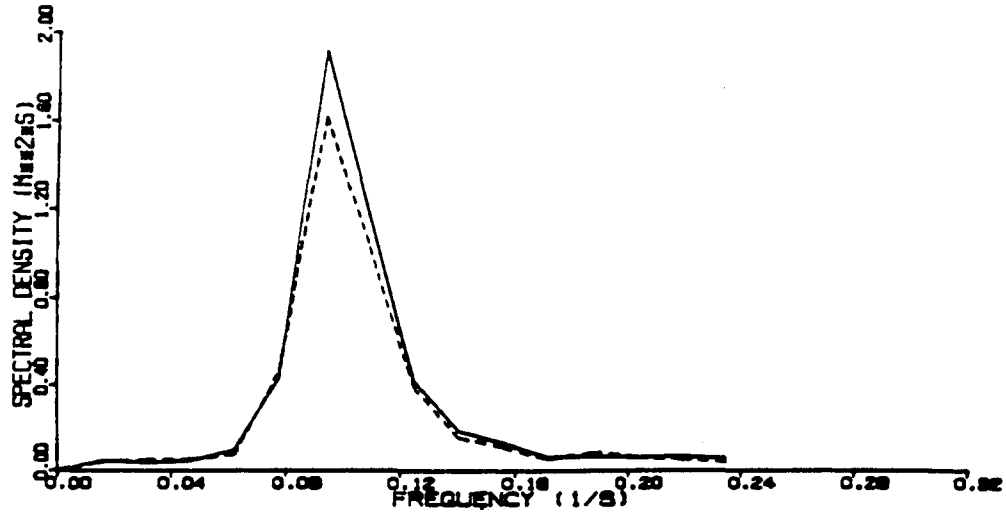
GREEN HARBOR, MASS

DATE: 29/2 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.074 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.068 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 38.7

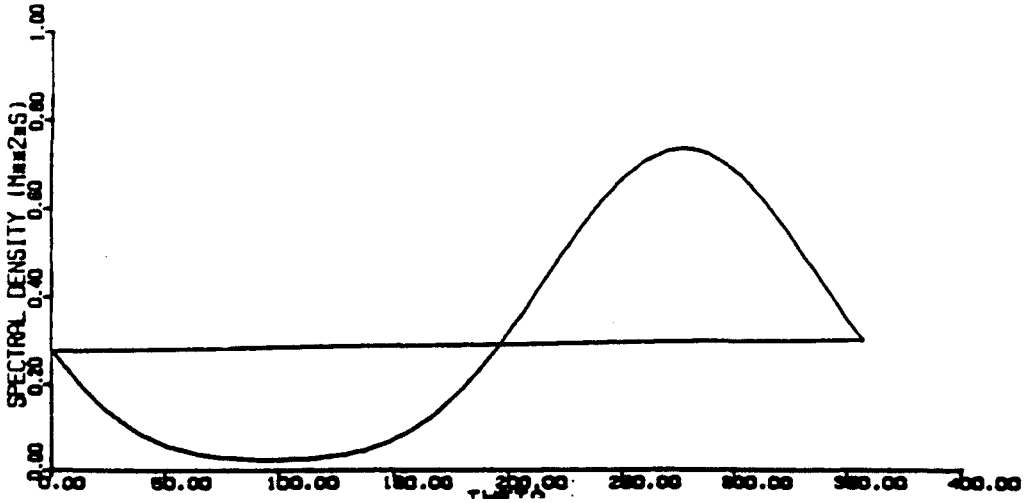


PLATE 30

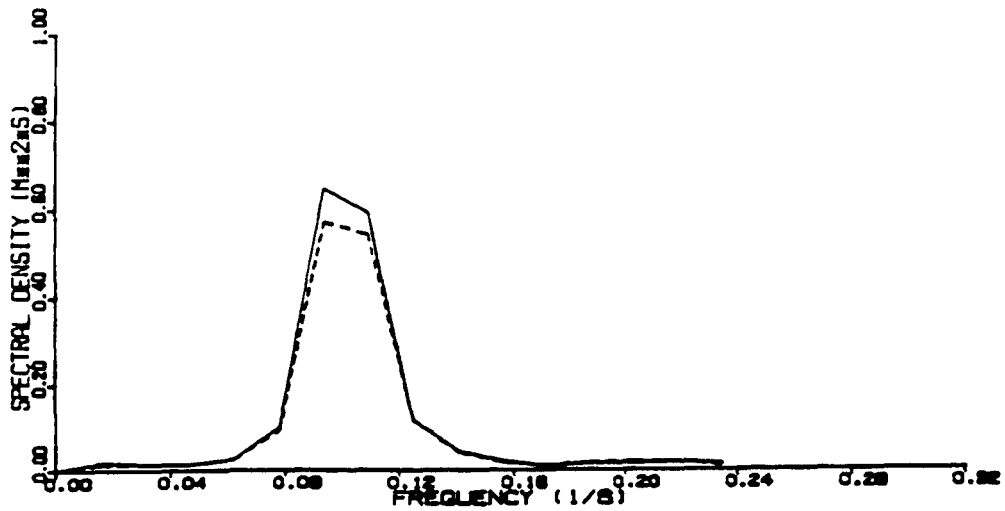
GREEN HARBOR, MASS

DATE: 29/2 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.025 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.023 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 38.4

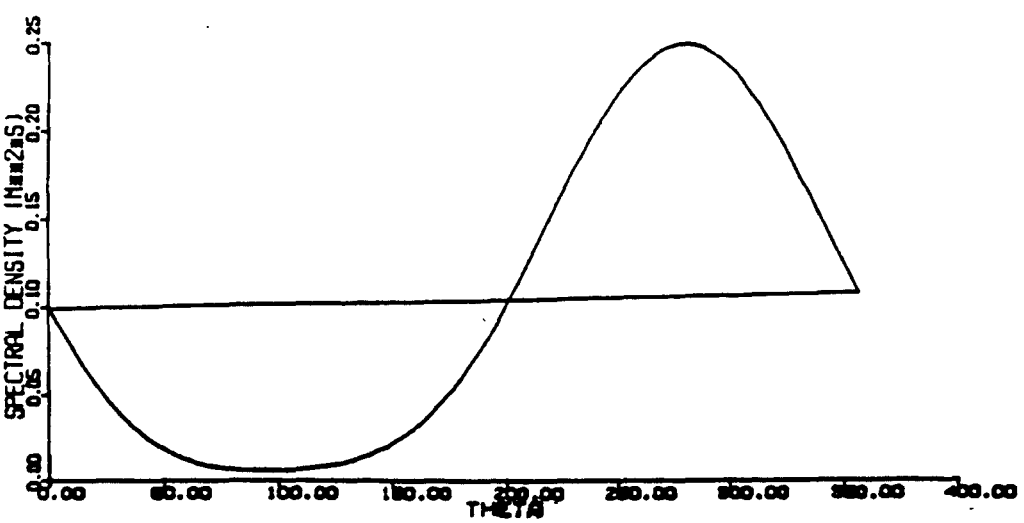


PLATE 31

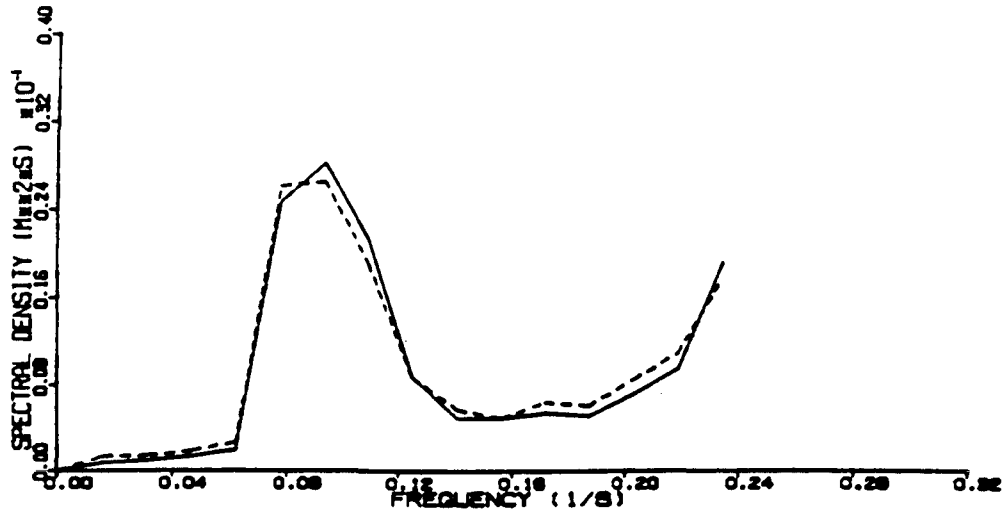
GREEN HARBOR. MASS

DATE: 9 /3 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.003 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.003 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 15.8

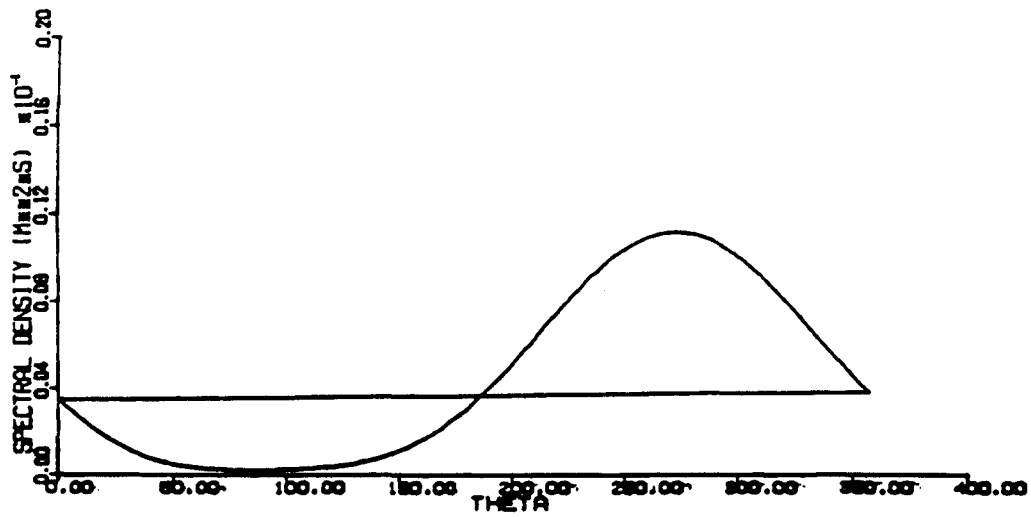


PLATE 32

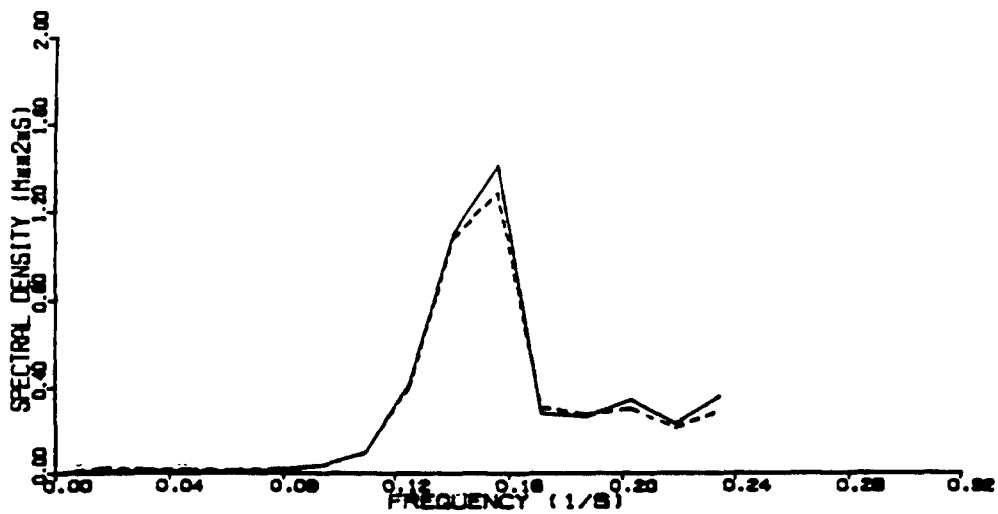
GREEN HARBOR. MASS

DATE: 9 /3 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.075 M**2

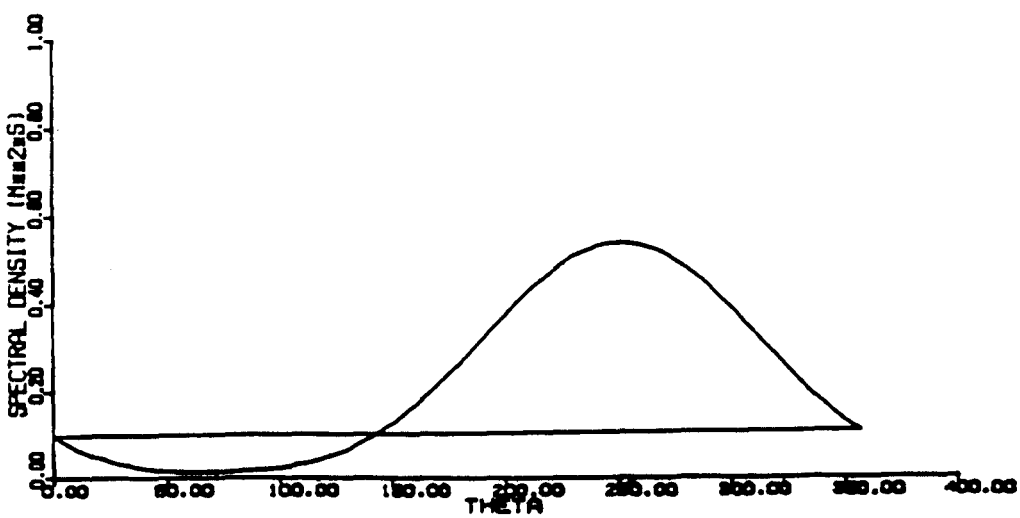
---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.071 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.15625 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 28.5



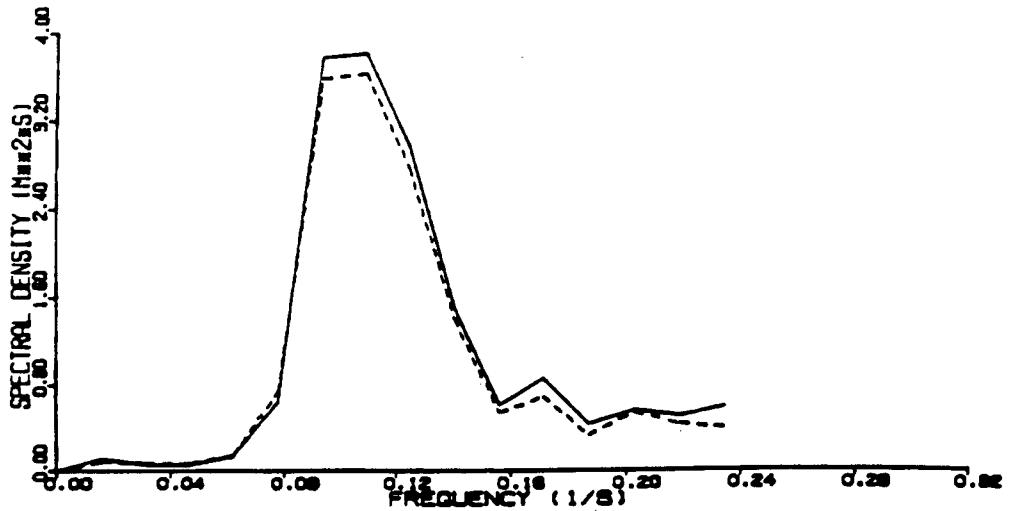
GREEN HARBOR, MASS

DATE: 9 /3 /84 TIME:1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.272 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.247 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.10937 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 23.0

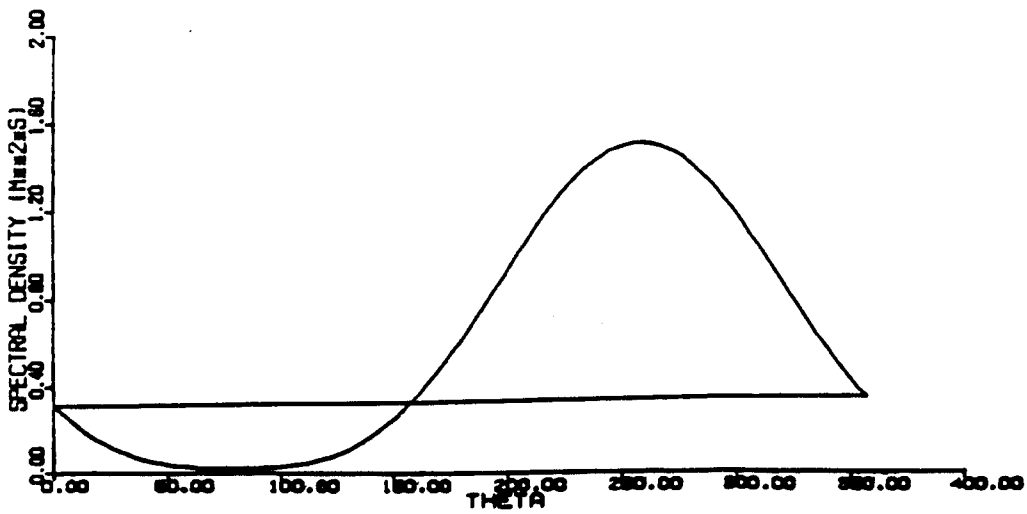


PLATE 34

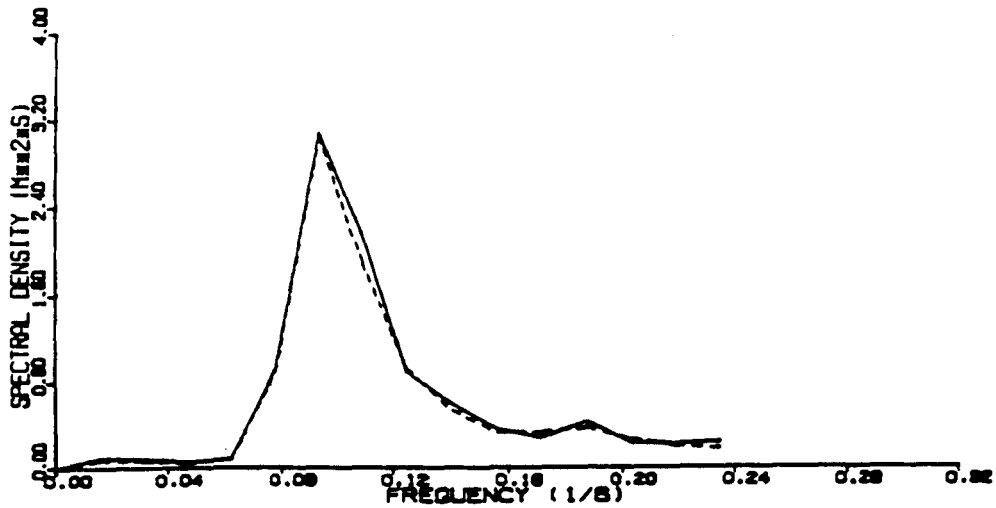
GREEN HARBOR, MASS

DATE: 10/3 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.151 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.143 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 33.1

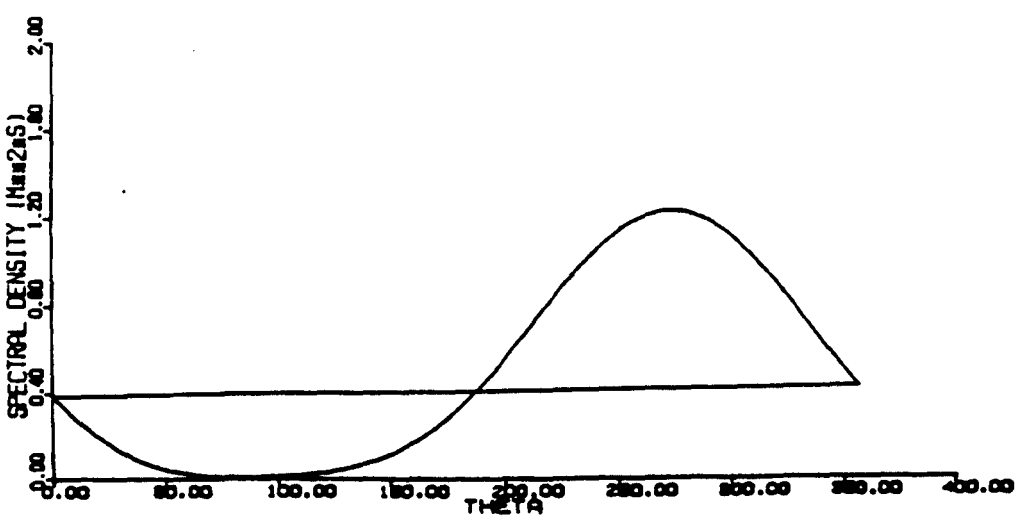


PLATE 35

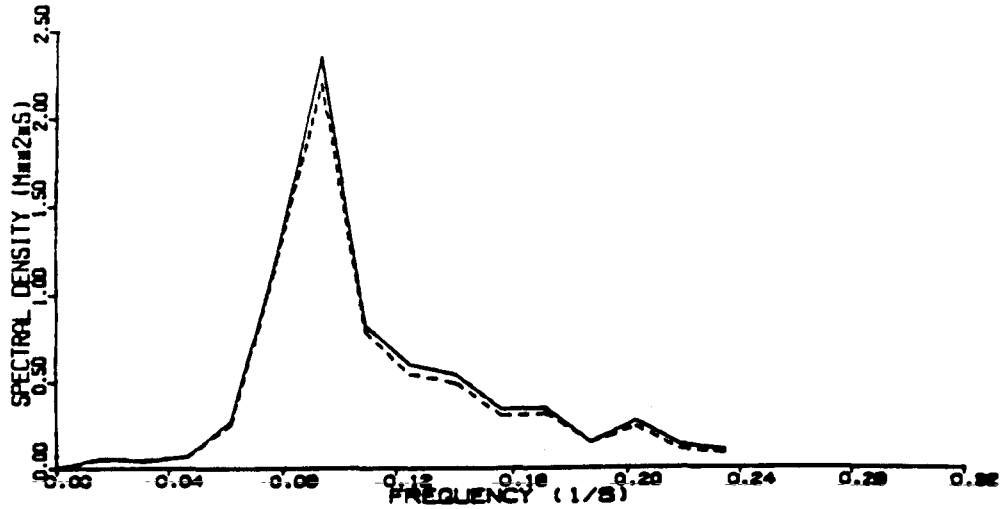
GREEN HARBOR, MASS

DATE: 10/3 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.114 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.108 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 32.4

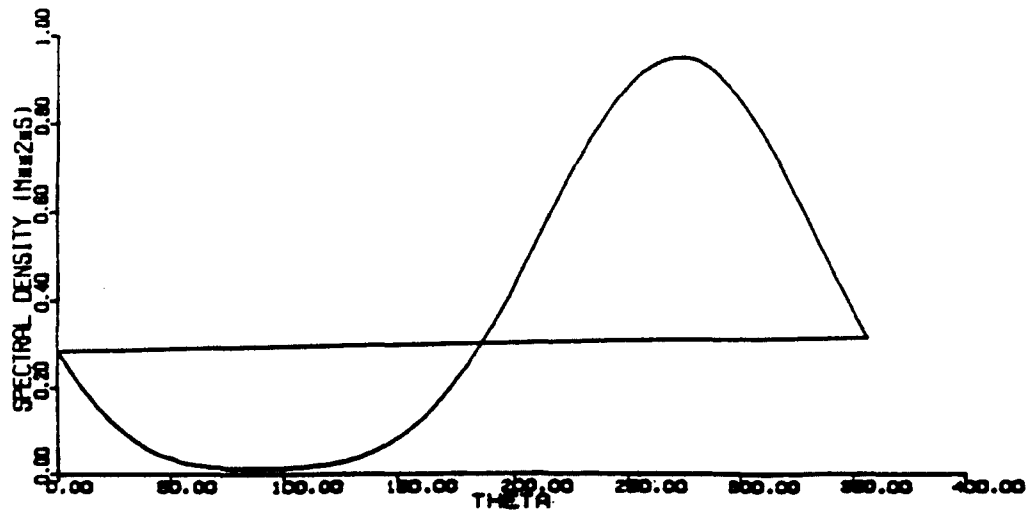


PLATE 36

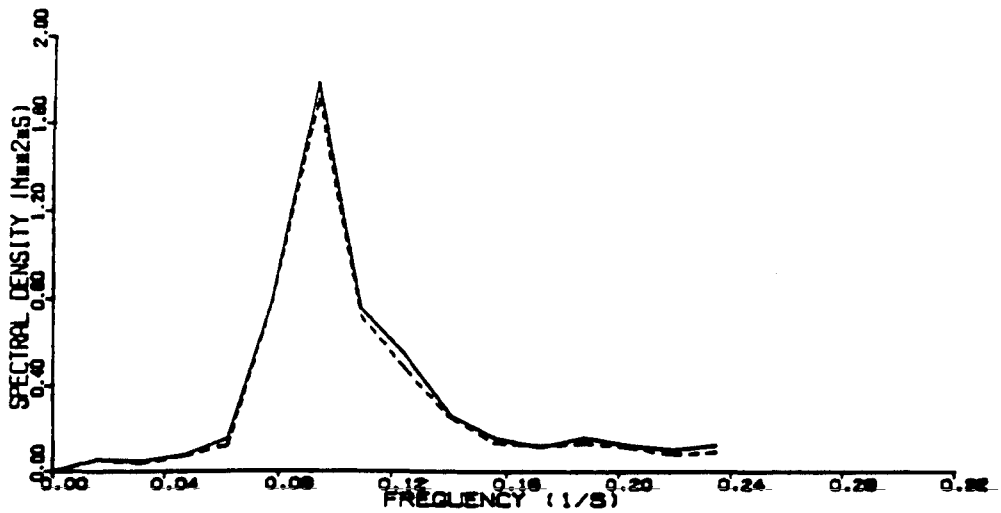
GREEN HARBOR, MASS

DATE: 10/3 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.081 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.075 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 35.5

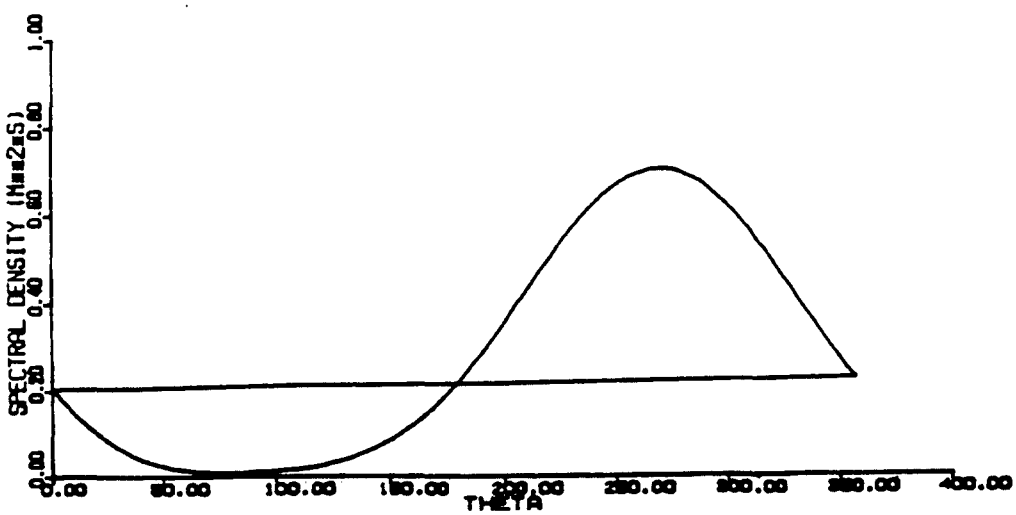


PLATE 37

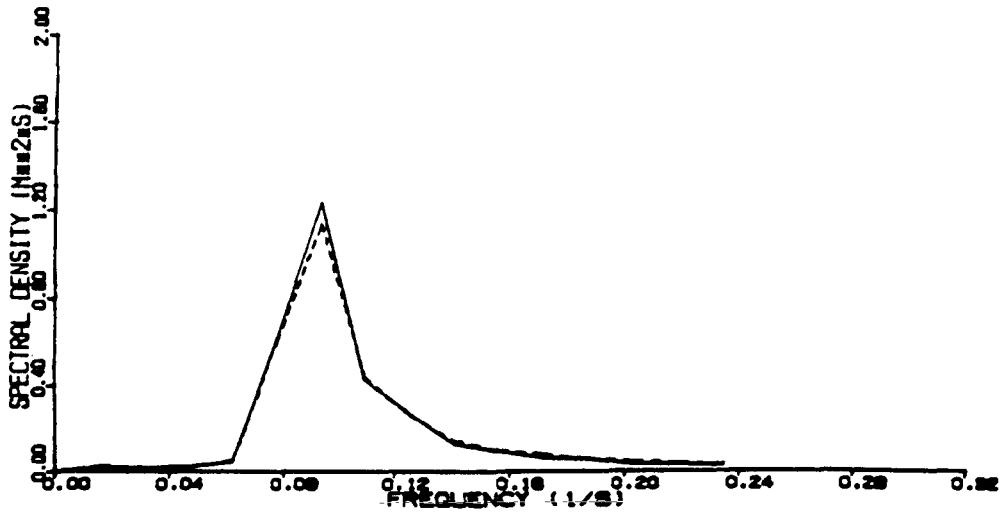
GREEN HARBOR, MASS

DATE: 11/3 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.048 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.047 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 38.0

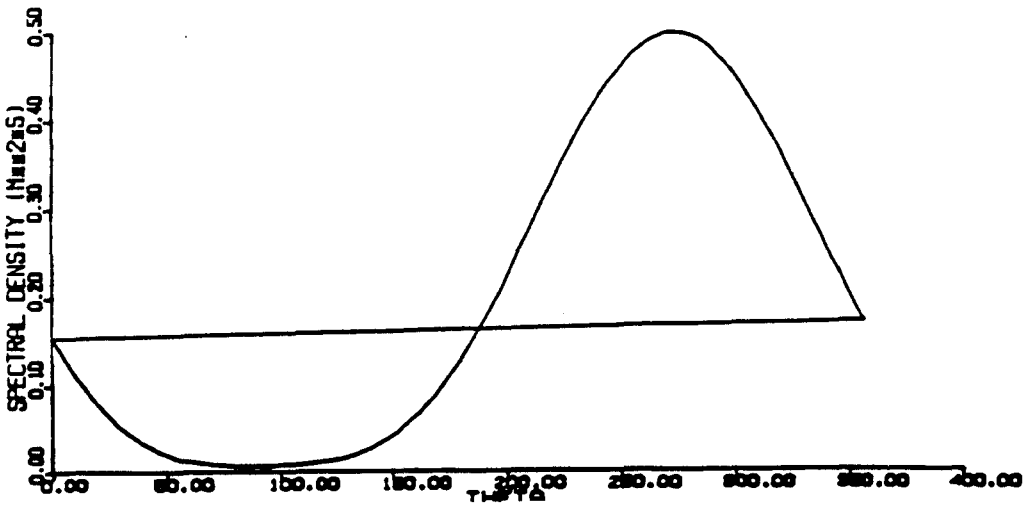


PLATE 38

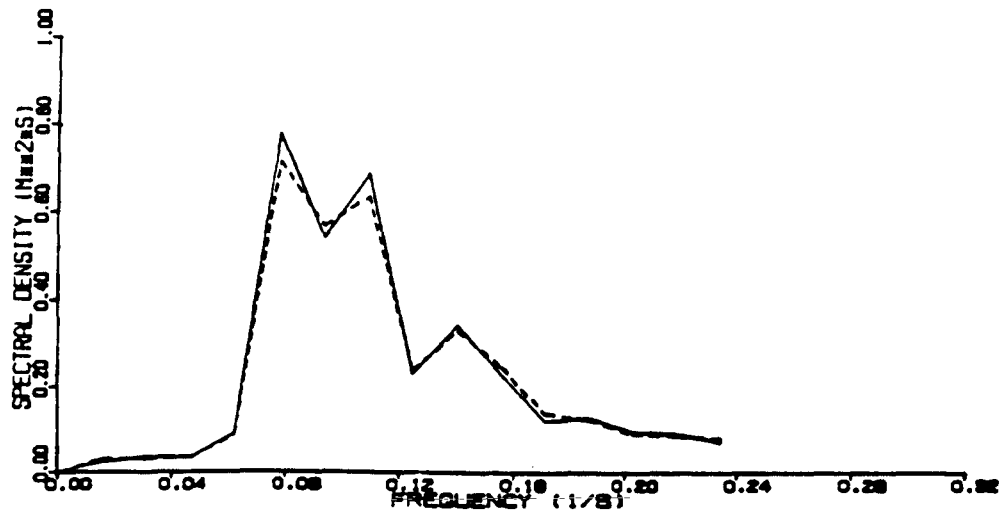
GREEN HARBOR, MASS

DATE: 15/3 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.055 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.053 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 20.9

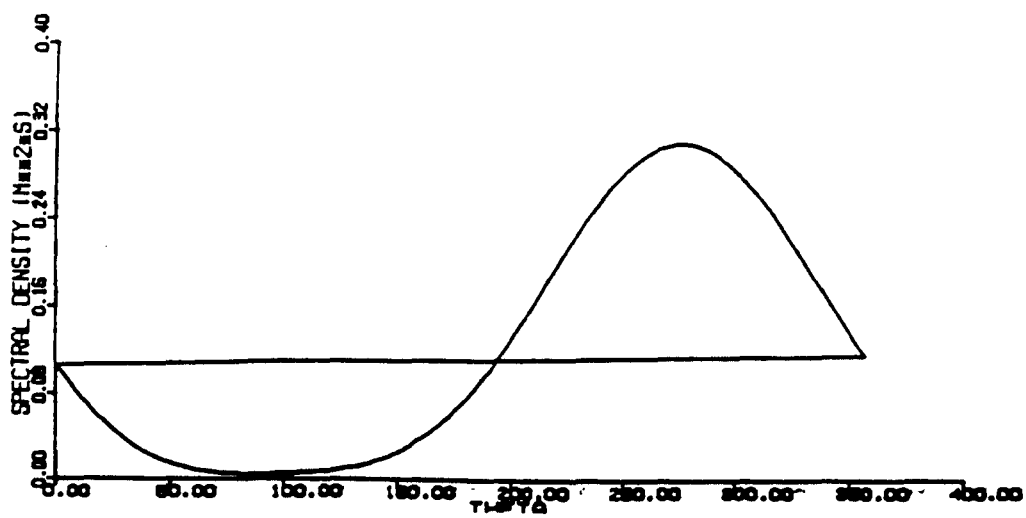


PLATE 39

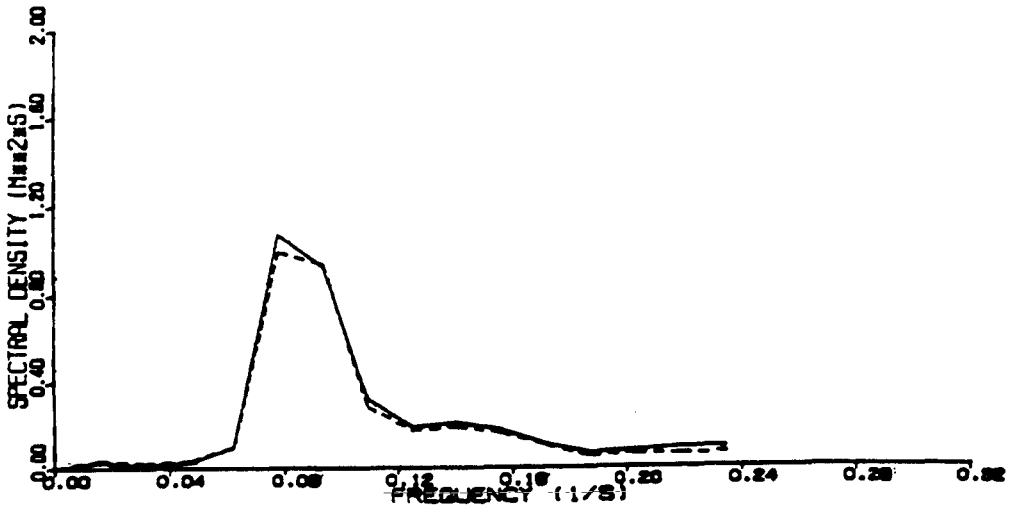
GREEN HARBOR, MASS

DATE: 16/3 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.055 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.051 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 30.6

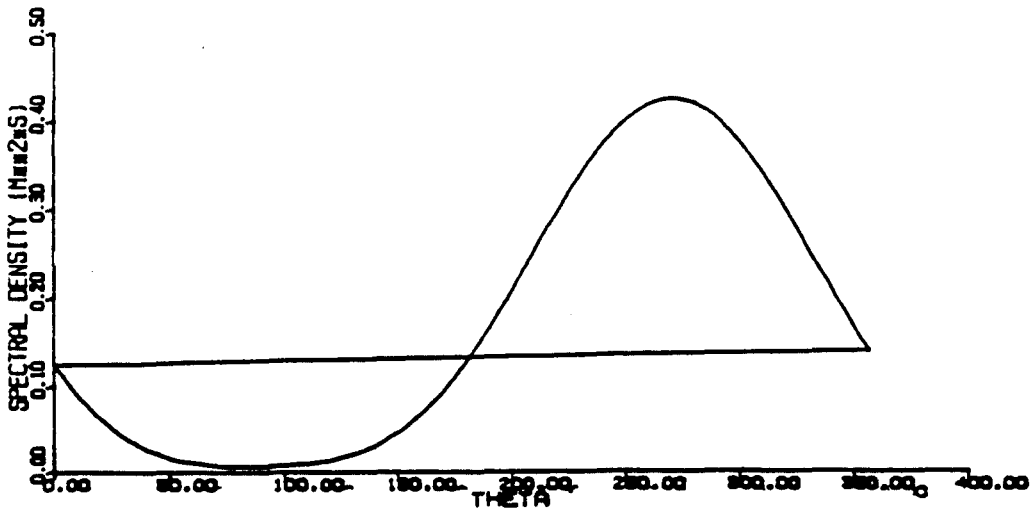


PLATE 40

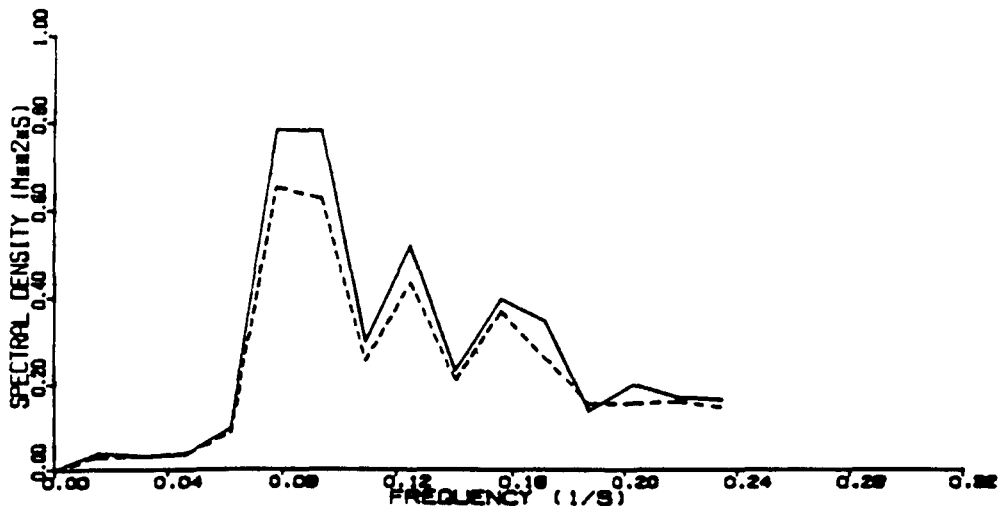
GREEN HARBOR, MASS

DATE: 16/3 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.087 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.057 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 18.0

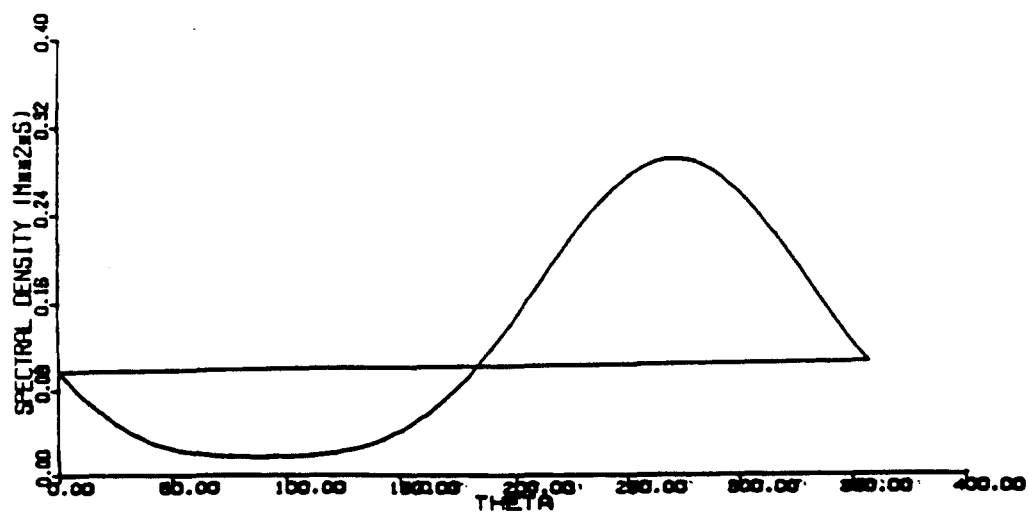


PLATE 41

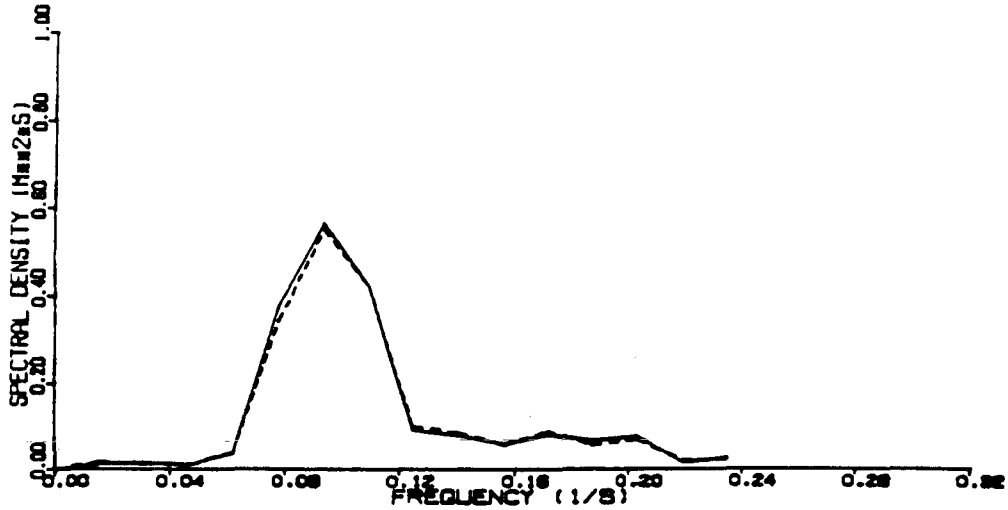
GREEN HARBOR, MASS

DATE: 16/3 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.030 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.030 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 29.2

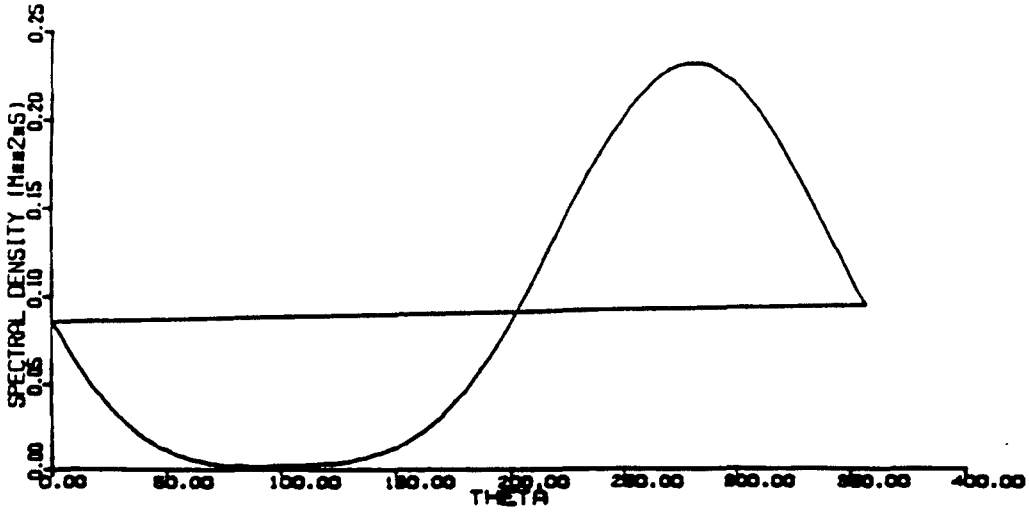


PLATE 42

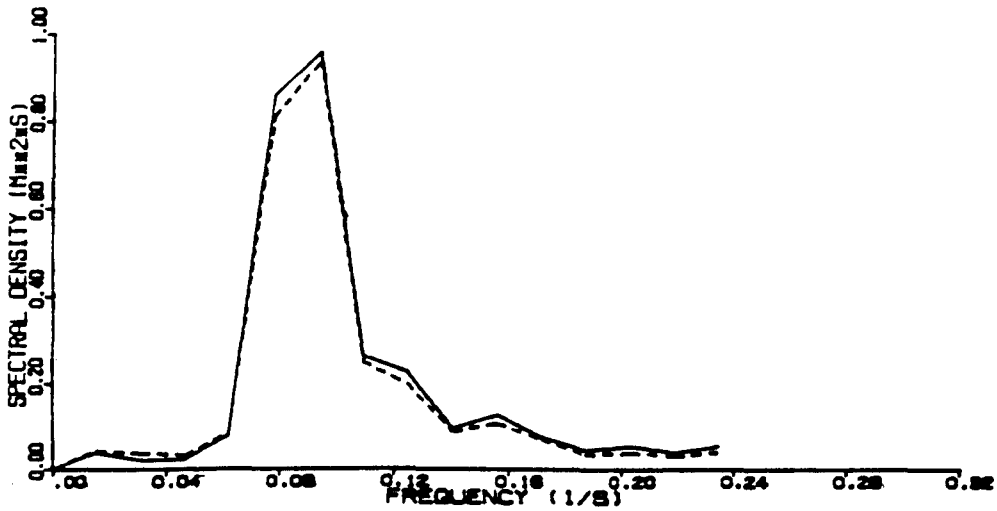
GREEN HARBOR, MASS

DATE: 17/3 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.048 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.043 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 34.4

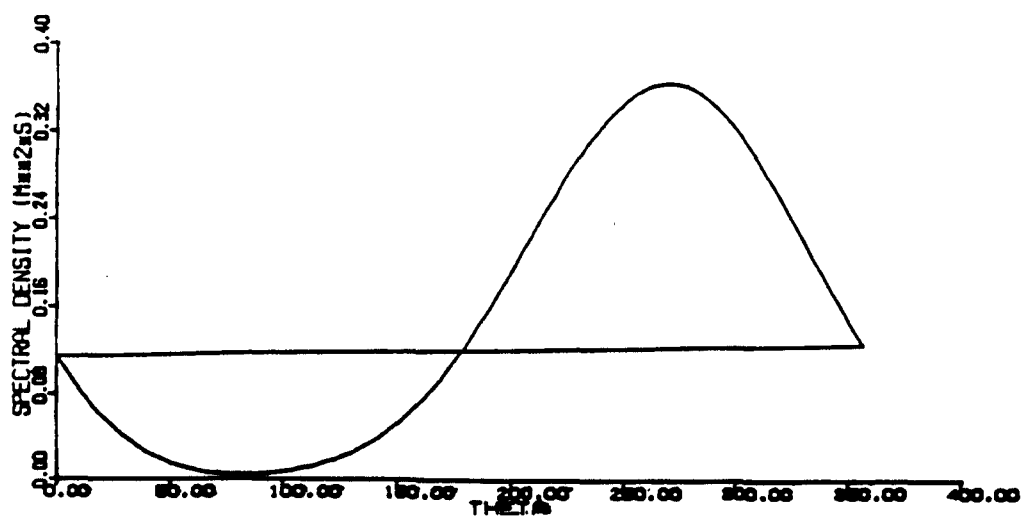


PLATE 43

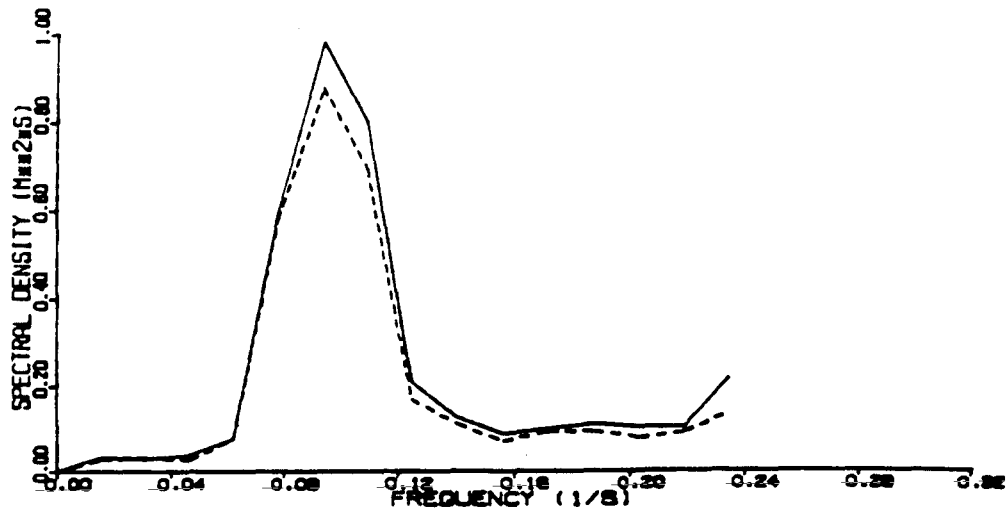
GREEN HARBOR, MASS

DATE: 17/3 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.060 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.061 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 28.7

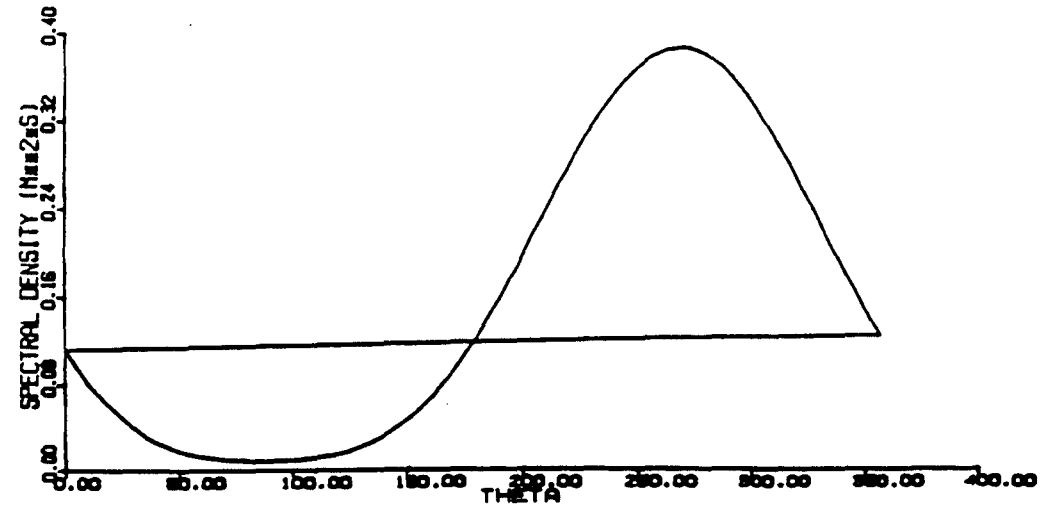


PLATE 44

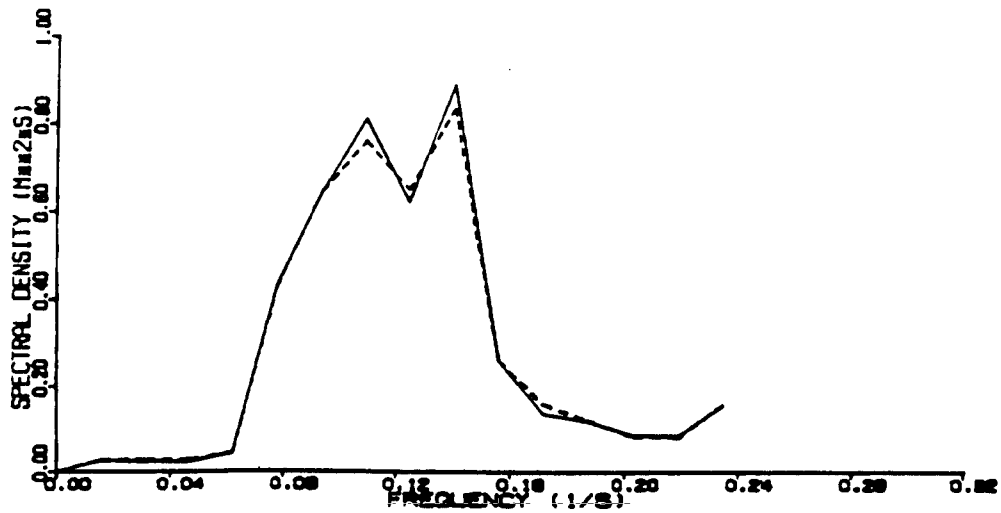
GREEN HARBOR. MASS

DATE: 17/3 /84 TIME: 1655

SEA SURFACE SPECTRUM

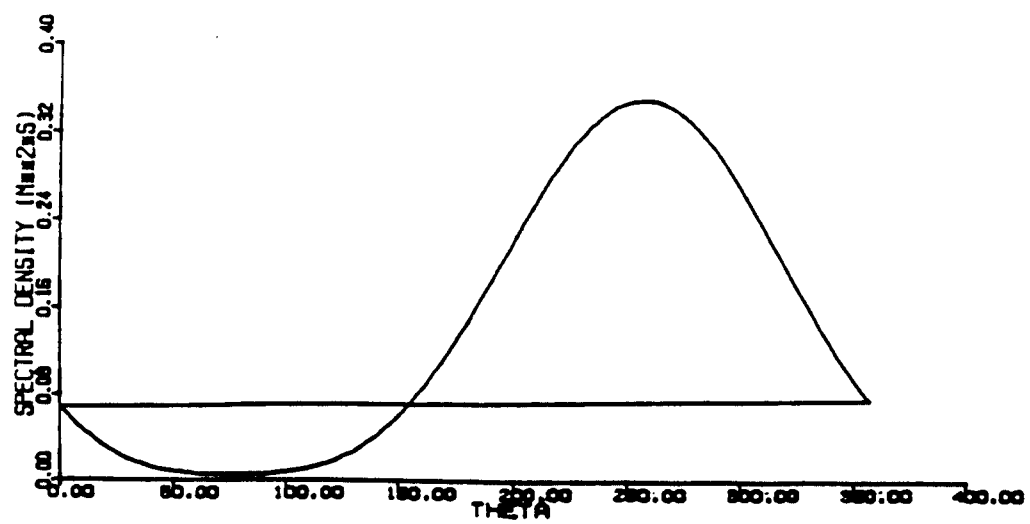
—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.068 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.067 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.14063 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 19.4



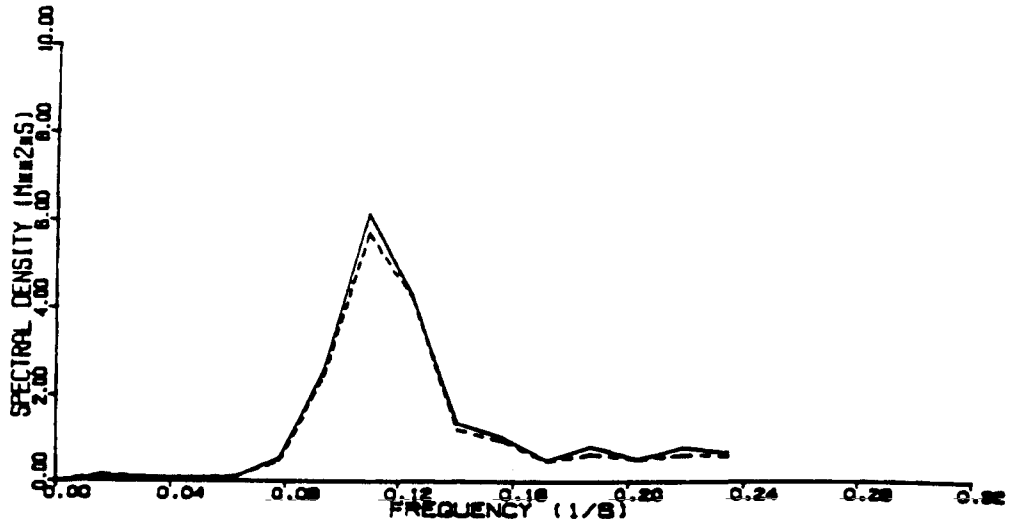
GREEN HARBOR, MASS

DATE: 18/3 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.320 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.293 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.10937 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 30.5

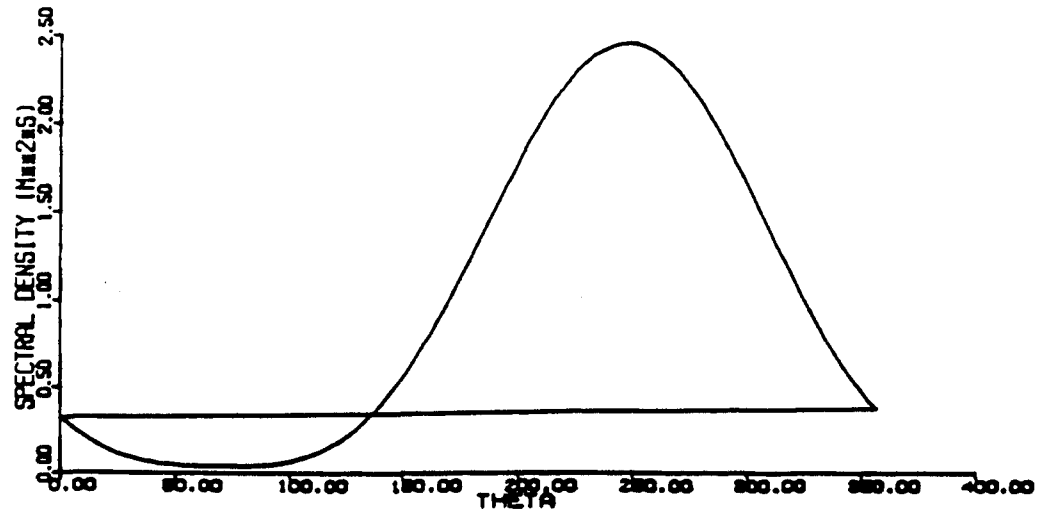


PLATE 46

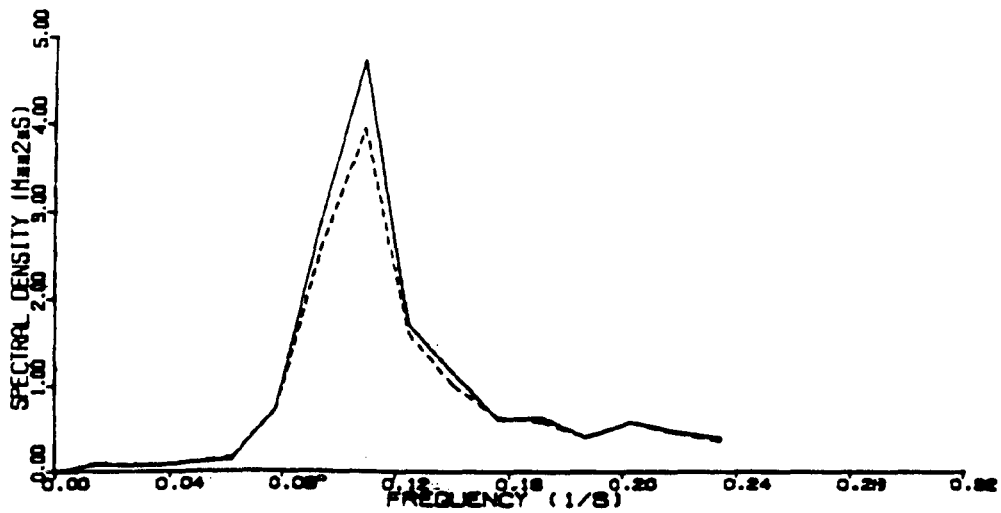
GREEN HARBOR, MASS

DATE: 18/3 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.234 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.210 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.10937 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 29.3

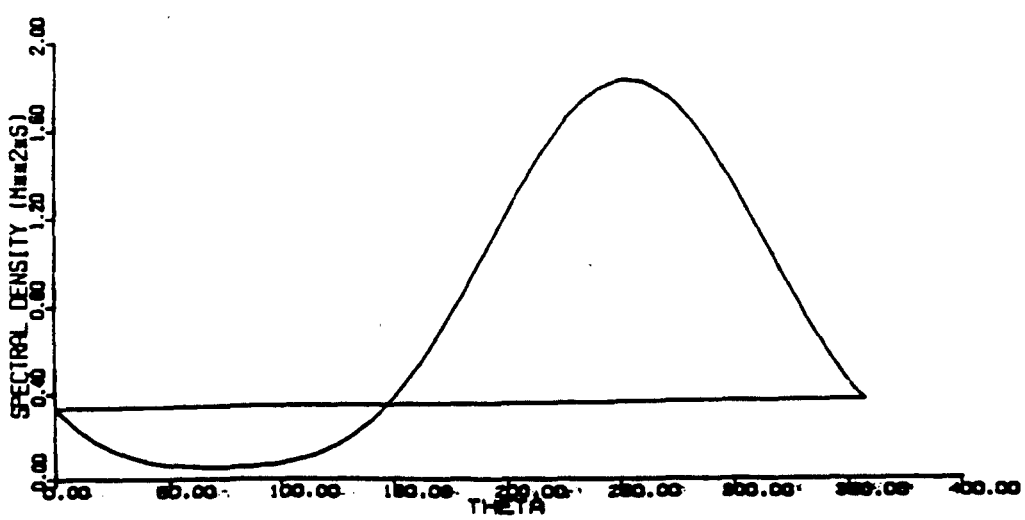


PLATE 47

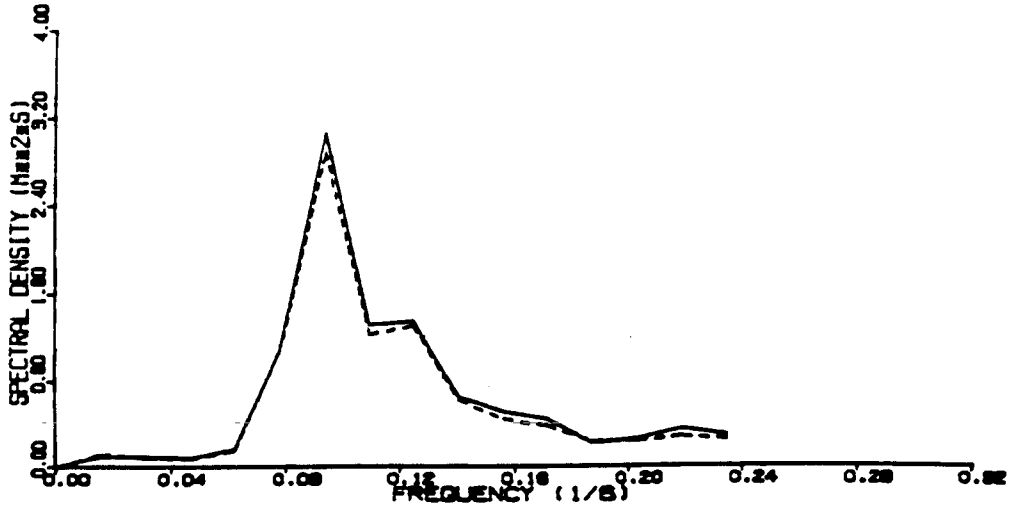
GREEN HARBOR, MASS

DATE: 18/3 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.158 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.145 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 31.1

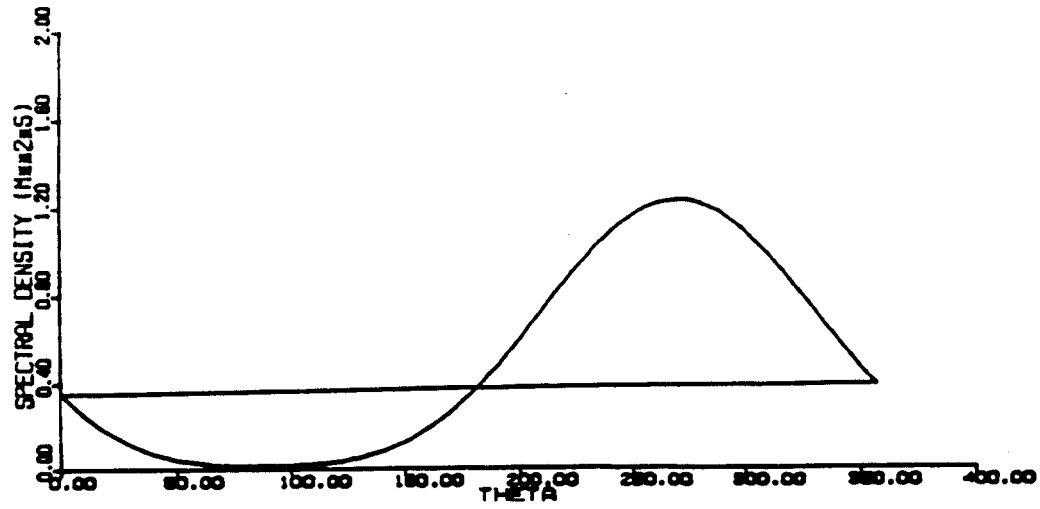


PLATE 48

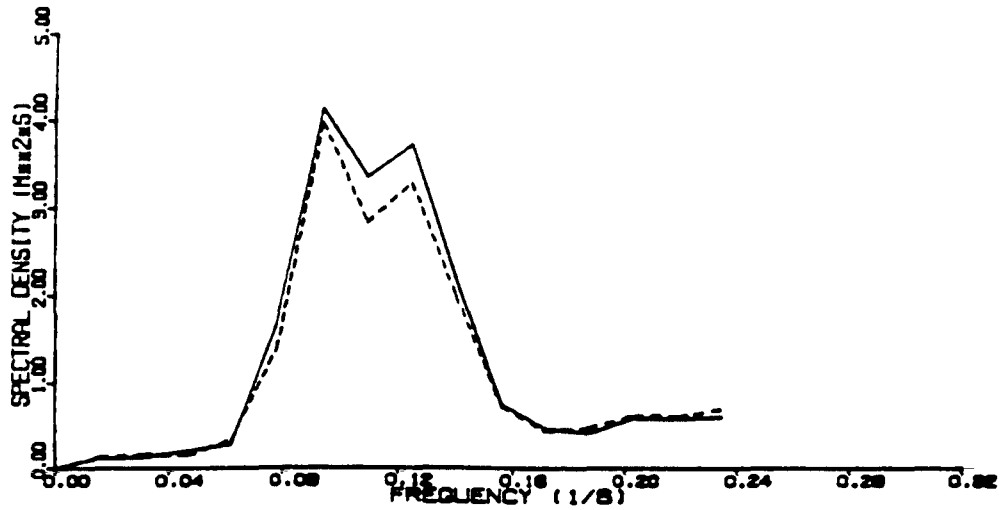
GREEN HARBOR, MASS

DATE: 19/3 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.298 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.277 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 22.4

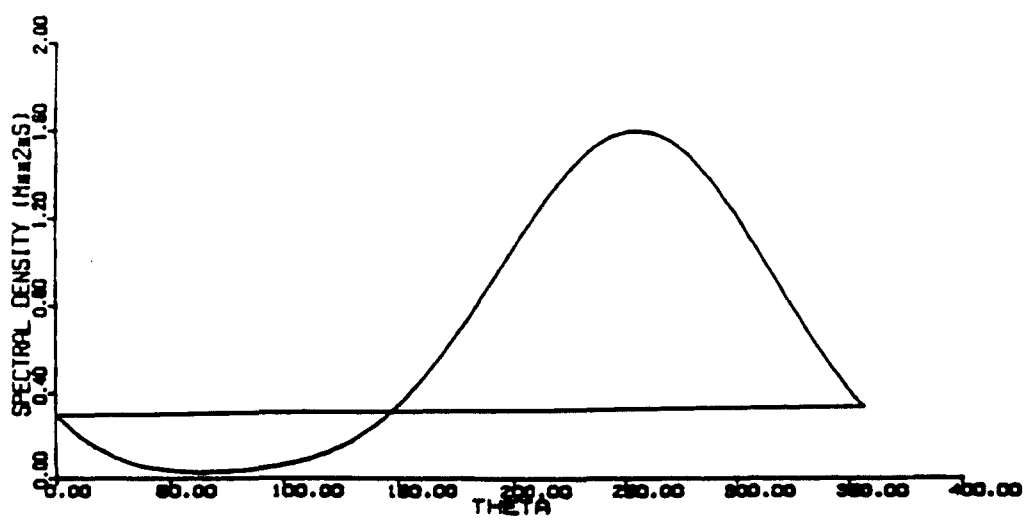


PLATE 49

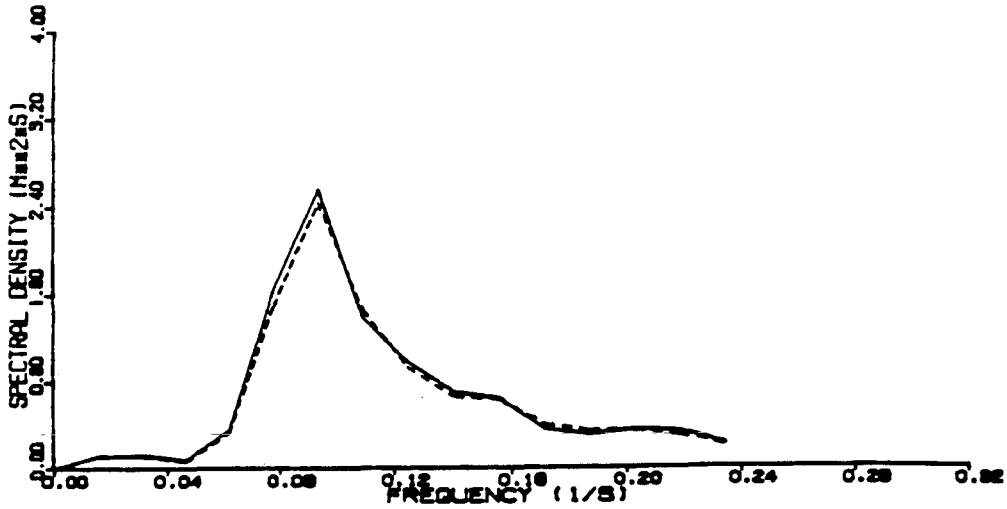
GREEN HARBOR, MASS

DATE: 19/3 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.159 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.153 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 24.9

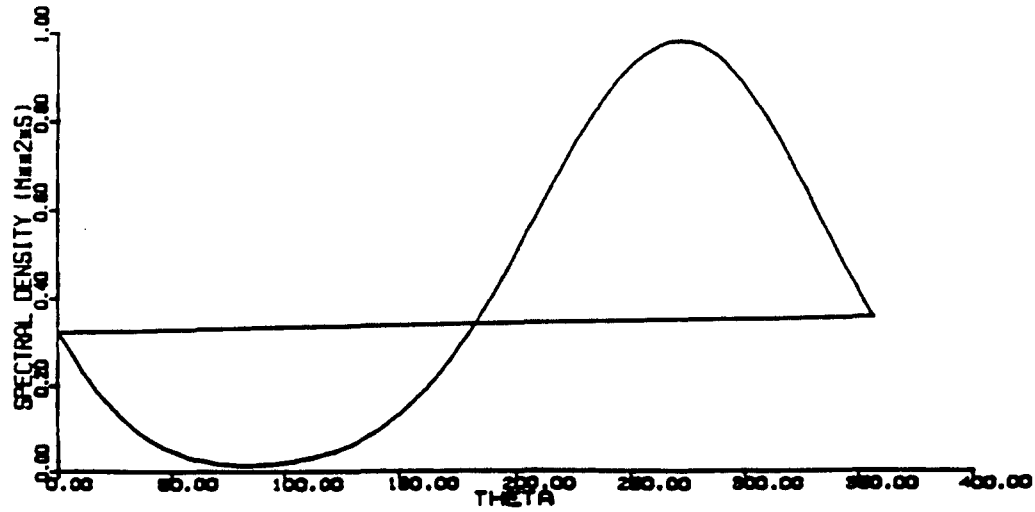


PLATE 50

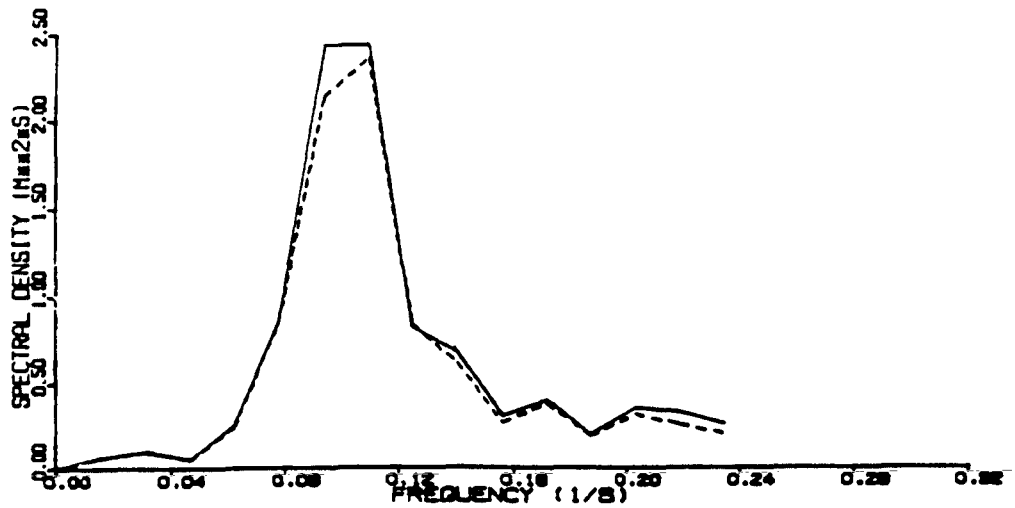
GREEN HARBOR, MASS

DATE: 19/3 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.148 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.137 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 24.5

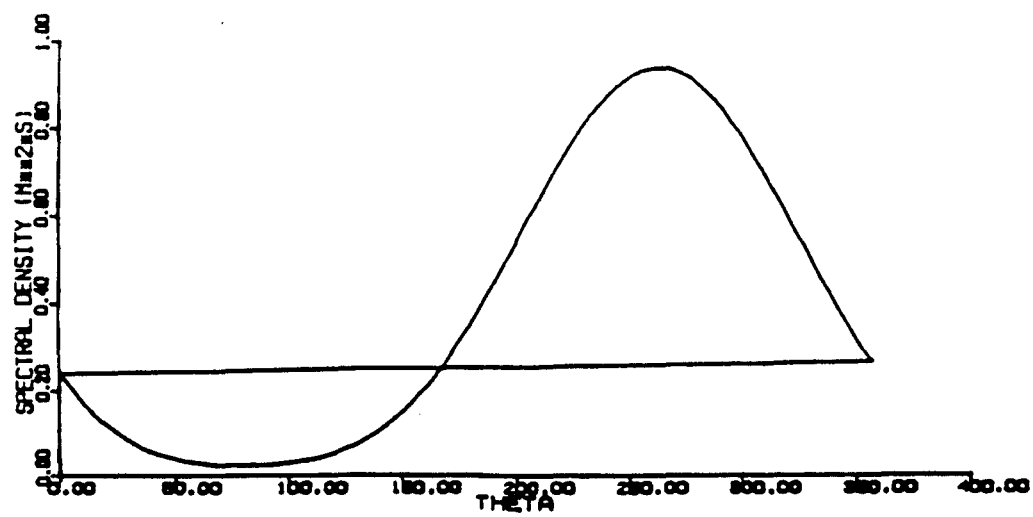


PLATE 51

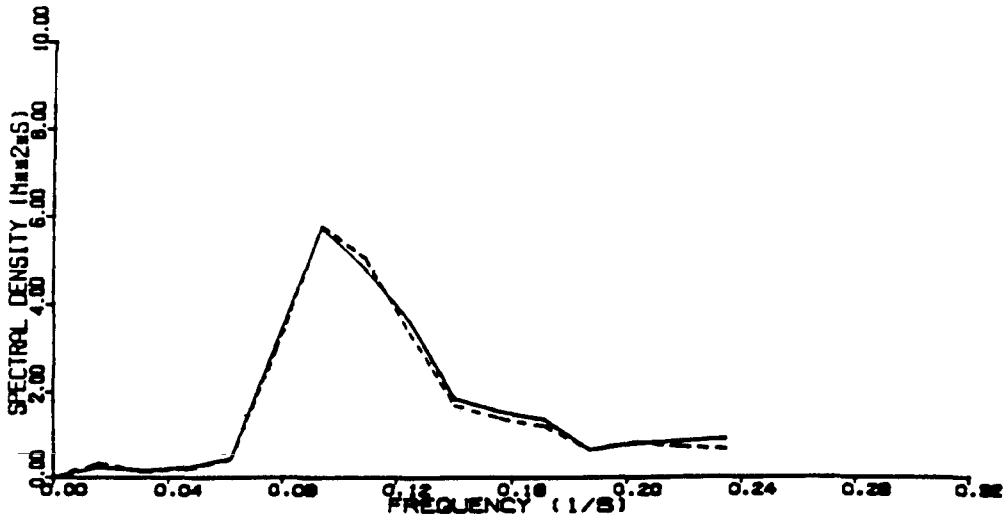
GREEN HARBOR, MASS

DATE: 20/3 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.411 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.393 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 23.1

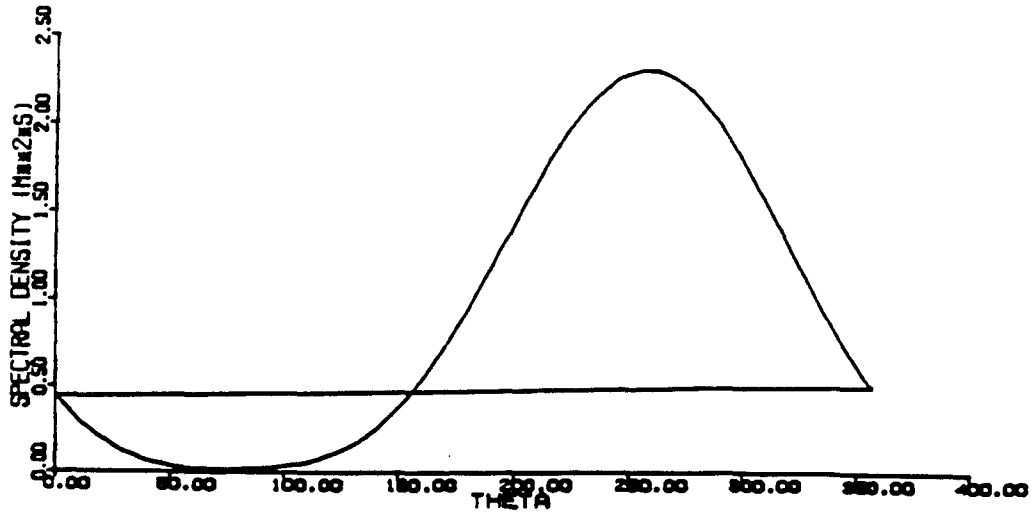


PLATE 52

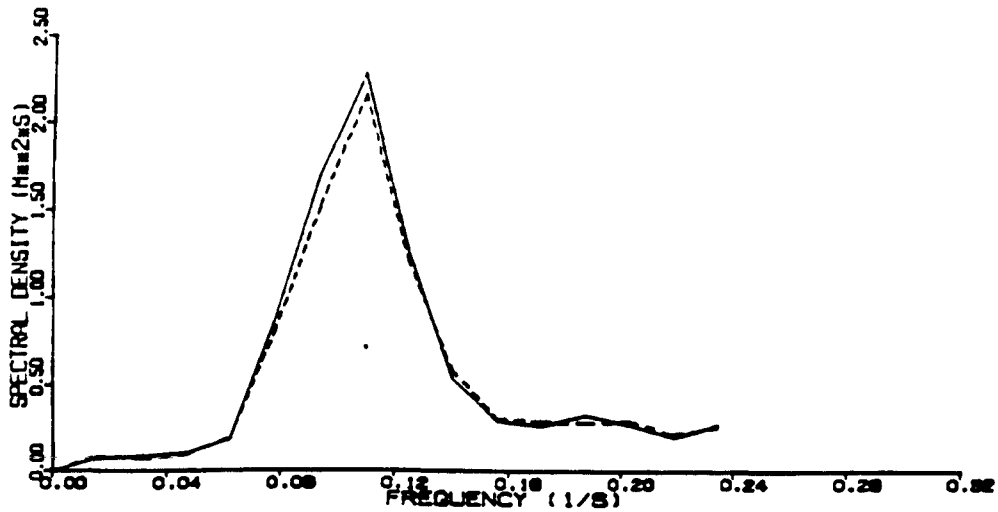
GREEN HARBOR, MASS

DATE: 20/3 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.136 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.129 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.10937 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 28.2

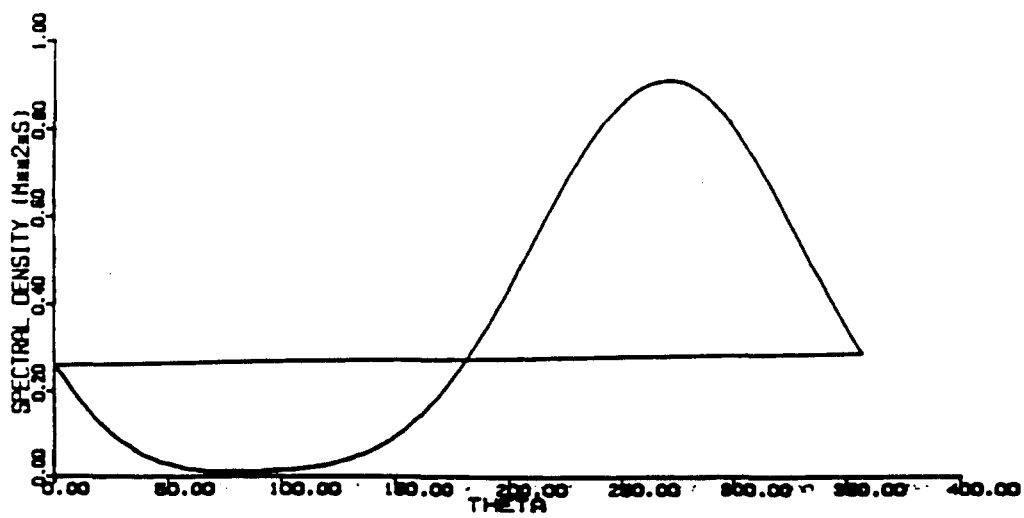


PLATE 53

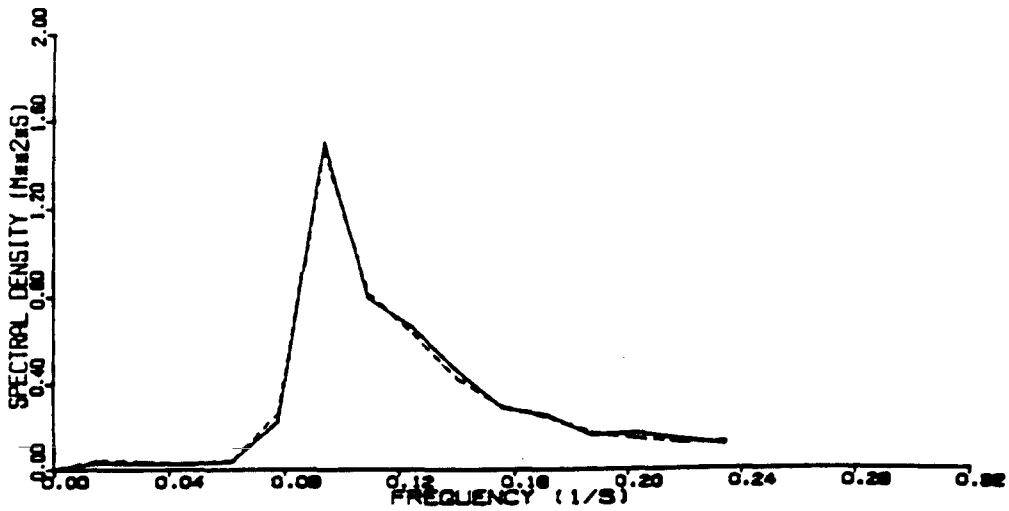
GREEN HARBOR, MASS

DATE: 20/3 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.078 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.077 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 30.0

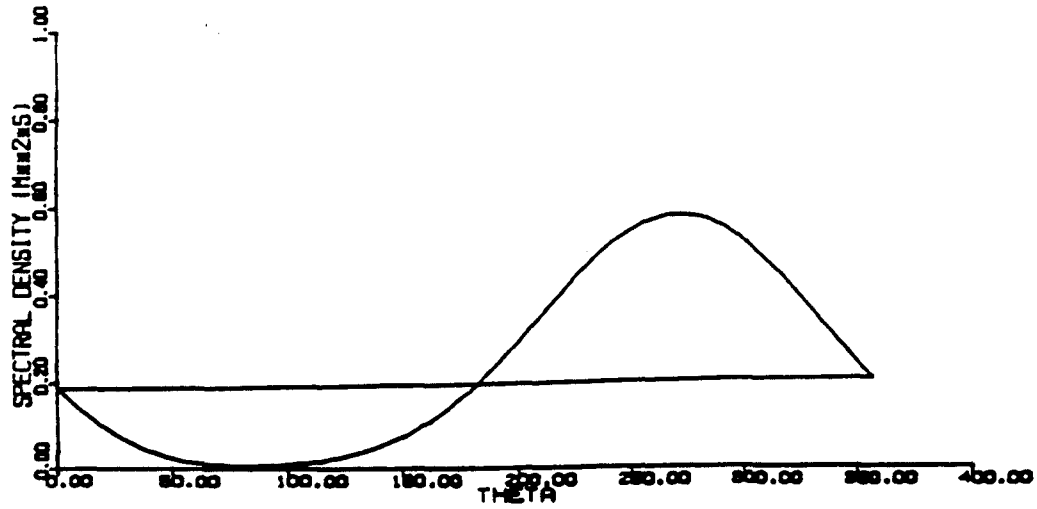


PLATE 54

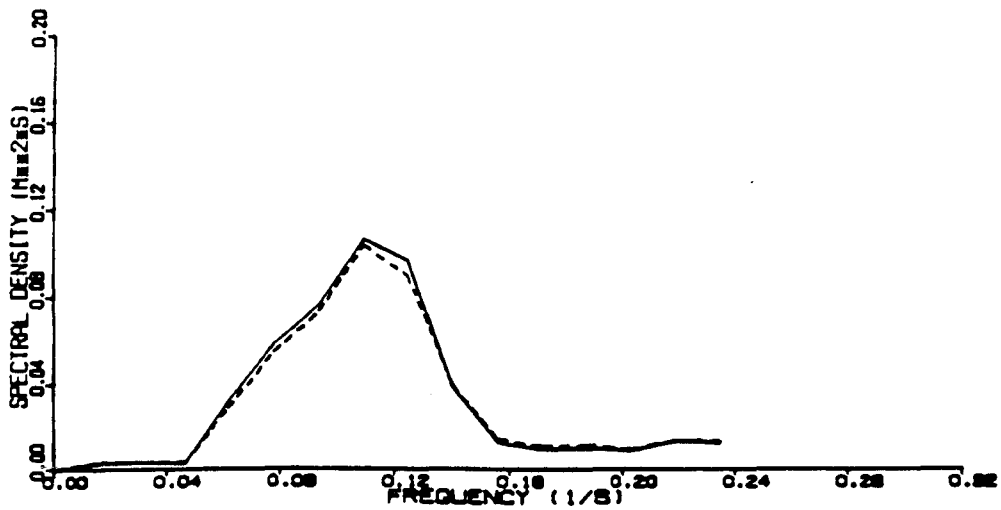
GREEN HARBOR, MASS

DATE: 28/3 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.008 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.007 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.10937 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 21.9

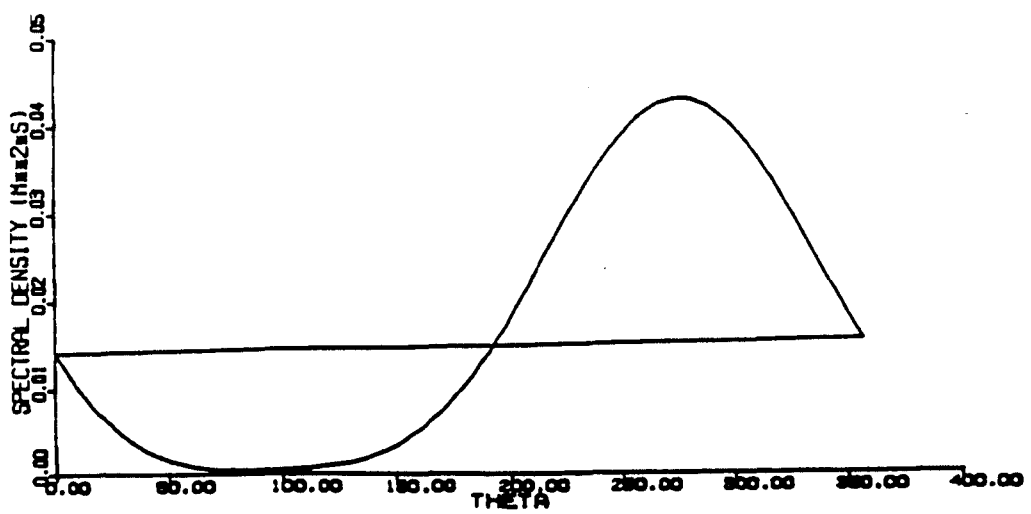


PLATE 55

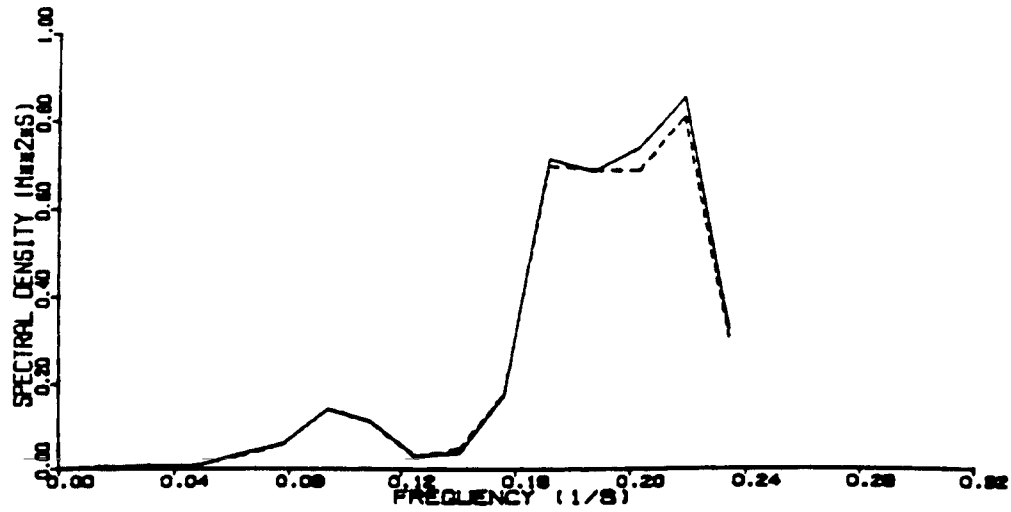
GREEN HARBOR, MASS

DATE: 29/3 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.087 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.085 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.21875 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 19.6

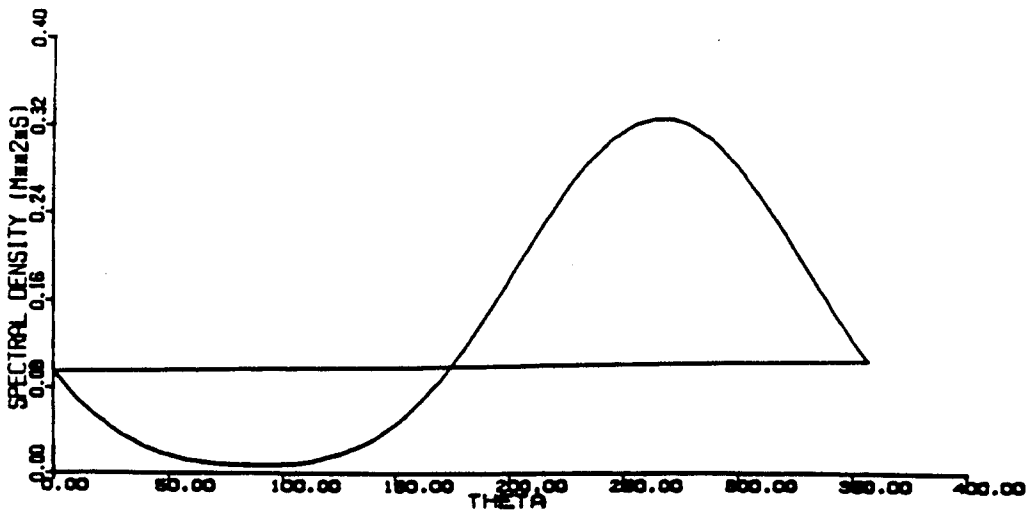


PLATE 56

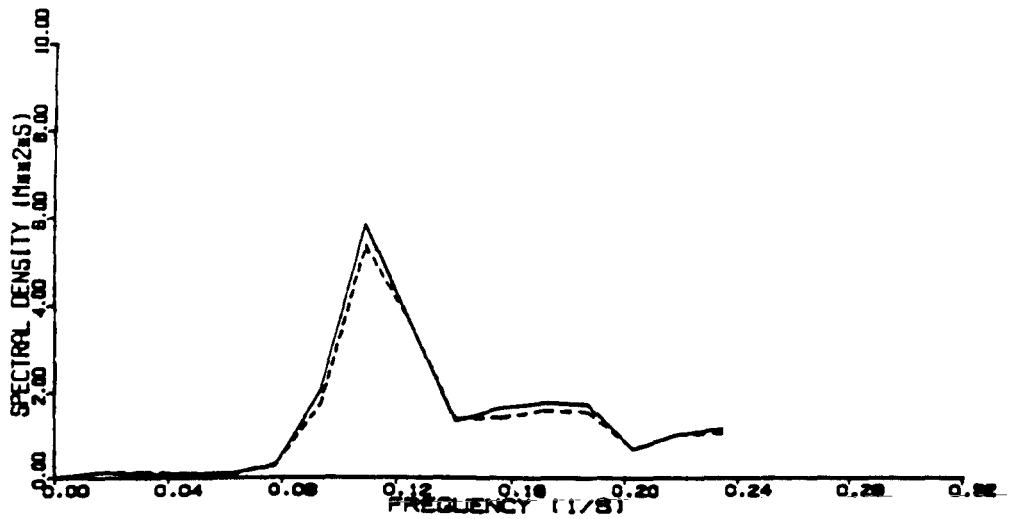
GREEN HARBOR, MASS

DATE: 29/3 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.340 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.317 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.10937 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 26.4

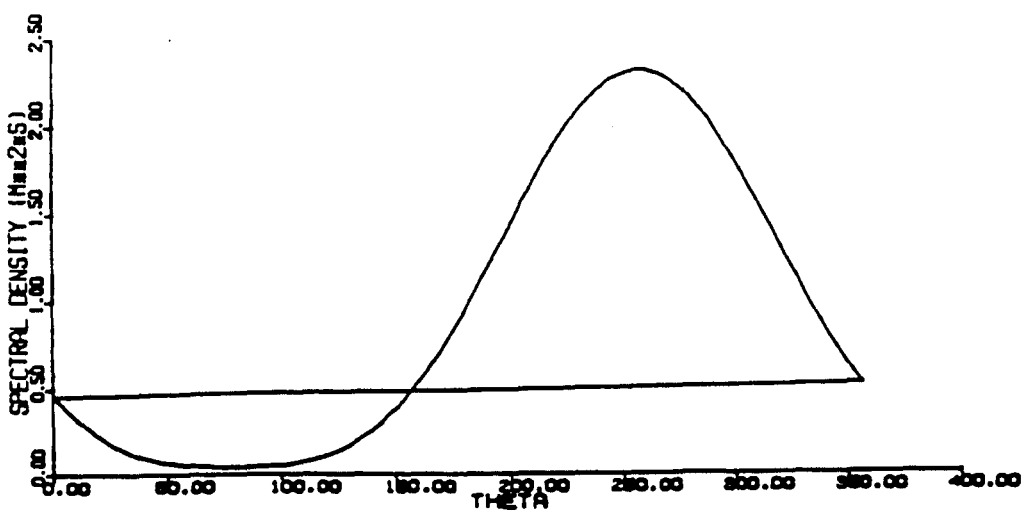


PLATE 57

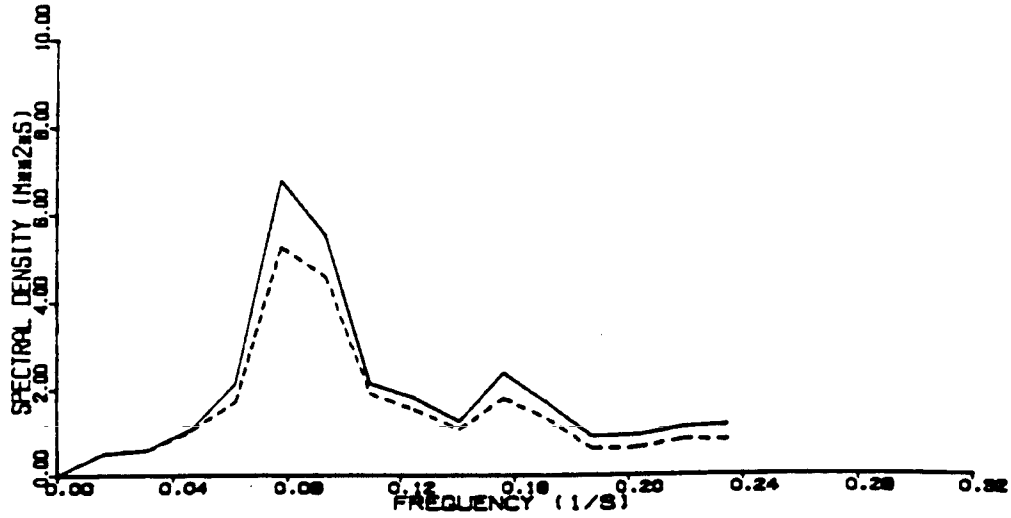
GREEN HARBOR, MASS

DATE: 29/3 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.449 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.354 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 23.3

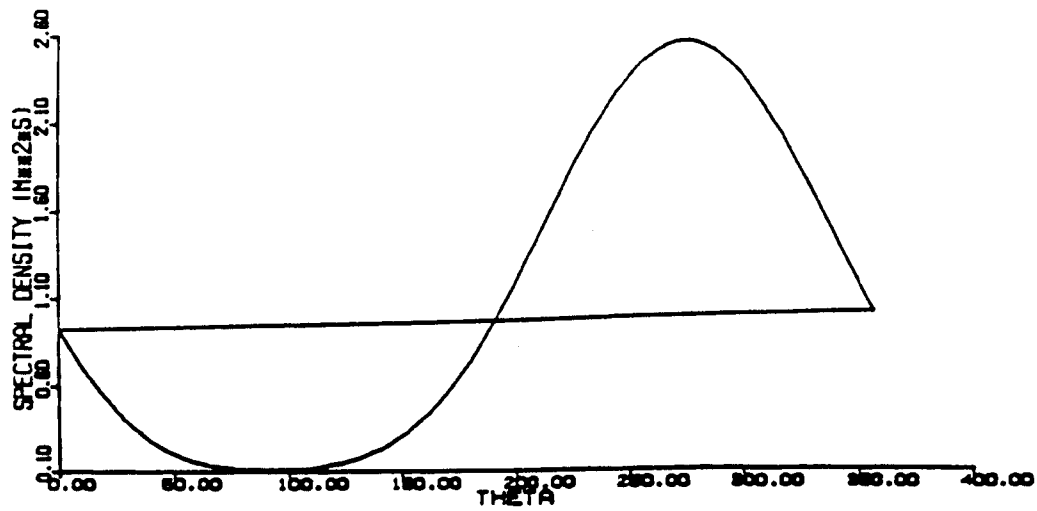


PLATE 58

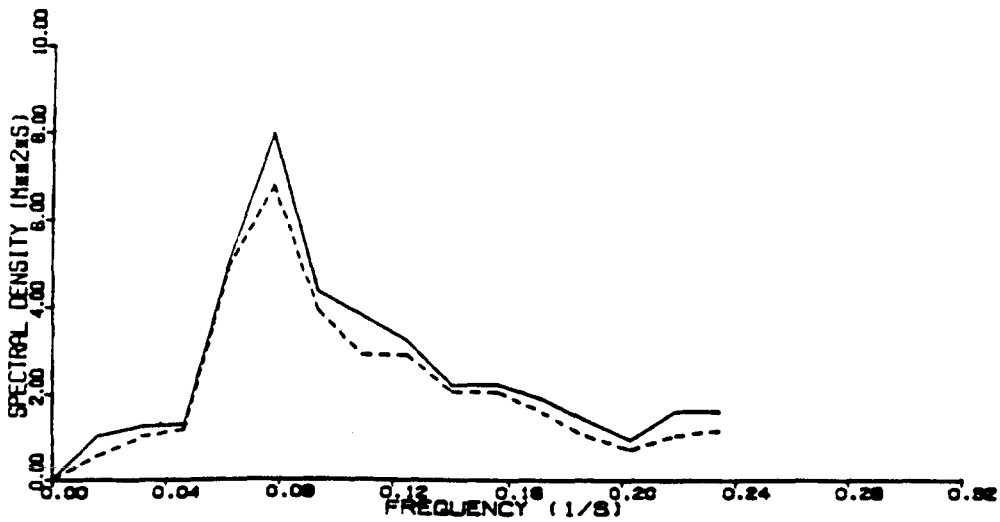
GREEN HARBOR, MASS

DATE: 30/3 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.587 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.498 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 21.4

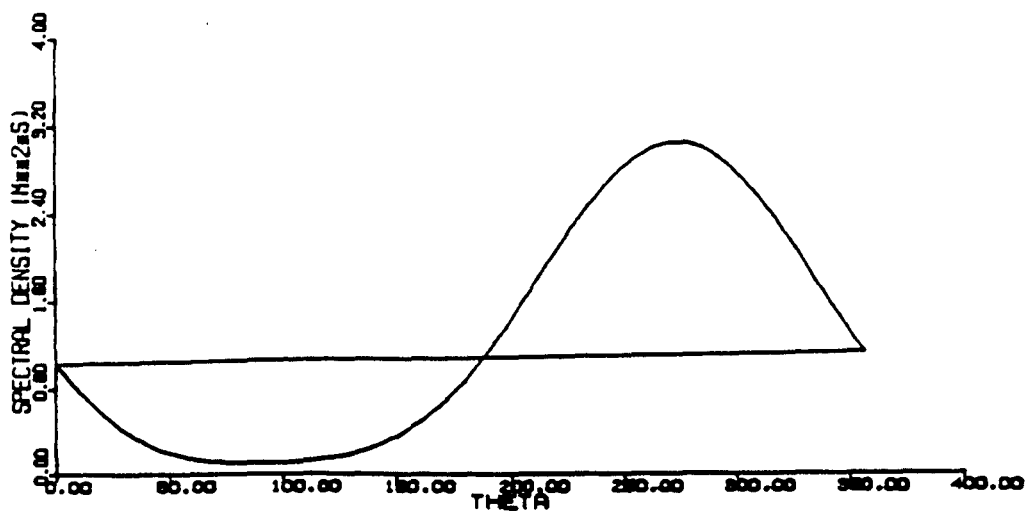


PLATE 59

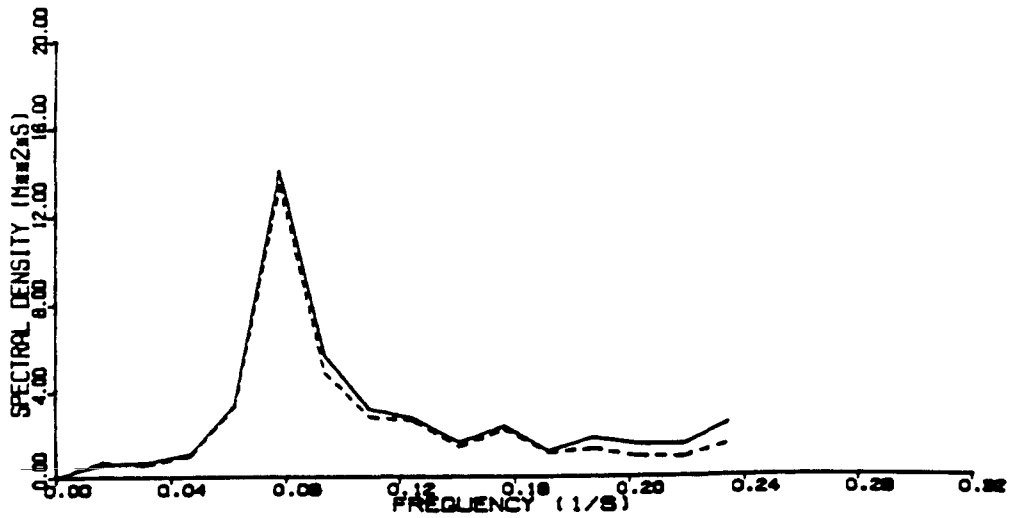
GREEN HARBOR, MASS

DATE: 30/3 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.697 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.589 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 35.7

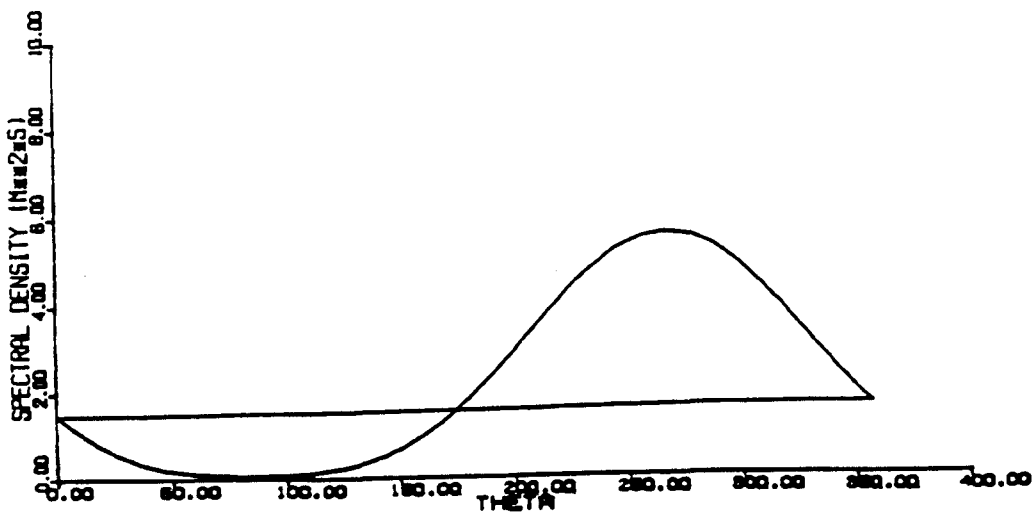


PLATE 60

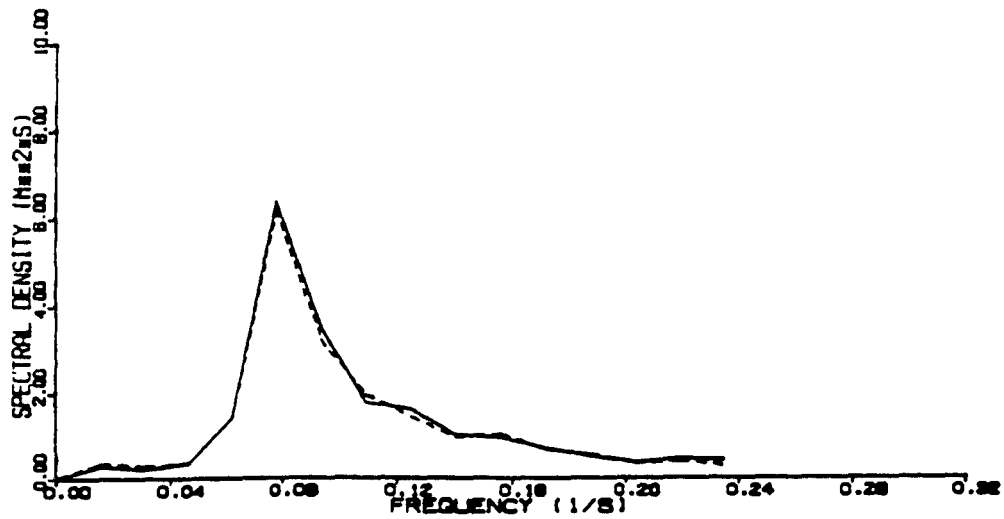
GREEN HARBOR, MASS

DATE: 30/3 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.304 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.293 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 33.0

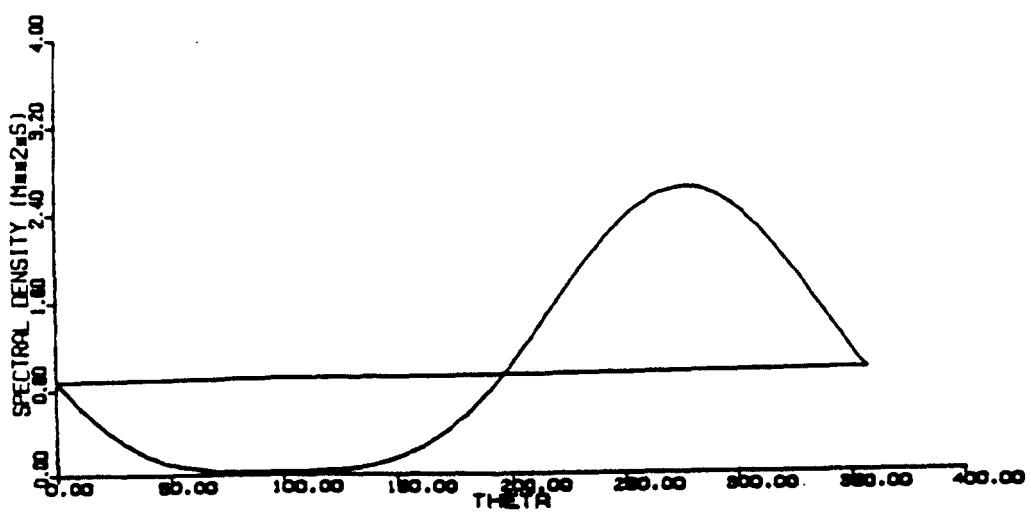


PLATE 61

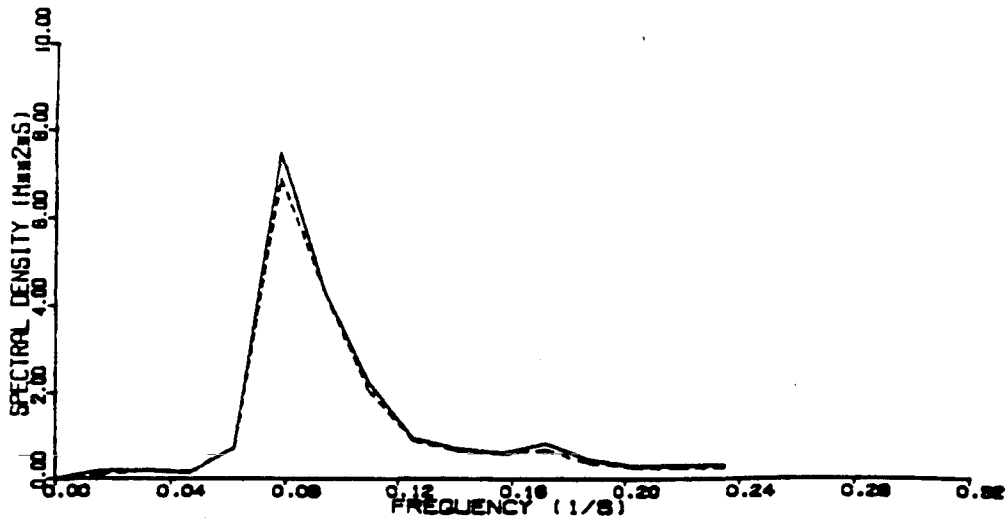
GREEN HARBOR, MASS

DATE: 31/3 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.308 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.288 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 37.6

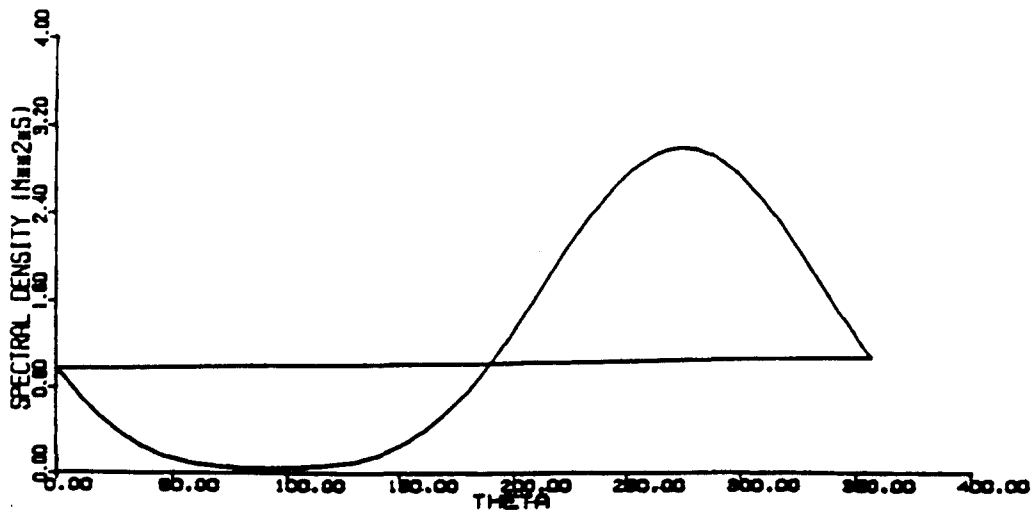


PLATE 62

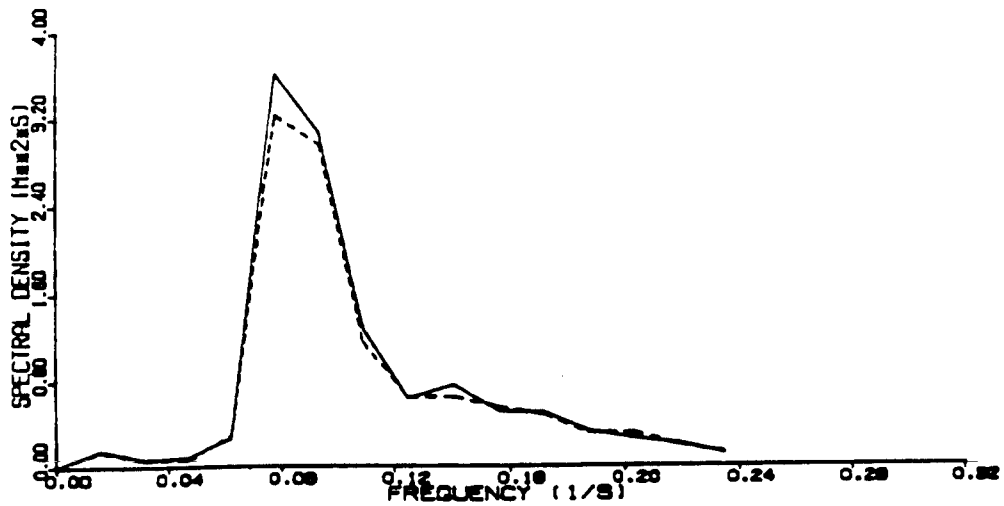
GREEN HARBOR, MASS

DATE: 31/3 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.183 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.173 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 29.2

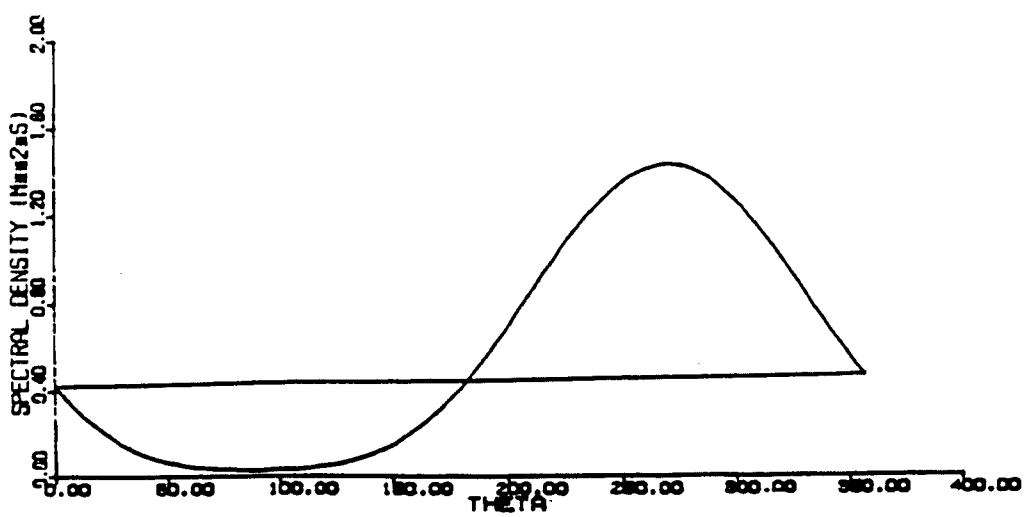


PLATE 63

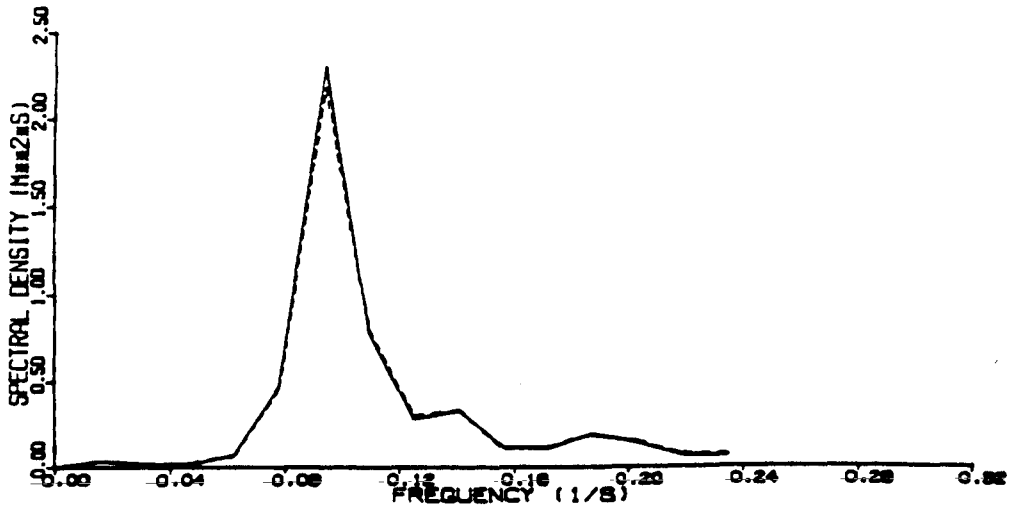
GREEN HARBOR, MASS

DATE: 31/3 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.078 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.077 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 44.4

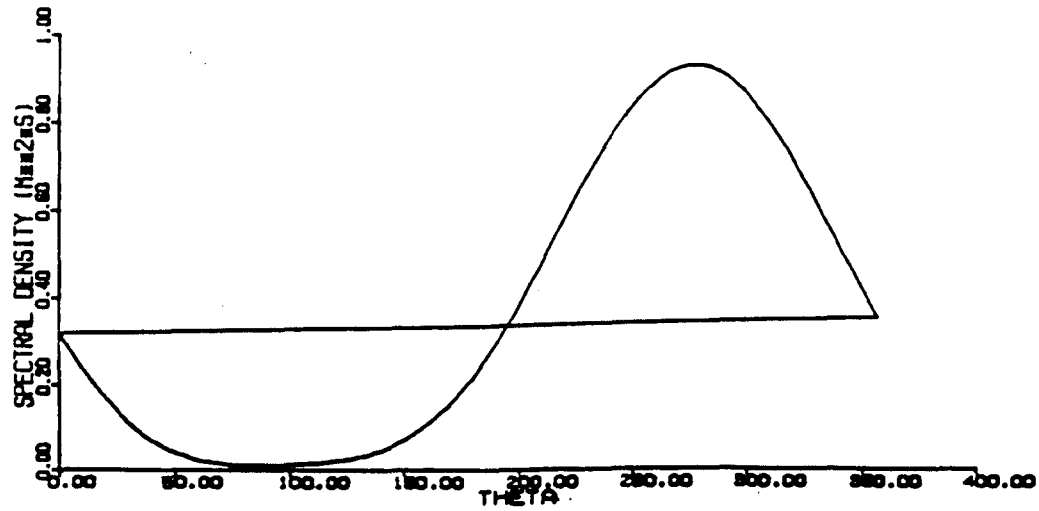


PLATE 64

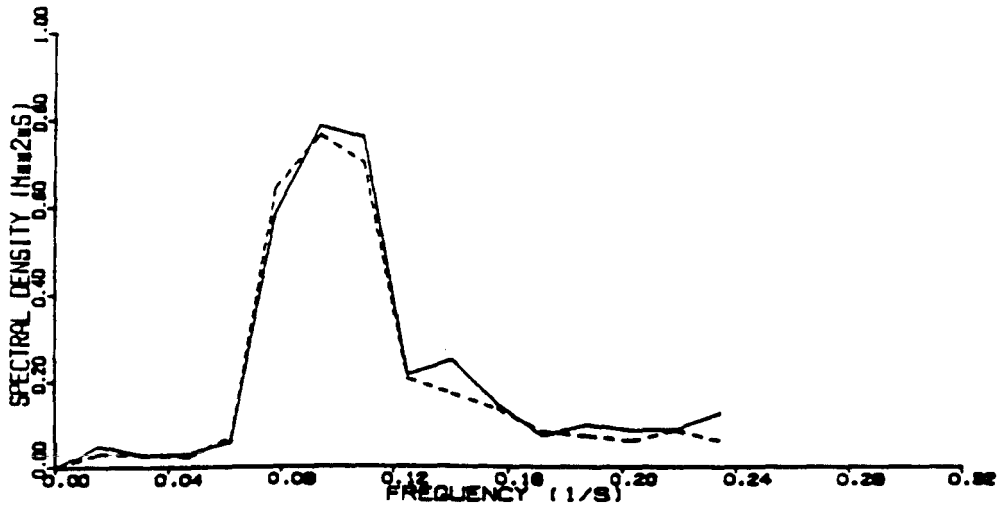
GREEN HARBOR, MASS

DATE: 1 /4 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.054 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.048 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 24.5

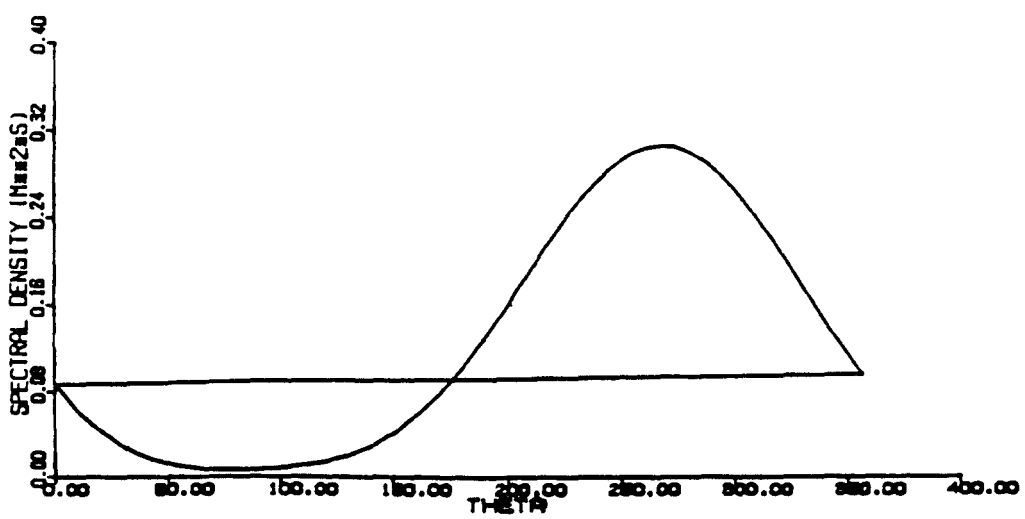


PLATE 65

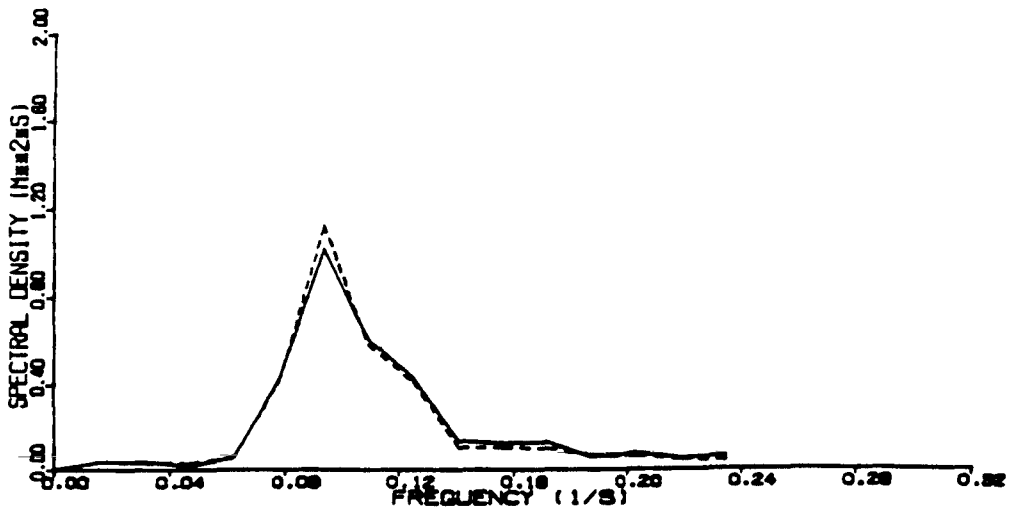
GREEN HARBOR, MASS

DATE: 1 /4 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.051 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.050 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.09375 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 35.6

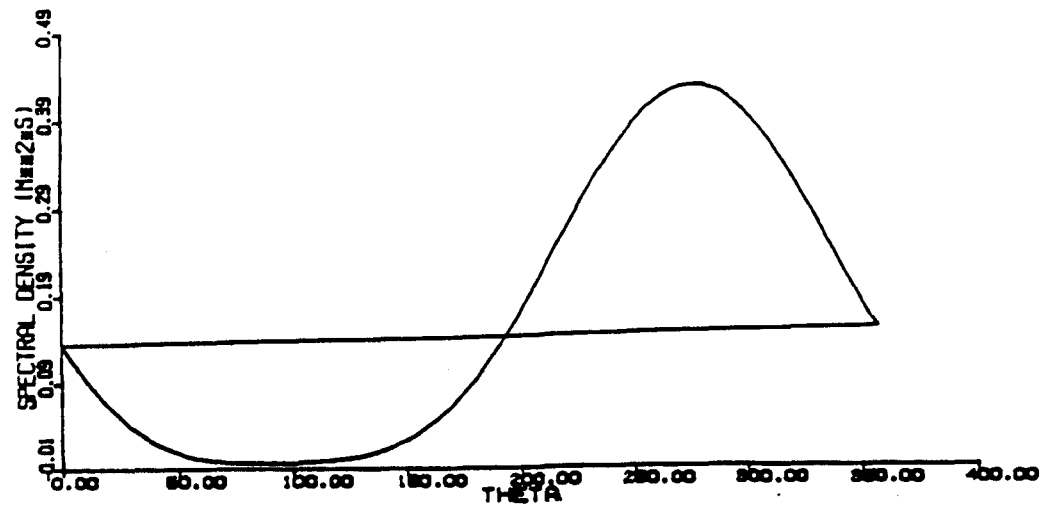


PLATE 66

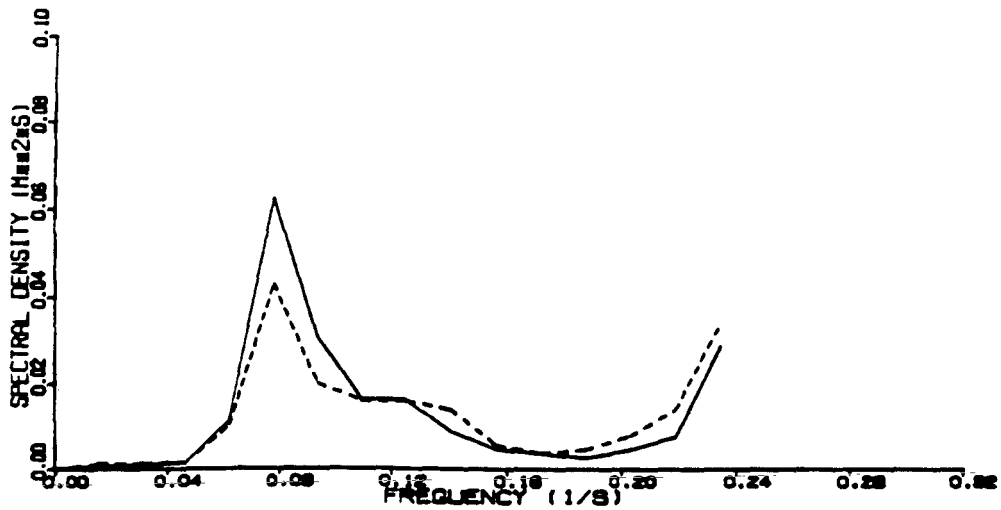
GREEN HARBOR, MASS

DATE: 5 /4 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.004 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.004 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.25000 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 29.8

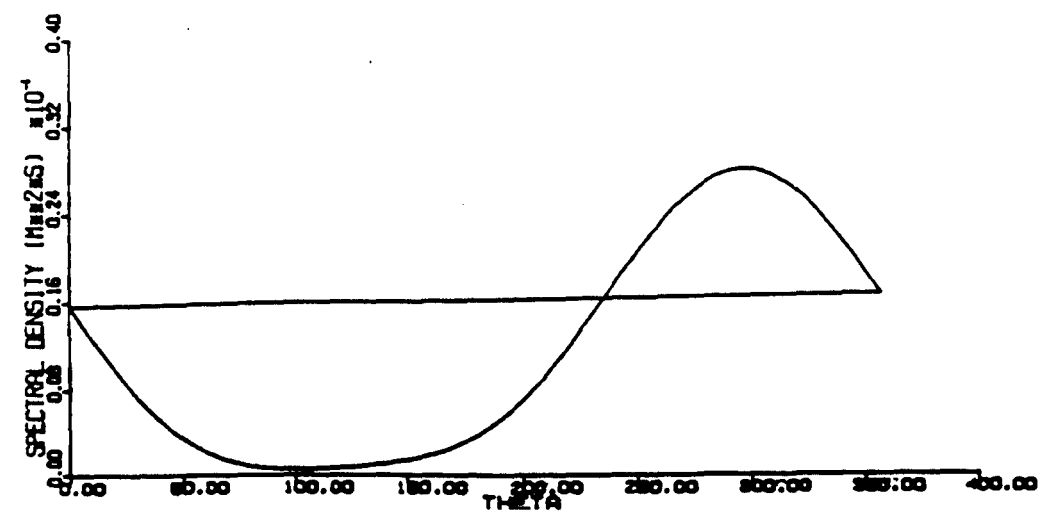


PLATE 67

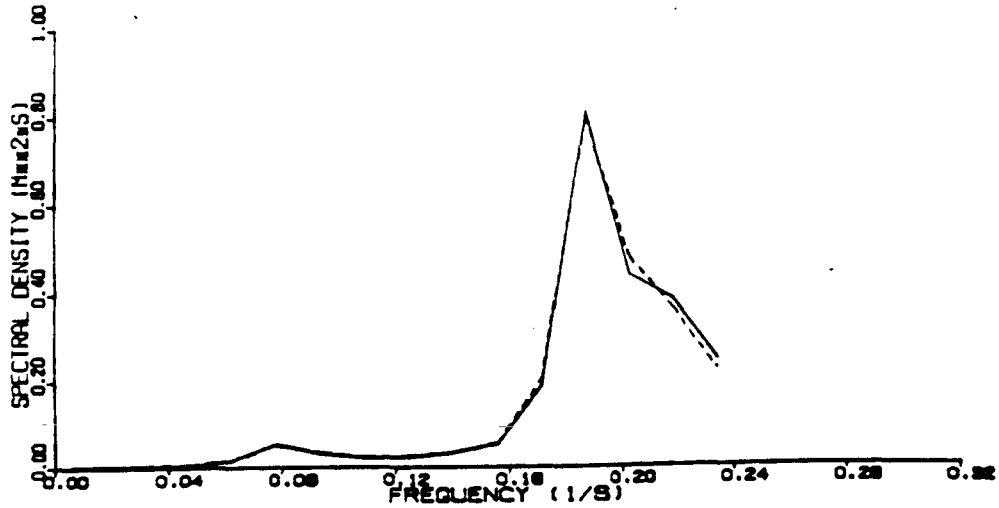
GREEN HARBOR, MASS

DATE: 5 /4 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.039 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.039 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.18750 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 31.7

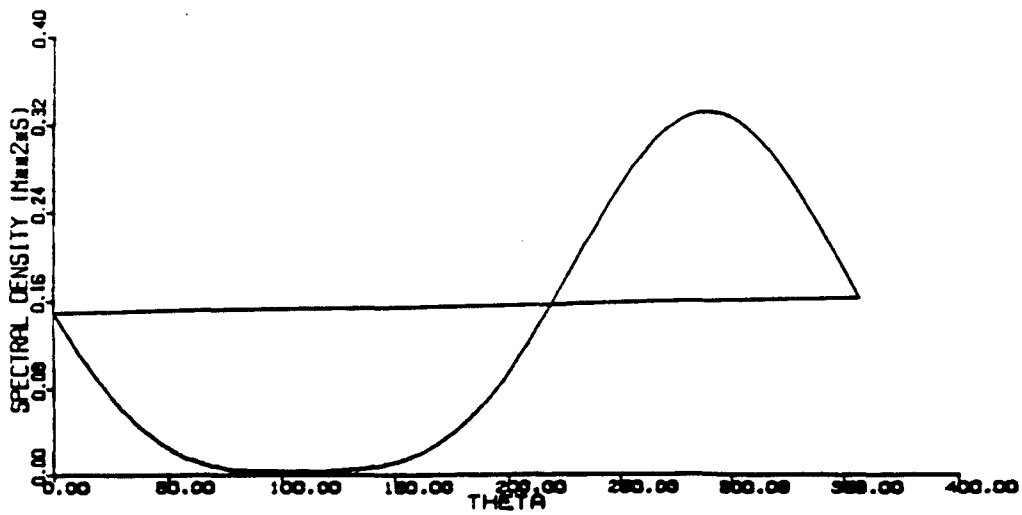


PLATE 68

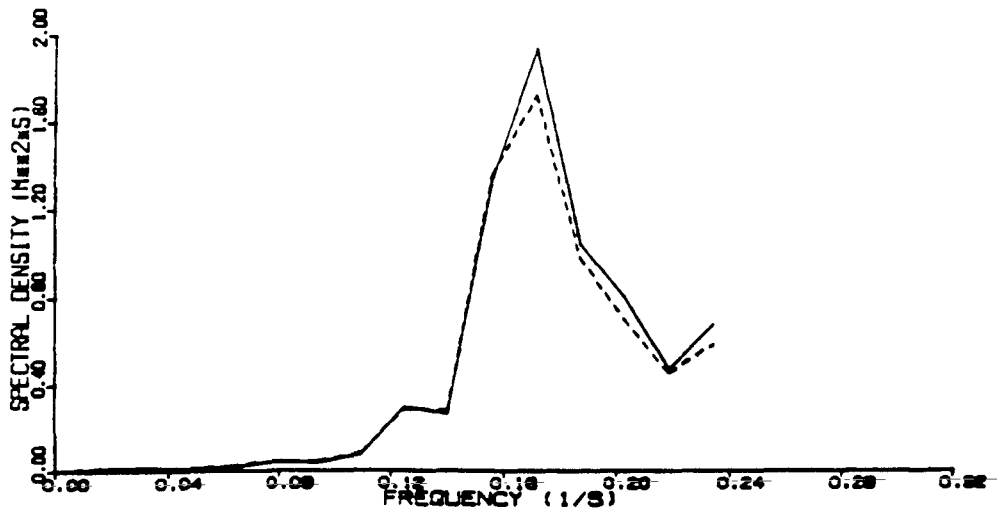
GREEN HARBOR, MASS

DATE: 5 /4 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.114 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.108 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.17188 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 24.9

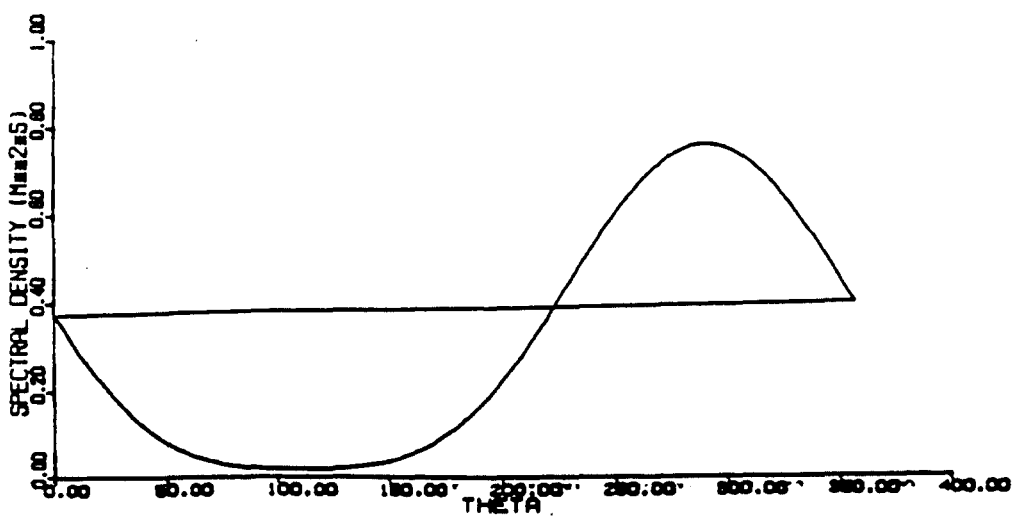


PLATE 69

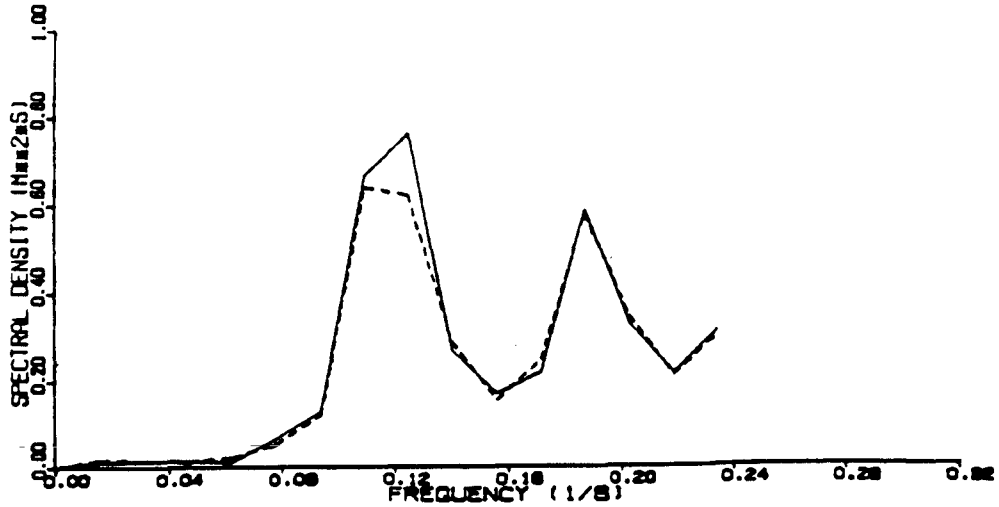
GREEN HARBOR, MASS

DATE: 6 /4 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.083 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.080 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.12500 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 18.2

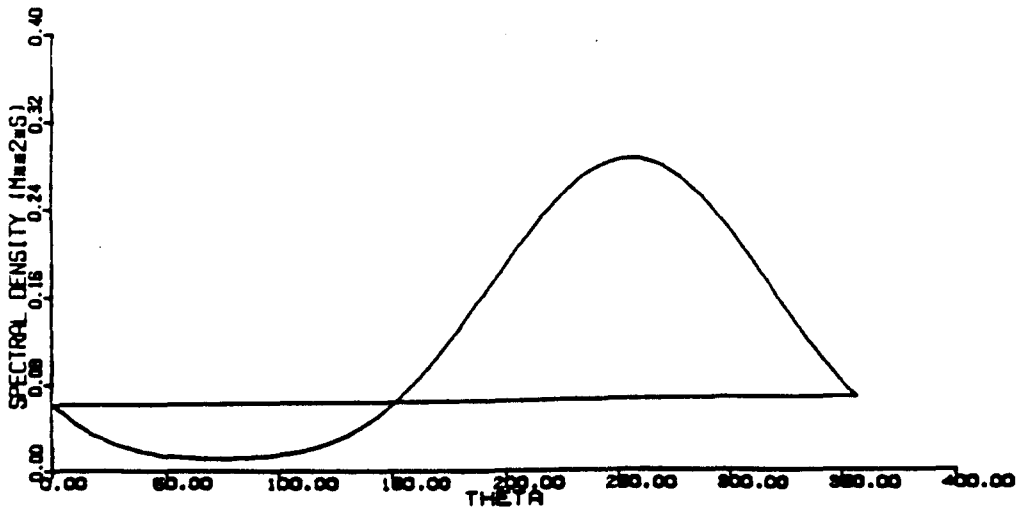


PLATE 70

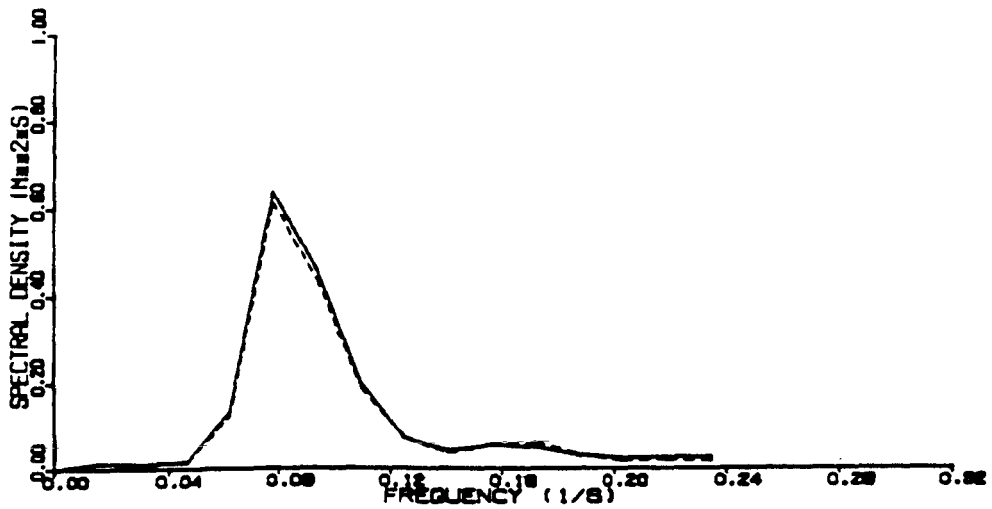
GREEN HARBOR, MASS

DATE: 8 /4 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.028 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.028 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.07813 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 38.4

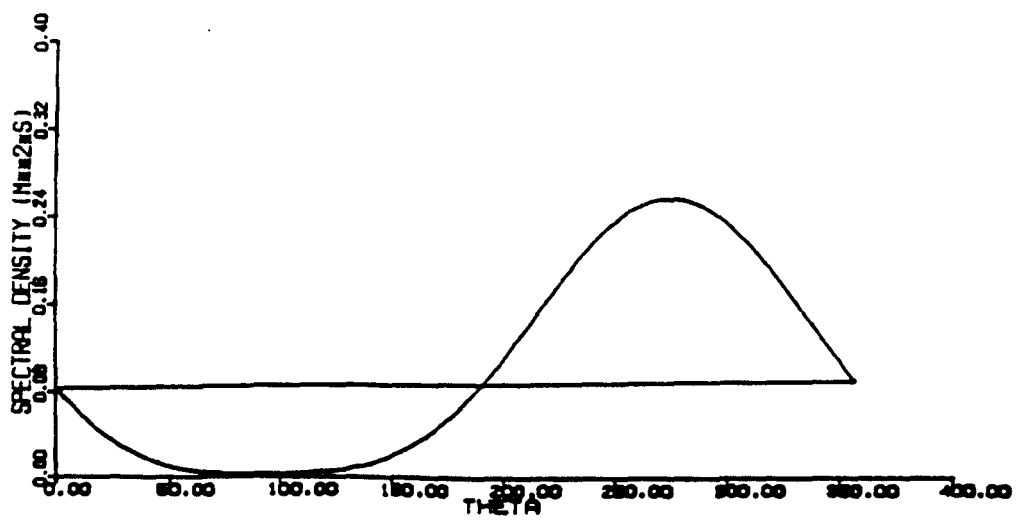


PLATE 71

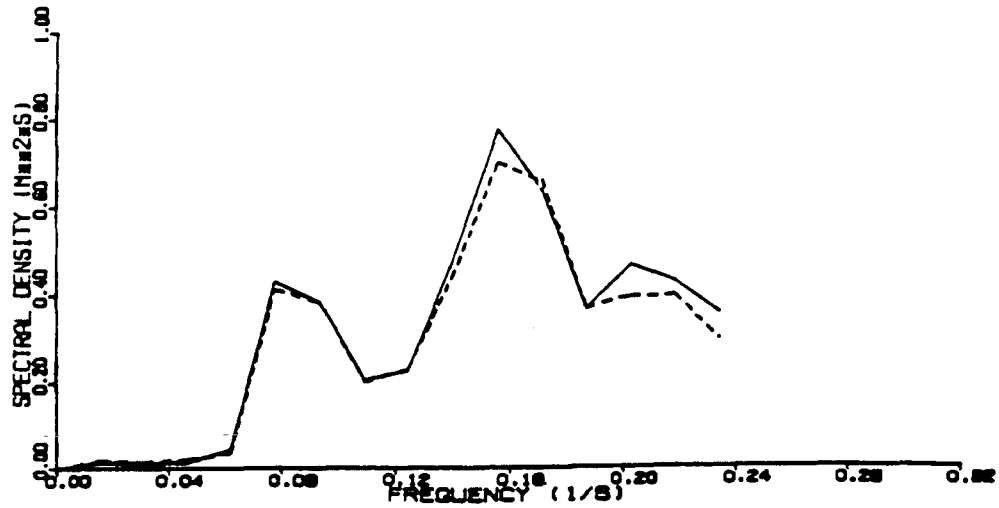
GREEN HARBOR, MASS

DATE: 8 /4 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.081 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.075 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.15625 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 14.5

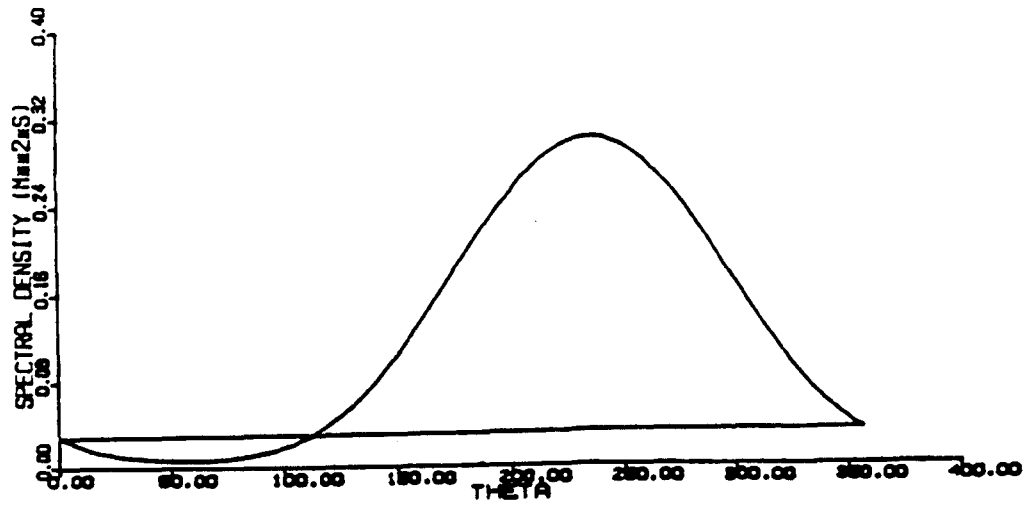


PLATE 72

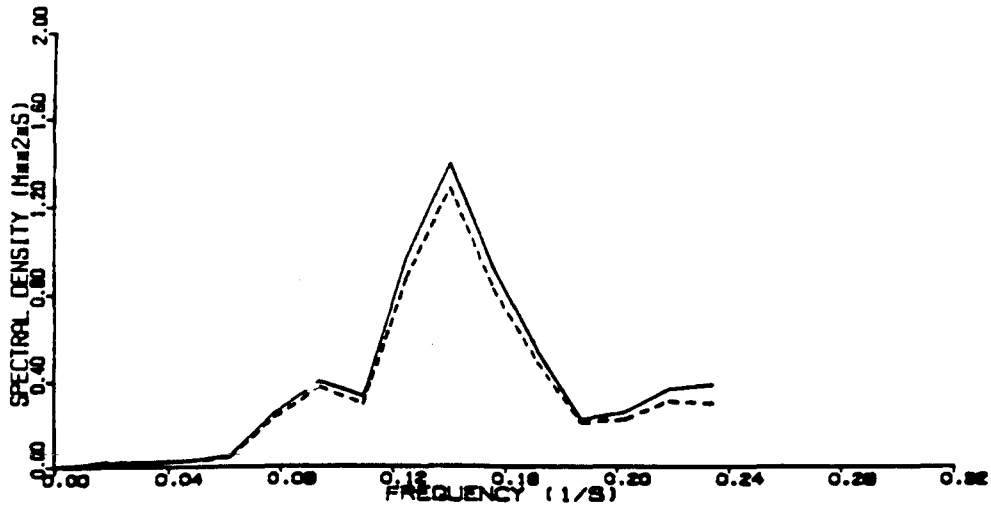
GREEN HARBOR, MASS

DATE: 9 /4 /84 TIME: 55

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.098 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.088 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.12500 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 23.6

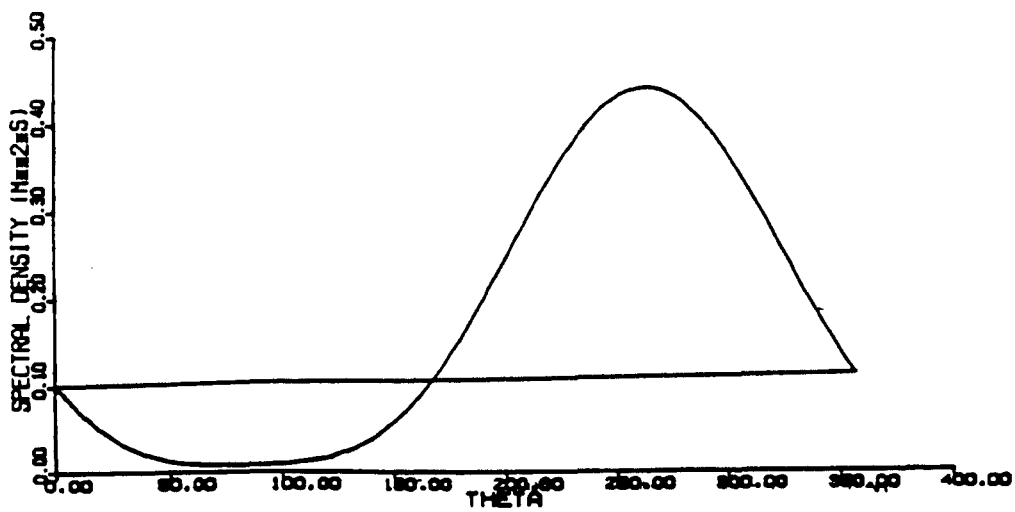


PLATE 73

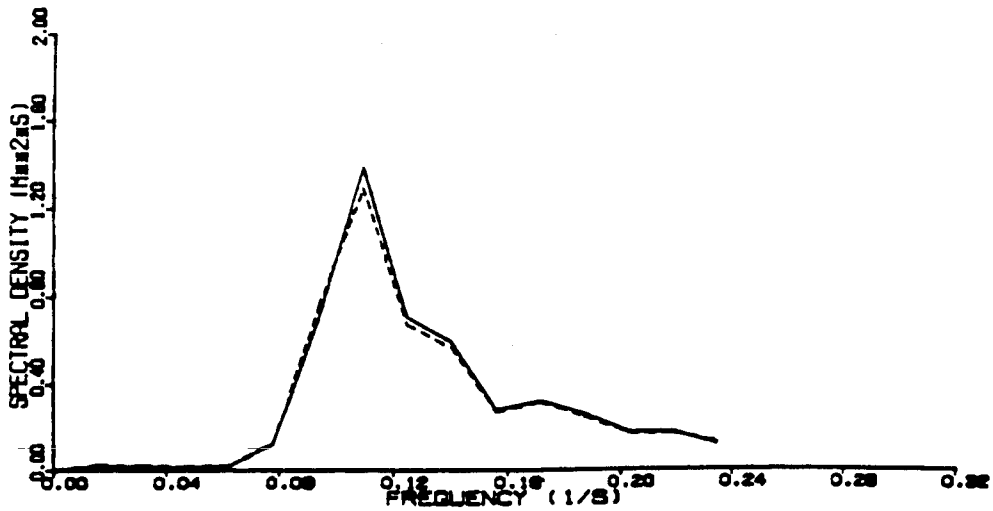
GREEN HARBOR. MASS

DATE: 9 /4 /84 TIME: 855

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.079 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.077 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.10937 S**-1

PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 26.5

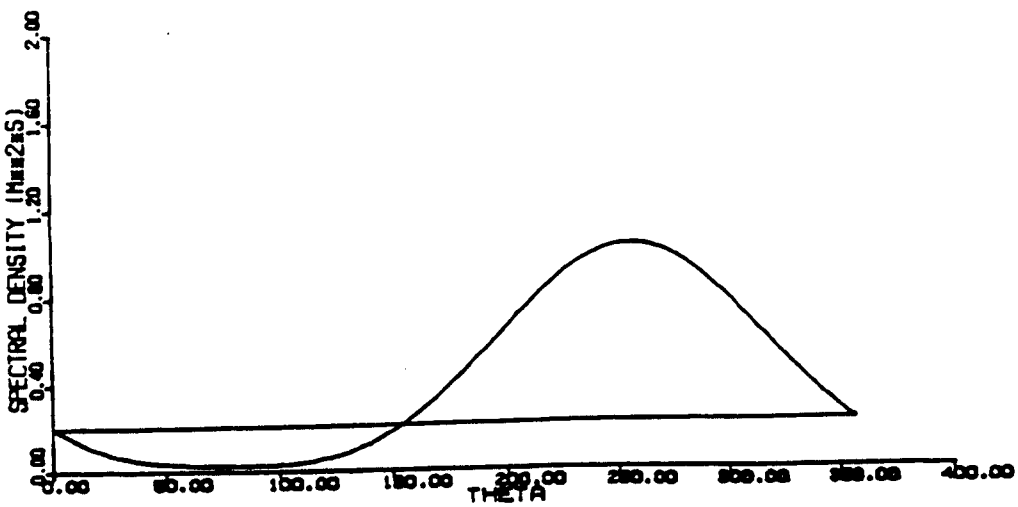


PLATE 74

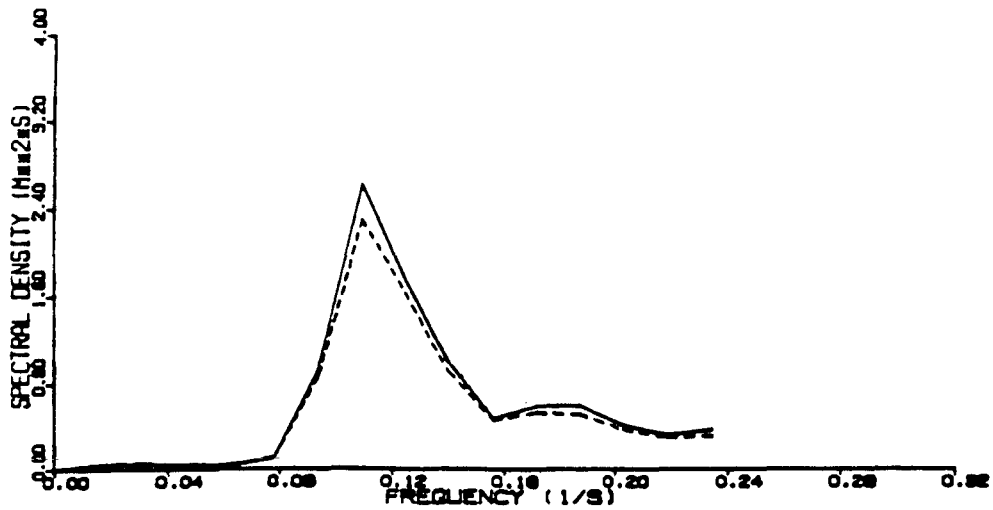
GREEN HARBOR, MASS

DATE: 9 /4 /84 TIME: 1655

SEA SURFACE SPECTRUM

—— COMPUTED FROM PRESSURE DATA
TOTAL VARIANCE = 0.149 M**2

---- COMPUTED FROM VELOCITY DATA
TOTAL VARIANCE = 0.135 M**2



SEA SURFACE SPECTRUM

FREQUENCY = 0.10937 S**-1
PERCENT OF VARIANCE IN THIS FREQUENCY BAND = 26.4

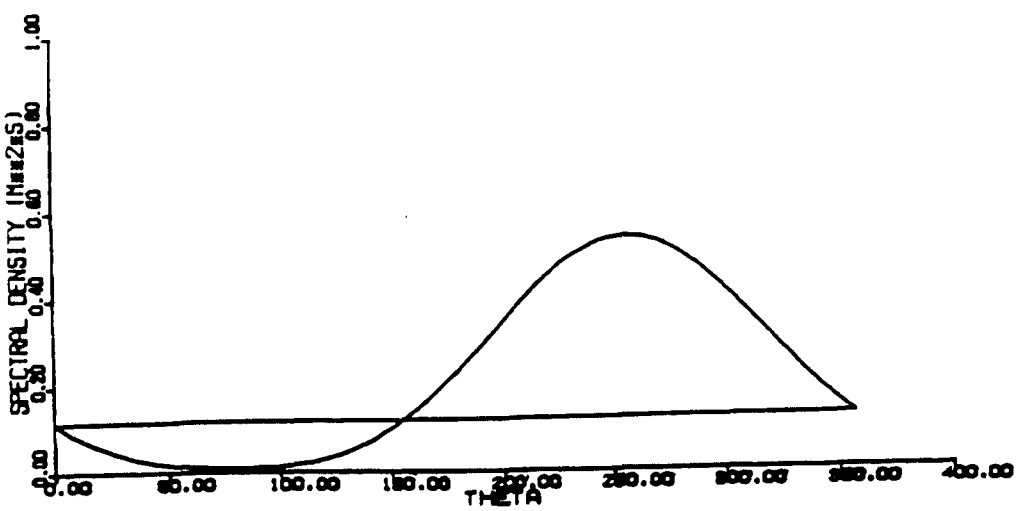
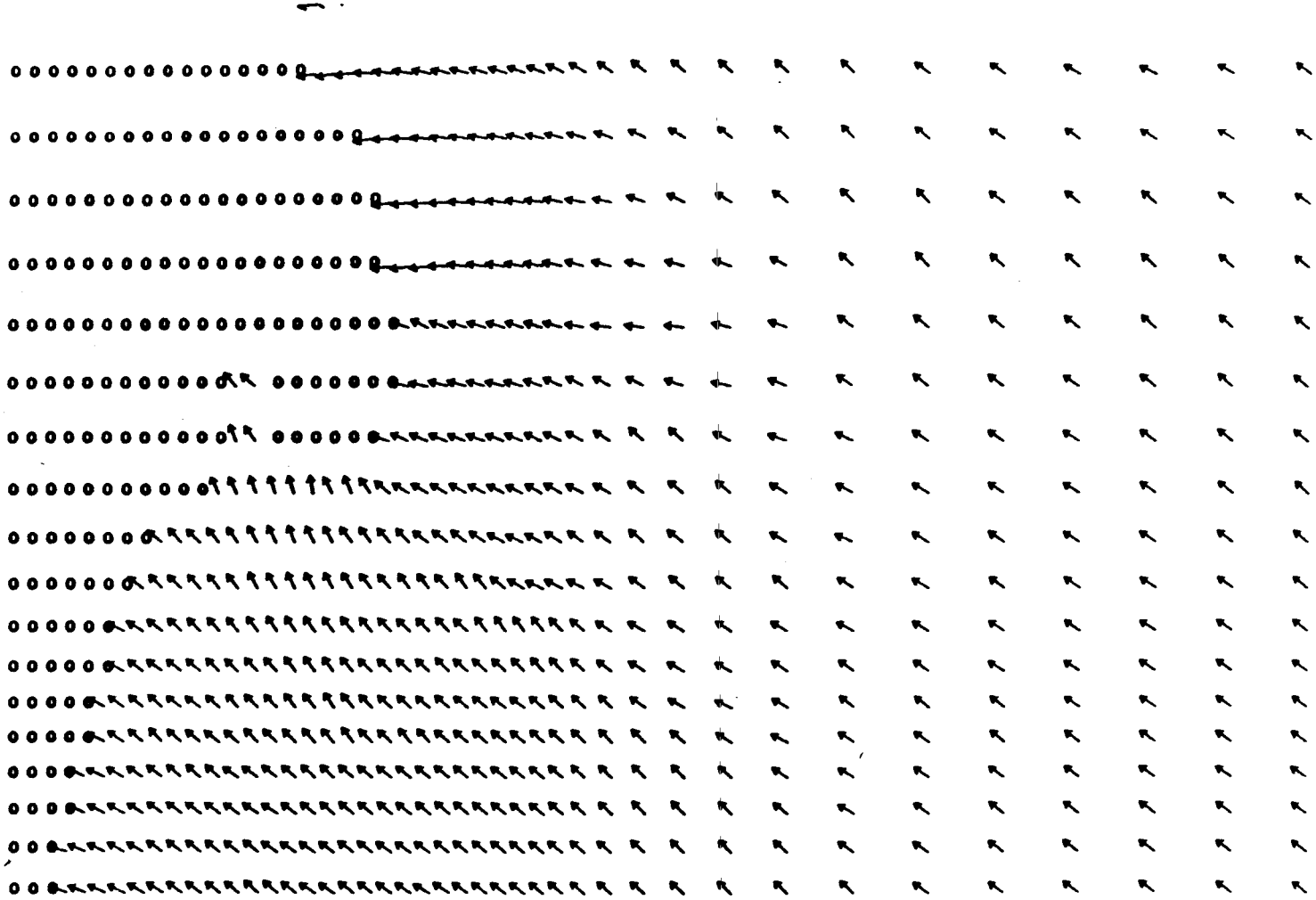
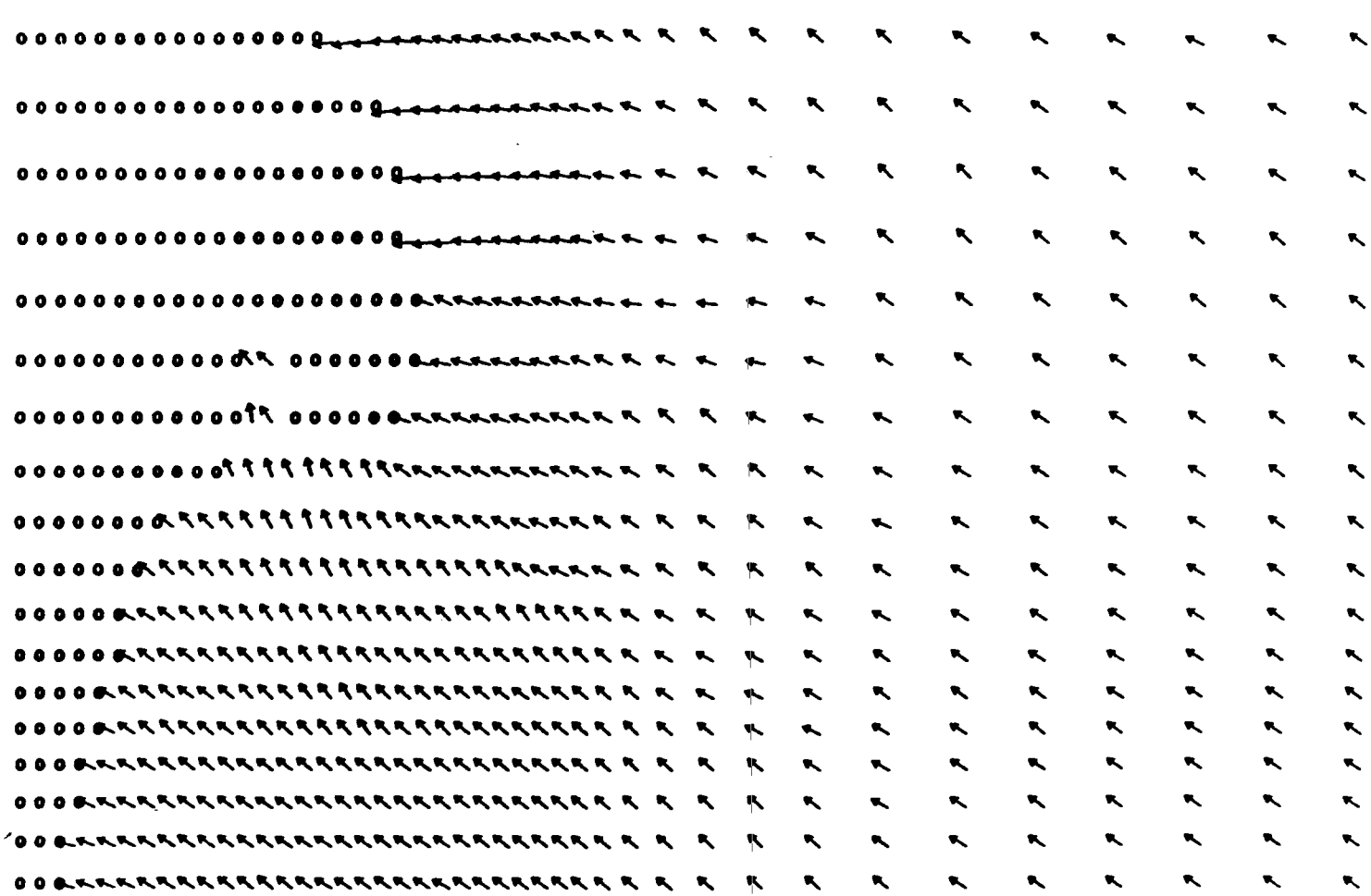


PLATE 75

PLATE 76



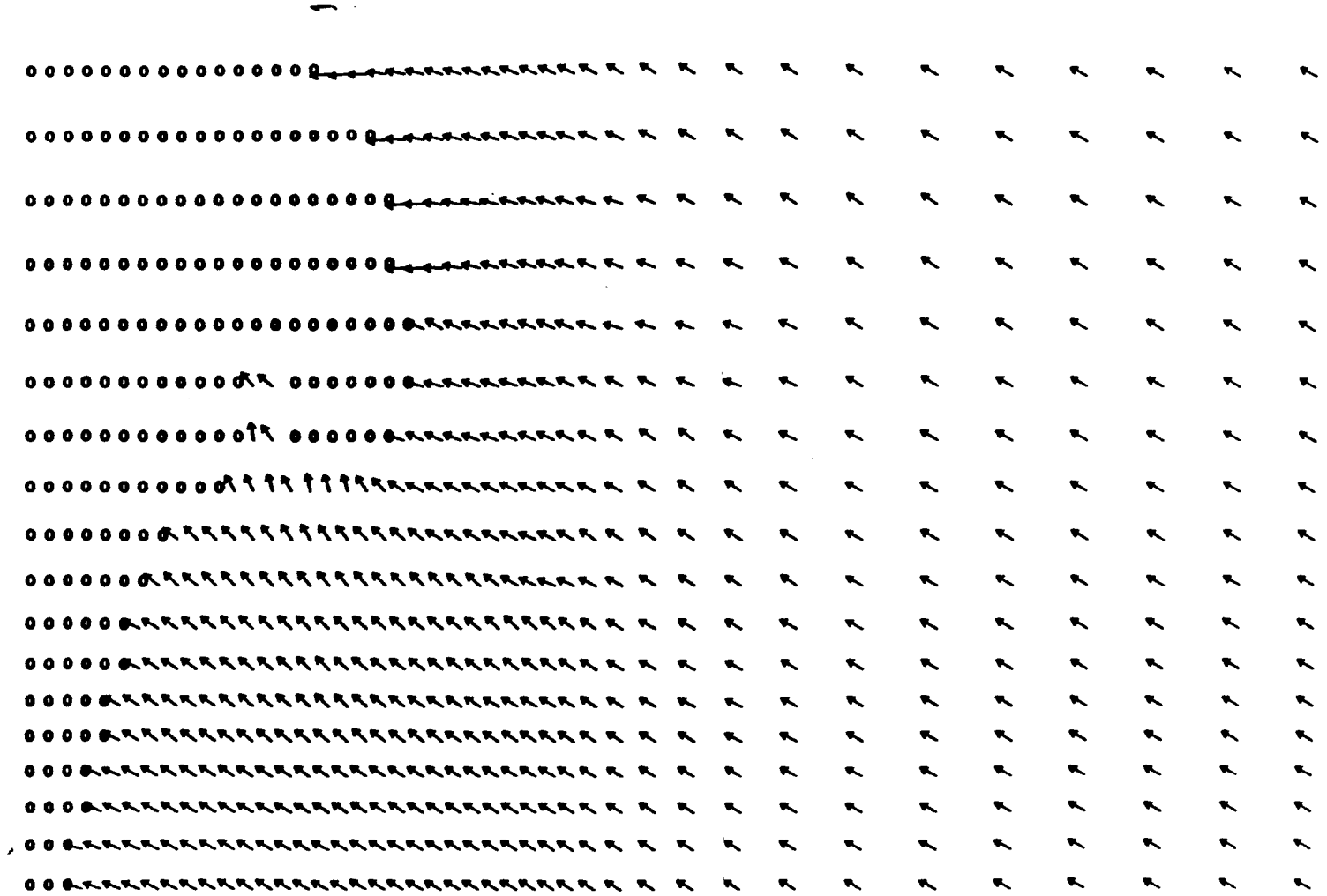
WAVE REFRACTION PATTERNS
T = 6.1 @ 290°



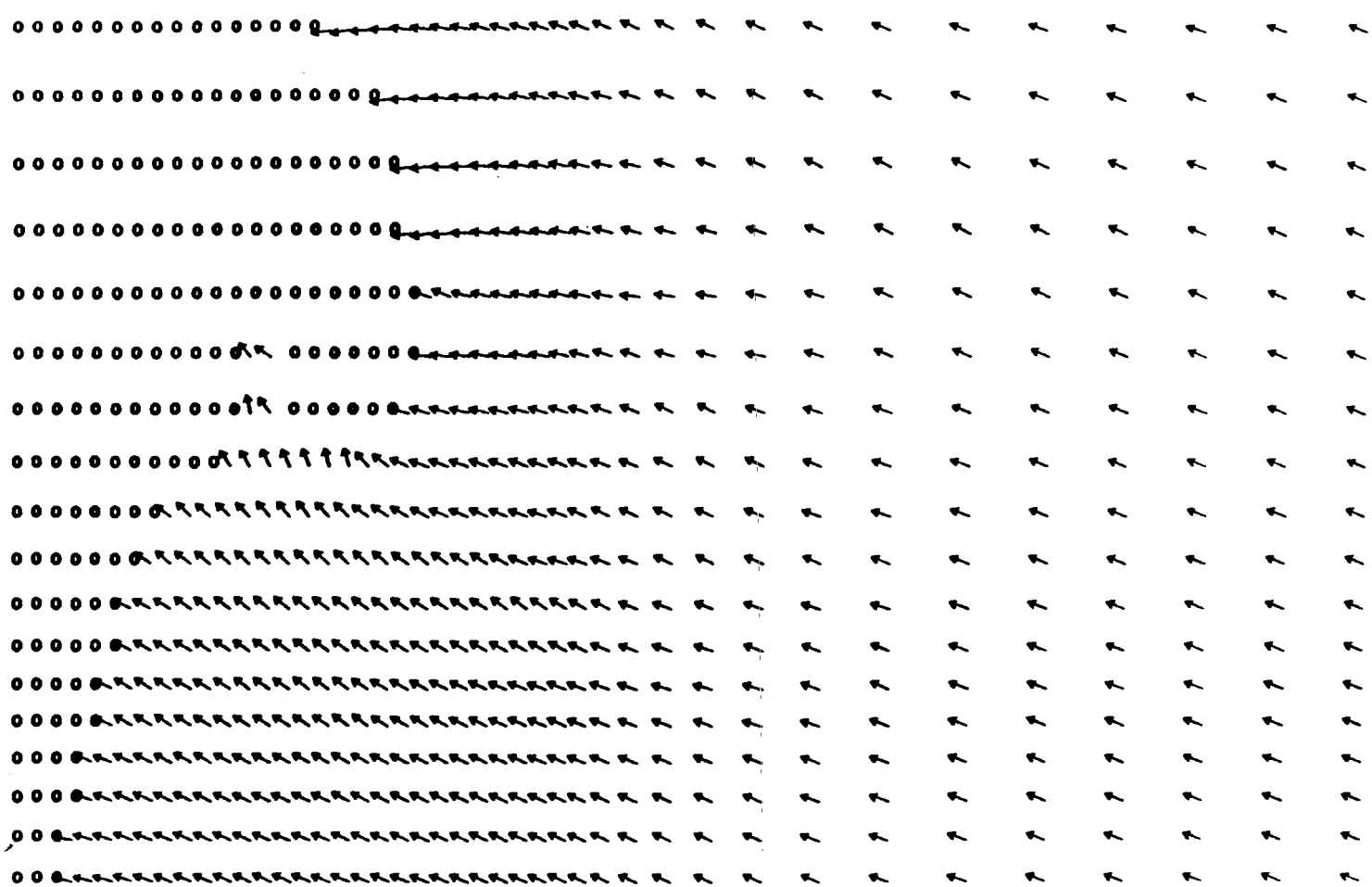
WAVE REFRACTION PATTERNS
T = 6.1 @ 280°

PLATE 77

PLATE 78



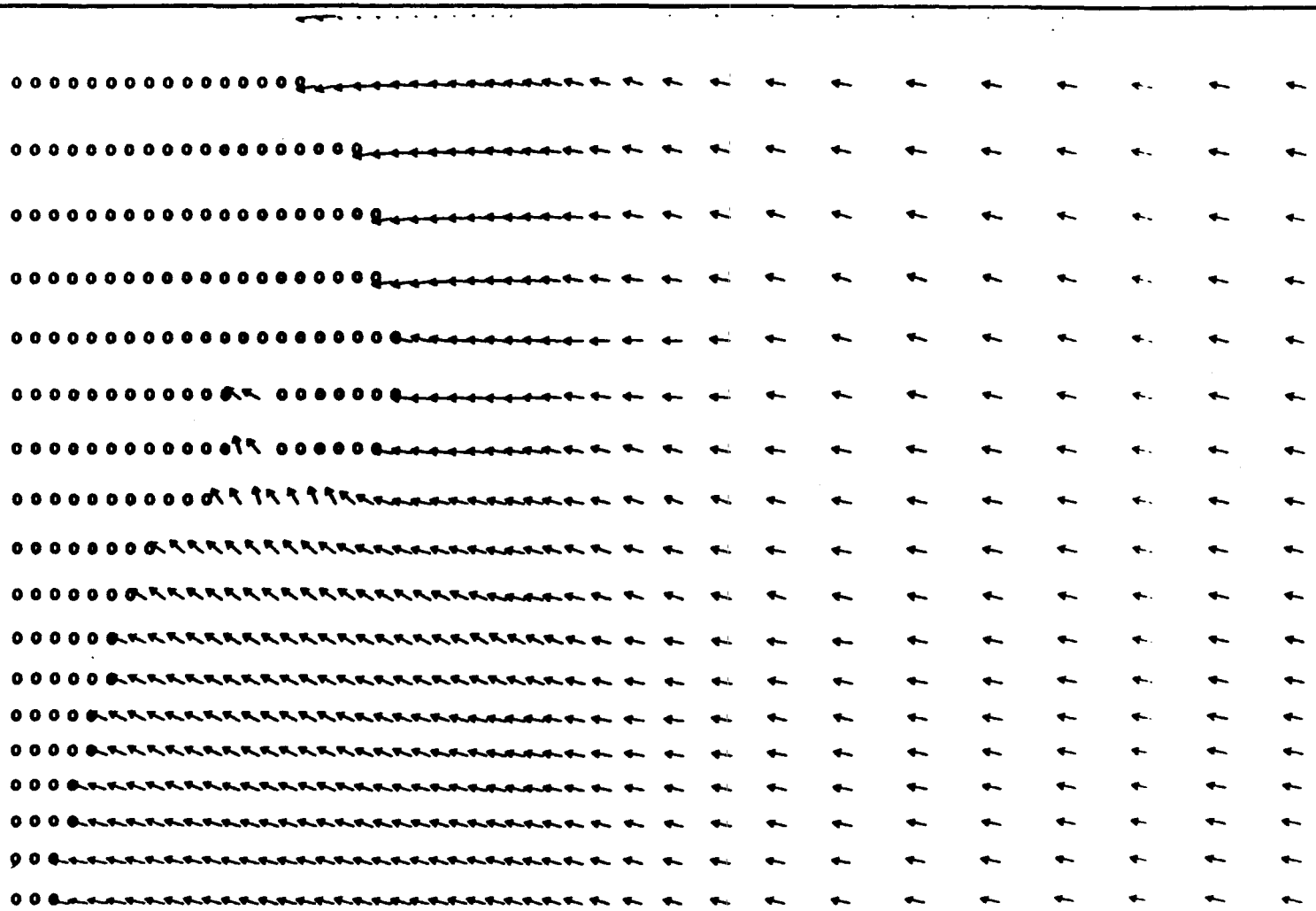
WAVE REFRACTION PATTERNS
T = 6.1 @ 270°



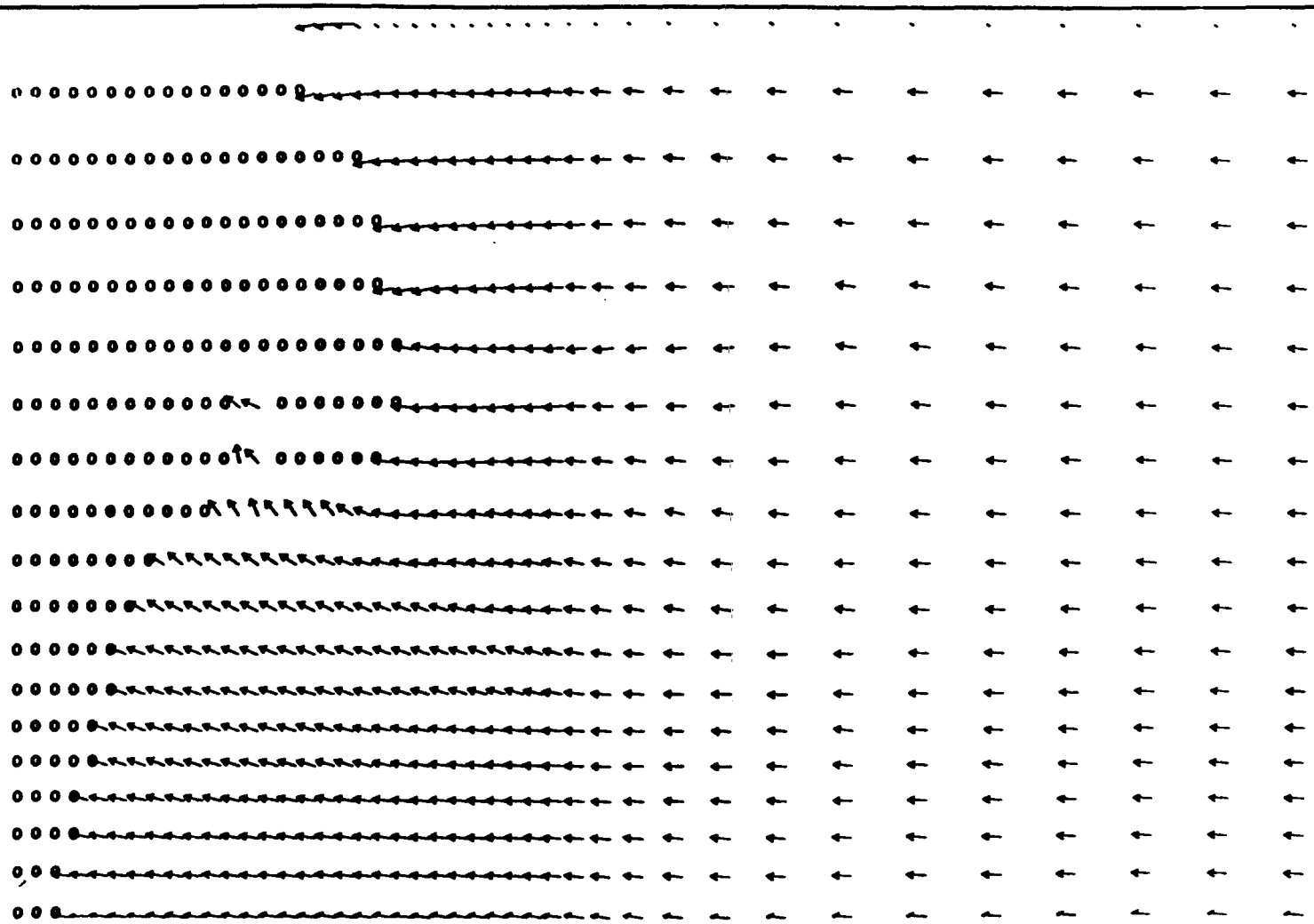
WAVE REFRACTION PATTERNS
T = 6.1 @ 260°

PLATE 79

PLATE 80



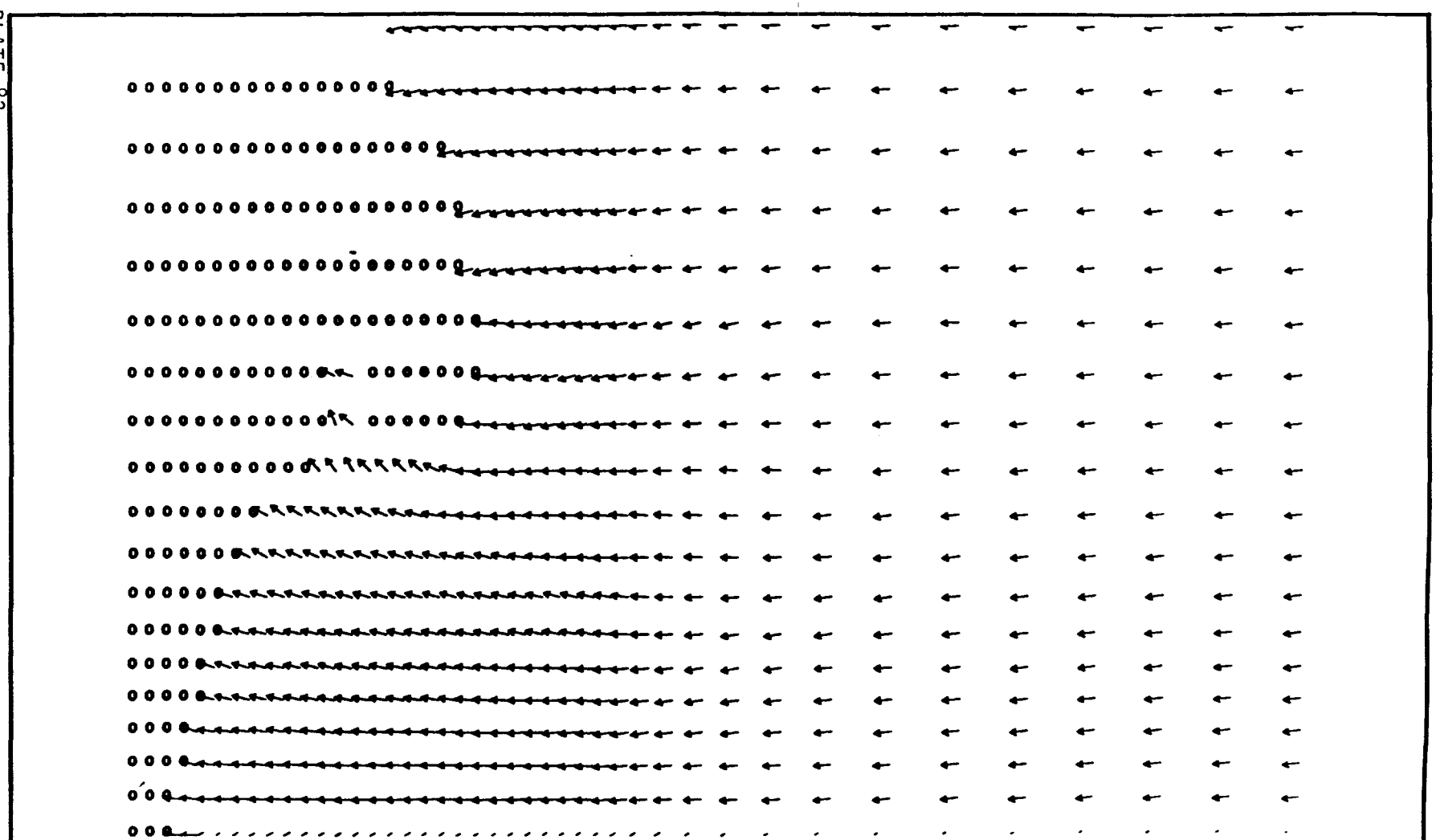
WAVE REFRACTION PATTERNS
T = 6.1 @ 250°



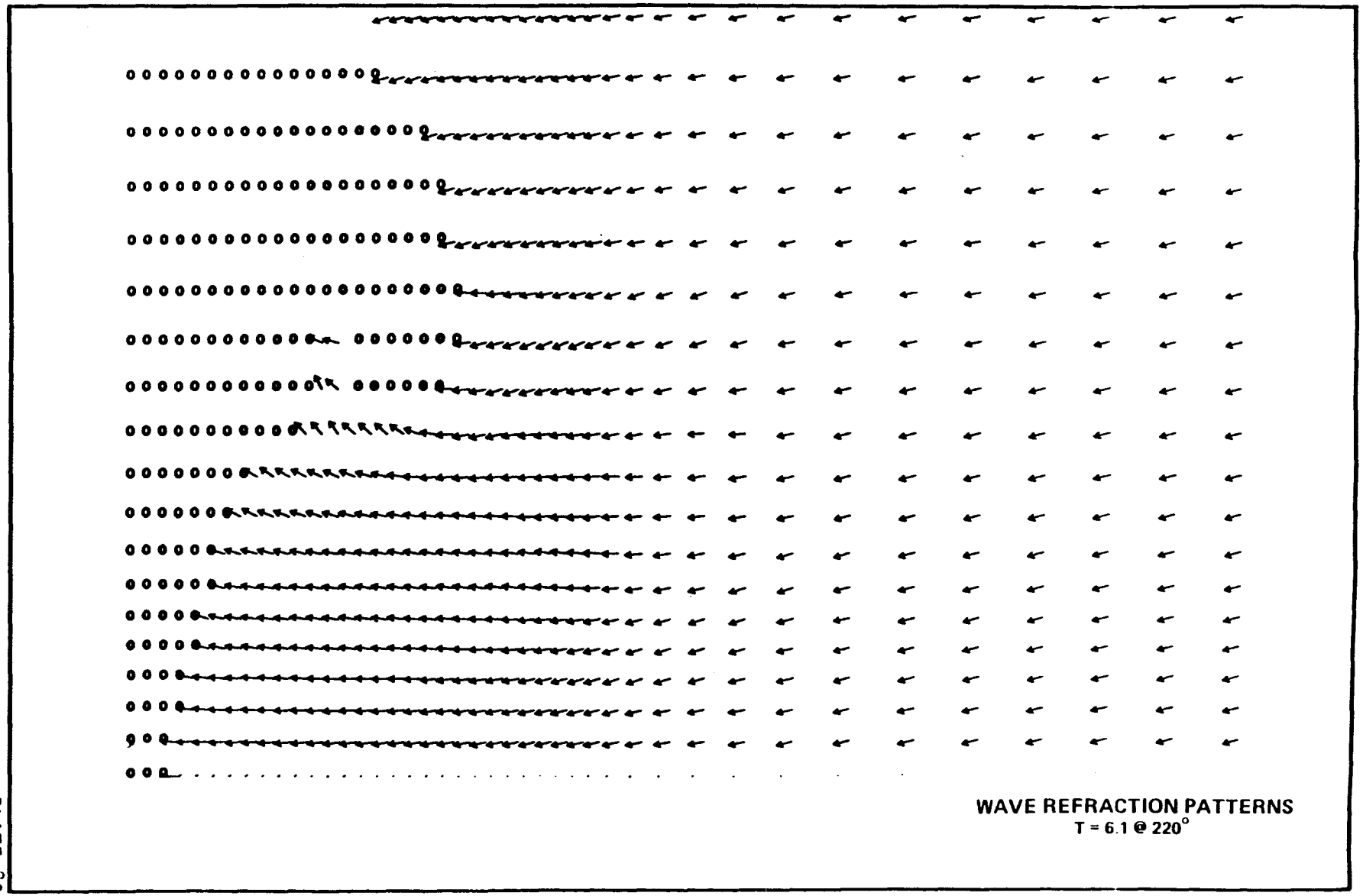
WAVE REFRACTION PATTERNS
T = 6.1 @ 240°

PLATE 31

PLATE 82



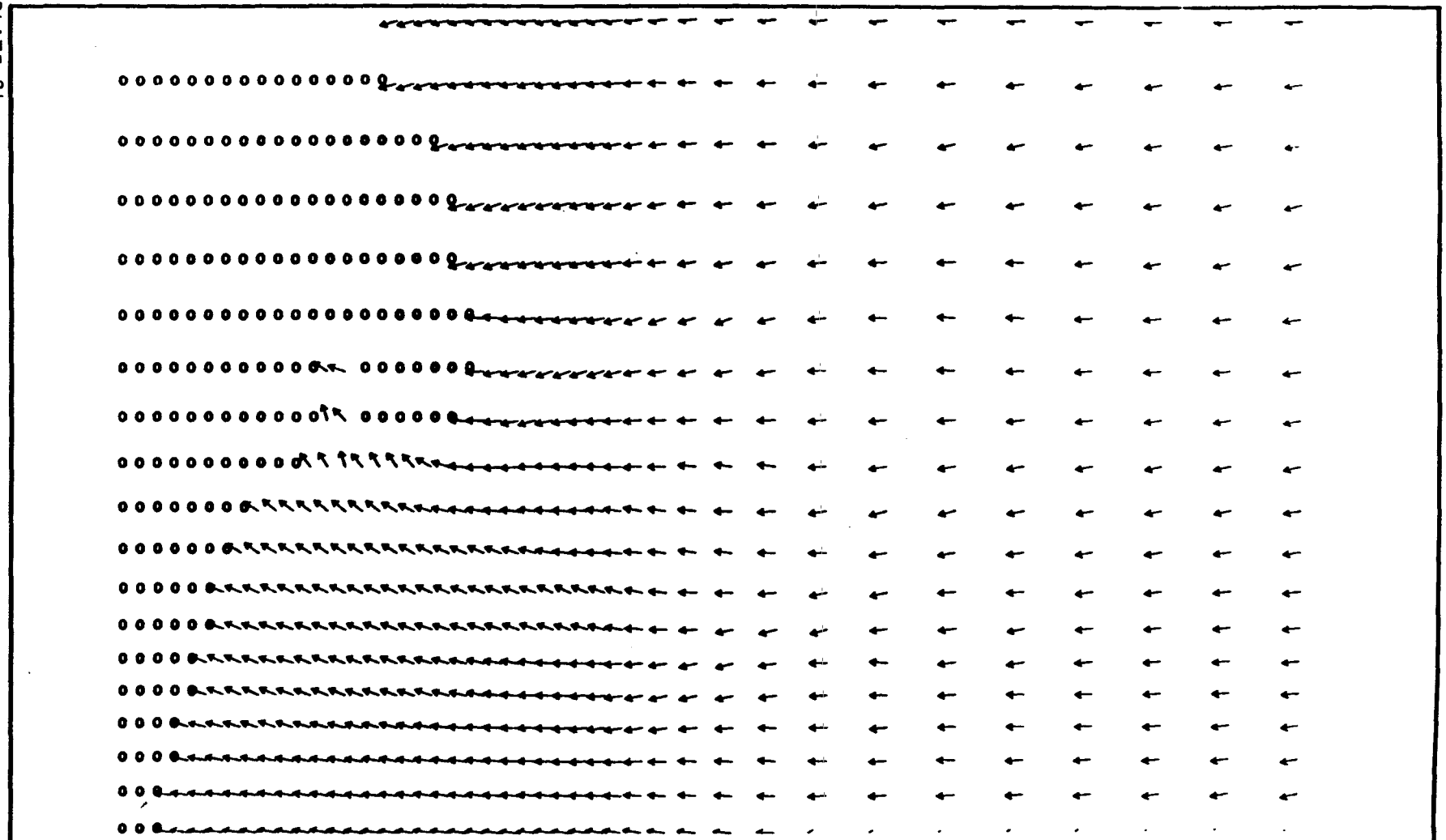
WAVE REFRACTION PATTERNS
T = 6.1 @ 230°



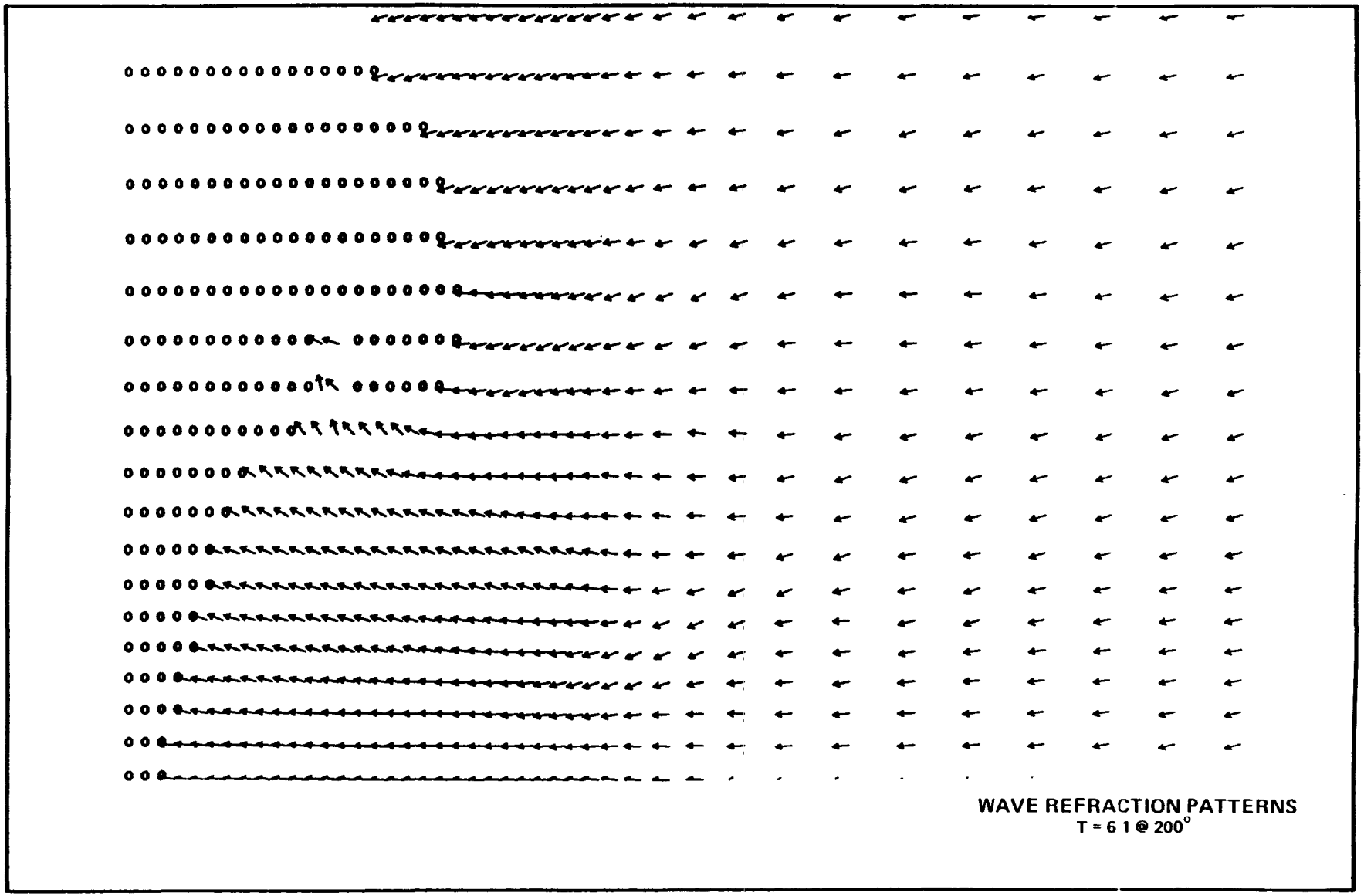
WAVE REFRACTION PATTERNS
T = 6.1 @ 220°

PLATE 33

PLATE 84



WAVE REFRACTION PATTERNS
T = 6.1 @ 210°



WAVE REFRACTION PATTERNS
T = 6 1 @ 200°

PLATE 35

APPENDIX A: GREEN HARBOR, MA, MAJOR EVENTS

Table A1

Chronological Sequence of Major Events

Date	Description of Major Event
1633	Cut River is excavated between Green Harbor and Duxbury Bay to allow vessels to travel from the Green Harbor estuary to Duxbury Bay without going out into Cape Cod Bay.
1636	Cut River is widened to 18 ft and deepened to 6 ft.
1794	A storm creates a new entrance to Green Harbor 5/8 miles south of the present location (Figure 6, main text). The width just above the mouth is 8 rods (132 ft) but widens quickly inside to 60 rods (990 ft). High tide is noted to have occurred at Green Harbor Bridge (located upstream of the present dike) about 2 hr after high tide at the shoreline.
1806	Local residents dig a new channel from Green Harbor to Duxbury Bay to drain the marsh flooded when the inlet was closed by a storm earlier this year. The inlet remains closed for a period of 4 to 5 days.
1810	A new inlet is opened by a storm in late 1810 or early 1811 near the present location. Tradition holds that the channel was begun artificially. The channel in 1812 is said to have been sufficient to admit a vessel of 100 tons. Approximate vessel dimensions for a 100-ton ship in this period is 80 ft long and 25 ft wide with a 7-ft draft (light).
1812	Green Harbor Beach is reported to be overwashed in places by high tides.
1826	The river entrance is reported as shifting and in an "uncertain state." Breaches and closures of new inlets in the beach are reported.
1827	An Act is passed to allow construction of "a seawall, palisades, or hedge fences to preserve and secure the whole of Marshfield Beach from incursions and encroachments of the sea." The act also restricts the grazing of livestock on the beach.
1831	Figure 6 (main text) shows the mouth of Green Harbor in roughly its present position.
1857	Soundings taken in 1854 and 1855 by the US Coast Survey show a sand bar across the mouth of Green Harbor River with a depth of 1 ft mlw. High and low water lines are shown extending a considerable distance up into the marsh, but no soundings are shown.
1871	Extracts published in the "5th Report of the Harbor Commissioners"* state that the distance from Turkey Point (site of the dike) is

(Continued)

* References cited in the Appendix can be found in the References at the end of the main text.

Table A1 (Continued)

Date	Description of Major Event
1871 (cont)	7/8 mile, and the maximum low water width scarcely exceeds 500 ft. "A sand bar obstructs the entrance, upon which there is 2 to 3 ft of water at ordinary low tide . . . and vessels can take the ground within the harbor at low tide without injury."
1872	The dike at Turkey Point is completed at a cost of $32,090. Construction of the dike reduces the area subject to the tide by about 1,334 acres.
1876	A survey of Harbor Commissioners indicates that 52,000 cu yd of sand have accumulated in the basin upstream of The Narrows since the 1857 survey, and 106,000 cu yd have accumulated on the bar at the harbor entrance since 1857. Accumulation is largely attributed to construction of the dike. Order issued for removal of accumulation as necessary to secure passage for vessels.
1878-1880	Sketches made by Harbor Commissioners indicate that sand is still entering the basin rapidly. Sand covering the basin bottom moves 800 ft upstream since the 1857 survey.
1879	The dike is widened to carry the road from Brant Rock to Green Harbor.
1880	Unidentified persons attempt to blow up the dike. The damage is repaired but leakage through the dike remains.
1896	A survey by Harbor Commissioners shows the point of Duxbury Beach (now known as Green Harbor Beach) increased in height between 1857 and 1876 and between 1876 and 1896; mean low water (mlw) and mean high water (mhw) lines are also advanced northerly during these periods. Also, Washburn's Point grows to the west into the channel. In 1857 The Narrows width was 125 ft mlw and 400 ft mhw; by 1876 the width was 35 ft mlw. In 1896, the width of The Narrows was 55 ft at mlw and 140 ft at mhw. Comparison of the 1876 and 1896 surveys indicates that about 75,000 cu yd of sand accumulated inside The Narrows, and 24,000 cu yd accumulated in the entrance area during this period.
1897	A survey of marshes behind the dike shows a settlement rate of 0.33 in. per year over the past 11 years because of removal of tidal influence in the marshes.
1898	The dike is breached by the Portland storm. The breach is reported as 50 ft wide and down to the level of the marsh.
1899	Entrance jetties are completed extending from the shore to 6 ft mlw. A timber training wall is constructed across the mouth of the Cut River to direct ebb flow.
1900	A survey of the channel shows current has scoured a channel through the bar just south of Washburn's Point. The bottom of the channel is 1.5 ft above mlw in 1898; it has scoured to 0.2 ft below mlw at this

(Continued)

Table A1 (Continued)

Date	Description of Major Event
1900 (cont)	time. Dredging of a 60-ft-wide, 5-ft-deep (mlw) channel between the jetties is undertaken, and 92,000 cu yd of material is removed. The disposal site is unknown. Backfill is placed at the landward end of the west jetty, and the timber bulkhead at the landward end is extended about 350 ft to mhw at an elevation of 15 ft.
1901	The depth in the channel has been reduced to 2 ft below mlw by shoaling. Shoaling has also reduced the anchorage area by one-third.
1902	Depth in the channel is reduced to 1 ft below mlw by shoaling. The location of the entrance channel at the end of the jetties has shifted to northeast and the location in The Narrows has shifted southwesterly because of drifting sand over the west jetty from Green Harbor Beach. The high-water line west of the west jetty has advanced 300 ft seaward; the anchorage area has been reduced by shoaling to one-half its area in 1900.
1904	The navigable depth has not changed substantially since 1902 but the channel at end of jetties has shifted farther to northeast while the channel in Narrows has shifted farther southwest. The anchorage area continues to diminish through shoaling. A decision is made to delay any further dredging until west jetty can be raised to reduce sand influx from the beach.
1908	Depth in channel is less than 1 ft at mlw. Location of the entrance end of the jetties has been pushed nearly over to the east jetty. The channel location in The Narrows is the same as in 1904. The anchorage area is nearly gone, and for the first time shoaling is noted beyond the ends of the jetties.
1930-1931	Timber fence (660 ft) is constructed on the west side of the west jetty. Both jetties are reconstructed.
1933	Stone riprap is placed at the landward end of each jetty.
1948	The west jetty is reconstructed and extended 60 ft.
1950	The damage to the west jetty is repaired.
1952	The entrance channel is dredged. Quantities and disposal area are unknown.
1954	The entrance channel is dredged. Quantities and disposal area are unknown.
1958	A total of 107,600 cu yd is dredged from the entrance channel and from anchorage located off present Town Pier. Disposal is behind the bulkhead in the area of the present Town Pier parking lot.
1964	A total of 25,900 cu yd is dredged from the entrance channel. Disposal is in an area of the present Town Pier parking lot.

(Continued)

Table A1 (Concluded)

Date	Description of Major Event
1968	The US Army Engineer Division, New England (NED), dredges 140,200 cu yd of material from the entrance channel, inner channel anchorage, and turning to construct the authorized Federal project. Sand and mud are disposed of in two disposal sites built in the marsh to the northeast of the harbor. One disposal site is subsequently used for construction of the town sewage treatment plant.
1969	NED extends the west jetty 200 ft and raises the east jetty to an elevation of +14 ft mlw. Maintenance dredging of the entrance channel is also performed this year: 35,294 cu yd was placed in the land-based disposal areas, and 660 cu yd of "gravel" from the entrance channel was dumped in an unspecified offshore area.
1970	NED constructs a revetment at the landward end of each jetty extending southerly to reduce erosion occurring along the beach in this area.
1973	Material (71,800 cu yd) is dredged from the entrance channel and anchorage and placed in the land-based disposal area.
1975	Repairs to the end of west jetty are completed. Because this jetty was intended only to prevent sand from entering the channel from Green Harbor Beach, it was constructed with smaller size stone than the east jetty. The portion of the west jetty which extends beyond the shadow zone of the east zone was subject to damage from large waves generated by northeasters.
1976	The wooden bulkhead on top of west jetty in the vicinity of The Narrows is replaced by Commonwealth.
1977	24,000 cu yd of material are removed from the entrance channel and placed on the beach area between Bluefish Rocks and the east jetty.
1980-1981	45,000 cu yd of material is dredged from the entrance channel and placed on the beach on the other side of Blackman's Point using a hydraulic dredge in 1980. In 1981, the channel has reshoaled and an additional 21,000 cu yd is dredged from the entrance channel and placed below mlw offshore of the end of the west jetty. Cobble is estimated to have been about 10 percent of the total material. Some additional material is also dredged from the anchorage and the local marinas and pumped to the land-based disposal area.
1983	A total of 66,965 cu yd of material is pumped from the entrance channel and placed on Green Harbor Beach between Pearl and Bay Avenues. About 12 percent of the material is estimated to have been cobbles.
1985	Maintenance dredging of the entrance channel is under way at the end of fiscal year 1985. Sand and cobbles are being removed from the entrance channel and disposed of in a nearshore disposal area extending about 3,000 ft west of the entrance channel along Green Harbor Beach.

APPENDIX B: CURRENT MEASUREMENTS OBTAINED AT GREEN HARBOR, MA

Table B1

ENDECO Current Meter Data at Inlet Offshore of Green Harbor Entrance

21 Sep 1981*			22 Sep 1981			23 Sep 1981			24 Sep 1981			25 Sep 1981**		
Time EDT	Speed fps	Direction True North	Time EDT	Speed fps	Direction True North	Time EDT	Speed fps	Direction True North	Time EDT	Speed fps	Direction True North	Time EDT	Speed fps	Direction True North
1630	0.40	49	0030	0.10	157	0030	0.19	17	0030	0.10	90	0030	0.15	63
1700	0.10	50	0100	0.10	221	0100	0.11	24	0100	0.06	84	0100	0.22	84
1730	0.17	44	0130	0.14	241	0130	0.12	299	0130	0.06	63	0130	0.22	103
1800	0.15	36	0200	0.11	257	0200	0.07	279	0200	0.08	72	0200	0.25	142
1830	0.25	44	0230	0.15	239	0230	0.07	313	0230	0.07	176	0230	0.29	119
1900	0.17	50	0300	0.06	250	0300	0.06	94	0300	0.07	66	0300	0.14	211
1930	0.21	58	0330	0.10	261	0330	0.21	61	0330	0.06	65	0330	0.11	244
2000	0.35	49	0400	0.10	263	0400	0.21	41	0400	0.03	124	0400	0.17	231
2030	0.26	52	0430	0.08	267	0430	0.15	31	0430	0.06	132	0430	0.17	248
2100	0.32	53	0500	0.08	264	0500	0.10	19	0500	0.06	160	0500	0.14	249
2130	0.26	50	0530	0.03	260	0530	0.03	22	0530	0.06	199	0530	0.07	279
2200	0.29	48	0600	0.01	53	0600	0.11	35	0600	0.01	247	0600	0.12	311
2230	0.25	50	0630	0.14	28	0630	0.21	35	0630	0.00	99	0630	0.07	308
2300	0.28	49	0700	0.22	47	0700	0.25	39	0700	0.03	74	0700	0.04	316
2330	0.29	56	0730	0.24	51	0730	0.24	47	0730	0.06	89	0730	0.11	328
2400	0.19	64	0800	0.30	60	0800	0.17	75	0800	0.00	89	0800	0.08	321
			0830	0.33	59	0830	0.10	130	0830	0.04	98	0830	0.07	329
			0900	0.32	64	0900	0.04	70	0900	0.01	9	0900	0.06	326
			0930	0.44	66	0930	0.04	224	0930	0.10	28	0930	0.10	324
			1000	0.50	68	1000	0.07	204	1000	0.03	49			
			1030	0.54	67	1030	0.03	213	1030	0.08	63			
			1100	0.48	63	1100	0.03	231	1100	0.10	75			
			1130	0.61	63	1130	0.01	32	1130	0.03	85			
			1200	0.64	65	1200	0.08	24	1200	0.14	53			
			1230	0.76	59	1230	0.11	25	1230	0.18	48			
			1300	0.60	55	1300	0.06	19	1300	0.30	42			
			1330	0.57	39	1330	0.07	313	1330	0.18	38			
			1400	0.58	44	1400	0.07	294	1400	0.14	32			
			1430	0.44	52	1430	0.03	280	1430	0.06	128			
			1500	0.28	34	1500	0.04	301	1500	0.10	223			
			1530	0.19	31	1530	0.04	309	1530	0.18	226			
			1600	0.18	37	1600	0.03	328	1600	0.12	244			
			1630	0.24	28	1630	0.04	334	1630	0.15	268			

(Continued)

* Data end at 2400 hours.
** Data end at 0930 hours.

Table B1 (Concluded)

21 Sep 1981			22 Sep 1981			23 Sep 1981			24 Sep 1981			25 Sep 1981		
Time EDT	Speed fps	Direction True North	Time EDT	Speed fps	Direction True North	Time EDT	Speed fps	Direction True North	Time EDT	Speed fps	Direction True North	Time EDT	Speed fps	Direction True North
			1700	0.22	25	1700	0.03	324	1700	0.07	295			
			1730	0.30	26	1730	0.03	326	1730	0.07	316			
			1800	0.19	21	1800	0.03	321	1800	0.11	325			
			1830	0.21	17	1830	0.01	317	1830	0.14	327			
			1900	0.30	21	1900	0.03	325	1900	0.12	331			
			1930	0.28	25	1930	0.07	331	1930	0.14	325			
			2000	0.39	31	2000	0.10	336	2000	0.10	344			
			2030	0.39	38	2030	0.06	9	2030	0.11	326			
			2100	0.32	42	2100	0.11	23	2100	0.10	12			
			2130	0.25	36	2130	0.17	40	2130	0.14	17			
			2200	0.22	26	2200	0.19	57	2200	0.11	26			
			2230	0.30	24	2230	0.14	62	2230	0.06	41			
			2300	0.25	26	2300	0.11	52	2300	0.12	85			
			2330	0.26	27	2330	0.08	61	2330	0.12	49			
			2400	0.32	28	2400	0.14	62	2400	0.14	59			

Table B2

Speed and Direction at The Narrows*

Time	Station A Depth ft, mlw	Station A Velocity fps	Station B Depth ft, mlw	Station B Velocity fps	Station C Depth ft, mlw	Station C Velocity fps
			23 Sep 81			
1030	4.0	-0.76	9.6	-0.80	7.2	-0.65
	3.6	-1.02	7.2	-0.91	5.4	-0.58
	1.2	-1.10	2.4	-1.02	1.8	-0.62
1200	4.8	-0.43	8.0	-1.00	4.8	-0.73
	3.6	-0.44	6.0	-1.10	3.6	-0.54
	1.2	-1.32	2.0	-0.98	1.2	-0.41
1300	4.8	-0.43	7.2	-0.62	4.8	-0.76
	3.6	--**	5.6	-0.80	3.6	-0.62
	1.2	--**	1.8	-0.80	1.2	0.32
1400	4.8	0.58	6.4	0.80	5.6	-0.21
	3.6	0.88	4.8	0.58	4.2	-0.12
	1.2	0.73	1.6	0.54	1.4	0.40
1500	6.4	0.36	8.0	0.36	5.6	-0.25
	4.8	0.32	6.0	0.21	4.2	-0.51
	1.6	0.25	2.0	0.14	1.4	-0.65
1600	7.2	0.62	8.0	0.58	6.4	0.69
	5.4	0.76	6.0	0.76	4.8	0.80
	1.8	0.99	2.0	0.88	1.6	0.88
1700	5.6	0.58	9.6	0.99	8.0	1.02
	4.2	0.69	7.2	1.13	6.0	1.06
	1.4	0.91	2.4	1.17	2.0	1.02
1800	8.0	0.95	11.2	1.10	9.6	0.73
	6.0	1.13	8.4	1.10	7.2	0.73
	2.0	1.24	2.8	1.10	2.4	0.69
1900	8.0	0.91	12.0	0.65	11.2	0.47
	6.0	0.99	9.0	0.69	8.4	0.62
	2.0	1.13	3.0	0.87	2.8	0.76
2000	7.2	0.25	13.6	0.17	11.2	0.21
	5.4	0.43	10.5	0.17	8.4	0.17
	1.8	0.17	3.4	0.17	2.8	0.21

(Continued)

* Ebb current direction shown as a minus.
** Meter fouled; no data taken.

Table B2 (Continued)

Time	Station A Depth ft, mlw	Station A Velocity fps	Station B Depth ft, mlw	Station B Velocity fps	Station C Depth ft, mlw	Station C Velocity fps
			23 Sep 81 (Continued)			
2100	9.6	-0.25	13.6	-0.58	10.4	-0.95
	7.2	-0.40	10.2	-0.76	7.8	-1.06
	2.4	-0.54	3.2	-0.99	2.6	-0.99
2200	8.8	-0.73	12.0	-0.65	8.0	-0.91
	6.6	-0.95	9.0	-0.76	6.0	-1.13
	2.2	-1.02	3.0	-0.88	2.0	-1.06
2300	8.8	-0.76	10.4	-1.28	8.0	-1.21
	6.6	-0.99	7.8	-1.32	6.0	-1.32
	2.2	-1.28	2.2	-1.35	1.6	-1.32
			24 Sep 81			
0100	4.8	-0.54	7.2	-0.62	4.8	-0.43
	3.6	-0.80	5.4	-0.54	3.6	-0.58
	1.2	-0.88	1.8	-0.58	1.2	-0.62
0200	5.6	-0.43	6.4	-0.51	4.0	-0.21
	4.2	-0.54	4.8	-0.47	3.0	-0.25
	1.4	-0.58	1.6	-0.51	1.0	-0.17
0300	4.8	-0.21	6.4	-0.17	3.6	-0.14
	3.6	-0.25	4.8	-0.29	2.7	-0.17
	1.2	-0.36	1.6	-0.32	0.9	-0.14
0400	4.8	0.21	6.4	0.17	4.4	0.40
	3.6	0.47	4.8	0.40	3.3	0.58
	1.2	0.47	1.6	0.51	1.1	0.65
0500	6.4	0.54	7.2	0.51	6.4	0.58
	4.8	0.54	5.4	0.54	4.8	0.80
	1.6	0.58	1.8	0.80	1.6	0.88
0600	6.4	0.95	9.6	0.99	8.0	0.99
	4.8	1.10	7.2	1.10	6.0	1.17
	1.6	1.17	2.4	1.35	2.0	1.21
0700	8.8	0.47	10.4	0.84	9.6	0.54
	6.6	0.65	7.8	0.84	7.2	0.58
	2.2	1.02	2.6	0.84	2.4	0.65
0800	7.2	0.27	12.0	0.36	10.4	0.56
	5.4	0.32	9.0	0.40	7.8	0.52
	1.8	0.37	3.0	0.55	2.6	0.52

(Continued)

Table B2 (Concluded)

Time	Station A Depth ft, mlw	Station A Velocity fps	Station B Depth ft, mlw	Station B Velocity fps	Station C Depth ft, mlw	Station C Velocity fps
			24 Sep 81 (Continued)			
0900	8.0	0.25	12.0	0.36	10.4	0.56
	6.0	0.17	9.0	0.21	8.4	0.40
	2.0	0.21	3.0	0.25	2.8	0.47
1000	10.4	-0.32	12.0	-0.43	9.0	-0.40
	7.8	-0.43	9.0	-0.42	7.2	-0.32
	2.6	-0.62	3.0	-0.58	2.4	-0.43
1100	8.8	-0.95	10.4	-0.91	6.4	-0.65
	6.6	-1.21	7.8	-1.06	4.8	-0.51
	2.2	-1.32	2.6	-1.02	1.6	-0.47

APPENDIX C: DIRECTIONAL SPECTRAL WAVE DATA OBTAINED OFFSHORE OF GREEN HARBOR, MA

Table C1

Wave Climate Summary, Green Harbor, MA, 15 Jun to 14 Aug 1983*

RUN	$\bar{h}$ (m)	E_T(cm^2)		$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
15 June 83 - 03	10.13	1	(6)	.04	.0781	12.8	230	55	0.4	0.03	-0.12
16 June 83 - 01	9.81	2	(21)	.06	.0781	12.8	260	88	0.5	0.02	-0.06
- 02	7.88	0	(19)	.00	----	----	---	--	---	-0.07	-0.01
- 03	10.51	6	(45)	.10	.1094	9.1	259	45	2.1	-0.06	-0.05
17 June 83 - 01	9.00	4	(49)	.08	.1250	8.0	259	59	0.7	0.01	-0.02
- 02	8.58	1	(30)	.04	----	---	---	--	---	-0.11	-0.09
- 03	10.60	--	(39)	.25(vel)	.1094	9.1	258	57	9.5(vel)	0.03	0.00
18 June 83 - 01	8.30	2	(18)	.06	.1094	9.1	269	51	0.6	-0.02	0.05
- 02	9.12	2	(14)	.06	.1094	9.1	287	71	0.5	-0.06	-0.03
- 03	10.31	2	(10)	.06	.0938	10.7	232	47	0.7	0.05	0.01
19 June 83 - 01	8.03	0	(11)	.00	----	----	---	--	---	-0.01	-0.01
- 02	9.79	1	(9)	.04	.1094	9.1	273	68	0.4	-0.10	-0.03
- 03	9.75	2	(15)	.06	.1094	9.1	274	53	0.9	0.05	0.00

(Continued)

* $\bar{h}$ = mean water depth (m). $E_T(\langle\eta^2\rangle)$ = total energy variance in wave (cm^2)--this parameter proportional to amount of energy in the wave; comparative values calculated from pressure and velocity; velocity calculated values in parentheses. $H_{1/3}$ = significant wave height (m)--this parameter being derived from E_T, where $H_{1/3} \approx \sqrt{\langle\eta^2\rangle}$. Peak T = peak wave period = 1/peak wave frequency. α_o = direction of peak wave propagation, measured in degrees clockwise from true north. $P(\alpha_o)$ = angular spread of direction of propagation of the peak wave. E_P = energy variance in peak frequency (cm^2). $\bar{U}$, $\bar{V}$ = components of current velocity (m/sec) relative to probe orientation. C_s = current speed (m/sec) as calculated from $\bar{U}$, $\bar{V}$, U being positive to the north and V being positive to the east. C_D = direction toward which the current is flowing in degrees true north as calculated from $\bar{U}$, $\bar{V}$. S.D. = standard deviation of indicated quantity.

Table C1 (Continued)

RUN	$\bar{h}$ (m)		E_T(cm^2)	$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
20 June 83 - 01	7.90	1	(18)	.04	.1094	9.1	278	76	0.4	-0.04	-0.04
- 02	10.26	3	(12)	.07	.0938	10.7	259	61	0.6	-0.02	-0.16
- 03	9.17	1	(17)	.04	.0781	12.8	264	44	0.2	-0.05	-0.06
21 June 83 - 01	8.27	1	(10)	.04	.1094	9.1	282	52	0.3	-0.15	-0.09
- 02	10.52	2	(12)	.06	.0781	12.8	236	79	0.4	-0.03	-0.17
- 03	8.69	1	(12)	.04	.0781	12.8	248	52	0.4	-0.05	-0.09
22 June 83 - 01	8.84	1	(5)	.04	.0781	12.8	270	47	0.3	-0.23	-0.07
- 02	10.33	3	(13)	.07	.0781	12.8	254	44	0.8	-0.08	-0.06
- 03	8.19	1	(5)	.04	.0938	10.7	260	73	0.1	-0.07	-0.05
23 June 83 - 01	9.45	1	(3)	.04	.0938	10.7	255	65	0.2	-0.18	-0.04
- 02	9.92	1	(5)	.04	.0938	10.7	252	53	0.3	0.00	-0.10
- 03	7.93	1	(4)	.04	.0938	10.7	292	56	0.2	-0.08	0.02
24 June 83 - 01	9.86	1	(4)	.04	.0938	10.7	268	53	0.3	-0.06	-0.08
- 02	9.39	1	(4)	.04	.0938	10.7	286	55	0.2	-0.04	-0.07
- 03	8.08	0	(5)	.00	----	----	---	--	---	-0.05	-0.02
25 June 83 - 01	10.30	1	(6)	.04	.0781	12.8	213	72	0.4	-0.11	-0.06
- 02	9.01	1	(6)	.04	.0781	12.8	237	42	0.2	-0.01	-0.06
- 03	8.24	1	(15)	.04	.0781	12.8	298	66	0.2	-0.02	-0.04
26 June 83 - 01	10.70	2	(10)	.06	.0938	10.7	251	74	1.0	-0.12	-0.13
- 02	8.65	1	(9)	.04	.1094	9.1	286	63	0.4	-0.05	-0.07
- 03	8.83	0	(14)	.00	----	----	---	--	---	-0.09	-0.10
27 June 83 - 01	10.75	2	(16)	.06	.0938	10.7	223	81	0.9	0.01	-0.05
- 02	8.24	2	(17)	.06	.1094	9.1	260	44	1.2	-0.01	-0.01
- 03	8.96	1	(9)	.04	.0938	10.7	271	72	0.4	-0.08	-0.05
28 June 83 - 01	10.64	4	(24)	.08	.1094	9.1	205	77	1.3	-0.02	-0.11
- 02	8.07	1	(17)	.04	.1094	9.1	267	49	0.3	0.06	-0.03
- 03	9.34	3	(41)	.07	.1094	9.1	298	81	0.5	-0.08	-0.11

(Continued)

Table C1 (Continued)

RUN	$\bar{h}$ (m)	E_T(cm^2)	$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
29 June 83 - 01	10.41	3 (21)	.07	.1250	8.0	244	65	0.5	0.06	-0.03
- 02	7.91	1 (8)	.04	.1094	9.1	275	72	0.2	-0.08	-0.02
- 03	9.71	2 (14)	.06	.1094	9.1	280	68	0.2	-0.05	-0.12
30 June 83 - 01	10.02	2 (8)	.06	.0781	12.8	268	55	0.8	0.00	0.05
- 02	7.93	1 (10)	.04	.0781	12.8	232	60	0.5	-0.03	0.01
- 03	9.97	6 (22)	.10	.0781	12.8	274	42	2.4	-0.05	-0.05
01 July 83 - 01	9.57	7 (34)	.11	.1094	9.1	270	45	2.3	-0.04	-0.02
- 02	8.09	3 (19)	.07	.0781	12.8	273	53	0.8	-0.01	-0.09
- 03	10.12	3 (14)	.07	.0781	12.8	242	65	0.7	-0.11	-0.06
02 July 83 - 01	9.12	4 (19)	.08	.1094	9.1	281	50	1.1	0.00	-0.02
- 02	8.41	3 (16)	.07	.1094	9.1	276	55	0.9	-0.02	-0.09
- 03	10.23	5 (17)	.09	.1094	9.1	276	57	1.3	-0.10	-0.06
03 July 83 - 01	8.79	4 (16)	.08	.1250	8.0	261	43	1.4	0.03	0.00
- 02	8.87	4 (15)	.08	.1250	8.0	282	56	1.1	-0.05	-0.17
- 03	10.27	6 (23)	.10	.1094	9.1	283	46	1.2	-0.05	-0.04
04 July 83 - 01	8.42	2 (9)	.06	.1094	9.1	289	38	0.4	-0.01	0.01
- 02	9.27	2 (11)	.06	.1094	9.1	285	65	0.6	-0.06	-0.07
- 03	10.04	3 (13)	.07	.1094	9.1	245	46	0.6	-0.03	-0.03
05 July 83 - 01	8.12	1 (4)	.04	.0938	10.7	271	32	0.4	-0.11	-0.04
- 02	9.68	2 (7)	.06	.0625	16.0	260	60	0.5	-0.01	-0.09
- 03	9.68	2 (5)	.06	.0938	10.7	286	42	0.6	-0.10	-0.03
06 July 83 - 01	8.06	1 (4)	.04	.0625	16.0	261	54	0.5	-0.02	-0.14
- 02	10.07	2 (4)	.06	.0625	16.0	262	47	1.2	0.01	-0.17
- 03	9.34	2 (5)	.06	.0625	16.0	260	49	0.6	-0.07	-0.02
07 July 83 - 01	8.33	2 (11)	.06	.0625	16.0	292	54	1.0	-0.06	-0.09
- 02	10.32	41 (124)	.26	.1875	5.3	248	51	11.	-0.07	-0.01
- 03	8.89	12 (38)	.14	.1094	9.1	288	41	2.0	0.03	-0.03
08 July 83 - 01	8.73	7 (20)	.11	.1094	9.1	264	63	1.6	-0.08	-0.03
- 02	10.32	12 (21)	.14	.1094	9.1	281	33	3.1	0.06	-0.01
- 03	8.29	6 (15)	.10	.1094	9.1	276	42	3.5	0.06	0.03

(Continued)

Table C1 (Continued)

RUN	$\bar{h}$ (m)	E_T(cm^2)		$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
09 July 83 - 01	9.33	3	(8)	.07	.0781	12.8	278	36	1.0	-0.14	-0.04
- 02	10.03	4	(10)	.08	.1094	9.1	267	67	1.0	0.01	-0.01
- 03	7.81	2	(6)	.06	.0781	12.8	268	46	0.4	-0.03	-0.03
10 July 83 - 01	10.11	6	(23)	.10	.0781	12.8	262	46	1.3	-0.02	-0.09
- 02	9.55	6	(27)	.10	.2500	4.0	237	58	1.3	-0.04	-0.12
- 03	7.69	2	(10)	.06	.0781	12.8	284	70	0.4	-0.06	-0.04
11 July 83 - 01	10.74	2	(6)	.06	.0781	12.8	193	79	0.5	-0.08	-0.04
- 02	8.84	1	(4)	.04	.0781	12.8	261	54	0.2	0.02	0.03
- 03	7.98	2	(4)	.06	.0781	12.8	275	45	0.6	-0.11	-0.04
12 July 83 - 01	11.21	4	(10)	.08	.0938	10.7	223	62	1.1	-0.05	-0.02
- 02	8.19	5	(13)	.09	.1094	9.1	273	51	1.5	-0.02	-0.01
- 03	8.68	4	(9)	.08	.1094	9.1	275	45	1.4	-0.04	-0.13
13 July 83 - 01	11.23	16	(31)	.16	.0781	12.8	230	62	8.8	-0.04	-0.02
- 02	7.52	48	(83)	.29	.1094	9.1	284	31	30.	-0.01	0.05
- 03	9.39	18	(31)	.17	.0938	10.7	277	32	4.9	0.06	-0.09
14 July 83 - 01	10.75	17	(28)	.16	.1094	9.1	252	48	3.6	-0.06	-0.04
- 02	7.39	8	(14)	.11	.1094	9.1	280	31	3.2	-0.02	-0.03
- 03	10.11	9	(25)	.12	.1094	9.1	242	49	1.9	-0.01	-0.07
15 July 83 - 01	9.96	5	(10)	.09	.1094	9.1	283	35	1.8	-0.02	-0.02
- 02	7.58	2	(7)	.06	.1094	9.1	270	53	0.8	-0.02	-0.06
- 03	10.58	5	(8)	.09	.1094	9.1	242	46	1.4	0.02	-0.12
16 July 83 - 01	9.13	4	(7)	.08	.1094	9.1	260	21	1.0	-0.06	-0.02
- 02	8.20	2	(5)	.06	----	---	(BROAD)	--	---	-0.04	-0.09
- 03	10.82	6	(11)	.10	.1094	9.1	213	65	1.3	-0.02	-0.02
17 July 83 - 01	8.48	2	(4)	.06	.1250	8.0	252	51	0.3	-0.01	0.02
- 02	8.97	2	(6)	.06	.0938	10.7	271	45	0.4	0.02	-0.05
- 03	10.60	6	(12)	.10	.1250	8.0	239	42	1.1	-0.04	0.02
18 July 83 - 01	7.99	6	(11)	.10	.1094	9.1	279	33	2.1	-0.06	0.02
- 02	9.58	4	(8)	.08	.1094	9.1	278	32	1.6	-0.03	-0.08
- 03	10.10	5	(8)	.09	.1094	9.1	280	47	1.6	-0.10	-0.02

(Continued)

Table C1 (Continued)

RUN	$\bar{h}$ (m)	E_T(cm^2)	$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
19 July 83 - 01	7.87	4 (11)	.08	.1094	9.1	285	45	2.2	-0.03	-0.02
- 02	10.07	5 (9)	.09	.1094	9.1	241	39	1.1	-0.01	-0.14
- 03	9.56	4 (7)	.08	.1094	9.1	280	37	1.2	-0.01	-0.01
20 July 83 - 01	8.13	3 (5)	.07	.1094	9.1	287	44	1.0	-0.13	-0.04
- 02	10.37	4 (8)	.08	.1094	9.1	214	53	0.7	-0.07	-0.08
- 03	9.02	3 (7)	.07	.1094	9.1	267	36	0.5	-0.02	0.01
21 July 83 - 01	8.64	2 (5)	.06	.1094	9.1	273	60	0.5	-0.10	-0.07
- 02	10.28	6 (12)	.10	.0938	10.7	256	43	1.2	0.00	-0.07
- 03	8.47	(9)	.12(vel)	.1250	8.0	270	41	1.2(vel)	-0.07	0.01
22 July 83 - 01	9.16	2 (7)	.06	.1094	9.1	277	49	0.5	-0.02	-0.06
- 02	10.07	5 (15)	.09	.0938	10.7	244	56	0.7	0.02	-0.02
- 03	8.28	65 (124)	.32	.1406	7.1	258	35	21.	-0.05	-0.01
23 July 83 - 01	9.75	110 (176)	.42	.1406	7.1	253	29	40.	-0.02	-0.05
- 02	9.71	187 (211)	.55	.1250	8.0	240	24	37.	0.03	-0.03
- 03	8.12	39 (57)	.25	.1406	7.1	261	26	12.	0.01	0.01
24 July 83 - 01	10.17	19 (28)	.17	.0938	10.7	284	45	2.8	-0.08	-0.06
- 02	9.26	11 (12)	.13	.0938	10.7	281	26	2.8	0.02	0.02
- 03	8.21	7 (14)	.11	.0938	10.7	282	43	2.3	-0.06	-0.06
25 July 83 - 01	10.60	13 (18)	.14	.0938	10.7	247	61	3.9	-0.11	-0.10
- 02	8.95	114 (145)	.43	.1875	5.3	244	30	33.	-0.05	0.02
- 03	8.47	22 (47)	.19	.2031	4.9	252	65	4.4	-0.03	-0.04
26 July 83 - 01	10.78	34 (47)	.23	.1875	5.3	248	43	5.5	-0.07	-0.07
- 02	8.57	11 (15)	.13	.1094	9.1	275	22	2.4	0.00	0.04
- 03	8.77	31 (47)	.22	.1250	8.0	265	46	8.2	-0.04	-0.07
27 July 83 - 01	10.78	98 (111)	.40	.1250	8.0	265	34	3.6	-0.12	-0.07
- 02	8.32	20 (24)	.18	.1250	8.0	272	21	7.0	0.00	0.00
- 03	9.12	23 (29)	.19	.1250	8.0	281	31	6.0	-0.03	-0.07
28 July 83 - 01	10.65	17 (19)	.16	.0781	12.8	257	39	4.6	-0.12	-0.06
- 02	8.09	6 (8)	.10	.1094	9.1	276	24	1.7	0.02	0.03
- 03	9.44	11 (12)	.13	.0781	12.8	281	48	3.5	-0.05	-0.17

(Continued)

Table C1 (Continued)

RUN	$\bar{h}$ (m)	E_T(cm^2)		$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
29 July 83 - 01	10.25	10	(11)	.13	.0781	12.8	279	34	3.6	-0.11	-0.05
- 02	7.87	7	(9)	.11	.1094	9.1	285	20	2.9	0.02	-0.02
- 03	9.75	4	(6)	.08	.0781	12.8	253	35	0.8	-0.08	-0.06
30 July 83 - 01	9.83	6	(9)	.10	.1094	9.1	274	42	1.5	0.03	-0.06
- 02	7.88	4	(6)	.08	.0938	10.7	268	32	1.3	-0.03	0.00
- 03	10.02	6	(9)	.10	.1094	9.1	278	42	1.1	-0.03	-0.03
31 July 83 - 01	9.39	6	(8)	.10	.0781	12.8	271	32	2.2	0.02	0.02
- 02	8.15	5	(8)	.09	.0781	12.8	277	32	1.4	-0.05	-0.06
- 03	10.33	13	(23)	.14	.0781	12.8	251	49	2.9	0.00	-0.09
01 Aug. 83 - 01	9.06	6	(9)	.10	.1094	9.1	285	36	0.9	-0.07	-0.01
- 02	8.50	6	(11)	.10	.0781	12.8	268	44	1.3	-0.04	-0.03
- 03	10.48	8	(11)	.11	.1094	9.1	267	65	1.4	-0.10	-0.05
02 Aug. 83 - 01	8.61	5	(7)	.09	.0781	12.8	271	26	1.2	-0.05	-0.07
- 02	8.84	3	(4)	.07	.0938	10.7	279	29	1.3	-0.03	-0.06
- 03	10.34	5	(6)	.09	.0938	10.7	262	43	1.3	-0.09	-0.04
03 Aug. 83 - 01	8.19	2	(3)	.06	.1094	9.1	287	28	0.7	0.01	-0.01
- 02	9.41	2	(2)	.06	.1094	9.1	278	38	0.4	-0.01	-0.15
- 03	10.14	4	(4)	.08	.0781	12.8	246	41	0.7	-0.01	0.00
04 Aug. 83 - 01	7.97	2	(2)	.06	.1094	9.1	293	35	0.4	-0.06	-0.02
- 02	9.84	3	(3)	.07	.0781	12.8	235	40	0.5	-0.04	0.00
- 03	9.72	3	(5)	.07	.0781	12.8	274	37	0.6	-0.01	-0.05
05 Aug. 83 - 01	8.03	2	(3)	.06	.0781	12.8	281	34	0.6	-0.04	-0.02
- 02	10.28	4	(4)	.08	.0938	10.7	250	47	1.4	-0.03	-0.08
- 03	9.26	2	(2)	.06	.0938	10.7	285	38	0.7	-0.07	-0.01
06 Aug. 83 - 01	8.43	1	(3)	.04	.0938	10.7	266	60	0.3	-0.01	-0.09
- 02	10.43	2	(5)	.06	.0938	10.7	229	56	0.5	-0.01	-0.08
- 03	8.56	1	(2)	.04	.1094	9.1	264	49	0.2	0.01	0.01
07 Aug. 83 - 01	9.08	2	(7)	.06	.1094	9.1	281	57	0.7	-0.06	-0.05
- 02	10.29	3	(7)	.07	.0938	10.7	215	58	0.7	0.02	-0.03
- 03	7.89	2	(6)	.06	.0938	10.7	285	76	0.5	-0.02	-0.01

(Continued)

Table C1 (Concluded)

RUN	$\bar{h}$ (m)	E_T(cm^2)		$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	P(α_o)	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
08 Aug. 83 - 01	9.85	2	(5)	.06	.0938	10.7	267	53	0.5	-0.08	-0.03
- 02	9.78	2	(8)	.06	.0938	10.7	257	67	0.3	-0.02	-0.02
- 03	7.55	1	(4)	.04	.0938	10.7	275	67	0.2	-0.04	-0.07
09 Aug. 83 - 01	10.56	4	(4)	.08	.0938	10.7	259	44	1.2	-0.07	-0.05
- 02	9.14	2	(4)	.06	.0781	12.8	275	39	0.5	0.01	0.01
- 03	7.74	1	(3)	.04	.0781	12.8	277	44	0.4	-0.02	-0.02
10 Aug. 83 - 01	11.23	4	(9)	.08	.0781	12.8	252	67	1.3	-0.06	-0.04
- 02	8.46	17	(45)	.16	.2031	4.9	252	63	3.4	0.00	0.06
- 03	8.37	7	(12)	.11	.0781	12.8	259	45	1.3	-0.10	-0.03
11 Aug. 83 - 01	11.30	11	(17)	.13	.0781	12.8	237	56	3.5	-0.02	-0.05
- 02	7.89	1	(4)	.04	.0781	12.8	272	47	0.4	-0.01	0.00
- 03	9.18	18	(67)	.17	.2500	4.0	290	79	8.9	-0.04	-0.14
12 Aug. 83 - 01	10.89	193	(386)	.56	.2188	4.9	300	46	66.	0.04	0.00
- 02	7.60	39	(96)	.25	.1406	7.1	260	58	7.3	-0.04	0.00
- 03	10.13	836	(1471)	1.16	.1094	9.1	247	50	261.	0.01	-0.03
13 Aug. 83 - 01	10.26	1209	(1669)	1.39	.1094	9.1	252	40	227.	0.04	0.02
- 02	7.72	189	(356)	.55	.1250	8.0	265	50	44.	0.04	0.03
- 03	10.63	304	(488)	.70	.1250	8.0	265	41	61.	-0.05	-0.05
14 Aug. 83 - 01	9.41	171	(288)	.52	.1094	9.1	278	50	36.	0.03	0.01
- 02	8.07	49	(84)	.28	.1094	9.1	284	44	14.	-0.09	-0.06
- 03	10.86	59	(84)	.31	.1250	8.0	262	49	11.	-0.07	-0.02
MEAN	9.27	25	(45)							-0.04	-0.04
S.D.	1.00	115	(173)							0.05	0.05

Table C2

Wave Climate Summary, Green Harbor, MA, 26 Aug 1983 to 27 Oct 1983*

DATE	TIME	$\bar{h}$ (m)	E_T(cm^2)		$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
26 Aug 83	1432	10.05	6.	(73.)*	0.10	0.1094	9.1	280.	72.	1.	0.02*	0.05*
	2232	8.45	6.	(7.)	0.10	0.1250	8.0	267.	34.	1.	-0.01	0.00
27 Aug 83	632	8.22	5.	(5.)	0.09	0.1094	9.1	278.	40.	2.	0.00	0.07
	1432	10.11	6.	(11.)	0.10	0.1094	9.1	274.	44.	1.	-0.04	-0.01
	2232	8.12	5.	(6.)	0.09	0.1250	8.0	268.	35.	1.	-0.01	-0.07
28 Aug 83	632	8.64	11.	(9.)	0.13	0.1094	9.1	266.	39.	2.	0.00	0.07
	1432	10.05	12.	(17.)	0.14	0.1250	8.0	261.	50.	5.	0.03	-0.04
	2232	7.85	5.	(6.)	0.09	0.1250	8.0	274.	33.	1.	-0.02	-0.02
29 Aug 83	632	8.99	7.	(43.)	0.11	0.1250	8.0	269.	39.	1.	-0.02	0.02
	1432	9.85	8.	(15.)	0.12	0.2500	4.0	230.	53.	2.	0.03	-0.04
	2232	7.66	12.	(14.)	0.14	0.2500	4.0	221.	29.	4.	-0.01	-0.06
30 Aug 83	632	9.38	28.	(28.)*	0.21	0.2500	4.0	213.	32.	9.	-0.02	0.05*
	1432	9.47	27.	(29.)	0.21	0.2500	4.0	238.	42.	7.	-0.05	0.01
	2232	7.69	12.	(14.)	0.14	0.2344	4.3	237.	28.	3.	0.01	0.07

(Continued)

* $\bar{h}$ = mean water depth (m). $E_T(\langle\eta^2\rangle)$ = total energy variance in wave (cm^2)--this parameter proportional to amount of energy in the wave; comparative values calculated from pressure and velocity; velocity calculated values in parentheses. $H_{1/3}$ = significant wave height (m)--this parameter being derived from E_T, where $H_{1/3} \approx \sqrt{\langle\eta^2\rangle}$. Peak T = peak wave period = 1/peak wave frequency. α_o = direction of peak wave propagation, measured in degrees clockwise from true north. $P(\alpha_o)$ = angular spread of direction of propagation of the peak wave. E_P = energy variance in peak frequency (cm^2). $\bar{U}$, $\bar{V}$ = components of current velocity (m/sec) relative to probe orientation. C_s = current speed (m/sec) as calculated from $\bar{U}$, $\bar{V}$, U being positive to the north and V being positive to the east. C_D = direction toward which the current is flowing in degrees true north as calculated from $\bar{U}$, $\bar{V}$. S.D. = standard deviation of indicated quantity.

Table C2 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T(cm^2)	$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
31 Aug 83	632	9.67	18. (22.)	0.17	0.1406	7.1	258.	36.	3.	-0.03	0.00
	1432	9.02	32. (34.)	0.23	0.1563	6.4	259.	27.	6.	0.01	0.08
	2232	7.94	64. (68.)	0.32	0.1094	9.1	270.	24.	20.	-0.13	-0.01
01 Sep 83	632	9.88	173. (192.)	0.53	0.1094	9.1	268.	28.	51.	-0.03	0.01
	1432	8.55	121. (121.)*	0.44	0.0938	10.7	265.	32.	38.	-0.02	-0.13*
	2232	8.48	80. (87.)	0.36	0.0938	10.7	269.	22.	39.	-0.02	0.02
02 Sep 83	632	9.77	96. (106.)	0.39	0.0938	10.7	272.	33.	36.	0.03	0.07
	1432	8.04	47. (44.)	0.27	0.1094	9.1	262.	36.	22.	-0.01	-0.10
	2232	9.07	33. (37.)	0.23	0.0938	10.7	261.	26.	14.	-0.05	0.02
03 Sep 83	632	9.33	31. (34.)	0.22	0.0938	10.7	263.	33.	10.	0.02	0.05
	1432	7.60	18. (22.)	0.17	0.0938	10.7	271.	33.	7.	-0.03	0.00
	2232	9.87	21. (25.)*	0.18	0.0938	10.7	268.	53.	6.	-0.02	0.05*
04 Sep 83	632	8.79	10. (11.)	0.13	0.0938	10.7	264.	43.	3.	0.01	0.01
	1432	7.55	10. (12.)	0.13	0.0781	12.8	257.	26.	5.	-0.02	0.01
	2232	10.43	23. (26.)*	0.19	0.0781	12.8	260.	63.	7.	-0.02*	1.32*
05 Sep 83	632	8.11	16. (19.)	0.16	0.0781	12.8	270.	28.	6.	0.01	-0.01
	1432	7.98	13. (56.)	0.14	0.0938	10.7	265.	61.	4.	-0.06	0.08
	2232	10.75	12. (19.)	0.14	0.0781	12.8	314.	59.	3.	-0.03	0.07
06 Sep 83	632	7.48	13. (16.)	0.14	0.1094	9.1	280.	30.	4.	0.03	-0.01
**	1432	8.71	12. (1.)	0.14	0.0781	12.8	413.	2.	4.	-0.10	0.05**
	2232	10.57	11. (12.)	0.13	0.0781	12.8	303.	54.	3.	0.03	0.06
07 Sep 83	632	6.98	11. (15.)	0.14	0.1094	9.1	280.	35.	4.	-0.03	-0.02
	1432	9.43	6. (10.)	0.10	0.0938	10.7	256.	33.	2.	-0.06	0.01
	2232	9.96	6. (11.)	0.10	0.0938	10.7	278.	67.	2.	-0.02	0.02
08 Sep 83	632	6.88	6. (8.)	0.10	0.0781	12.8	272.	27.	2.	-0.03	-0.02
	1432	10.10	6. (8.)	0.10	0.0938	10.7	271.	38.	2.	-0.02	0.08
	2232	9.16	6. (9.)	0.10	0.0938	10.7	266.	48.	1.	0.07	-0.01
09 Sep 83	632	7.23	3. (5.)	0.07	0.1094	9.1	278.	36.	1.	-0.04	0.06
	1432	10.52	5. (6.)	0.09	0.1094	9.1	231.	66.	1.	0.00	0.06
	2232	8.26	2. (4.)	0.06	0.0938	10.7	257.	38.	1.	-0.02	0.05

(Continued)

Table C2 (Continued)

DATE	TIME	$\bar{h}$ (m)	$E_T(cm^2)$	$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	$E_P(cm^2)$	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
10 Sep 83	632	7.84	2. (4.)	0.05	0.1094	9.1	271.	32.	1.	-0.03	0.06
	1432	10.54	3. (7.)	0.07	0.1094	9.1	282.	52.	1.	-0.03	0.02
	2232	7.74	6. (7.)	0.09	0.2344	4.3	284.	49.	2.	0.01	-0.04
11 Sep 83	632	8.72	3. (6.)	0.07	0.0625	16.0	269.	45.	1.	-0.05	0.05
	1432	10.36	6. (10.)	0.10	0.2500	4.0	272.	72.	1.	0.01	0.05
	2232	7.31	3. (5.)	0.07	0.0625	16.0	276.	34.	1.	-0.03	-0.05
12 Sep 83	632	9.26	3. (5.)	0.07	0.0781	12.8	261.	34.	1.	-0.08	0.02
	1432	9.79	7. (7.)*	0.11	0.0781	12.8	271.	83.	1.	0.06*	0.00*
	2232	7.35	3. (3.)	0.07	0.0781	12.8	280.	40.	1.	0.02	0.09
13 Sep 83	632	9.70	3. (6.)	0.07	0.0781	12.8	278.	48.	1.	-0.04	0.01
	1432	9.23	79. (81.)	0.36	0.2031	4.9	234.	25.	23.	-0.03	0.04
	2232	7.78	18. (26.)	0.17	0.2031	4.9	256.	37.	5.	-0.06	0.04
14 Sep 83	632	9.97	440. (654.)	0.84	0.1875	5.3	240.	28.	115.	-0.02	0.06
	1432	8.77	274. (281.)	0.66	0.1719	5.8	245.	25.	81.	0.01	-0.03
	2232	8.42	138. (155.)	0.47	0.1563	6.4	252.	19.	30.	-0.01	0.05
15 Sep 83	632	9.93	202. (209.)	0.57	0.2031	4.9	252.	31.	50.	-0.02	-0.04
	1432	8.36	145. (152.)	0.48	0.1719	5.8	237.	23.	50.	-0.02	-0.03
	2232	9.03	33. (36.)	0.23	0.1563	6.4	265.	28.	7.	-0.02	0.09
16 Sep 83	632	9.58	50. (127.)	0.28	0.0938	10.7	280.	24.	8.	0.00	-0.03
	1432	8.04	27. (29.)	0.21	0.1094	9.1	264.	23.	7.	-0.02	0.00
	2232	9.51	67. (75.)	0.33	0.2500	4.0	294.	40.	21.	-0.02	0.08
17 Sep 83	632	9.06	131. (135.)	0.46	0.2500	4.0	252.	32.	33.	-0.01	0.01
	1432	7.99	75. (111.)*	0.35	0.1563	6.4	270.	24.	13.	0.00*	0.02*
	2232	9.92	94. (99.)	0.39	0.1094	9.1	266.	35.	16.	-0.02	0.04
18 Sep 83	632	8.60	72. (71.)	0.34	0.1406	7.1	264.	26.	10.	-0.01	-0.01
	1432	8.14	56. (56.)	0.30	0.1094	9.1	278.	22.	15.	-0.05	0.05
	2232	10.11	54. (124.)*	0.29	0.1406	7.1	262.	39.	11.	0.01*	1.05*
19 Sep 83	632	8.21	45. (45.)	0.27	0.1250	8.0	273.	32.	14.	0.00	-0.02
	1432	8.46	20. (23.)	0.18	0.1250	8.0	264.	27.	6.	-0.06	0.03
	2232	10.15	23. (27.)	0.19	0.1250	8.0	249.	32.	5.	-0.03	-0.06

(Continued)

Table C2 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T(cm^2)	$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
20 Sep 83	632	7.88	23. (23.)	0.19	0.1250	8.0	273.	28.	7.	0.00	-0.04
	1432	8.79	20. (19.)	0.18	0.0938	10.7	270.	34.	5.	0.00	0.00
	2232	10.05	55. (61.)	0.30	0.0938	10.7	259.	47.	15.	0.05	0.02
21 Sep 83	632	7.62	75. (64.)	0.35	0.1094	9.1	259.	36.	46.	0.01	-0.06
	1432	9.12	22. (23.)	0.19	0.0938	10.7	260.	27.	8.	-0.03	0.03
	2232	9.83	65. (58.)	0.32	0.0938	10.7	267.	37.	24.	-0.02	-0.02
22 Sep 83	632	7.48	43. (108.)*	0.26	0.0938	10.7	263.	30.	9.	-0.01*	0.81*
	1432	9.47	40. (37.)	0.25	0.0938	10.7	268.	25.	21.	-0.03	0.02
	2232	9.51	39. (158.)*	0.25	0.0938	10.7	265.	33.	11.	-0.05*	2.25*
23 Sep 83	632	7.48	37. (33.)	0.24	0.1094	9.1	271.	26.	14.	-0.02	0.05
	1432	9.80	33. (34.)	0.23	0.0938	10.7	271.	29.	10.	0.01	0.04
	2232	9.16	25. (25.)	0.20	0.1094	9.1	270.	33.	7.	0.03	-0.01
24 Sep 83	632	7.69	14. (12.)	0.15	0.0938	10.7	256.	51.	4.	0.01	0.06
	1432	10.12	13. (76.)	0.14	0.1250	8.0	245.	61.	2.	-0.06	0.00
	2232	8.73	29. (29.)	0.22	0.2344	4.3	225.	38.	8.	0.00	0.06
25 Sep 83	632	7.97	10. (8.)	0.12	0.0938	10.7	270.	38.	3.	-0.01	0.07
	1432	10.34	23. (25.)	0.19	0.0781	12.8	261.	43.	7.	-0.06	0.04
	2232	8.30	33. (26.)	0.23	0.0938	10.7	266.	28.	13.	0.00	0.00
26 Sep 83	632	8.28	26. (19.)	0.20	0.0781	12.8	273.	31.	11.	-0.04	0.07
	1432	10.34	30. (27.)	0.22	0.0938	10.7	269.	34.	11.	-0.03	-0.01
	2232	7.88	34. (27.)	0.23	0.0781	12.8	265.	36.	11.	-0.01	0.02
27 Sep 83	632	8.70	33. (26.)	0.23	0.0781	12.8	267.	35.	16.	-0.02	0.03
	1432	10.18	38. (101.)*	0.25	0.0938	10.7	271.	45.	14.	-0.01*	-0.05*
	2232	7.63	43. (118.)*	0.26	0.0781	12.8	264.	39.	19.	0.00*	0.30*
28 Sep 83	632	9.21	137. (122.)	0.47	0.2188	4.6	223.	31.	31.	-0.01	0.01
	1432	9.89	273. (221.)	0.66	0.1563	6.4	238.	28.	66.	-0.04	-0.03
	2232	7.57	70. (57.)	0.33	0.1719	5.8	258.	31.	12.	-0.02	0.01
29 Sep 83	632	9.65	85. (126.)*	0.37	0.2500	4.0	254.	35.	12.	0.00*	0.02*
	1432	9.40	59. (47.)	0.31	0.2344	4.3	253.	35.	13.	-0.01	-0.03
	2232	7.72	19. (15.)	0.17	0.1094	9.1	281.	35.	3.	-0.01	0.03

(Continued)

Table C2 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T(cm^2)	$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
30 Sep 83	632	9.76	23. (17.)	0.19	0.0781	12.8	258.	44.	3.	0.00	0.03
	1432	8.79	17. (13.)	0.16	0.1875	5.3	251.	35.	2.	-0.01	-0.03
	2232	8.31	9. (8.)	0.12	0.0938	10.7	264.	40.	3.	-0.02	0.04
01 Oct 83	632	10.03	11. (10.)	0.13	0.0938	10.7	267.	66.	2.	0.00	0.05
	1432	8.22	6. (5.)	0.10	0.1094	9.1	260.	43.	1.	-0.01	-0.03
	2232	8.99	5. (5.)	0.09	0.1094	9.1	264.	44.	1.	-0.02	0.08
02 Oct 83	632	9.65	9. (6.)	0.12	0.0938	10.7	268.	42.	2.	0.00	-0.02
	1432	7.65	9. (37.)*	0.12	0.1094	9.1	257.	50.	2.	0.00*	-0.03*
	2232	9.70	14. (88.)*	0.15	0.0781	12.8	266.	57.	4.	-0.03*	0.06*
03 Oct 83	632	9.10	26. (20.)	0.21	0.1094	9.1	270.	38.	5.	0.02	0.01
	1432	7.45	21. (12.)	0.18	0.1094	9.1	276.	48.	5.	-0.01	0.05
	2232	10.29	19. (12.)	0.17	0.0781	12.8	265.	58.	5.	-0.01	0.04
04 Oct 83	632	8.38	12. (8.)	0.14	0.0781	12.8	269.	51.	4.	0.01	0.02
	1432	7.83	8. (6.)	0.11	0.0781	12.8	262.	41.	3.	-0.03	0.01
	2232	10.70	10. (9.)	0.13	0.0781	12.8	285.	56.	3.	0.00	-0.01
05 Oct 83	632	7.90	26. (15.)	0.20	0.0781	12.8	267.	51.	5.	0.01	-0.02
	1432	8.61	40. (30.)	0.25	0.1563	6.4	244.	35.	9.	-0.07	0.04
	2232	10.62	52. (38.)	0.29	0.2500	4.0	283.	45.	8.	0.00	0.01
06 Oct 83	632	7.27	16. (10.)	0.16	0.0781	12.8	264.	47.	6.	0.00	-0.01
	1432	9.25	10. (7.)	0.13	0.0781	12.8	259.	52.	4.	0.00	0.04
	2232	10.08	14. (10.)	0.15	0.0781	12.8	276.	52.	5.	-0.03	0.02
07 Oct 83	632	7.03	8. (5.)	0.11	0.0781	12.8	273.	45.	3.	0.00	-0.01
	1432	9.98	8. (7.)	0.11	0.0781	12.8	250.	45.	3.	-0.03	0.03
	2232	9.35	7. (364.)*	0.11	0.0781	12.8	256.	75.	2.	0.00*	0.09*
08 Oct 83	632	7.29	7. (3.)	0.11	0.0781	12.8	261.	51.	2.	0.00	0.02
	1432	10.47	19. (11.)	0.17	0.2500	4.0	267.	51.	5.	-0.01	0.01
	2232	8.63	8. (5.)	0.11	0.0938	10.7	252.	50.	2.	0.00	0.00

(Continued)

Table C2 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T(cm^2)	$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
09 Oct 83	632	7.76	10. (4.)	0.13	0.0938	10.7	252.	52.	3.	-0.01	0.05
	1432	10.70	309. (441.)*	0.70	0.2031	4.9	227.	41.	88.	-0.01*	0.15*
	2232	8.08	105. (151.)*	0.41	0.1719	5.8	257.	39.	30.	0.01*	-0.01*
10 Oct 83	632	8.51	269. (176.)	0.66	0.1719	5.8	248.	35.	89.	-0.01	0.01
	1432	10.69	495. (318.)	0.89	0.1563	6.4	241.	37.	110.	-0.01	-0.01
	2232	7.80	132. (86.)	0.46	0.2500	4.0	245.	34.	21.	0.00	-0.04
11 Oct 83	632	9.19	95. (59.)	0.39	0.1563	6.4	255.	40.	15.	-0.02	0.03
	1432	10.28	265. (149.)	0.65	0.2500	4.0	271.	40.	85.	-0.01	-0.04
	2232	7.60	284. (166.)	0.67	0.2500	4.0	285.	39.	64.	-0.03	-0.05
12 Oct 83	632	9.51	164. (105.)*	0.51	0.2500	4.0	258.	38.	40.	-0.01	1.01*
	1432	9.64	110. (61.)	0.42	0.2500	4.0	256.	59.	17.	0.00	-0.03
	2232	7.72	299. (171.)	0.69	0.2031	4.9	293.	44.	88.	-0.03	0.03
13 Oct 83**	632	9.77	223. (80.)	0.60	0.2500	4.0	----	5.	30.	-0.01	0.06**
	1432	9.02	120. (66.)	0.44	0.1406	7.1	266.	51.	19.	-0.01	-0.01
	2232	8.07	71. (35.)	0.34	0.1094	9.1	278.	50.	18.	0.00	0.01
14 Oct 83	632	9.78	99. (43.)	0.40	0.0938	10.7	269.	53.	24.	0.01	0.04
	1432	8.49	55. (71.)	0.30	0.1250	8.0	276.	42.	17.	0.00	0.00
	2232	8.58	36. (58.)	0.24	0.1094	9.1	265.	49.	16.	-0.01	0.00
15 Oct 83	632	9.55	23. (69.)	0.19	0.1094	9.1	261.	58.	7.	-0.01	-0.01
	1432	8.16	14. (7.)	0.15	0.1094	9.1	269.	52.	5.	0.00	-0.01
	2232	9.12	64. (33.)	0.32	0.2188	4.6	212.	43.	11.	-0.01	0.01
16 Oct 83	632	9.37	56. (27.)	0.30	0.1875	5.3	232.	47.	16.	-0.01	-0.02
**	1417	7.76	27. (8.)	0.21	0.0156	64.0	----	6.	10.	-0.15	0.07**
17 Oct 83	632	9.08	44. (14.)	0.27	0.2500	4.0	227.	54.	8.	-0.01	-0.02
	1432	8.11	17. (38.)	0.16	0.0938	10.7	267.	61.	4.	-0.01	0.01
	2232	9.89	23. (8.)	0.19	0.0938	10.7	260.	62.	11.	-0.01	0.02
18 Oct 83	632	8.58	19. (8.)	0.17	0.0938	10.7	272.	58.	5.	0.00	0.00
	1432	8.14	12. (5.)	0.14	0.0938	10.7	278.	57.	4.	-0.01	0.01
	2232	10.06	17. (7.)	0.17	0.0938	10.7	273.	57.	4.	0.00	0.00

(Continued)

Table C2 (Concluded)

DATE	TIME	$\bar{h}$ (m)	E_T(cm^2)	$H_{1/3}$(m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P(cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)
19 Oct 83	632	8.37	66. (29.)	0.33	0.2500	4.0	220.	46.	23.	0.00	-0.01
	1432	8.52	49. (22.)	0.28	0.2500	4.0	238.	47.	9.	-0.02	0.01
	2232	10.24	46. (354.)*	0.27	0.2344	4.3	225.	51.	13.	-0.01*	3.06*
20 Oct 83	632	8.15	220. (95.)	0.59	0.1563	6.4	238.	49.	54.	0.01	-0.03
	1432	8.87	218. (99.)	0.59	0.1563	6.4	226.	48.	44.	-0.01	0.00
	2232	10.09	299. (131.)	0.69	0.1563	6.4	248.	47.	58.	0.00	-0.01
21 Oct 83	632	7.87	235. (101.)	0.61	0.1719	5.8	263.	52.	66.	0.01	-0.04
	1432	9.33	566. (223.)	0.95	0.1406	7.1	256.	48.	167.	-0.04	-0.04
	2232	9.80	575. (242.)	0.96	0.1406	7.1	251.	50.	90.	0.00	-0.02
22 Oct 83	632	7.74	239. (92.)	0.62	0.1250	8.0	266.	53.	64.	-0.02	-0.04
	1432	9.61	227. (95.)	0.60	0.1094	9.1	265.	50.	37.	-0.01	0.01
	2232	9.42	340. (136.)	0.74	0.1250	8.0	273.	49.	69.	0.00	-0.03
23 Oct 83	632	7.61	224. (96.)	0.60	0.0938	10.7	277.	50.	70.	-0.01	-0.01
	1432	9.99	334. (134.)	0.73	0.0938	10.7	268.	51.	109.	-0.04	0.00
	2232	8.99	268. (104.)	0.65	0.0781	12.8	273.	50.	84.	-0.02	-0.02
24 Oct 83	632	7.72	270. (102.)	0.66	0.0781	12.8	274.	53.	100.	-0.02	0.02
	1432	10.52	1534. (533.)	1.57	0.1406	7.1	239.	54.	523.	0.01	-0.03
	2232	8.67	1704. (724.)	1.65	0.1250	8.0	255.	47.	370.	0.01	0.08
25 Oct 83	632	8.39	1212. (635.)	1.39	0.1094	9.1	260.	48.	279.	0.00	-0.06
	1432	10.75	2160. (872.)	1.86	0.1094	9.1	252.	49.	475.	0.00	-0.01
	2232	8.34	865. (359.)	1.18	0.1094	9.1	265.	50.	231.	0.00	-0.05
26 Oct 83	632	8.67	848. (380.)	1.16	0.0938	10.7	270.	47.	236.	-0.01	0.03
	1432	10.50	895. (400.)	1.20	0.0781	12.8	277.	49.	308.	0.00	-0.01
	2232	7.62	187. (70.)	0.55	0.0781	12.8	267.	53.	60.	0.00	-0.01
27 Oct 83	632	8.99	96. (30.)	0.39	0.0781	12.8	262.	57.	39.	-0.01	0.02
MEAN		8.92	120. (74.)							-0.01	0.01
S.D.		1.00	277. (131.)							0.02	0.04

Table C3

Wave Climate, Green Harbor, MA, 10 Nov to 14 Dec 1983*

DATE	TIME	$\bar{h}$ (m)	E_T (cm²)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm²)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	W_s	W_D
10 NOV 83 -	1546	10.15	64. (65.)	0.32	0.2344	4.3	45.	30.	15.	0.01	-0.02	05	140
10 NOV 83 -	2346	8.49	1435.(1565.)	1.52	0.1563	6.4	332.*	26.	417.	0.04	0.14	17	150
11 NOV 83 -	746	8.58	475. (521.)	0.87	0.1094	9.1	266.*	23.	156.	0.02	-0.09	10	200
11 NOV 83 -	1546	10.15	548. (502.)	0.94	0.1094	9.1	4.**	33.	142.	0.02	0.02	11	170
11 NOV 83 -	2346	7.91	164. (177.)	0.51	0.1250	8.0	282.	25.	61.	-0.01	-0.04	15	240
12 NOV 83 -	746	8.85	93. (94.)	0.39	0.1094	9.1	74.	24.	34.	-0.01	-0.06	14	260
12 NOV 83 -	1546	9.64	38. (48.)	0.25	0.0938	10.7	352.	34.	13.	-0.04	0.01	16	310
12 NOV 83 -	2346	7.75	37. (42.)	0.24	0.1094	9.1	3.	27.	7.	-0.04	-0.03	12	320
13 NOV 83 -	746	9.28	38. (47.)	0.25	0.1719	5.8	39.	27.	4.	-0.03	-0.06	13	320
13 NOV 83 -	1546	9.35	116. (115.)	0.43	0.1875	5.3	51.	20.	27.	0.01	0.05	08	030
13 NOV 83 -	2346	8.01	38. (42.)	0.25	0.2031	4.9	43.	32.	7.	-0.01	-0.04	00	000
14 NOV 83 -	746	9.79	208. (215.)	0.58	0.2500	4.0	360.	29.	55.	0.00	-0.04	08	080
14 NOV 83 -	1546	9.06	235. (249.)	0.61	0.2031	4.9	35.	22.	41.	-0.02	0.05	17	060
14 NOV 83 -	2346	8.25	188. (199.)	0.55	0.1719	5.8	37.	23.	45.	-0.01	-0.03	12	070

(Continued)

* $\bar{h}$ = mean water depth (m). $E_T(\langle\eta^2\rangle)$ = total energy variance in wave (cm^2)--this parameter proportional to amount of energy in the wave; comparative values calculated from pressure and velocity; velocity calculated values in parentheses. $H_{1/3}$ = significant wave height (m)--this parameter being derived from E_T, where $H_{1/3} \approx \sqrt{\langle\eta^2\rangle}$. Peak T = peak wave period = 1/peak wave frequency. α_o = direction of peak wave propagation, measured in degrees clockwise from true north. $P(\alpha_o)$ = angular spread of direction of propagation of the peak wave. E_P = energy variance in peak frequency (cm^2). $\bar{U}$, $\bar{V}$ = components of current velocity (m/sec) relative to probe orientation. C_s = current speed (m/sec) as calculated from $\bar{U}$, $\bar{V}$, U being positive to the north and V being positive to the east. C_D = direction toward which the current is flowing in degrees true north as calculated from $\bar{U}$, $\bar{V}$. S.D. = standard deviation of indicated quantity.

Table C3 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	W_s	W_D	
15 NOV 83 -	746	10.09	151. (154.)	0.49	0.2344	4.3	54.	29.	28.	-0.01	0.01	10	090	
15 NOV 83 -	1546	8.63	129. (136.)	0.45	0.1563	6.4	311.	20.	18.	-0.01	0.04	08	080	
15 NOV 83 -	2346	8.58	617. (613.)	0.99	0.2188	4.6	300.*	22.	151.	0.07	-0.06	17	120	
16 NOV 83 -	746	10.20	2534.(2503.)	2.01	0.1563	6.4	290.*	23.	509.	0.08	-0.13	20(28)	150	
16 NOV 83 -	1546	8.18	844. (849.)	1.16	0.1094	9.1	243.*	21.	342.	0.00	-0.03	14(20)	220	
16 NOV 83 -	2346	8.93	373. (386.)	0.77	0.0938	10.7	301.*	26.	130.	0.00	-0.07	08	240	
17 NOV 83 -	746	10.01	277. (297.)	0.67	0.0938	10.7	281.*	29.	85.	-0.01	0.01	08	250	
17 NOV 83 -	1546	7.66	135. (146.)	0.46	0.1094	9.1	260.*	27.	51.	-0.02	-0.02	10	270	
17 NOV 83 -	2346	9.18	79. (85.)	0.36	0.0938	10.7	49.	22.	34.	-0.02	-0.04	22(30)	280	
18 NOV 83 -	746	9.77	54. (58.)	0.30	0.0938	10.7	5.	29.	20.	0.00	-0.01	14(20)	300	
18 NOV 83 -	1546	7.45	44. (47.)	0.26	0.0781	12.8	343.	30.	16.	-0.02	0.00	08	290	
18 NOV 83 -	2346	9.45	28. (25.)	0.21	0.0938	10.7	9.	30.	12.	0.01	-0.07	10	300	
19 NOV 83 -	746	9.45	15. (18.)	0.15	0.0938	10.7	307.	33.	4.	-0.02	0.02	04	300	
19 NOV 83 -	1546	7.42	12. (13.)	0.14	0.0781	12.8	330.	35.	3.	0.00	-0.04	00	000	
19 NOV 83 -	2346	9.92	15. (17.)	0.16	0.0781	12.8	267.	49.	6.	-0.01	-0.03	00	000	
20 NOV 83 -	746	9.26	11. (14.)	0.13	0.0781	12.8	324.	30.	4.	-0.03	0.03	00	000	
20 NOV 83 -	1546	7.67	15. (18.)	0.16	0.0781	12.8	26.	27.	6.	0.03	-0.06	08	170	E
20 NOV 83 -	2346	10.24	106. (116.)	0.41	0.2500	4.0	172.	28.	46.	-0.01	-0.08	10	160	E
21 NOV 83 -	746	8.82	127. (137.)	0.45	0.2188	4.6	187.	27.	31.	0.00	-0.01	06	150	E
21 NOV 83 -	1546	8.09	34. (32.)	0.23	0.1250	8.0	286.	23.	8.	0.00	-0.09	12	290	
21 NOV 83 -	2346	10.15	57. (59.)	0.30	0.1406	7.1	61.	26.	12.	-0.03	-0.02	13	250	
22 NOV 83 -	746	8.27	28. (30.)	0.21	0.1406	7.1	24.	24.	7.	-0.02	0.02	12	260	
22 NOV 83 -	1546	8.61	26. (26.)	0.20	0.1094	9.1	6.	26.	7.	0.02	-0.08	13	310	
22 NOV 83 -	2346	10.17	24. (31.)	0.20	0.1406	7.1	40.	36.	5.	-0.04	0.04	00	000	
23 NOV 83 -	746	7.96	64. (70.)	0.32	0.2031	4.9	26.	26.	12.	-0.03	0.01	07	320	
23 NOV 83 -	1546	9.27	132. (143.)	0.46	0.1719	5.8	24.	28.	26.	-0.01	-0.08	08	040	
23 NOV 83 -	2346	9.79	75. (78.)	0.35	0.2344	4.3	37.	41.	10.	-0.03	0.07	00	000	
24 NOV 83 -	746	7.76	83. (90.)	0.36	0.1250	8.0	331.	24.	27.	0.00	-0.02	08	170	
24 NOV 83 -	1546	9.92	184. (184.)	0.54	0.2500	4.0	154.	23.	60.	0.03	-0.12	12	170	
24 NOV 83 -	2346	9.10	80. (88.)	0.36	0.2500	4.0	113.	29.	16.	-0.02	-0.02	18	210	

(Continued)

Table C3 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	W_s	W_D	
25 NOV 83	746	7.75	143. (131.)	0.48	0.2500	4.0	121.	31.	36.	0.02	-0.15	12	170	
25 NOV 83	1546	10.30	74. (83.)	0.34	0.2188	4.6	6.	30.	12.	-0.04	-0.06	26(40)	280	
25 NOV 83	2346	7.86	42. (48.)	0.26	0.0938	10.7	331.	31.	10.	-0.02	-0.02	18(28)	270	
26 NOV 83	746	7.87	16. (18.)	0.16	0.0781	12.8	305.	33.	5.	0.00	-0.06	18	260	
26 NOV 83	1546	9.99	16. (22.)	0.16	0.0781	12.8	341.	52.	6.	-0.03	-0.03	17(24)	270	
26 NOV 83	2346	7.67	8. (9.)	0.12	0.0781	12.8	340.	36.	3.	0.00	0.00	10	280	
27 NOV 83	746	8.52	9. (10.)	0.12	0.0781	12.8	38.	35.	2.	0.01	-0.07	10	290	
27 NOV 83	1546	10.04	11. (13.)	0.13	0.2344	4.3	28.	47.	3.	-0.03	0.00	08	300	
27 NOV 83	2346	7.69	17. (19.)	0.17	0.2188	4.6	25.	27.	3.	-0.03	0.01	06	320	
28 NOV 83	746	9.53	84. (83.)	0.37	0.2344	4.3	32.	31.	18.	0.02	-0.01	00	000	
28 NOV 83	1546	9.83	89. (85.)	0.38	0.1875	5.3	44.	27.	18.	0.03	0.02	04	110	
28 NOV 83	2346	7.52	269. (239.)	0.66	0.2344	4.3	285.*	33.	83.	0.04	-0.06	10(20)	150	
29 NOV 83	746	10.16	403. (351.)	0.80	0.2188	4.6	285.*	35.	101.	0.05	-0.10	05	160	
29 NOV 83	1546	8.93	121. (128.)	0.44	0.1250	8.0	308.	20.	37.	-0.04	0.00	10	270	
29 NOV 83	2346	7.67	54. (51.)	0.29	0.1250	8.0	344.	21.	18.	0.00	-0.05	10	270	
30 NOV 83	746	10.25	24. (25.)	0.20	0.1094	9.1	325.	36.	5.	-0.02	-0.04	08	250	
30 NOV 83	1546	7.88	11. (12.)	0.13	0.1094	9.1	299.	23.	3.	-0.02	0.00	16	240	
30 NOV 83	2346	8.31	9. (9.)	0.12	0.0938	10.7	29.	32.	2.	0.01	-0.06	12	280	
1 DEC 83	746	10.38	7. (8.)	0.10	0.0781	12.8	1.	48.	1.	0.00	-0.02	12	280	
1 DEC 83	1546	7.53	5. (6.)	0.09	0.1094	9.1	290.	32.	1.	-0.04	0.01	06	320	
1 DEC 83	2346	9.09	6. (7.)	0.10	0.0625	16.0	355.	42.	1.	0.01	-0.05	04	280	
2 DEC 83	746	10.30	8. (8.)	0.11	0.0625	16.0	351.	58.	1.	-0.01	0.06	06	290	
2 DEC 83	1546	7.16	6. (5.)	0.09	0.0781	12.8	2.	35.	2.	-0.01	-0.01	10	270	
2 DEC 83	2346	9.59	5. (6.)	0.09	0.0781	12.8	339.	55.	3.	-0.01	-0.02	06	260	
3 DEC 83	746	9.62	4. (4.)	0.08	0.0781	12.8	5.	54.	2.	0.00	0.00	09	280	
3 DEC 83	1546	7.19	9. (9.)	0.12	0.0781	12.8	346.	37.	1.	-0.02	-0.03	02	360	
3 DEC 83	2346	10.10	36. (34.)	0.24	0.2344	4.3	19.	27.	10.	0.00	-0.03	00	000	
4 DEC 83	746	9.22	138. (127.)	0.47	0.2500	4.0	260.*	41.	43.	-0.02	0.07	08	090	
4 DEC 83	1546	7.86	1191. (781.)	1.38	0.1875	5.3	265.*	38.	267.	0.04	-0.03	20(27)	090	E
4 DEC 83	2346	10.53	2640.(2098.)	2.06	0.1094	9.1	267.*	33.	456.	0.00	0.06	18(26)	040	E

(Continued)

Table C3 (Concluded)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	W_s	W_D	
5 DEC 83	746	8.83	1765.(1460.)	1.68	0.0938	10.7	258.*	25.	692.	0.00	0.05	12	040	
5 DEC 83	1546	8.26	1975.(1527.)	1.78	0.0938	10.7	259.*	31.	706.	-0.02	-0.02	10	340	
5 DEC 83	2346	10.31	894. (707.)	1.20	0.0938	10.7	276.*	31.	325.	0.01	-0.01	06	310	
6 DEC 83	746	8.22	393. (313.)	0.79	0.0938	10.7	279.*	26.	100.	0.01	0.03	00	000	
6 DEC 803	1546	8.76	483. (323.)	0.88	0.2500	4.0	269.*	46.	105.	-0.01	-0.14	10	140	E
6 DEC 83	2346	9.93	775. (569.)	1.11	0.1719	5.8	268.*	34.	125.	-0.04	-0.10	16(24)	210	E
7 DEC 83	746	7.54	64. (58.)	0.32	0.1094	9.1	275.*	29.	22.	-0.04	-0.03	36(46)	250	
7 DEC 83	1546	8.89	17. (17.)	0.16	0.0781	12.8	267.*	36.	5.	-0.04	-0.05	26(40)	260	
7 DEC 83	2346	9.00	259. (18.)	0.18	0.0781	12.8	259.*	41.	6.	-0.04	0.00	22(32)	270	
8 DEC 83	746	7.51	11. (10.)	0.13	0.0781	12.8	272.*	29.	4.	-0.01	-0.02	12(20)	280	
8 DEC 83	1546	9.47	12. (12.)	0.14	0.0781	12.8	247.*	41.	5.	0.00	-0.08	14	290	
8 DEC 83	2346	8.72	10. (11.)	0.13	0.0938	10.7	271.*	34.	3.	0.01	0.03	00	000	
9 DEC 83	746	7.79	7. (8.)	0.11	0.0938	10.7	259.*	28.	2.	-0.03	-0.04	00	000	
9 DEC 83	1546	9.97	7. (8.)	0.10	0.0781	12.8	235.*	48.	2.	-0.01	-0.02	06	240	
9 DEC 83	2346	8.60	7. (6.)	0.10	0.0781	12.8	269.*	41.	2.	-0.01	-0.01	00	000	
10 DEC 83	746	8.12	8. (8.)	0.11	0.0781	12.8	264.*	32.	2.	0.00	-0.04	04	240	
10 DEC 83	1546	10.02	12. (13.)	0.14	0.0938	10.7	249.*	51.	3.	-0.03	-0.04	07	240	
10 DEC 83	2346	8.24	11. (9.)	0.13	0.0938	10.7	263.*	30.	5.	-0.01	0.01	00	000	
11 DEC 83	746	8.69	419. (368.)	0.82	0.1406	7.1	254.*	26.	98.	0.03	0.04	10	040	
11 DEC 83	1546	10.03	345. (329.)	0.74	0.1563	6.4	250.*	22.	82.	0.01	0.02	10	070	
11 DEC 83	2346	8.00	154. (134.)	0.50	0.1719	5.8	257.*	26.	23.	0.02	0.03	09	090	
12 DEC 83	746	9.19	724. (467.)	1.08	0.2188	4.6	280.*	47.	211.	0.01	-0.03	12	130	E
12 DEC 83	1546	9.88	777. (519.)	1.11	0.2031	4.9	247.*	38.	143.	0.01	-0.06	19	120	E
12 DEC 83	2346	7.98	585. (392.)	0.97	0.1094	9.1	278.*	33.	166.	0.00	-0.06	14(20)	150	E
13 DEC 83	746	9.38	501. (352.)	0.90	0.1094	9.1	274.*	33.	155.	-0.03	-0.08	10	140	E
13 DEC 83	1546	9.23	201. (173.)	0.57	0.1250	8.0	32.	24.	46.	0.00	0.01	14	120	E
13 DEC 83	2346	7.92	126. (104.)	0.45	0.1250	8.0	35.	34.	24.	0.00	0.00	10	140	E
14 DEC 83	746	9.78	293. (234.)	0.68	0.0938	10.7	34.	32.	90.	-0.01	-0.01	10	190	
MEAN		8.92	258. 225.	0.47		8.64								
S.D.		0.95	484. 419.	0.43		3.29								

* - Corrected Directional Estimate

Table C4

Wave Climate, Green Harbor, MA, 23 Feb 1984 to 1 Jun 1984*

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	C_s	C_D
23 FEB 84	1655	9.95	4.(6.)	0.08	0.0781	12.8	277.	53.	2.	0.00	-0.02	0.02	114.
24 FEB 84	55	8.20	5.(6.)	0.09	0.0938	10.7	273.	32.	1.	0.05	0.03	0.06	227.
24 FEB 84	855	8.79	250.(267.)	0.63	0.1563	6.4	278.	26.	42.	0.07	0.02	0.07	211.
24 FEB 84	1655	9.75	597.(521.)	0.98	0.1406	7.1	263.	27.	182.	0.00	0.07	0.07	286.
25 FEB 84	55	7.77	369.(346.)	0.77	0.1406	7.1	267.	23.	69.	0.08	0.04	0.09	223.
25 FEB 84	855	9.28	209.(196.)	0.58	0.1250	8.0	258.	25.	39.	0.00	-0.01	0.01	101.
25 FEB 84	1655	9.04	106.(105.)	0.41	0.0938	10.7	276.	33.	21.	0.07	0.02	0.07	216.
26 FEB 84	55	7.74	36.(35.)	0.24	0.0938	10.7	277.	29.	8.	0.01	0.04	0.04	272.
26 FEB 84	855	9.79	45.(50.)	0.27	0.2344	4.3	222.	32.	7.	-0.05	0.05	0.07	333.
26 FEB 84	1655	8.36	80.(75.)	0.36	0.1563	6.4	246.	23.	20.	-0.01	0.07	0.07	301.
27 FEB 84	55	7.97	24.(24.)	0.19	0.1563	6.4	254.	28.	4.	-0.01	0.01	0.01	315.
27 FEB 84	855	10.13	36.(39.)	0.24	0.1875	5.3	232.	36.	7.	-0.01	-0.01	0.01	72.
27 FEB 84	1655	8.04	9.(10.)	0.12	0.0938	10.7	285.	22.	2.	0.02	0.02	0.03	235.

(Continued)

* $\bar{h}$ = mean water depth (m). $E_T(\langle\eta^2\rangle)$ = total energy variance in wave (cm^2)--this parameter proportional to amount of energy in the wave; comparative values calculated from pressure and velocity; velocity calculated values in parentheses. $H_{1/3}$ = significant wave height (m)--this parameter being derived from E_T, where $H_{1/3} \simeq \sqrt{\langle\eta^2\rangle}$. Peak T = peak wave period = 1/peak wave frequency. α_o = direction of peak wave propagation, measured in degrees clockwise from true north. $P(\alpha_o)$ = angular spread of direction of propagation of the peak wave. E_P = energy variance in peak frequency (cm^2). $\bar{U}$, $\bar{V}$ = components of current velocity (m/sec) relative to probe orientation. C_s = current speed (m/sec) as calculated from $\bar{U}$, $\bar{V}$, U being positive to the north and V being positive to the east. C_D = direction toward which the current is flowing in degrees true north as calculated from $\bar{U}$, $\bar{V}$. S.D. = standard deviation of indicated quantity.

Table C4 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	C_s	C_D
28 FEB 84	55	8.45	6.(7.)	0.10	0.0938	10.7	283.	30.	1.	-0.04	0.01	0.05	2.
28 FEB 84	855	10.30	707.(690.)	1.06	0.2031	4.9	273.	30.	151.	0.07	0.02	0.08	210.
28 FEB 84	1655	7.96	2220.(981.)	1.88	0.1563	6.4	299.	26.	421.	0.08	-0.04	0.08	173.
29 FEB 84	55	9.07	1703.(490.)	1.65	0.0938	10.7	280.	26.	692.	0.01	-0.01	0.01	144.
29 FEB 84	855	9.90	743.(656.)	1.09	0.0938	10.7	269.	37.	301.	0.01	0.04	0.04	272.
29 FEB 84	1655	7.37	253.(232.)	0.64	0.0938	10.7	284.	31.	101.	0.03	0.02	0.03	225.
1 MAR 84	55	9.16	80.(82.)	0.36	0.0938	10.7	280.	28.	39.	0.02	0.02	0.03	250.
1 MAR 84	855	9.50	43.(45.)	0.26	0.0938	10.7	274.	28.	11.	0.06	0.02	0.06	215.
1 MAR 84	1655	7.32	18.(19.)	0.17	0.0938	10.7	285.	32.	5.	0.02	0.04	0.04	263.
2 MAR 84	55	9.45	14.(13.)	0.15	0.0781	12.8	264.	36.	4.	0.00	0.01	0.01	265.
2 MAR 84	855	9.09	10.(13.)	0.12	0.0781	12.8	284.	37.	3.	0.06	0.07	0.09	250.
2 MAR 84	1655	7.38	6.(7.)	0.10	0.0781	12.8	293.	31.	2.	0.00	0.05	0.05	291.
3 MAR 84	55	9.70	8.(8.)	0.11	0.0938	10.7	271.	38.	2.	0.01	0.00	0.01	187.
3 MAR 84	855	8.84	7.(11.)	0.11	0.0781	12.8	284.	43.	3.	0.05	0.08	0.09	258.
3 MAR 84	1655	7.70	14.(12.)	0.15	0.0781	12.8	270.	36.	5.	-0.03	0.03	0.05	336.
4 MAR 84	55	10.00	17.(17.)	0.16	0.0781	12.8	261.	51.	6.	-0.01	0.03	0.03	317.
4 MAR 84	855	8.48	52.(56.)	0.29	0.2031	4.9	238.	27.	8.	0.04	0.05	0.07	248.
4 MAR 84	1655	8.02	44.(40.)	0.26	0.0781	12.8	280.	28.	20.	0.00	0.00	0.00	319.
5 MAR 84	55	10.17	51.(42.)	0.29	0.0781	12.8	287.	57.	19.	0.01	0.00	0.01	200.
5 MAR 84	855	8.11	63.(69.)	0.32	0.0781	12.8	287.	23.	36.	0.05	0.04	0.06	233.
5 MAR 84	1655	8.41	138.(126.)	0.47	0.2500	4.0	304.	28.	39.	-0.05	0.01	0.05	2.
6 MAR 84	55	10.09	126.(126.)	0.45	0.2188	4.6	302.	31.	32.	0.01	0.04	0.04	271.
6 MAR 84	855	7.75	81.(81.)	0.36	0.0781	12.8	288.	21.	20.	0.06	0.03	0.07	226.
6 MAR 84	1655	8.78	113.(95.)	0.43	0.0781	12.8	278.	22.	51.	-0.01	0.04	0.04	309.
7 MAR 84	55	9.88	82.(86.)	0.36	0.0781	12.8	259.	30.	32.	0.03	0.00	0.03	204.
7 MAR 84	855	7.54	81.(81.)	0.36	0.0938	10.7	288.	31.	25.	0.08	0.04	0.09	227.
7 MAR 84	1655	9.15	45.(45.)	0.27	0.0781	12.8	253.	34.	15.	0.05	0.09	0.11	359.
8 MAR 84	55	9.54	54.(56.)	0.29	0.0781	12.8	272.	34.	16.	0.03	0.04	0.05	346.
8 MAR 84	855	7.48	42.(43.)	0.26	0.0781	12.8	266.	23.	12.	0.08	0.01	0.08	300.
8 MAR 84	1655	9.42	37.(45.)	0.24	0.0781	12.8	269.	22.	5.	0.06	0.06	0.08	342.

(Continued)

Table C4 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	C_s	C_D
9 MAR 84 -	55	9.30	26.(26.)	0.21	0.0938	10.7	273.	36.	4.	0.04	0.00	0.04	290.
9 MAR 84 -	855	7.96	746.(705.)	1.09	0.1563	6.4	254.	24.	221.	0.05	-0.14	0.15	225.
9 MAR 84 -	1655	9.82	2716.(2469.)	2.08	0.1094	9.1	259.	32.	597.	0.02	-0.05	0.06	231.
10 MAR 84 -	55	9.14	1505.(1435.)	1.55	0.0938	10.7	269.	21.	481.	0.03	-0.05	0.06	242.
10 MAR 84 -	855	8.17	1143.(1062.)	1.35	0.0938	10.7	267.	28.	368.	0.08	0.03	0.09	314.
10 MAR 84 -	1655	9.72	806.(753.)	1.14	0.0938	10.7	266.	26.	280.	0.07	0.02	0.07	309.
11 MAR 84 -	55	8.41	477.(469.)	0.87	0.0938	10.7	275.	24.	193.	0.05	-0.03	0.05	266.
11 MAR 84 -	855	8.47	162.(136.)	0.51	0.0781	12.8	267.	27.	63.	0.04	0.13	0.14	8.
11 MAR 84 -	1655	9.48	31.(37.)	0.22	0.0781	12.8	257.	38.	8.	0.08	0.05	0.09	330.
12 MAR 84 -	55	7.79	9.(12.)	0.12	0.0938	10.7	277.	36.	2.	0.10	0.02	0.10	305.
12 MAR 84 -	855	9.21	8.(14.)	0.11	0.2500	4.0	211.	43.	2.	0.07	0.07	0.10	339.
12 MAR 84 -	1655	9.09	11.(15.)	0.13	0.0781	12.8	267.	33.	2.	0.08	-0.01	0.08	285.
13 MAR 84 -	55	7.72	12.(14.)	0.14	0.0938	10.7	276.	28.	2.	0.04	0.00	0.04	295.
13 MAR 84 -	855	9.84	20.(26.)	0.18	0.2500	4.0	222.	39.	4.	0.04	0.05	0.06	350.
13 MAR 84 -	1655	8.74	847.(864.)	1.16	0.2031	4.9	278.	26.	260.	0.02	0.01	0.02	319.
14 MAR 84 -	55	7.99	1096.(1108.)	1.32	0.1094	9.1	284.	20.	350.	0.00	0.10	0.10	25.
14 MAR 84 -	855	10.53	2250.(2156.)	1.90	0.0938	10.7	260.	27.	764.	0.04	0.12	0.13	9.
14 MAR 84 -	1655	8.26	917.(928.)	1.21	0.1094	9.1	282.	29.	238.	-0.01	-0.01	0.01	172.
15 MAR 84 -	55	8.25	717.(682.)	1.07	0.0938	10.7	282.	24.	190.	0.08	0.06	0.10	333.
15 MAR 84 -	855	10.62	1242.(1112.)	1.41	0.1250	8.0	252.	27.	233.	0.03	0.06	0.06	2.
15 MAR 84 -	1655	7.51	549.(534.)	0.94	0.0781	12.8	270.	23.	121.	0.03	-0.05	0.06	237.
16 MAR 84 -	55	8.90	552.(508.)	0.94	0.0781	12.8	271.	28.	168.	0.06	0.11	0.12	356.
16 MAR 84 -	855	10.38	670.(568.)	1.04	0.0781	12.8	277.	41.	123.	0.03	0.00	0.03	291.
16 MAR 84 -	1655	6.92	303.(295.)	0.70	0.0938	10.7	281.	22.	89.	0.04	-0.02	0.05	267.
17 MAR 84 -	55	9.65	461.(427.)	0.86	0.0938	10.7	265.	30.	150.	0.06	0.12	0.13	356.
17 MAR 84 -	855	9.81	595.(515.)	0.98	0.0938	10.7	271.	28.	154.	0.06	0.06	0.08	338.
17 MAR 84 -	1655	6.92	679.(670.)	1.04	0.1406	7.1	262.	32.	139.	0.03	-0.08	0.08	228.
18 MAR 84 -	55	10.47	3198.(2928.)	2.26	0.1094	9.1	249.	20.	961.	0.02	0.00	0.02	295.
18 MAR 84 -	855	9.12	2341.(2103.)	1.94	0.1094	9.1	256.	26.	737.	0.03	-0.07	0.08	226.
18 MAR 84 -	1655	7.53	1559.(1452.)	1.58	0.0938	10.7	274.	26.	479.	0.03	-0.06	0.07	230.

(Continued)

Table C4 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	C_s	C_D
19 MAR 84 -	55	10.92	2978.(2766.)	2.18	0.0938	10.7	250.	25.	647.	0.02	-0.02	0.03	260.
19 MAR 84 -	855	8.27	1592.(1531.)	1.60	0.0938	10.7	263.	32.	401.	0.05	-0.05	0.07	252.
19 MAR 84 -	1655	8.21	1487.(1366.)	1.54	0.0938	10.7	266.	41.	381.	0.04	0.01	0.04	314.
20 MAR 84 -	55	10.96	4105.(3931.)	2.56	0.0938	10.7	260.	26.	902.	0.07	-0.01	0.07	290.
20 MAR 84 -	855	7.61	1358.(1292.)	1.47	0.1094	9.1	267.	24.	356.	0.02	-0.07	0.07	218.
20 MAR 84 -	1655	8.95	778.(770.)	1.12	0.0938	10.7	276.	29.	236.	0.05	0.06	0.08	345.
21 MAR 84 -	55	10.53	865.(838.)	1.18	0.1094	9.1	260.	31.	155.	0.08	0.06	0.09	331.
21 MAR 84 -	855	7.13	607.(601.)	0.99	0.0938	10.7	280.	18.	158.	0.06	-0.03	0.07	272.
21 MAR 84 -	1655	9.40	431.(398.)	0.83	0.0938	10.7	261.	25.	167.	0.07	0.07	0.10	341.
22 MAR 84 -	55	9.82	710.(703.)	1.07	0.0938	10.7	259.	30.	114.	0.09	0.03	0.10	313.
22 MAR 84 -	855	7.08	224.(225.)	0.60	0.1094	9.1	283.	28.	61.	0.05	0.04	0.07	333.
22 MAR 84 -	1655	9.74	156.(133.)	0.50	0.0938	10.7	276.	37.	53.	0.06	0.17	0.18	5.
23 MAR 84 -	55	9.05	169.(166.)	0.52	0.1094	9.1	271.	30.	59.	0.05	0.01	0.05	306.
23 MAR 84 -	855	7.54	59.(59.)	0.31	0.1094	9.1	277.	28.	19.	0.04	0.09	0.10	1.
23 MAR 84 -	1655	9.84	65.(60.)	0.32	0.0938	10.7	274.	46.	18.	0.09	0.06	0.11	329.
24 MAR 84 -	55	8.40	25.(30.)	0.20	0.0938	10.7	276.	25.	9.	0.10	0.01	0.10	304.
24 MAR 84 -	855	8.25	18.(21.)	0.17	0.0781	12.8	271.	23.	5.	0.06	0.07	0.09	347.
24 MAR 84 -	1655	9.62	19.(20.)	0.17	0.0938	10.7	273.	40.	6.	0.02	0.07	0.08	13.
25 MAR 84 -	55	8.04	12.(13.)	0.14	0.0781	12.8	275.	36.	3.	0.05	-0.02	0.06	274.
25 MAR 84 -	855	8.96	9.(10.)	0.12	0.0938	10.7	284.	35.	3.	0.01	0.06	0.06	13.
25 MAR 84 -	1655	9.21	11.(13.)	0.13	0.2344	4.3	235.	31.	2.	0.03	0.00	0.03	298.
26 MAR 84 -	55	7.80	7.(10.)	0.11	0.0781	12.8	269.	33.	2.	0.06	0.07	0.09	343.
26 MAR 84 -	855	9.52	179.(170.)	0.54	0.1875	5.3	243.	26.	45.	0.04	0.02	0.04	319.
26 MAR 84 -	1655	8.78	53.(57.)	0.29	0.2188	4.6	233.	28.	22.	0.05	-0.02	0.05	270.
27 MAR 84 -	55	8.01	11.(15.)	0.13	0.2500	4.0	234.	35.	2.	0.06	0.07	0.09	346.
27 MAR 84 -	855	9.91	112.(127.)	0.42	0.1875	5.3	238.	25.	23.	0.05	0.08	0.09	354.
27 MAR 84 -	1655	8.32	42.(45.)	0.26	0.2031	4.9	238.	26.	9.	0.01	-0.03	0.03	228.
28 MAR 84 -	55	8.30	38.(42.)	0.25	0.1875	5.3	251.	26.	5.	0.04	0.08	0.09	357.
28 MAR 84 -	855	10.10	96.(90.)	0.39	0.1094	9.1	266.	35.	23.	0.02	0.09	0.10	10.
28 MAR 84 -	1655	7.92	76.(74.)	0.35	0.1094	9.1	270.	22.	17.	0.04	0.01	0.04	305.

(Continued)

Table C4 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	C_s	C_D
29 MAR 84 -	55	8.75	671.(645.)	1.04	0.2188	4.6	268.	30.	133.	0.02	0.05	0.06	1.
29 MAR 84 -	855	10.42	3400.(3174.)	2.33	0.1094	9.1	254.	27.	915.	0.02	-0.12	0.12	213.
29 MAR 84 -	1655	8.46	4493.(3543.)	2.68	0.0781	12.8	269.	25.	1061.	-0.36	-0.21	0.42	146.
30 MAR 84 -	55	9.62	5874.(4956.)	3.07	0.0781	12.8	275.	30.	1246.	-0.04	-0.23	0.23	196.
30 MAR 84 -	855	10.18	6968.(5893.)	3.34	0.0781	12.8	264.	22.	2202.	0.01	-0.16	0.16	207.
30 MAR 84 -	1655	7.89	3041.(2931.)	2.21	0.0781	12.8	277.	24.	997.	-0.02	-0.12	0.12	196.
31 MAR 84 -	55	9.65	3079.(2864.)	2.22	0.0781	12.8	273.	23.	1174.	0.05	0.04	0.07	333.
31 MAR 84 -	855	9.58	1832.(1734.)	1.71	0.0781	12.8	268.	21.	566.	0.05	-0.01	0.05	287.
31 MAR 84 -	1655	7.64	783.(769.)	1.12	0.0938	10.7	279.	24.	361.	0.05	-0.02	0.05	269.
1 APR 84 -	55	9.88	537.(489.)	0.93	0.0938	10.7	267.	34.	123.	0.07	0.11	0.13	352.
1 APR 84 -	855	9.19	512.(495.)	0.91	0.0938	10.7	281.	27.	160.	0.04	0.00	0.04	301.
1 APR 84 -	1655	7.63	282.(277.)	0.67	0.0938	10.7	265.	21.	95.	0.04	0.06	0.07	352.
2 APR 84 -	55	10.13	227.(225.)	0.60	0.0938	10.7	269.	42.	67.	0.06	0.08	0.10	351.
2 APR 84 -	855	8.71	182.(175.)	0.54	0.1094	9.1	273.	36.	57.	0.03	0.03	0.04	337.
2 APR 84 -	1655	7.82	80.(78.)	0.36	0.0938	10.7	273.	21.	25.	0.06	0.09	0.11	353.
3 APR 84 -	55	10.30	111.(92.)	0.42	0.1094	9.1	272.	46.	37.	0.05	0.10	0.11	358.
3 APR 84 -	855	8.33	69.(70.)	0.33	0.1250	8.0	273.	32.	19.	0.05	0.03	0.05	327.
3 APR 84 -	1655	8.13	26.(29.)	0.20	0.1094	9.1	275.	25.	7.	0.02	0.07	0.07	11.
4 APR 84 -	55	10.39	42.(46.)	0.26	0.0938	10.7	284.	58.	8.	0.07	0.05	0.09	332.
4 APR 84 -	855	7.96	19.(23.)	0.18	0.1094	9.1	278.	37.	6.	0.06	0.00	0.06	292.
4 APR 84 -	1655	8.54	19.(21.)	0.17	0.0938	10.7	261.	30.	5.	0.03	0.06	0.06	359.
5 APR 84 -	55	10.32	42.(42.)	0.26	0.2500	4.0	297.	32.	11.	0.05	-0.02	0.05	271.
5 APR 84 -	855	7.74	392.(391.)	0.79	0.1875	5.3	287.	24.	126.	0.03	0.02	0.04	328.
5 APR 84 -	1655	9.00	1141.(1076.)	1.35	0.1719	5.8	287.	28.	301.	-0.01	0.12	0.12	31.
6 APR 84 -	55	10.08	626.(598.)	1.00	0.1250	8.0	247.	36.	119.	0.03	0.06	0.07	356.
6 APR 84 -	855	7.47	198.(189.)	0.56	0.1094	9.1	262.	33.	35.	0.04	0.00	0.04	290.
6 APR 84 -	1655	9.24	250.(230.)	0.63	0.1094	9.1	271.	23.	61.	0.07	0.04	0.08	324.
7 APR 84 -	55	9.66	351.(314.)	0.75	0.0938	10.7	256.	31.	102.	0.04	0.03	0.05	329.
7 APR 84 -	855	7.51	211.(204.)	0.58	0.0938	10.7	267.	32.	80.	0.06	0.04	0.07	331.
7 APR 84 -	1655	9.59	422.(407.)	0.82	0.0781	12.8	272.	33.	174.	0.05	0.07	0.09	345.

(Continued)

Table C4 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	C_s	C_D
8 APR 84 -	55	9.20	399.(370.)	0.80	0.0781	12.8	275.	27.	138.	0.04	0.02	0.04	319.
8 APR 84 -	855	7.78	279.(263.)	0.67	0.0781	12.8	279.	23.	100.	0.06	0.02	0.06	310.
8 APR 84 -	1655	9.89	806.(751.)	1.14	0.1563	6.4	241.	28.	121.	0.04	0.01	0.04	314.
9 APR 84 -	55	8.89	983.(881.)	1.25	0.1406	7.1	251.	19.	217.	0.05	-0.03	0.06	263.
9 APR 84 -	855	8.51	793.(765.)	1.13	0.1094	9.1	263.	26.	217.	0.05	0.05	0.07	337.
9 APR 84 -	1655	9.97	1486.(1349.)	1.54	0.1094	9.1	259.	22.	409.	0.07	-0.01	0.07	291.
10 APR 84 -	55	8.42	700.(661.)	1.06	0.1250	8.0	265.	27.	172.	0.03	-0.02	0.03	259.
10 APR 84 -	855	9.13	1036.(962.)	1.29	0.0938	10.7	268.	33.	184.	0.03	0.00	0.03	296.
10 APR 84 -	1655	9.75	1136.(1010.)	1.35	0.1094	9.1	252.	27.	227.	0.05	-0.04	0.07	257.
11 APR 84 -	55	7.90	713.(664.)	1.07	0.1094	9.1	263.	31.	162.	0.02	-0.02	0.03	253.
11 APR 84 -	855	9.81	774.(711.)	1.11	0.1094	9.1	257.	27.	160.	0.00	0.03	0.03	21.
11 APR 84 -	1655	9.13	575.(549.)	0.96	0.1406	7.1	262.	36.	131.	0.04	-0.02	0.04	262.
12 APR 84 -	55	7.72	213.(220.)	0.58	0.0938	10.7	272.	33.	51.	0.04	0.01	0.04	314.
12 APR 84 -	855	10.41	757.(666.)	1.10	0.1250	8.0	261.	30.	189.	0.00	0.06	0.06	22.
12 APR 84 -	1655	8.48	933.(897.)	1.22	0.1250	8.0	276.	29.	257.	-0.01	0.01	0.01	66.
13 APR 84 -	55	8.06	555.(541.)	0.94	0.1094	9.1	261.	29.	170.	0.04	0.08	0.09	358.
13 APR 84 -	855	10.67	702.(642.)	1.06	0.1250	8.0	240.	26.	172.	0.00	0.07	0.07	28.
13 APR 84 -	1655	7.85	260.(244.)	0.65	0.1563	6.4	247.	50.	49.	0.03	-0.05	0.06	239.
14 APR 84 -	55	8.82	181.(181.)	0.54	0.1406	7.1	264.	19.	42.	0.02	0.07	0.08	12.
14 APR 84 -	855	10.59	289.(294.)	0.68	0.1250	8.0	271.	36.	60.	0.05	-0.01	0.05	286.
14 APR 84 -	1655	7.24	438.(446.)	0.84	0.0938	10.7	284.	31.	159.	0.03	-0.03	0.05	250.
15 APR 84 -	55	9.50	241.(236.)	0.62	0.0938	10.7	270.	29.	88.	0.01	0.07	0.07	21.
15 APR 84 -	855	9.96	410.(378.)	0.81	0.0938	10.7	272.	39.	98.	0.04	-0.03	0.05	264.
16 APR 84 -	55	10.24	401.(407.)	0.80	0.2188	4.6	237.	32.	49.	0.03	0.04	0.05	345.
16 APR 84 -	855	9.18	391.(367.)	0.79	0.1094	9.1	275.	31.	58.	0.05	0.01	0.05	307.
16 APR 84 -	1655	7.30	205.(198.)	0.57	0.1250	8.0	266.	25.	38.	0.04	0.02	0.05	316.
17 APR 84 -	55	10.68	252.(211.)	0.64	0.1250	8.0	256.	57.	49.	0.03	0.07	0.08	358.
17 APR 84 -	855	8.36	227.(219.)	0.60	0.1094	9.1	282.	36.	36.	0.02	0.02	0.03	343.
17 APR 84 -	1655	7.77	108.(101.)	0.42	0.1094	9.1	271.	31.	25.	0.03	0.10	0.11	9.

(Continued)

Table C4 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	C_s	C_D
18 APR 84 -	55	10.78	193.(188.)	0.56	0.1094	9.1	286.	48.	39.	0.04	0.07	0.08	351.
18 APR 84 -	855	7.65	201.(195.)	0.57	0.1250	8.0	275.	26.	67.	0.02	-0.03	0.03	241.
18 APR 84 -	1655	8.59	68.(63.)	0.33	0.1094	9.1	262.	29.	16.	0.04	0.11	0.12	3.
19 APR 84 -	55	10.72	159.(164.)	0.50	0.1094	9.1	261.	44.	33.	0.02	0.07	0.07	7.
19 APR 84 -	855	7.38	199.(193.)	0.56	0.1875	5.3	248.	21.	40.	0.03	-0.01	0.03	266.
19 APR 84 -	1655	9.24	489.(473.)	0.88	0.1094	9.1	272.	32.	120.	0.06	0.09	0.11	350.
20 APR 84 -	55	10.13	436.(439.)	0.84	0.1250	8.0	260.	23.	121.	0.06	0.03	0.07	320.
20 APR 84 -	855	7.16	156.(157.)	0.50	0.1250	8.0	274.	26.	51.	0.04	0.01	0.04	313.
20 APR 84 -	1655	9.56	91.(94.)	0.38	0.1094	9.1	285.	31.	17.	0.05	0.05	0.07	343.
21 APR 84 -	55	9.38	71.(70.)	0.34	0.1250	8.0	256.	31.	15.	0.03	0.00	0.03	297.
21 APR 84 -	855	7.50	25.(27.)	0.20	0.1094	9.1	280.	31.	14.	0.05	0.00	0.05	296.
21 APR 84 -	1655	9.82	127.(131.)	0.45	0.1875	5.3	223.	28.	21.	0.08	0.07	0.11	333.
22 APR 84 -	55	8.82	420.(383.)	0.82	0.1406	7.1	248.	26.	103.	0.11	0.05	0.12	318.
22 APR 84 -	855	8.28	541.(515.)	0.93	0.1406	7.1	252.	20.	165.	0.08	0.04	0.09	323.
22 APR 84 -	1655	9.84	641.(617.)	1.01	0.1094	9.1	247.	23.	149.	0.04	0.05	0.06	344.
23 APR 84 -	55	8.41	95.(96.)	0.39	0.1406	7.1	254.	34.	19.	0.06	0.03	0.06	320.
23 APR 84 -	855	8.67	41.(42.)	0.26	0.1094	9.1	274.	27.	9.	0.05	0.07	0.09	350.
23 APR 84 -	1655	9.52	46.(47.)	0.27	0.0938	10.7	267.	45.	11.	0.03	0.01	0.04	317.
24 APR 84 -	55	8.00	39.(38.)	0.25	0.1094	9.1	283.	28.	13.	0.02	0.01	0.02	335.
24 APR 84 -	855	9.33	268.(262.)	0.65	0.1875	5.3	253.	23.	46.	0.06	0.03	0.07	323.
24 APR 84 -	1655	9.31	241.(234.)	0.62	0.1563	6.4	263.	21.	55.	0.05	0.04	0.07	331.
25 APR 84 -	55	7.99	227.(220.)	0.60	0.1250	8.0	246.	29.	62.	0.04	-0.01	0.04	280.
25 APR 84 -	855	9.80	212.(186.)	0.58	0.1250	8.0	253.	40.	48.	0.03	0.07	0.07	2.
25 APR 84 -	1655	8.82	175.(160.)	0.53	0.1250	8.0	271.	24.	30.	0.03	0.03	0.04	343.
26 APR 84 -	55	8.10	200.(181.)	0.57	0.1719	5.8	241.	27.	33.	0.09	0.09	0.13	339.
26 APR 84 -	855	10.13	682.(596.)	1.04	0.1406	7.1	252.	27.	90.	0.06	0.04	0.07	325.
26 APR 84 -	1655	8.46	822.(758.)	1.15	0.1094	9.1	274.	22.	272.	0.01	-0.04	0.04	216.
27 APR 84 -	55	8.49	360.(321.)	0.76	0.0938	10.7	271.	26.	106.	0.07	0.08	0.10	341.
27 APR 84 -	855	10.20	244.(229.)	0.62	0.1250	8.0	260.	30.	45.	0.03	0.07	0.08	2.
27 APR 84 -	1655	8.20	265.(257.)	0.65	0.1094	9.1	273.	25.	50.	0.02	0.02	0.03	337.

(Continued)

Table C4 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	C_s	C_D
28 APR 84 -	55	8.87	139.(141.)	0.47	0.1094	9.1	261.	27.	34.	0.04	0.06	0.07	353.
28 APR 84 -	855	10.05	218.(211.)	0.59	0.1094	9.1	256.	30.	68.	0.04	0.04	0.05	341.
28 APR 84 -	1655	7.93	256.(259.)	0.64	0.1094	9.1	277.	25.	101.	0.03	-0.03	0.04	251.
29 APR 84 -	55	9.21	328.(304.)	0.72	0.0938	10.7	264.	20.	132.	0.07	0.11	0.13	354.
29 APR 84 -	855	9.74	450.(437.)	0.85	0.0938	10.7	271.	30.	173.	0.02	0.02	0.03	348.
29 APR 84 -	1655	7.61	315.(312.)	0.71	0.1094	9.1	267.	18.	100.	0.02	-0.01	0.02	268.
30 APR 84 -	55	9.54	192.(206.)	0.55	0.0938	10.7	270.	28.	62.	0.07	0.11	0.13	353.
30 APR 84 -	855	9.35	320.(295.)	0.72	0.0938	10.7	268.	24.	127.	0.05	0.01	0.05	311.
30 APR 84 -	1655	7.50	103.(100.)	0.41	0.1094	9.1	276.	25.	54.	0.05	-0.01	0.06	281.
1 MAY 84 -	55	9.81	118.(121.)	0.44	0.1094	9.1	268.	34.	37.	0.07	0.11	0.13	350.
1 MAY 84 -	855	8.87	83.(80.)	0.36	0.1094	9.1	279.	30.	22.	0.03	0.02	0.04	330.
1 MAY 84 -	1655	7.61	50.(51.)	0.28	0.1094	9.1	275.	22.	26.	0.06	0.02	0.06	318.
2 MAY 84 -	55	10.11	39.(38.)	0.25	0.1250	8.0	258.	43.	7.	0.00	0.03	0.03	22.
2 MAY 84 -	855	8.42	8.(10.)	0.11	0.1250	8.0	286.	34.	2.	0.08	0.03	0.08	316.
2 MAY 84 -	1655	7.83	6.(8.)	0.10	0.1094	9.1	280.	33.	2.	0.05	0.00	0.05	297.
3 MAY 84 -	55	10.34	7.(10.)	0.11	0.1250	8.0	262.	50.	1.	0.01	0.11	0.11	18.
3 MAY 84 -	855	8.01	9.(10.)	0.12	0.1250	8.0	263.	32.	2.	0.03	0.02	0.04	331.
3 MAY 84 -	1655	8.21	4.(6.)	0.08	0.1094	9.1	271.	41.	1.	0.05	0.10	0.11	0.
4 MAY 84 -	55	10.42	16.(18.)	0.16	0.2500	4.0	234.	40.	7.	0.01	0.08	0.08	15.
4 MAY 84 -	855	7.71	209.(209.)	0.58	0.2188	4.6	277.	28.	39.	0.07	0.00	0.07	293.
4 MAY 84 -	1655	8.66	96.(103.)	0.39	0.1406	7.1	257.	21.	30.	0.10	0.05	0.11	320.
5 MAY 84 -	55	10.36	248.(252.)	0.63	0.1719	5.8	252.	30.	38.	0.01	0.00	0.01	284.
5 MAY 84 -	855	7.36	56.(60.)	0.30	0.1406	7.1	258.	25.	14.	0.05	-0.03	0.06	266.
5 MAY 84 -	1655	9.13	46.(47.)	0.27	0.0938	10.7	262.	28.	8.	0.05	0.01	0.05	309.
6 MAY 84 -	55	9.91	34.(34.)	0.23	0.0938	10.7	260.	41.	9.	0.01	0.04	0.04	17.
6 MAY 84 -	855	7.23	8.(11.)	0.12	0.0938	10.7	267.	39.	1.	0.05	0.00	0.05	294.
6 MAY 84 -	1655	9.55	8.(12.)	0.12	0.0938	10.7	279.	38.	3.	0.03	0.04	0.05	344.
7 MAY 84 -	55	9.41	6.(9.)	0.10	0.1094	9.1	292.	49.	1.	0.04	0.00	0.04	300.
7 MAY 84 -	855	7.62	4.(6.)	0.08	0.1250	8.0	263.	40.	1.	0.04	0.06	0.07	349.
7 MAY 84 -	1655	9.90	7.(8.)	0.10	0.0625	16.0	293.	55.	2.	0.03	0.04	0.05	344.

(Continued)

Table C4 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	C_s	C_D
8 MAY 84 -	55	8.79	5.(8.)	0.09	0.0625	16.0	253.	37.	2.	0.04	0.02	0.04	320.
8 MAY 84 -	855	8.09	5.(6.)	0.09	0.0625	16.0	260.	38.	2.	0.00	0.05	0.05	29.
8 MAY 84 -	1655	10.02	229.(226.)	0.61	0.2031	4.9	304.	28.	56.	0.02	0.07	0.08	11.
9 MAY 84 -	55	8.20	28.(29.)	0.21	0.2031	4.9	271.	39.	4.	0.04	-0.01	0.04	286.
9 MAY 84 -	855	8.79	22.(28.)	0.19	0.1250	8.0	277.	33.	4.	0.05	0.08	0.09	354.
9 MAY 84 -	1655	9.79	41.(41.)	0.26	0.1406	7.1	240.	41.	5.	0.01	-0.01	0.02	247.
10 MAY 84 -	55	7.60	32.(32.)	0.23	0.1094	9.1	272.	23.	10.	0.05	-0.02	0.05	275.
10 MAY 84 -	855	9.45	24.(24.)	0.19	0.1094	9.1	277.	38.	8.	0.02	0.04	0.05	0.
10 MAY 84 -	1655	9.25	28.(30.)	0.21	0.1250	8.0	263.	32.	5.	0.03	0.04	0.05	348.
11 MAY 84 -	55	7.44	11.(12.)	0.13	0.1406	7.1	264.	29.	3.	0.00	0.02	0.02	22.
11 MAY 84 -	855	10.00	14.(16.)	0.15	0.0781	12.8	282.	60.	2.	-0.02	0.10	0.10	34.
11 MAY 84 -	1655	8.60	11.(15.)	0.14	0.2500	4.0	309.	37.	2.	0.05	0.07	0.09	350.
12 MAY 84 -	55	7.79	6.(7.)	0.10	0.0781	12.8	263.	29.	2.	0.04	0.09	0.10	3.
12 MAY 84 -	855	10.37	26.(36.)	0.20	0.2500	4.0	307.	59.	10.	0.05	0.08	0.09	353.
12 MAY 84 -	1655	8.01	13.(15.)	0.15	0.2500	4.0	305.	40.	4.	0.04	0.04	0.06	341.
13 MAY 84 -	55	8.43	8.(8.)	0.11	0.0781	12.8	260.	36.	2.	0.05	0.10	0.12	0.
13 MAY 84 -	855	10.30	12.(17.)	0.14	0.1719	5.8	272.	41.	2.	0.05	0.06	0.08	346.
13 MAY 84 -	1655	7.47	13.(13.)	0.14	0.1094	9.1	274.	35.	2.	0.00	-0.04	0.04	206.
14 MAY 84 -	55	9.16	11.(12.)	0.13	0.1250	8.0	269.	42.	2.	0.01	0.11	0.11	22.
14 MAY 84 -	855	9.84	17.(20.)	0.17	0.2500	4.0	258.	46.	2.	0.04	-0.06	0.07	238.
14 MAY 84 -	1655	7.12	13.(15.)	0.14	0.1250	8.0	274.	36.	1.	0.08	0.00	0.08	295.
15 MAY 84 -	55	9.83	24.(26.)	0.19	0.2031	4.9	254.	44.	4.	0.03	0.12	0.12	11.
15 MAY 84 -	855	9.08	26.(26.)	0.21	0.1719	5.8	261.	33.	3.	0.03	0.01	0.04	319.
15 MAY 84 -	1655	7.20	24.(26.)	0.20	0.1094	9.1	277.	20.	9.	0.04	0.03	0.05	329.
16 MAY 84 -	55	10.34	40.(45.)	0.25	0.0938	10.7	272.	47.	13.	0.05	0.08	0.09	354.
16 MAY 84 -	855	8.45	68.(64.)	0.33	0.0938	10.7	267.	28.	22.	0.03	0.06	0.07	2.
16 MAY 84 -	1655	7.64	69.(66.)	0.33	0.0938	10.7	279.	19.	41.	0.02	0.05	0.06	2.
17 MAY 84 -	55	10.64	42.(40.)	0.26	0.0938	10.7	276.	57.	13.	0.04	0.11	0.12	6.
17 MAY 84 -	855	7.91	75.(74.)	0.35	0.1094	9.1	284.	28.	21.	0.02	0.05	0.05	359.
17 MAY 84 -	1655	8.33	36.(39.)	0.24	0.1094	9.1	270.	26.	9.	-0.02	0.06	0.06	45.

(Continued)

Table C4 (Continued)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	C_s	C_D
18 MAY 84 -	55	10.63	45.(49.)	0.27	0.1250	8.0	282.	39.	9.	0.03	0.01	0.03	317.
18 MAY 84 -	855	7.59	79.(76.)	0.36	0.1094	9.1	275.	25.	18.	0.04	0.00	0.04	301.
18 MAY 84 -	1655	8.98	226.(237.)	0.60	0.0938	10.7	270.	26.	41.	0.01	0.04	0.04	5.
19 MAY 84 -	55	10.20	712.(637.)	1.07	0.0938	10.7	268.	32.	281.	0.03	0.01	0.03	308.
19 MAY 84 -	855	7.23	315.(311.)	0.71	0.1094	9.1	281.	27.	102.	0.04	-0.01	0.04	281.
19 MAY 84 -	1655	9.31	99.(99.)	0.40	0.1094	9.1	276.	26.	21.	0.02	0.04	0.04	357.
20 MAY 84 -	55	9.61	97.(102.)	0.39	0.0938	10.7	269.	32.	30.	0.04	0.03	0.04	330.
20 MAY 84 -	855	7.39	66.(62.)	0.32	0.0938	10.7	278.	24.	29.	0.03	-0.01	0.03	276.
20 MAY 84 -	1655	9.66	71.(75.)	0.34	0.0938	10.7	278.	31.	33.	0.03	0.02	0.04	332.
21 MAY 84 -	55	9.06	60.(56.)	0.31	0.0938	10.7	265.	26.	22.	0.01	0.00	0.01	315.
21 MAY 84 -	855	7.80	61.(60.)	0.31	0.0938	10.7	273.	25.	22.	0.01	0.04	0.04	9.
21 MAY 84 -	1655	9.83	86.(79.)	0.37	0.0938	10.7	260.	37.	37.	0.01	0.04	0.04	3.
22 MAY 84 -	55	8.60	93.(95.)	0.39	0.0938	10.7	272.	27.	45.	0.04	0.02	0.04	318.
22 MAY 84 -	855	8.35	44.(45.)	0.27	0.1094	9.1	277.	25.	15.	0.07	0.06	0.09	336.
22 MAY 84 -	1655	9.76	34.(40.)	0.23	0.0938	10.7	272.	50.	11.	-0.01	0.03	0.04	43.
23 MAY 84 -	55	8.16	38.(40.)	0.25	0.1094	9.1	275.	23.	14.	0.06	0.02	0.06	312.
23 MAY 84 -	855	8.79	24.(25.)	0.20	0.1094	9.1	277.	21.	10.	0.04	0.07	0.08	358.
23 MAY 84 -	1655	9.42	21.(18.)	0.19	0.1094	9.1	271.	42.	5.	0.04	0.15	0.16	10.
24 MAY 84 -	55	7.84	10.(13.)	0.13	0.1250	8.0	270.	30.	3.	0.07	0.04	0.08	323.
24 MAY 84 -	855	9.22	7.(8.)	0.11	0.0938	10.7	277.	36.	1.	0.02	0.03	0.04	355.
24 MAY 84 -	1655	9.15	7.(7.)	0.11	0.1094	9.1	274.	35.	2.	-0.04	0.00	0.04	121.
25 MAY 84 -	55	7.85	6.(6.)	0.09	0.1094	9.1	275.	32.	1.	-0.01	0.00	0.01	130.
25 MAY 84 -	855	9.62	8.(11.)	0.11	0.1250	8.0	290.	61.	1.	0.05	0.09	0.11	355.
25 MAY 84 -	1655	8.75	8.(11.)	0.11	0.1250	8.0	269.	31.	2.	0.06	0.11	0.13	356.
26 MAY 84 -	55	7.91	4.(16.)	0.08	0.1094	9.1	307.	58.	1.	0.02	0.09	0.10	15.
26 MAY 84 -	855	9.81	6.(9.)	0.10	0.0781	12.8	276.	69.	1.	0.05	0.06	0.08	347.
26 MAY 84 -	1655	8.39	3.(5.)	0.07	0.1094	9.1	281.	39.	0.	0.05	0.06	0.08	345.
27 MAY 84 -	55	8.26	3.(5.)	0.07	0.0781	12.8	257.	49.	1.	0.06	0.11	0.12	357.
27 MAY 84 -	855	9.89	6.(9.)	0.10	0.0625	16.0	298.	54.	1.	-0.02	0.05	0.05	46.
27 MAY 84 -	1655	8.19	6.(7.)	0.10	0.1250	8.0	269.	36.	1.	-0.01	-0.02	0.02	163.

(Continued)

Table C4 (Concluded)

DATE	TIME	$\bar{h}$ (m)	E_T (cm^2)	$H_{1/3}$ (m)	Peak F (sec^{-1})	Peak T (sec)	α_o	$P(\alpha_o)$	E_P (cm^2)	$\bar{U}$ (m/sec)	$\bar{V}$ (m/sec)	C_s	C_D
28 MAY 84 -	55	8.75	7.(6.)	0.10	0.0625	16.0	270.	47.	2.	0.05	0.11	0.13	1.
28 MAY 84 -	855	9.82	10.(12.)	0.12	0.1094	9.1	290.	60.	1.	0.01	-0.02	0.03	234.
28 MAY 84 -	1655	7.94	9.(8.)	0.12	0.0781	12.8	266.	45.	1.	0.00	-0.04	0.04	208.
29 MAY 84 -	55	9.20	135.(130.)	0.46	0.2500	4.0	279.	36.	53.	0.02	0.03	0.04	350.
29 MAY 84 -	855	9.53	229.(235.)	0.61	0.2188	4.6	286.	21.	65.	0.05	-0.04	0.06	256.
29 MAY 84 -	1655	7.66	53.(57.)	0.29	0.1563	6.4	266.	18.	17.	0.05	0.04	0.06	334.
30 MAY 84 -	55	9.59	68.(71.)	0.33	0.1875	5.3	252.	20.	15.	0.06	0.12	0.14	360.
30 MAY 84 -	855	9.18	95.(86.)	0.39	0.1406	7.1	249.	26.	14.	0.02	-0.03	0.04	243.
30 MAY 84 -	1655	7.56	26.(29.)	0.20	0.1563	6.4	249.	40.	4.	0.02	0.04	0.05	356.
31 MAY 84 -	55	9.94	24.(25.)	0.20	0.2500	4.0	295.	52.	6.	0.01	0.06	0.06	20.
31 MAY 84 -	855	8.70	39.(40.)	0.25	0.2500	4.0	302.	29.	12.	0.02	0.03	0.04	354.
31 MAY 84 -	1655	7.69	20.(19.)	0.18	0.1406	7.1	262.	26.	3.	0.01	0.01	0.02	340.
1 JUN 84 -	40	10.36	19.(29.)	0.18	0.0938	10.7	288.	57.	2.	0.03	0.09	0.09	8.
Mean		8.92	398.(368.)	0.59		9.2	269.		109.	0.03	0.03		
SD		0.85	816.(729.)	0.55		2.6	15.		229.	0.04	0.05		