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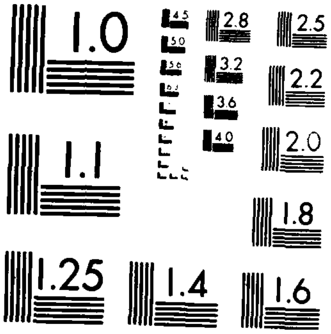

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GUIDELINES FOR PREDICTING MAXIMUM NEARSHORE SAND LEVEL CHANGES ON UNOBSTRUCTED BEACHES

by

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Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
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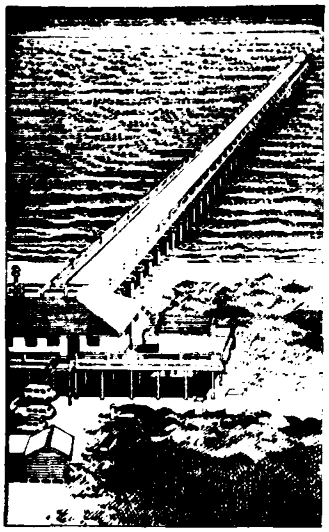

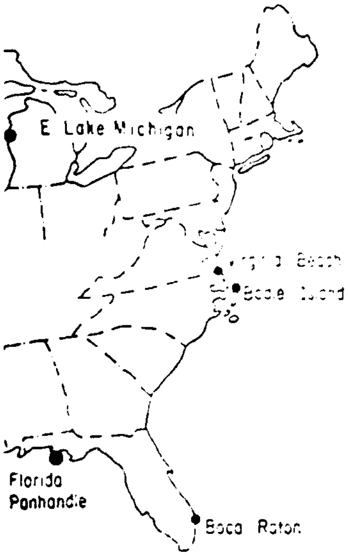

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the results of an office study of the magnitude of short-term (less than two years) beach profile changes at several locations along the U. S. East Coast, Gulf Coast, West Coast, and Lake Michigan Coast. Typical maximum sand-level change values ranged from 4 to 8 feet. A maximum short-term sand-level change was slightly less than 15 feet. A brief field experiment at a pile-supported pier documented scour that was approximately 10 feet below the original sea bed.

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PREFACE

The work described in this report was conducted during 1979 by the U. S. Army Corps of Engineers Coastal Engineering Research Center (CERC) for the Naval Civil Engineering Laboratory (CEL), Port Hueneme, California. On 1 July 1983, CERC became part of the U. S. Army Engineer Waterways Experiment Station (WES).

Mr. Allan E. DeWall, Geologist, Engineer Topographic Laboratories, formerly of the Coastal Processes Branch, Research Division, CERC, conducted the investigation and prepared this report with the assistance of Ms. Julie A. Christenson, Civil Engineering Technician. Work was conducted under the general direction of Mr. Curtis Mason, former Chief, Coastal Processes Branch, Mr. Rudolph P. Savage, former Chief, Research Division, and Dr. Robert Whalin, Chief, CERC. The CEL project monitor was Mr. J. Michael Atturio.

The authors gratefully acknowledge the enthusiastic support provided by the staff of the CERC Field Research Facility and the diving assistance from Messrs. Michael Leffler and Michael Dickey.

Commander and Director of WES during the publication of this report was COL Tilford C. Creel, CE. Mr. F. R. Brown was Technical Director.

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TABLES (Continued)

FIGURES

CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

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

Multiply	By	To Obtain
feet	0.3048	meters
feet per second	0.3048	meters per second
inches	25.4	millimeters
miles (U. S. statute)	1.609344	kilometers
miles per hour	1.609344	kilometers per hour

GUIDELINES FOR PREDICTING MAXIMUM NEARSHORE SAND LEVEL CHANGES ON UNOBSTRUCTED BEACHES

by

Allan E. DeWall and Julie A. Christenson

I. INTRODUCTION

A. General. The constant motion of sediments in the nearshore zone due to waves and currents is a prime consideration in the design of coastal projects. The designer of a navigable inlet and harbor complex is concerned with accretion rates that may result in unacceptable shoaling of channels, while erosion may result in the scour and ultimate undermining of protective structures such as jetties and seawalls. Aside from the problem of channel shoaling, erosion of protective beaches and scour at the base of structures are among the most difficult problems facing the coastal engineer.

In its "National Shoreline Study," the Army Corps of Engineers (1971) concluded that 24% of the ocean and Great Lakes shorelines of the United States, Puerto Rico, and the Virgin Islands is undergoing significant erosion. The North Atlantic region--north from the Virginia-North Carolina border--was identified as having the largest percentage, which was 87%. Even on sandy shorelines classified as "noneroding" there is a seasonal, or at least alternating change between erosion and accretion. This change, which is reflected in the shoreline movement, affects the beach topography from the frontal dune to some limiting water depth where sediment movement, due to wave action, is insignificant for engineering purposes.

B. Purpose. The purpose of this report is to summarize a "quick look" at available beach profile data that document significant short-term elevation changes in the beach and nearshore region. This survey was conducted by the U.S. Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC) at the request of the U.S. Naval Civil Engineering Laboratory (CEL). CEL required guidelines for predicting nearshore profile changes on unobstructed beaches as well as probable scour and fill characteristics at a pile-supported pier.

The criteria used for "significant short-term elevation changes" were changes of one foot* or more at a given location occurring within a two-year period. Only sites within the U.S. were considered, although data from foreign sites are available--notably Australia, China, Great Britain, Holland, and Japan.

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* A table of factors for converting inch-pound units of measurement to metric (SI) units is presented on p. iv.

This report analyzes the magnitude of the envelope or sweep zone of these short-term beach profile changes at several locations along the U.S. East Coast, Gulf Coast, West Coast, and Great Lakes Coast. Specifically, the analysis is focused on the magnitude and location of the maximum elevation change within the envelope of short-term profile change. An attempt is made to relate this maximum change to site-specific parameters such as exposure and coastal processes.

C. Previous Work. Shepard (1950) documented the seasonal on-offshore exchange of sand between the subaerial beach and nearshore zone on several southern California beaches. Storm waves common in the winter season tend to remove sand from the upper beach and deposit it in nearshore bars, while the flatter swell of the summer season tends to reverse this process (Figure 1).

In a five-year study of beach profile changes on Cape Cod, Zeigler and Tuttle (1961) found that the envelope of change was greatest on the most exposed beaches and at mid- and low-water levels.

Thompson and Hartlett (1968) found that on Del Monte Beach, California, beach erosion was positively correlated with wave height and steepness.

Gorsline (1966) found that in the low- to medium-energy environment of the west coast of Florida, maximum annual sand level changes do not appear to relate to wave height but rather to exposure. Wave heights below one foot did correlate with the rate of sand level change, however.

In a study of beach changes at eight East Coast beaches resulting from a moderate northeaster, DeWall, et al. (1977) found that maximum vertical changes in sand level occurred on coarser, steeper beaches. This has been observed by a number of other investigators (e.g. Shepard, 1950; King, 1972). The steep gradient of coarse beaches causes waves to break closer inshore with their energy being dissipated over a narrow beach zone. On the steeper beaches, the backwash also has greater power (King, 1972).

The CERC Shore Protection Manual (1977) has recommended that the deepest shore-parallel contour be used as an estimator of the seaward limit of significant profile change for a given locality. This depth varies from 15 feet to perhaps 60 feet or more along U.S. coasts.

Hallermeier (1977) determined that the seaward depth limit for significant depth change can be estimated by doubling the annual extreme wave height-high wave conditions that can be expected 12 hours per year on exposed coasts. Hallermeier (1978) found quite good agreement between measured and calculated close-out depths at three sites with very different extreme wave conditions (Table 1).

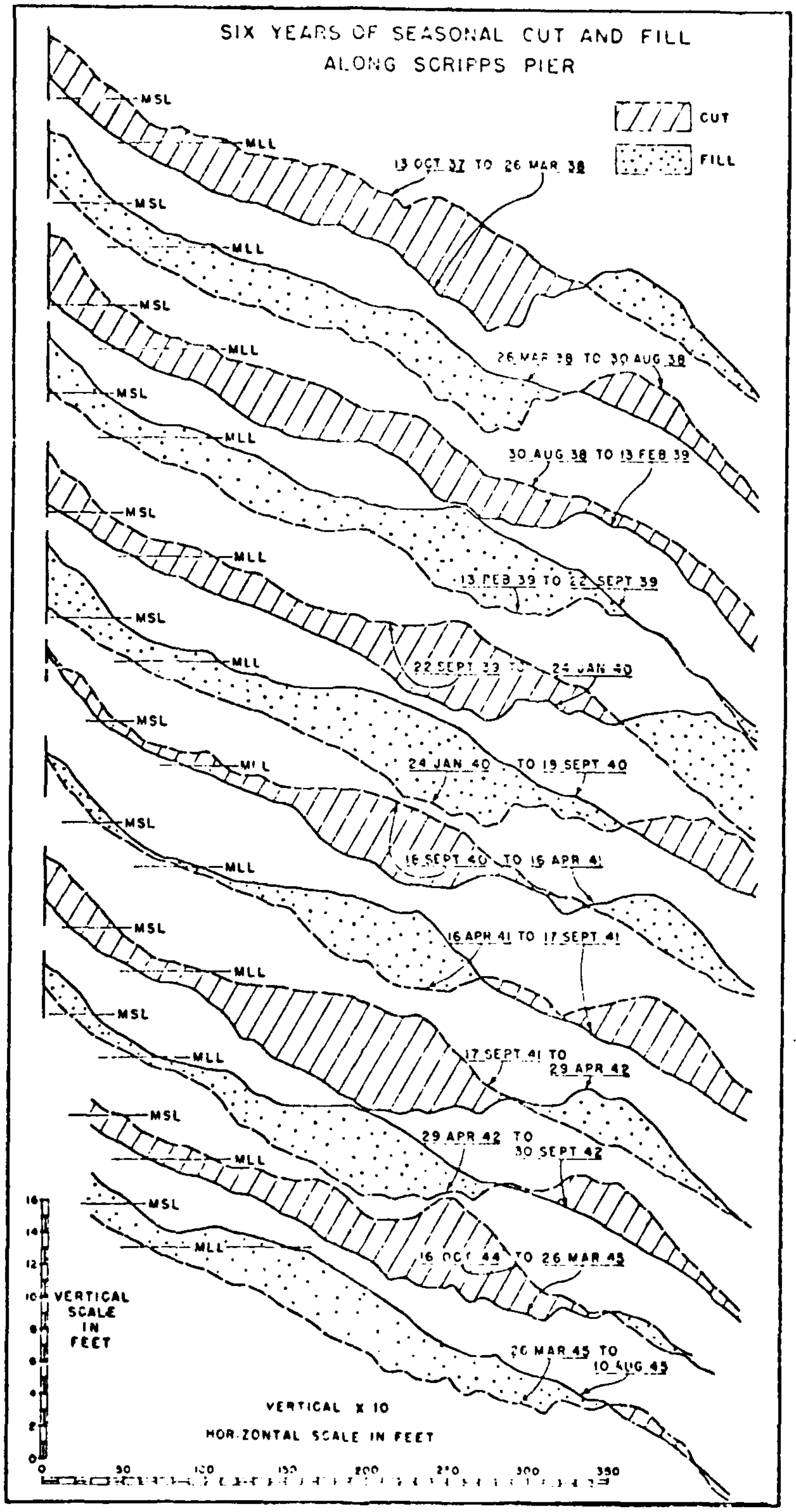

Figure 1. Seasonal Nearshore Profile Changes at Scripps Pier (from Shepard, 1950)

Table 1. Comparison of Estimated and Measured Profile Close-out Depths**

Locality Reference	Description of Data Set Profiles	Description of Data Set Waves	Design Wave H_e, Ft	Design Wave T_e, Sec	Predicted Close-out Depth, Ft	Measured Close-out Depth*, Ft	Profile Line Name
Gold Coast, Australia, S. Pacific Ocean; Delft Hydr. Lab., 1970 (D = 0.2 mm)	5 leadline surveys Jun 66-Dec 68	4/day records from deep-water wave-riders (1 year)	14.5	8	26.1	28.5	Letitia
						(>25.5)	Greenmount
						25.5	Tugun
						29.5	Palm
						34.5	Broadbeach
						30.5	The Spit
Avondale, Fla., U.S., Gulf of Mexico; Balsillie, 1975; Poche, 1972 (D = 0.3 mm)	8 leadline surveys, Jan-Aug 70	97% daily breaker observations (1 year)	7.9	5.4	13.5	14.8	Pier
Torrey Pines, Cal., U.S., N. Pacific Ocean; Nordstrom & Inman, 1975; Pawka et al., 1976 (D = 0.12 mm)	24 fathometer surveys, Jun 72-Apr 74	64% daily breaker observations (2 years); 4/day pressure records (16 months)	11	14	23.8	22.8	North
						24.3	Indian
					24.8		South

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*Profiles superpose to within ±0.5 ft; depth is average of two yearly cycles, except for Balsillie (1975).

**These comparisons result from field studies reporting repetitive nearshore profiles and wave measurements. Water depths are with respect to local mean low(er) tide level, and sand sizes are near estimated limit depths (from Hallermeier, 1978).

While documenting the rate of scour around mines placed on the nearshore bottom at Mission Beach, California, Dill (1958) concluded that there was no indication that the profile elevation beyond the surf zone varies over two inches from year to year. Dill noted that scour around an obstruction placed on the sea floor was strongly dependent on sediment size with a fine sand bottom scouring more rapidly than a medium sand bottom under otherwise similar conditions. Dill found that scour at Mission Beach was reduced by dense organic mats formed on the bottom by worms and plants. In some areas these mats were observed to extend into the sediment for a depth of at least two feet and inhibited normal sediment slumping into scour holes.

II. PROCEDURE

A. Criteria. The principal criterion for site selection was the availability of repetitive beach profile surveys (at least biannually) extending to a depth of at least 10 feet. Although unobstructed sites were desired, several sites using soundings from piers were also used. One site--Imperial Beach, California--was rejected because of a large beach nourishment project that was conducted during the survey period.

The primary source of data was from published reports on file in the CERC library. Data sources were also identified through the University of Virginia Information System, a computerized inventory of coastal data which has been developed under contract to the Office of Naval Research (Dolan, et al., 1977). Additional data sources were from active CERC projects at Virginia Beach, Virginia, Bodie Island, North Carolina, and on the Eastern Shore of Lake Michigan.

B. Data. A total of 33 data sets (1,049 profiles), representing eight coastal localities, was used in the analysis (Figure 2 and Table 2).

Once suitable sites had been identified, data concerning coastal exposure, type, and wave climate were collected. National Ocean Survey (NOS) charts were used to determine coastal exposure, shoreline orientation, and general bathymetry. Reports accompanying the beach profile data often included data on winds, waves, tides, currents, and sediment size. When these data were not included, other sources, such as tide and current prediction tables and Littoral Environment Observations (LEO) were used (Berg, 1968). If wave data were not reported for a given site, nearby gage data were used when possible (Thompson, 1977). If gage data were unavailable, visual observation data were used.

Profiles were generally available as plots. When digital data were available, these were coded for computer plotting and analysis. Envelopes of maximum and minimum elevations were constructed by overlaying the plotted profiles, or they were computed and plotted using an automatic plotter. The example shown in Figure 3 is an envelope for

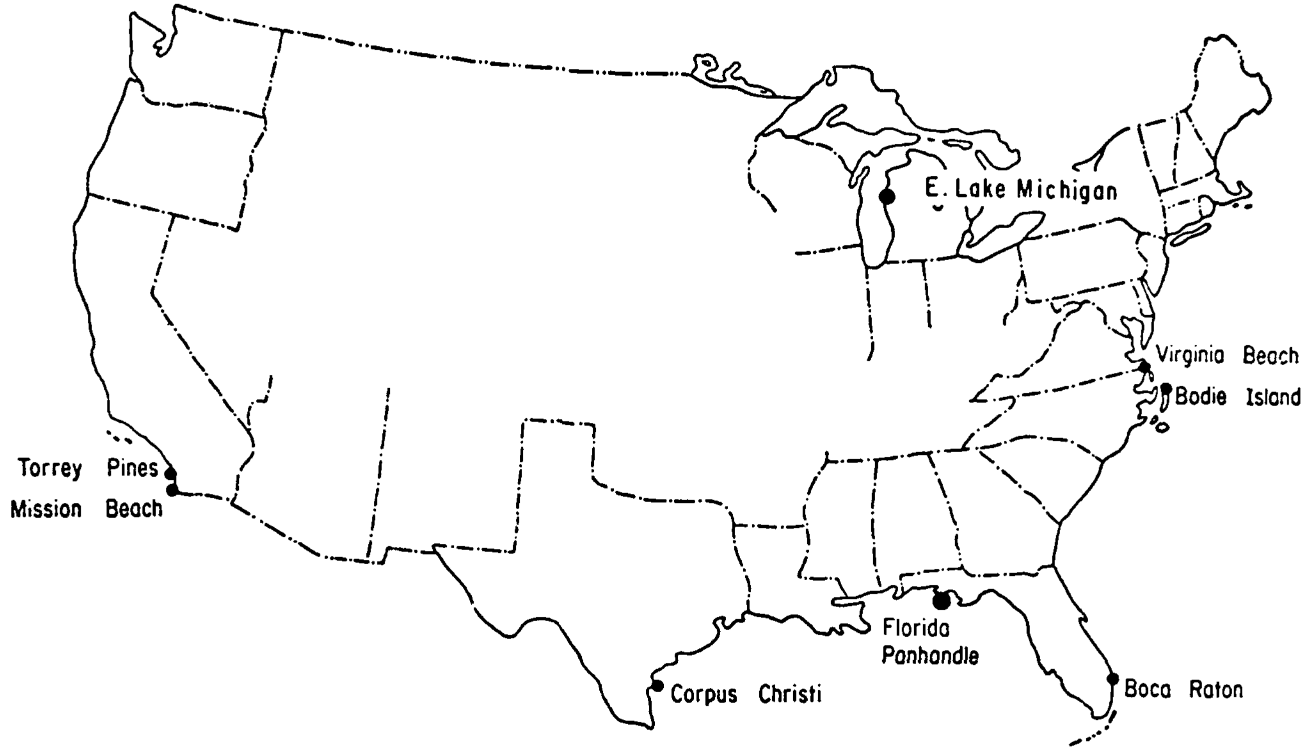

Figure 2. Site Locations for Beach Profile Surveys

Table 2. Profile Locations and Sources

Location	Source	Type
Virginia Beach, VA	Corps of Engineers (Unpublished)	Sea Sled and Pier Soundings
Bodie Island, NC	Everts and DeWall (In Preparation)	Pier Soundings
Boca Raton, FL	DeWall (1977)	Pipe Profiles
Florida Panhandle	Balsillie (1975)	Pier Soundings
Corpus Christi, TX	Behrens, et al. (1977)	Sea Sled
Mission Beach, CA	Bruun (1954)	Fathometer
Torrey Pines, CA	Nordstrom and Inman (1975)	Fathometer
	Shepard (1950)	Pier Soundings
Eastern Lake Michigan	Hands (1980)	Fathometer

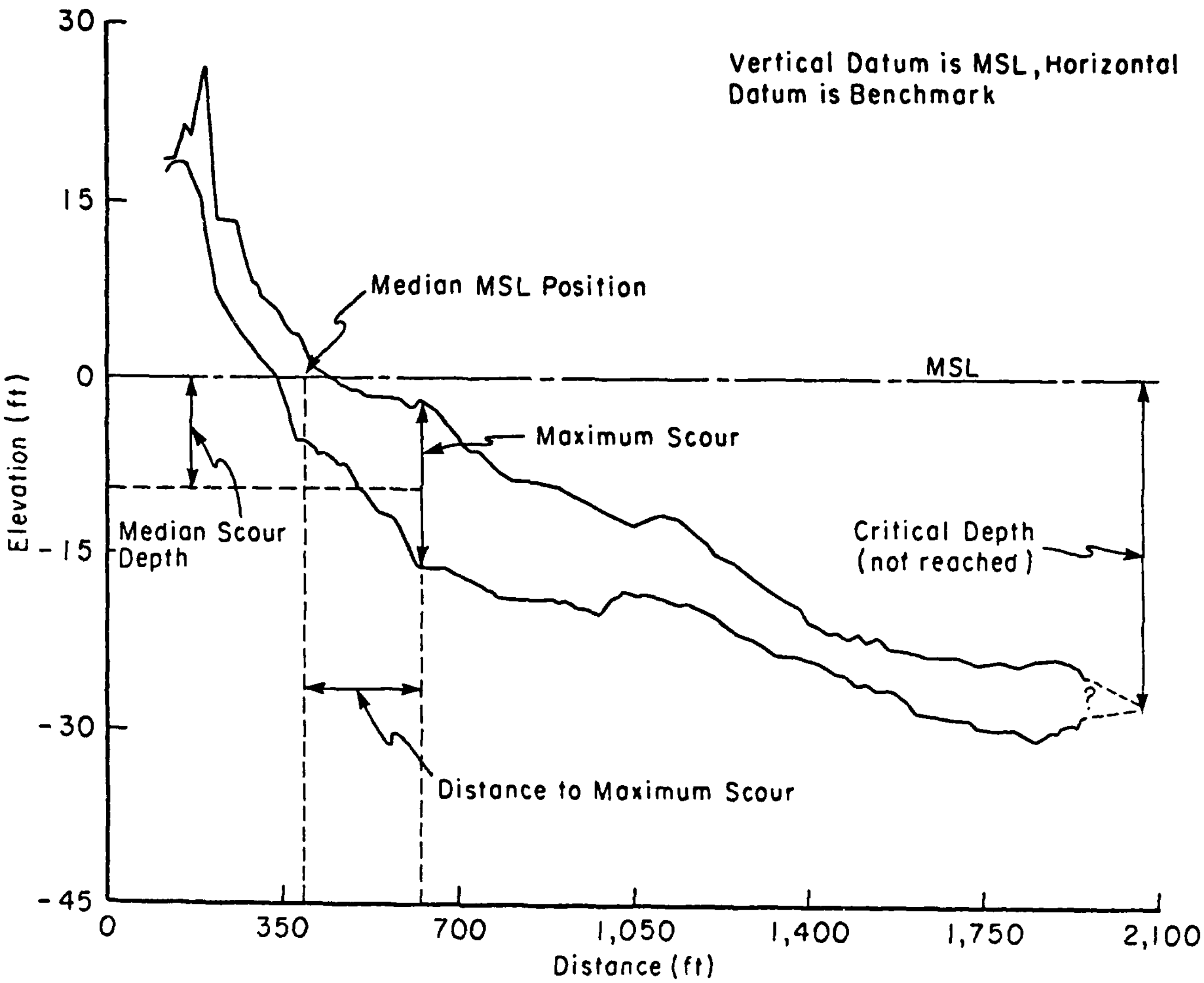

Figure 3. Envelope of 80 Weekly Profile Surveys from CERC Pier, July 1977 to January 1979

80 profiles collected weekly between July 1977 and January 1979 at the CERC Field Research Facility in Duck, North Carolina. These data illustrate the broad sweep zone characteristic of an exposed site. Note that the envelope is thickest at a distance of about 650 feet from the bench mark, which corresponds to a distance of about 400 feet from the median shoreline (zero elevation) position. At this point the bottom elevation ranged from -2.0 feet to -16.7 feet. Note also that the envelope does not close at its seaward end, where the MSL elevation fluctuated between -25.3 feet and -28.6 feet MSL.

C. Definitions. The variables collected and analyzed for each site are described in this section. Measurements taken from the profile envelopes are illustrated in Figure 3.

1. Shore-normal Azimuth. The azimuth, measured clockwise from north, of the line normal to the shoreline, extending seaward.

2. Exposure. The sum of all land-free arcs, extending from the site, open to a radius greater than or equal to 300 miles.

3. Grain Size. The mean grain size of the mid-swash zone.

4. Tide Range. Predicted range for maximum astronomic tide (i.e. spring or diurnal range).

5. Mean Wave Height. The average of the reported monthly significant wave heights.

6. Extreme Wave Height. The wave height that is exceeded for 12 hours per year (0.137%) and is obtained using the average significant wave height, H, and the standard deviation of height, σ, as follows: $H_e = \bar{H} + 5.6\,\sigma$ (Hallermeier, 1978).

7. Wave Period. The average of the reported monthly wave periods.

8. Longshore Current. The maximum reported longshore current velocity. A positive value was assigned to a value that was in the same direction as the net sediment transport direction; a negative value was assigned to an opposite direction.

9. Foreshore Slope. An average slope of the beach profile at the MSL elevation. This was obtained from LEO data or directly from the profiles if a value was not reported.

10. Nearshore Slope. The slope of a line drawn seaward from the base of the foreshore along the general trend of the offshore profile.

11. Berm. The maximum berm elevation from the available profiles and the (negative) distance from the MSL shoreline to the berm crest.

12. Bar. The maximum bar height above the landward trough and the (positive) distance from the MSL shoreline.

13. Median MSL Shoreline. The average mean sea level position within a given envelope from which further distance measurements are made (seaward = positive).

14. Maximum Scour. The largest change in elevation at any distance within the envelope.

15. Distance to Maximum Scour. The seaward distance from the median MSL shoreline.

16. Median Depth at Maximum Scour. Measured from the MSL elevation at the maximum scour distance.

17. Critical Depth. The shallowest depth, below MSL, where the change in elevation is one foot or less.

III. RESULTS

A. Exposure. A summary of site exposure and wave climate is presented in Table 3. Of the data considered, the most exposed sites were Bodie Island and Virginia Beach. The Gulf Coast sites in Florida and at Corpus Christi are exposed to generally moderate conditions but have a much higher incidence of hurricane conditions.

One tropical storm and one hurricane occurred during the study of the Florida Panhandle. Balsillie (1975) reports that the effects of these storms were less severe than an extratropical winter storm that also occurred, however. The exposure at the Mission Beach and Torrey Pines sites is somewhat limited by the Channel Islands. Boca Raton is sheltered from the open Atlantic by the Bahamas Banks. Additionally, this site is naturally stabilized by protective offshore reefs and an underlying coquina beach rock which effectively retards erosion (DeWall, 1977). The eastern Lake Michigan site has a maximum fetch of 131 miles, with a directly onshore fetch of 64 miles. The beach at this site is effectively protected from erosion during most of the winter months by ice conditions.

Significant wave height was found to range from 1.5 feet in Lake Michigan to 3.9 feet at Torrey Pines, while calculated extreme wave heights ranged from 7.0 feet at Mission Beach to 12.8 feet at Bodie Island (Nags Head).

Table 3. Site Exposure and Wave Climate

Site	Shore-Normal Azimuth	Exposure (degrees)	Grain Size (mm)	Tide Range (ft)	Mean Wave Ht. (ft)	Extreme Wave Ht. (ft)	Wave Period (sec)	Longshore Current (ft/sec)
Virginia Beach	76	131	0.32	4.1	2.2 (1)	8.9	8.4	+ 4.6
Bodie Island	65	131	0.48	3.8	3.1 (1)	12.8	8.9	+ 5.8
Boca Raton	94	83	0.70	3.3	2.0 (2)	9.9	4.8	+ 4.5
Florida Panhandle	190	109	0.38	1.2	1.8 (1)	8.1	5.8	+ 3.6
Corpus Christi	119	117	0.14	2.5	2.6 (2)	8.4	6.5	+ 3.2
Mission Beach	269	95	0.23	5.2	1.6 (2)	7.0 (3)	13.3	+ 3.3
Torrey Pines	266	74	0.20	5.2	3.9 (1)	11.0	12.0	+ 3.8
E. Lake Michigan	290	136 (4)	0.34	1.7 (5)	1.5 (2)	9.3	3.1	-0.95

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(1) Gage

(2) Visual Observation

(3) Maximum Observed 6-hr Occurrence

(4) 131-mile maximum fetch

(5) Lake level range, July 1967 to June 1971

B. Profiles. Table 4 summarizes the characteristics of the measured profiles and profile envelopes.

Because of the high variability in frequency of surveys these data are not directly comparable from site to site, but they do give an indication of the magnitude of changes that occurs in the nearshore region. Survey frequency ranged from weekly at Boca Raton and the CERC Pier to annually for the Virginia Beach sea sled surveys. Because seasonal sand level changes are much larger than year-to-year changes at most coastal locations, data listed for sites with fewer than four surveys per year are probably not true indicators of maximum change. This is illustrated by comparing the maximum scour measured by the annual sea sled surveys at Virginia Beach and the maximum scour measured by the bimonthly leadline soundings from two nearby fishing piers. The sea sled data indicate a maximum sand level change of 3.9 feet from year to year (the surveys are conducted in June). The leadline sounding data show that the maximum seasonal sand level change each year averages 6.3 feet. Therefore, the seasonal sand level change at Virginia Beach is more than one-and-a-half times greater than the year-to-year change.

Even more significant are changes resulting from storms, which are rarely documented. An example is shown in Figure 4. Soundings from the CERC Pier immediately before and after the passage of Hurricane David show that the sand level was scoured a maximum of 6 feet in less than two days, when a large offshore bar was formed at the location of a prestorm sand terrace. Most of the scour data listed in Table 4 probably do not include maximum storm changes, since post-storm recovery of profiles can be quite rapid. DeWall, et al. (1977) reported a sand level recovery of 3 feet on the foreshore of a profile at Westhampton Beach, New York, within one day following a moderate northeaster. During the studies at Bodie Island and at Boca Raton an effort was made to obtain rapid post-storm surveys. Scour data from these sites are probably reasonably accurate estimates of maximum scour for sites with similar exposure and wave climate. Scour data from the other sites are considered to be low estimates of maximum scour.

Average foreshore slope was found to range from 0.03 to 0.20. The highest foreshore slopes were found on the most sheltered beaches, which also had the coarsest grain size (Boca Raton and Eastern Lake Michigan). The average nearshore slope was found to be a more uniform 0.01 to 0.03.

The maximum berm elevation ranged from 4 to 10 feet. Lower berms were generally found on the more sheltered beaches (Florida Panhandle and Corpus Christi).

The position of the maximum bar height was highly variable. On the exposed sites there were generally one or two pronounced bars which tended to move both onshore and offshore. Hands (1980) reports that on the Eastern Shore of Lake Michigan the relief of the multiple bars (five or more) increases significantly in the lakeward direction and that

Table 4. Characteristics of Profiles and Profile Envelopes

PROFILE SET	Foreshore Slope	Nearshore Slope	Berm Elevation (Ft)	Berm Distance (Ft)	Bar Height (Ft)	Bar Distance (Ft)	Maximum Scour (Ft)	Scour Distance (Ft)	Median Scour Depth (Ft)	Critical Depth (Ft)	Number Profiles	Months *
Virginia Beach, VA												
Timber Pier												
9/63-6/64	0.05	0.02	5.3	-76	1.3	354	5.1	370	-12.1	<-20	6	10
8/64-5/65	0.04	0.02	5.6	-66	1.2	200	7.1	70	-4.3	-15	6	9
7/65-6/66	0.04	0.02	7.1	-135	1.1	714	6.1	140	-5.1	-19	6	11
8/66-5/67	0.06	0.02	5.2	-82	1.8	200	6.4	130	-5.8	-19	6	10
7/72-3/73	0.05	0.02	5.8	-85	0.6	415	5.4	-75	+ 3.1	-19	6	8
8/73-5/74	0.05	0.02	6.7	-115	1.7	308	5.4	480	-13.6	<-16	6	8
Steel Pier												
9/63-6/64	0.10	0.03	7.2	-63	1.2	341	6.5	5	+ 1.5	<-16	6	10
8/64-5/65	0.04	0.01	9.8	-148	1.7	380	7.7	385	-10.7	<-15	6	9
7/65-6/66	0.05	0.02	10.0	-145	1.3	445	5.3	240	-6.7	-12	6	11
8/66-5/67	0.05	0.02	9.1	-102	1.5	393	6.0	-8	+ 0.1	<-12	6	10
7/72-3/73	0.09	0.01	8.5	-44	1.5	300	7.7	-47	+ 1.1	<-12	6	8
8/73-5/74	0.05	0.01	8.7	-143	1.6	220	6.5	-47	+ 2.4	<-10	6	8
Sea Sled (R18)	0.09	0.02	6.4	-61	1.2	135	3.9	148	-5.1	-11	4	36
Bodie Island, NC												
CERC Pier (N)	0.05	0.01	8.2	-86	5.2	245	12.9	294	-10.1	<-28	58	17
CERC Pier (S)	0.05	0.01	7.8	-68	7.8	765	14.7	238	-9.3	<-28	80	17
Kitty Hawk Pier	0.07	0.02	-	-	4.9	425	10.6	300	-10.7	<-20	109	38
Avalon Pier	0.08	0.01	-	-	5.2	425	12.2	405	-14.5	<-20	109	38
Nags Head Pier	0.07	0.01	-	-	6.9	705	10.2	303	-10.2	<-20	109	38
Jennette's Pier	0.07	0.01	-	-	4.9	790	11.8	243	-10.7	<-20	109	38
Outer Banks Pier	0.07	0.01	-	-	5.7	395	13.0	318	-12.7	<-20	109	38
Boca Raton, FL	0.20	0.02	8.5	-77	3.5	225	6.8	73	-6.3	<-12	232	12
Florida Panhandle												
St. Andrew Pier	0.05	0.03	4.0	-63	5.5	190	5.9	180	-4.8	<-12	8	8
Avondale Pier	0.09	0.03	5.4	-57	2.9	220	5.3	380	-9.3	-15	8	8
Crystal Pier	0.10	0.03	4.7	-38	2.5	226	4.0	190	-4.6	<-16	8	8
Beasley Pier	0.09	0.03	6.2	-39	3.7	139	5.4	80	-2.3	<-10	8	8
Navarre Pier	0.09	0.03	6.1	-39	2.5	239	6.5	5	+ 0.2	<-13	8	8
Corpus Christi, TX	0.03	0.01	4.8	-170	4.7	940	5.8	640	-7.6	-12	15	41
Mission Beach, CA	0.05	0.01	8.7	-140	0.8	280	4.1	480	-9.8	-23	8	11
Torrey Pines, CA												
North	0.05	0.02	8.8	-250	-	-	6.4	435	-8.4	-23	28	23
Indian Canyon	0.04	0.02	8.2	-180	-	-	6.0	-170	+ 5.6	-24	28	23
South	0.03	0.02	8.2	-165	-	-	5.2	-120	+ 4.8	-25	28	23
Scripps Pier	0.05	0.02	-	-	3.0	325	6.2	160	-7.5	<-21	14	94
E. Lake Michigan	0.10	0.01	-	-	6.8	585	7.7	602	-11.8	-23	6	25

*Number of months covered by survey data analyzed. Changes are listed for 24 months or less.

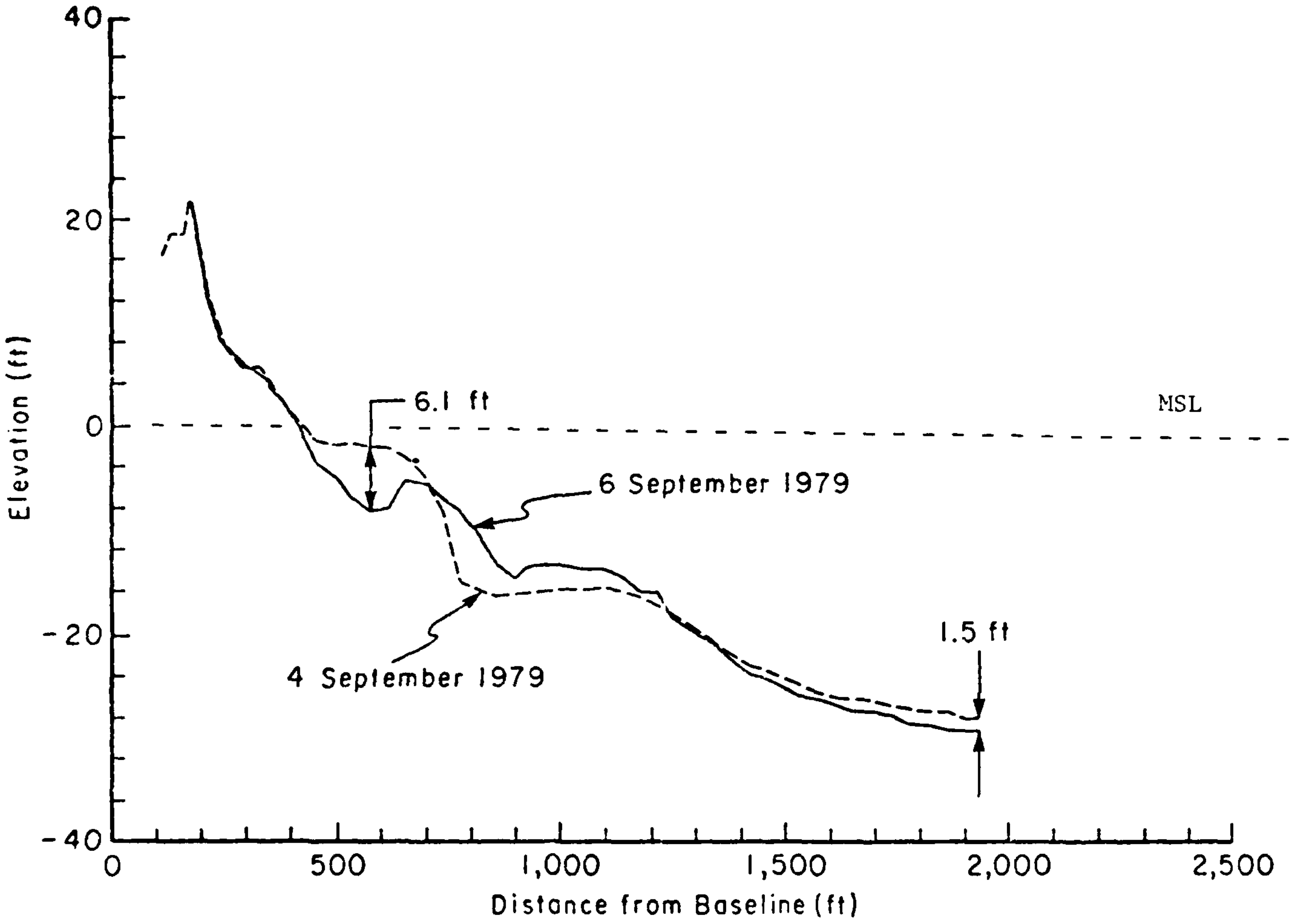

Figure 4. Profiles Before and After Hurricane David from CERC Pier, Duck, North Carolina

beyond the outer bar the envelope of bottom change narrows abruptly.

Maximum scour occurs from landward of the average shoreline position up to a distance of 640 feet seaward. The sand level fluctuation ranges from 3.9 feet for the once-per-year surveys at Virginia Beach to 14.7 feet for the weekly surveys at the CERC Pier in North Carolina.

Most profile surveys analyzed did not reach a closure depth (less than one foot of change in elevation).

The arbitrary categories--"exposed," "moderately exposed," and "sheltered"--were assigned by using the site exposure and wave climate data listed in Table 3 as well as the qualitative information that was collected from each site. Within each of the categories data were averaged for the characteristics that appear to have the most significance. These data are listed in Table 5. Although an attempt was made to statistically identify significant parameters affecting scour, this was not successful. A larger sample would presumably improve the statistical approach. A strong correlation ($r^2 = 0.74$) was found between the extreme wave height and the average maximum scour for each site. A simple linear regression fit to the maximum scour (ΔY_{max}) and extreme wave height (H_e) data yields:

$$\Delta Y_{max} = 1.15H_e - 4.1$$

for units in feet (Figure 5). This suggests that at least order-of-magnitude estimates of maximum scour can be made for a sand beach knowing only the annual significant wave height and standard deviation, where extreme wave height ranges from approximately 6.5 to 12.5 feet (95% confidence interval).

If the annual significant wave period (T_s) is included, the prediction for maximum scour for these data improves ($r^2 = 0.78$) to:

$$\Delta Y_{max} = 1.15H_e - 0.15T_s - 2.9$$

IV. DISCUSSION

A. Data Limitations. As stated earlier, the sand level changes listed in Table 4 are not directly comparable due to differences in survey frequency. The more frequent surveys have a higher probability of documenting the short-term changes, which are generally much larger than year-to-year changes. Few, if any, of the data sets document the extreme sand level changes caused by severe storms. Changes due to

Table 5. Summary of Profile Scour Characteristics

CATEGORY	Av. Exposure (Degrees)	Av. Extreme Wave Ht (Ft)	Av. Maximum Current (Ft/Sec)	Av. Grain Size (mm)	Av. Foreshore Slope	Av. Bar Height (Ft)	Maximum Scour (Ft)	Av. Distance To Maximum Scour (Ft)	Av. Median Scour Depth (Ft)	Critical Depth (Ft)
Exposed Virginia Beach Bodie Island	131	10.8	5.2	0.40	0.06	1.4	14.7	138	-6.7	< -28
Moderately Exposed Torrey Pines Mission Beach Florida Panhandle Corpus Christi	99	8.6	3.5	0.24	0.06	3.2	6.5	751	-4.0	-20
Sheltered Boca Raton E. Lake Michigan	110 *	9.6	2.7	0.52	0.26	5.2	7.7	338	-9.0	-12 > x > -23

* Limited Fetch

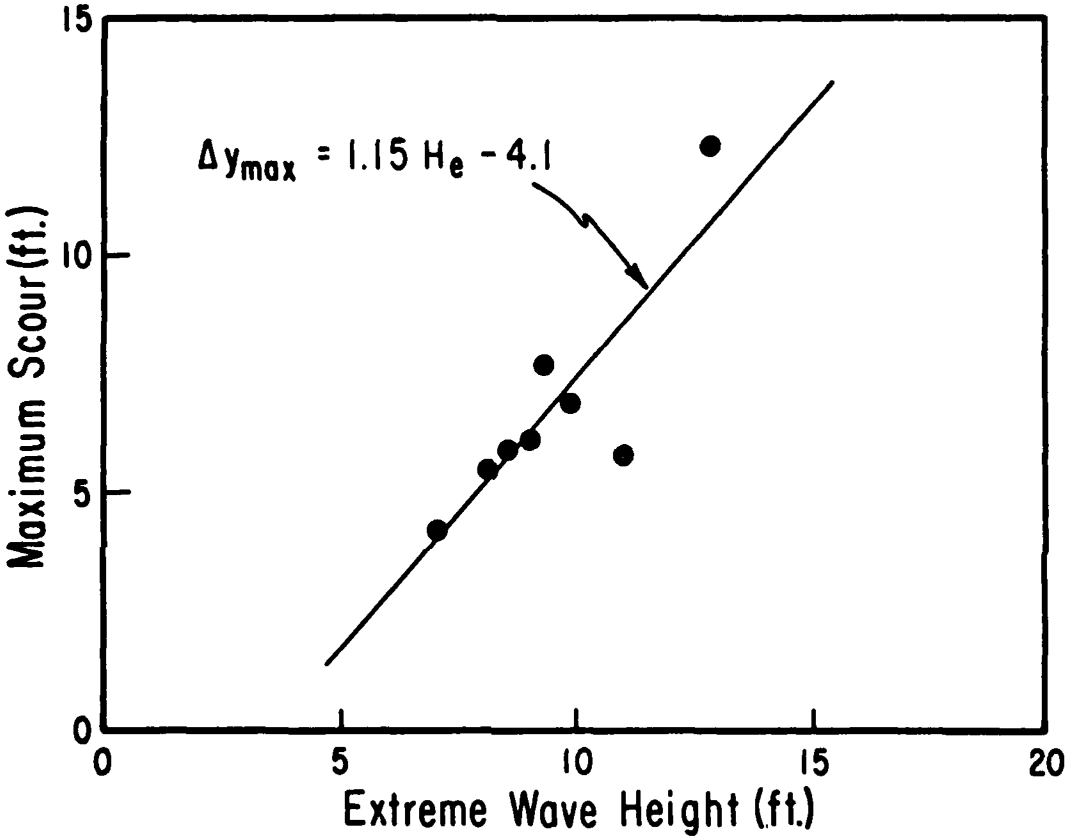

Figure 5. Maximum Scour (ΔY_{max}) Vs. Extreme Wave Height (H_e) (Conditions Expected To Be Exceeded 12 Hours Per Year)

moderate storms, with a frequency of two or three per year, are included in the Bodie Island and Boca Raton data sets. Other factors that have not been quantified include beach fill projects, structural influence, ice conditions, and biological activity.

A more-or-less continuous beach nourishment and sediment bypassing project was in operation at Virginia Beach throughout the period of analyzed surveys. This project would have had the most influence on the changes measured from the Timber pier, which is just downdrift of Rudee Inlet, and the least influence on the sea-sled surveyed range, which is outside of the nourishment project limits. Icing conditions similar to those on the Great Lakes have also been observed to a limited extent on beaches along the east coast. Depending on the extent of ice cover, effects may range from a protective cover over the subaerial beach to significant wave attenuation from ice floes along the coast during conditions that would otherwise be expected to cause severe erosion.

Biological activity has been observed to have various effects on beach processes--from the almost complete protection afforded by shore-parallel organic reefs, such as along the southeast coast of Florida, to the sediment-binding organic mats described by Dill (1958).

B. Pier Effects. A basic question which is legitimately raised about any profile data collected by sounding from a pier concerns the influence on the coastal processes by the structure itself.

Everts and DeWall (in manuscript) conclude that the piers used on Bodie Island do not appear to have a major effect on the bottom topography of the nearshore. Pier bents are widely spaced, and piles are not clustered; so the pier structure is highly permeable to sand moving in an alongshore direction. The five wooden fishing piers are supported by 10-inch to 16-inch diameter piles, spaced at 10 to 17 feet. The CERC Pier is supported by steel piles, which are 30 and 36 inches in diameter. Pile diameters increase to 48 and 54 inches at the ocean bottom where abrasion collars have been installed. Each bent consists of 2 piles on 15-foot centers; bent spacing is 40 feet.

Soundings from the CERC pier were taken at stations established midway between bents in order to minimize the influence of scour around piles. Soundings from the 5 fishing piers were taken at 50-foot station intervals, so that the influence from nearby piles was variable.

In an attempt to quantify the extent of scour around the CERC Pier, several sets of measurements were collected during the summer of 1979. These measurements ranged from leadline soundings during relatively high energy conditions to detailed underwater surveying using divers during moderate conditions. A summary of a detailed leadline survey is included as Appendix A. Contour maps, summarizing diver surveys of piles which had exhibited maximum scour, are in Appendix B. The leadline surveys revealed a maximum scour of at least 2.9 feet below the adjacent bottom at a pile 360 feet seaward of the shoreline and at a depth of 15.8 feet. Underwater surveys of this same pile, under more moderate wave conditions, revealed a maximum scour of 3.3 feet below the adjacent ocean bottom (Figure B-2). The scour radius extended approximately 12 feet from the center of the 48-inch pile. These measurements fall well within the maximum scour limits reported by Wells and Sorensen (1970) of approximately one pile diameter. If this limit were used at the CERC Pier, the potential maximum scour would be 4.5 feet below the natural bed--or a total probable maximum range of scour of 19 feet--including the maximum envelope of profile change.

C. Construction Effects. In October 1979 a bathymetric survey was conducted in the vicinity of the CERC Field Research Facility--approximately 2-1/2 years after completion of the 1800-foot research pier. The results of this survey are shown in Figure 6. The survey indicates a significant zone of scour along the south side of the pier with maximum scour occurring near the seaward end. At the normal position of the 21-foot-contour, the amount of scour is about 8 feet. Figure 7 shows pre- and post-construction profiles of the pier site. The 19 July 1973 through November 1974 surveys were conducted by divers along a profile line 45 feet south of and parallel to the pier centerline. Reference pipes were jetted into the bottom at 100-foot intervals along the profile line. Horizontal and vertical control was established on each reference pipe using an onshore transit and 21-foot-long level rod. Subsequent profiles were obtained by sand-level measurements at each pipe. Leadline soundings in September and October 1975 were from a temporary wooden construction pier which was installed immediately south of the CERC Pier. The January 1977 profiles were leadline soundings from the north and south sides of the newly completed 20-foot-wide research pier. The 1977 profiles indicate that approximately 10 feet of scour occurred along the seaward 500 feet of the pier since the 1973 surveys. Subsequent surveys (Figures 3, 4, and 6) indicate that the profile has been more-or-less maintained in its post-construction shape. The reason for the development of this scour zone is not known. Subsequent research conducted at the CERC Field Research Facility since completion of this study has confirmed significant pier effects on nearshore processes and profile changes (Miller, et al., 1983).

V. RECOMMENDATIONS

A. Site Specific Design Considerations. For design studies at a site where repetitive profiles, sediment size, and wave climate data are available, an approach similar to the one outlined in this report will give reasonable estimates of the magnitude and extent of wave-induced scour on an unstructured sandy beach.

Where these data are not available but time allows for data collection, the following approach is recommended:

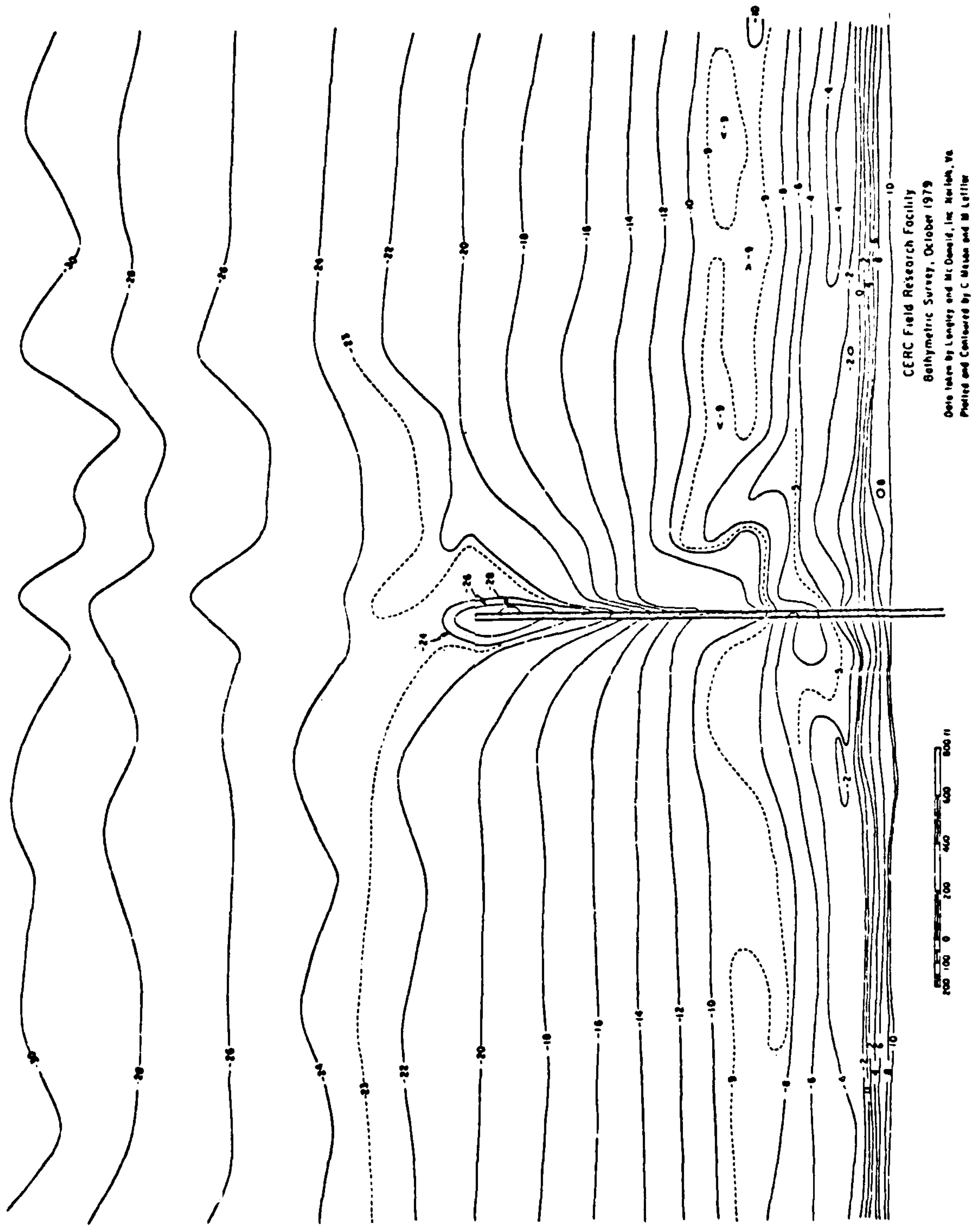

Figure 6. Bathymetric Map of CERC Field Research Facility, October 1979

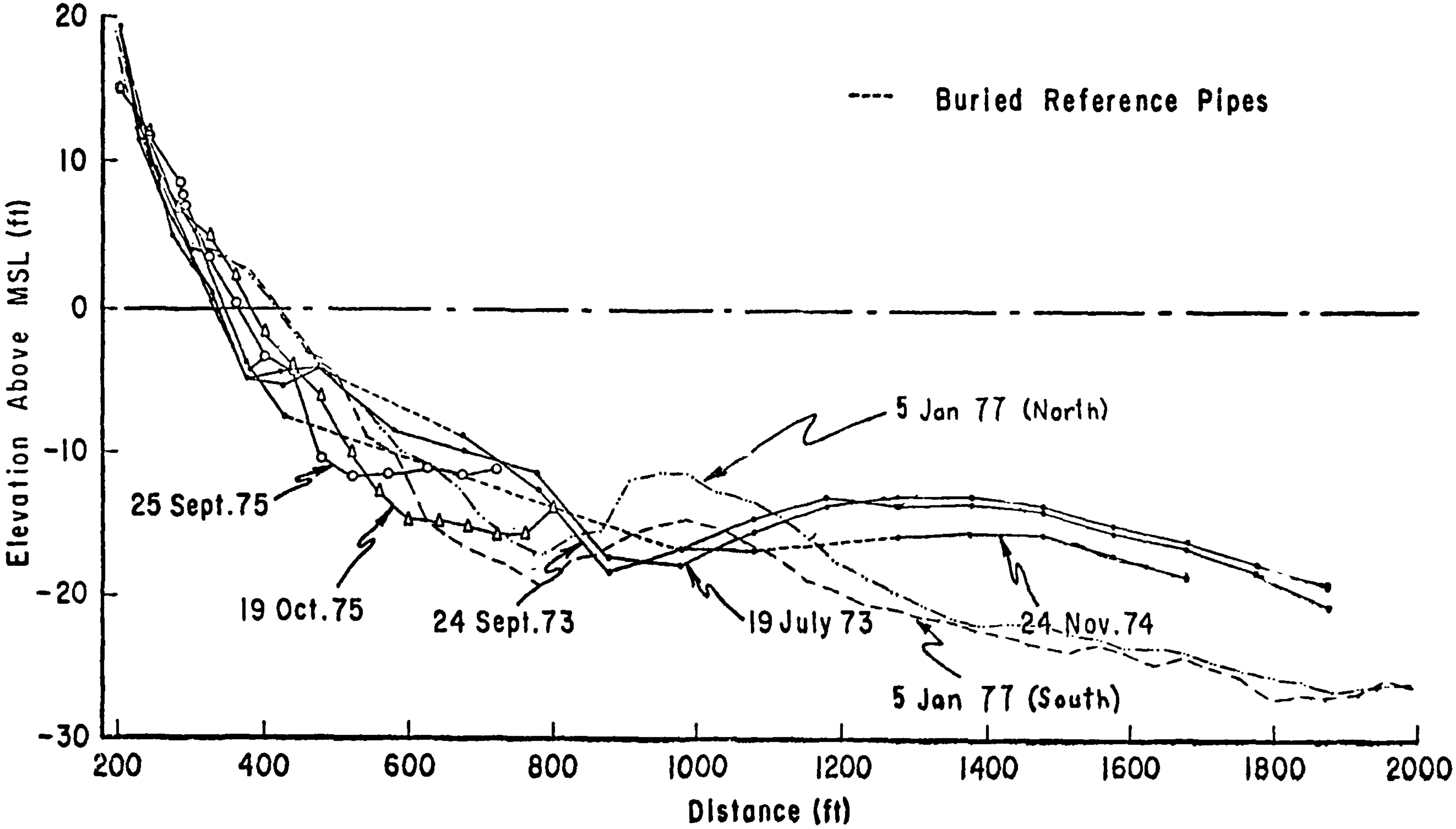

Figure 7. Pre- and Post-Construction Profiles at CERC Pier (Construction Was Under Way From July 1975 to December 1976)

1. Collection of at least daily nearshore wave measurements for a full year to determine significant and extreme wave heights and periods. Ideally, these would be wave gage measurements but could be obtained using visual observers following a procedure similar to the CERC Littoral Environment Observation Program (Berg, 1968). Visual observations allow obtaining an additional parameter of wave direction.

2. Collection of quarterly beach profile surveys, extending from the frontal dune, cliff, or other stable zone to a minimum depth of predicted significant sediment movement. This prediction can be based on the extreme wave height, if known, or else to a depth equal to the deepest shore-parallel contour. Along U.S. coasts this depth varies from 15 to 60 feet or more. If quarterly surveys are not practical, a minimum of two surveys should be obtained in order to document the seasonal sand level changes between summer-type swell conditions and the short-period, high energy sea conditions more typical of winter. Examination of aerial photographs, taken several times per year, will often give an indication of when to expect maximum erosion or accretion. Also, aerial photographs will often reveal obstructions such as submerged reef or rock outcrop. The accuracy of the surveys should be to the nearest foot of distance and tenth-foot of elevation for the onshore work. The offshore profiles should be accurate to the nearest 10 feet of distance and the nearest half-foot of elevation. Stationing along the profile line should be at breaks in slope and at maximum intervals of 50 feet onshore, extending to intervals of 100 feet offshore.

3. Collection of daily Littoral Environment Observations. If personnel are available, the collection of a full year of at least daily LEO measurements will provide information on wind and wave climate, longshore current velocity, beach slope, and sediment size.

B. Envelope of Profile Change Considerations. Where only very limited information is available, such as nautical charts and perhaps a single bathymetric survey, scour prediction should be based on information known from a site with similar characteristics, exposure, and wave climate. The magnitude of the envelope of profile change can be estimated using the following methods:

1. Determine significant and extreme wave height for the site using a hindcast technique such as outlined in Chapter 3 of the CERC Shore Protection Manual (1977). Doubling the extreme wave height gives an estimate of the limiting depth of significant sediment movement. The extreme wave height also approximates the median depth of the scour maximum.

2. From the available nautical charts, determine the depth of the deepest shore-parallel contour for an additional estimate of the limiting depth of significant sediment movement.

3. Using available bathymetric survey data, determine the presence of one or more longshore bars. The position of the largest longshore bar can be used to estimate the position of maximum scour. The data analyzed in this report indicate that the magnitude of maximum scour averages twice the maximum bar height, but maximum scour is as much as three times the maximum bar height in some locations.

4. Utilizing repetitive, high-resolution satellite imagery and high-altitude photography, which is available for virtually all of the world's coastlines, determine an additional estimate of the envelope of nearshore profile changes. From these repetitive images the seasonal fluctuation in shoreline position can be estimated. If the rule-of-thumb that one foot of shoreline change is equal to one cubic yard per foot of volume change is used (Shore Protection Manual, 1977), the seasonal change in volume--actually the cross-sectional area--of the profile envelope can be determined.

C. Recommendations for Further Study. Part of the CERC beach profile studies research is being conducted at the Field Research Facility in Duck, North Carolina. As an extension of this work, the effects of scour around the research pier and, in particular, the magnitude of scour around pilings can be addressed. If modified surveying techniques such as pipe profiling and the underwater surveying described in Appendix B are used, the geometry and magnitude of scour around piles of various dimensions can be measured. Through the use of recording fathometers, mounted near the bottom, scour during extreme events can be monitored. This technique was used successfully in a study for the U.S. Coast Guard conducted by Dames and Moore (1975).

VI. SUMMARY

Envelopes of significant short-term profile change--defined as sand level changes of one foot or more--extend from the frontal dune, seaward, to a profile closure depth that can be estimated by doubling the annual extreme wave height (conditions exceeded for 12 hours per year). The zone of maximum sand level fluctuation within the envelopes extends from the berm to a median depth that is approximated by the annual extreme wave height at the site. For an exposed site on the U.S. East Coast, the maximum short-term sand-level change was slightly less than 15 feet. A relatively sheltered site on the S.E. Florida Coast had a maximum sand level change of about half that amount. Typical maximum scour values for moderately exposed sites on the U.S. West Coast, Gulf Coast, and East Coast of Lake Michigan ranged from 4 to 8 feet.

These data are only order-of-magnitude estimates and do not include erosion caused by extreme events. Likewise, these data represent normal sand level fluctuation due to waves on unstructured sandy beaches. Scour due to wave-structure interaction or to tidal or other currents would be in addition to the values reported. The Corps of Engineers

(1977) recommends allowing an additional amount equal to the maximum unbroken wave height that can be supported at the original water depth for scour at the toe of the coastal structure.

Scour around a pile-supported pier at an exposed site was observed to be approximately 10 feet below the original sea bed. The cause of this scour is uncertain.

Techniques are outlined for estimating the magnitude of the envelope of profile change at a given coastal site using only limited information.

It is recommended that field data collection be undertaken to assess the magnitude of scour around pile-supported structures--especially during extreme events.

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APPENDIX A

SCOUR MEASUREMENTS AT FRF

DEPARTMENT OF THE ARMY
COASTAL ENGINEERING RESEARCH CENTER
CORPS OF ENGINEERS
KINGMAN BUILDING
FORT BELVOIR, VIRGINIA 22060

CERRE-CP

3 July 1979

MEMORANDUM FOR: CHIEF, COASTAL PROCESSES BRANCH

SUBJECT: Scour Measurements at FRF

1. Profile data were collected from lead-line soundings from the FRF pier in Duck, North Carolina on 20 June 1979. Local conditions included a 25 miles-per hour NE wind and an average wave height of about 4 ft. as recorded from visual observations. Other LEO are summarized on attached table.*

2. Soundings along the south side of the pier began at 0950 hrs. Initially 6 lbs. of lead weight were used at the end of a tape measure with a correction made for the attachment of the weights. However, this did not prove adequate for accurate soundings due to the high wind conditions. So after 9 readings, 4 lbs. were added and a new correction noted. Allan DeWall performed soundings while Karen Jacobs recorded the measurements as read by Julie Christenson.

3. Soundings were taken every 20 ft., ie. at pile and mid-bent, for the length of the pier starting at Sta. 2+00 to Sta. 19+40. The pile soundings were made on the landward side of the pile to gain protection from the wind and in a few instances an additional sounding was made on the seaward side of the pile. Sounding the south side of the pier required approximately two hours.

4. Sounding proceeded on the north side of the pier beginning at the seaward end, Sta. 19+60. Again soundings were taken at 20 ft. intervals by Allan DeWall landward to Sta. 1+40. Readings were made by Karen Jacobs and recorded by Julie Christenson. This time the pile soundings were made on the seaward side of the pile for wind protection with additional landward soundings on numerous occasions.

5. The data were later reduced and plotted using mid-bent data to form profiles for each side of the pier. (Graphs attached)** Added points showing elevations at each pile were plotted to indicate scour around the pile.

6. Upon examination of the graphs, it was found that the maximum scour (2.8 to 2.9 ft.) occurred at the same station for both sides of

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* Table A-1.

** Figures A-1 and A-2.

the pier, ie. Sta. 7+60, at an average depth of 15.9 ft. This is in the trough seaward of the nearshore bar suggesting that a current parallel to the shoreline may be the major cause of scour.

7. Also characterized by the graph is the greater scour occurring on the seaward side of the piles. In 8 of the 9 cases on the south profile where landward and seaward measurements were made, the seaward side proves to be deeper. Some of this effect may be attributed to the sheltered landward readings where less deflection due to wind and current is experienced in the tape. Likewise 8 of the 10 cases where both measurements were taken around a pile on the north profile show greater depths on the seaward side of the piles. However, in this case the landward readings had more deflection so the apparent depths would be less than recorded, making the seaward scour even more significant.

8. Scour was calculated by taking the difference between the sand elevation at the pile and an interpolated value at the pile as derived from the mid-bent elevations on either side of the pile. Comparison of the average scour values is also a probable indication that maximum scour occurs on the seaward side of the pile. The average scour for the north side of the pier, where soundings were taken on the seaward side, was 1.2 ft. while only 0.5 ft. on the south side where soundings were taken on the landward side of each pile. Thus assuming little difference across the bent, it appears that the greater scour on the north side reflects the greater seaward scour condition.

9. However, tape deflection must be a consideration in average scour determination. Due to the greater wind exposure at mid-bents, deflection of the tape will produce an apparent elevation which is lower than actual. This in turn effects the interpolated elevation at the pile, giving a smaller apparent value for scour. Thus the average scour may be even more significant than is seen from the data and graphs.

10. Besides wind deflection, a strong current (averaging 1.25/ft/sec.) made sounding more difficult. Leading into the wind and current was necessary in order to place the weights in a suitable position for measurement. However, on numerous occasions when sounding were repeated, identical results or results within a few tenths(.4 on the average) were obtained. Thus the data appear to be accurate.to the nearest half-foot.

11. Therefore, despite unfavorable conditions, reasonably accurate soundings were obtained. The data revealed a maximum scour in a trough seaward of the nearshore bar and a consistently greater scour on the seaward side

of the piles.

Julie Christenson

JULIE CHRISTENSON
Civil Engineering Technician
Coastal Processes Division

3 Incl
1. LEO Data
2. North Profile, 20 June 79
3. South Profile, 20 June 79

Table A1. Summarization of LEO Data

	Regular Observer		AD/KJ/JC
	Pier	Beach	Beach/Pier
Time	1210 hrs.		0915 hrs.
Breaker Height	3.5 ft.	4.0 ft.	4.5 ft.
Wave Period(10 waves)	63 sec.	68 sec.	131 sec. 175 sec. 68 sec.
Wave Angle	80°	85°	
Wave Type		Spill/Plunge	Spilling
Wind Speed	19 mph	19 mph	25 mph
Wind Direction	NE	NE	NE
Foreshore Slope		6°	5°
Current Speed	1.67 ft/sec. at end of pier	.75 ft/sec. 20 ft. from shoreline	1.5 ft/sec at Sta. 7+00 1.1 ft/sec at Sta. 5+80
Current Direction	South	South	South

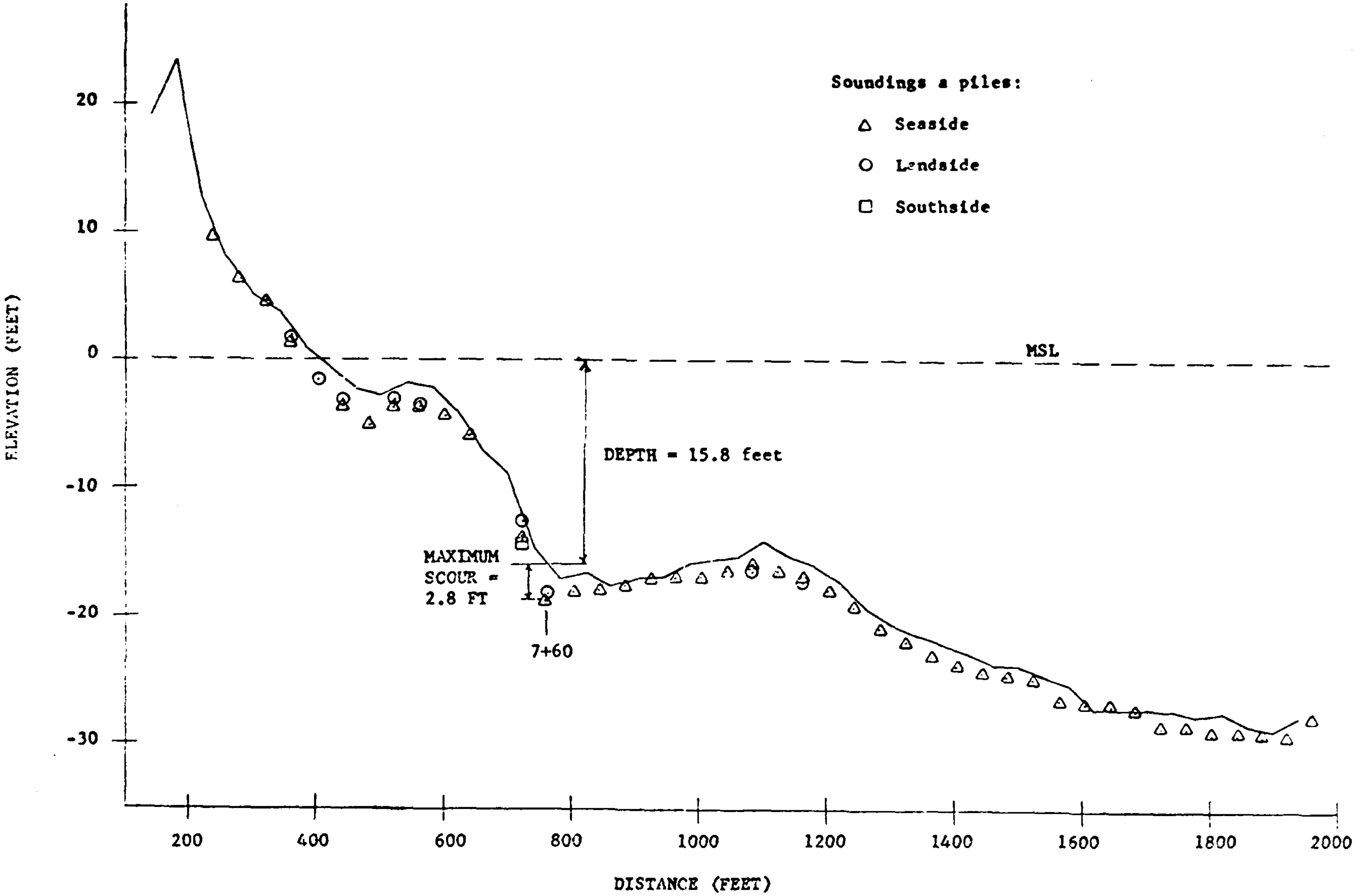

Figure A-1. Nearshore profile and pile scour depths along north side of CERC pier, 20 June 1979

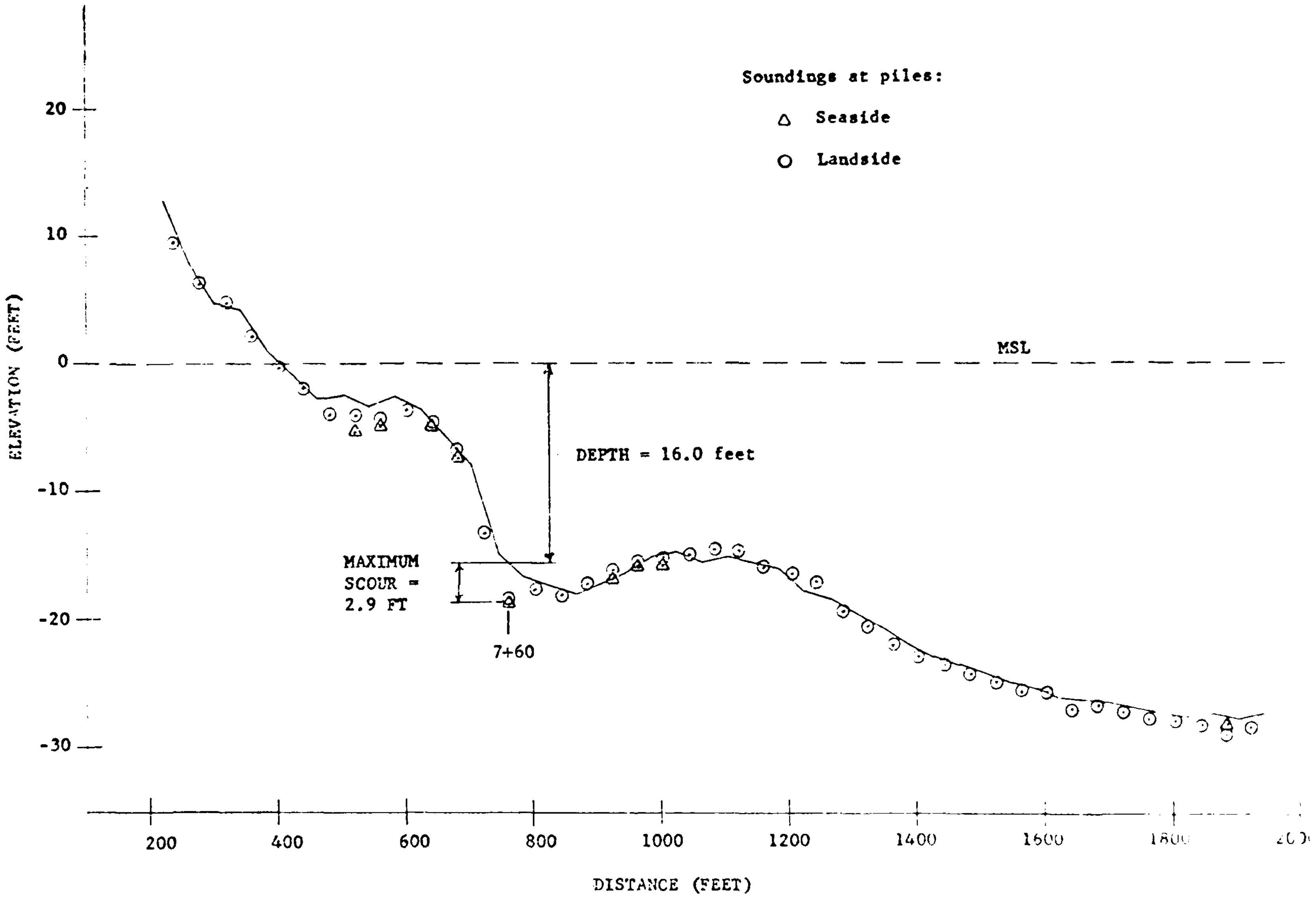

Figure A-2. Nearshore profile and pile scour depths along south side of CERC pier, 20 June 1979

APPENDIX B

SURVEYS OF PILES EXHIBITING MAXIMUM SCOUR

DETAILED MAPPING OF SCOUR HOLES

On 7-8 August 1979 an underwater survey was conducted at the CERC Field Research Facility to map the extent of scour at selected piles supporting the research pier.

The 1800-foot long pier is supported by 30- to 36-inch piles, which increase in diameter at the sea floor from 48 to 54 inches. The two-pile bents are spaced at 40-foot intervals, with the piles at 15 feet, center-to-center, spacing within each bent.

A series of leadline soundings made under varying wave energy conditions showed that piles with maximum scour were at bent number 7 + 60, which is approximately 360 feet seaward of the shoreline at an average depth of 10 feet.

The surveying technique required two SCUBA divers using a graduated 10-foot rod fastened above the base of the pile and held horizontally, using a carpenter's level. The azimuth of the rod was determined with the diver's wrist compass. The elevation of the rod was determined using a sounding lead lowered from a known elevation on the pier deck. Sand level elevations were then determined by taping down from the rod to the bottom at one foot intervals along the azimuth line. It was planned to survey at 45° azimuths radiating from the pile, but this proved to be very time-consuming. Each azimuth line required nearly 10 minutes to set up and survey as a result of the bottom surge and limited visibility. Ultimately, four azimuth lines at 90° arcs were surveyed at each pile. As the divers became more proficient, a pile could be surveyed in 30 minutes.

Survey data were reduced in the office to MSL elevations, and contours of bottom elevation were constructed. Contour maps from four piles--in bents 7 + 60 and 8 + 00 --are presented in Figures B-1 through B-4. These maps show that scour extends laterally at least 10 feet from the pile and up to 3.3 feet below the normal sea bed. The shape of the scour hole is not symmetrical around the pile but tends to be steeper on the seaward side and deeper on the landward side.

Sea conditions during the survey were quite moderate with a wave height of 2 feet and period of 12 seconds. Longshore current velocity was -1 ft/sec.

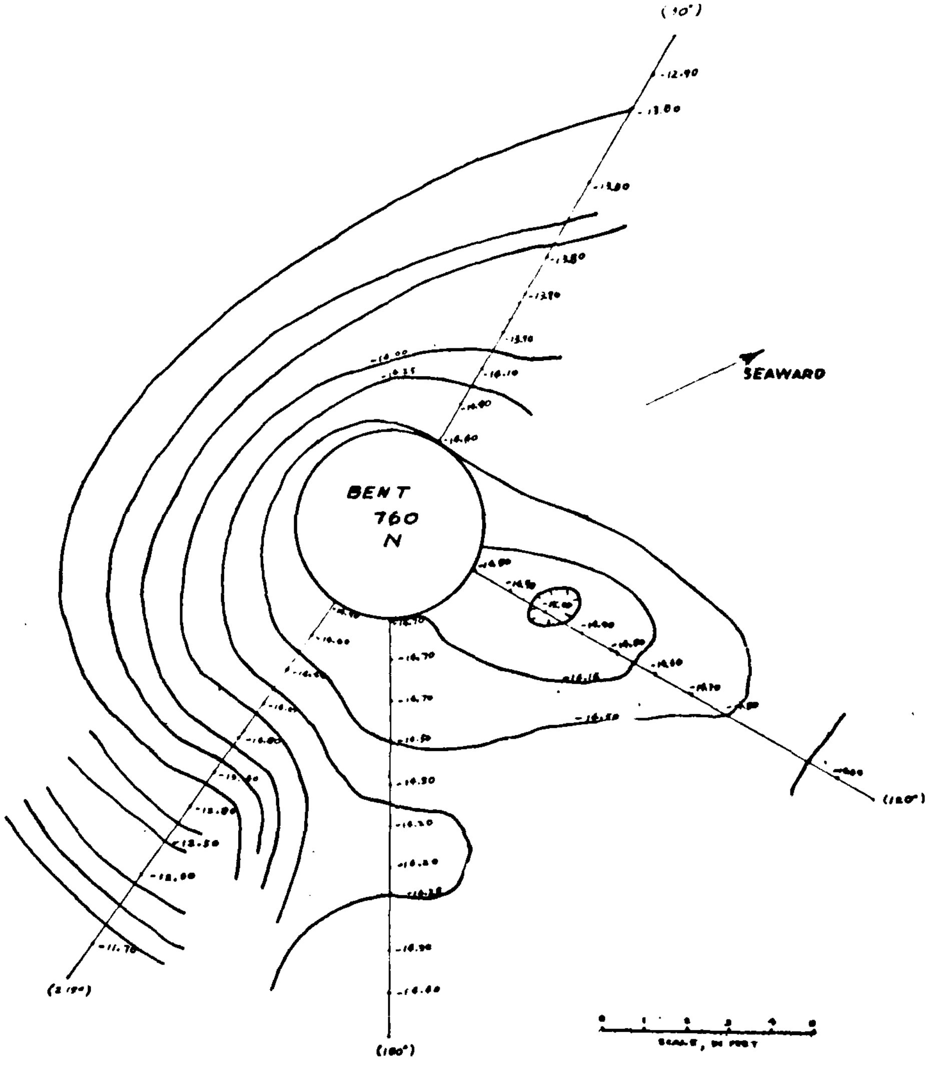

Figure B-1. Scour at Pile 760-N, 7 August 1979, CERC Pier (Depths in Feet Below MSL)

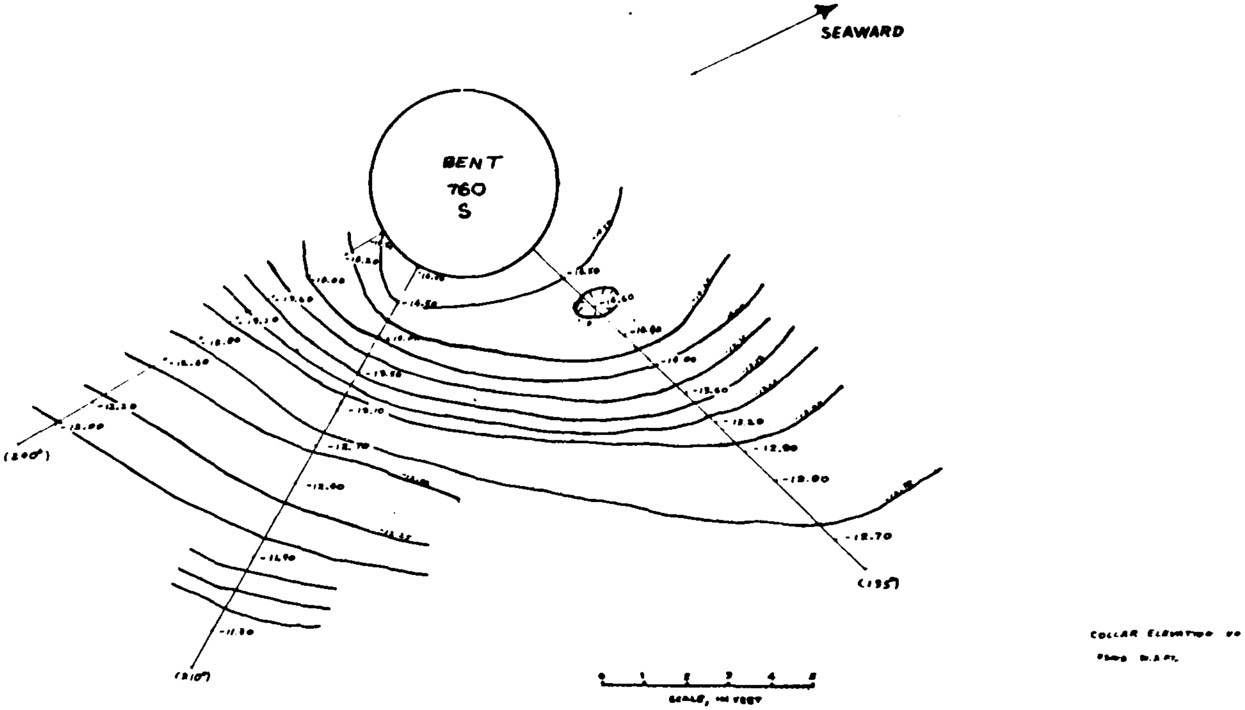

Figure B-2. Scour at Pile 760-S, 7 August 1979, CERC Pier (Depths in Feet Below MSL)

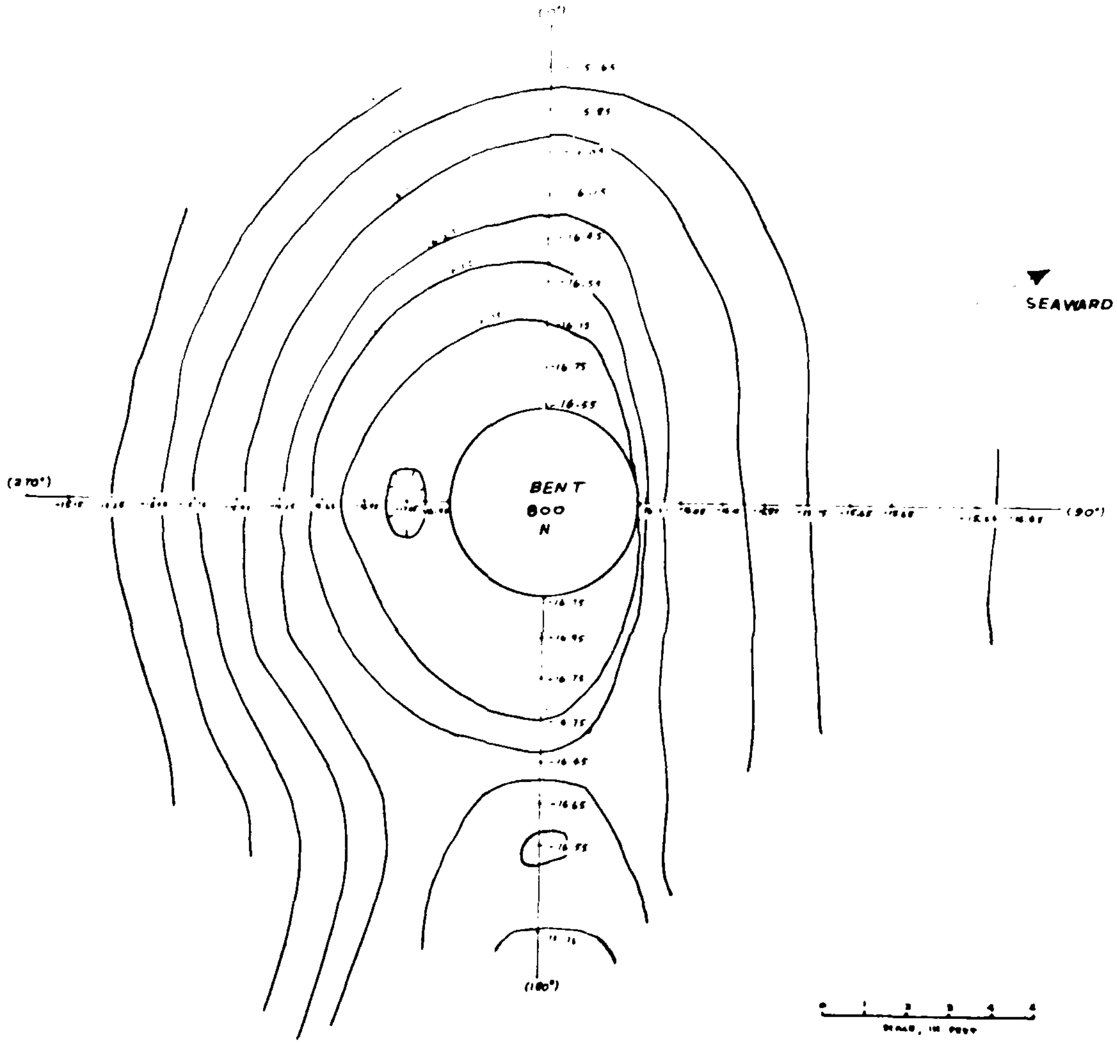

Figure B-3. Scour at Pile 800-N, 8 August 1979, CERC Pier (Depths in Feet Below MSL)

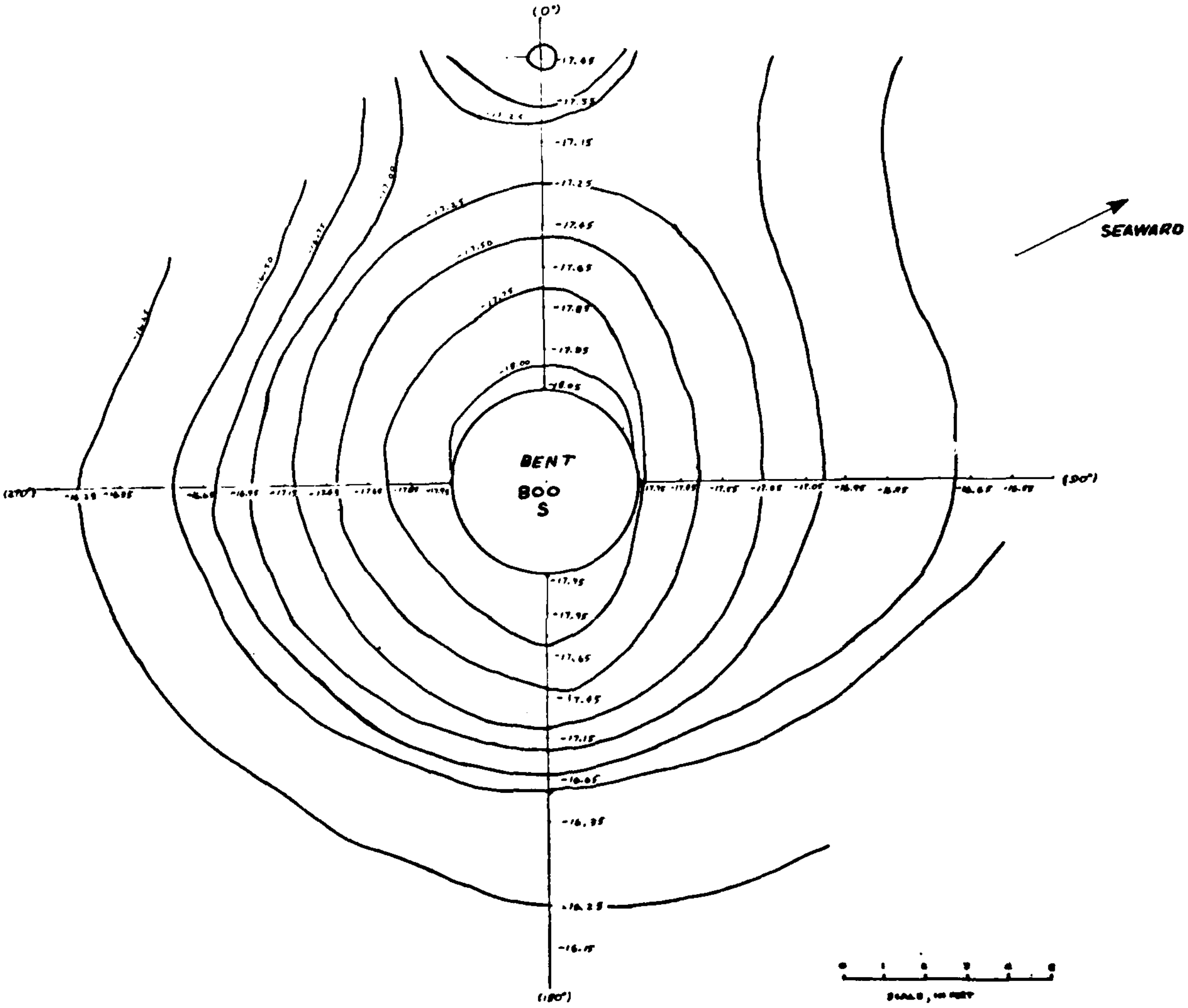

Figure B-4. Scour at Pile 800-S, 8 August 1979, CERC Pier (Depths in Feet Below MSL)