CHAPTER 80

COMPARISON OF MODEL AND BEACH SCOUR PATTERNS

by

John B Herbich, Ph D , P E
Professor and Head
Coastal and Ocean Engineering Division
Texas A&M University
College Station, Texas 77843

ABSTRACT

Artificial or natural barriers may be divided into two classes, those from which waves are reflected and those on which waves break In general, any intermediate type that gives a combination of reflection and breaking may set up severe erosive action of the beach in front of barriers When the reflected waves are superimposed on the incident waves a stationary spatial envelope of the combined incident and reflected waves is produced Previous laboratory studies indicated that the crests of the sand bed appear fairly closely under the nodes of the envelope and troughs of the scoured sand bed under the loops of the envelope The predominant scouring pattern had a spacing between crests equal to one-half the wave length

Other studies by Keulegan and Shepard established characteristic parameters for bar and trough depth for laboratory conditions and for several field locations Their studies were compared with beach profiles taken along the Texas Gulf Coast

Relationships between (a) scour depth and sand crest wave length, (b) between trough depth and sand bar depth and between wave characteristics and beach scour were established for selected locations along the Texas Coast

INTRODUCTION

Natural or artificial barriers may be divided in two classes, those from which waves are reflected and those on which waves break In general, any intermediate type that gives a combination of reflection and breaking may cause excessive erosive action seaward from the barrier

One laboratory study was confined to non-breaking waves at the seawall and the main objective was to investigate the nature of scour of a flat, horizontal sand beach in front of a seawall due to wave action Some of the results were presented at the Eleventh Conference on Coastal Engineering (1)* Since then field data were acquired and analyzed for several locations along the Gulf of Mexico Texas coast Another study by Sato et al, also in laboratory, principally dealt with waves breaking at the seawall The principal objective of that investigation was to determine the basic characteristics and to determine possible measures to prevent erosion around coastal structures (2) The study was followed up by field investigations which indicated that beach scour depends not only on wave characteristics just in front of structures and wave reflection from the structures but also on the currents set up by waves around the structures

Studies by Otto (3), Hartnack (4), Keulegan (5) and Shepard (6) dealt with laboratory or field studies on characteristics of offshore sand bars formed by waves

In recent years a beach profile and jetty condition survey along the Texas Gulf Coast was undertaken (7) and preliminary analysis indicates that scour patterns and other characteristics resemble those obtained in laboratories and at other field locations

Unfortunately data for waves which produced these patterns are very scarce, if at all available, so that any comparisons between laboratory and field conditions can only be very approximate

LITERATURE REVIEW

Underwater sand bars are found in all parts of the world along the coastlines of lakes, seas and oceans There may be only one distinct bar consisting of a crest, or ridge on the seaward side and a trough on the landward side, or there may be a series of bars with related crests and troughs

The bar formations have been studied by geologists and geographers for over a century and considerable field data of the form, number of bars and dimensions are available However, only a few laboratory

* Numbers in parenthesis refer to references at the end of paper

studies were made and only limited explanations of the hydromechanics process have been put forward

Field observations of form and dimensions of natural, underwater beach profiles were made along the Baltic Coast, Lake Michigan, California and the Texas Coast

Otto and Hartnack (3, 4) reported on measurements along the Pomeranian Baltic Coast, while Evans (8) reported field measurements of the bars along Lake Michigan There were essentially three distinct bars measured on the Eastern shore of Lake Michigan

Keulegan (5) indicated that the form of experimental bars varies considerably from that of the natural bars In general the natural bars are flatter and longer than the bars formed in a laboratory wave channel This may be due in large part to the fact that one cannot scale down the size of sand used, as most of the laboratory investigations employed natural sands of approximately the same size as the prototype sands It should also be noted that the laboratory beach profiles are usually subject to monochromatic waves while the prototype waves are usually irregular and contain a spectrum of wave heights and wave lengths However, Keulegan also noted that the ratio of depth of crest (h_c) to the depth of the bar (h_T) was similar in the model and prototype

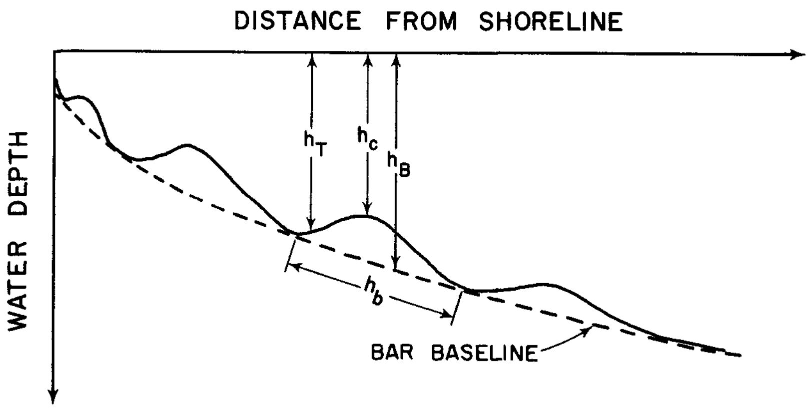


FIG I DEFINITION SKETCH

Shepard (6) examined thousands of beach profiles taken along the ocean piers in California and indicated that the troughs which lie between the shoreline and the submerged beach bars are formed by the plunging breakers and by the longshore currents which feed the rip currents He also found that there is a relationship between the depth of the bars and troughs and the wave height

SAND SCOUR ON SLOPING SURFACES

Previous Investigations

Both Keulegan (5) and Shepard (6) conducted investigations concerning the characteristics of beach scour patterns in response to breaking waves Keulegan conducted a series of laboratory experiments and found that the scour trough forms at the breaker plunge point, with a corresponding accumulation of sand, or the sand bar, forming just seaward of this location It was found that after initiation of uniform wave patterns over the sloping bottom, a trough-bar complex developed rapidly, migrating onshore until an equilibrium position was reached Thereafter only small changes in the scour pattern occurred Similar results were reported by Herbich and Ko (1), indicating that the scour depth limit is approached asymptotically

Shepard (6) summarized the results of three hundred and fifty three beach profiles taken at Scripps Pier at La Jolla, California

Both Keulegan and Shepard stress the importance of wave characteristics as influencing the scour pattern Keulegan's results show that the ratio of H/h_B

where H - wave height, and

h_B - distance from still water level to the bar base (see Fig 1)

increases with wave steepness (H/L) up to a steepness of 0 04 For greater values of steepness the ratio of H/h_B is independent of wave steepness and remains constant at about 0 83 This relationship was found to be independent of beach slopes for slopes between 1 15 to 1 70

Keulegan and Shepard also examined the ratio of h_T/h_c where

h_T = trough depth from still water level, and

h_c = sand crest depth from still water level (see Fig 1)

Keulegan noted that the h_T/h_c ratio was practically independent of wave steepness and beach slope and computed an average value of 1 69 for his laboratory experiments

Shepard also determined a relatively uniform relationship of h_T/h_c with an average value of 1 16 at Scripps Pier (using mean sea level as datum)

Current Investigations

A survey report prepared by U S Army Corps of Engineers (7) presents beach profiles taken at selected locations along the Texas Gulf Coast during the past several years Analysis of these profiles was made to determine the characteristics of natural scour pattern along the coast, and to compare with previous laboratory and field studies The data were analyzed for the following locations

(1) East Beach, Galveston, Texas (Fig 2)

(2) Groin Area, Galveston, Texas

(3) West Beach, Galveston, Texas

(4) Panther Point, Matagorda - Port Aransas, Texas

(5) Yarborough Pass, Padre Island, Texas

Since space limitation prevents reproduction of all tabulated data, only average values and selected sample data are given

Table I gives the average values of distances between sand crests (sand wave lengths) and average depth of scour for East Beach at Galveston Tables II through V gives similar information for Groin Area - Galveston, West Beach - Galveston, Panther Point - Matagorda - Port Aransas and Yarborough Pass, Padre Island

Fig 3 presents sample beach profile for East Beach at Galveston The crests of bars were joined to indicate the crest pattern along the beach section Fig 4 is for Panther Point and Fig 5 is for Yarborough Pass location

Relationship Between Scour Depth and Sand Crest Wave Length

Scour depth readings as well as scour wave length measurements were taken for all locations and a sample location is given in Fig 6 Although the scatter is considerable (as may be expected) the relationship may be approximated by a straight line having a slope of 0 004

Relationship Between Trough Depth and Sand Bar Depth

Values of trough depth to sand bar depth (h_T/h_c) were determined at each location along the Texas Coast for various times of the year

The ratio of trough depth to sand bar depth was plotted for three locations along the Texas Coast as a function of time (Figure 7) It will be noted that there is some annual variation in this ratio which, of course, may be caused by major storms, or hurricanes, but the variation is within fairly narrow limits of h_T/h_c For example for Matagorda Bay the variation is between 1 15 and 1 42, with an average value of about 1 25

Figure 8 shows the relationship for other locations in addition to locations shown in Figure 7 The data indicate that this ratio tends toward an equilibrium value characteristic of each location, but at times a significant deviation from this value may occur

Depth of trough is plotted in Figure 9, against the depth of bar for several field locations along the Texas Coast Field data from Washington and Oregon coast and data from California are also plotted as well as Keulegan's laboratory data Remarkably consistent results are obtained for all locations with field data ranging between h_T/h_c values of 1 16 and 1 60 The laboratory data gives a value of 1 69

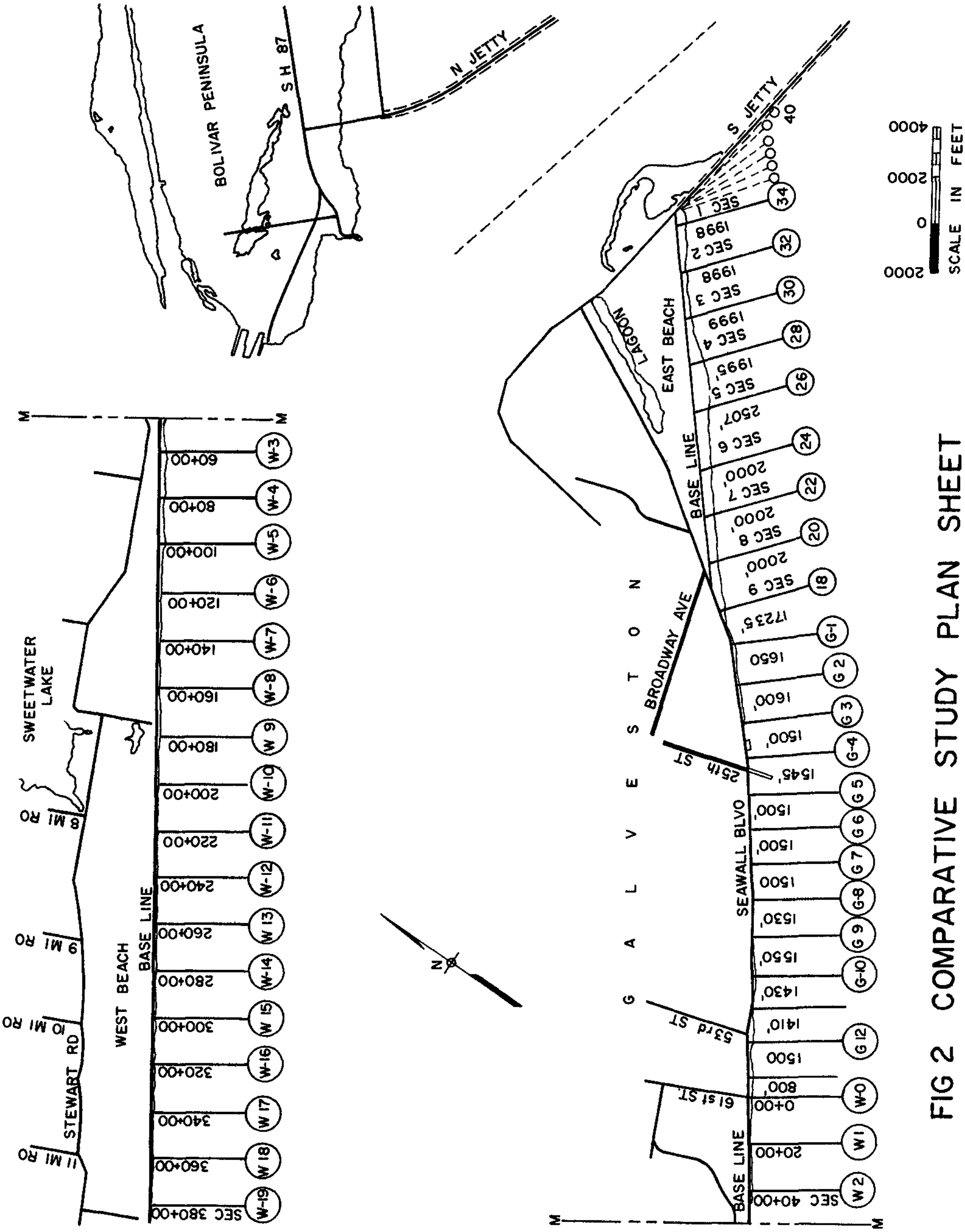


FIG 2 COMPARATIVE STUDY PLAN SHEET GALVESTON (FROM REF 7)

EAST BEACH

GALVESTON, TEXAS

Section	Period	Average Distance Between Sand Crests (ft)	Average Depth of Scour (ft)
1	1934-68	301	76
2	1934-68	257	68
3	1934-68	354	99
4	1934-68	327	93
5	1934-68	298	97
6	1934-68	354	87
7	1934-68	277	1 23
8	1934-68	310	1 04
9	1934-68	272	73
10	1949-68	240	1 07
11	1949-69	314	70
12	1949-69	345	77
13	1949-69	252	89
	Average	300	89

TABLE I

GROIN AREA

GALVESTON, TEXAS

Section	Period	Average Distance Between Sand Crests (ft)	Average Depth of Scour (ft)
14	1949-69	280	70
15	1949-69	202	48
16	1949-69	180	45
17	1949-69	286	88
18	1949-69	232	87
19	1949-69	247	67
20	1949-69	227	48
21	1949-68	305	1 38
22	1949-69	192	45
23	1949-69	206	44
24	1949-69	230	1 18
25	1949-69	207	26
26	1949-69	212	35
27	1949-69	187	49
28	1949-69	178	36
29	1949-69	165	48
30	1949-69	202	91
31	1949-69	242	35
32	1949-69	189	43
33	1949-69	186	37
34	1949-69	178	46
35	1949-69	178	68
36	1949-69	227	48
37	1949-69	181	58
38	1949-69	276	61
39	1949-69	221	47
40	1949-69	194	64
41	1949-69	220	77
42	1949-69	262	61
43	1949-69	279	62
44	1949-69	209	50
45	1949-69	195	37
46	1949-69	341	60
47	1949-69	230	61
	Average	222	59

TABLE II

WEST BEACH

GALVESTON, TEXAS

Section	Period	Average Distance Between Sand Crests (ft)	Average Depth of Scour (ft)
0 + 00	1949-69	231	70
20 + 00	1949-68	200	80
40 + 00	1949-68	210	1 0
60 + 00	1949-68	215	95
80 + 00	1949-68	181	1 03
100 + 00	1949-68	304	75
120 + 00	1949-68	273	1 17
140 + 00	1949-68	178	1 3
160 + 00	1949-68	198	1 0
180 + 00	1949-68	363	78
200 + 00	1949-68	231	73
220 + 00	1949-68	244	83
240 + 00	1961-68	187	83
260 + 00	1961-68	218	1 07
280 + 00	1961-68	373	77
300 + 00	1961-68	311	87
320 + 00	1961-68	423	1 03
340 + 00	1961-68	184	70
360 + 00	1961-68	221	73
380 + 00	1961-68	184	67
400 + 00	1961-68	226	90
420 + 00	1961-68	202	60
440 + 00	1961-68	310	73
460 + 00	1961-68	333	67
470 + 00	1961-68	279	60
	Average	251	84

TABLE III

PANTHER POINT

MATAGORDA - PORT ARANSAS, TEXAS

Section	Date	Distance Between Sand Crests* (In Feet)	Avg	Depth of Scour, Ft	Avg
0 + 00	5/23/1967	85, 40, 50, 100, 70, 140, 100, 65	81		
0 + 00	11/5/1967	45, 100, 150, 150, 110, 85	107		
0 + 00	7/26/1968	104, 160	132	0 2, 0 5	0 35
0 + 00	10/10/1968	47, 57	52	0 4, 0	0 2
0 + 00	1/9/1969	150	150	0 3	0 3
0 + 00	3/10/1969	80	80	0 25	0 25
0 + 00	7/15/1969	165	165	0 8	0 8
0 + 00	1/21/1970	100	100	0 3	0 3
10 + 00	5/23/1967	45, 85, 70, 115, 95, 100, 70, 70	81		
10 + 00	11/5/1967	60, 90, 140, 160, 90, 100	107		
10 + 00	7/26/1968	152, 95	123	0 4, 0 6	0 5
10 + 00	3/10/1969	110, 40	75	0, 0	0
10 + 00	7/15/1969	95, 105, 90	97	0 4,0 2,0 15	0 25
20 + 00	5/23/1967	165, 70, 90, 100, 75, 95, 65, 125	98		
20 + 00	11/5/1967	70, 105, 180, 125, 45, 140	111		
20 + 00	7/25/1968	165	165	0 9	0 9
20 + 00	7/9/1969	283	283	0 8	0 8
20 + 00	3/10/1969	95	95	0 2	0 2
20 + 00	7/15/1969	190, 97	143	0 3, 0 8	0 55
20 + 00	1/21/1970	300	300	0 5	0 5
30 + 00	5/23/1967	100, 70, 60, 165, 75, 85, 80, 125	95		
30 + 00	11/5/1967	50, 115, 195, 125, 40, 180	118		
30 + 00	7/26/1968	235	235	0 6	0 6
30 + 00	1/9/1969	210	210	0 7	0 7
30 + 00	3/10/1969	95, 45, 75	72	0 4,0 2,0 1	0 22
30 + 00	7/15/1969	115, 207	161	0 4, 0 5	0 45
30 + 00	1/21/1970	153, 45	100	0 5, 0 4	0 45
All Sections	5/23/1967	Average	89		
All Sections	11/5/1967	Average	111		
All Sections	7/26/1968		152		0 33
All Sections	10/10/1968		52		0 20
All Sections	1/9/1969		214		0 6
All Sections	3/10/1969		77		16
All Sections	7/15/1969		133		44
All Sections	1/21/1970		150		43
0 + 00		Average	121	Average	46
10 + 00			97		25
20 + 00			171		59
30 + 00			142		48

* Some of the data relate to sand bars formed during the hurricanes which are now above water surface

TABLE IV

YARBOROUGH PASS

PADRE ISLAND, TEXAS

Section	Date	Distance Between Sand Crests* (In Feet)	Avg	Depth of Scour, Ft	Avg
0 + 00	5/19/1967	160	160		
0 + 00	11/9/1967	160	160		
0 + 00	6/19/1968	160, 190	175		
0 + 00	1/7/1969	140	140	1	2
0 + 00	3/5/1969	110, 100	105	0 2, 1	0 6
0 + 00	7/11/1969	225	225	1 9	1 9
0 + 00	1/20/1970	125, 132	128	1 1, 1 5	1 3
10 + 00	5/19/1967	165	165		
10 + 00	11/9/1967	135	135		
10 + 00	6/19/1968	120, 210	165		
10 + 00	1/7/1969	115	115	2 5	2 5
10 + 00	7/11/1969	118	188	2 75	2 75
10 + 00	1/20/1970	110, 150	130	1 1, 1 5	1 3
20 + 00	5/19/1967	145	145		
20 + 00	11/9/1967	135	135		
20 + 00	6/19/1968	85, 250	168		
20 + 00	1/7/1969	125	125	1 8	1 8
20 + 00	3/5/1969	110	110	2 65	2 65
20 + 00	7/11/1969	215	215	2 0	2 0
20 + 00	1/20/1970	105, 110	107	1 0, 1 0	1 0
30 + 00	5/19/1967	175	175		
30 + 00	11/9/1967	110	110		
30 + 00	6/19/1968	145, 240	193		
30 + 00	7/11/1969	160	160	2 0	2 0
30 + 00	1/20/1970	210	210	2 4	2 4
All Sections	5/19/1967	Average	161		
All Sections	11/9/1967	Average	135		
All Sections	6/19/1968	Average	175		
All Sections	1/7/1969		127		2 25
All Sections	3/5/1969		108		0 88
All Sections	7/11/1969		197		2 16
All Sections	1/20/1970		135		1 37
0 + 00		Average	156	Average	1 5
10 + 00			150		2 2
20 + 00			159		2 1
30 + 00			170		2 2

* Some of the data relate to sand bars formed during the hurricanes which are now above water surface

TABLE V

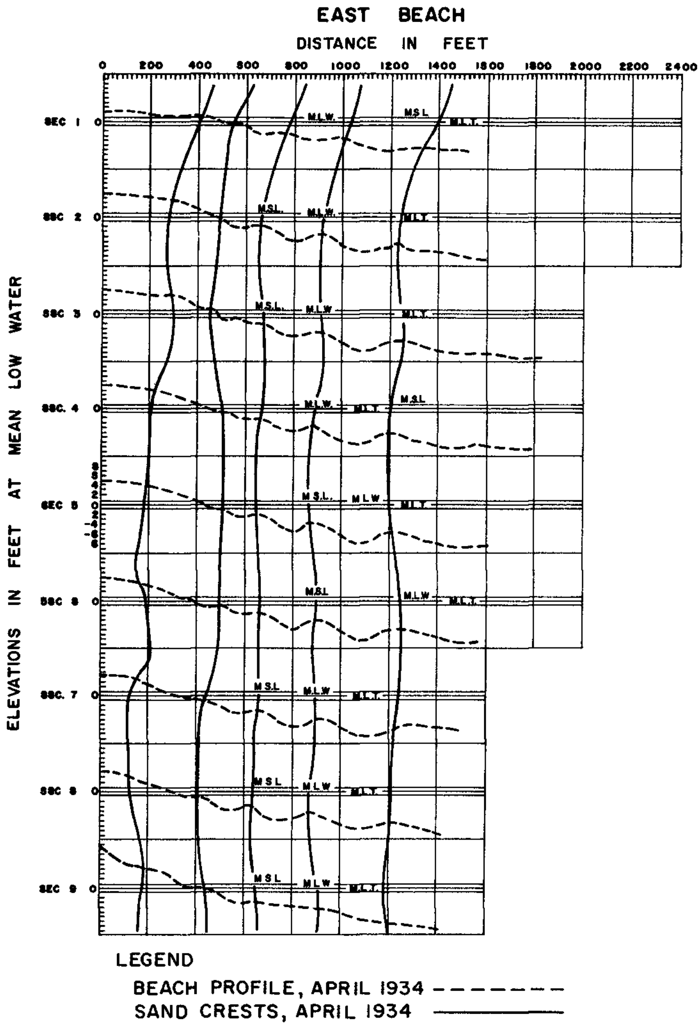
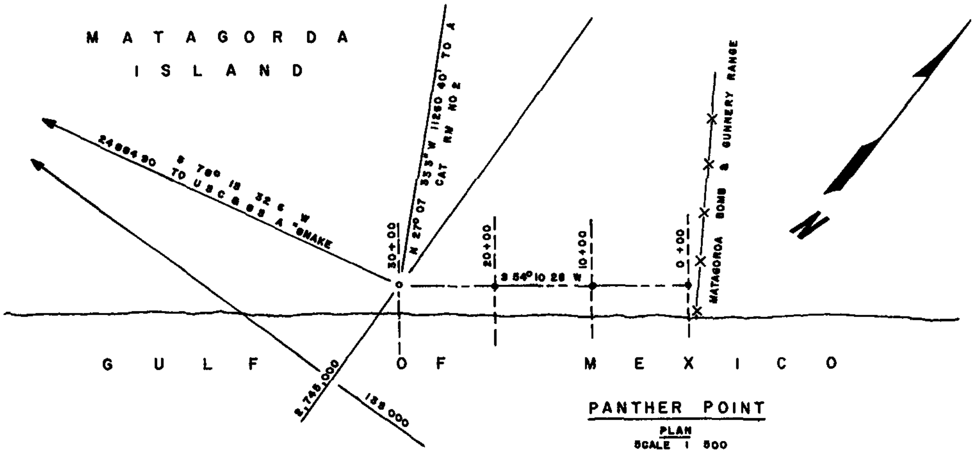
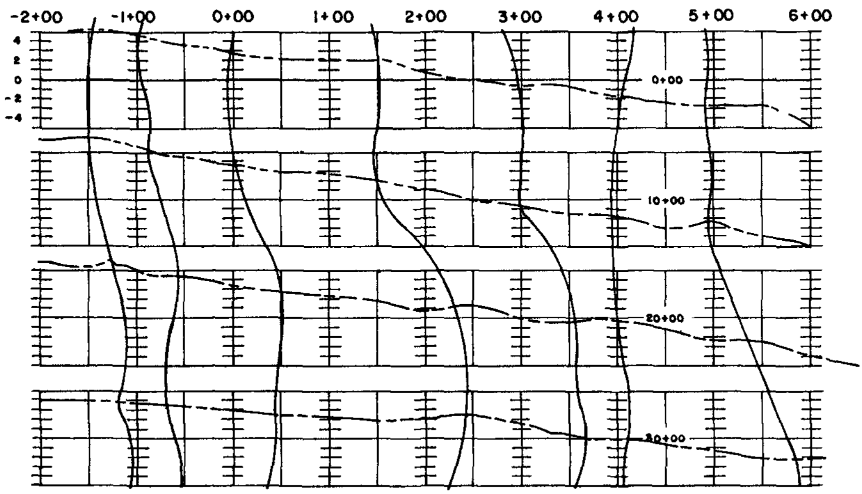


FIG 3 BEACH PROFILE AND SAND CRESTS AT EAST BEACH, GALVESTON (FROM REF 7)





LEGEND
BEACH PROFILE, 5 NOV 1967 – – – –
SAND CREST, 5 NOV 1967 ———

FIG 4 BEACH PROFILE AND SAND CRESTS AT PANTHER POINT (FROM REF 7)

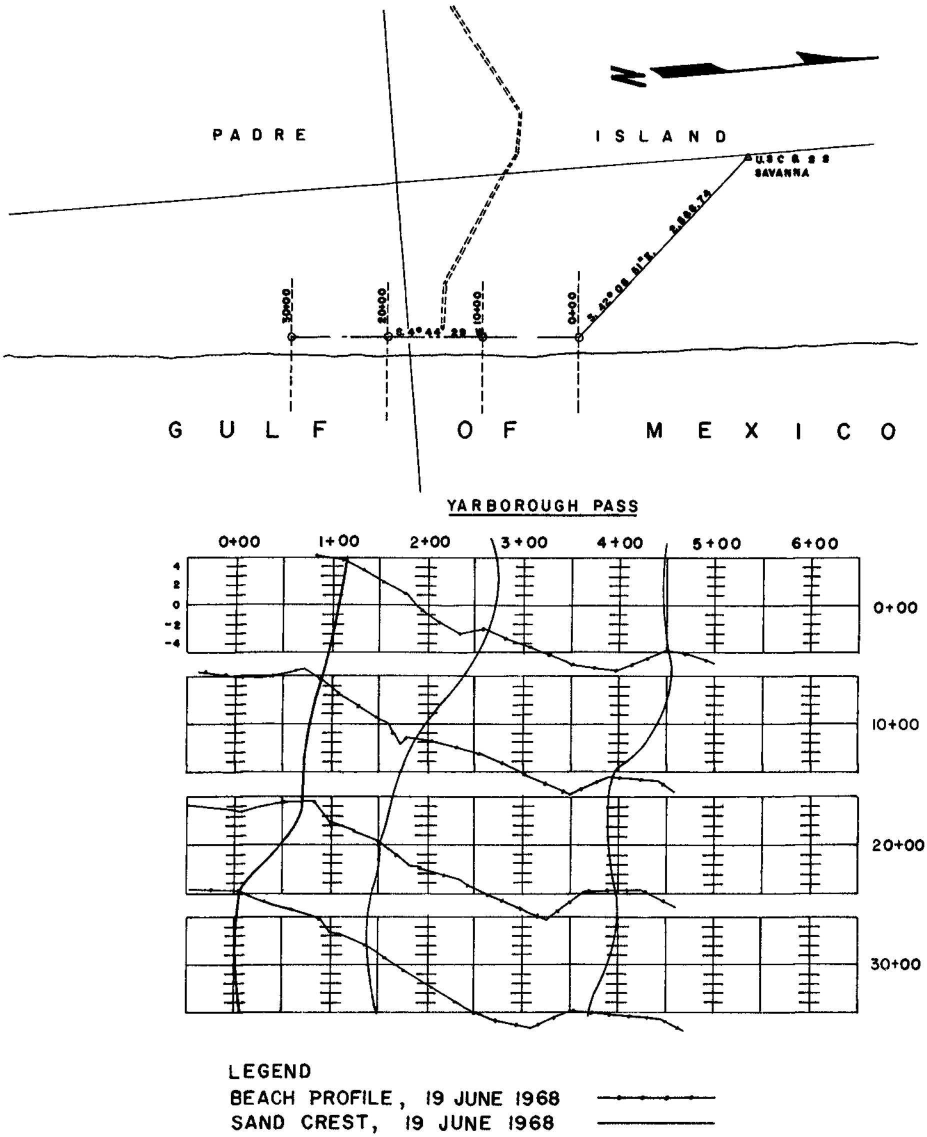


FIG 5 BEACH PROFILE AND SAND CRESTS AT YARBOROUGH PASS (FROM REF 7)

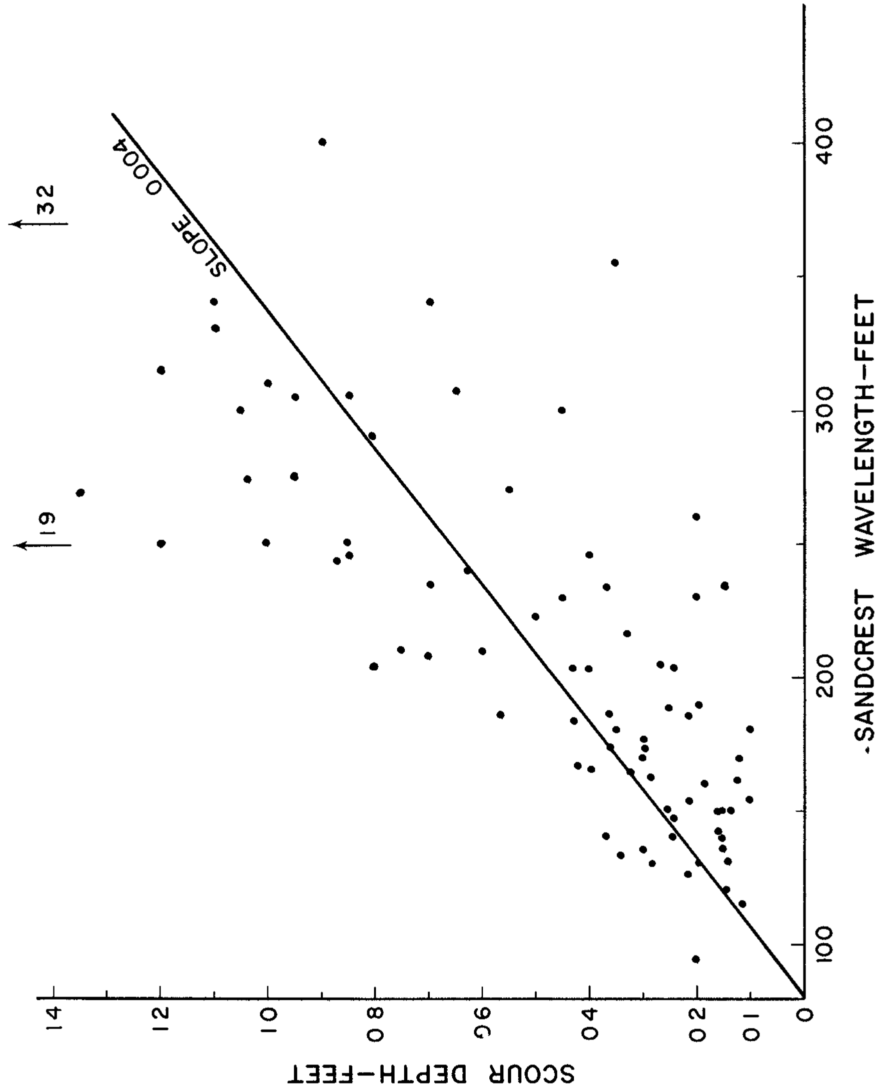


FIG 6 RELATIONSHIP BETWEEN DEPTH OF SCOUR AND SCOUR WAVE LENGTH FOR EAST BEACH AT GALVESTON, TEXAS

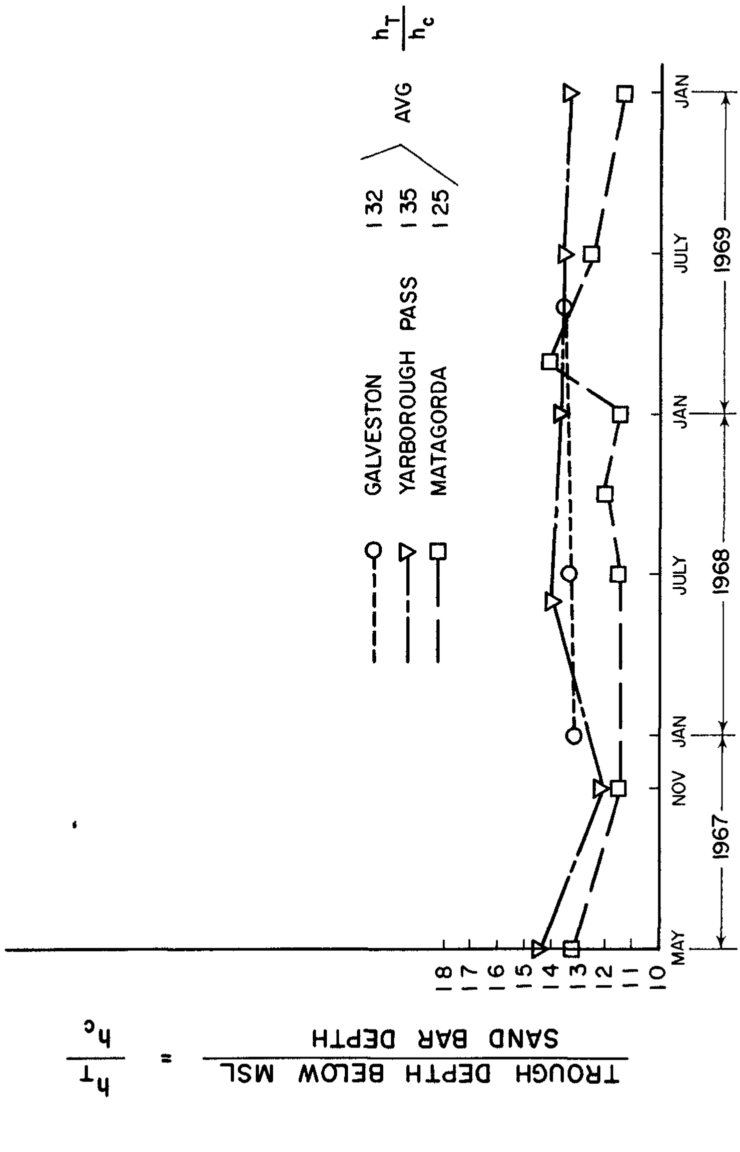


FIG 7 TROUGH DEPTH-SAND BAR DEPTH RATIO AS A FUNCTION OF TIME

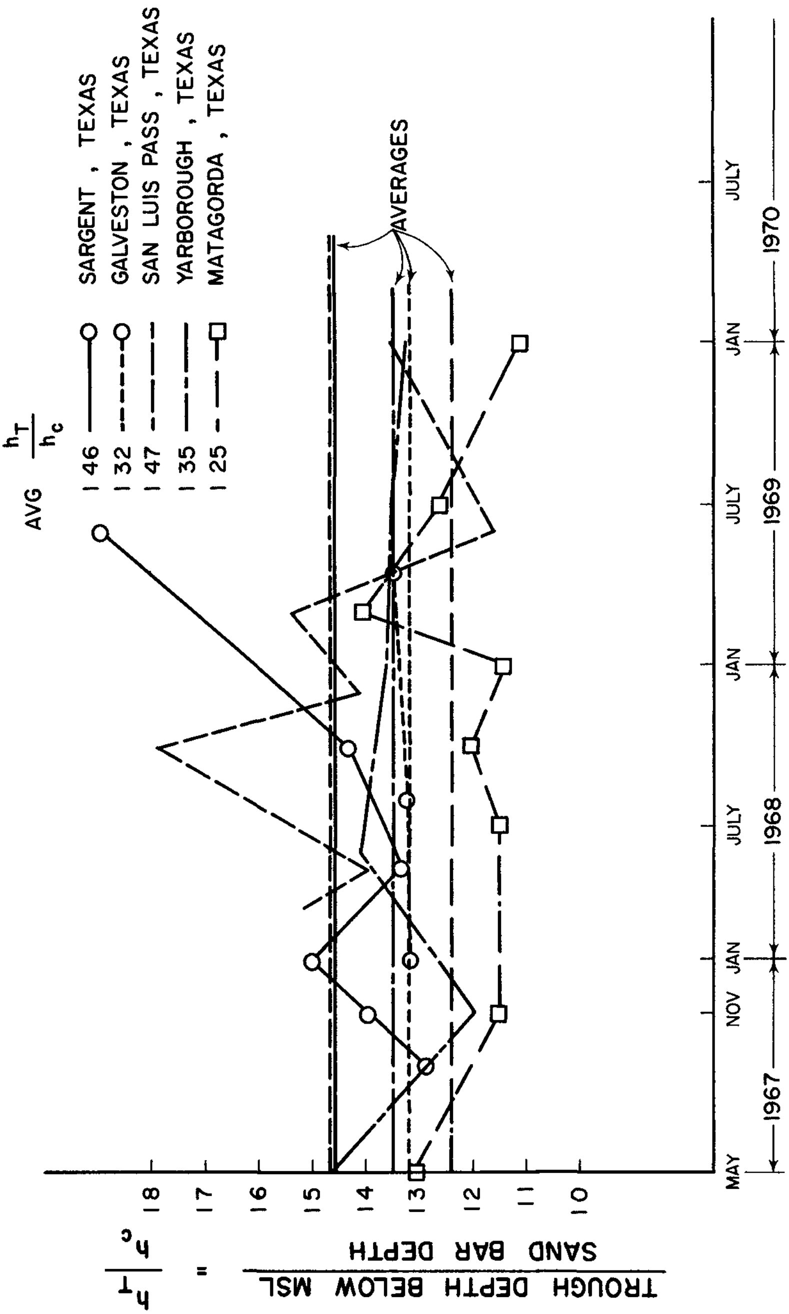


FIG 8 TROUGH DEPTH—SANDBAR DEPTH RATIO AS A FUNCTION OF TIME FOR SEVERAL TEXAS LOCATIONS

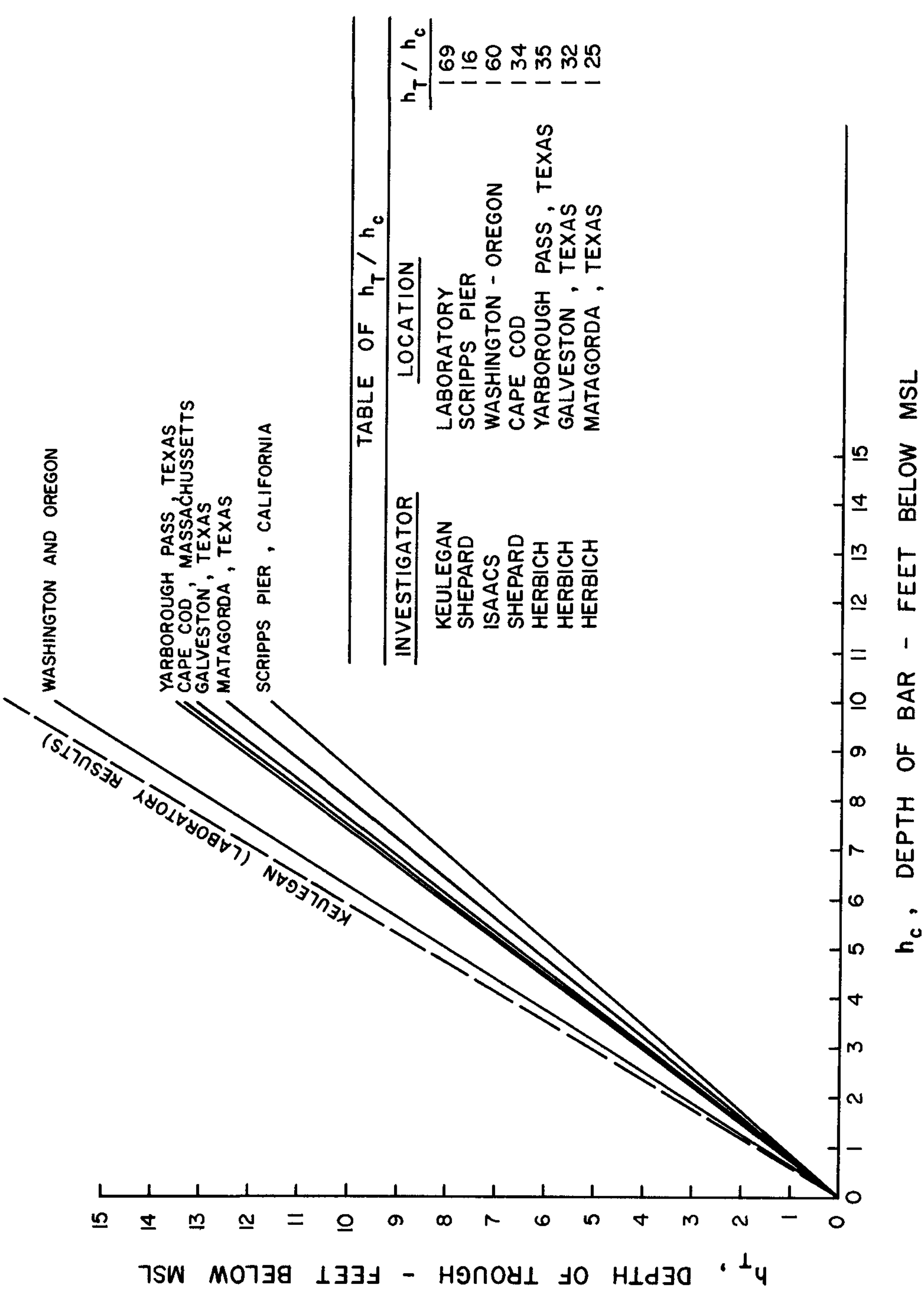


TABLE OF h_T / h_c

INVESTIGATOR	LOCATION	h_T / h_c
KEULEGAN	LABORATORY	1 69
SHEPARD	SCRIPPS PIER	1 16
ISAACS	WASHINGTON - OREGON	1 60
SHEPARD	CAPE COD	1 34
HERBICH	YARBOROUGH PASS , TEXAS	1 35
HERBICH	GALVESTON , TEXAS	1 32
HERBICH	MATAGORDA , TEXAS	1 25

FIG 9 RELATIONSHIP BETWEEN DEPTH OF TROUGH AND DEPTH OF BAR

Relationship Between Waves and Beach Scour

Analyses of Texas beach profiles indicate that in most cases more than one bar-trough complex formation was created by wave action Laboratory experiments by Herbich and Ko (1) and by Sato et al (2) have revealed that the distance between suceeding bar crests is a function of wave length, and was generally equal to one half the wave length generated, for several sand sizes employed

In general wave data for locations where beach profiles are measured are very scarce, or difficult to obtain For the purpose of this analysis wave data taken during hurricane Beulah (October 1967) at Galveston were obtained from the Coastal Engineering Research Center (9) The wave data were analyzed, using spectral methods, and equivalent wave height and period at maximum spectral density were obtained

Beach profiles taken in January, 1968 were also analyzed The results of the analyses are as follows

Location	Average Length Between Crests (ft)	Average Deep** Water Wave Length (ft)	Average* Wave Length at 18' Depth	Average Scour Depth (ft)	Equivalent** Wave Height (ft)
East Beach	330	261	159	0 86	5 36
Groin Area	312	261	159	0 76	5 36

* Wave gauge was located at 18 ft depth
**Analyzed using power spectrum method

Comparison of the beach profiles at Galveston indicates that the average spacing between crests was greater than the deep water wave length and about twice as long as the average wave length at 18 ft depth, which does not agree with laboratory studies The relationship between average scour depth and the average wave height is approximately equal to 0 160 for the East Beach area and equal to 0 142 for the Groin area

CONCLUSIONS

Definite relationship exist between

(1) trough depth and sand crest depth

(2) average length between sand crests and the average wave length

(3) average scour depth and average wave height

(4) additional studies, particularly in the field, should be conducted

ACKNOWLEDGEMENT

Cooperation of Galveston District of U S Army Engineers in providing beach profile data along the Texas Coast is appreciated Assistance of Miss Rosella Duke, a civil engineering student and Messrs Ch Chestnutt, C McClenan and C Mason, graduate students in coastal and ocean engineering in data reduction is acknowledged

REFFRENCES

1 Herbich, J B and S C Ko, "Scour of Sand Beaches in Front of Seawalls", Proceedings of the Eleventh Conference on Coastal Engineering, London, England, Chapter 40, pp 622-643, September 1968

2 Sato, S , M Tanaka and I Irie, "Study on Scouring at the Feet of Coastal Structures", Proceedings of the Eleventh Conference on Coastal Engineering, London, England, Chapter 37, pp 579-598, September 1968

3 Otto, T , "Der Darss und Zingst", Jahresber Geogr Ges Greisswald, Vol 12, 1911-12

4 Hartnack, W , "Uber Sandriffe", Jahresber Geogr Ges Greisswald, Vol 40-42, 1924

5 Keulegan, G H , "An Experimental Study of Submarine Sand Bars", Technical Report No 3, Beach Erosion Board, Corps of Engineers, U S Army, 40 pp , 1948

6 Shepard, F P , "Longshore-Bars and Longshore-Troughs", Technical Memorandum No 15, Beach Erosion Board, Corps of Engineers, U S Army, 31 pp , January 1950

7 "Texas Coast Inlet Studies", Galveston District, Corps of Engineers, U S Army, 1968, 1969

8 Evans, O F , "The Low and Ball of the Eastern Shore of Lake Michigan", Journal of Geology, Vol 48, p 476, 1940

9 Personal communication from Dr Harris, Coastal Engineering Research Center, U S Army Corps of Engineers, August 1970