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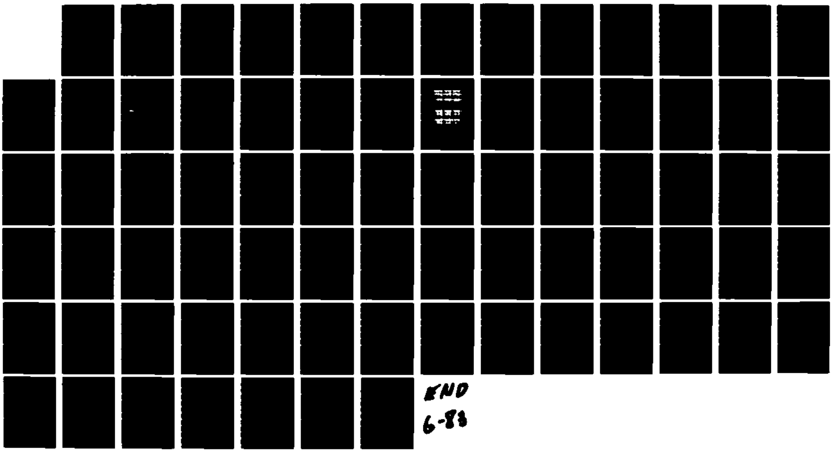

MR 83-1

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The Elevation and Duration of Wave Crests

by

William N. Seelig, John P. Ahrens,

and

William G. Grosskopf

MISCELLANEOUS REPORT NO. 83-1

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The stream-function wave theory of Dean (1974) is used together with monochromatic and irregular laboratory wave data to develop methods for estimating the elevation and duration of wave crests. The resulting prediction techniques are applied to a wide range of wave conditions measured at CERC's Field Research Facility in Duck, North Carolina, and are shown to give reliable and often conservative estimates of crest elevation. The techniques presented in this report can be used for both nonbreaking and breaking wave conditions.

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PREFACE

As waves move toward the shoreline they become increasingly nonlinear with the elevation of the wave crests becoming relatively large and short in duration. This report is published to provide coastal engineers with techniques for estimating crest elevation and duration. The techniques were developed using laboratory data from a number of sources covering a wide range of conditions for both monochromatic and irregular waves under nonbreaking and breaking conditions. Predictions compare favorably with wave observations made at the U.S. Army Coastal Engineering Research Center's (CERC) Field Research Facility at Duck, North Carolina. The work was carried out under CERC's Wave Estimation for Design work unit, Coastal Flooding and Storm Protection Program, Coastal Engineering Area of Civil Works Research and Development.

This report was prepared by William N. Seelig, Research Hydraulic Engineer, John P. Ahrens, Oceanographer, and William G. Grosskopf, Hydraulic Engineer, under the general supervision of Dr. R.M. Sorenson, Chief, Coastal Processes and Structures Branch and Mr. R.P. Savage, Chief, Research Division.

Technical Director of CERC was Dr. Robert W. Whalin, P.E.

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TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.
To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

SYMBOLS AND DEFINITIONS

A_1, A_1^*, A_2, A_3	empirical coefficients
C_1, C_2, C_3	empirical coefficients
d	water depth
d_b	water depth at the breaking point
H	wave height
H_b	breaking wave height
H_o'	unrefracted deepwater significant wave height
H_s	significant wave height for irregular waves
L_A	wavelength given by Airy wave theory
L_o	deepwater wavelength given by Airy theory
m	beach slope (tangent of the angle between the slope and the horizontal)
p	probability level of exceedance
T	wave period
T_c	duration of wave crest
T_p	period of peak energy density for irregular waves
T_t	duration of the wave trough
$(\overline{T_c/T})_p$	mean dimensionless crest duration for all crests above the probability of exceedance level, p
U_R	Ursell number = HL_A^2/d^3
η	water level
η_b	crest elevation at breaking
η_c	elevation of the wave crest above the mean water level (MWL)
$(\eta_c)_p$	elevation of wave crest associated with a probability of exceedance, p
η_{rms}	root-mean-square (rms) water level
η_t	elevation of wave trough (negative)

THE ELEVATION AND DURATION OF WAVE CRESTS

by

William N. Seelig, John P. Ahrens, and *William G. Grosskopf*

I. INTRODUCTION

Coastal structures are generally built to withstand extreme waves that occur infrequently. One of the important aspects of these waves is that they may be highly nonlinear if the wave steepness is large or the relative water depth is small. Two of the important engineering characteristics of nonlinear waves are that the crest elevations are more than half of the wave height and the duration of the crests are less than half of the wave period.

Crest elevation is important because the forces on a structure may be more strongly related to crest elevation above the water level than the trough distance below the water level. Uplift forces on piers and fixed structures are particularly sensitive to wave crest elevation, which is one of the reasons why most offshore platforms and piers are built well above the water level. Crest elevation also influences wave runup and overtopping (Weggel, 1976a).

The relatively short duration of nonlinear wave crests is important, because the combination of high elevation and short duration produces large water particle motions and accelerations. These hydraulic characteristics have the potential for suspending sediment, lifting armor units, and causing surprisingly high drag forces on coastal structures.

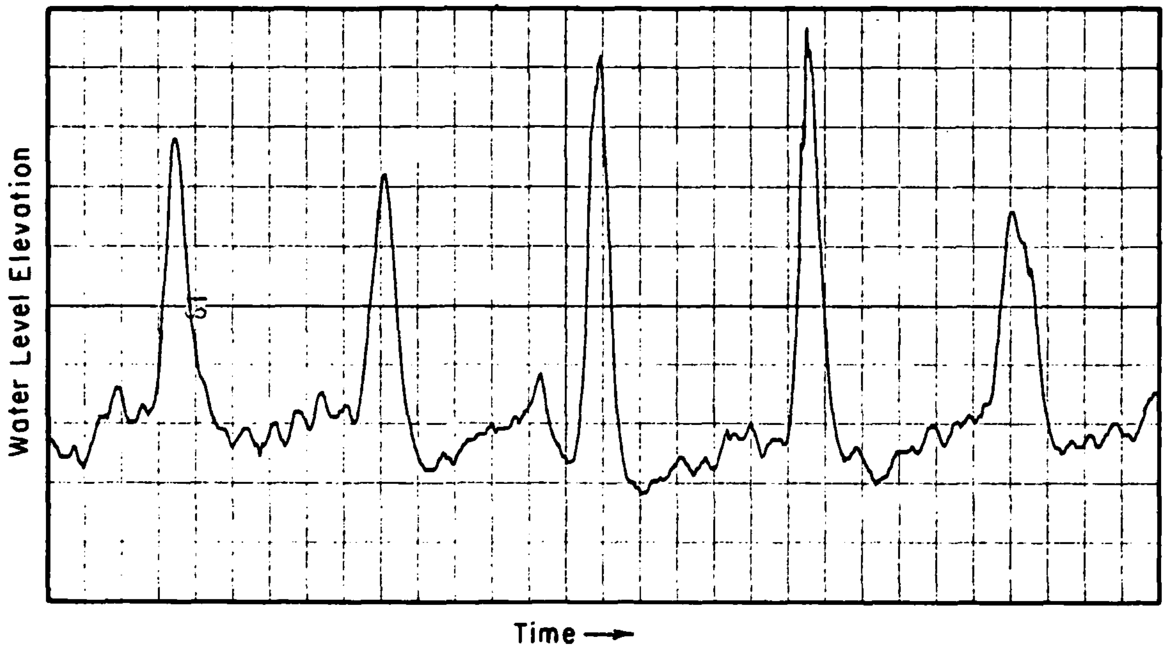
Figure 1 is a sample wave record made as part of the Coastal Engineering Research Center's (CERC) coastal wave collection program (Thompson, 1977). This example clearly shows the high crest elevations and short crest durations that may occur in coastal waters.

This study develops methods of predicting crest elevations and duration for monochromatic and irregular waves. Laboratory waves are used to minimize the influence of refraction, diffraction, irregular topography, directional spread of wave energy, and multiple wave trains on the characteristics of wave crests. Assumed independent variables used in the prediction methods are water depth, wave period or period of peak energy density for irregular waves, wave height (significant wave height for irregular waves), and beach slope. Predictions are compared to selected prototype wave measurements taken at the CERC Field Research Facility (FRF) at Duck, North Carolina.

II. LITERATURE REVIEW

Goda (1964) performed some basic research on the elevation of monochromatic laboratory wave crests. Using his own data and the data of Bretschneider (1958), Goda found that the ratio of wave height to water depth played a dominant role in determining the relative crest elevation. However, there are considerable scatter in the results.

Jahns and Wheeler (1973) and others have performed theoretical derivations of expected crest heights for irregular wave conditions. Without including nonlinear effects they conclude that a Rayleigh-type distribution should



Significant wave height = 1.96 m
Period of peak energy density = 14 s
Water depth (approximately) = 6 m

Figure 1. Example of an extremely nonlinear wave condition (recorded by a CERC continuous-wire staff at Lake Worth, Florida, 28 March 1971 at 0820).

provide an upper limit or conservative estimate of crest elevations corresponding to various probabilities of exceedance. Actual irregular wave data have crests that are higher than given by this theory, so Jahns and Wheeler (1973) suggest an empirical correction factor. One limitation of the correction factor is that the observed probability of exceedance may deviate several or many orders of magnitude from the Rayleigh distribution.

Dean (1974) developed one of the most comprehensive theories to date for predicting properties of monochromatic waves traveling over a flat bottom. This higher order stream-function theory can be used to predict crest elevation and duration for a wide range of wave and water level conditions. The theory indicates that in the Airy limit, where the wave amplitude approaches zero, the wave crest elevation is approximately equal to one-half the wave height and the duration of the crest is half the wave period. In the cnoidal wave limit the crest elevation approaches the wave height and the duration of the crest becomes small compared to the wave period. Figure 2 is an example predicted water level time history for a highly nonlinear wave. In this extreme condition the ratio of crest elevation, η_c, to wave height, H, is $\eta_c/H = 0.90$. The duration of the crest, T_c, is one-fourth the wave period, T, or $T_c/T = 0.25$.

Singamsetti and Wind (1980) presented wave crest characteristics for monochromatic laboratory wave conditions at the point of breaking for constant beach slopes, m, of 1 on 40, 1 on 20, 1 on 10, and 1 on 5.

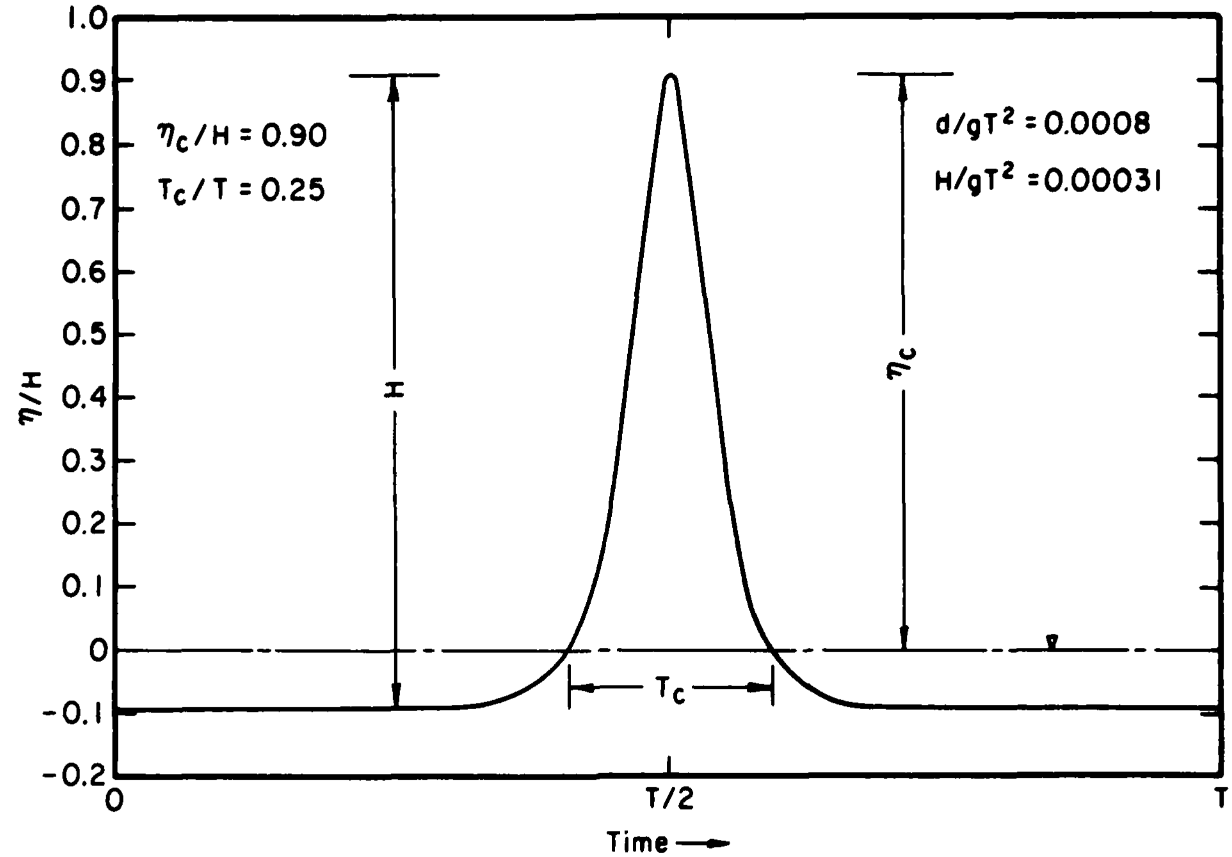


Figure 2. Predicted monochromatic wave profile (after Dean, 1974).

III. SOURCES OF DATA

Sources of data upon which the predictive techniques are based include laboratory data collected by the authors for a wide range of conditions, laboratory data collected by other authors, and field data from the FRF at Duck, North Carolina. Conditions under which these data were collected and methods of analysis are described below.

1. Laboratory Tests Conducted by Authors.

a. Wave Conditions, Data, and Test Setups. Most of the monochromatic wave data and all the irregular wave data collected over a horizontal bottom were obtained in a 105.7-centimeter-wide channel within CERC's 1.2-meter-high by 4.5-meter-wide by 42.6-meter-long wave tank. The monochromatic wave data are tabulated in Appendix A and the irregular wave data are tabulated in Appendixes B and C. A gravel absorber beach with a slope 1 on 12 was used at the end of the channel to reduce wave reflection to a low level. Four paralleled wire resistance-type wave gages were used in the channel to record the wave conditions. A plan view and a profile view of the test setup with gage locations are shown in Figure 3. Figure 4 shows a short section of typical irregular wave records taken approximately simultaneously at each of the four gages. The time axis of the records has been shifted slightly to place the highest crest in the center of each section to show the differences in the time

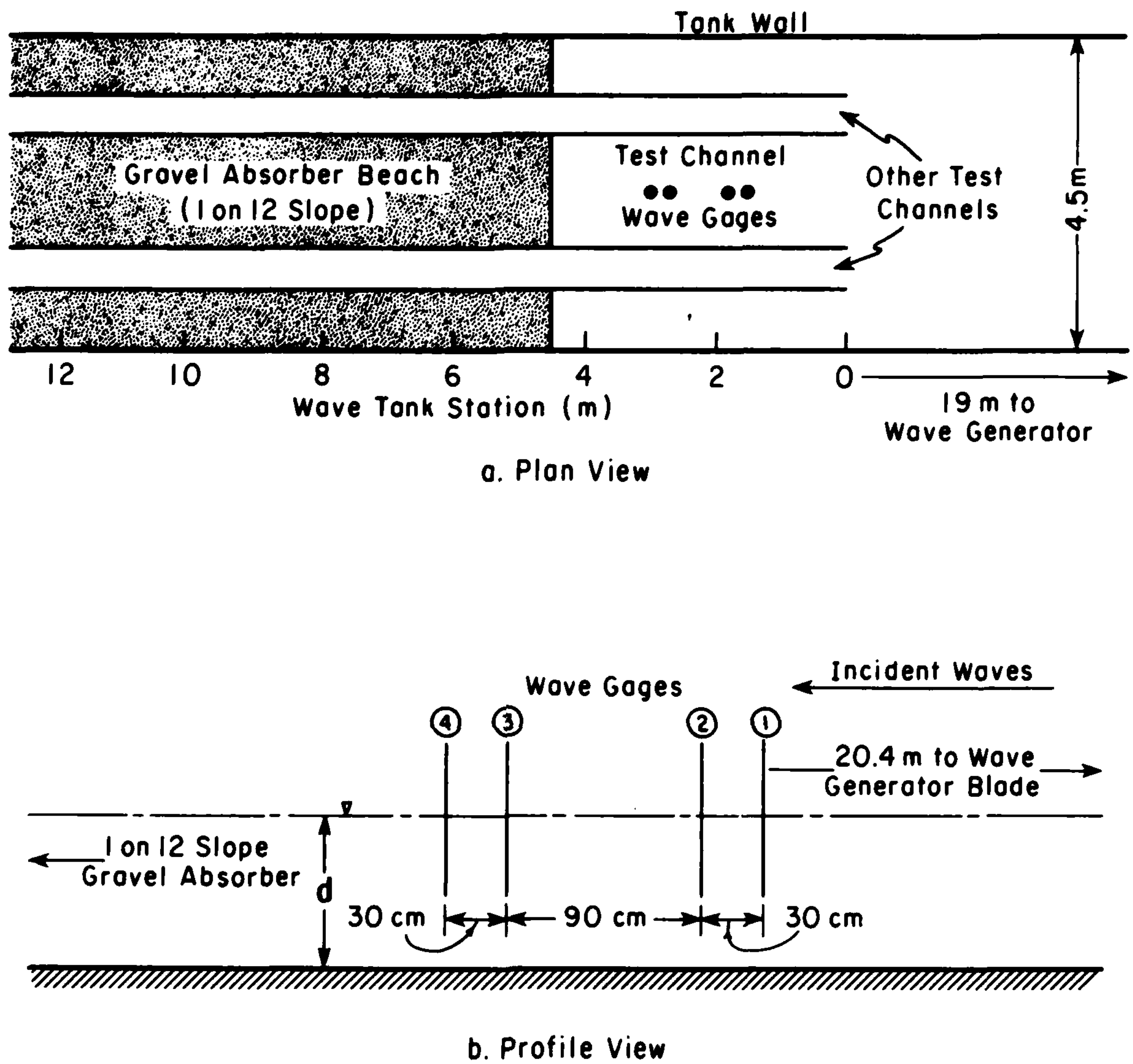


Figure 3. Experimental setup in CERC's 4.5-meter-wide tank.

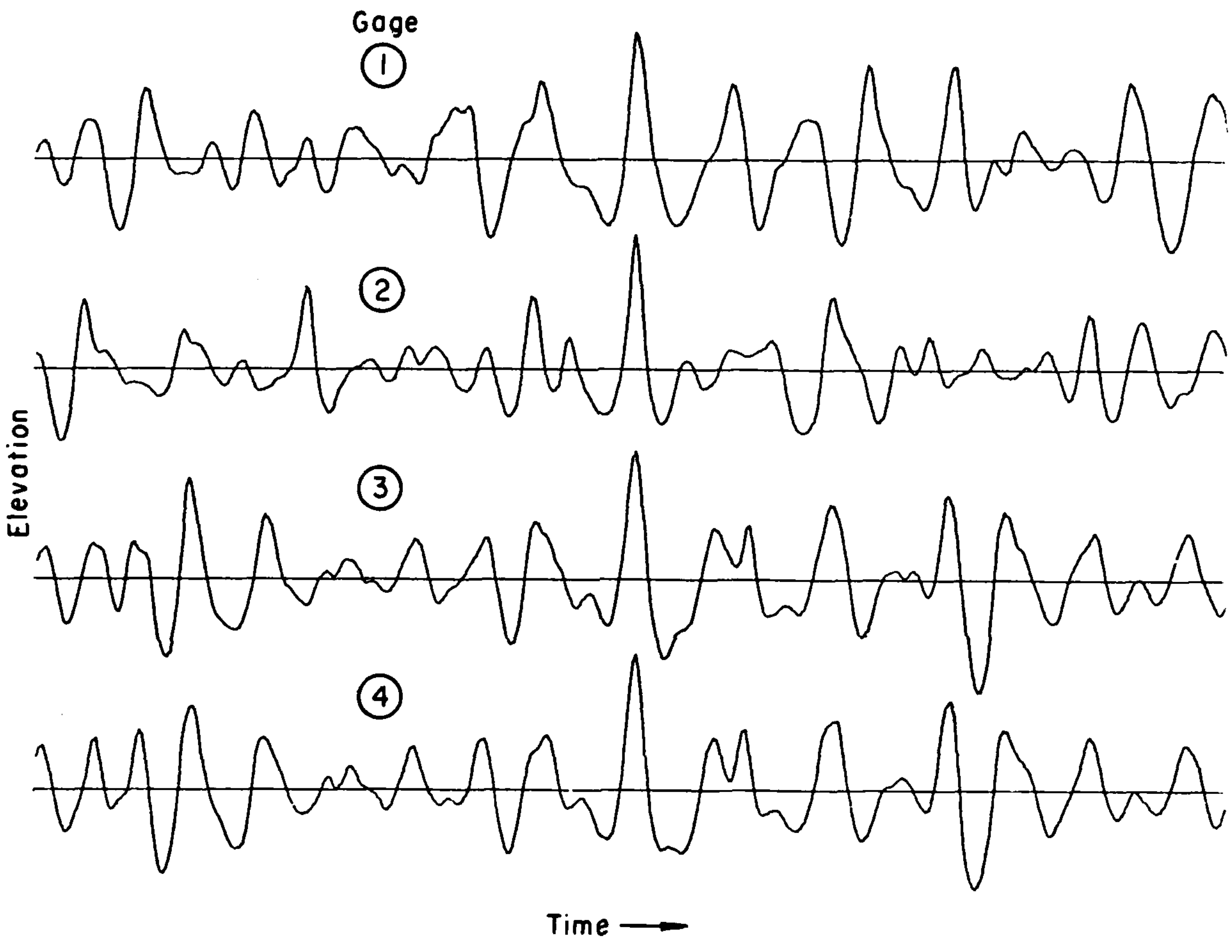


Figure 4. Sample of water level time histories taken at four gages during an irregular wave test (time axis was shifted for the highest crest to appear at the center of each plot).

sequences of the records. Since gages 1 and 4 are the farthest apart they show the greatest differences. The data from gages 1 and 4 are tabulated in Appendixes A, B, and C.

Some additional monochromatic wave data over a horizontal bottom were collected in CERC's 0.9-meter-high by 0.9-meter-wide by 45.7-meter-long wave tank. This tank has a 1 on 30 hogs hair absorber beach to keep reflected wave energy to very low levels. Three parallel wire resistance-type wave gages were used to record the wave conditions. A profile view of the test setup is shown in Figure 5; the data are tabulated in Appendix A.

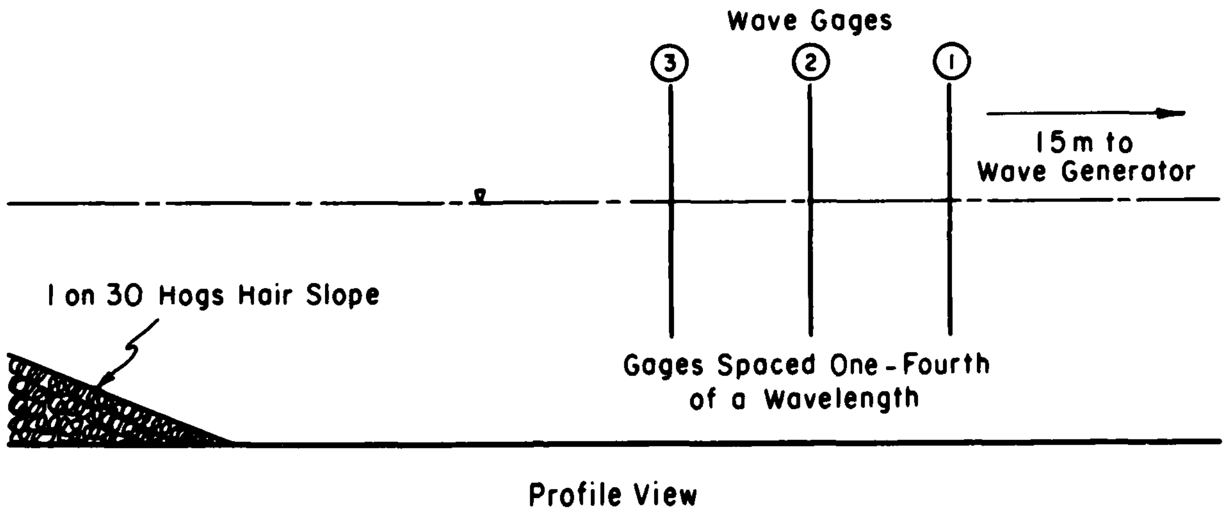


Figure 5. Experimental setup in CERC's 0.9-meter-wide tank.

Wave data were also collected in CERC's 0.9-meter-high by 0.4-meter-wide by 45.7-meter-long wave tank. The setup in this tank was designed to obtain data on the shoaling and breaking of irregular waves. Ten parallel wire wave gages were used: three gages over the horizontal tank bottom and seven over a 1 on 3 concrete slope. Figure 6 shows a profile view of the test setup and gage locations; the data are tabulated in Appendix D.

Table 1 provides a summary of the wave conditions, data and test setups used in the laboratory tests.

b. Procedures and Analysis. All the waves were generated using hydraulically actuated piston-type wave makers. The monochromatic waves studied included waves with sinusoidal blade motion with Ursell numbers less than 25 and cnoidal waves with Ursell numbers greater than 25. The Ursell number, U_R, is defined

$$U_R = \frac{HL_A^2}{d^3} \tag{1}$$

where H is the average wave height over the flat bottom part of the wave tank and L_A the local wavelength, calculated using linear theory and defined by

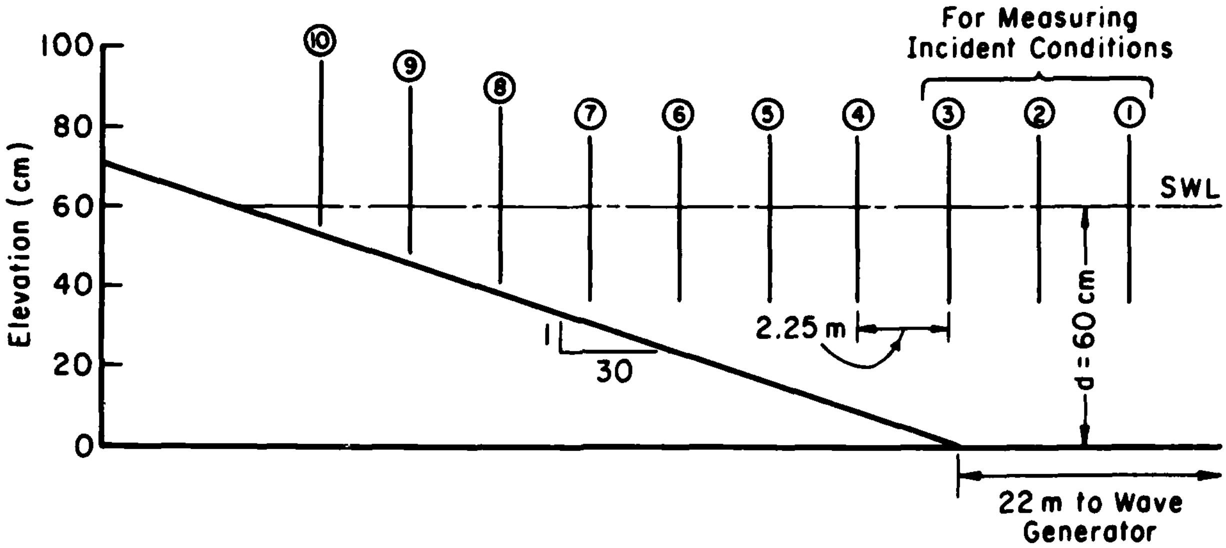


Figure 6. Experimental setup in CERC's 0.4-meter-wide tank

Table 1. Summary of CERC laboratory test data.

Wave tank	Wave conditions	Bottom slope	Test setup, Fig. No.	Data in App.
1.2 by 4.5 by 42.6 m	Monochromatic	Horizontal	3	A
1.2 by 4.5 by 42.6 m	Irregular	Horizontal	3	B, C
0.9 by 0.9 by 45.7 m	Monochromatic	Horizontal	5	A
0.9 by 0.4 by 45.7 m	Irregular	Horizontal and 1 on 30	6	D

$$L_A = \frac{gT^2}{2\pi} \tanh\left(\frac{2\pi d}{L_A}\right) \qquad (2)$$

where T is the wave period and d the water depth. For sinusoidal blade motion the restriction on the Ursell number was to eliminate the influence of secondary waves; the cnoidal wave data were collected by Weggel (1976b) and are discussed in Section 2.

The irregular waves used in this study included a wide range of spectral types and relative depths. Spectra were simulated by taking various theoretical spectra, such as Pierson-Moskowitz, Joint North Sea Wave Project (JONSWAP), Bretschneider, and the six-parameter spectra of Ochi and Hubble (1976), and slicing the spectra into 60 equal area segments with each segment represented by a sinusoidal component at the frequency of the midpoint of the segment. Each component was transformed into a piston blade motion using Biesel's equation (Biesel, 1951) at the given frequency and assuming a random-phase relation among the components. The time histories of the 60 components were linearly superimposed to determine the generator blade motion. Figure 7 shows a sample of observed and predicted wave spectra.

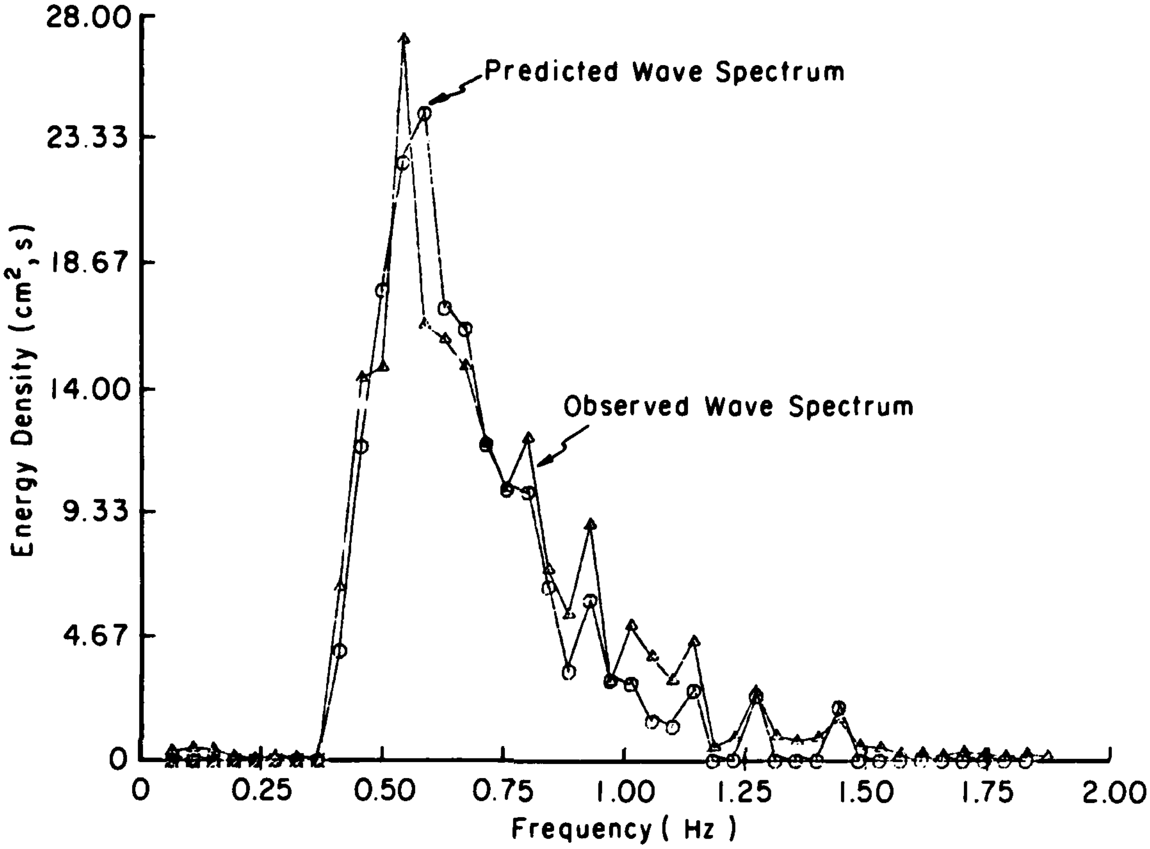


Figure 7. Observed and predicted wave spectra (sample of Pierson-Moskowitz spectra).

In all tests the water surface time history was recorded at each wave gage for 4,096 data points. A sampling rate of 16 times per second was used for waves with periods less than 3 seconds, and a rate of 8 times per second was used for waves with periods greater than 3 seconds. The data were digitized and recorded on magnetic tape through the use of a Data Acquisition System (DAS). An analysis of the tapes was performed later on a general-purpose computer.

Two distinct types of data analysis were performed on the digitized wave records: a fast Fourier transform (FFT) and a zero up-crossing analysis. The FFT was used to determine the spectrum of the wave record, such as shown in Figure 7, which in turn was used to determine the period of peak energy density. The period of peak energy density, Tp, is the reciprocal of the frequency of the midpoint of the 11 consecutive spectral lines with the most wave energy. The zero up-crossing method of analysis is used to determine the wave heights, crest heights, wave periods, and crest durations of individual waves in irregular wave trains or average values for monochromatic wave trains. Crest height, η_c, is measured relative to the mean water level (MWL) and crest duration, T_c, is the time difference between an adjacent zero up-cross and a zero down-cross; zero indicates the MWL of the record. The significant wave height, H_s, for irregular waves was computed by multiplying the root-mean-square (rms) water surface displacement by four. All the analysis was based on the assumption that there was no wave reflection in any of the channels where data were collected.

For irregular wave conditions the elevations of the wave crests were ranked from the highest to the lowest and the probability of exceedance, p, for various levels of probability were calculated. For example, $\eta_{0.01}$ indicates a crest height with a probability of being exceeded by 1 percent of the crest heights, i.e., p = 0.01. Since the larger waves were of the most interest the following probability levels for crest heights were calculated: p = 0.005, 0.01, 0.02, 0.05, 0.10, 0.135, 0.15. Dimensionless wave crest height probability levels, $(\eta_c)_p/H_s$, for wave gages 1 and 4 of the test setup shown in Figure 3 are tabulated in Appendix B. The mean dimensionless crest duration, $(\overline{T_c/T})_p$, was also determined for the highest 5, 10, 15, 20, 25, 33, and 100 percent of the wave crests for gages 1 and 4 and is tabulated in Appendix C.

2. Other Laboratory Tests Used.

Weggel (1976b) conducted tests using nonsinusoidal blade motion to generate cnoidal waves. These waves have Ursell numbers between 27 and 184 and are relatively free of secondary waves. The cnoidal wave conditions are given in Appendix E.

Singamsetti and Wind (1980) studied the breaking of monochromatic waves on a number of smooth laboratory slopes. The relative crest elevations at breaking η_b/H_b and the relative crest durations at breaking, $(\overline{T_c/T})_b$ are tabulated in Appendix A, where η_b is the height of the crest above MWL at breaking, H_b is the wave height at breaking, and T is the period of a monochromatic wave.

3. Prototype Data Used.

Prototype wave data collected at FRF, Duck, North Carolina, are used in this study, particularly the data measured during a major storm in October 1980 in which a large variety of wave steepnesses were observed. The gages were Waverider buoys located 0.5, 3, 6, and 12 kilometers from shore in an area where the bottom contours were generally straight and parallel. The dominant wave direction was approximately along the line of the instruments. The data were analyzed in the same manner as that previously described for the laboratory data.

IV. TEST RESULTS AND PREDICTION TECHNIQUES FOR MONOCHROMATIC WAVES

Monochromatic laboratory wave test results are compared with Dean's stream-function wave theory (1974) and the resulting prediction techniques are discussed.

1. Monochromatic Wave Crest Elevations.

a. Waves Traveling Over a Horizontal Bottom. Dean (1974) developed a stream-function wave theory to predict a number of wave characteristics for waves propagating over a flat horizontal bottom for a number of relative depths and wave heights equal to 0.25, 0.50, 0.75, and 1.00 of the breaking limit. An examination of the tabular values of η_c/H (Dean, 1974, Vol. II) shows that relative crest height can be approximated using the empirical relation:

$$\frac{\eta_c}{H} = \frac{A_1}{1.0 + \tanh\left[-A_2 \,\ell n \left(A_3 \frac{H}{L_o}\right)\right]} \tag{3}$$

where L_o is the deepwater wavelength given by Airy theory as

$$L_o = \frac{gT^2}{2\pi} \tag{4}$$

Wave trough elevation, η_t, is equal to wave height minus crest elevation. Dean's tabular results are compared with equation (3) and A_1 is found to be 1.0 for wave traveling over a flat bottom (m = 0.0). Values of A_2 and A_3 are functions of relative depth (d/L_o or $d/(gT^2)$), as shown in Figure 8 and given in Table 2.

Laboratory data in this study show excellent agreement with Dean's stream-function theory and give a value $A_1 = 0.992 \pm 0.0393$ (Table 3). Cnoidal waves ($U_R > 25$) have slightly smaller values of this empirical parameter with $A_1 = 0.95 \pm 0.038$ (Table 3).

b. Waves on a Slope. Singamsetti and Wind's (1980) data are used to evaluate A_1 for monochromatic waves at the breaking point on various beach slopes. Wave crest elevations, as indicated by A_1, decrease approximately linearly with beach slope, m (Table 3, Fig. 9). For example, waves at the breaking point on a 1 on 5 slope (m = 0.20) have only 67 percent of the crest elevations of a wave with same $H/(gT^2)$ and $d/(gT^2)$ traveling over a flat bottom.

Figure 10 illustrates the predicted influence of beach slope on the breaking crest elevation for a sample wave tank condition. In this case waves in the incident flat part of the tank have $d/(gT^2) = 0.019$ and $H/d = 0.37$. The figure shows the predicted crest elevation at the breaking point using the method described in Appendix F for estimating η_c. In this example slopes flatter than 1 on 20 have little influence on the crest elevation, while slopes steeper than 1 on 20 produce lower crest elevations.

2. Crest Elevation Prediction Aids.

Equation (3), which is used for predicting monochromatic wave crest elevations, can be presented in a number of graphical forms useful for predicting and understanding trends in relative crest elevation. Figure 11 shows η_c/H versus relative depth for various wave steepnesses. Relative crest elevation,

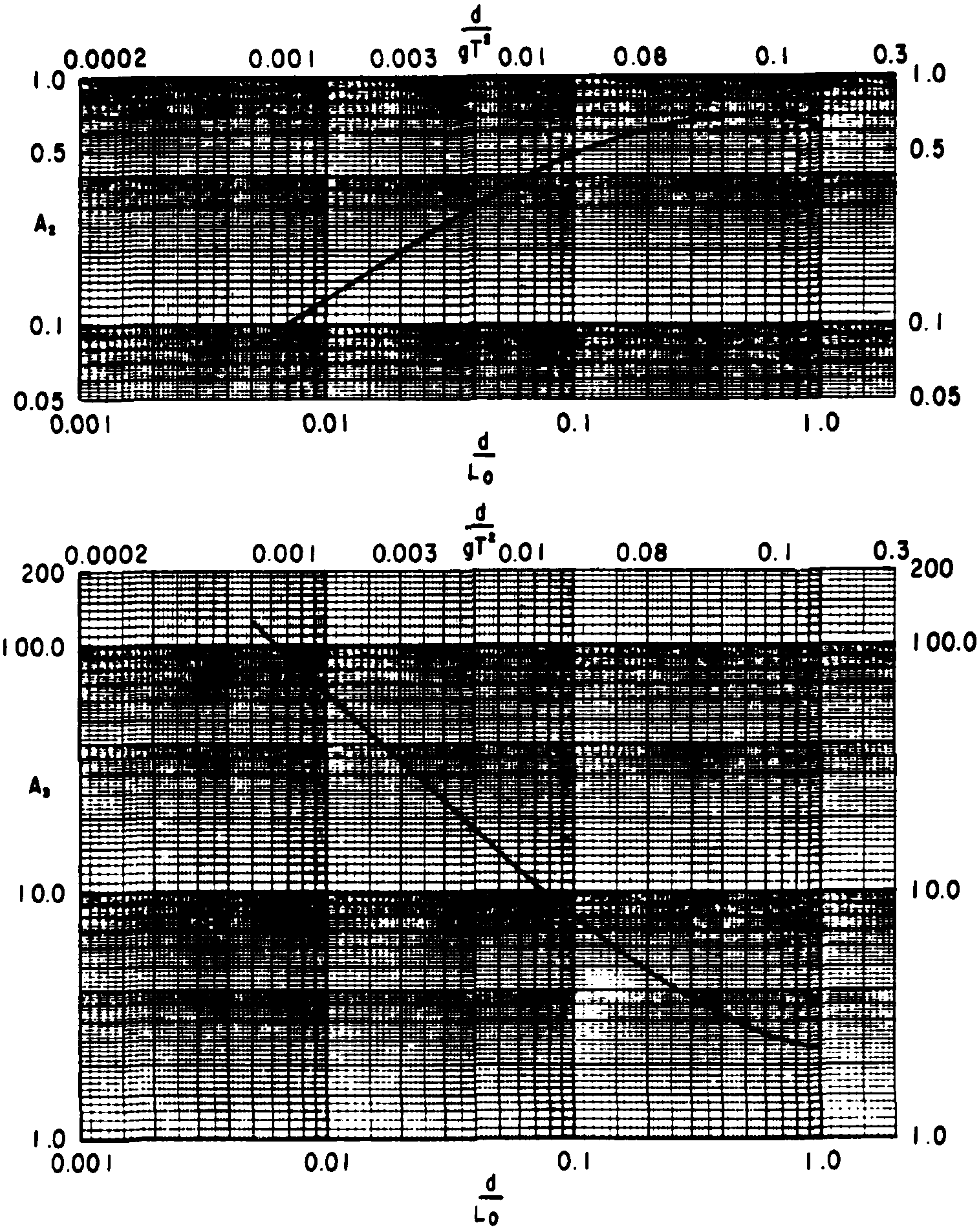


Figure 8. Empirical coefficients A_2 and A_3 for estimating η_c/H.

Table 2. Values of the empirical coefficients A_2 and A_3 for predicting relative crest.[1]

d/L_o	d/gT^2	A_2	A_3
0.005	0.000796	0.0791	125.9
0.01	0.00159	0.124	67.6
0.02	0.00318	0.197	35.5
0.05	0.00796	0.353	15.07
0.10	0.0159	0.498	7.71
0.20	0.0318	0.609	4.11
0.50	0.0796	0.698	2.82
1.0	0.159	0.624	2.37

[1]Elevation for horizontal bottoms, using equation (3) and $A_1 = 1.0$.

Table 3. Observed versus predicted relative crest elevations for monochromatic waves.

Type of wave generator motion	1/m	A_1	Std. dev.	Coefficient of variation (pct)	No. of tests	U_R range	Source
Sine	00	0.992	0.0393	4.0	53	0.3 to 25	This study
Cnoidal	00	0.95	0.038	4.0	13	27 to 184	Weggel (1976b)
Sine	40	0.909[1]	0.0375	4.1	26	3.7 to 24	Singamsetti and Wind (1980)
Sine	20	0.88[1]	0.035	4.0	12	1.8 to 24	Singamsetti and Wind (1980)
Sine	10	0.818[1]	0.0752	9.2	22	2.5 to 23	Singamsetti and Wind (1980)
Sine	5	0.672[1]	0.0370	5.5	21	2.0 to 22	Singamsetti and Wind (1980)

[1]At the breaking point.

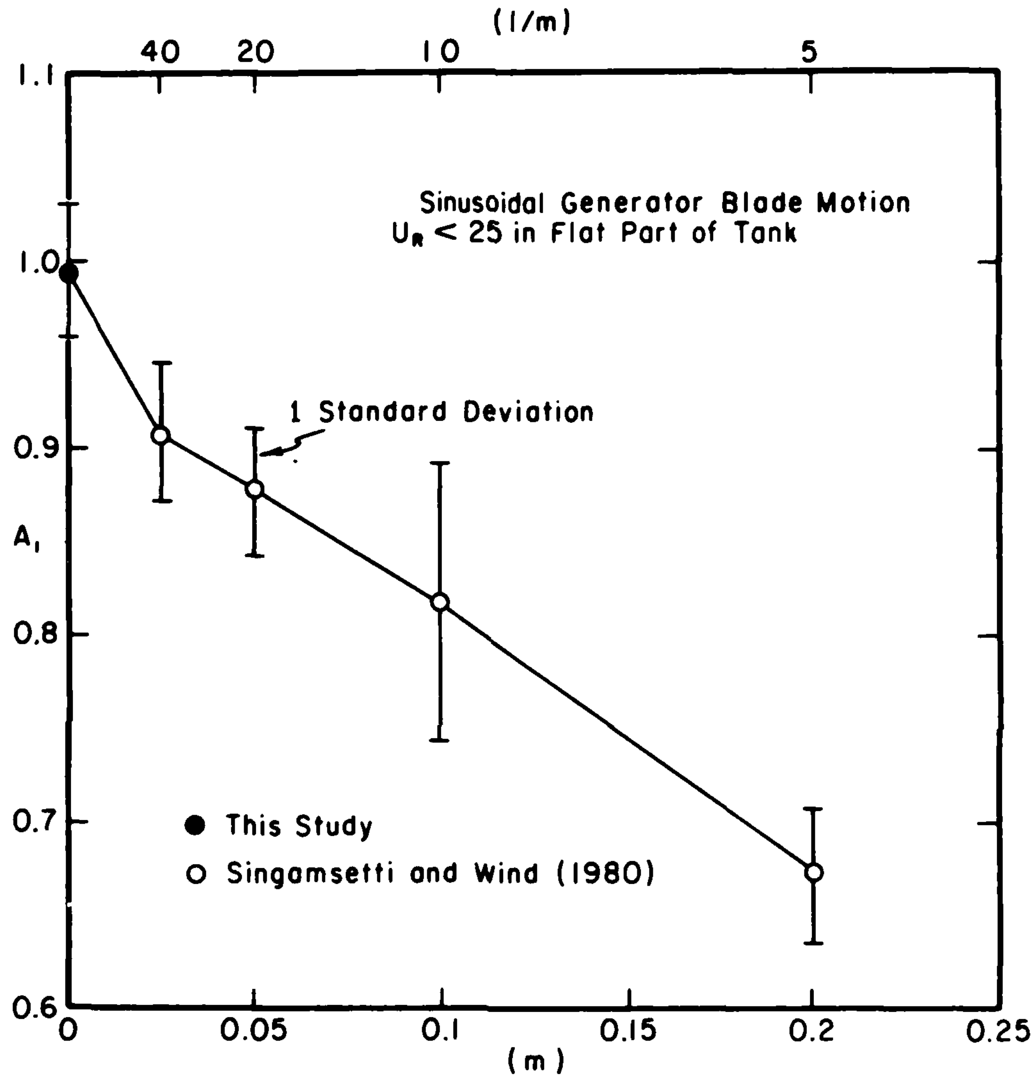


Figure 9. Effect of beach slope on relative wave crest elevation.

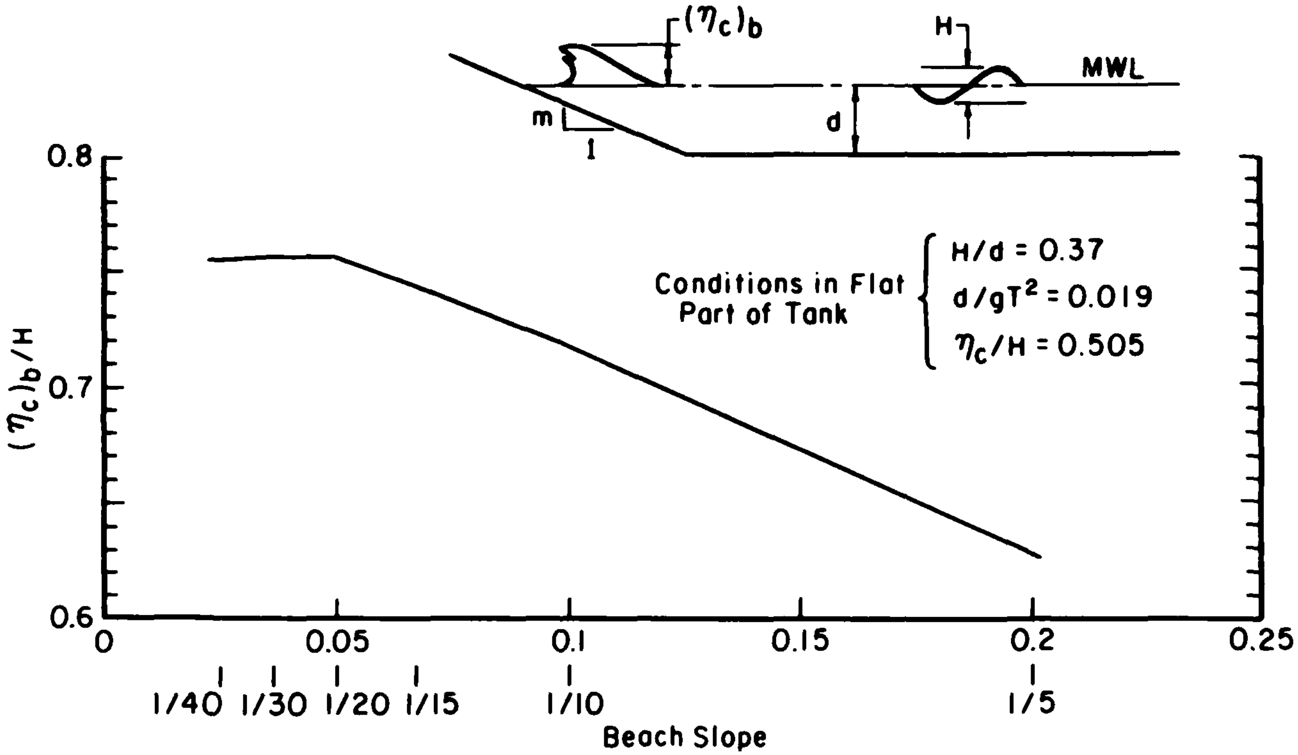


Figure 10. Effect of beach slope on breaker crest elevation.

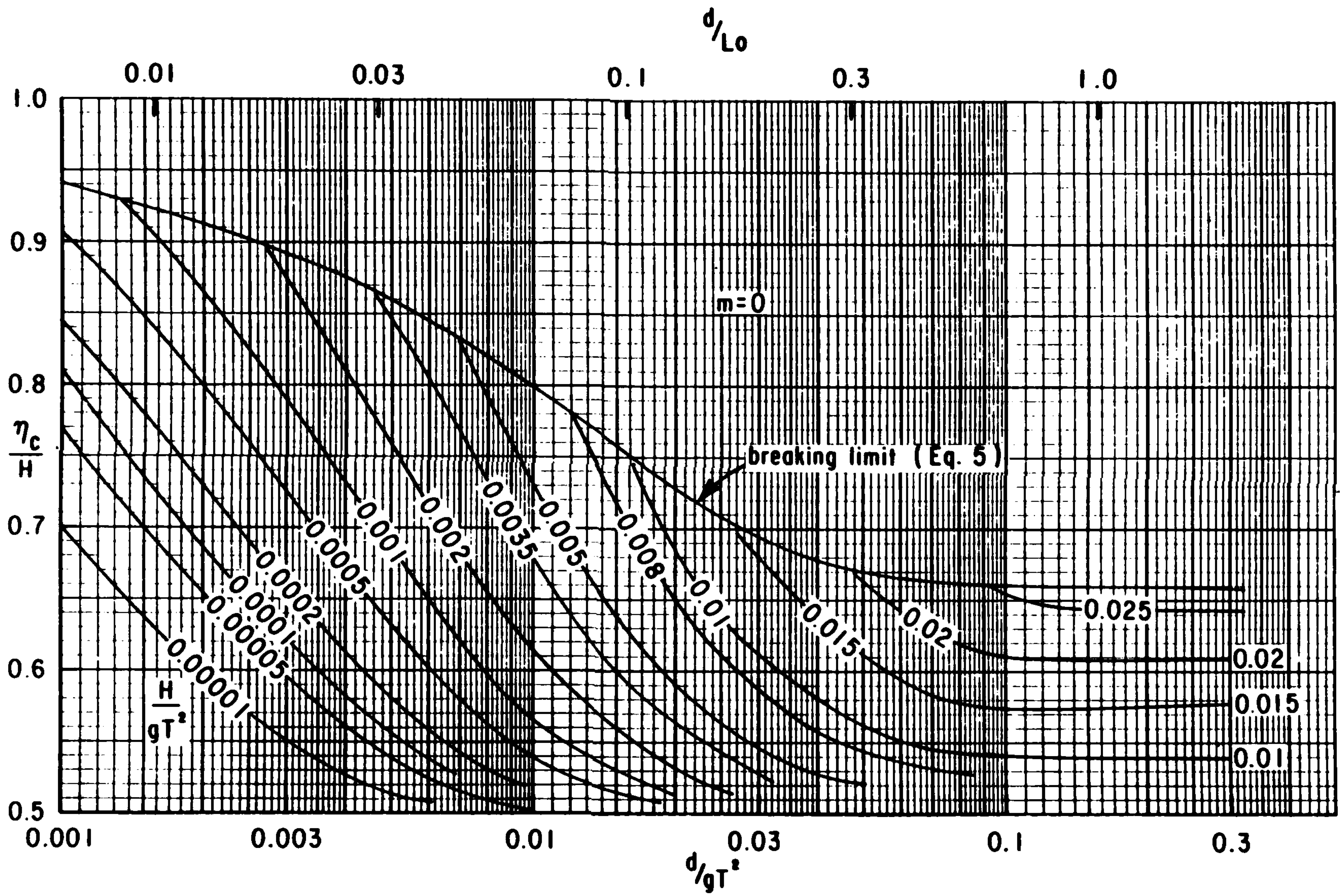


Figure 11. Wave crest elevation for constant values of wave steepness.

η_c/H, is strongly influenced by $d/(gT^2)$ for a given value of wave steepness for $d/(gT^2) > 0.05$. The breaking limit, H_b, given in this figure is from Goda (1975):

$$H_b = 0.17 L_o \left\{1.0 - \exp\left(-4.712 \frac{d}{L_o}\left[1.0 + 15m^{1.333}\right]\right)\right\} \qquad (5)$$

Figure 12 presents η_c/H for constant values of the ratio of wave height to breaker height, H/H_b. The figure shows that in relatively deep water, η_c/H only deviates from the Airy condition of $\eta_c/H = 0.5$ when the wave height becomes a significant fraction of the breaking wave height. Relatively shallower water causes a wave to become more nonlinear, even when the wave height is small compared to the maximum possible breaker height. For example, $\eta_c/H = 0.75$ at $d/(gT^2) = 0.0015$ for $H/H_b = 0.1$ (Fig. 12).

The parameter η_c/d is presented in Figure 13 for constant values of H/d at various values of $d/(gT^2)$. This figure shows the combined influence of wave steepness and water depth on crest elevation. η_c/d reaches a minimum for constant values of H/d at $d/(gT^2)$ in the neighborhood of 0.03. At values of $d/(gT^2)$ larger than 0.03 the increasing wave steepness causes η_c/d to increase until the breaking point is reached. For smaller values of $d/(gT^2)$ the decreased depth or increased period produces greater wave nonlinearity and increased η_c/d.

3. Relative Crest Duration for Monochromatic Waves.

As waves become increasingly nonlinear the duration of the crest, T_c, decreases to less than half of the wave period. Values of relative crest duration, T_c/T, predicted by stream-function theory (Dean, 1974) can be approximated by the empirical relation:

$$\frac{T_c}{T} = C_1 \tanh\left[C_2 \ln\left(C_3 \frac{L_o}{H}\right)\right] \qquad (6)$$

where C_1, C_2, and C_3 are empirical coefficients with $C_1 = 0.5$ for waves on a flat bottom ($m = 0.0$). Values of C_2 and C_3 are given in Figure 14 and Table 4. Good correlation is found between equation (6) and experimental data for small beach slopes as shown in Table 5. However, the equation does not apply to beach slopes steeper than 1 on 20 ($m = 0.05$).

Figure 15 presents predicted values of T_c/T as functions of $d/(gT^2)$ and $H/(gT^2)$. Note that the duration of the wave trough, T_t is given by

$$\frac{T_t}{T} = 1.0 - \frac{T_c}{T} \qquad (7)$$

V. TEST RESULTS AND PREDICTION TECHNIQUES FOR IRREGULAR WAVES

Irregular wave crest elevations and durations are more variable than monochromatic wave conditions because wave energy is distributed over a range of frequencies. This energy distribution produces waves with a variety of heights and periods, which have varying amounts of nonlinearity. Larger waves are of

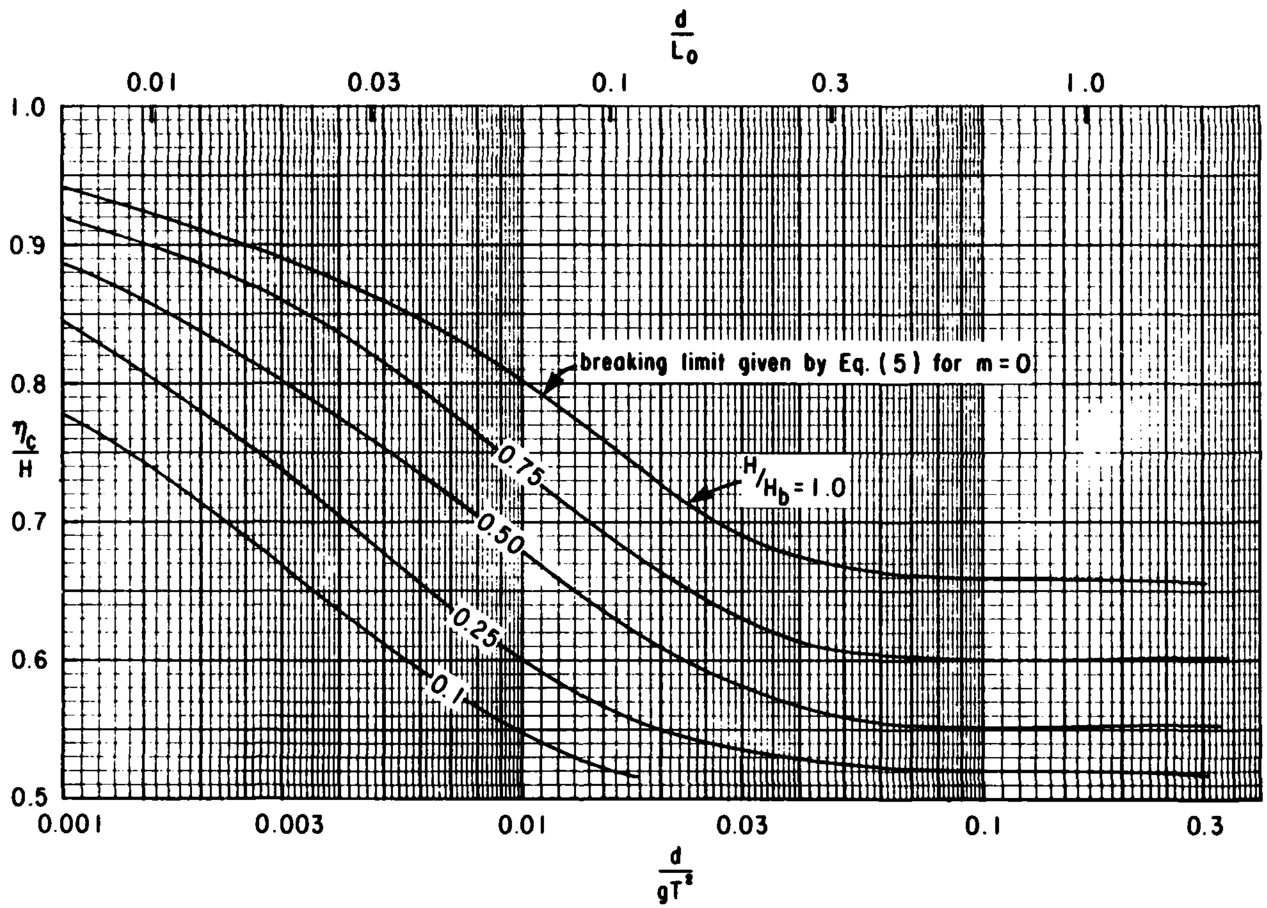


Figure 12. Wave crest elevation for constant values of H/H_b.

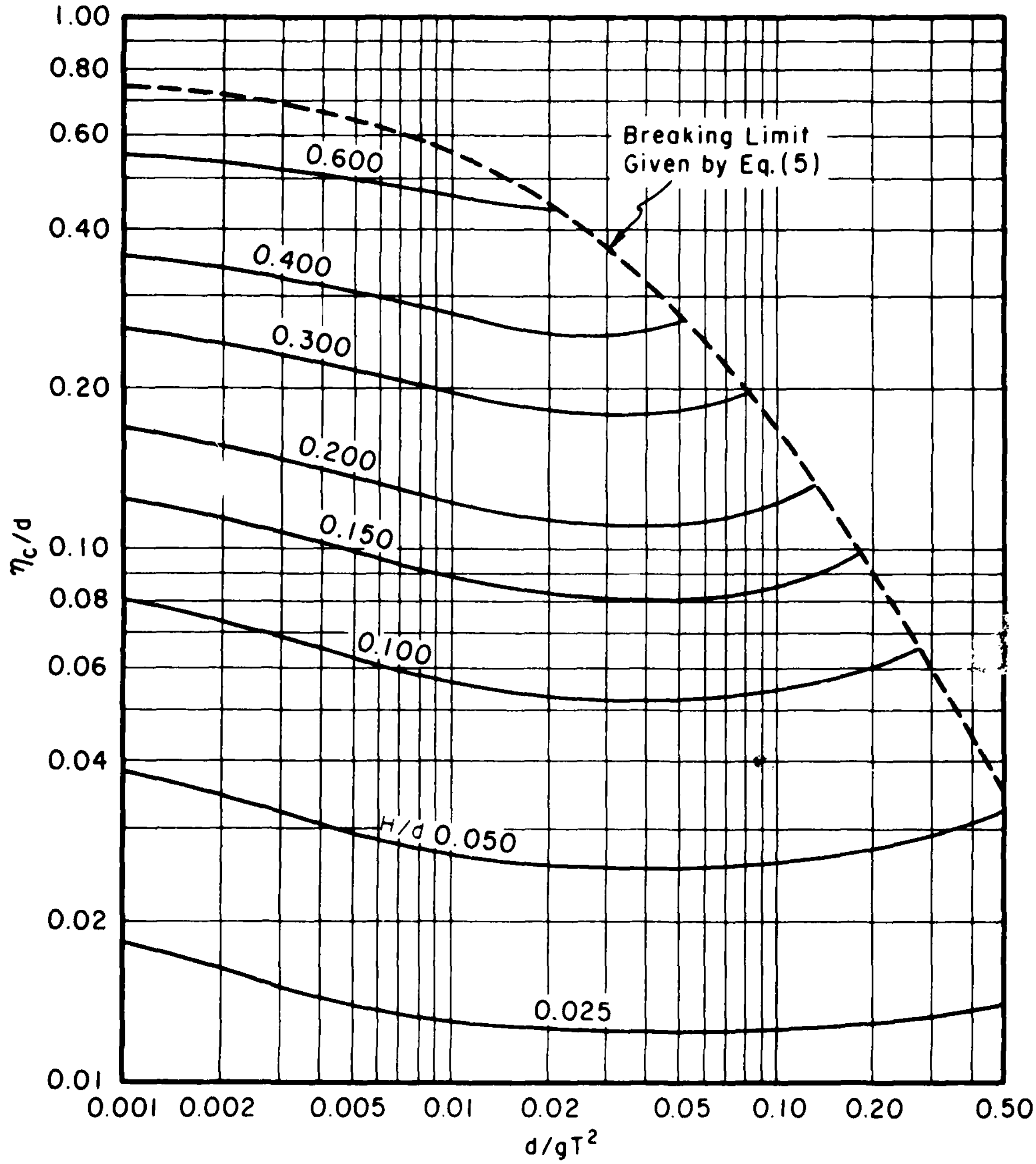


Figure 13. η_c/d for constant values of wave height to depth.

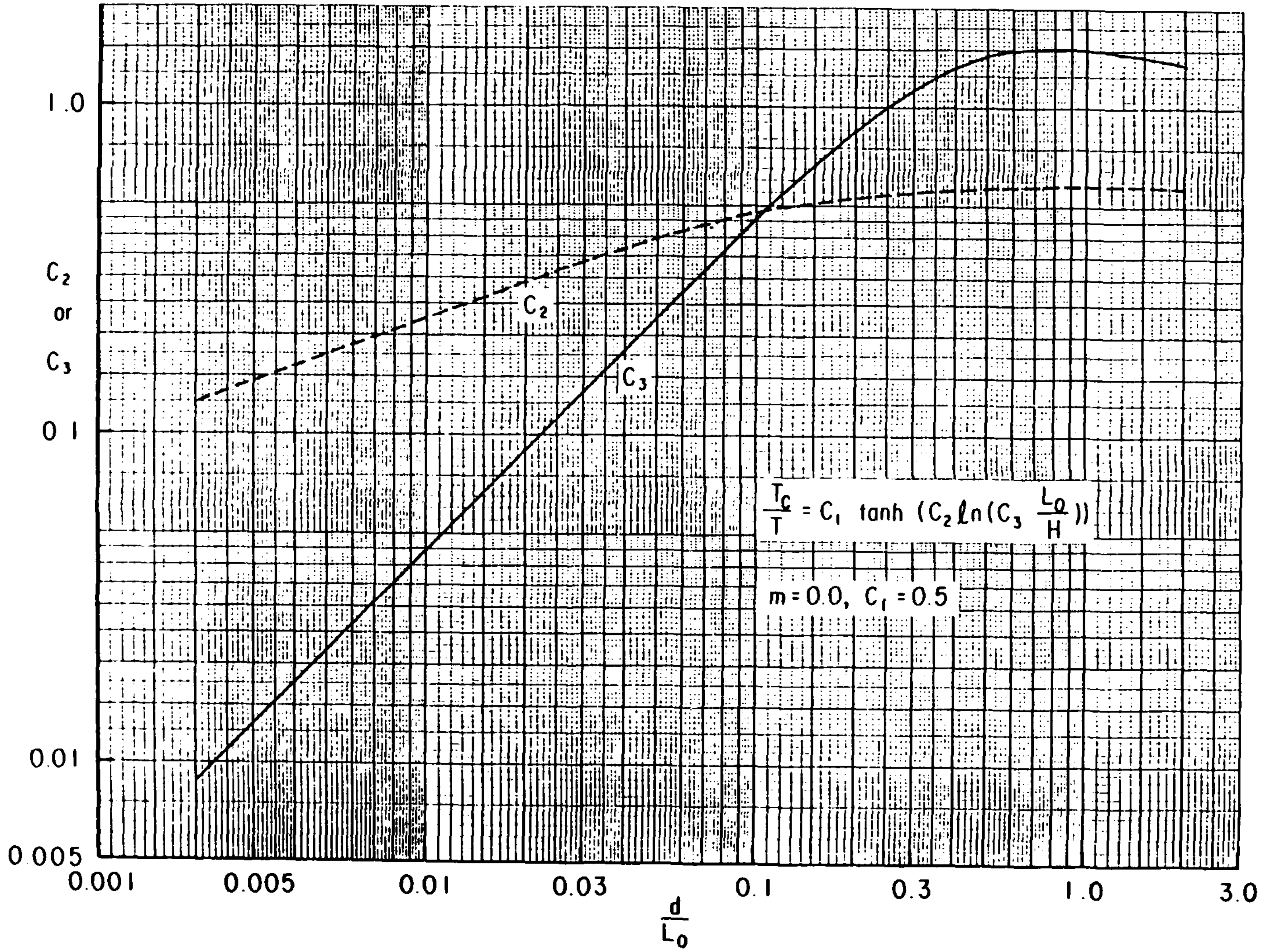


Figure 14. Empirical parameters for estimating wave crest durations (m = 0.0).

Table 4. Coefficients for estimating the duration of wave crests.[1]

d/L_o	d/gT^2	C_2	C_3
0.002	0.00032	0.1242	0.00788
0.005	0.00080	0.1784	0.0205
0.01	0.0016	0.2025	0.044
0.02	0.0032	0.2903	0.0852
0.05	0.0080	0.4036	0.2058
0.1	0.016	0.4702	0.4529
0.2	0.032	0.5442	0.8268
0.5	0.080	0.5518	1.448
1.0	0.16	0.5542	1.4601
2.0	0.32	0.5691	1.363

[1] $C_1 = 0.5$ for waves on a flat bottom ($m = 0.0$).

Table 5. Observed versus predicted relative crest durations (monochromatic waves-sinusoidal generator blade motion).

$1/m$	Mean value of C_1	Std. dev. of C_1	Coefficient of variation of C_1 (pct)	No. of tests	Source
∞	0.498	0.042	8.4	23	This study
40[1]	0.53	0.104	19.6	26	Singamsetti and Wind (1980)
20[1]	0.56	0.11	19.6	24	Singamsetti and Wind (1980)
10[1]	0.70	0.42	60.0	22	Singamsetti and Wind (1980)
5[1]	0.91	0.32	35.2	21	Singamsetti and Wind (1980)

[1] At the breaking point.

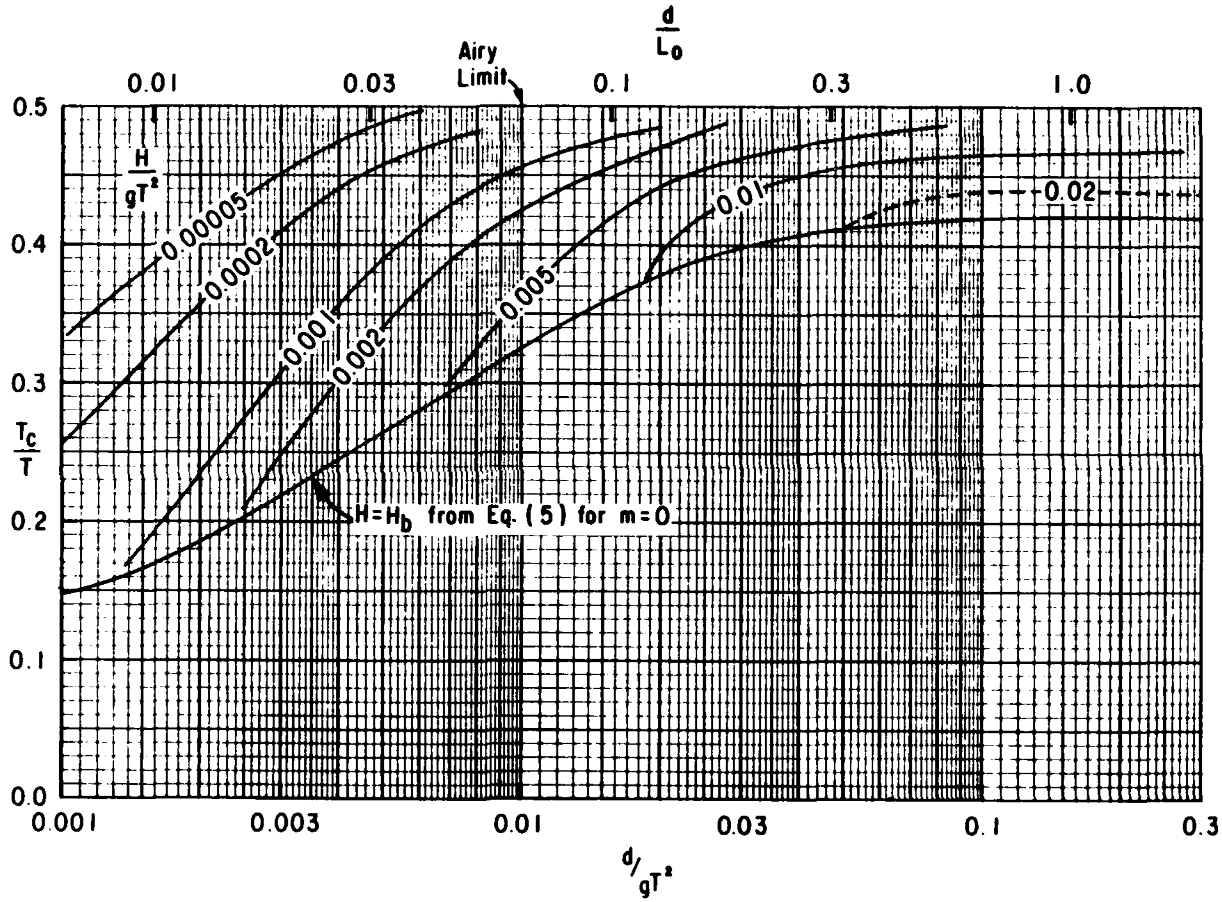


Figure 15. Values of dimensionless wave crest duration.

greatest interest, so the primary emphasis of this analysis is on the highest 15 percent of wave crests in a wave train. The variable p is used to designate the probability level of exceedance of interest. For example, $(\eta_c)_{p=0.05}$, where the subscript $p = 0.05$, indicates that 5 percent of the crest elevations exceed the value of η_c.

Assumed independent variables are significant wave height, H_s (defined as four times the rms water level, η_{rms}), period of peak energy density, T_p, water depth, d, and beach slope, m.

1. Irregular Wave Crest Elevations.

Figure 16 presents several irregular wave records illustrating various amounts of nonlinearity. Records A and B have crests which are slightly larger than half of their zero up-crossing wave heights; record C has crest elevations which are a large fraction of wave height. Table 6, which is a compilation of selected wave record results, indicates the elevation of maximum crests for various water depth, significant wave height, and period of peak energy density

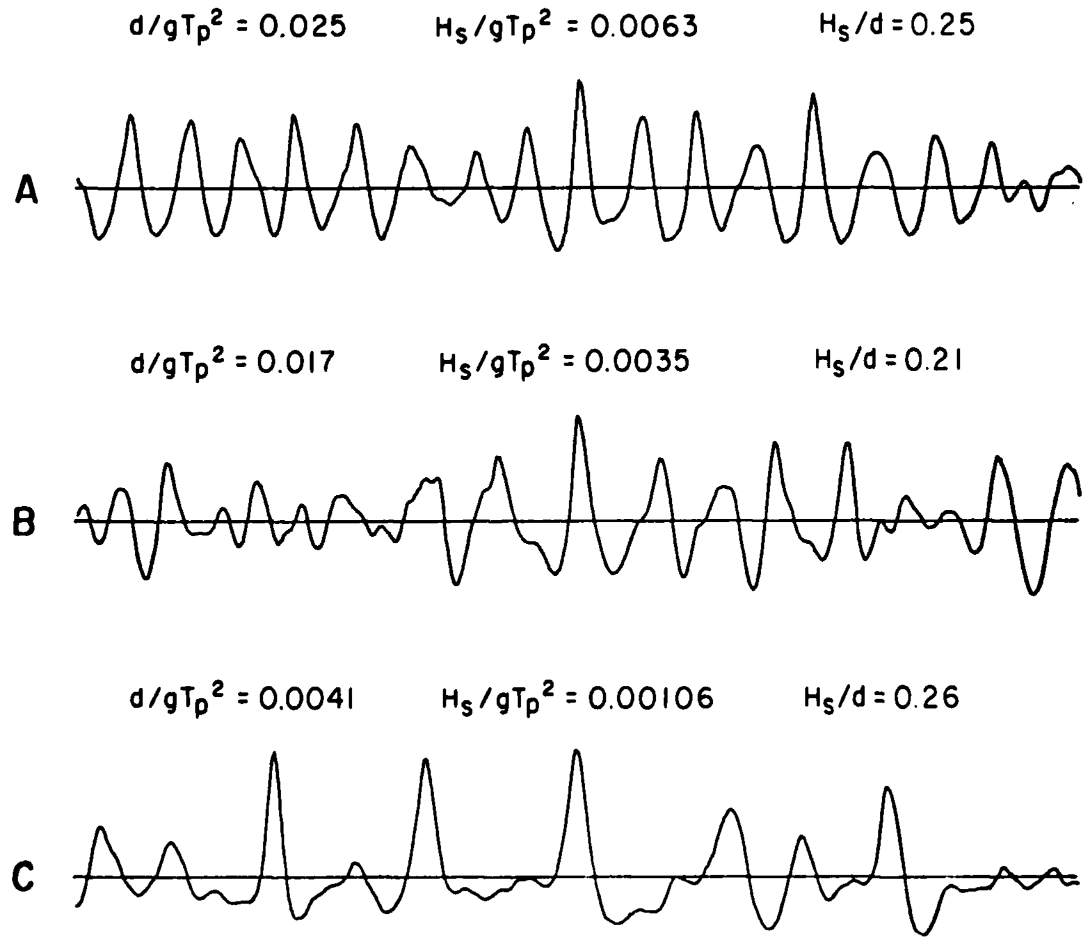


Figure 16. Sample of irregular wave time histories.

Table 6. Selected irregular wave crest elevation data.

Location	Date	Time	H_s/d	H_s/gT_p^2	d/gT_p^2	No. of waves	Highest crest observed		Source
							η_c/H_s	η_c/d	
Field Data									
Atlantic City, N.J.	2 Mar. 69	2001	0.47	0.0036	0.0078	60	1.088	0.51	Thompson (1980)
Atlantic City, N.J.	21 Jan. 69	1202	0.54	0.0032	0.0058	52	1.31	0.71	Thompson (1980)
Nags Head, N.C.	19 Oct. 72	1840	0.45	0.0055	0.012	106	0.897	0.40	Thompson (1980
Lake Worth, Fla.	28 Mar. 71	0820	0.32	0.001	0.0031	72	1.65	0.53	Thompson (1980)
Gulf of Mexico	Hurricanes and storms		(Small?)	?	?	22,194	1.308	0.41	Jahns and Wheeler (1973)
Laboratory Data (m = 0)									
	17 Oct. 80	1404	0.084	0.00035	0.0042	288	1.71	0.14	This study
	17 Oct. 80	1241	0.285	0.00061	0.0021	300	1:63	0.47	This study
	17 Oct. 80	1427	0.27	0.00057	0.0021	300	1.406	0.38	This study
	6 Oct. 80	1257	0.122	0.0055	0.045	224	1.40	0.17	This study
	6 Oct. 80	1306	0.158	0.0053	0.0337	205	1.449	0.23	This study
	6 Oct. 80	1417	0.117	0.0057	0.049	236	1.28	0.15	This study

combinations. Thompson (1980) discussed several coastal gage records with large ratios of H_s/d that have η_c/H_s ratios on the order of one for the highest crest observed, while η_c/d for the largest crest is somewhat less than one. Jahns and Wheeler (1973) found similar extremes for hurricane and storm waves in the Gulf of Mexico. Large values of η_c/H_s can be obtained if the significant wave height is small compared to the water depth and the wave steepness is low. Individual wave crests with elevations greater than 1.5 times the significant wave height were observed in a number of the laboratory experiments, where $H_s/d < 0.3$ and $d/(gT_p^2) < 0.005$ for $m = 0.0$.

Similar values of maximum wave crest elevation were found for irregular waves shoaling on a 1 on 30 laboratory smooth slope. An examination of a typical set of results showed that crest elevation increases as the wave shoals, then decreases as the wave breaks (Fig. 17). Note that in this figure both the crest elevation and the stillwater depth have been normalized by the deepwater equivalent significant wave height, H_o'. Typical values of the single highest crest observed during an irregular wave test of 260 seconds for model time are presented in Table 7. Water level time histories at several gages at various depths along the 1 on 30 slope are given in Figure 18 for an irregular wave condition.

Jahns and Wheeler (1973) suggested a method for predicting irregular wave crest statistics, using the dimensionless parameter $(\eta_c)/H_s$. A Rayleigh-type distribution is assumed, then an empirical correction factor is recommended to increase the probability of occurrence of crests. One of the disadvantages of this approach is that the data often dramatically differ from a Rayleigh distribution because actual probabilities are orders of magnitude larger than predicted. For example, Figure 19 compares crest height distributions for the wave records A, B, and C shown in Figure 16 with the Rayleigh distribution.

The approach taken in this report is to predict crest elevations in terms of local parameters for a given probability level in terms of H_s, d, and T_p. Figure 20 shows values of η_c/d for wave records A, B, and C illustrated in Figure 16.

The suggested method for predicting irregular wave crest elevations is to use the stream-function results to determine the general form of the equation and laboratory results to calibrate the prediction technique for various probability levels. The equation used is

$$\frac{(\eta_c)_p}{H_s} = \frac{A_1^*}{1.0 + \tanh\left(-A_2\ \ell n\left(A_3\ \frac{H_s}{L_o}\right)\right)} \qquad (8)$$

where the parameters A_2 and A_3 are taken from stream-function results (Fig. 8 and Table 2), and A_1^* is an empirical parameter determined from the experimental data. The laboratory data (App. C) indicate that A_1^* is a function of the probability of exceedance, with A_1^* increasing as the probability, p, decreases (Fig. 21, Table 8). Equation (8) shows good correlation with the laboratory data as indicated by the small standard deviation of A_1^* about the mean for values of $p = 0.01$ and greater (Tables 8 and 9). A_1^* at $p = 0.005$ has poor resolution because the data collection runs had only a few crests more than 200 crests per run. Figure 22 gives observed and predicted crest elevations at the 2-percent probability level of exceedance.

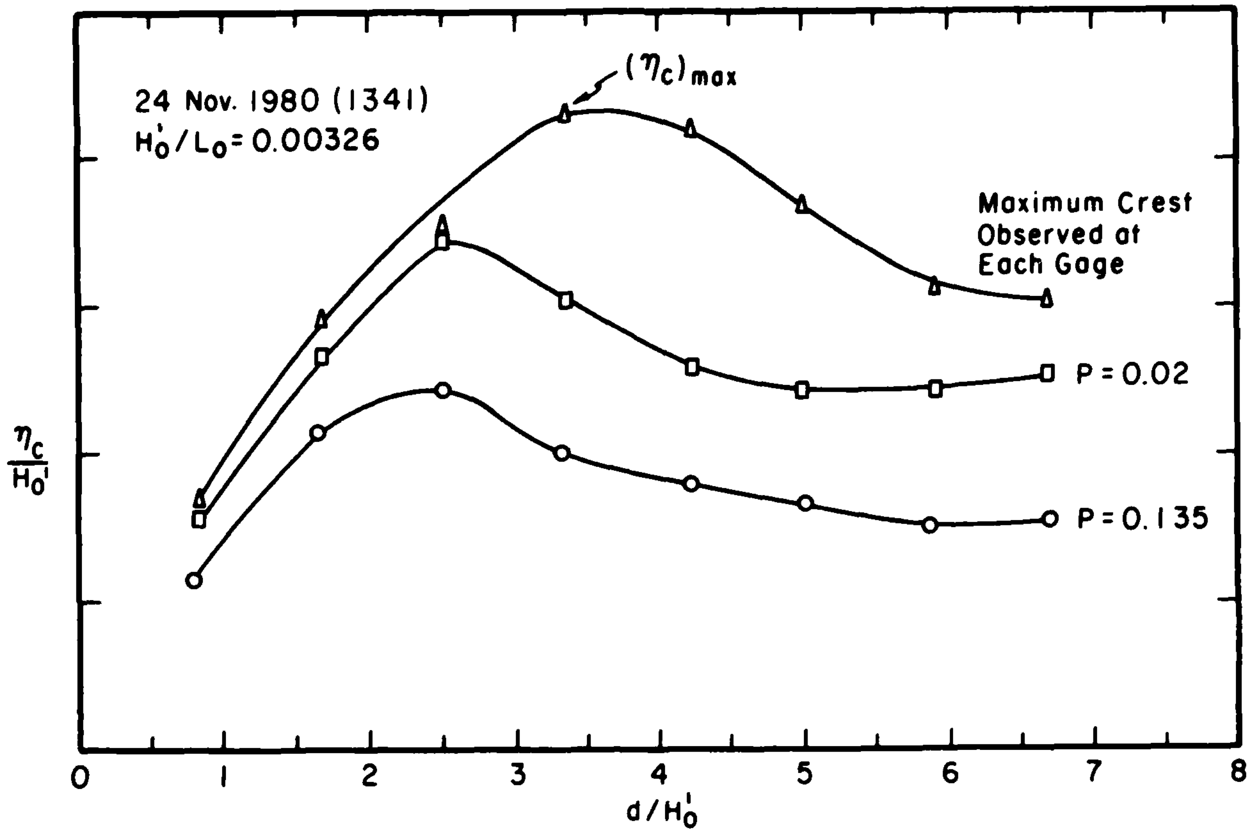


Figure 17. Variation in wave crest elevation for a 1 on 30 slope.

Table 7. Selected irregular wave crest data for waves breaking on a 1 on 30 slope.

Date	Time	H_o'/L_o	Wave and crest data at the occurrence of the highest single crest				
			H_s/d	d/gT_p^2	$(\eta_c)_{max}/H_s$	$(\eta_c)_{max}/d$	$(\eta_c)_{max}/H_o'$
25 Nov. 80	1223	0.040	0.27	0.12	1.23	0.33	1.03
25 Nov. 80	1110	0.032	0.35	0.067	1.25	0.44	1.08
24 Nov. 80	1517	0.024	0.41	0.051	1.29	0.53	1.15
24 Nov. 80	1310	0.021	0.33	0.057	1.27	0.42	1.15
24 Nov. 80	1431	0.0115	0.38	0.031	1.60	0.60	1.60
24 Nov. 80	1259	0.0050	0.27	0.021	1.86	0.50	2.13
24 Nov. 80	1332	0.0033	0.29	0.014	1.75	0.51	2.16

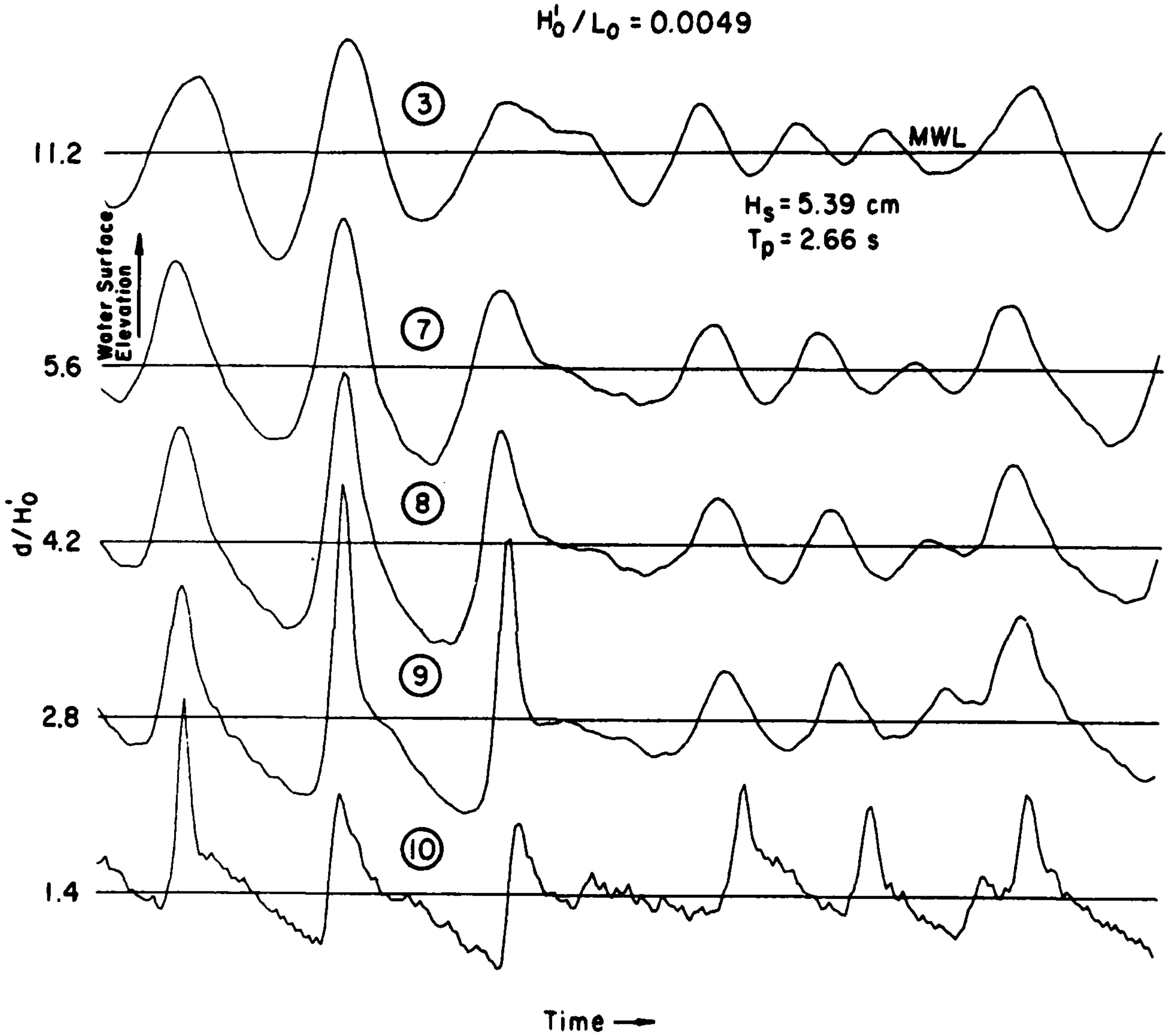


Figure 18. Sample of water level time histories for irregular waves at selected locations along a 1 on 30 slope.

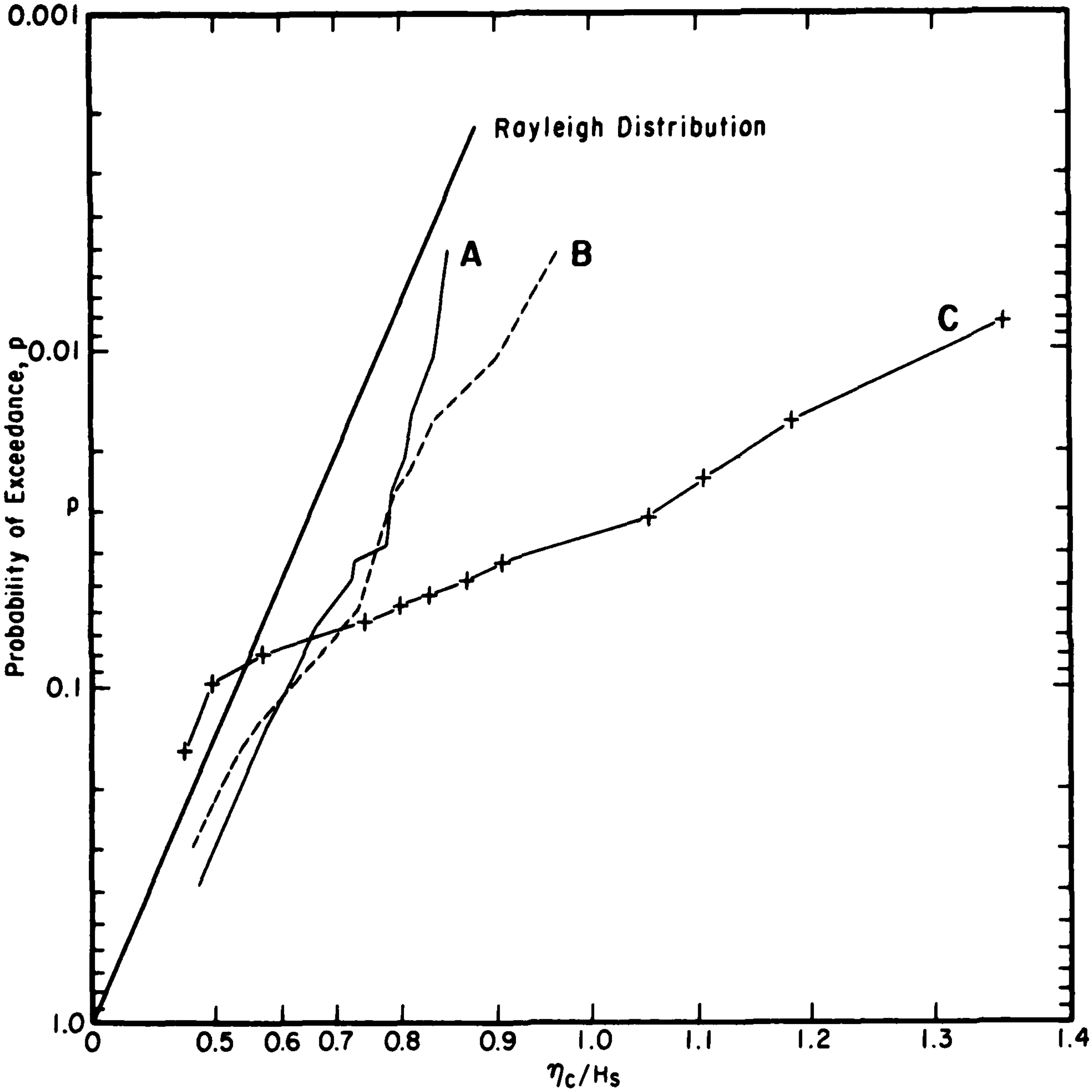


Figure 19. Sample of irregular wave crest elevation distributions (from wave records shown in Fig. 16).

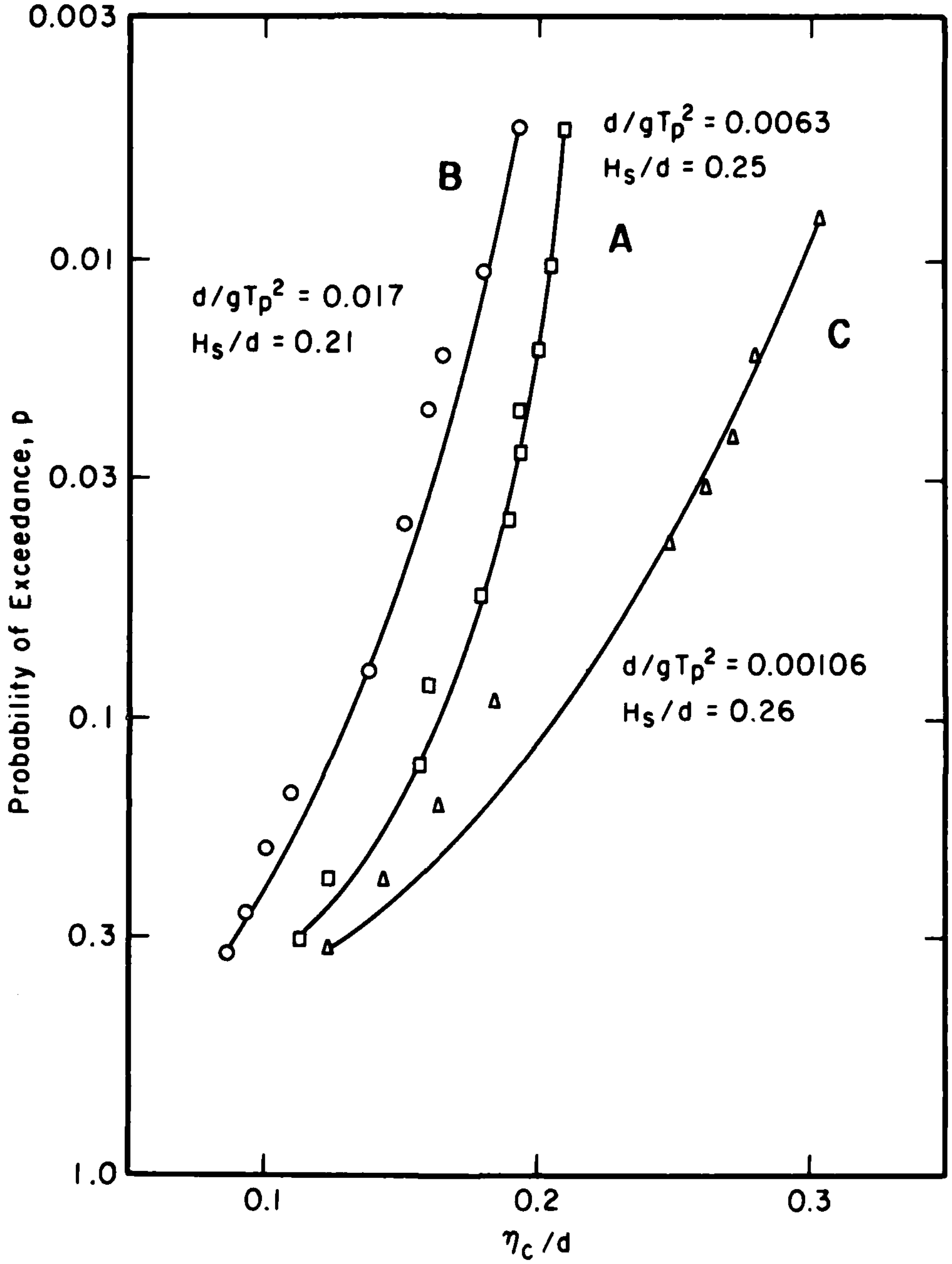


Figure 20. Sample of wave crest distributions (from wave records shown in Fig. 16).

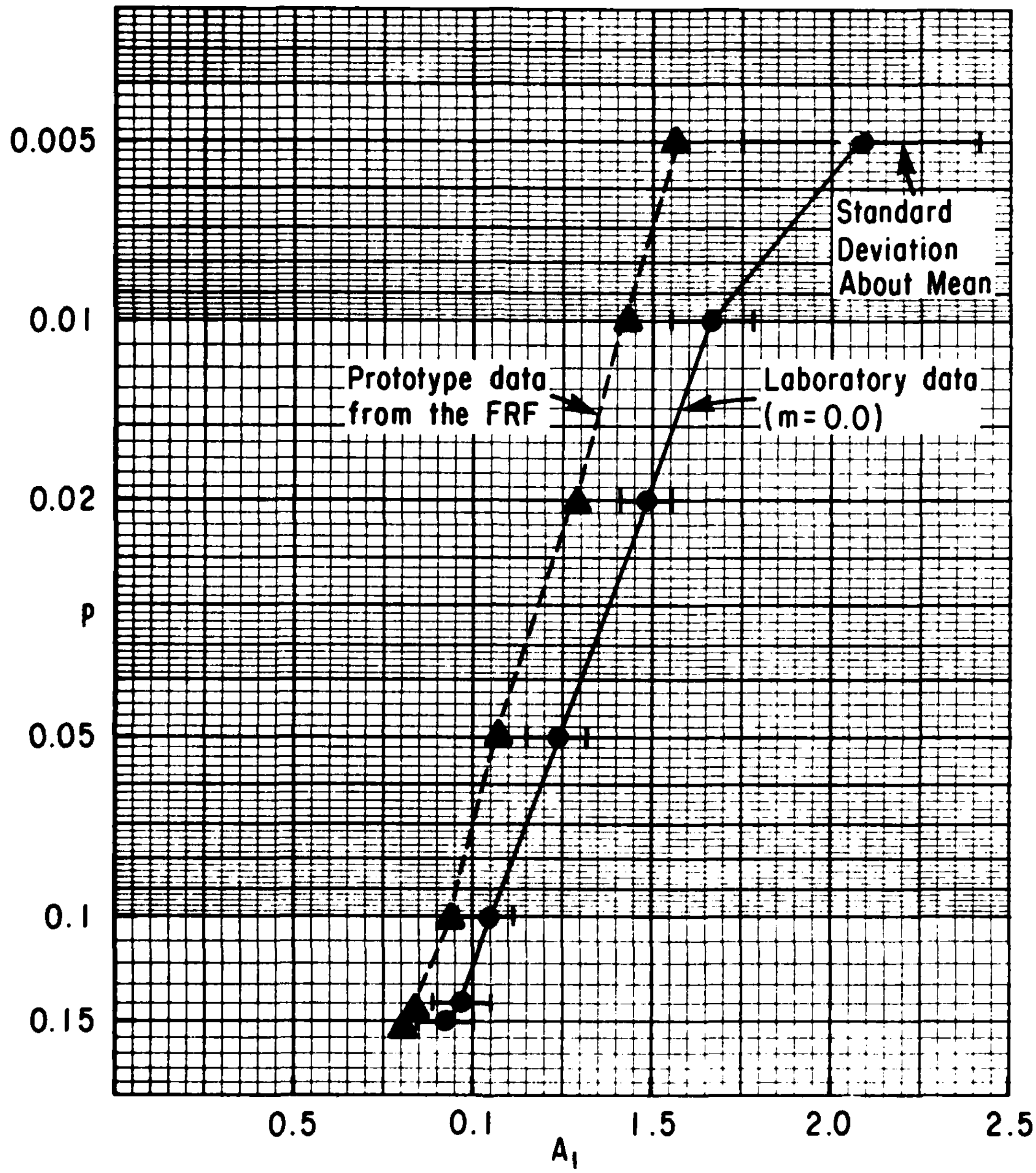


Figure 21. Values of A_1^* for probability of exceedance for irregular waves.

Table 8. Values of A_1^* for levels of probability of exceedance for irregular waves ($m = 0.0$), derived from 122 laboratory experiments.

Probability of exceedance, p	A_1^*	Std. dev. of A_1^*	Coefficient of variation (pct)
0.150	0.929	0.082	8.8
0.135	0.960	0.083	8.6
0.100	1.048	0.082	7.8
0.050	1.240	0.085	6.9
0.020	1.488	0.152	10.2
0.010	1.669	0.209	12.5
0.005	2.119	0.33	15.6

Table 9. Values of A_1^* for levels of probability of exceedance for irregular waves on a 1 on 30 laboratory slope ($m = 0.033$), derived from 192 laboratory measurements.

Probability of exceedance, p	A_1^*	Std. dev. of A_1^*	Coefficient of variation (pct)
0.150	0.919	0.058	6.3
0.135	0.948	0.061	6.4
0.100	1.029	0.075	7.3
0.050	1.20	0.099	8.2
0.020	1.46	0.176	12.1
0.010	1.70	0.285	16.8

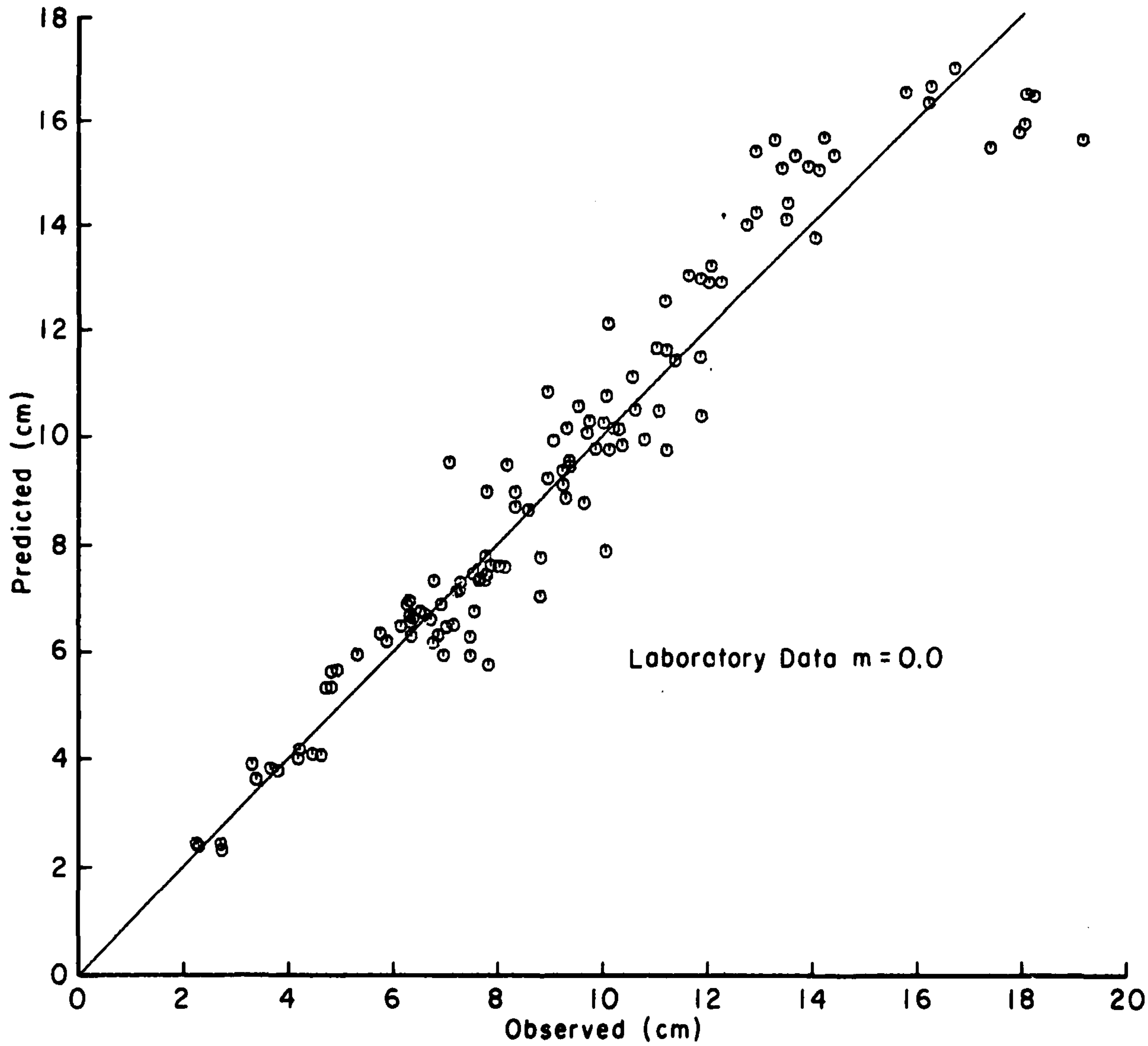


Figure 22. Observed and predicted crest elevations exceeded by 2 percent of the wave crests.

The wave crest elevation of irregular waves on a 1 on 30 slope may also be described in terms of deepwater wave characteristics. An examination of the data indicates that deepwater wave steepness and local stillwater depth control the magnitude of crest elevation at a given probability level. For example, Figure 23 presents the crest elevation exceeded by 13.5 percent of the wave crests for the deepwater wave steepness range $0.0035 < H_o'/L_o < 0.0075$ for $m = 0.0333$ (a 1 on 30 slope with the experimental setup shown in Fig. 6). The irregular wave data show a consistent trend with crest elevation increasing in the shoaling region and decreasing after breaking.

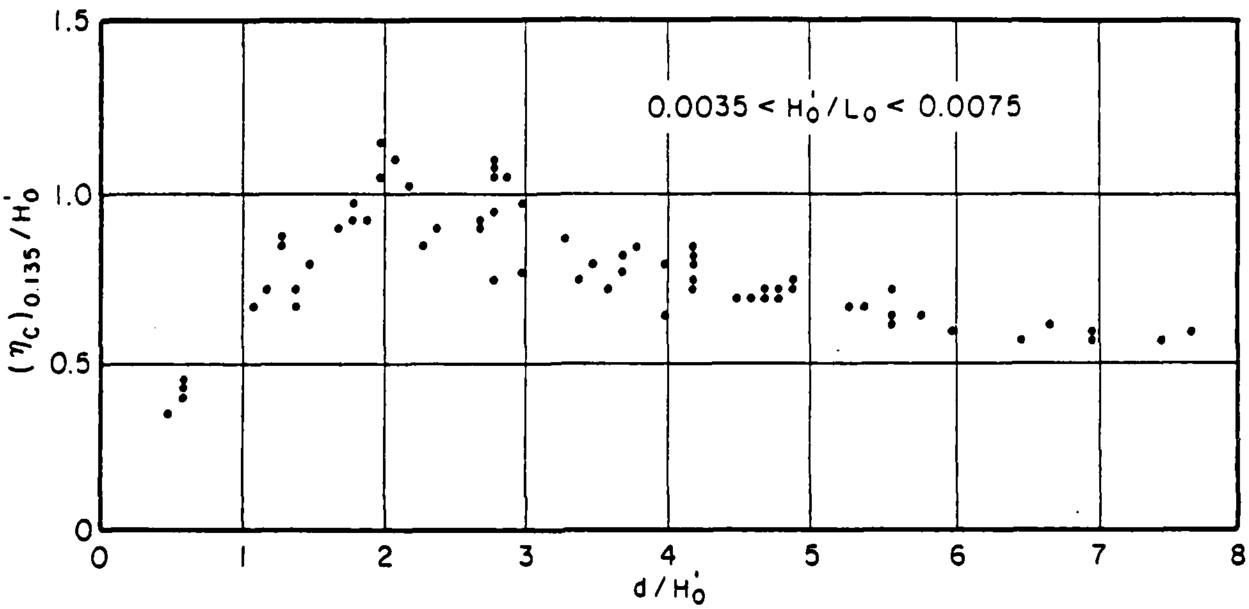


Figure 23. Wave crest elevation exceeded by 13.5 percent of the wave crests.

2. Crest Elevation Prediction Aids.

Irregular wave crest elevations may be predicted in terms of local wave conditions using equation (8). Figure 24 gives crest elevation exceeded by 2 percent of the wave crests ($p = 0.02$) normalized by the water depth. Curves of constant H_s/d are plotted with $d/(gT_p^2)$ on the abscissa. As a first estimate the upper limit of wave height is assumed to be given by equation (5) and the crest elevation of this condition is shown as a dashline. Figure 25 presents crest elevations exceeded by 13.5 percent of the wave crests. Figures 24 and 25 may be used for waves traveling over a flat bottom and for plane slopes as steep as 1 on 30.

Crest elevations are presented in terms of deepwater wave characteristics for incident waves normal to a 1 on 30 slope for the 2- and 13.5-percent probability of exceedance levels in Figure 26. These curves were determined using the laboratory data presented in Appendix D. A dashline is used to indicate a region of uncertainty.

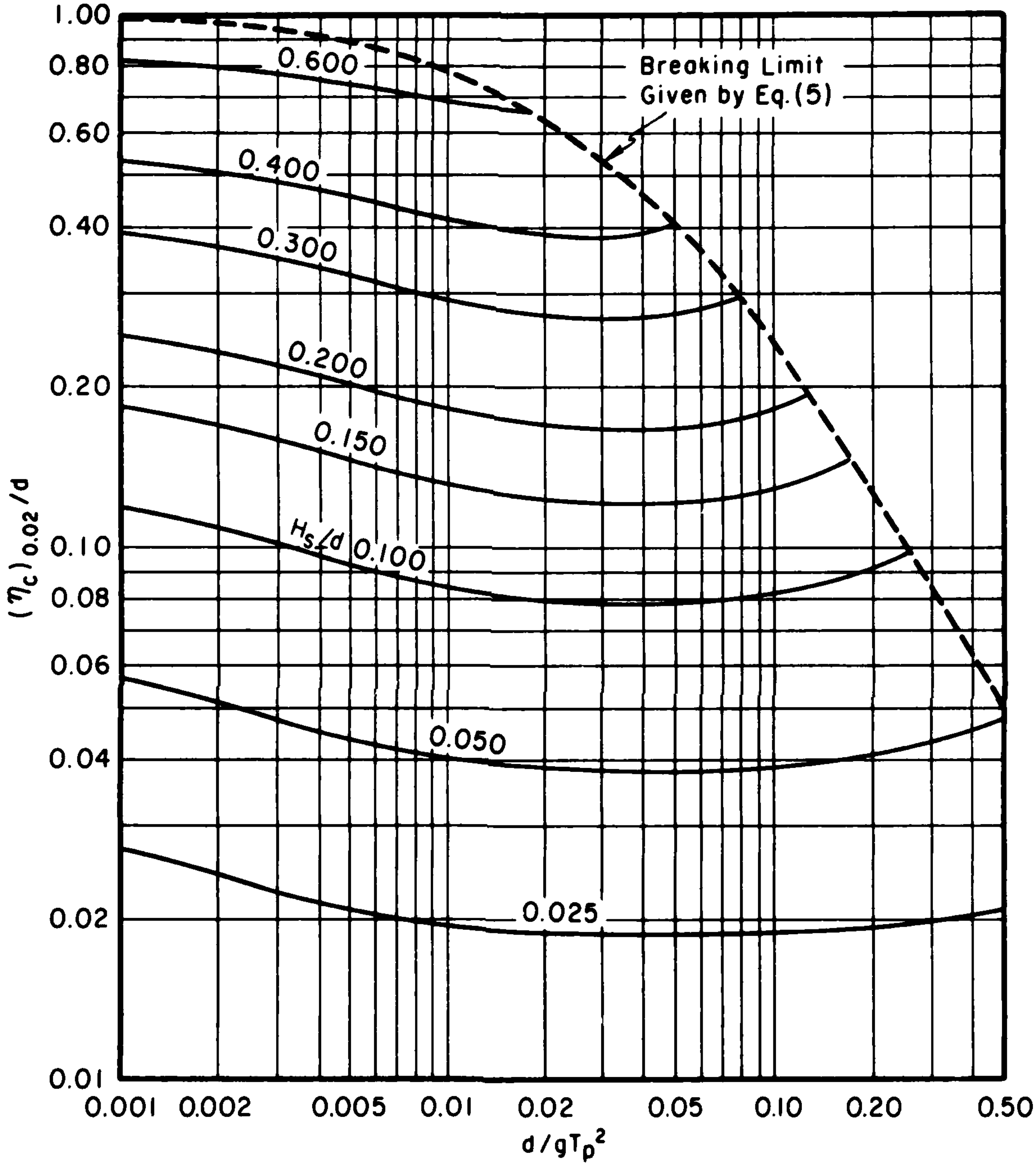


Figure 24. Crest elevation at the 2-percent probability level of exceedance for irregular waves.

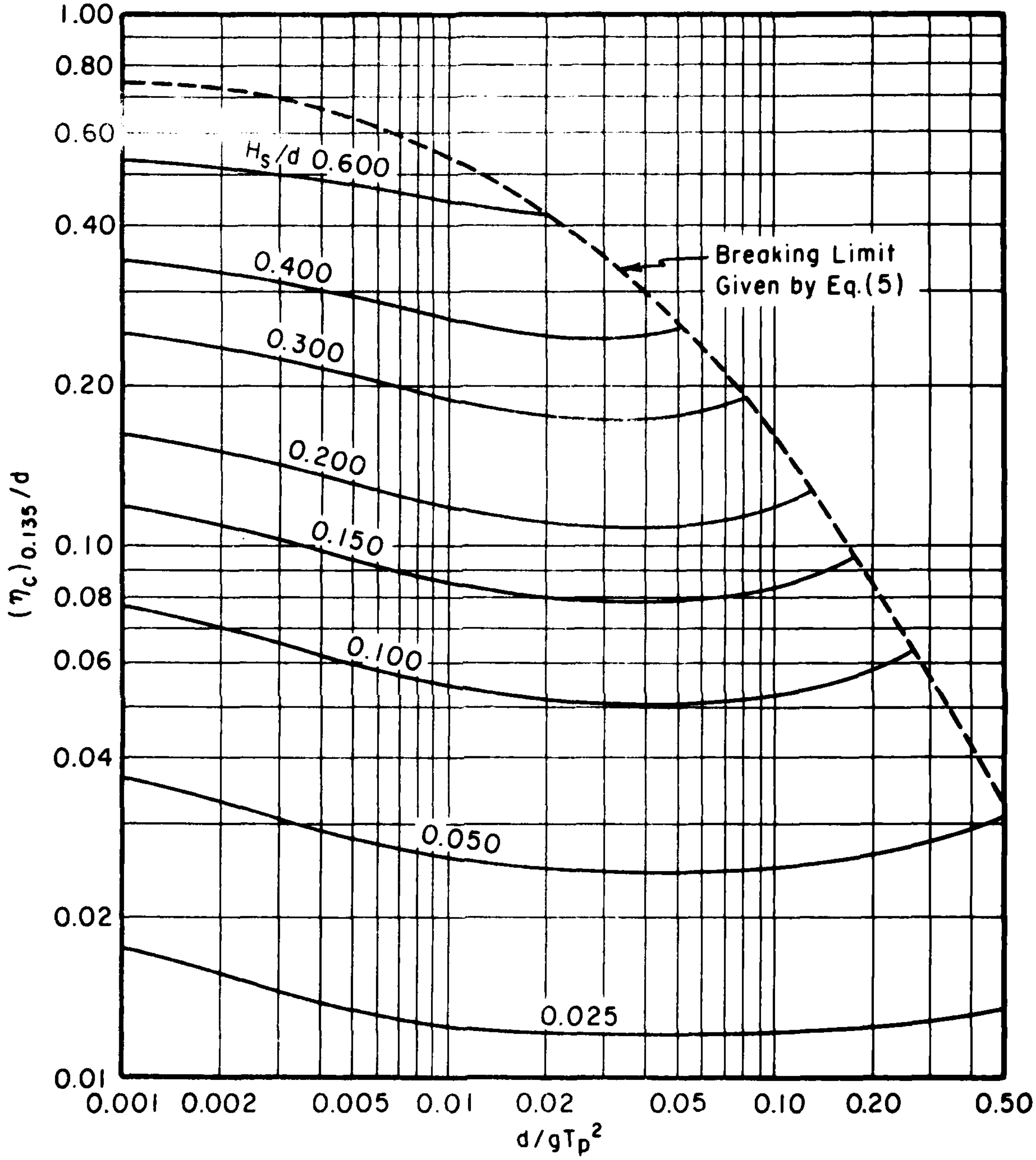
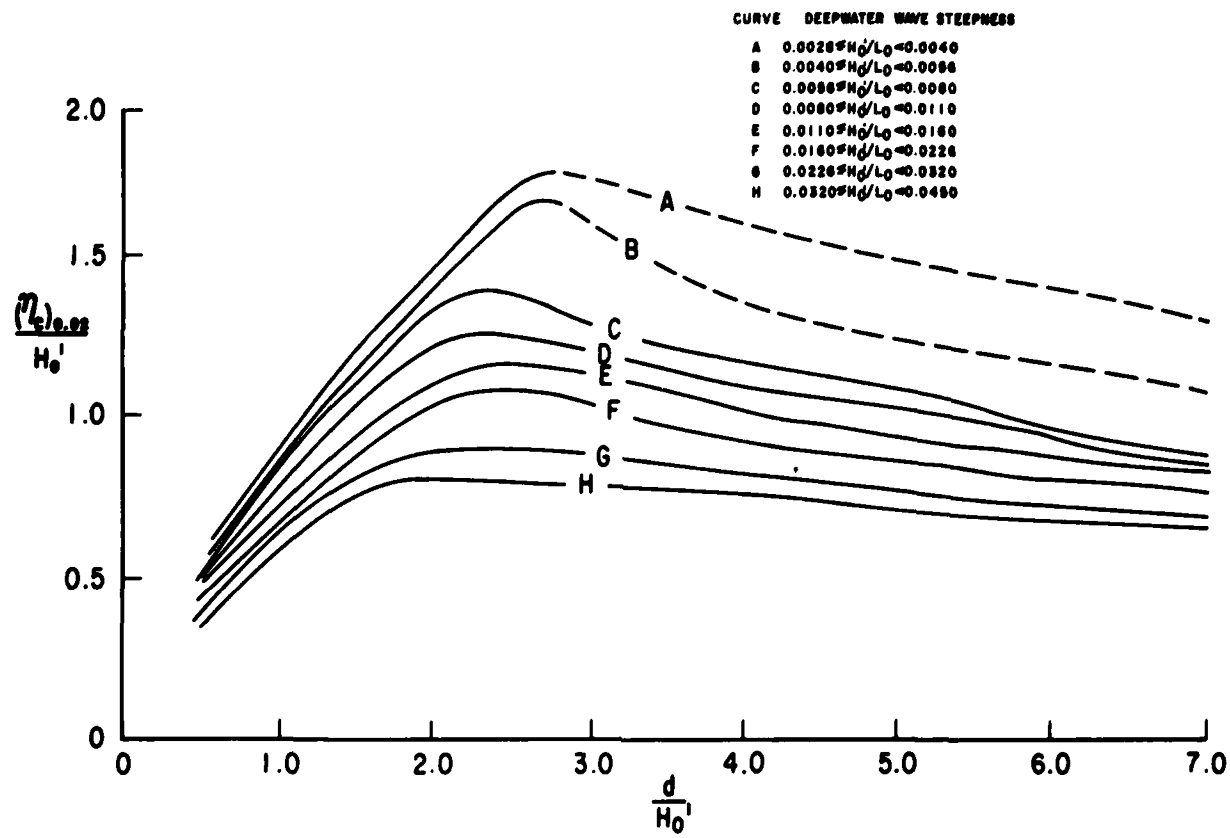


Figure 25. Crest elevation at the 13.5-percent probability level of exceedance for irregular waves.



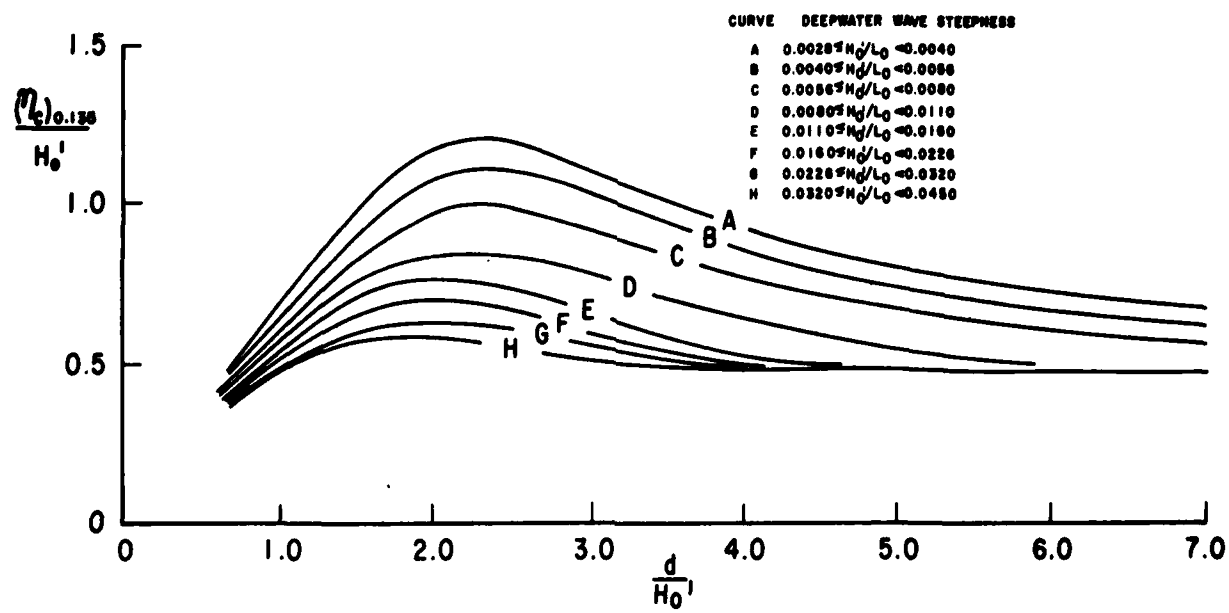


Figure 26. Wave crest elevations along a 1 on 30 slope for 2- and 13.5-percent probability of exceedance levels.

3. The Duration of Irregular Wave Crests.

The larger waves in an irregular wave train have the greatest nonlinearity, so the duration of the crests of these waves tends to be small relative to wave period. Figure 27 illustrates this trend by presenting the mean relative crest duration for various probability levels of exceedance for waves traveling over a flat bottom. For example, 5 percent of the largest crests have a mean dimensionless crest duration $\overline{T_c/T} = 0.406$, while the average value for all of the wave crests (at the 100-percent level) have $\overline{T_c/T} = 0.473$.

VI. COMPARISON OF RESULTS FOR PROTOTYPE DATA

The techniques presented in the previous section are to be used for the future prediction of wave characteristics in field situation. In this section, field data collected at the FRF in Duck, North Carolina, are analyzed in the same manner as the laboratory data previously described and comparisons are presented to demonstrate the applicability of the predictive techniques.

1. Field Conditions.

Four Waverider buoys were used to obtain the prototype data in an area where the bottom contours are essentially straight and parallel. Table 10 gives the locations of the gages and the mean water depths. The data were collected in the third week of October 1980 during a severe storm that produced wave heights exceeding 4 meters. The data set has widely varying significant wave height and period of peak energy density combinations resulting as the storm moved into and through the study area. Table 10 summarizes the range of wave conditions used in this report.

2. Prototype Verification.

The field data were analyzed in the same manner as the laboratory data used in formulating the predictive parameters. The observed crest elevations were compared with those predicted by equation (8), using values of A_1^* for $m = 0.0$ (Table 8), since the bottom slope was very gentle. Table 11 shows the results of this comparison for decreasing exceedance probabilities. It should be noted that the predicted crest elevations are slightly conservative, with the coefficient of variation approximately 8.5 percent. Figures 28 and 29 illustrate the predictive ability of equation (8); the diagonal line indicates perfect agreement. The scatter decreases for higher probability of exceedance levels, in part, because the data for higher probability levels are more statistically reliable. These figures also show that the scatter from the prediction line increases slightly as H_s/d increases. This increase in conservatism with increasing wave height-to-depth ratio may be due to the fact that the waves are interacting with a bottom that is slightly sloping and comprised of a porous sandy material (rather than a rigid floor used in the laboratory experiments). The directional characteristics of the prototype waves could also be influencing these results because a spectrum of wave directions was present, even though the primary wave direction was along the line of the Waveriders.

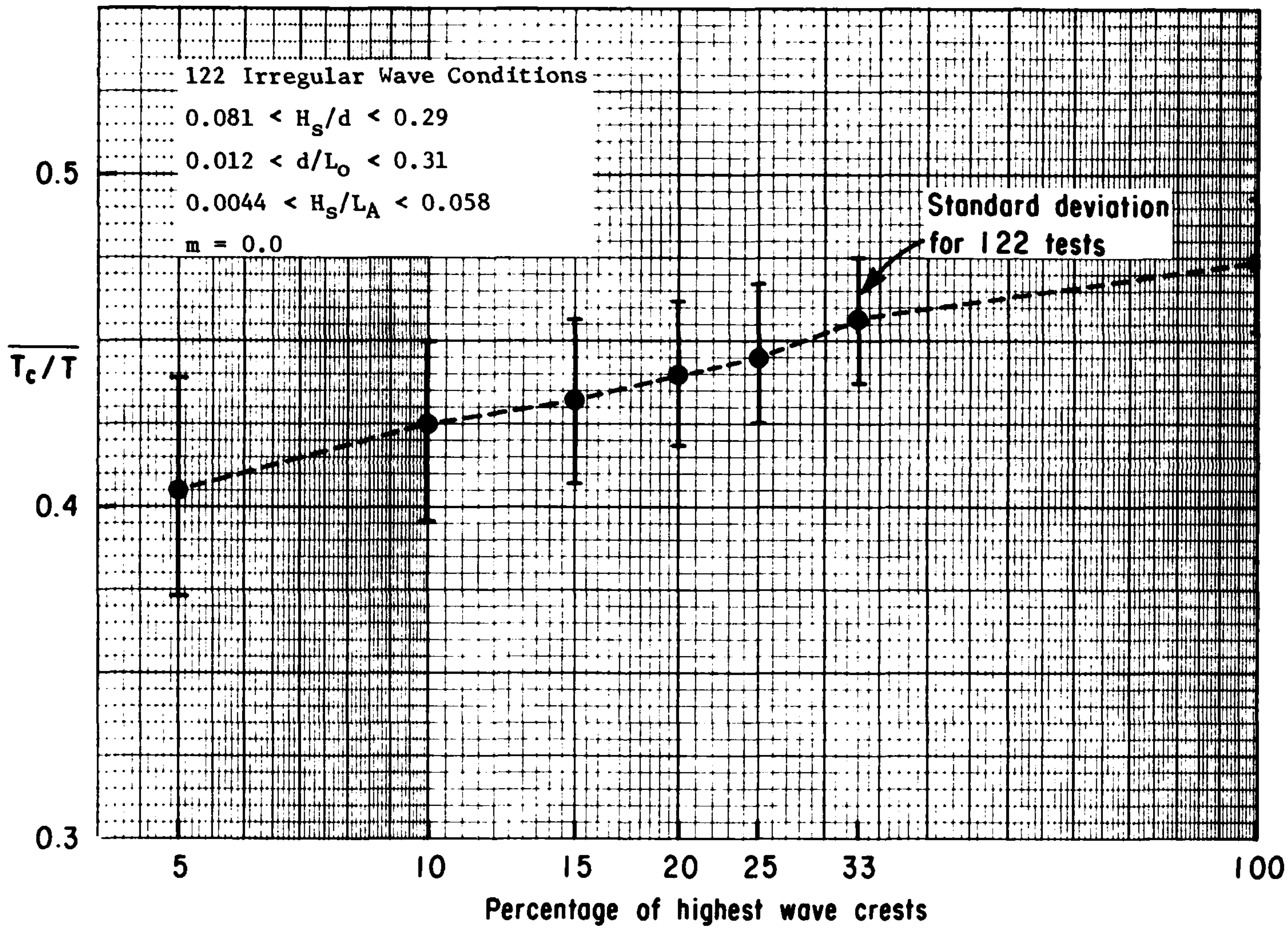


Figure 27. Dimensionless wave crest duration for irregular waves (m = 0.0).

Table 10. Summary of prototype wave conditions.

Waverider distance from shore (km)	Water depth (m)	H_s (m)		T_p (s)		Wave steepness	
		Max.	Min.	Max.	Min.	Max.	Min.
0.5	7	3.6	0.5	14	3	0.0641	0.0016
3.0	17	3.8	0.5	14	3	0.0570	0.0016
6.0	18	4.3	0.4	14	3	0.0570	0.0013
12.0	25	4.4	0.4	14	3	0.0570	0.0013

Table 11. Values of crest heights observed and predicted for waves at Duck, North Carolina.[1]

Probability of exceedance	Mean ratio of observed and predicted crest elevations[2]	A_1^* Observed	Coefficient of variation (pct)
0.150	0.912	0.847	8.5
0.135	0.909	0.873	8.3
0.100	0.902	0.945	8.6
0.050	0.877	1.087	8.7
0.020	0.861	1.281	8.6
0.010	0.848	1.415	9.0
0.005	0.729	1.545	11.6

[1]Values derived from 100 20-minute wave records taken in October 1980.

[2]Values of A_1^* from Table 8 used to make predictions.

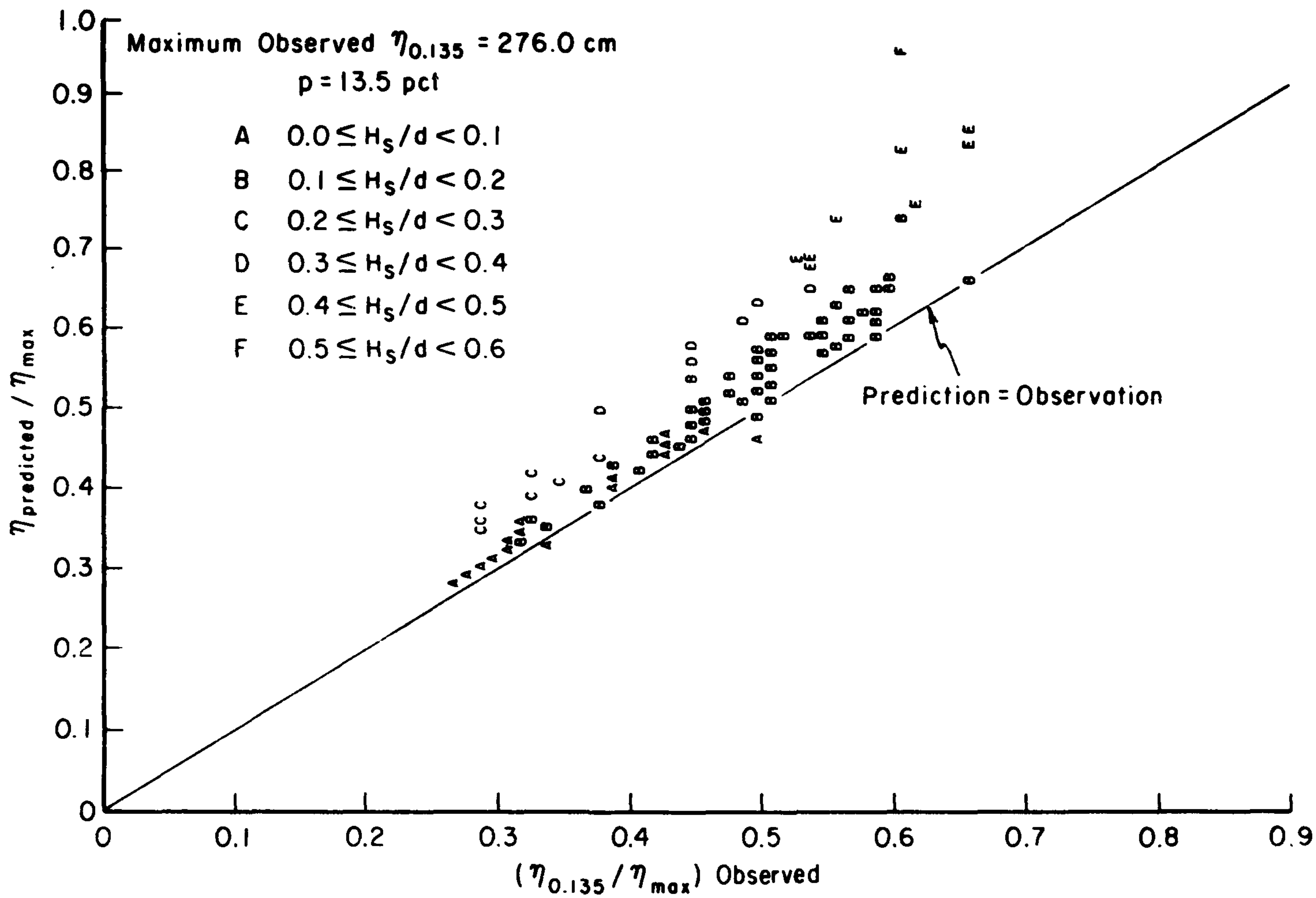


Figure 28. Observed versus predicted crest elevations (p = 0.135).

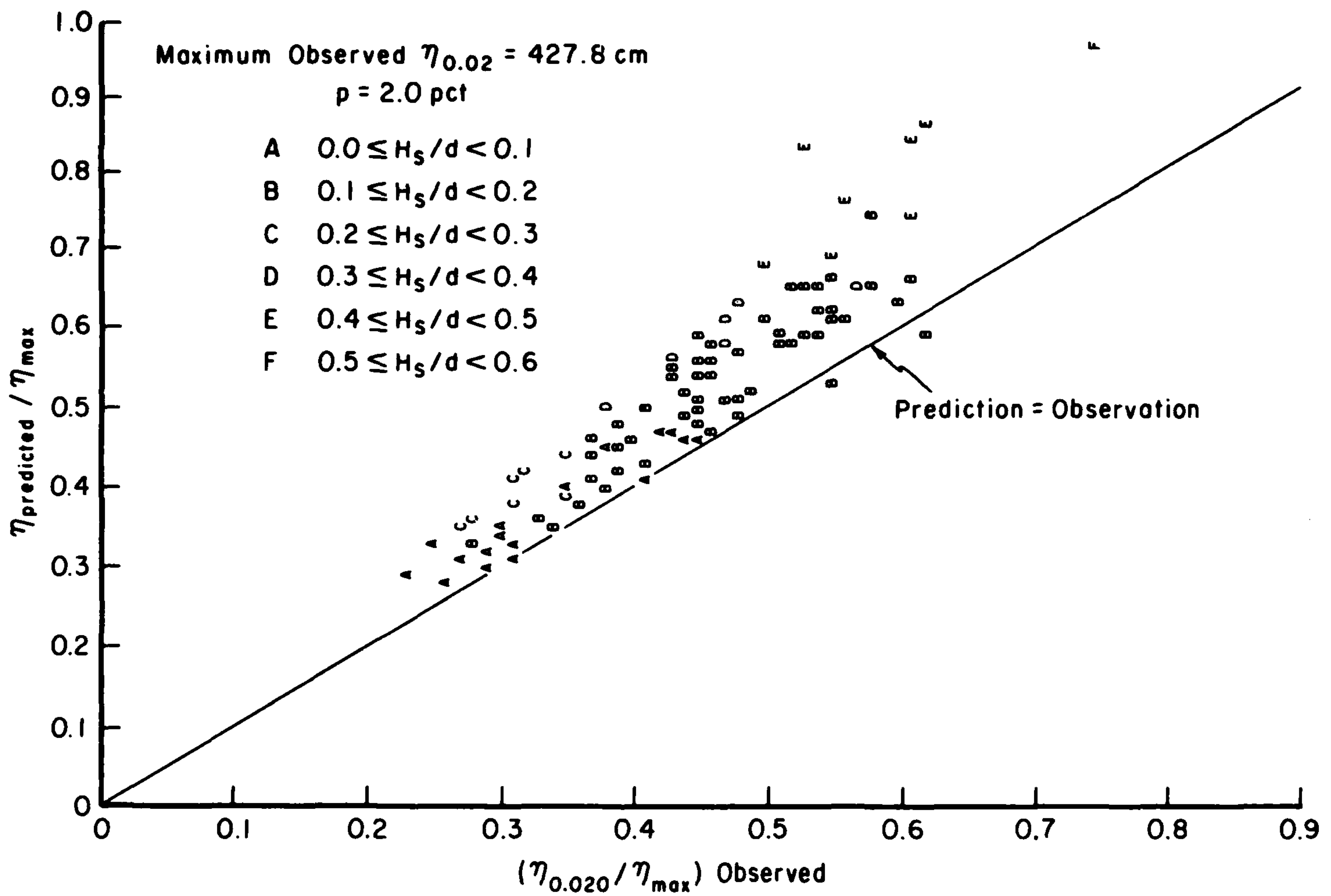


Figure 29. Observed versus predicted crest elevations (p = 0.020).

VII. SUMMARY AND CONCLUSIONS

The stream-function tables of Dean (1974) are used to develop empirical formulas for estimating monochromatic wave crest elevations and durations. The resulting formulas are calibrated with laboratory data. The method for predicting crest elevations was found to work well for waves traveling over a flat bottom or at the breaker point on plane smooth slopes. The equation for predicting crest elevations was calibrated for irregular wave conditions traveling over a flat bottom and shoaling on a 1 on 30 plane slope. The irregular wave data taken with the 1 on 30 slope were also expressed in terms of deepwater conditions and it was found that deepwater steepness and local water depth could be used to predict crest elevations.

Prediction equations developed from two-dimensional irregular laboratory waves were found to be conservative in predicting crest elevations when compared to field measurements taken at CERC's Field Research Facility, Duck, North Carolina. The conservatism is slight and increases with increasing H_s/d.

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APPENDIX A

MONOCHROMATIC TESTS RESULTS

BREAKING MONOCHROMATIC WAVE DATA
COT(M)= 5
DATA BY SINGAMSETTI AND WIND(1980)

HB(CM)	T(SEC)	DB(CM)	DB/LO	HB/LO	ETA C/H	TC/T
11.7	1.55	12.7	0.034	0.0311	0.568	0.411
19.3	1.55	15.6	0.041	0.0513	0.625	0.422
15.5	1.28	12.2	0.048	0.0606	0.663	0.408
9.6	1.28	10.2	0.040	0.0376	0.608	0.453
9.5	1.55	7.2	0.019	0.0252	0.654	0.412
10.5	1.04	8.0	0.048	0.0628	0.653	0.373
15.9	1.28	13.0	0.051	0.0621	0.645	0.407
9.0	1.04	7.7	0.046	0.0538	0.639	0.408
11.7	1.04	9.6	0.057	0.0696	0.675	0.419
18.3	1.72	19.3	0.042	0.0398	0.581	0.392
12.4	1.72	11.3	0.024	0.0270	0.628	0.424
16.2	1.28	13.6	0.053	0.0631	0.648	0.397
12.1	1.28	10.1	0.039	0.0471	0.674	0.440
8.9	1.28	8.0	0.031	0.0347	0.657	0.445
9.2	1.55	9.6	0.025	0.0246	0.619	0.402
8.7	1.04	8.0	0.047	0.0518	0.638	0.398
15.0	1.28	13.0	0.051	0.0582	0.615	0.370
7.7	1.04	9.7	0.058	0.0458	0.635	0.436
11.7	1.04	9.6	0.057	0.0699	0.638	0.400
18.3	1.72	19.2	0.042	0.0398	0.610	0.464
12.3	1.72	17.5	0.038	0.0268	0.586	0.498

SUM, SUM1, NO= 0.6720 1.0858 21
SD, SD1 =0.036970.09162
TC/T N, AVERAGE SD= 21 1.8236 0.3165

BREAKING MONOCHROMATIC WAVE DATA
COT(M)= 10
DATA BY SINGAMSETTI AND WIND(1980)

HB(CM)	T(SEC)	DB(CM)	DB/LO	HB/LO	ETA C/H	TC/T
13.7	1.55	12.7	0.034	0.0366	0.673	0.422
16.9	1.55	19.9	0.053	0.0451	0.740	0.292
11.7	1.28	12.8	0.050	0.0460	0.745	0.350
8.6	1.28	10.6	0.042	0.0336	0.727	0.367
11.1	1.55	10.1	0.027	0.0296	0.722	0.430
9.1	1.03	11.2	0.067	0.0545	0.739	0.326
13.5	1.28	14.4	0.056	0.0526	0.725	0.366
7.2	1.03	9.6	0.058	0.0434	0.678	0.342
10.5	1.03	12.7	0.076	0.0631	0.738	0.342
16.9	1.72	18.4	0.040	0.0367	0.729	0.323
14.0	1.72	11.4	0.025	0.0305	0.741	0.419
15.0	1.28	18.2	0.071	0.0587	0.755	0.331
14.1	1.55	12.8	0.034	0.0376	0.674	0.431
17.0	1.55	18.7	0.050	0.0454	0.000	0.000
11.8	1.28	13.0	0.051	0.0462	0.741	0.348
10.1	1.28	8.8	0.034	0.0395	0.728	0.306
11.9	1.55	10.5	0.028	0.0318	0.000	0.000
8.6	1.03	8.8	0.053	0.0520	0.743	0.339
14.3	1.28	17.1	0.067	0.0559	0.748	0.345
7.7	1.03	7.7	0.047	0.0468	0.719	0.361
11.2	1.03	13.3	0.080	0.0677	0.686	0.390
17.4	1.71	18.2	0.040	0.0383	0.752	0.373
14.0	1.71	12.2	0.027	0.0307	0.732	0.332
15.6	1.28	18.6	0.073	0.0610	0.734	0.314

SUM, SUM1, NO= 0.8131 1.2420 22
SD, SD1 0.07500.08541
TC/T N, AVERAGE SD= 22 1.4907 0.4204

BREAKING MONOCHROMATIC WAVE DATA
COT(M)= 20
DATA BY SINGAMSETTI AND WIND(1980)

HB(CM)	T(SEC)	DB(CM)	DB/LO	HB/LO	ETA C/H	TC/T
14.0	1.55	17.0	0.045	0.0374	0.751	0.307
17.4	1.55	20.0	0.053	0.0464	0.745	0.309
11.4	1.28	12.5	0.049	0.0449	0.770	0.273
9.6	1.28	10.0	0.039	0.0379	0.782	0.274
10.5	1.55	10.1	0.027	0.0281	0.779	0.295
8.8	1.04	10.7	0.064	0.0521	0.756	0.325
13.5	1.28	17.2	0.068	0.0530	0.767	0.333
7.8	1.04	9.2	0.055	0.0467	0.778	0.330
10.0	1.04	12.8	0.076	0.0598	0.752	0.360
17.6	1.73	20.0	0.043	0.0377	0.756	0.322
13.2	1.73	12.4	0.027	0.0284	0.792	0.269
16.2	1.28	20.2	0.079	0.0638	0.741	0.331
14.2	1.55	15.2	0.040	0.0379	0.789	0.289
18.0	1.55	20.7	0.055	0.0482	0.758	0.293
11.8	1.28	13.4	0.053	0.0465	0.768	0.300
10.0	1.28	10.8	0.043	0.0394	0.804	0.277
10.5	1.55	10.2	0.027	0.0281	0.772	0.290
9.1	1.04	11.0	0.066	0.0544	0.747	0.298
13.2	1.28	15.7	0.061	0.0520	0.766	0.320
7.7	1.04	8.9	0.053	0.0458	0.751	0.314
10.1	1.04	12.6	0.075	0.0601	0.770	0.336
17.1	1.73	17.9	0.038	0.0366	0.805	0.286
13.1	1.73	12.5	0.027	0.0282	0.774	0.265
16.5	1.28	20.8	0.082	0.0648	0.784	0.328

SUM, SUM1, NO= 0.8806 1.3052 24
SD, SD1 =0.032740.08863
TC/T N, AVERAGE SD= 24 1.1256 0.1118

BREAKING MONOCHROMATIC WAVE DATA
COT(M)= 40
DATA BY SINGAMSETTI AND WIND(1980)

HB(CM)	T(SEC)	DB(CM)	DB/LO	HB/LO	ETA C/H	TC/T
13.6	1.55	14.5	0.039	0.0363	0.805	0.292
17.0	1.55	20.2	0.054	0.0453	0.783	0.302
11.9	1.28	13.9	0.055	0.0468	0.793	0.301
9.2	1.28	11.0	0.043	0.0364	0.779	0.240
11.1	1.55	11.7	0.031	0.0297	0.822	0.259
9.6	1.04	11.6	0.069	0.0571	0.751	0.328
7.9	1.04	9.2	0.055	0.0470	0.766	0.316
15.9	1.28	21.9	0.086	0.0625	0.758	0.311
13.6	1.28	15.0	0.059	0.0537	0.747	0.356
11.0	1.04	15.2	0.090	0.0654	0.750	0.366
12.4	1.04	16.8	0.100	0.0738	0.767	0.335
13.3	1.04	20.4	0.122	0.0791	0.718	0.349
13.1	1.72	14.9	0.032	0.0285	0.824	0.266
13.6	1.55	14.5	0.039	0.0363	0.798	0.277
16.8	1.55	21.2	0.056	0.0450	0.775	0.302
11.8	1.28	12.9	0.051	0.0464	0.741	0.354
9.1	1.28	10.1	0.040	0.0360	0.752	0.286
11.0	1.55	11.7	0.031	0.0295	0.823	0.274
9.5	1.04	12.6	0.075	0.0565	0.761	0.324
7.7	1.04	9.2	0.055	0.0461	0.790	0.301
15.9	1.28	19.4	0.076	0.0627	0.722	0.375
13.2	1.28	16.4	0.065	0.0517	0.772	0.309
10.9	1.[illegible]	14.2	0.084	0.0648	0.697	0.316
12.5	1.04	16.3	0.097	0.0744	0.759	0.338
13.7	1.04	19.4	0.116	0.0815	0.738	0.337
14.0	1.72	15.4	0.033	0.0303	0.822	0.270

MONOCHROMATIC WAVE TEST (M=0.0)
SINUSOIDAL BLADE MOTION

H(CM)	T(SEC)	D(CM)	D/LO	H/LO	ETA C/H	TC/T
5.47	1.79	50.	0.100	0.0110	0.539	
9.07	1.79	50.	0.100	0.0181	0.567	
12.66	1.79	50.	0.100	0.0253	0.587	
16.27	1.79	50.	0.100	0.0326	0.600	
19.68	1.79	50.	0.100	0.0394	0.601	
3.33	0.96	50.	0.348	0.0232	0.517	
6.57	0.96	50.	0.348	0.0457	0.534	
8.11	0.96	50.	0.348	0.0564	0.545	
9.63	0.96	50.	0.348	0.0670	0.540	
10.96	0.96	50.	0.348	0.0762	0.554	
12.23	0.96	50.	0.348	0.0851	0.570	
13.44	0.96	50.	0.348	0.0935	0.576	
14.65	0.96	50.	0.348	0.1019	0.579	
6.05	3.03	50.	0.035	0.0042	0.626	
7.41	3.03	50.	0.035	0.0052	0.647	
8.85	3.03	50.	0.035	0.0062	0.665	
10.34	3.03	50.	0.035	0.0072	0.680	
11.83	3.03	50.	0.035	0.0083	0.694	
13.31	3.03	50.	0.035	0.0093	0.706	
14.88	3.03	50.	0.035	0.0104	0.716	
16.53	3.03	50.	0.035	0.0115	0.728	
18.14	3.03	50.	0.035	0.0127	0.734	
3.36	0.80	50.	0.501	0.0337	0.521	
4.99	0.80	50.	0.501	0.0500	0.546	
6.65	0.80	50.	0.501	0.0666	0.555	
8.06	0.80	50.	0.501	0.0807	0.565	
9.34	0.80	50.	0.501	0.0936	0.567	
10.51	0.80	50.	0.501	0.1052	0.580	
5.31	2.53	50.	0.050	0.0053	0.590	
6.71	2.53	50.	0.050	0.0067	0.602	
8.16	2.53	50.	0.050	0.0082	0.613	
10.40	2.53	50.	0.050	0.0104	0.625	
12.67	2.53	50.	0.050	0.0127	0.629	
14.20	2.53	50.	0.050	0.0142	0.637	
16.57	2.53	50.	0.050	0.0166	0.639	
19.00	2.53	50.	0.050	0.0190	0.645	
5.88	4.00	50.	0.020	0.0024	0.688	
7.63	4.00	50.	0.020	0.0031	0.609	
9.44	4.00	50.	0.020	0.0038	0.636	
11.29	4.00	50.	0.020	0.0045	0.657	
13.23	4.00	50.	0.020	0.0053	0.673	
12.38	4.00	50.	0.020	0.0050	0.683	
11.32	4.00	50.	0.020	0.0045	0.697	
12.44	4.00	50.	0.020	0.0050	0.693	
8.26	1.27	50.	0.199	0.0328	0.545	
13.41	1.27	50.	0.199	0.0533	0.580	
17.00	1.27	50.	0.199	0.0676	0.562	
20.61	1.27	50.	0.199	0.0319	0.621	
6.89	1.27	50.	0.199	0.0274	0.538	
5.61	5.66	50.	0.010	0.0011	0.527	

H(CM)	T(SEC)	D(CM)	D/LO	H/LO	ETA C/H	TC/T
6.27	5.66	50.	0.010	0.0013	0.539	
7.27	5.66	50.	0.010	0.0015	0.537	
8.34	5.66	50.	0.010	0.0017	0.547	
9.45	5.66	50.	0.010	0.0019	0.569	
11.90	5.66	50.	0.010	0.0024	0.599	
13.77	5.66	50.	0.010	0.0028	0.616	
15.60	5.66	50.	0.010	0.0031	0.631	
17.11	5.66	50.	0.010	0.0034	0.641	
1.64	1.60	60.	0.150	0.0041	0.520	0.481
7.16	1.60	60.	0.150	0.0179	0.543	0.475
10.90	1.60	60.	0.150	0.0273	0.551	0.476
15.37	1.60	60.	0.150	0.0385	0.585	0.449
20.05	1.60	60.	0.150	0.0502	0.592	0.448
1.81	1.75	60.	0.126	0.0038	0.511	0.494
6.28	1.75	60.	0.126	0.0131	0.542	0.472
8.57	1.75	60.	0.126	0.0179	0.563	0.460
11.38	1.75	60.	0.126	0.0238	0.581	0.454
16.24	1.75	60.	0.126	0.0340	0.603	0.432
2.80	1.96	60.	0.100	0.0047	0.524	0.489
10.52	1.96	60.	0.100	0.0176	0.599	0.438
14.93	1.96	60.	0.100	0.0249	0.629	0.411
20.67	1.96	60.	0.100	0.0345	0.673	0.395
26.08	1.96	60.	0.100	0.0435	0.716	0.373
1.63	2.27	60.	0.075	0.0020	0.518	0.490
7.90	2.27	60.	0.075	0.0098	0.578	0.455
10.99	2.27	60.	0.075	0.0137	0.601	0.442
15.27	2.27	60.	0.075	0.0190	0.629	0.418
21.73	2.27	60.	0.075	0.0270	0.655	0.380
2.72	2.77	60.	0.050	0.0023	0.523	0.488
7.79	2.77	60.	0.050	0.0065	0.575	0.450
11.18	2.77	60.	0.050	0.0093	0.617	0.414
16.45	2.77	60.	0.050	0.0137	0.648	0.375
23.16	2.77	60.	0.050	0.0193	0.716	0.336
29.31	2.77	60.	0.050	0.0245	0.761	0.322
1.79	5.06	60.	0.015	0.0004	0.523	0.485

APPENDIX B

IRREGULAR WAVE CREST ELEVATIONS

IRREGULAR WAVE CREST ELEVATIONS (LAB DATA)

D/(G*T2)	HS/(G*T2)	D(CM)	HS(CM)	TP(SEC)	ETA C/HS FOR PROBABILITY LEVELS= P=0.15	0.135	0.10	0.05	0.02	0.01	0.005
.0251	.00627	60.0	14.97	1.56	.563	.578	.631	.720	.792	.828	
.0251	.00624	60.0	14.90	1.56	.547	.557	.614	.654	.822	.879	
.0257	.00691	60.0	16.10	1.54	.589	.616	.669	.756	.837	.847	
.0257	.00686	60.0	16.00	1.54	.542	.561	.598	.685	.796	.826	
.0066	.00069	60.0	6.29	3.05	.533	.545	.584	.716	.767	.779	
.0066	.00066	60.0	5.98	3.05	.524	.536	.588	.721	.789	.806	
.0061	.00102	60.0	9.94	3.16	.535	.541	.591	.689	.710	.871	
.0061	.00096	60.0	9.45	3.16	.551	.566	.666	.733	.824	1.045	
.0173	.00346	60.0	12.01	1.88	.548	.586	.626	.745	.811	.907	
.0173	.00341	60.0	11.86	1.88	.547	.558	.601	.728	.869	.906	
.0048	.00099	60.0	12.22	3.56	.579	.598	.680	.799	.915	1.036	
.0048	.00096	60.0	11.80	3.56	.598	.616	.666	.727	.851	.919	
.0041	.00106	60.0	15.58	3.86	.642	.687	.707	.929	1.071	1.139	
.0041	.00104	60.0	15.29	3.88	.640	.658	.762	.873	1.062	1.090	
.0270	.00687	60.0	15.26	1.51	.557	.575	.636	.708	.790	.807	
.0270	.00673	60.0	14.95	1.51	.564	.570	.599	.704	.804	1.024	
.0216	.00585	60.0	16.25	1.66	.579	.589	.650	.729	.831	.887	
.0216	.00578	60.0	16.07	1.68	.561	.582	.604	.713	.803	.884	
.0057	.00058	60.0	6.17	3.28	.523	.533	.563	.743	.799	.811	
.0057	.00055	60.0	5.86	3.28	.531	.539	.589	.754	.824	.848	
.0173	.00345	60.0	11.98	1.88	.558	.570	.611	.745	.836	.919	
.0173	.00342	60.0	11.87	1.88	.528	.557	.610	.715	.859	.865	
.0200	.00522	45.0	11.74	1.51	.578	.598	.648	.731	1.011	1.132	1.181
.0200	.00503	45.0	11.31	1.51	.545	.550	.588	.663	.801	.885	.927
.0147	.00399	45.0	12.19	1.77	.593	.607	.656	.747	.866	.956	
.0147	.00391	45.0	11.94	1.77	.529	.502	.597	.650	.750	.868	
.0065	.00062	45.0	4.30	2.67	.518	.543	.567	.792	.853	.888	
.0065	.00059	45.0	4.09	2.67	.516	.539	.583	.756	.832	.893	
.0099	.00185	45.0	8.41	2.15	.535	.554	.585	.664	.952	1.090	1.308
.0049	.00179	45.0	8.14	2.15	.526	.548	.601	.693	.832	.881	
.0033	.00071	45.0	9.60	3.71	.653	.688	.769	.905	1.152	1.190	
.0035	.00071	45.0	9.07	3.61	.672	.678	.709	.875	1.115	1.126	
.0035	.00096	45.0	12.26	3.61	.650	.693	.761	.908	1.145	1.185	
.0035	.00092	45.0	11.70	3.61	.688	.702	.739	.876	.994	1.123	
.0045	.00095	45.0	9.54	3.20	.605	.619	.661	.828	1.132	1.172	
.0020	.00040	45.0	9.19	4.83	.584	.610	.717	.872	1.095	1.234	
.0062	.00092	45.0	6.72	2.72	.577	.581	.640	.723	.856	.869	
.0062	.00087	45.0	6.35	2.72	.535	.556	.592	.721	.835	.850	
.0163	.00383	75.0	17.69	2.17	.530	.572	.684	.802	1.082	1.105	
.0157	.00367	75.0	17.50	2.21	.543	.573	.643	.772	.993	1.111	

.0354	.00845	75.0	17.94	1.47	.590	.596	.624	.691	.761	.928	
.0358	.00845	75.0	17.88	1.46	.574	.596	.634	.718	.758	.901	
.0273	.00695	75.0	19.07	1.67	.617	.635	.699	.799	.947	1.050	
.0273	.00696	75.0	19.11	1.67	.560	.577	.600	.716	.825	.928	
.0086	.00093	75.0	8.05	2.98	.544	.555	.580	.655	.784	.834	
.0088	.00089	75.0	7.76	2.98	.556	.572	.622	.673	.814	.842	
.0200	.00370	75.0	13.85	1.95	.553	.576	.590	.672	.795	.948	
.0210	.00363	75.0	13.70	1.91	.518	.538	.593	.718	.865	.947	
.0056	.00115	75.0	15.57	3.71	.601	.640	.652	.603	.911	1.093	
.0056	.00115	75.0	15.53	3.71	.605	.610	.659	.769	.854	1.013	
.0157	.00376	75.0	17.95	2.21	.545	.568	.665	.752	1.005	1.084	
.0152	.00359	75.0	17.72	2.25	.536	.573	.652	.827	1.012	1.078	
.0354	.00846	75.0	17.95	1.47	.595	.601	.624	.696	.802	.842	
.0354	.00832	75.0	17.66	1.47	.576	.587	.634	.698	.799	.853	
.0273	.00693	75.0	19.02	1.67	.601	.644	.696	.795	.957	1.007	
.0273	.00689	75.0	18.91	1.67	.562	.577	.617	.735	.857	.980	
.0066	.00092	75.0	7.99	2.98	.532	.542	.611	.694	.784	.845	
.0103	.00106	75.0	7.76	2.72	.551	.559	.620	.692	.797	.851	
.0086	.00135	75.0	11.74	2.98	.580	.590	.622	.764	.812	.893	
.0088	.00131	75.0	11.33	2.98	.537	.549	.612	.698	.821	.885	
.0200	.00369	75.0	13.81	1.95	.544	.558	.587	.689	.811	.899	
.0200	.00364	75.0	13.61	1.95	.511	.527	.581	.734	.835	.939	
.0064	.00131	75.0	15.39	3.46	.643	.658	.682	.799	.902	1.098	
.0056	.00114	75.0	15.33	3.71	.598	.604	.658	.771	.841	1.015	
.0374	.00420	75.0	8.41	1.43	.556	.582	.611	.680	.759	.821	.903
.0374	.00415	75.0	8.32	1.43	.492	.503	.564	.637	.760	.816	.918
.0439	.00483	75.0	8.23	1.32	.541	.553	.595	.695	.868	1.010	1.116
.0439	.00467	75.0	7.97	1.32	.529	.542	.561	.662	.936	.982	1.070
.0354	.00446	75.0	9.50	1.47	.524	.535	.586	.688	.802	.879	1.050
.0349	.00434	75.0	9.32	1.48	.544	.551	.598	.685	.822	1.002	1.140
.0435	.00565	75.0	9.75	1.33	.545	.569	.621	.701	.796	.893	.950
.0439	.00557	75.0	9.51	1.32	.530	.545	.560	.666	.855	1.075	1.217
.0358	.00520	75.0	10.91	1.46	.525	.536	.598	.733	.883	.968	1.178
.0358	.00514	75.0	10.77	1.46	.544	.553	.596	.704	.796	.905	.956
.0491	.00557	75.0	8.51	1.25	.566	.596	.630	.721	.886	1.009	1.254
.0491	.00546	75.0	8.34	1.25	.553	.561	.620	.702	.804	.947	1.236
.0453	.00558	75.0	9.23	1.30	.528	.535	.567	.643	.839	1.037	1.239
.0453	.00544	75.0	9.01	1.30	.511	.523	.565	.663	.807	.822	1.431
.0334	.00525	75.0	11.81	1.51	.541	.563	.608	.660	.793	.840	1.270
.0334	.00516	75.0	11.61	1.51	.533	.553	.578	.639	.795	.995	1.412
.0341	.00552	75.0	12.13	1.50	.537	.573	.628	.706	.854	1.163	1.461
.0341	.00548	75.0	12.03	1.50	.514	.527	.563	.672	.932	1.235	1.391
.0356	.00382	75.0	8.02	1.46	.544	.567	.614	.683	.790	.857	.907
.0374	.00394	75.0	7.90	1.43	.507	.523	.568	.692	.744	.775	.845

.0439	.00480	75.0	8.19	1.32	.546	.562	.620	.720	.856	1.004	1.170
.0439	.00469	75.0	8.01	1.32	.513	.521	.549	.713	.855	.952	1.070
.0349	.00438	75.0	9.39	1.48	.524	.548	.606	.761	.828	.926	1.038
.0349	.00430	75.0	9.25	1.48	.508	.528	.567	.709	.789	.948	1.134
.0435	.00554	75.0	9.55	1.33	.551	.578	.624	.684	.823	.919	.999
.0439	.00549	75.0	9.37	1.32	.522	.534	.557	.671	.803	1.041	1.223
.0358	.00525	75.0	11.02	1.46	.549	.566	.606	.765	.843	.992	1.265
.0358	.00517	75.0	10.84	1.46	.548	.559	.597	.689	.769	.874	
.0491	.00578	75.0	8.84	1.25	.584	.591	.640	.732	.996	1.100	1.288
.0491	.00567	75.0	8.67	1.25	.548	.564	.596	.668	.797	1.099	1.242
.0453	.00558	75.0	9.23	1.30	.527	.534	.570	.633	.827	1.027	1.269
.0453	.00543	75.0	8.98	1.30	.514	.524	.564	.656	.803	.835	1.368
.0334	.00520	75.0	11.70	1.51	.564	.573	.623	.663	.801	.877	1.397
.0334	.00509	75.0	11.45	1.51	.514	.536	.589	.668	.782	1.028	1.473
.0341	.00515	75.0	11.30	1.50	.539	.565	.636	.730	.818	.902	1.342
.0341	.00508	75.0	11.16	1.50	.540	.570	.597	.665	.746	1.043	1.406
.0034	.00043	30.0	3.82	2.99	.573	.584	.651	.726	.870	.966	1.018
.0032	.00039	30.0	3.68	3.08	.565	.616	.678	.777	1.035	1.066	1.092
.0033	.00068	30.0	6.16	3.05	.570	.585	.676	.858	1.070	1.184	1.332
.0028	.00056	30.0	6.06	3.32	.566	.603	.696	.815	1.075	1.238	1.354
.0020	.00059	30.0	8.66	3.88	.606	.627	.703	.941	1.223	1.309	1.500
.0023	.00064	30.0	8.44	3.68	.633	.683	.755	.974	1.149	1.431	1.606
.0042	.00035	30.0	2.53	2.71	.492	.532	.579	.790	.913	1.064	1.172
.0028	.00023	30.0	2.43	3.28	.545	.556	.627	.781	.928	1.128	1.149
.0042	.00056	30.0	4.04	2.71	.590	.606	.663	.874	1.037	1.191	1.323
.0028	.00037	30.0	3.95	3.30	.585	.599	.717	.858	1.069	1.266	1.366
.0077	.00160	30.0	6.24	1.99	.518	.542	.652	.899	1.196	1.280	1.396
.0077	.00156	30.0	6.08	1.99	.586	.598	.717	.872	1.285	1.465	1.583
.0022	.00057	30.0	7.96	3.76	.613	.634	.695	.902	1.026	1.292	1.487
.0075	.00195	30.0	7.83	2.02	.650	.692	.759	.937	1.125	1.238	1.377
.0039	.00053	30.0	4.05	2.80	.503	.532	.641	.828	1.143	1.266	1.349
.0031	.00041	30.0	3.94	3.12	.544	.554	.664	.885	1.133	1.183	1.267
.0041	.00035	30.0	2.57	2.72	.451	.476	.539	.739	1.063	1.330	1.626
.0042	.00034	30.0	2.46	2.71	.481	.491	.556	.794	1.115	1.274	1.534
.0078	.00169	30.0	6.47	1.98	.617	.645	.722	.677	1.044	1.101	1.217

NA= 119
NB= 771

N= 60DGT1,DGT2,FM= .10000E-02 .20000E-02 .38273E+00
B1,B2,RMS E= .80000E+01 .80000E+00 .88561E+03

N= 101DGT1,DGT2,FM= .20000E-02 .40000E-02 .45006E-01
B1,B2,RMS E= .80000E+01 .80000E+00 .45697E+06

N= 170DGT1,DGT2,FM= .40000E-02 .80000E-02 .85638E-02
B1,B2,RMS E= .80000E+01 .80000E+00 .62273E+06

N= 79DGT1,DGT2,FM= .80000E-02 .16000E-01 .31639E-01

APPENDIX C

IRREGULAR WAVE CREST DURATIONS

IRREGULAR WAVE AVERAGE DIMENSIONLESS CREST DURATIONS

D/(G*T2)	HS/(G*T2)	D(CM)	HS(CM)	TP(SEC)	AVERAGE TC/T P=1.00	0.33	0.25	0.20	0.15	0.10	0.05
.0251	.00627	60.0	14.97	1.56	.434	.432	.424	.423	.415	.400	.401
.0251	.00624	60.0	14.90	1.56	.435	.426	.426	.427	.424	.416	.400
.0257	.00691	60.0	16.10	1.54	.436	.422	.414	.407	.394	.383	.369
.0257	.00686	60.0	16.00	1.54	.449	.438	.424	.417	.413	.405	.387
.0066	.00069	60.0	6.29	3.05	.452	.450	.448	.449	.440	.433	.427
.0066	.00066	60.0	5.98	3.05	.459	.458	.457	.455	.466	.480	.428
.0061	.00102	60.0	9.94	3.16	.450	.450	.449	.452	.461	.446	.439
.0061	.00098	60.0	9.45	3.16	.442	.442	.439	.434	.425	.437	.444
.0173	.00346	60.0	12.01	1.88	.457	.444	.436	.425	.407	.379	.383
.0173	.00341	60.0	11.86	1.88	.460	.466	.462	.463	.436	.436	.400
.0048	.00099	60.0	12.22	3.56	.465	.452	.445	.432	.428	.433	.428
.0049	.00096	60.0	11.86	3.56	.455	.456	.427	.432	.425	.386	.380
.0041	.00106	60.0	15.58	3.88	.443	.440	.439	.426	.423	.379	.298
.0041	.00104	60.0	15.29	3.88	.460	.460	.421	.416	.389	.372	.325
.0270	.00687	60.0	15.26	1.51	.433	.424	.411	.407	.404	.399	.391
.0270	.00673	60.0	14.95	1.51	.433	.431	.426	.421	.418	.411	.382
.0216	.00585	60.0	16.25	1.68	.431	.416	.412	.404	.396	.383	.374
.0216	.00578	60.0	16.07	1.68	.430	.426	.415	.411	.407	.393	.384
.0057	.00058	60.0	6.17	3.28	.463	.461	.456	.450	.447	.440	.419
.0057	.00055	60.0	5.86	3.28	.460	.460	.454	.442	.445	.439	.423
.0173	.00345	60.0	11.98	1.88	.456	.445	.428	.420	.411	.388	.367
.0173	.00342	60.0	11.87	1.88	.456	.456	.448	.441	.427	.416	.422
.0200	.00622	45.0	11.74	1.51	.433	.425	.409	.402	.390	.380	.356
.0200	.00603	45.0	11.31	1.51	.447	.443	.434	.430	.417	.401	.386
.0147	.00349	45.0	12.19	1.77	.438	.436	.422	.413	.393	.376	.349
.0147	.00341	45.0	11.94	1.77	.456	.450	.419	.420	.418	.422	.396
.0065	.00062	45.0	4.30	2.67	.460	.460	.450	.451	.450	.438	.430
.0065	.00059	45.0	4.09	2.67	.453	.455	.455	.444	.445	.427	.424
.0099	.00185	45.0	8.41	2.15	.472	.471	.475	.485	.472	.463	.408
.0099	.00179	45.0	8.14	2.15	.480	.480	.488	.488	.456	.458	.465
.0035	.00071	45.0	9.60	3.71	.421	.421	.412	.395	.371	.366	.378
.0035	.00071	45.0	9.07	3.61	.447	.451	.424	.421	.401	.350	.367
.0035	.00096	45.0	12.26	3.61	.451	.444	.430	.426	.427	.412	.368
.0035	.00092	45.0	11.70	3.61	.449	.452	.449	.457	.452	.461	.406
.0045	.00095	45.0	9.54	3.20	.462	.462	.457	.451	.443	.423	.379
.0029	.00040	45.0	9.19	4.83	.466	.466	.468	.460	.429	.443	[illegible]
.0062	.00092	45.0	6.72	2.72	.439	.441	.435	.426	.429	.435	.433
.0062	.00087	45.0	6.35	2.72	.437	.438	.422	.424	.431	.419	.421
.0163	.00383	75.0	17.69	2.17	.480	.446	.438	.417	.408	.393	[illegible]
.0157	.00367	75.0	17.50	2.21	.487	.456	.425	.414	.407	.390	.376

.0354	.00845	75.0	17.94	1.47	.476	.431	.426	.422	.414	.406	.394
.0358	.00843	75.0	17.68	1.46	.491	.440	.428	.424	.412	.395	.395
.0273	.00695	75.0	19.07	1.67	.463	.422	.401	.391	.387	.376	.359
.0273	.00696	75.0	19.11	1.67	.499	.446	.430	.423	.429	.416	.396
.0088	.00093	75.0	8.05	2.98	.488	.468	.466	.468	.446	.449	.459
.0086	.00089	75.0	7.76	2.98	.501	.469	.464	.448	.450	.448	.430
.0200	.00370	75.0	13.65	1.95	.478	.450	.438	.437	.425	.414	.417
.0210	.00383	75.0	13.71	1.91	.503	.468	.462	.453	.438	.417	.395
.0056	.00115	75.0	15.57	3.71	.472	.450	.412	.403	.373	.376	.354
.0056	.00115	75.0	15.55	3.71	.486	.439	.420	.420	.397	.382	.379
.0157	.00376	75.0	17.95	2.21	.479	.438	.427	.423	.395	.391	.370
.0152	.00359	75.0	17.72	2.25	.486	.453	.441	.435	.433	.409	.384
.0354	.00846	75.0	17.95	1.47	.473	.433	.425	.418	.408	.406	.403
.0354	.00832	75.0	17.66	1.47	.487	.442	.436	.431	.422	.410	.414
.0273	.00693	75.0	19.02	1.67	.460	.421	.411	.397	.386	.373	.358
.0273	.00689	75.0	18.91	1.67	.494	.440	.433	.426	.423	.414	.381
.0088	.00092	75.0	7.99	2.98	.494	.470	.464	.466	.450	.450	.453
.0103	.00106	75.0	7.70	2.72	.497	.461	.459	.441	.442	.445	.433
.0088	.00135	75.0	11.74	2.98	.485	.444	.436	.432	.440	.424	.419
.0086	.00131	75.0	11.33	2.98	.496	.456	.451	.427	.427	.421	.416
.0200	.00369	75.0	13.81	1.95	.476	.463	.457	.457	.426	.403	.407
.0200	.00364	75.0	13.61	1.95	.506	.474	.463	.450	.443	.403	.391
.0064	.00131	75.0	15.34	3.46	.464	.448	.422	.409	.396	.373	.351
.0056	.00114	75.0	15.33	3.71	.492	.436	.412	.415	.418	.407	.391
.0374	.00420	75.0	8.41	1.43	.485	.466	.457	.461	.451	.442	.440
.0374	.00415	75.0	8.32	1.43	.498	.478	.470	.469	.462	.454	.449
.0439	.00483	75.0	8.23	1.32	.478	.467	.456	.442	.432	.432	.432
.0439	.00467	75.0	7.97	1.32	.486	.462	.451	.452	.445	.437	.425
.0354	.00448	75.0	9.59	1.47	.485	.480	.477	.475	.475	.453	.458
.0349	.00434	75.0	9.32	1.48	.480	.457	.447	.445	.431	.414	.410
.0435	.00565	75.0	9.75	1.33	.480	.460	.447	.447	.440	.437	.436
.0439	.00557	75.0	9.51	1.32	.495	.465	.452	.452	.453	.430	.409
.0358	.00520	75.0	10.91	1.46	.481	.470	.471	.469	.455	.452	.425
.0358	.00514	75.0	10.77	1.46	.490	.460	.454	.452	.445	.442	.421
.0491	.00557	75.0	8.51	1.25	.482	.453	.447	.441	.444	.441	.433
.0491	.00546	75.0	8.34	1.25	.488	.450	.442	.437	.439	.431	.432
.0453	.00558	75.0	9.23	1.30	.497	.477	.461	.472	.463	.448	.442
.0453	.00544	75.0	9.01	1.30	.494	.464	.460	.459	.454	.451	.423
.0334	.00525	75.0	11.81	1.51	.475	.456	.450	.447	.445	.439	.424
.0334	.00516	75.0	11.61	1.51	.495	.471	.459	.449	.444	.435	.411
.0341	.00552	75.0	12.13	1.50	.476	.454	.442	.434	.432	.424	.417
.0341	.00548	75.0	12.03	1.50	.514	.464	.460	.455	.442	.427	.408
.0358	.00382	75.0	8.02	1.46	.484	.473	.461	.453	.444	.441	.429
.0374	.00394	75.0	7.90	1.43	.493	.483	.469	.455	.457	.443	.419

.0439	.00480	75.0	8.19	1.32	.491	.465	.467	.456	.452	.451	.441
.0439	.00469	75.0	8.01	1.32	.506	.478	.474	.465	.457	.440	.430
.0349	.00438	75.0	9.39	1.48	.491	.462	.469	.459	.454	.453	.463
.0349	.00430	75.0	9.23	1.48	.485	.461	.458	.446	.440	.444	.414
.0435	.00554	75.0	9.55	1.33	.491	.457	.450	.449	.446	.436	.424
.0439	.00549	75.0	9.37	1.32	.497	.461	.460	.458	.462	.446	.442
.0358	.00525	75.0	11.02	1.46	.475	.464	.459	.464	.455	.443	.431
.0358	.00517	75.0	10.84	1.46	.495	.467	.451	.453	.450	.452	.435
.0491	.00578	75.0	8.84	1.25	.481	.451	.440	.438	.435	.431	.421
.0491	.00567	75.0	8.67	1.25	.492	.460	.450	.443	.444	.440	.430
.0453	.00558	75.0	9.25	1.30	.496	.472	.468	.469	.458	.457	.437
.0453	.00543	75.0	8.98	1.30	.504	.467	.461	.461	.454	.443	.424
.0334	.00520	75.0	11.70	1.51	.474	.458	.449	.445	.442	.438	.437
.0334	.00509	75.0	11.45	1.51	.494	.472	.457	.452	.447	.442	.418
.0341	.00515	75.0	11.30	1.50	.476	.439	.436	.427	.424	.435	.409
.0341	.00508	75.0	11.16	1.50	.502	.468	.450	.456	.446	.440	.423
.0034	.00043	30.0	3.82	2.99	.494	.424	.427	.423	.404	.394	.387
.0032	.00039	30.0	3.68	3.08	.458	.426	[illegible]	.422	.417	.409	.382
.0033	.00068	30.0	6.16	3.05	.484	.429	[illegible]	.397	.395	.373	.365
.0028	.00056	30.0	6.06	3.32	.470	.444	.436	.437	.414	.380	.358
.0020	.00059	30.0	8.68	3.88	.452	.515	.489	.466	.447	.433	.378
.0023	.00064	30.0	8.44	3.68	.444	.465	.454	.441	.418	.420	.326
.0042	.00035	30.0	2.53	2.71	.495	[illegible]	.460	.447	.433	.444	.407
.0028	.00023	30.0	2.43	3.28	.464	.452	[illegible]	.441	.439	.444	.424
.0042	.00056	30.0	4.64	2.71	.494	[illegible]	.429	.418	.400	.381	.361
.0028	.00037	30.0	3.95	3.30	.465	[illegible]	.419	.409	.379	.370	.348
.0077	.00160	30.0	6.24	1.99	.485	[illegible]	.486	.472	.460	.438	.391
.0077	.00156	30.0	6.08	1.99	.467	[illegible]	[illegible]	.474	.449	.423	.379
.0022	.00057	30.0	7.96	3.76	.465	.490	.488	.471	.457	.441	.402
.0075	.00195	30.0	7.83	2.02	.451	.450	.446	.439	.441	.428	.375
.0039	.00053	30.0	4.05	2.80	.492	.467	.459	.445	.435	.410	.417
.0031	.00041	30.0	3.94	3.12	.479	.445	.430	.415	.415	.404	.400
.0041	.00035	30.0	2.57	2.72	.490	.483	.472	.465	.463	.460	.460
.0042	.00034	30.0	2.46	2.71	.471	.471	.465	.454	.444	.431	.426
.0078	.00169	30.0	6.47	1.98	.468	.498	.472	.481	.479	.490	.529
.0078	.00163	30.0	6.26	1.98	.461	.496	.485	.468	.443	.443	.416
.0021	.00058	30.0	8.17	3.79	.458	.520	.497	.503	.494	.471	.429
.0080	.00214	30.0	8.01	1.95	.442	.494	.498	.501	.495	.473	.477

APPENDIX D

IRREGULAR WAVE DATA FOR SHOALING CONDITIONS

WAVE CREST ELEVATION WITH A 1/30 PLANE SLOPE

ID	SENSOR	TP(S)	HS(CM)	D(CM)	CREST ELEVATION/HS P= 0.15	0.135	0.10	0.05	0.02	0.01	0.005
A011251110 157 10											
	2	1.30	8.62	60.0	.535	.551	.604	.679	.757	.795	.818
	3	1.30	8.49	60.0	.518	.528	.567	.669	.773	.888	1.026
	4	1.46	8.35	60.0	.529	.543	.580	.647	.723	.759	.945
	5	1.46	8.29	52.5	.533	.555	.570	.665	.731	.803	.842
	6	1.43	8.04	45.0	.534	.546	.587	.682	.796	.874	1.012
	7	1.43	7.87	37.5	.523	.535	.555	.670	.845	.882	.954
	8	1.43	7.60	30.0	.561	.577	.613	.715	.791	.880	.937
	9	1.43	7.95	22.5	.569	.604	.693	.798	.939	1.011	1.226
	10	1.55	7.60	15.0	.691	.703	.763	.874	.948	1.048	1.056
	11	1.58	5.22	7.5	.740	.745	.796	.887	.998	1.060	1.135
A011251118 257 10											
	2	1.32	8.93	60.0	.526	.552	.575	.629	.794	.886	.976
	3	1.32	8.80	60.0	.507	.518	.557	.654	.853	.998	1.060
	4	1.12	8.67	60.0	.515	.547	.589	.686	.858	.879	1.004
	5	1.32	8.59	52.5	.554	.582	.607	.697	.871	.971	.992
	6	1.32	8.38	45.0	.530	.546	.593	.722	.841	.926	1.043
	7	1.32	8.21	37.5	.546	.574	.649	.739	.917	.941	1.058
	8	1.32	8.00	30.0	.596	.624	.655	.752	.881	.918	.980
	9	1.32	7.96	22.5	.575	.604	.712	.790	.983	1.001	1.010
	10	1.32	7.41	15.0	.693	.711	.741	.812	.920	.983	1.011
	11	1.48	5.11	7.5	.721	.729	.765	.826	.944	1.039	1.109
A011251129 357 10											
	2	1.48	9.53	60.0	.570	.581	.597	.653	.749	.815	.881
	3	1.37	9.40	60.0	.542	.547	.581	.722	.765	.837	.942
	4	1.41	9.29	60.0	.537	.553	.581	.712	.795	.839	.961
	5	1.41	9.25	52.5	.554	.561	.592	.709	.778	.884	.912
	6	1.41	9.06	45.0	.545	.553	.610	.733	.870	.938	.944
	7	1.57	8.93	37.5	.547	.555	.604	.726	.783	.830	1.047
	8	1.53	8.97	30.0	.597	.614	.660	.735	.845	.880	
	9	1.57	9.10	22.5	.636	.657	.732	.864	.950	.993	
	10	1.75	8.36	15.0	.745	.757	.791	.865	.954	1.026	
	11	1.86	5.36	7.5	.724	.733	.758	.860	.934	1.001	
A011251138 457 5											
	2	1.21	5.16	60.0	.490	.510	.548	.656	.768	.808	.845
	3	1.32	5.06	60.0	.513	.526	.563	.646	.762	.862	.908
	4	1.32	5.01	60.0	.510	.524	.547	.606	.742	.918	.977
	5	1.32	4.95	52.5	.499	.511	.569	.664	.777	.935	1.071
	6	1.32	4.80	45.0	.499	.516	.557	.648	.750	.840	.914
	7	1.32	4.66	37.5	.528	.557	.600	.699	.768	.832	.874
	8	1.32	4.70	30.0	.506	.518	.552	.632	.731	.790	.960
	9	1.32	4.70	22.5	.546	.553	.572	.704	.845	.949	1.013
	10	1.32	4.74	15.0	.613	.628	.692	.751	.933	.981	1.073
	11	1.42	4.44	7.5	.747	.773	.803	.883	.937	.994	1.013
A011251147 457 5											
	2	1.32	9.68	60.0	.515	.551	.590	.696	.803	.861	.903
	3	1.32	9.57	60.0	.540	.555	.601	.709	.860	.911	.921
	4	1.32	9.37	60.0	.547	.555	.597	.687	.832	1.006	1.095
	5	1.32	9.28	52.5	.542	.552	.590	.679	.738	.998	1.197
	6	1.32	9.16	45.0	.556	.571	.601	.704	.899	.934	1.154
	7	1.32	9.00	37.5	.532	.554	.595	.731	.956	1.145	1.192
	8	1.32	8.89	30.0	.556	.583	.627	.786	.905	1.053	1.097
	9	1.32	8.78	22.5	.606	.627	.680	.758	.911	1.030	1.097
	10	1.33	7.91	15.0	.695	.730	.781	.838	.923	.987	1.002
	11	1.60	5.25	7.5	.705	.716	.748	.872	1.031	1.087	1.123
A011251156 557 5											
	2	1.46	5.42	60.0	.501	.526	.563	.645	.726	.777	.790
	3	1.46	5.39	60.0	.503	.506	.548	.657	.715	.790	.836
	4	1.46	5.30	60.0	.508	.523	.590	.706	.766	.782	.939
	5	1.46	5.27	52.5	.524	.537	.570	.639	.744	.855	1.082
	6	1.41	5.17	45.0	.519	.519	.570	.629	.808	.934	
	7	1.41	5.08	37.5	.497	.509	.596	.687	.797	.834	.975
	8	1.41	5.07	30.0	.523	.546	.638	.710	.814	.873	.876
	9	1.41	5.21	22.5	.552	.562	.608	.701	.925	1.008	1.033
	10	1.70	5.24	15.0	.652	.666	.727	.906	1.023	1.045	
	11	8.53	4.59	7.5	.603	.612	.633	.693	1.006	1.055	1.184

80112512 5 557 5										
	2	1.46	10.79	60.0	.554	.560	.628	.766	.838	.878	1.021
	3	1.46	10.54	60.0	.521	.547	.630	.711	.827	.944	1.187
	4	1.46	10.39	60.0	.548	.564	.619	.722	.862	1.082	1.126
	5	1.46	10.39	52.5	.532	.551	.642	.752	.640	.853	
	6	1.46	10.15	45.0	.571	.581	.609	.686	.859	.934	.985
	7	1.46	10.13	37.5	.554	.574	.642	.747	.900	1.040	
	8	1.46	10.05	30.0	.584	.616	.666	.902	.999	1.012	
	9	1.46	9.93	22.5	.652	.660	.720	.822	.954	.977	
	10	1.52	8.69	15.0	.743	.755	.776	.852	.889	.961	
	11	8.83	5.45	7.5	.722	.727	.777	.867	.951	1.040	
801125122 3 657 5										
	2	1.25	9.07	60.0	.526	.536	.566	.621	.693	1.018	1.114
	3	1.25	8.93	60.0	.515	.534	.552	.644	.913	1.068	1.086
	4	1.25	8.83	60.0	.528	.544	.595	.672	.796	.871	.989
	5	1.25	8.72	52.5	.550	.560	.602	.731	.816	.876	.886
	6	1.25	8.40	45.0	.516	.533	.586	.677	.928	1.092	1.124
	7	1.25	8.25	37.5	.552	.559	.602	.724	.922	1.081	1.165
	8	1.25	8.09	30.0	.579	.591	.645	.705	.882	.982	1.179
	9	1.23	7.92	22.5	.674	.687	.725	.769	.924	.976	.999
	10	1.23	7.32	15.0	.715	.720	.750	.850	.966	.987	.995
	11	1.53	4.92	7.5	.725	.736	.761	.839	.877	.936	1.044
801125123 3 757 5										
	2	1.30	9.33	60.0	.511	.522	.568	.710	.834	1.022	1.196
	3	1.30	9.26	60.0	.543	.548	.574	.684	.786	.888	1.175
	4	1.30	9.04	60.0	.561	.574	.611	.677	.817	.961	1.165
	5	1.30	8.97	52.5	.561	.572	.604	.666	.901	1.033	1.236
	6	1.30	8.76	45.0	.539	.556	.610	.706	.793	1.064	1.146
	7	1.30	8.59	37.5	.550	.572	.645	.729	.832	1.020	1.244
	8	1.30	8.47	30.0	.577	.584	.639	.751	.908	1.043	1.145
	9	1.30	8.41	22.5	.619	.640	.707	.846	.967	1.020	1.237
	10	1.30	7.62	15.0	.714	.722	.745	.819	.899	.966	1.005
	11	9.14	5.05	7.5	.715	.735	.776	.849	.932	.949	1.057
801125124 5 857 5										
	2	1.46	6.21	60.0	.471	.484	.517	.603	.789	1.231	1.359
	3	1.46	6.16	60.0	.473	.486	.510	.576	.974	1.116	1.354
	4	1.46	6.10	60.0	.467	.489	.528	.573	.704	1.136	1.306
	5	1.46	6.06	52.5	.504	.511	.547	.580	.820	1.290	1.211
	6	1.46	5.92	45.0	.478	.486	.540	.658	.968	1.171	1.585
	7	1.46	5.87	37.5	.476	.499	.535	.642	1.227	1.491	1.506
	8	1.46	5.90	30.0	.483	.514	.543	.615	1.125	1.519	
	9	1.52	5.92	22.5	.523	.534	.571	.686	1.244	1.591	
	10	1.54	5.52	15.0	.666	.696	.735	.819	.957	1.165	
	11	1.54	4.78	7.5	.787	.796	.836	.873	.989	1.081	
80112513 6 657 6										
	2	1.52	9.56	60.0	.513	.520	.589	.725	.836	1.044	1.284
	3	1.52	9.48	60.0	.529	.556	.609	.661	.793	1.109	1.374
	4	1.52	9.38	60.0	.525	.535	.595	.666	.811	.893	1.266
	5	1.52	9.32	52.5	.516	.524	.556	.623	.830	1.312	
	6	1.52	9.14	45.0	.526	.534	.572	.651	.820	1.226	
	7	1.52	9.04	37.5	.523	.529	.573	.686	.889	1.177	
	8	1.52	8.87	30.0	.553	.564	.619	.699	.878	1.176	
	9	1.52	8.76	22.5	.617	.630	.676	.774	.921	1.023	
	10	1.54	8.11	15.0	.729	.760	.790	.820	.878	.895	
	11	1.57	5.28	7.5	.675	.698	.747	.841	1.032	1.142	
80112510 1 645 10										
	2	1.77	12.81	60.0	.581	.590	.627	.725	.833	.900	
	3	1.77	12.73	60.0	.526	.563	.614	.661	.798	.895	
	4	1.77	12.62	60.0	.526	.536	.566	.660	.726	.816	
	5	1.77	12.64	52.5	.551	.561	.636	.705	.784	.844	
	6	1.77	12.55	45.0	.600	.620	.635	.702	.746	.837	
	7	1.77	12.52	37.5	.611	.627	.661	.730	.945	1.039	
	8	1.77	12.31	30.0	.654	.662	.713	.767	.907	.968	
	9	1.77	11.96	22.5	.751	.763	.790	.884	.909	.939	
	10	2.03	9.83	15.0	.792	.806	.825	.871	.959	1.014	
	11	2.39	6.03	7.5	.665	.672	.721	.886	1.007	1.041	
8011251010 645 5										
	2	1.79	6.26	60.0	.516	.537	.568	.622	.709	.752	
	3	1.77	6.18	60.0	.526	.554	.582	.642	.799	.908	
	4	1.79	6.13	60.0	.473	.482	.551	.653	.785	.847	
	5	1.78	6.13	52.5	.508	.516	.564	.675	.751	.798	
	6	1.79	6.09	45.0	.536	.546	.566	.641	.684	.829	
	7	1.78	6.09	37.5	.531	.550	.570	.645	.761	.833	
	8	1.67	6.12	30.0	.539	.554	.621	.711	.794	.855	
	9	1.67	6.35	22.5	.627	.640	.690	.746	.786	.909	
	10	2.03	6.39	15.0	.731	.753	.831	.918	1.012	1.048	
	11	2.03	4.91	7.5	.815	.824	.872	.964	1.024	1.126	

8011251020 745 5											
	2	3.51	6.68	60.0	.560	.615	.664	.772	.949	.994	
	3	3.46	6.58	60.0	.590	.604	.623	.754	.912	.999	
	4	3.51	6.57	60.0	.520	.530	.597	.788	.934	1.094	
	5	3.46	6.66	52.5	.547	.576	.625	.745	.869	1.091	
	6	3.51	6.79	45.0	.557	.564	.585	.703	.632	1.073	
	7	3.46	6.90	37.5	.546	.550	.575	.736	.656	1.047	
	8	3.66	7.10	30.0	.603	.626	.660	.722	1.013	1.161	
	9	3.71	7.64	22.5	.705	.715	.780	.957	1.099	1.292	
	10	4.27	7.73	15.0	.660	.684	1.040	1.160	1.396	1.474	
	11	3.88	5.62	7.5	.797	.811	.869	.966	1.055	1.148	
8011251024 745 10											
	2	3.71	14.63	60.0	.659	.686	.748	.964	1.154	1.202	
	3	3.46	13.91	60.0	.640	.656	.758	.881	1.099	1.179	
	4	3.46	13.83	60.0	.571	.630	.690	.857	.985	1.274	
	5	3.46	13.92	52.5	.650	.661	.712	.803	.881	1.302	
	6	3.66	14.12	45.0	.596	.657	.705	.804	.981	1.172	
	7	3.41	14.32	37.5	.665	.673	.688	.916	1.192	1.213	
	8	3.41	14.69	30.0	.765	.780	.841	1.020	1.213	1.290	
	9	3.71	14.09	22.5	.809	.817	.893	1.069	1.257	1.294	
	10	3.88	11.18	15.0	.791	.815	.848	.963	1.129	1.135	
	11	11.13	8.19	7.5	.625	.636	.697	.778	.870	.925	
8011241517 345 5											
	2	1.67	9.54	60.0	.532	.552	.575	.681	.730	.860	
	3	1.67	9.35	60.0	.534	.546	.591	.677	.838	.900	
	4	1.67	9.29	60.0	.520	.546	.596	.647	.633	.946	
	5	1.67	9.27	52.5	.505	.527	.575	.673	.614	.975	
	6	1.67	9.15	45.0	.549	.559	.599	.706	.797	.921	
	7	1.67	9.03	37.5	.546	.610	.648	.721	.843	1.105	
	8	1.67	9.10	30.0	.571	.576	.614	.715	.858	1.234	
	9	1.67	9.15	22.5	.713	.722	.765	.900	1.019	1.117	
	10	1.67	8.47	15.0	.611	.623	.866	.942	1.050	1.091	
	11	1.83	5.48	7.5	.730	.704	.800	.905	.981	1.064	
801125 942 545 10											
	2	3.12	10.56	60.0	.524	.546	.638	.860	.989	1.156	
	3	3.12	10.59	60.0	.500	.512	.660	.654	1.059		
	4	3.12	10.49	60.0	.573	.576	.654	.798	1.006	1.092	
	5	3.12	10.70	52.5	.600	.624	.671	.832	1.000		
	6	3.12	10.83	45.0	.615	.643	.680	.793	1.070		
	7	3.12	11.18	37.5	.681	.700	.746	.891	1.221	1.229	
	8	3.12	11.33	30.0	.731	.672	.973	1.060	1.387	1.473	
	9	3.12	10.95	22.5	.904	.941	1.031	1.104	1.251		
	10	3.33	9.27	15.0	.654	.676	.963	1.102	1.209	1.239	
	11	15.06	6.83	7.5	.613	.647	.732	.672	1.026	1.300	
801125 951 545 8											
	2	3.16	8.33	60.0	.512	.526	.607	.775	.918	1.091	
	3	3.16	8.33	60.0	.500	.533	.634	.800	.985	1.010	
	4	3.16	8.28	60.0	.546	.564	.637	.773	.925		
	5	3.16	8.44	52.5	.573	.580	.640	.819	.940		
	6	3.16	8.55	45.0	.585	.605	.629	.804	1.049		
	7	3.16	8.76	37.5	.635	.646	.708	.785	1.148		
	8	3.16	8.93	30.0	.692	.757	.679	.972	1.340		
	9	3.16	9.14	22.5	.851	.910	1.045	1.291	1.402	1.567	
	10	3.37	8.01	15.0	.899	.918	1.022	1.149	1.236	1.267	
	11	15.06	6.03	7.5	.682	.707	.605	.956	1.036	1.265	
8011241439 145 5											
	2	2.17	8.20	60.0	.468	.471	.524	.671	.825	1.012	
	3	2.17	8.16	60.0	.505	.509	.557	.621	.755	.908	
	4	2.17	8.07	60.0	.536	.542	.623	.691	.752	.945	
	5	2.21	8.11	52.5	.490	.507	.558	.646	.750	1.004	
	6	2.21	8.05	45.0	.476	.485	.555	.711	.871	1.165	
	7	2.21	8.06	37.5	.511	.531	.622	.788	.926	1.079	
	8	2.21	8.30	30.0	.581	.607	.636	.760	.880	1.140	
	9	1.68	8.46	22.5	.726	.751	.639	.961	1.075	1.360	
	10	2.31	7.94	15.0	.791	.818	.871	1.078	1.113	1.171	
	11	2.37	5.46	7.5	.704	.706	.743	.834	1.042	1.148	
8011241446 245 5											
	2	1.47	9.17	60.0	.513	.528	.582	.628	.712	.762	
	3	1.46	9.04	60.0	.514	.525	.539	.611	.678	.753	
	4	1.47	8.90	60.0	.539	.562	.576	.637	.767	.860	.891
	5	1.47	8.85	52.5	.529	.545	.558	.623	.724	.761	
	6	1.47	8.75	45.0	.527	.545	.588	.648	.737	.817	
	7	1.47	8.72	37.5	.545	.560	.610	.689	.748	.786	
	8	1.47	8.82	30.0	.569	.587	.612	.684	.791	.934	
	9	1.47	9.04	22.5	.652	.669	.714	.820	.915	.987	
	10	1.47	8.52	15.0	.743	.770	.820	.897	.945	.984	
	11	1.52	5.30	7.5	.700	.717	.765	.893	.924	1.074	

8011241457 245 5

2	1.46	9.18	60.0	.516	.520	.579	.624	.721	.737	
3	1.46	9.06	60.0	.523	.529	.546	.625	.679	.722	
4	1.46	8.92	60.0	.551	.562	.584	.635	.748	.833	
5	1.46	8.86	52.5	.542	.546	.559	.638	.727	.781	
6	1.46	8.72	45.0	.525	.556	.600	.657	.744	.841	
7	1.47	8.69	37.5	.559	.570	.608	.690	.742	.803	
8	1.47	8.81	30.0	.571	.583	.614	.687	.785	.925	
9	1.47	9.04	22.5	.638	.671	.714	.805	.925	.985	
10	1.47	8.51	15.0	.754	.764	.799	.887	.957	.971	
11	1.59	5.32	7.5	.694	.699	.787	.872	.975	1.035	1.062

80112415 7 345 5

2	1.67	9.54	60.0	.533	.552	.573	.689	.740	.857
3	1.67	9.34	60.0	.535	.544	.590	.701	.637	.900
4	1.67	9.28	60.0	.523	.542	.594	.644	.829	.942
5	1.67	9.27	52.5	.517	.532	.579	.685	.816	.969
6	1.67	9.15	45.0	.545	.566	.587	.731	.801	.938
7	1.67	9.02	37.5	.550	.589	.657	.721	.854	1.109
8	1.67	9.09	30.0	.568	.576	.600	.719	.863	1.245
9	1.67	9.17	22.5	.700	.719	.760	.916	1.003	1.074
10	1.67	8.46	15.0	.808	.832	.867	.965	1.016	1.026
11	1.87	5.47	7.5	.707	.733	.809	.902	1.012	1.078

8011241439 145 5

2	2.17	8.20	60.0	.468	.471	.524	.671	.825	1.012
3	2.17	8.16	60.0	.505	.509	.557	.621	.755	.908
4	2.17	8.07	60.0	.536	.542	.623	.691	.752	.945
5	2.21	8.11	52.5	.490	.507	.558	.646	.750	1.004
6	2.21	8.05	45.0	.476	.485	.555	.711	.871	1.165
7	2.21	8.06	37.5	.511	.531	.622	.788	.926	1.079
8	2.21	8.30	30.0	.581	.607	.635	.760	.880	1.140
9	1.68	8.46	22.5	.726	.751	.639	.961	1.075	1.360
10	2.31	7.94	15.0	.791	.812	.671	1.078	1.113	1.171
11	2.37	5.46	7.5	.704	.706	.743	.834	1.042	1.148

8011241448 245 5

2	1.47	9.17	60.0	.513	.52[illegible]	.582	.628	.712	.762	
3	1.46	9.04	60.0	.514	.525	.539	.611	.678	.753	
4	1.47	8.90	60.0	.539	.562	.576	.637	.767	.860	.891
5	1.47	8.85	52.5	.529	.545	.558	.623	.724	.761	
6	1.47	8.75	45.0	.527	.545	.583	.648	.737	.817	
7	1.47	8.72	37.5	.545	.560	.610	.689	.748	.786	
8	1.47	8.82	30.0	.569	.587	.612	.684	.791	.934	
9	1.47	9.04	22.5	.652	.669	.714	.820	.915	.987	
10	1.47	8.52	15.0	.743	.770	.820	.897	.945	.984	
11	1.52	5.30	7.5	.700	.717	.765	.893	.924	1.074	

8011241457 245 5

2	1.46	9.18	60.0	.516	.520	.579	.624	.721	.737	
3	1.46	9.06	60.0	.523	.529	.546	.625	.679	.722	
4	1.46	8.92	60.0	.551	.562	.584	.635	.748	.833	
5	1.46	8.86	52.5	.542	.546	.559	.638	.727	.781	
6	1.46	8.72	45.0	.525	.556	.600	.657	.744	.841	
7	1.47	8.69	37.5	.559	.570	.608	.690	.742	.803	
8	1.47	8.81	30.0	.571	.583	.614	.687	.785	.925	
9	1.47	9.04	22.5	.638	.671	.714	.805	.925	.985	
10	1.47	8.51	15.0	.754	.764	.799	.887	.957	.971	
11	1.59	5.32	7.5	.694	.699	.787	.872	.975	1.035	1.062

80112415 7 345 5

2	1.67	9.54	60.0	.533	.552	.573	.689	.740	.857
3	1.67	9.34	60.0	.535	.544	.590	.701	.637	.900
4	1.67	9.28	60.0	.523	.542	.594	.644	.829	.942
5	1.67	9.27	52.5	.517	.532	.579	.685	.816	.969
6	1.67	9.15	45.0	.545	.566	.587	.731	.801	.938
7	1.67	9.02	37.5	.550	.589	.657	.721	.854	1.109
8	1.67	9.09	30.0	.568	.576	.600	.719	.863	1.245
9	1.67	9.17	22.5	.700	.719	.760	.916	1.003	1.074
10	1.67	8.46	15.0	.808	.832	.867	.965	1.016	1.026
11	1.87	5.47	7.5	.707	.733	.809	.902	1.012	1.078

8011241321 675 10

2	1.84	10.11	60.0	.529	.539	.573	.641	.768	.869
3	1.74	10.04	60.0	.537	.546	.603	.748	.919	.996
4	1.84	9.96	60.0	.505	.512	.574	.665	.757	.778
5	1.84	9.43	52.5	.536	.548	.564	.625	.917	.960
6	1.84	9.90	45.0	.544	.576	.589	.656	.798	.939
7	1.84	9.80	37.5	.572	.579	.606	.750	.868	1.098
8	1.86	9.83	30.0	.587	.605	.666	.785	.967	1.135
9	1.84	9.83	22.5	.685	.712	.760	.876	1.052	1.109
10	1.86	8.77	15.0	.759	.767	.817	.876	.998	1.068
11	2.10	5.57	7.5	.691	.722	.781	.862	.973	1.106

A011241332 775 10											
	2	4.20	10.90	60.0	.567	.575	.635	.771	1.008	1.051	
	3	4.20	10.64	60.0	.583	.597	.627	.761	1.044	1.160	
	4	4.20	10.66	60.0	.631	.638	.728	.775	1.105	1.202	
	5	4.20	10.73	52.5	.612	.638	.691	.736	1.043	1.290	
	6	4.20	10.89	45.0	.672	.677	.713	.818	.999	1.457	
	7	4.20	11.04	37.5	.692	.713	.766	.833	1.069	1.723	
	8	4.20	11.34	30.0	.784	.820	.879	.940	1.280	1.650	
	9	4.20	11.62	22.5	.923	.937	.989	1.088	1.280	1.334	
	10	4.20	10.31	15.0	.688	.915	.949	1.043	1.177	1.287	
	11	4.41	7.04	7.5	.642	.668	.725	.792	.895	.916	
A011241341 775 10											
	2	4.20	10.85	60.0	.574	.603	.647	.602	1.022	1.067	
	3	4.20	10.73	60.0	.566	.573	.624	.758	1.049	1.168	
	4	4.20	10.73	60.0	.608	.641	.726	.768	1.114	1.231	
	5	4.27	10.85	52.5	.603	.623	.678	.729	1.028	1.263	
	6	4.27	10.88	45.0	.680	.684	.703	.813	1.014	1.477	
	7	4.27	11.06	37.5	.698	.715	.754	.827	1.044	1.688	
	8	4.27	11.32	30.0	.769	.791	.873	.972	1.197	1.666	
	9	4.20	11.63	22.5	.941	.946	.993	1.127	1.315	1.362	
	10	4.20	10.36	15.0	.886	.923	.974	1.059	1.189	1.264	
	11	4.66	7.14	7.5	.675	.696	.735	.793	.985	1.026	
A011241431 145 5											
	2	2.17	8.12	60.0	.477	.481	.525	.682	.838	1.030	
	3	2.17	8.04	60.0	.500	.511	.565	.624	.767	.908	
	4	2.17	7.95	60.0	.541	.553	.618	.705	.781	.958	
	5	2.17	7.99	52.5	.495	.505	.546	.648	.746	1.014	
	6	2.17	8.04	45.0	.483	.493	.550	.719	.697	1.158	
	7	2.17	8.01	37.5	.508	.527	.591	.785	.940	1.061	
	8	2.17	8.21	30.0	.550	.586	.639	.773	.909	1.101	
	9	1.68	8.44	22.5	.720	.728	.826	.971	1.084	1.327	
	10	2.31	7.97	15.0	.782	.800	.856	1.016	1.111	1.138	
	11	2.37	5.46	7.5	.737	.746	.775	.842	1.001	1.163	
A011241156 475 10											
	2	2.72	8.11	60.0	.571	.577	.649	.776	.835	.852	
	3	2.72	8.13	60.0	.556	.573	.604	.740	.770	.811	
	4	2.72	8.07	60.0	.540	.575	.618	.741	.809	.892	
	5	2.72	8.22	52.5	.552	.576	.634	.723	.815	.979	
	6	2.70	8.42	45.0	.588	.593	.634	.797	.899	1.145	
	7	2.70	8.59	37.5	.665	.681	.712	.942	1.083	1.278	
	8	2.70	8.85	30.0	.740	.763	.875	1.135	1.235	1.488	
	9	2.67	9.10	22.5	.935	.964	1.158	1.326	1.492	1.505	
	10	3.51	8.06	15.0	.948	.966	1.027	1.171	1.231	1.256	
	11	9.14	5.71	7.5	.751	.763	.798	.852	1.176	1.305	
A011241249 575 10											
	2	2.61	5.36	60.0	.509	.516	.574	.733	.941		
	3	2.61	5.35	60.0	.470	.488	.539	.712	.874	.950	
	4	2.61	5.30	60.0	.491	.503	.576	.729	.916	.971	
	5	2.61	5.37	52.5	.492	.503	.578	.725	.925	.994	
	6	2.61	5.45	45.0	.529	.559	.661	.763	.937	1.164	
	7	2.61	5.57	37.5	.565	.581	.730	.925	1.020	1.318	
	8	2.61	5.75	30.0	.593	.622	.777	.950	1.313	1.537	
	9	2.61	6.06	22.5	.661	.705	.825	1.141	1.436	1.826	
	10	2.59	5.91	15.0	.692	.956	1.026	1.452	1.570	1.712	
	11	3.51	4.53	7.5	.790	.819	.914	1.021	1.192	1.248	
A011241259 575 10											
	2	2.61	5.36	60.0	.503	.509	.577	.723	.945	1.067	
	3	2.61	5.36	60.0	.476	.492	.537	.713	.884	.961	
	4	2.61	5.32	60.0	.492	.590	.584	.722	.904	.968	
	5	2.61	5.39	52.5	.493	.517	.573	.732	.934	1.010	
	6	2.61	5.47	45.0	.530	.558	.671	.766	.939	1.167	
	7	2.61	5.58	37.5	.560	.572	.717	.909	1.017	1.323	
	8	2.61	5.78	30.0	.596	.607	.768	.959	1.341	1.554	
	9	2.61	6.09	22.5	.712	.749	.986	1.232	1.639	1.858	
	10	2.59	5.91	15.0	.896	.975	1.040	1.442	1.572	1.765	
	11	3.51	4.56	7.5	.793	.671	.965	1.099	1.165	1.173	
A011241310 675 10											
	2	1.84	10.17	60.0	.522	.536	.585	.667	.783	.840	
	3	1.74	10.05	60.0	.521	.546	.604	.751	.900	1.002	
	4	1.84	9.96	60.0	.510	.519	.569	.675	.744	.780	
	5	1.84	9.92	52.5	.533	.545	.562	.612	.929	.955	
	6	1.84	9.89	45.0	.541	.566	.598	.668	.861	.937	
	7	1.84	9.75	37.5	.576	.586	.624	.771	.869	1.136	
	8	1.86	9.83	30.0	.594	.613	.665	.801	.968	1.141	
	9	1.84	9.61	22.5	.686	.704	.759	.876	1.061	1.114	
	10	2.08	8.75	15.0	.790	.804	.835	.887	.969	1.060	
	11	2.10	5.55	7.5	.662	.720	.764	.833	1.030	1.071	1.208

80112411 2 275 10										
	2	1.47	13.84	60.0	.537	.540	.582	.673	.752	.838
	3	1.46	13.65	60.0	.559	.563	.618	.667	.759	.828
	4	1.46	13.47	60.0	.556	.565	.593	.688	.799	.833
	5	1.46	13.48	52.5	.575	.608	.626	.673	.839	.916
	6	1.46	13.32	45.0	.603	.609	.642	.715	.869	.906
	7	1.47	13.11	37.5	.595	.602	.624	.752	.856	.920
	8	1.47	13.01	30.0	.655	.680	.737	.786	.835	.895
	9	1.47	12.30	22.5	.709	.717	.742	.793	.838	.873
	10	1.47	9.65	15.0	.723	.727	.757	.813	.943	1.052
	11	8.53	5.68	7.5	.682	.684	.745	.889	.954	1.028
8011241111 275 10										
	2	1.46	13.86	60.0	.530	.537	.587	.679	.752	.878
	3	1.46	13.69	60.0	.558	.569	.602	.684	.756	.803
	4	1.46	13.60	60.0	.560	.571	.593	.691	.806	.852
	5	1.46	13.52	52.5	.573	.593	.618	.672	.851	.908
	6	1.46	13.33	45.0	.586	.597	.651	.709	.895	.941
	7	1.47	13.16	37.5	.586	.599	.639	.734	.844	.884
	8	1.47	13.06	30.0	.678	.686	.723	.795	.854	.880
	9	1.47	12.30	22.5	.697	.708	.753	.832	.874	.889
	10	1.47	9.76	15.0	.726	.743	.770	.829	.936	1.016
	11	8.53	5.70	7.5	.639	.653	.712	.877	.957	1.059
8011241121 375 10										
	2	1.67	13.87	60.0	.565	.605	.636	.722	.833	.929
	3	1.67	13.76	60.0	.533	.542	.577	.687	.800	1.056
	4	1.67	13.65	60.0	.562	.564	.589	.686	.769	1.116
	5	1.67	13.66	52.5	.526	.542	.598	.738	.871	1.091
	6	1.67	13.40	45.0	.612	.627	.670	.741	.837	.981
	7	1.67	13.16	37.5	.628	.651	.716	.820	.940	.954
	8	1.67	12.49	30.0	.690	.722	.750	.856	.920	.955
	9	1.67	12.43	22.5	.706	.717	.764	.856	.958	1.042
	10	1.87	9.66	15.0	.709	.712	.769	.871	.954	1.032
	11	8.26	6.03	7.5	.628	.652	.713	.797	.919	1.088
8011241130 375 10										
	2	1.67	14.05	60.0	.578	.602	.621	.717	.803	.918
	3	1.67	13.96	60.0	.532	.546	.577	.680	.804	.984
	4	1.67	13.79	60.0	.546	.556	.591	.677	.769	1.059
	5	1.67	13.74	52.5	.532	.537	.580	.700	.841	1.097
	6	1.67	13.30	45.0	.600	.626	.670	.751	.833	.950
	7	1.67	13.09	37.5	.641	.651	.708	.805	.925	1.014
	8	1.67	12.47	30.0	.686	.703	.790	.858	.926	.963
	9	1.67	12.39	22.5	.738	.752	.787	.866	.912	.985
	10	1.67	9.71	15.0	.694	.708	.766	.852	.908	.975
	11	8.20	6.05	7.5	.622	.637	.681	.800	.924	1.140
8011211416 760 10										
	2	3.56	12.17	59.9	.587	.618	.736	.912	1.151	1.205
	3	3.56	11.94	59.9	.634	.642	.673	.899	1.096	1.158
	4	3.56	11.84	59.9	.591	.605	.731	.847	1.115	1.132
	5	3.56	12.02	52.4	.632	.657	.735	.818	1.064	1.090
	6	3.56	12.11	44.9	.619	.665	.760	.862	1.061	1.226
	7	3.56	12.39	37.4	.677	.700	.747	.933	1.148	1.221
	8	3.56	12.67	29.9	.740	.766	.857	.968	1.365	1.418
	9	4.66	12.81	22.4	.660	.694	.992	1.072	1.217	1.340
	10	4.66	10.65	14.9	.820	.651	.691	1.026	1.121	1.262
	11	4.49	7.44	7.4	.576	.591	.704	.791	.886	.948
8011211425 860 10										
	2	3.61	12.18	59.9	.600	.629	.739	.930	1.175	1.209
	3	3.61	12.00	59.9	.632	.643	.694	.902	1.100	1.150
	4	3.61	11.90	59.9	.601	.660	.716	.844	1.097	1.114
	5	3.61	12.16	52.4	.659	.672	.732	.829	1.057	1.084
	6	3.61	12.24	44.9	.661	.716	.776	.857	1.039	1.203
	7	3.61	12.57	37.4	.675	.687	.764	.934	1.131	1.170
	8	3.61	12.86	29.9	.760	.803	.846	.976	1.340	
	9	3.61	12.98	22.4	.841	.909	.955	1.091	1.165	1.256
	10	4.66	10.79	14.9	.850	.869	.940	1.030	1.122	1.274
	11	4.49	7.64	7.4	.587	.597	.683	.791	.906	1.012
8011211445 86010										
	2	3.41	14.54	59.9	.617	.653	.733	.814	.964	1.194
	3	3.41	14.28	59.9	.581	.607	.685	.793	.994	1.105
	4	3.41	14.22	59.9	.637	.655	.690	.869	1.015	1.260
	5	3.41	14.28	52.4	.565	.597	.679	.836	.957	1.353
	6	3.41	14.26	44.9	.661	.702	.755	.864	1.076	1.434
	7	3.41	14.48	37.4	.665	.676	.721	.957	1.102	1.269
	8	3.51	14.95	29.9	.749	.754	.678	1.089	1.183	1.400
	9	4.83	13.98	22..	.822	.844	.887	.970	1.079	1.217
	10	4.92	11.40	14.9	.762	.780	.659	.893	1.018	1.107
	11	5.02	7.73	7.4	.606	.621	.689	.808	.937	1.052

8011211456 260 4										
	2	1.52	7.68	59.9	.471	.487	.521	.611	.803	1.096 1.601
	3	1.52	7.50	59.9	.534	.544	.582	.630	.876	1.258 1.306
	4	1.54	7.40	59.9	.504	.513	.580	.643	.831	1.379 1.478
	5	1.54	7.38	52.4	.476	.490	.538	.683	.916	1.185 1.257
	6	1.54	7.27	44.9	.511	.516	.546	.633	.824	1.007 1.530
	7	1.54	7.12	37.4	.522	.533	.570	.639	.951	1.366 1.406
	8	1.54	7.40	29.9	.518	.532	.595	.701	1.014	1.403 1.535
	9	1.54	7.14	22.4	.575	.581	.626	.820	.952	1.539
	10	1.56	6.79	14.9	.692	.730	.803	.983	1.104	1.152
	11	1.56	5.13	7.4	.710	.724	.754	.874	.953	1.051 1.115
80112115 5 260 4										
	2	1.50	8.71	59.9	.452	.465	.541	.665	1.018	1.254 1.448
	3	1.50	8.49	59.9	.496	.502	.526	.725	1.153	1.186 1.610
	4	1.50	8.46	59.9	.486	.514	.537	.691	.951	1.275 1.323
	5	1.50	8.44	52.4	.497	.506	.543	.700	.915	1.146 1.406
	6	1.50	8.34	44.9	.494	.512	.535	.639	.886	1.213
	7	1.50	8.16	37.4	.500	.512	.526	.700	1.039	1.234
	8	1.50	8.36	29.9	.528	.542	.572	.717	1.185	1.241
	9	1.52	7.85	22.4	.575	.608	.664	.797	.993	1.336
	10	1.52	7.37	14.9	.733	.767	.818	.920	.994	1.057
	11	1.52	5.26	7.4	.712	.740	.811	.907	.989	1.047 1.119
8011211514 360 4										
	2	1.67	8.00	59.9	.461	.483	.532	.635	1.044	1.298
	3	1.67	7.86	59.9	.472	.483	.500	.582	.834	1.215
	4	1.67	7.77	59.9	.494	.511	.541	.601	.829	1.219
	5	1.67	7.78	52.4	.477	.502	.561	.656	.845	1.228
	6	1.67	7.69	44.9	.494	.501	.545	.654	.927	1.263
	7	1.67	7.66	37.4	.522	.542	.575	.657	1.107	1.229
	8	1.67	7.98	29.9	.546	.567	.625	.741	1.234	1.536
	9	1.67	7.57	22.4	.641	.649	.721	.821	1.056	1.308
	10	1.71	7.24	14.9	.799	.818	.878	.968	1.098	1.128
	11	1.73	5.16	7.4	.700	.707	.776	.896	1.018	1.151
8011211523 360 4										
	2	1.66	8.30	59.9	.476	.494	.538	.635	1.007	1.253
	3	1.66	8.10	59.9	.476	.480	.511	.578	.821	1.169
	4	1.66	7.99	59.9	.516	.518	.549	.605	.805	1.204
	5	1.66	7.98	52.4	.495	.527	.577	.686	.859	1.228
	6	1.66	7.92	44.9	.484	.493	.578	.674	.946	1.250
	7	1.66	7.91	37.4	.542	.557	.596	.640	1.079	1.192
	8	1.66	8.23	29.9	.568	.592	.664	.754	1.177	1.505
	9	1.66	7.87	22.4	.649	.688	.738	.805	1.065	1.255
	10	1.67	7.47	14.9	.812	.832	.887	.985	1.104	1.143
	11	1.67	5.20	7.4	.724	.732	.770	.893	.983	1.114

APPENDIX E

CNOIDAL WAVE TESTS RESULTS

Wave height (cm)	Wave period (s)	Water depth (cm)	Relative crest height η/H
11.278	2.30	44.05	0.6260
11.583	2.80	44.05	0.6658
11.433	3.40	44.05	0.7526
11.468	4.10	44.05	0.7678
11.590	4.80	44.05	0.7767
11.464	5.70	44.05	0.8118
21.58	1.60	44.05	0.6330
21.67	2.00	44.05	0.6470
23.38	2.40	44.05	0.6895
23.52	2.40	44.05	0.7258
21.88	2.90	44.05	0.7724
23.104	3.39	44.05	0.7228
22.25	4.00	44.05	0.8036

APPENDIX F

ESTIMATING THE WAVE CREST ELEVATION AT BREAKING ON A PLANE SLOPE

The equations of Singamsetti and Wind (1980) can be used with the methods developed in this report to predict the crest elevation at the breaking point for monochromatic waves normally incident to a slope. This technique uses as input water depth, d, wave height, H, and period, T, in a constant depth region offshore of a plane slope, m. Deepwater wave height is found from

$$H_o' = \frac{H}{\sqrt{\dfrac{1.0}{\tanh\left(\dfrac{2\pi d}{L_A}\right)\left[1.0 + \dfrac{4\pi\ d/L_A}{\sinh\ (4\pi\ d/L_A)}\right]}}} \qquad \text{(F-1)}$$

where L_A is the wavelength from Airy theory

$$L_A = \frac{gT^2}{2\pi} \tanh\left(\frac{2\pi d}{L_A}\right) \qquad \text{(F-2)}$$

Breaking wave height may be determined from

$$H_b = H_o'\ 0.575(m)^{0.031}\ (H_o'/L_o)^{-0.254} \qquad \text{(F-3)}$$

where L_o is deepwater Airy wavelength

$$L_o = \frac{gT^2}{2\pi} \qquad \text{(F-4)}$$

Depth at breaking, d_b, is found from

$$d_b = H_b\ (1.067)(m)^{-0.155} (H_o'/L_o)^{0.130} \qquad \text{(F-5)}$$

$$\text{for}\ \frac{1}{40} < m < \frac{1}{5}$$

$$d_b = H_b\ (1.761)(m)^{-0.107}\ (H_o'/L_o)^{0.237}$$

$$\text{for}\ m = \frac{1}{5}$$

The value of d_b/L_o is used to determine A_2 and A_3 from Figure 6 in the test of this report; A_1 is determined from the value of the beach slope using Figure 7. Crest height at breaking, $(\eta_c)_b$, is then given by

$$(\eta_c)_b = \frac{A_1\ H_b}{1.0 + \tanh\left[-A_2\ \ell n\left(A_3\ \dfrac{H_b}{L_o}\right)\right]} \qquad \text{(F-6)}$$

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