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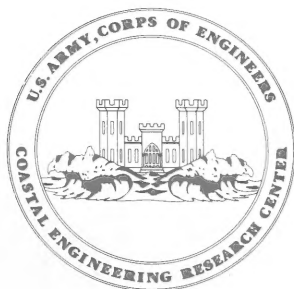
# Two-Dimensional Tests of Wave Transmission and Reflection Characteristics of Laboratory Breakwaters

by

William N. Seelig

TECHNICAL REPORT NO. 80-1

JUNE 1980



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procedure was found to be an important tool for predicting the amount of transmission through permeable breakwaters. Suggested procedures for estimating transmission coefficients have been incorporated into the computer programs OVER and MADSEN (included as appendixes) and these programs may be used to predict wave transmission coefficients for nonbreaking, breaking, monochromatic, and irregular wave conditions:

## PREFACE

This report presents the results of research conducted to develop methods for estimating wave transmission past submerged, subaerial, permeable, and impermeable breakwaters. The final prediction techniques are given in the form of computer programs, and the laboratory data used to develop and test the methods are included in appendixes to this report. These methods supplement Section 7.23 of the Shore Protection Manual (SPM). The work was carried out under the offshore breakwaters for shore stabilization program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by William N. Seelig, Hydraulic Engineer, under the general supervision of Dr. R.M. Sorensen, Chief, Coastal Processes and Structures Branch. J. Ahrens and M. Titus provided a significant contribution to this report by their many useful suggestions and valuable laboratory assistance.

Comments on this publication are invited.

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

## CONTENTS

	Page
CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) . . . . .	8
SYMBOLS AND DEFINITIONS. . . . .	9
I INTRODUCTION . . . . .	11
II LITERATURE REVIEW. . . . .	11
III LABORATORY TESTING . . . . .	13
1. Laboratory Test Setup . . . . .	13
2. Methods of Generating Waves . . . . .	13
3. Data Collection . . . . .	14
4. Data Reduction Methods. . . . .	15
5. Breakwaters Tested. . . . .	20
6. Test Conditions . . . . .	20
7. Test Results. . . . .	21
IV ANALYSIS OF TEST RESULTS . . . . .	22
1. Wave Transmission and Reflection for Impermeable Breakwaters. . . . .	22
2. Wave Transmission and Reflection for Permeable Breakwaters. . . . .	39
V MODEL SCALE EFFECTS. . . . .	58
1. Causes of Physical Model Scale Effects. . . . .	58
2. Interpreting and Applying Laboratory Results to Prototype Conditions . . . . .	58
VI EXAMPLE OF ESTIMATING WAVE TRANSMISSION COEFFICIENTS . . . . .	60
VII SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS. . . . .	62
LITERATURE CITED . . . . .	64
APPENDIX	
A BREAKWATER GEOMETRIES. . . . .	67
B MATERIAL CHARACTERISTICS . . . . .	77
C TEST RESULTS (SINUSOIDAL BLADE MOTION) . . . . .	80
D TEST RESULTS (IRREGULAR WAVES) . . . . .	89
E TEST RESULTS (GRAPHICAL FORM). . . . .	93
F DOCUMENTATION OF THE PROGRAM OVER . . . . .	169
G DOCUMENTATION OF THE COMPUTER PROGRAM MADSEN . . . . .	175

CONTENTS--Continued

TABLES

	Page
1 Range of conditions tested with monochromatic and irregular waves. . .	21
2 Empirical wave runup prediction coefficients for smooth impermeable slopes. . . . .	26
3 Wave runup prediction coefficients using the Ahrens and McCartney (1975) method . . . . .	28
4 Effect of relative depth on prediction of $K_{Tt}$ . . . . .	44
5 Porosity of various armor units. . . . .	50

FIGURES

1 Plan view of wave tank . . . . .	14
2 Determination of incident and reflected waves using the method of Goda and Suzuki (1976). . . . .	15
3 The spectral peakedness, $Q_p$ , for various spectral shapes . . . . .	17
4 Sample incident laboratory wave spectra. . . . .	18
5 Sample laboratory wave records showing various levels of wave grouping. . . . .	19
6 Percent of incident wave energy at the period of wave generator blade motion for sinusoidal wave generator blade motion . . . . .	20
7 Definition of terms for wave transmission by overtopping . . . . .	22
8 Wave reflection coefficients and fraction of wave energy dissipated for a 1 on 1.5 smooth slope with no wave transmission . . . . .	23
9 Wave reflection coefficients for a breakwater with zero freeboard compared to a similar structure with no overtopping . . . . .	23
10 Wave transmission and reflection coefficients for a smooth impermeable breakwater. . . . .	25
11 Wave runup on riprap . . . . .	27
12 Wave runup prediction for rough structures using the Ahrens and McCartney (1975) method . . . . .	28
13 Wave transmission coefficients for smooth impermeable breakwaters with 1 on 1.5 slopes. . . . .	29
14 Wave transmission coefficients for vertical, smooth impermeable breakwaters using Goda's (1969) data. . . . .	30

CONTENTS

FIGURES--Continued

		Page
15	The effect of the relative structure width on wave transmission of impermeable breakwaters . . . . .	32
16	Wave transmission coefficients for BW14. . . . .	32
17	Wave transmission coefficients for a breakwater tested by Saville (1963) with $B/h = 0.88$ . . . . .	33
18	Wave transmission coefficients for a breakwater tested by Saville (1963) with $B/h = 3.2$ . . . . .	33
19	Observed and predicted coefficients of wave transmission by overtopping . . . . .	34
20	Percent of wave energy at the forcing wave period for wave transmission by overtopping of a smooth impermeable structure . . . . .	34
21	Sample incident, reflected, and transmitted wave spectra . . . . .	36
22	Spectral peakedness of incident, reflected, and transmitted wave spectra . . . . .	37
23	Zero up-crossing analysis. . . . .	37
24	Transmitted versus incident wave height distributions for a breakwater with $d_g/h = 0.8$ . . . . .	38
25	Transmitted versus incident wave height distributions for a breakwater with $d_g/h = 1.0$ . . . . .	38
26	Sample incident and transmitted joint distributions of wave height and period. . . . .	39
27	Definition of terms for wave transmission for permeable breakwaters. . . . .	40
28	Wave transmission and reflection coefficients for BW3. . . . .	41
29	Sample observed and predicted reflection coefficients for permeable subaerial breakwaters . . . . .	41
30	Wave transmission coefficients for a subaerial and a submerged breakwater. . . . .	42
31	Observed and predicted transmission coefficients for BW3 . . . . .	45
32	Observed and predicted transmission coefficients for BW12. . . . .	45
33	Observed and predicted transmission coefficients for BW4 . . . . .	46
34	Observed and predicted transmission coefficients for breaking and nonbreaking conditions. . . . .	46



CONTENTS

FIGURES--Continued

	Page
35 Observed and predicted transmission coefficients for a breakwater with dolos armor units. . . . .	47
36 Wave transmission past a heavily overtopped breakwater with tribar armor units . . . . .	48
37 Observed and predicted transmission coefficients for BW16. . . . .	49
38 Example of the influence of porosity on the predicted coefficient of transmission for a rubble-mound breakwater. . . . .	51
39 The relative importance of transmission by overtopping as a function of the incident wave height and the water depth-to-structure height ratio. . . . .	51
40 Observed and predicted transmission coefficients for submerged permeable structures assuming $K_{Tt} = 0$ . . . . .	52
41 Percent of wave energy at the forcing period for waves transmitted past a permeable breakwater . . . . .	53
42 Sample incident, reflected, and transmitted wave spectra for BW16. . . . .	54
43 Spectral peakedness of transmitted and reflected wave spectra versus incident spectral peakedness for a permeable breakwater . . . . .	54
44 Comparison between incident and transmitted wave height distribution for a permeable breakwater. . . . .	55
45 Autocorrelation of zero up-crossing wave heights for transmitted and incident wave records for a permeable breakwater. . . . .	57
46 Sample joint distributions of wave height and period for an irregular wave condition and a permeable breakwater . . . . .	57
47 Trapezoidal multilayered breakwater tested by Sollitt and Cross (1976). . . . .	59
48 Physical model results and correction factors determined from the analytical model of Madsen and White (1976) . . . . .	59
49 Breakwater cross sections used in the example for estimating wave transmission coefficients . . . . .	60
50 Predicted wave transmission coefficients . . . . .	61
51 Predicted transmitted wave height as a function of breakwater crest height. . . . .	61

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	$1.0197 \times 10^{-3}$	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 <sup>1</sup>

<sup>1</sup>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	material identifier
$A_1$	spectral coefficients
$A_2$	spectral coefficients
a	empirical rough-slope runup coefficient
$a_I$	incident wave amplitude at a spectral line
$a_R$	reflected wave amplitude at a spectral line
B	breakwater top width
$B_1$	spectral coefficients
$B_2$	spectral coefficients
b	empirical rough-slope runup coefficient
C	transmission by overtopping coefficient
$C_1$	empirical wave runup on smooth-slope coefficients
$C_2$	empirical wave runup on smooth-slope coefficients
$C_3$	empirical wave runup on smooth-slope coefficients
CF	physical model correction factor = $(K_{Tt})_{\text{prototype}} / (K_{Tt})_{\text{model}}$
d	water depth
$d_s$	water depth at toe of a structure
$d_{50}$	median material diameter
F	breakwater freeboard = $h - d_s$
f	wave frequency = $1/T$
g	acceleration due to gravity
H or $H_I$	incident wave height
$H_R$	reflected wave height
$H_{rms}$	root-mean-square (rms) wave height
$H_s$	significant wave height
$H_T$	transmitted wave height
$\bar{H}$	mean wave height
ID	a 10-digit identification code (year, month, day, hour, minute) assigned to each data collection run
j	spectral line number

SYMBOLS AND DEFINITIONS--Continued

$K_R$	reflection coefficient
$K_T$	transmission coefficient = $\sqrt{K_{T0}^2 + K_{Tt}^2}$
$K_{T0}$	wave transmission by overtopping coefficient
$K_{Tt}$	coefficient of wave transmission through a permeable breakwater
$k$	wave number = $2\pi/L$
$L$	wavelength
$L_0$	deepwater wavelength
$P$	material porosity
$p$	probability
$Q_p$	spectral-peakedness parameter
$Q_{pi}$	incident spectral-peakedness parameter
$Q_{pr}$	reflected spectral-peakedness parameter
$Q_{pt}$	transmitted spectral-peakedness parameter
$R$	wave runup
$r(H, H + 1)$	autocorrelation of wave heights
$r(H, T)$	correlation of wave heights and periods
$T$	wave period
$T_p$	period of peak energy density
$W_{50}$	median weight of material
$\gamma$	specific weight
$\Delta f$	band width
$\Delta \ell$	gage spacing
$\eta_{rms}$	root-mean-square water level
$\theta$	angle of seaward face of a breakwater
$\nu$	kinematic viscosity of water
$\xi$	surf parameter = $(\tan \theta / \sqrt{H/L_0})$
$\rho$	autocorrelation of zero up-crossing wave heights <ul style="list-style-type: none"> <li>● for incident waves</li> <li>● for transmitted waves</li> </ul>

# TWO-DIMENSIONAL TESTS OF WAVE TRANSMISSION AND REFLECTION CHARACTERISTICS OF LABORATORY BREAKWATERS

by  
*William N. Seelig*

## I. INTRODUCTION

The primary function of a breakwater is to reduce wave heights in an area being sheltered. Breakwaters are primarily used to protect harbors from excessive wave action, to prevent beach erosion, and to trap sediment for mechanical bypassing at an inlet or harbor entrance. A secondary use of breakwater design is to reduce the wave reflection from the structure. Reflected waves combined with incident waves can produce undesirable water motions that may be a nuisance to navigation or encourage scour at the toe of a structure.

Since the cost of building breakwaters is generally high, methods are needed to estimate transmitted and reflected wave heights to enable comparison of alternative structure designs. This report presents suggested methods for predicting transmission and reflection characteristics of breakwaters based on laboratory experiments, including the work of previous investigators. These methods supplement Section 7.23 of the Shore Protection Manual (SPM) (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977). The basic types of breakwaters considered are permeable and impermeable structures with crest elevations above the stillwater level (subaerial) and below the stillwater level (submerged). The other factors investigated include wave height, period, breakwater cross-section design, and material characteristics. Both monochromatic and irregular waves were tested.

Section II of this report presents a brief review of research conducted by previous investigators. Section III describes the laboratory setup and procedures; Sections IV, V, and VI present data analysis methods and definitions. The conditions tested are summarized in Section VII. Detailed descriptions of the breakwaters tested and materials used are given in Appendixes A and B; summary tables and figures of laboratory results are presented in Appendixes C, D, and E.

Laboratory results are used in this study to develop a method for predicting wave transmission by overtopping coefficients using the ratio of breakwater freeboard to wave runup (suggested by Cross and Sollitt, 1971) and the breakwater crest width (suggested by Saville, 1963). The wave transmission by overtopping prediction method is then combined with the model of wave transmission through permeable structures of Madsen and White (1976) and this combination package is verified with the laboratory results over a wide range of conditions. Prediction methods are summarized in the computer programs OVER and MADSEN (Apps. F and G). An example breakwater design is worked with the aid of the two computer programs to illustrate how the prediction methods can be used to compare alternative breakwater designs, and to illustrate the importance of various design parameters.

## II. LITERATURE REVIEW

Some of the important sources of ideas and data used in preparing this report are summarized below in chronological order.

Saville (1963) tested a large number of similar rough structures with a 1 on 2 front-face slope for a proposed breakwater at Point Loma, California. Most of Saville's breakwater models had a crest elevation near the stillwater level, so wave transmission in most of the tests was primarily due to overtopping. Some of the breakwaters tested were first modeled in the large wave tank at the Coastal Engineering Research Center (CERC), then re-tested at a smaller scale to examine scale effects. Some tests were repeated with otherwise identical permeable and impermeable breakwaters to assess the influence of wave transmission through the permeable breakwaters and wave transmission by overtopping. The breakwater crest width was also varied over a wide range of values to determine the influence of width on the wave transmission coefficient. Since wave reflection coefficients were not measured, the burst method was used during testing to avoid laboratory effects caused by re-reflection of waves from the generator blade.

Lamarre (1967) measured wave transmission by overtopping for a structure with a comparatively narrow crest width and 1 on 1.5 structure slopes. Wave conditions and the height of the structure were varied.

Goda (1969) tested vertical, smooth impermeable structures for wave transmission by overtopping. The breakwater crest width was varied and a wide range of submerged and subaerial structure heights and a number of wave conditions were tested. Wave reflection coefficients were measured to determine the incident wave height acting on the structure. A nonlinear empirical equation was developed for predicting wave transmission coefficients. In this formula the transmission coefficient is a function of the ratio of the breakwater freeboard to the incident wave height and two empirical coefficients, where the coefficients are related to structure geometry and the relative water depth.

Davidson (1969) tested a 1 on 40 scale model of a breakwater proposed for Monterey Harbor, California. The breakwater had tribar armor units and experienced a combination of wave transmission over and through the structure.

Cross and Sollitt (1971) developed a semiempirical model for wave transmission by overtopping of subaerial breakwaters. The model was compared to Lamarre's (1967) data for a smooth impermeable structure with a 1 on 1.5 front-face slope. Cross and Sollitt's model suggests that wave transmission by overtopping is a nonlinear function of the ratio of breakwater freeboard to runup. Examination of Saville's (1963) data suggests that a linear model would form an upper envelope for wave transmission over rough structures.

Keulegan (1973) measured wave transmission through a number of vertical-faced permeable breakwaters using a wide variety of materials and wave conditions. Comparison of results led to development of a method for designing scale models that consider scale effects.

Sollitt and Cross (1976) tested wave transmission through a permeable rubble-mound breakwater and used this information to develop an analytical-empirical model.

Bottin, Chatham, and Carver (1976) tested 1 on 22 rubble-mound scale and concrete armor unit breakwaters proposed for Waianae Harbor, Hawaii. Wave transmission consisted of a combination of wave transmission by overtopping

and wave transmission through the structures. Wave reflection coefficients were not measured. Wave runoff on dolos was observed.

Madsen and White (1976) developed a analytical-empirical model for the prediction of wave transmission and reflection coefficients for wave transmission through subaerial rubble-mound breakwaters. The model employs the long wave assumption, so predictions using their model are expected to be most reliable for shallow-water waves. Comparison of the Madsen and White model with physical model tests by Keulegan (1973) and Cross and Sollitt (1976) shows that the wave transmission coefficient can be predicted more reliably than the reflection coefficient.

The data from independent tests of wave transmission by overtopping conducted in this study, together with the results of Saville (1963), Lamarre (1967), Goda (1969), and Cross and Sollitt (1971), are used to develop a wave transmission by overtopping equation similar to one proposed by Cross and Sollitt (1971). The equation is then combined with the model of wave transmission through permeable breakwaters of Madsen and White (1976) to form a generalized model of wave transmission for breakwaters. This model is verified by comparing numerical and physical model results for a wide range of conditions.

### III. LABORATORY TESTING

#### 1. Laboratory Test Setup.

Laboratory tests were performed at CERC in a wave tank 4.57 meters wide, 42.7 meters long, and 1.22 meters deep. A part of the tank was divided by four walls to form two interior test flumes, each 61 centimeters wide; the remaining tank width contained a 1 on 12 absorber beach made of crushed stone with a median diameter of 2.9 centimeters (Fig. 1). This arrangement allowed two experiments to be performed simultaneously, and energy reflecting off of the test structures diffracts out of the test flume to minimize re-reflection of waves off of the generator blade.

The laboratory breakwaters were located between stations 5 and 10 meters along the flume and parallel-wire resistance gages were used to measure wave conditions in the flume. Gages placed at stations 1.40, 2.35, and 2.70 meters along the test flumes were used to document incident and reflected wave conditions. One or two gages placed landward were used to measure transmitted waves (Fig. 1).

A wave absorber consisting of a crushed gravel slope covered with a 0.6-meter-thick layer of hogshair was placed at the end of the test flume to absorb a majority of the transmitted wave energy. The test flume was terminated 3 meters before the end of the wave tank to allow water overtopping the test structure to escape from the flume through the absorber gravel. This arrangement prevented the buildup of water on the landward side of the test structure.

#### 2. Methods of Generating Waves.

Waves in this facility were generated by a programable piston-type generator with a mean blade position 19 meters seaward of the entrance to the test flumes. A minicomputer was used to produce monochromatic waves of a specified wave height and period by moving the blade with a sinusoidal motion. Irregular waves

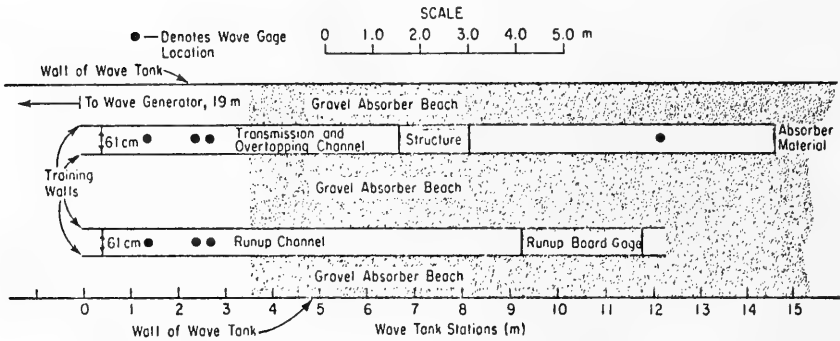
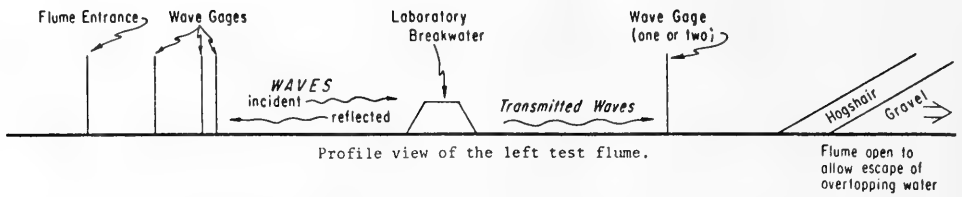


Figure 1. Plan view of wave tank setup.

were produced by using the CERC Data Acquisition System (DAS) to create a signal to move the blade. Irregular waves were made by summing 50 components of varying amplitude, period, and random phase to produce a wide variety of spectral shapes.

### 3. Data Collection.

The laboratory data collection scheme was designed after the CERC field wave data monitoring program. Data collection was performed automatically by the DAS in the following sequence:

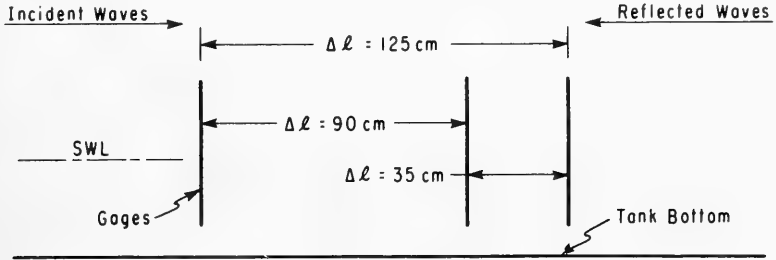
- (a) Wave gages were calibrated.
- (b) Waves were produced for several minutes to allow tank startup transient conditions to die out.
- (c) Wave gages collected data at a sampling rate of 16 times a second over a 256-second sampling interval.
- (d) The 4,096 data points from each gage were then stored on magnetic tape for analysis.
- (e) A 10-digit identification code consisting of the year, month, day, hour, and minute of the data run was assigned (e.g., ID 7804260916 is a run made 1978, April, 26th day at 09:16).



#### 4. Data Reduction Methods.

Laboratory data sorted on magnetic tape were analyzed on a CDC 6600 computer using a variety of data reduction schemes. The mean water level and the least squares, best-fit linear trend in the data was first removed from each gage record. A Fourier analysis was then performed on each gage record using a fast Fourier transform (FFT) routine and cosine bell function that is part of the CERC wave analysis package.

Incident and reflected waves, which are mixed together in each of the gage records, were separated using the method of Goda and Suzuki (1976) shown in Figure 2. This technique gives an estimate of the incident and reflected wave amplitudes,  $a_I$  and  $a_R$ , at each spectral line for each gage pair. Using three gages in front of the structure gives three estimates of the incident and reflected wave amplitude spectra. Calculations show that in this study the three estimates of wave amplitudes seldom differed by more than 5 percent, so the average incident and reflected wave amplitudes at each spectral line,  $j$ , were taken as representative; i.e.,  $(a_I)_j$  is the average incident wave amplitude at spectral line,  $j$ . The wave amplitude at each of the spectral lines was also determined for transmitted wave conditions; i.e.,  $(a_T)_j$  is the average transmitted wave amplitude at spectral line,  $j$ .



$$a_I = \frac{1}{2|\sin k\Delta l|} \sqrt{(A_2 - A_1 \cos k\Delta l - B_1 \sin k\Delta l)^2 + (B_2 + A_1 \sin k\Delta l - B_1 \cos k\Delta l)^2}$$

$$a_R = \frac{1}{2|\sin k\Delta l|} \sqrt{(A_2 - A_1 \cos k\Delta l + B_1 \sin k\Delta l)^2 + (B_2 - A_1 \sin k\Delta l - B_1 \cos k\Delta l)^2}$$

A, B = spectral coefficients

k = wave number =  $\frac{2\pi}{L}$

$\Delta l$  = gage spacing

where

$$0.05 \leq \frac{\Delta l}{L} \leq 0.45$$

and

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

where  $g$  equals acceleration due to gravity;  $d$  equals water depth; and  $T$  equals wave period.

Figure 2. Determination of incident and reflected waves using the method of Goda and Suzuki (1976).

Incident, reflected, and transmitted wave heights ( $H_I$ ,  $H_R$ ,  $H_T$ ) are defined as

$$H_I = 2 \sqrt{\sum_{j=12}^{411} (a_I)^2_j} \quad (1)$$

$$H_R = 2 \sqrt{\sum_{j=12}^{411} (a_R)^2_j} \quad (2)$$

$$H_T = 2 \sqrt{\sum_{j=12}^{411} (a_T)^2_j} \quad (3)$$

where  $H_I$  is the height of the wave moving landward toward the breakwater,  $H_R$  the height of the wave reflecting from the breakwater and moving seaward, and  $H_T$  the height of the wave transmitted past and in the lea of the breakwater.

Wave reflection and transmission coefficients,  $K_R$  and  $K_T$ , are defined as

$$K_R = \frac{H_R}{H_I} \quad (4)$$

and

$$K_T = \frac{H_T}{H_I} \quad (5)$$

Wave transmission by overtopping has a transmission coefficient defined as  $K_{TO}$ ; wave transmission through porous structures is given by a transmission coefficient  $K_{Tt}$ . The coefficient for total wave transmission over and through a structure,  $K_T$ , is

$$K_T = \sqrt{K_{Tt}^2 + K_{TO}^2} \quad (6)$$

In the case of irregular waves the significant wave height,  $H_S$  (average of the highest one-third of the waves), is typically used to describe the wave conditions. To include the effects of wave reflection from the structure, significant height is defined as (Goda and Suzuki, 1976)

$$H_S = \frac{4 \eta_{rms}}{\sqrt{1 + K_R^2}} \quad (7)$$

where  $\eta_{rms}$  is the average root-mean-square (rms) water level from the three seaward gages. The mean wave height,  $\bar{H}$ , is defined as

$$\bar{H} = 0.625 H_B = \frac{2.5 \eta_{rms}}{\sqrt{1 + K_R^2}} \quad (8)$$

The wave period used to describe irregular wave conditions is the period of peak energy density,  $T_p$ . The spectral-peakedness parameter,  $Q_p$  (Goda, 1970), is used to characterize the spectral width for irregular wave conditions,

$$Q_p = \frac{1}{\Delta f} \frac{\sum_{j=1}^{36} f_j a_j^4}{\left( \frac{\sum_{j=1}^{36} a_j^2}{36} \right)^2} \quad (9)$$

where  $j$  is the band number (11 spectral lines are used to make each band),  $f_j$  the frequency midpoint of the band, and  $\Delta f$  the bandwidth frequency.  $a_j$  may be the incident, reflected, or transmitted wave amplitude associated with band,  $j$ , so that three values of  $Q_p$  (incident, reflected, and transmitted) are determined for each irregular wave run.  $Q_p$  was selected as the parameter to describe the spectral peakedness because it is an especially stable parameter not strongly influenced by the spectral techniques used to determine its value (Rye, 1977). The higher the value of  $Q_p$ , the more peaked a spectrum. For example, white noise has a  $Q_p$  value of 1.0, a Pierson-Moskowitz spectrum a value of 2.0, and JONSWAP values of  $Q_p$  vary between 3.0 and 9.0 with a value of 3.15 for the mean JONSWAP spectrum (Fig. 3). Values of  $Q_p$  associated with several incident wave spectra used in this study are illustrated in Figure 4.

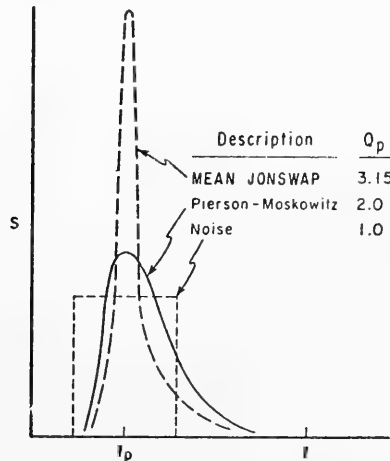


Figure 3. The spectral peakedness,  $Q_p$ , for various spectral shapes.

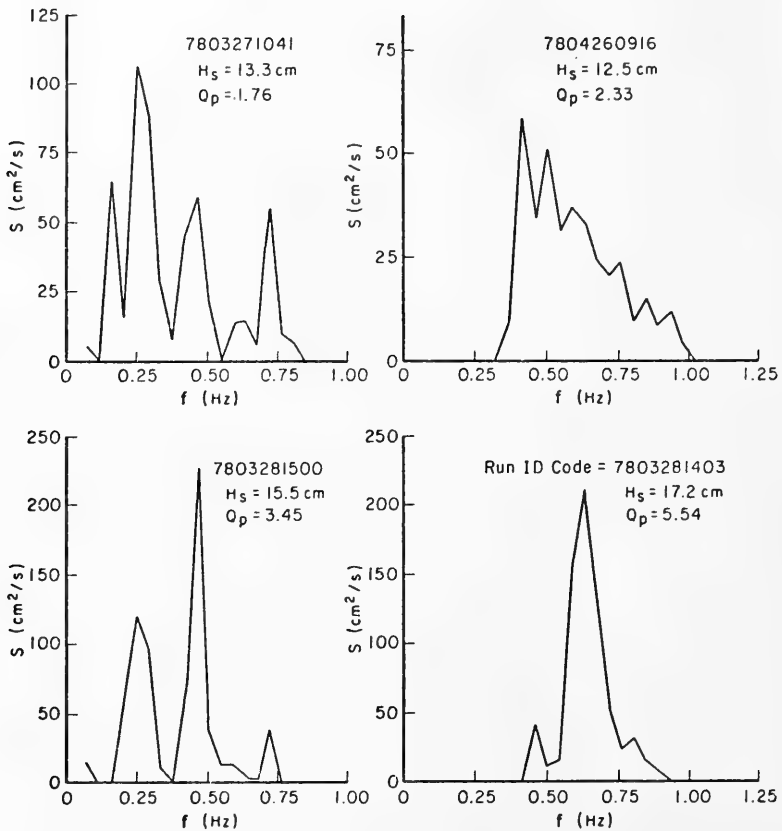


Figure 4. Sample incident laboratory wave spectra.

The zero up-crossing method was also used to analyze wave records. In this method the height of an individual wave is defined as the difference in extreme water elevations (maximum level minus minimum level) between two successive points in time where the water level up-crosses the mean water level. The period associated with that wave is the time between up-crossings. This type of analysis is useful for examining wave characteristics such as wave height, period, or joint wave height-period distributions. Zero up-crossing results may also be used to describe wave grouping (Rye, 1974). A high level of wave grouping means that there is a strong probability that a wave of approximately the same height will follow the previous wave (i.e., large waves are followed by large waves and small waves are followed by small waves). In this study the autocorrelation of zero up-crossing wave heights is used to quantify the amount of wave grouping. The wave gage records seaward of the test structure are somewhat contaminated by reflected waves, depending on the amount of reflection, so the autocorrelation of incident wave heights,  $\rho_I$ , is taken as the average wave height autocorrelation of the three gage records seaward of the structure.

Autocorrelation of transmitted waves,  $\rho_T$ , is taken as the average autocorrelation of any gage measuring transmitted waves. (Note that  $\rho$  may vary between 1.0 and -1.0.) A large positive value of  $\rho$  means that waves are strongly grouped. Values of  $\rho$  near zero mean that there is little relation between successive wave heights. A negative value of the autocorrelation implies that small waves follow large waves and vice versa. Several wave records measured in this study with various values of  $\rho$  are shown in Figure 5. Note that in all cases the water levels have been normalized by the significant wave height.

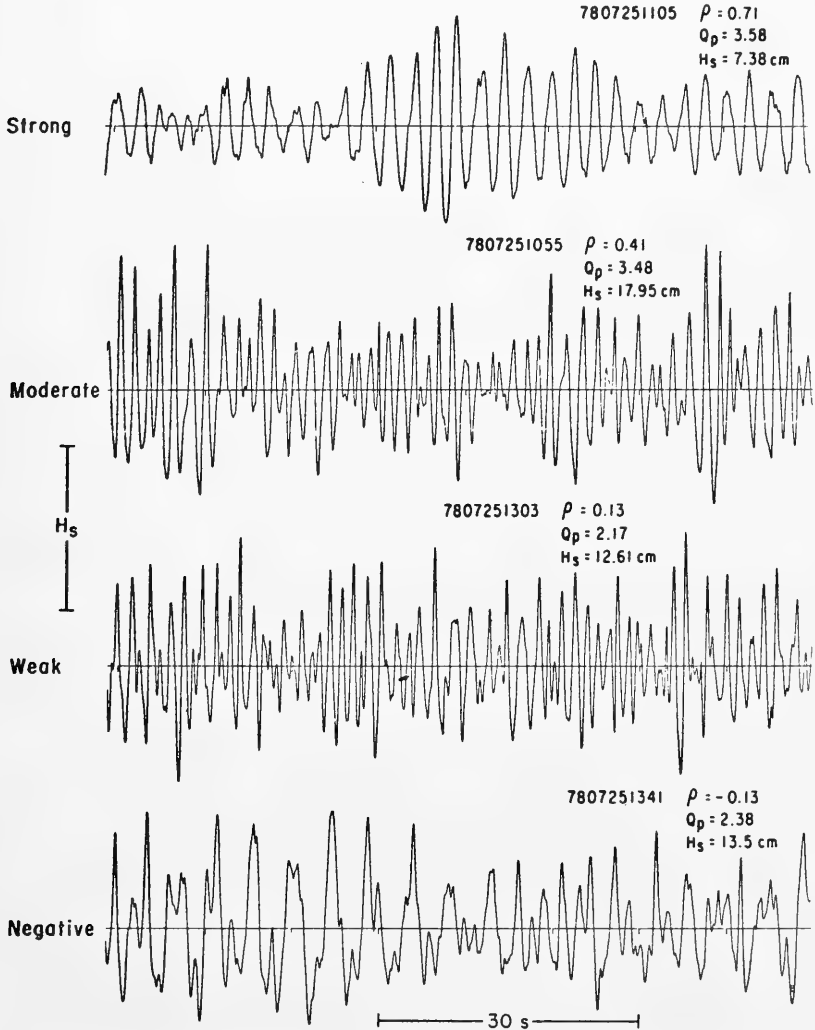


Figure 5. Sample laboratory wave records showing various levels of wave grouping.

For monochromatic wave tests, wave period,  $T$ , is defined as the period of wave generator blade motion. For most of the monochromatic wave conditions tested, 90 percent or more of the incident wave energy was found to be in the spectral band containing the blade frequency (Fig. 6). At a given value of wave steepness the amount of wave energy at higher harmonics of the blade frequency increases as the relative depth,  $d/gT^2$ , decreases. This energy shift occurs because the waveform becomes more cnoidal and less sinusoidal in shape as  $d/gT^2$  decreases and  $H/d$  increases.

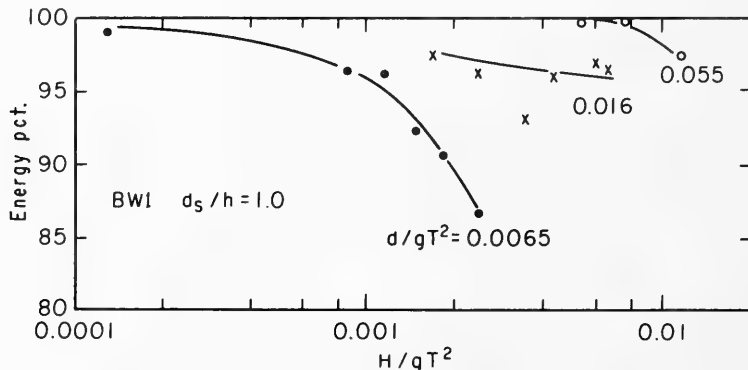


Figure 6. Percent of incident wave energy at the period of wave generator blade motion for sinusoidal wave generator blade motion.

## 5. Breakwaters Tested.

Cross sections for 17 breakwaters were tested for wave transmission and reflection; the cross-section geometries are illustrated in Appendix A. Each of the structures was assigned the letters BW and a number to identify the structure. Breakwaters BW1 to BW12 were built and tested on the flat bottom of the flume. However, BW13 to BW17 were constructed with a 1 on 15 fronting slope 25 centimeters high and 3.75 meters long. The fronting slope was used to simulate a sloping bottom and allow higher waves to break on the structure being tested.

Most of the breakwaters tested were of rubble-mound construction, because this is the most common type built. However, BW1 and BW14 were smooth and impermeable. BW2 had an impermeable core, and BW8 and BW9 had dolos armor units and an impermeable cap. BW3, BW4, and BW15 were tested with and without a vertical, thin impermeable plate placed in the center of the structure to prevent transmission through the lower section of the breakwater. The symbol W is used to indicate tests where the impermeable plate was used; e.g., BW3 tested with a plate is designated as BW3W. Materials used to construct the breakwaters are described in Appendix B.

## 6. Test Conditions.

Each breakwater was built with a fixed geometry, then tested at various water depths and wave periods. A number of wave heights were generally examined for each wave period. Most of the experiments were run with monochromatic waves

produced by sinusoidal motion of the piston-type generator blade. The ranges of dimensionless water depths (water depth at the toe of the structure divided by structure height,  $d_g/h$ ) tested with monochromatic waves are given in Table 1. Major emphasis was placed on  $d/gT^2 = 0.016$  because laboratory waves at this value of relative depth are comparatively free from secondary and Benjamin-Fier waves.

Table 1. Range of conditions tested with monochromatic and irregular waves.

Breakwater	Monochromatic waves		Irregular wave testing <sup>1</sup>
	$\frac{d_g}{h}$	$\frac{d}{gT^2}$	
	(range)	(range)	
BW1	0.6 to 1.2	0.0065 to 0.055	L
BW2	0.87	0.013 to 0.079	N
BW3	0.69 to 1.4	0.0038 to 0.037	N
BW3W	0.69 to 1.3	0.0065 to 0.08	N
BW4	0.68 to 1.3	0.0065 to 0.055	L
BW4W	0.76 to 1.3	0.0065 to 0.055	L
BW5	0.92 to 2.3	0.0065 to 0.055	L
BW6	0.75 to 1.3	0.0056 to 0.055	L
BW7	0.98 to 1.63	0.0065 to 0.055	N
BW8	0.64 to 0.86	0.016	N
BW9	0.64 to 1.1	0.0065 to 0.055	L
BW10	0.68 to 1.1	0.0065 to 0.055	L
BW11	0.51 to 0.75	0.0065 to 0.055	N
BW12	0.64 to 1.1	0.0065 to 0.055	N
BW13	1.1 to 1.8	0.0038 to 0.055	L
BW14	0.91 to 2.0	0.0038 to 0.055	L
BW15	0.61 to 1.4	0.0039 to 0.055	L
BW15W	0.91 to 1.5	0.0038 to 0.055	L
BW16	0.61 to 1.8	0.002 to 0.055	E
BW17	0.58 to 0.83	0.001 to 0.022	E

<sup>1</sup>Testing: E = extensive; L = limited; N = none.

Breakwaters BW16 and BW17 were tested extensively with a wide variety of irregular wave conditions. A limited number of irregular wave runs were also made for several other breakwaters (Table 1).

## 7. Test Results.

Test results for monochromatic and irregular wave conditions are presented in tabular form in Appendixes C and D; monochromatic results are presented in graphical form in Appendix E.

#### IV. ANALYSIS OF TEST RESULTS

This section provides an analysis of the wave transmission and reflection results of the model tests. Impermeable and permeable breakwaters were investigated, and a separate discussion is devoted to each type breakwater. The first part of this section describes observed trends in the values of the transmission and reflection coefficients as a function of the parameters varied in this study. The second part includes development, description, and evaluation of methods for predicting wave transmission coefficients. The third part discusses the effect of a breakwater on other wave characteristics, such as the wave height distribution and shape of the transmitted wave spectra. Since good models are not available for predicting wave reflection coefficients for breakwaters, it is recommended that the model tests be used directly to estimate breakwater wave reflection coefficients.

##### 1. Wave Transmission and Reflection for Impermeable Breakwaters.

a. Observed Trends in Transmission and Reflection Coefficients. As a wave approaches an impermeable breakwater some of the wave energy is supplied to wave runup, some of the energy is dissipated, and the remaining wave energy moves seaward in the form of a reflected wave. If the runup exceeds the crest elevation of the breakwater, waves will be regenerated on the landward side of the structure. Figure 7 shows aspects of this process and defines some of the terms used in wave transmission by overtopping.

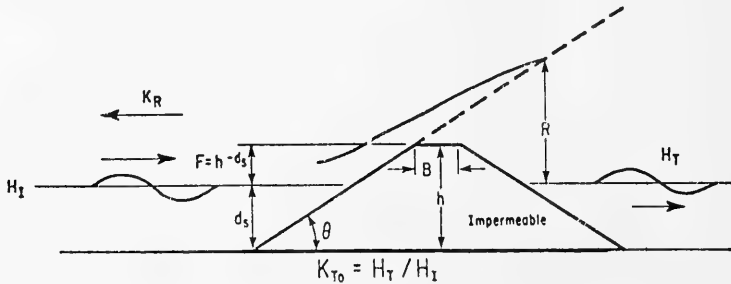


Figure 7. Definition of terms for wave transmission by overtopping.

Madsen and White (1976) found that low reflection coefficients and correspondingly large amounts of wave energy are dissipated on smooth nonovertopping structures. This observation has been verified using the data of Ahrens (1979) for breaking and nonbreaking waves. The data show that for the case of no overtopping the reflection coefficient decreases and a larger fraction of the wave energy is dissipated as the wave steepness increases (Fig. 8). More than 80 percent of the wave energy is dissipated by the smooth slope of 1 on 1.5 for the steepest waves tested. Note that the magnitude of the wave reflection coefficient is approximately the same for monochromatic and irregular waves, for a given value of wave steepness.

As the height of the breakwater is reduced the magnitude of the wave reflection coefficient decreases because much of the wave energy is transmitted by overtopping. For example, with a freeboard of zero (water level at the breakwater crest) BWL has reflection coefficients that are less than 20 percent of the reflection coefficient for a structure that is not overtopped for the steeper waves tested (Fig. 9). At values of small wave steepness the size of



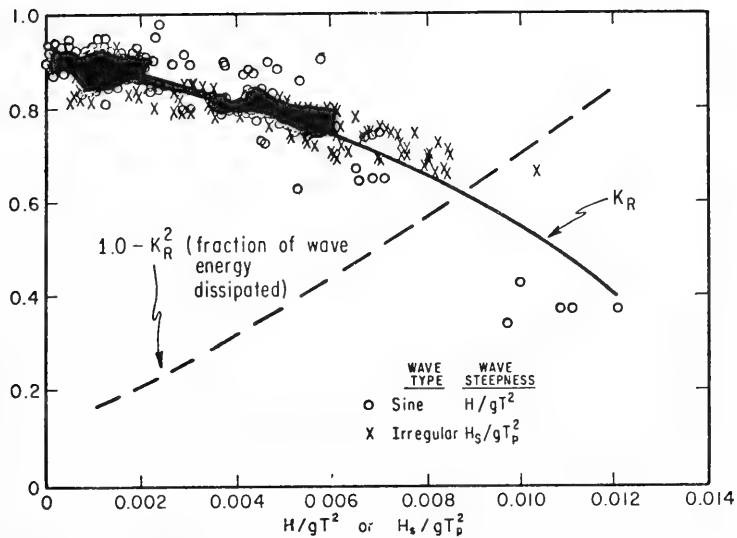


Figure 8. Wave reflection coefficients and fraction of wave energy dissipated for a 1 on 1.5 smooth slope with no wave transmission (data from Ahrens, 1979).

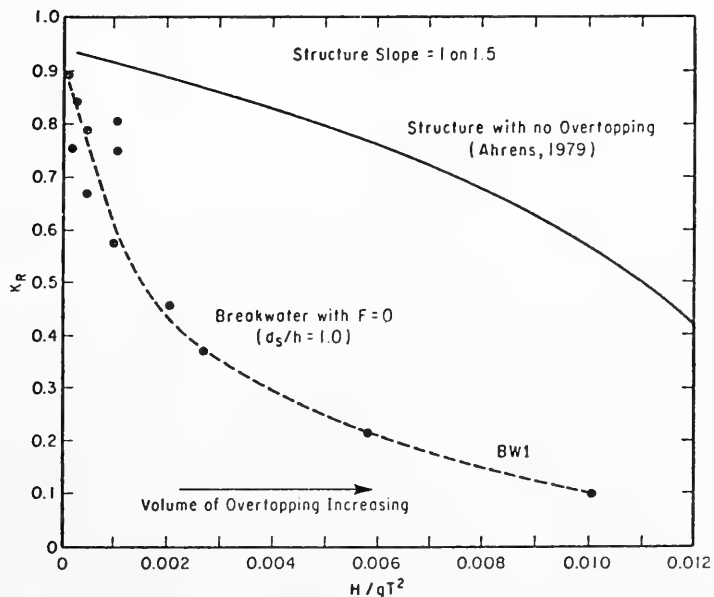


Figure 9. Wave reflection coefficients for a breakwater with zero freeboard compared to a similar structure with no overtopping.

the reflection coefficients for the breakwater and smooth impermeable slope is approximately the same because breakwater overtopping is small.

The wave reflection coefficient decreases as the wave height or steepness increases for a subaerial breakwater, but shows the opposite trend for a submerged breakwater (Fig. 10). There is a slight increase in the reflection coefficient as the wave height increases for the conditions tested.

The variation of the wave transmission coefficient for a smooth impermeable breakwater is the reverse of that found for the reflection coefficient. If the wave runup is less than the breakwater freeboard there is no wave transmission. As soon as the runup exceeds the crest of the breakwater, wave transmission by overtopping occurs. All other factors being fixed, as the wave height increases the size of the runup and the transmission by overtopping coefficient increase (Fig. 10); as the ratio of the water depth to structure height,  $d_g/h$ , approaches 1.0 the transmission coefficient increases. Even with zero freeboard ( $d_g/h = 1$ ) there is some increase in the wave transmission coefficient as wave steepness increases (Fig. 10). However, for a submerged breakwater of fixed geometry the wave transmission coefficient declines as wave height or steepness increases (Fig. 10).

b. Estimating Wave Transmission by Overtopping Coefficients. Wave transmission by overtopping is closely related to wave runup and overtopping of a breakwater. Weggel (1976) found that overtopping rates are a function of the ratio of the structure freeboard,  $F$ , to the runup,  $R$ , on a similar structure high enough to prevent overtopping (Fig. 7). Cross and Sollitt (1971) also recommend the dimensionless parameter,  $F/R$ , for predicting wave transmission by overtopping coefficients.

Several methods are available for estimating wave runup on smooth impermeable slopes; some of these methods are summarized in Stoa (1978). The runup prediction equation developed by Franzius (1965) gives the best estimate of wave runup for predicting wave transmission coefficients. The runup is given by

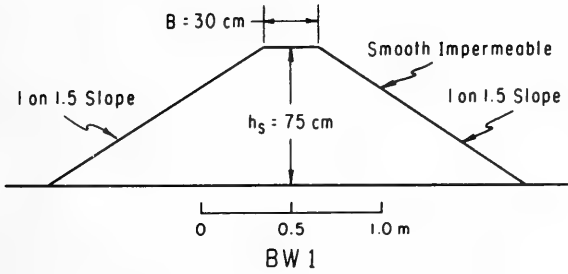
$$R = HC_1 \left( 0.123 \frac{L}{H} \right) (C_2 \sqrt{H/d} + C_3) \quad (10)$$

where  $L$  is the local wavelength determined from linear theory using

$$L = \frac{gT^2}{2\pi} \tanh \left( \frac{2\pi d}{L} \right) \quad (11)$$

and  $C_1$ ,  $C_2$ , and  $C_3$  are empirical coefficients. Franzius suggests values for the coefficients, but improved coefficients were obtained in this study using the data of Saville (1955) and Savage (1959) with a nonlinear error minimization computer routine. The recommended values of the empirical coefficients are given in Table 2. These values are linearly interpolated to estimate values of the coefficients for other slopes. An advantage of using equation (10) is that it includes effects of wave height, structure slope, wave steepness, and the ratio of water depth to wave height on wave runup.

The runup on rough slopes is also a complex function of many factors (Stoa, 1978). Madsen and White (1976) give an analytical-empirical model for estimating



	$d_s/gT^2$	
○	1.20	Submerged Breakwater
△	1.13	
+	1.07	
×	1.00	Subaerial Breakwater
◇	0.93	
†	0.87	
×	0.80	
Z	0.73	
Y	0.67	
X	0.60	

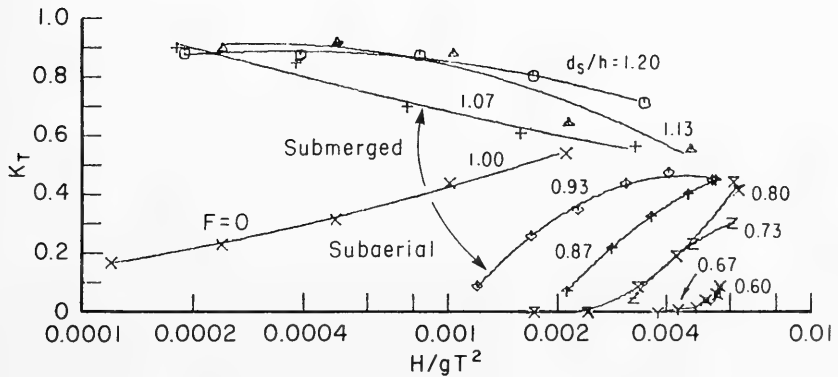
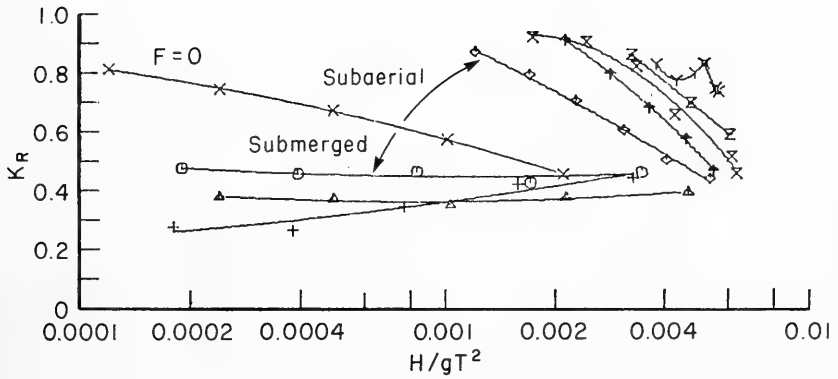


Figure 10. Wave transmission and reflection coefficients for a smooth impermeable breakwater (BW1,  $d_s/gT^2 = 0.016$ , monochromatic waves).

Table 2. Empirical wave runup prediction coefficients for smooth impermeable slopes.

Front-face slope of breakwater	$C_1$	$C_2$	$C_3$
Vertical	0.958	0.228	0.0578
1 on 0.5	1.280	0.390	-0.091
1 on 1.0	1.469	0.346	-0.105
1 on 1.5	1.991	0.498	-0.185
1 on 2.25	1.811	0.469	-0.080
1 on 3.0	1.366	0.512	0.040

runup on an impermeable rough slope armored with one layer of stone. Ahrens and McCartney (1975) present an empirical method for estimating the runup on two layers of riprap overlying a 0.2-meter thick underlayer (Fig. 11). In their method the runup is predicted as a nonlinear function of the surf parameter,  $\xi$ ,

$$\frac{R}{H} = \frac{a\xi}{1 + b\xi} \quad ; \quad \xi = \frac{\tan \theta}{\sqrt{\frac{H}{L_0}}} \quad (12)$$

where  $a$  and  $b$  are empirical coefficients with values of  $a = 0.956$  and  $b = 0.398$ .

Both the Madsen and White and Ahrens and McCartney prediction methods tend to give high or conservative estimates of wave runup for predicting wave transmission coefficients. However, Hudson (1958) made numerous observations of runup over a wide range of breakwater conditions; the Ahrens and McCartney empirical curve (eq. 1) was fitted to the Hudson data to give the recommended runup coefficients of  $a = 0.692$  and  $b = 0.504$  (Table 3). These coefficients gave a lower prediction of runup than that given for riprap (Fig. 12). The equation

$$\frac{R}{H} = \frac{0.692 \xi}{1 + 0.504 \xi} \quad (13)$$

is recommended for predicting runup on stable permeable and impermeable stone breakwaters until a more comprehensive model becomes available. Coefficients for dolos were also estimated using Bottin, Chatham, and Carper's (1976) data for breaking and nonbreaking waves (Table 3). Stoa (1978) provides additional information on runup; runup data for nonbreaking waves on breakwaters are provided in Jackson (1968):

Runup predictions were made for the conditions tested, and observed wave transmission by overtopping coefficients,  $K_{T0}$ , were plotted as a function of  $F/R$  (Fig. 13). This figure shows the case of breakwaters with a slope of 1 on 1.5. The upper part of Figure 13 shows results from BW1 for tests that had a

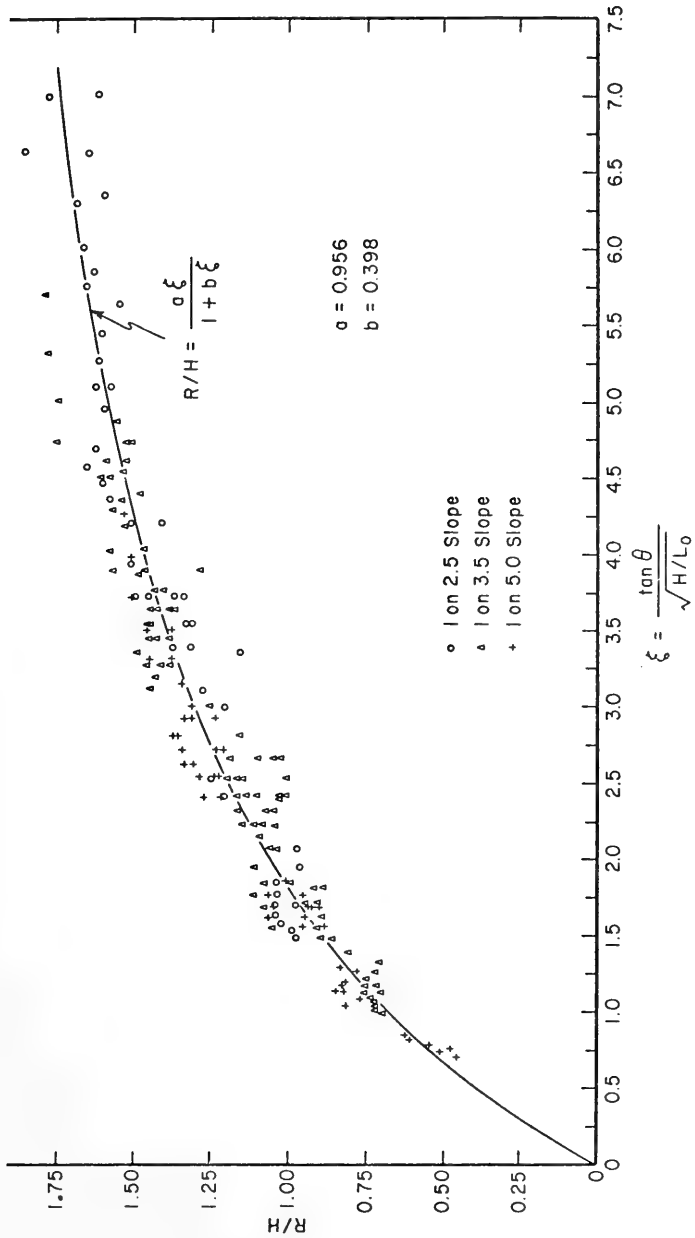


Figure 11. Wave runup on riprap (after Ahrens and McCartney 1975).

Table 3. Wave runup prediction coefficients using the Ahrens and McCartney (1975) method.

Armor unit	No. of layers	Permeability <sup>1</sup>	2		$\frac{d}{gT^2}$ (range)	$\frac{H}{gT^2}$ (range)	Cot $\theta$ (range)	Source
			a	b				
Rubble	2	I	0.956	0.398	0.0036 to 0.059	0.0004 to 0.013	2.5 to 5.0	Ahrens and McCartney (1975) <sup>3</sup> (large-scale tests)
Rubble	0	P	0.692	0.504	0.0088 to 0.08	0.0004 to 0.02	1.25 to 5.0	Hudson (1958) <sup>4</sup>
Rubble	2	I	0.775	0.361	----- <sup>5</sup>	-----	2.5	Gunbak (1979) <sup>6</sup>
Dolos	2	I	0.988	0.703	0.009 to 0.002	0.0002 to 0.006	2.0	Bottin, Chatham, and Carver (1976)

<sup>1</sup>P = permeable; I = impermeable.

<sup>4</sup>Means of observations.

<sup>2</sup> $R/H = a\xi/(1+b\xi)$ ;  $\xi = \tan \theta / \sqrt{H/L_0}$ .

<sup>5</sup>Conditions unknown.

<sup>3</sup>Revised a and b.

<sup>6</sup> $1.2 < \xi < 4.8$ .

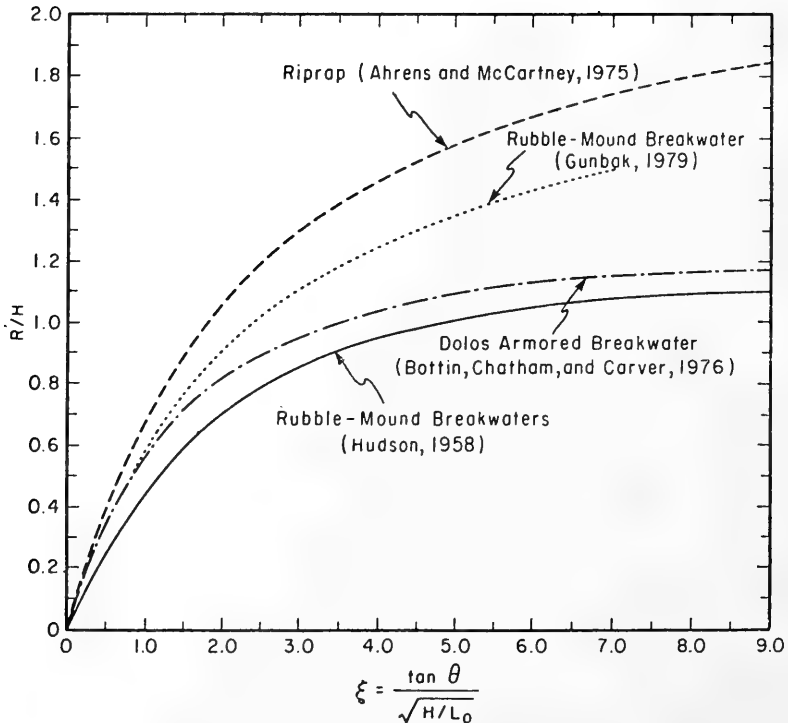


Figure 12. Wave runup prediction for rough structures using the Ahrens and McCartney (1975) method.

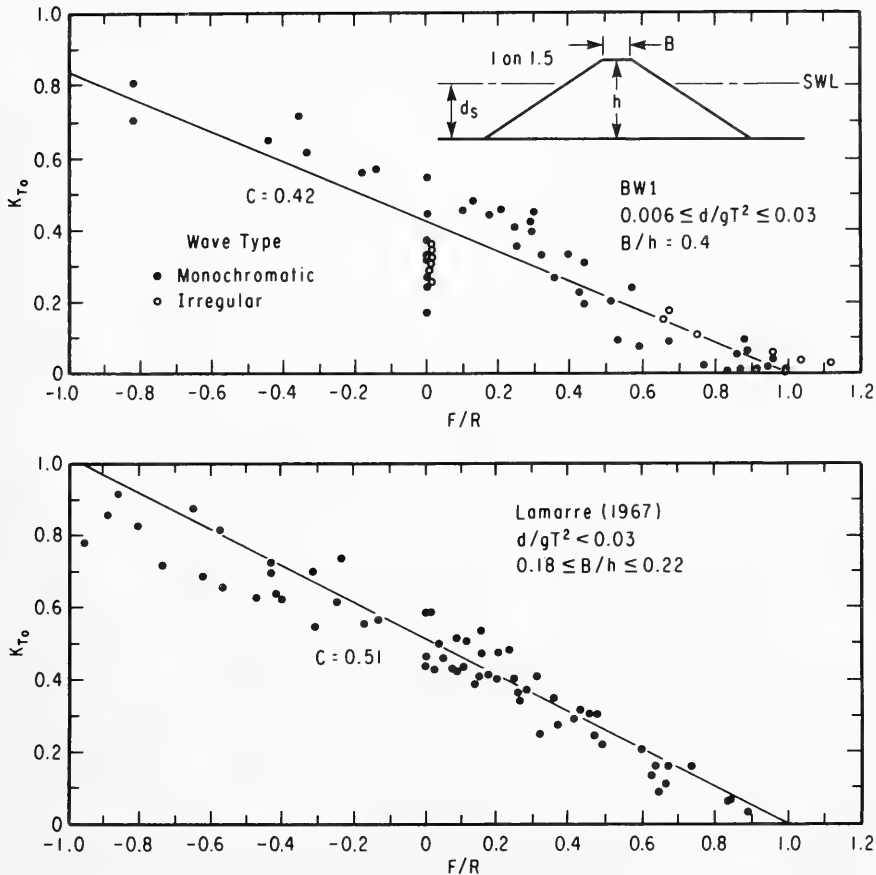


Figure 13. Wave transmission coefficients for smooth impermeable breakwaters with 1 on 1.5 slopes.

breakwater crest width-to-structure height ratio of  $B/h = 0.4$ . The lower part of the figure gives test results from Lamarre (1967), who tested structures with smaller values of  $B/h$ . Although there is some scatter in these data sets, it appears that the wave transmission coefficient decreases approximately linearly as  $F/R$  increases and that this linear trend is found for submerged as well as subaerial breakwaters. Most of the scatter occurs where the crest elevation is at the stillwater level ( $F/R = 0$ ) for BW1, with small waves having significantly lower wave transmission coefficients than are present in the linear trend. Fortunately, small waves are generally not of interest for design purposes. The few irregular waves tested with BW1 suggest that wave transmission coefficients for irregular waves follow the same trend as for monochromatic waves. The mean wave height, taken as 63 percent of the significant wave height, should be used in equation (12) to determine the effective runup for predicting wave transmission coefficients for irregular wave conditions.

Comparison of the upper and lower parts of Figure 13 suggests that the structure tested by Lamarre (1967) with a smaller relative crest width has slightly higher wave transmission coefficients than found for BW1.

Results from laboratory tests by Goda (1969) for breakwaters with vertical faces (Fig. 14) have the same trends as observed for breakwaters with 1 on 1.5 slopes.

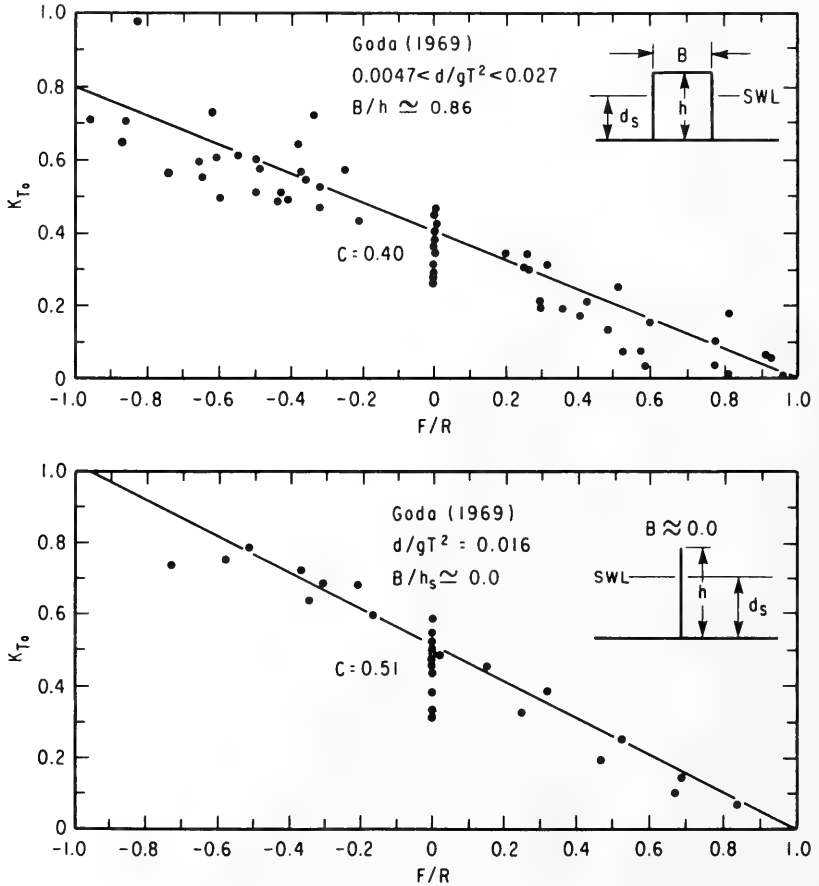


Figure 14. Wave transmission coefficients for vertical, smooth impermeable breakwaters using Goda's (1969) data.

The recommended formula for predicting the wave transmission by overtopping coefficient for the range  $0.006 \leq d/gT^2 \leq 0.03$  is

$$K_{T0} = C \left( 1 - \frac{F}{R} \right) \quad (14)$$



where  $C$  is an empirical coefficient and the minimum and maximum values of  $K_{T0}$  are 0.0 and 1.0, respectively. The recommended value of  $C$  is given by

$$C = 0.51 - \frac{0.11 B}{h} ; \quad 0 \leq \frac{B}{h} \leq 3.2 \quad (15)$$

for smooth impermeable structures tested over the range  $0 \leq B/h \leq 0.86$  and rough impermeable breakwaters tested over the range  $0.88 \leq B/h \leq 3.2$  (Fig. 15). However, for submerged breakwaters tested with 1 on 15 fronting slopes, equation (14) underestimates the wave transmission coefficient. For example, equation (14) underestimates the wave transmission coefficient for BW14 when submerged and the error increases as the breakwater becomes relatively more submerged (Fig. 16). The data from BW14 and from Saville (1963) show that for submerged breakwaters with  $0.88 \leq B/h \leq 3.2$  and with a 1 on 15 fronting slope equation (14) should be adjusted to

$$K_{T0} = C \left( 1 - \frac{F}{R} \right) - (1 - 2C) \frac{F}{R} ; \quad \frac{F}{R} < 0 \quad \text{and 1 on 15 fronting slope} \quad (16)$$

Figures 17 and 18 illustrate the observed and predicted wave transmission coefficients for two of the rough impermeable breakwaters tested by Saville (1963) for two values of crest width. Figure 17 shows the case of a structure with a crest width-to-structure height ratio of 0.88; Figure 18 shows the same information for a much wider structure with a width-to-height ratio of 3.2. A scatter plot of observed and predicted transmission coefficients using Saville's (1963) data indicates the level of ability to predict  $K_{T0}$  (Fig. 19).

The above discussion shows that the breakwater freeboard and wave runup have a major influence on the magnitude of the wave transmission by overtopping coefficient. Breakwater crest width has a much smaller effect and only large changes in breakwater crest width could be used to reduce the size of the transmission coefficient for a given design situation.

Wave transmission by overtopping coefficients may be predicted for impermeable structures using the computer program OVER (App. F) which applies methods described in this section.

c. Influence of a Breakwater on Other Wave Characteristics. The magnitude of the wave transmission by overtopping coefficient,  $K_{T0}$ , is generally the most important parameter to determine for the design of an impermeable breakwater used to reduce wave height. However, in addition to reducing the average wave height, the breakwater may also alter other characteristics of the waves, such as spectral shape or wave height distributions. Since these additional wave characteristics may be considered in some design problems, they are briefly discussed below.

The case of monochromatic waves incident on the structure is the condition most often used to test wave transmission of laboratory breakwaters in previous studies. This type of wave is similar to swell wave conditions in the prototype where the incident wave height and period are approximately constant. Spectral analysis of water level records for gages landward of the breakwater indicates that a significant part of the wave energy of transmitted waves may be at harmonic frequencies of the forcing wave (Saville, 1963; Goda, 1969). The fraction of wave energy at the forcing period (Fig. 20) shows the same trend

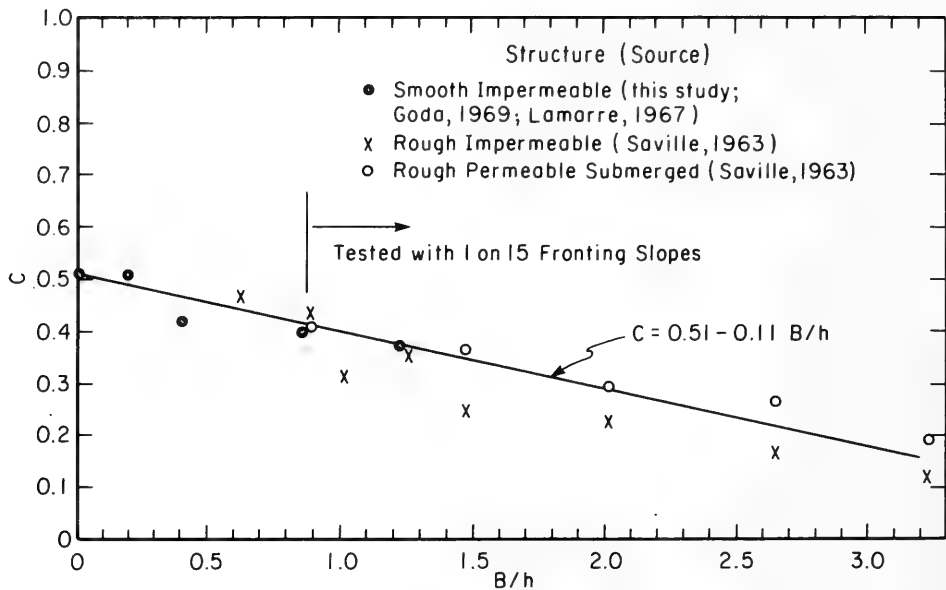


Figure 15. The effect of the relative structure width on wave transmission of impermeable breakwaters.

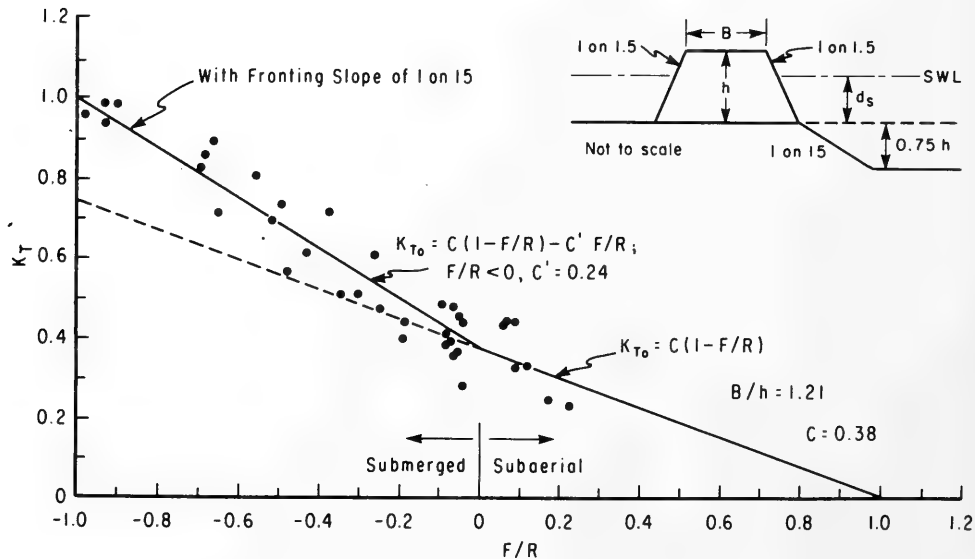


Figure 16. Wave transmission coefficients for BW14.

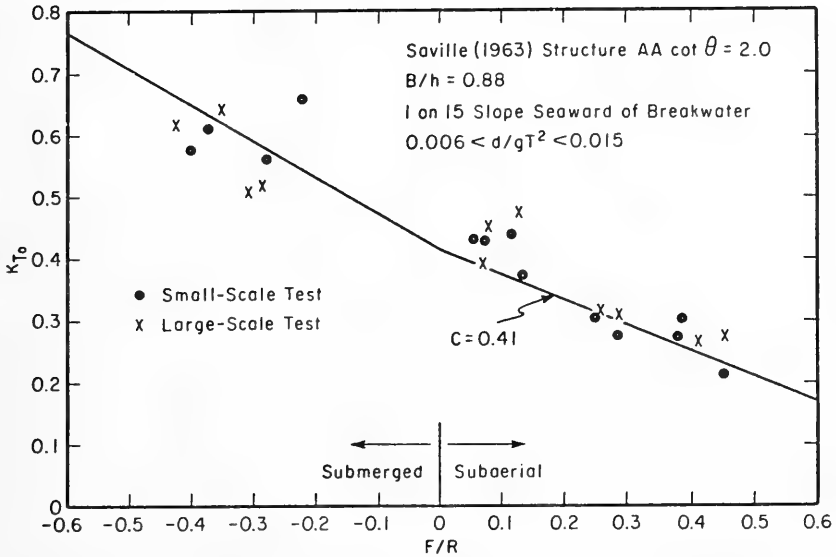


Figure 17. Wave transmission coefficients for a breakwater tested by Saville (1963) with  $B/h = 0.88$ .

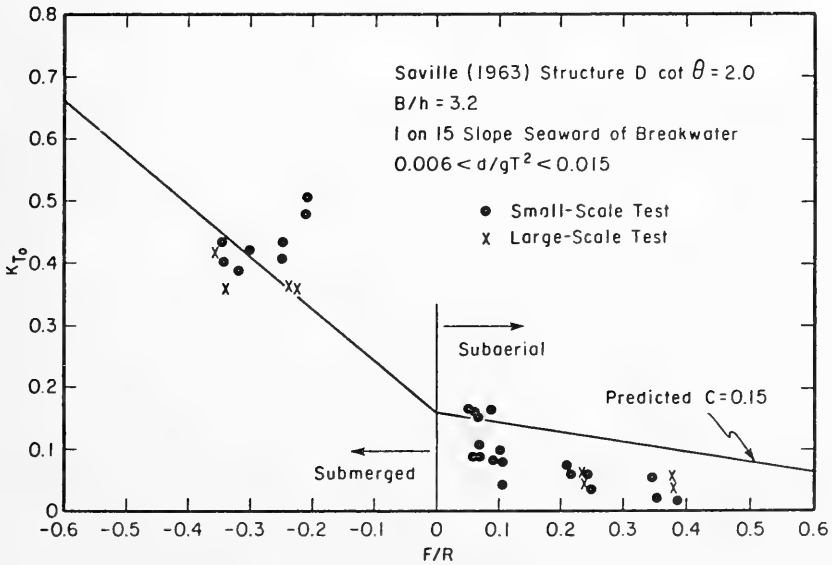


Figure 18. Wave transmission coefficients for a breakwater tested by Saville (1963) with  $B/h = 3.2$ .

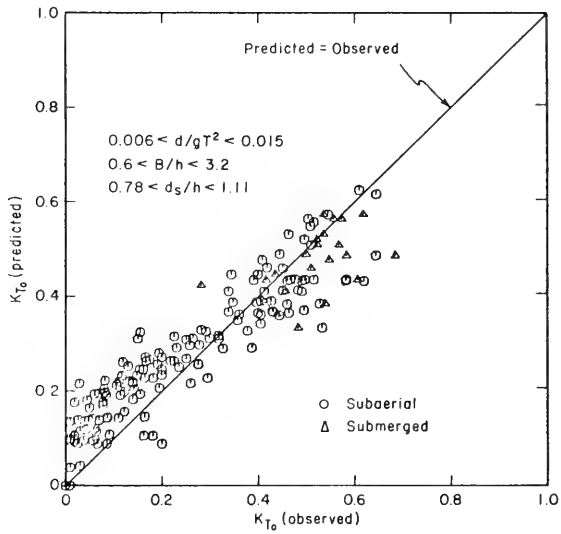


Figure 19. Observed and predicted coefficients of wave transmission by overtopping (Saville, 1963; impermeable breakwaters).

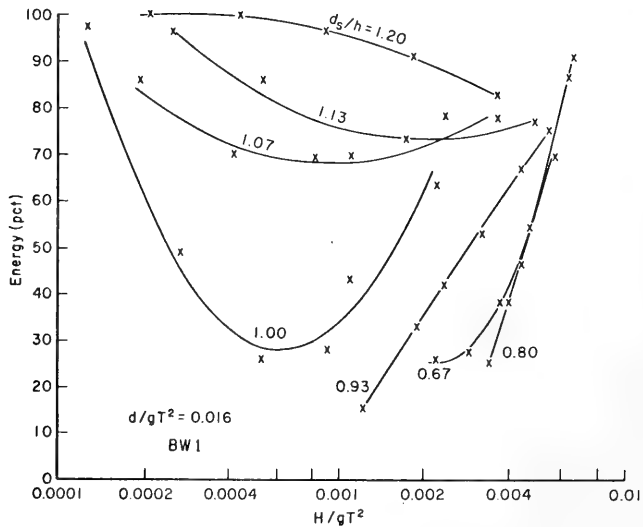


Figure 20. Percent of wave energy at the forcing wave period for wave transmission by overtopping of a smooth impermeable structure (monochromatic waves).

as was found for the transmission coefficient,  $K_{T0}$  (lower half of Fig. 10). Comparison of Figures 10 and 20 suggests that the amount of wave energy found at the forcing period will increase as the transmission by overtopping coefficient increases.

The case of irregular waves is where the incident wave energy is distributed over a range of wave frequencies (several measured incident laboratory wave records and computed wave spectra are shown in Figs. 4 and 5). Tests with irregular waves indicate that the shapes of the incident and reflected wave spectra are approximately the same (two examples are given in Fig. 21). The approximately constant spectral shape is shown by the spectral-peakedness parameter,  $Q_p$ , where the value for the reflected waves,  $Q_{pr}$ , is approximately equal to the incident spectral peakedness,  $Q_{pi}$  (Fig. 22). The shape of the transmitted spectrum may be approximately equal to or sharper than the incident spectrum (Fig. 22) with the spectral-peakedness parameter of the transmitted waves,  $Q_{pt}$ , greater than or equal to  $Q_{pi}$  (Fig. 22). Secondary waves may appear in the transmitted wave spectrum at harmonics of the period of peak energy density,  $T_p$ , (Fig. 21).

A zero up-crossing analysis (Fig. 23) was performed on the wave records to allow statistical examination of individual wave heights and periods. Since reflected waves contaminate the incident wave conditions, an analysis was performed for the record from each gage, then results averaged to minimize the influence of reflection. Cumulative height distributions were then prepared for incident and transmitted waves. The cumulative curves were put into dimensionless form by dividing by the observed rms wave height,  $H_{rms}$ , and the dimensionless heights at various probability levels,  $p$ , determined ( $p = 0.01, 0.02, 0.05, \dots, 0.60$ ). A plot of these dimensionless heights for transmitted versus incident waves indicates the shape of the transmitted wave height distribution as a function of the incident wave height distribution. For the case of a breakwater with the water depth at the crest level ( $d_g/h = 1.0$  or  $F = 0$ ) the transmitted wave height distribution is approximately the same as the incident height distribution (Fig. 24). If the water level is below the crest elevation ( $d_g/h = 0.80$ , positive freeboard), the transmitted wave height distribution is skewed toward larger waves (Fig. 25). This means that the larger transmitted waves are bigger than predicted by the transmission coefficient,  $K_{T0}$ . For example, at the 5-percent level, transmitted waves are 30 percent larger than expected from the overall transmission coefficient and at the 1-percent level 100 percent larger.

The above observations are consistent with the wave transmission by overtopping model given by equation (14). At zero freeboard the transmission coefficient is approximately constant, so all waves in a distribution will transmit the same amount and the distribution will remain unchanged. However, for subaerial breakwaters the larger waves will have smaller  $F/R$  ratios and transmit more efficiently than small waves, so that the transmitted wave distribution is skewed toward large waves.

The joint distributions of wave heights and periods observed in the laboratory illustrate the same overall trends found in the field. Larger waves have a mean period approximately equal to the period of peak energy density in the spectrum,  $T_p$  (Goda, 1978), with the average wave period decreasing for smaller wave heights (Fig. 26). The correlation between

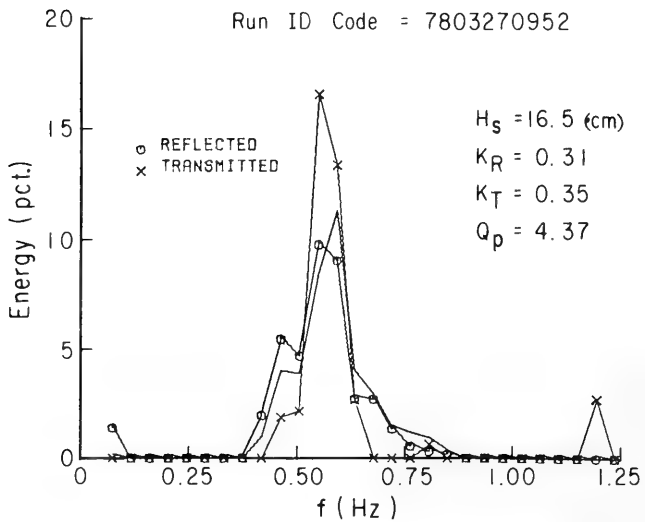
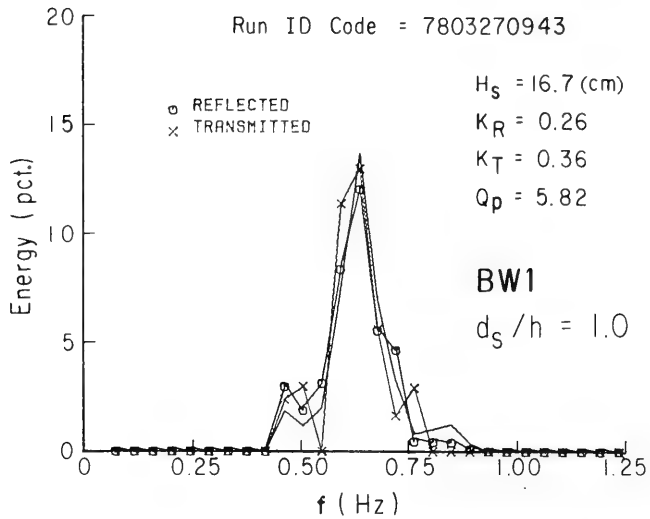


Figure 21. Sample incident, reflected, and transmitted wave spectra.

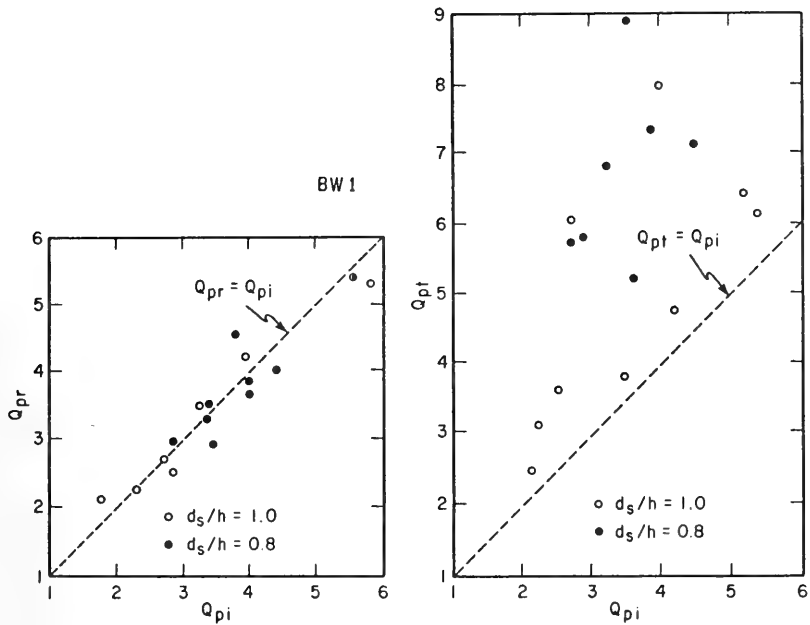


Figure 22. Spectral peakedness of incident, reflected, and transmitted wave spectra.

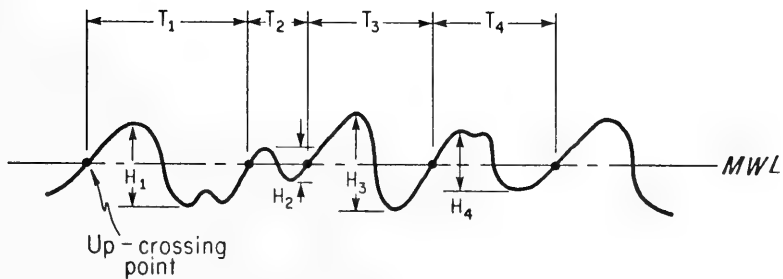


Figure 23. Zero up-crossing analysis.

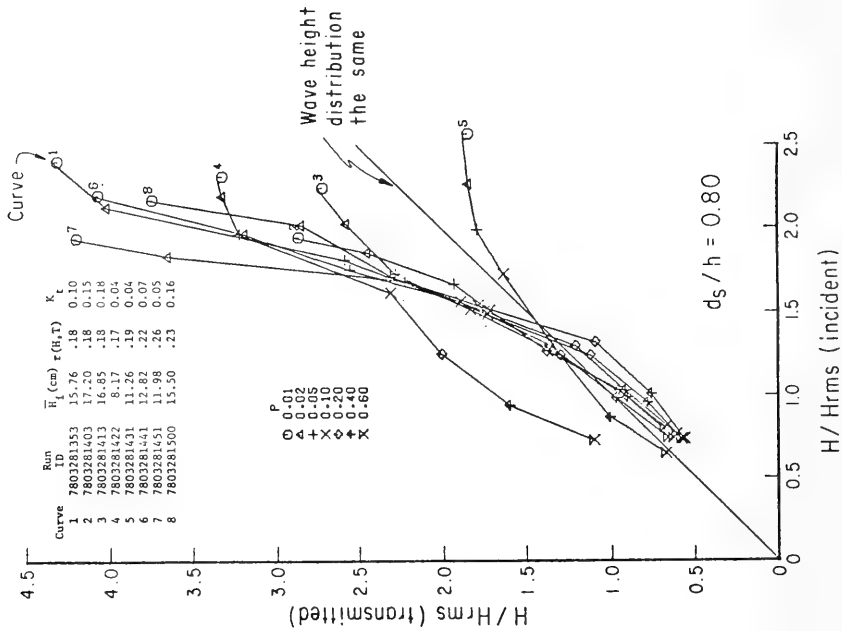


Figure 25. Transmitted versus incident wave height distributions for a breakwater with  $d_5/h = 1.0$ .

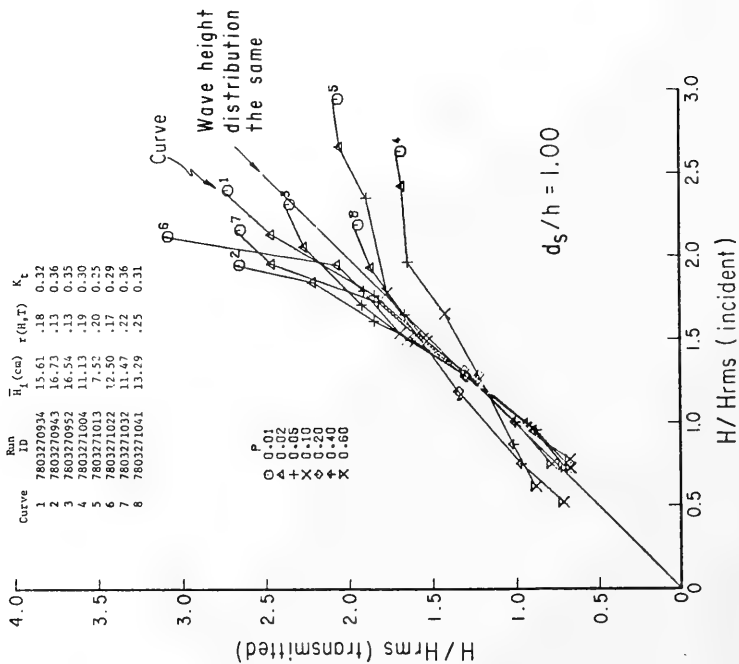


Figure 24. Transmitted versus incident wave height distributions for a breakwater with  $d_5/h = 0.8$ .



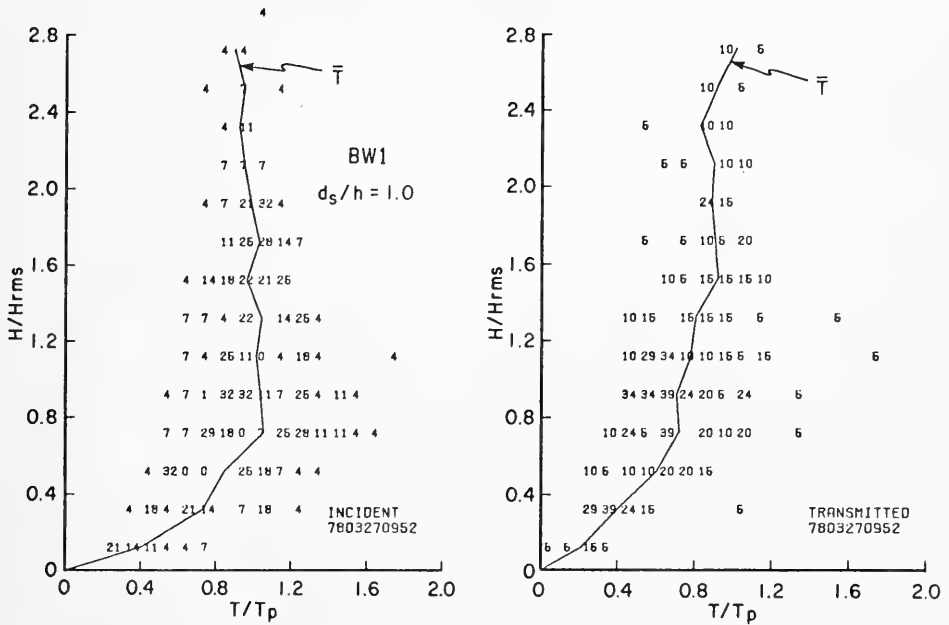
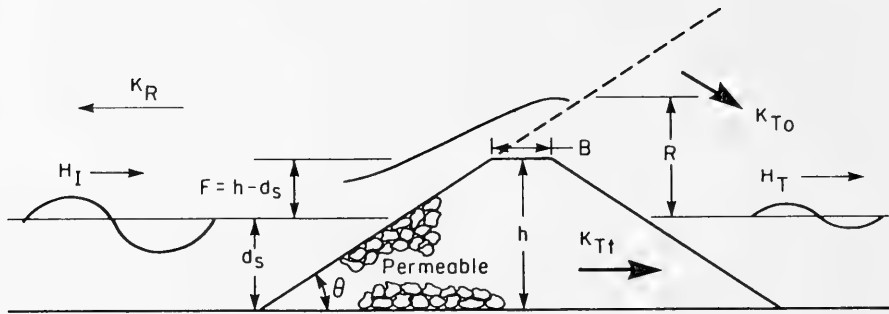


Figure 26. Sample incident and transmitted joint distributions of wave height and period.

heights and periods (Goda, 1978) was observed to be  $0.13 \leq r(H,T) \leq 0.26$  for the incident wave conditions tested with approximately the same values for transmitted waves. The major difference between observed and transmitted joint distributions of height and periods is that the mean period of smaller waves is lower for the transmitted waves (Fig. 26) than for the incident waves.

## 2. Wave Transmission and Reflection for Permeable Breakwaters.

a. Observed Trends in Transmission and Reflection Coefficients. As a wave approaches and interacts with a rough permeable breakwater the sequence of action is similar to that for an impermeable breakwater, but with important differences. First, some of the wave energy moves through the permeable breakwater and this flow through the porous medium may dissipate a significant amount of wave energy. Second, because the breakwater absorbs some of the wave energy and water, the runup and reflection coefficients on a rough permeable breakwater are less than for the same wave condition on a similar smooth impermeable structure. If the runup level exceeds the height of the structure, wave transmission by both overtopping and transmission through the structure will contribute to the overall transmission coefficient,  $K_T$  (Fig. 27).



$$K_T = \sqrt{(K_{T0})^2 + (K_{Tt})^2} = H_T/H_I$$

Figure 27. Definition of terms for wave transmission for permeable breakwaters.

The relative water depth,  $d/gT^2$ , is one of the most important parameters controlling the reflection coefficient,  $K_R$  (Fig. 28), with the reflection coefficient increasing as  $d/gT^2$  decreases. The wave steepness,  $H/gT^2$ , and the ratio of water depth to structure height,  $d_s/h$ , have less influence. In general, the reflection coefficients for rough permeable breakwaters are much less than for similar smooth impermeable breakwaters (Fig. 10). Since no comprehensive model is currently available for predicting reflection coefficients, laboratory model results should be used to estimate  $K_R$ . A rough estimate of the reflection coefficient for permeable subaerial breakwaters may be obtained using the method of Madsen and White (1976) (computer program MADSEN in App. G). Typical comparisons between predictions and laboratory measurements are shown in Figure 29.

The wave transmission coefficient,  $K_T$ , is primarily a function of wave steepness for a given permeable breakwater design and hydraulic conditions where there is no transmission by overtopping (Fig. 28). Since the wave steepness increases the amount of energy dissipated on the face and inside the breakwater increases (Madsen and White, 1976), the transmission coefficient decreases. However, as soon as the wave runoff level exceeds the breakwater crest, wave transmission by overtopping occurs and the transmission coefficient increases with increasing steepness. Figure 30 (lower part) shows the case where no overtopping occurs and  $K_T$  decreases (low steepness waves), then  $K_T$  increases with increasing steepness where transmission by overtopping and transmission through a breakwater occur simultaneously. In the case of a submerged breakwater the wave transmission coefficient decreases as the wave steepness increases (upper part of Fig. 30).

b. Estimation of the Coefficient of Wave Transmission Through Permeable Breakwaters Using the Madsen and White Model. The advantages of the Madsen and White (1976) model for predicting transmission coefficients are that the model is completely self-contained and it can be used to predict coefficients over a wide range of conditions. Parameters that can be varied include the breakwater height, breakwater width, breakwater slope, the size and relative location of various layers in the breakwater, and the size and porosity of materials used in the breakwater. Another advantage of the model is that it can be used to

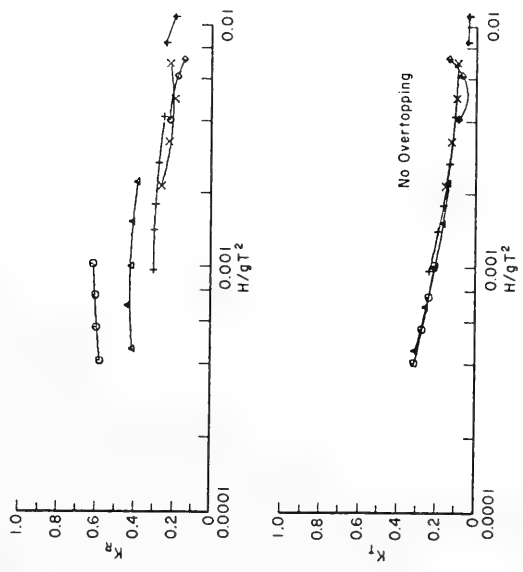
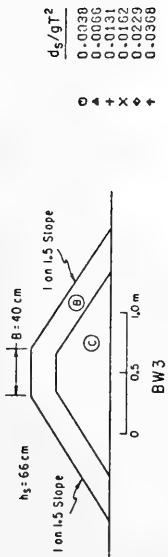


Figure 28. Wave transmission and reflection coefficients for BW3 ( $d_g/h = 0.69$ ).

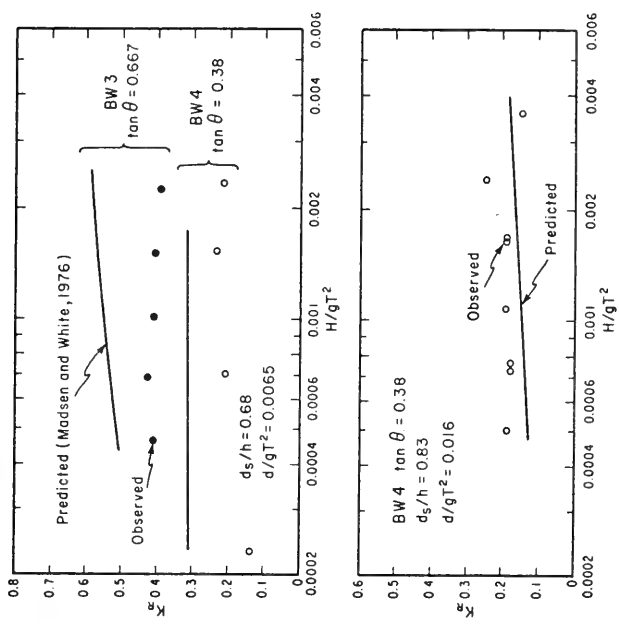


Figure 29. Sample observed and predicted reflection coefficients for permeable subaerial breakwaters.

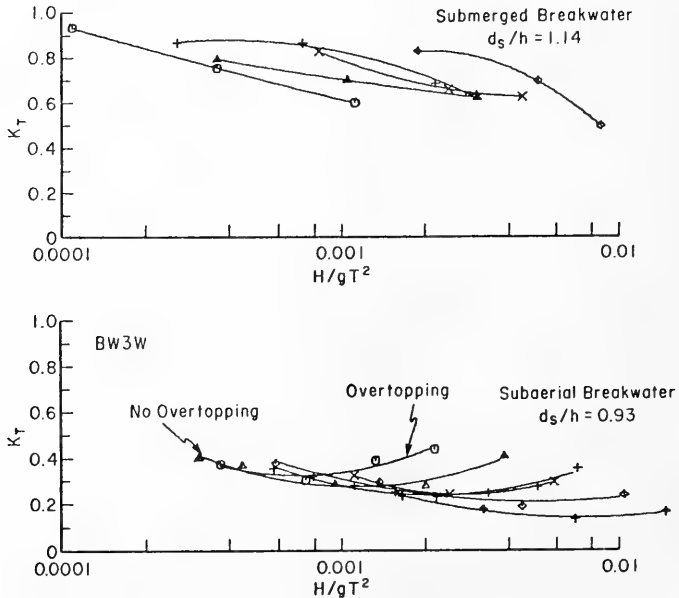
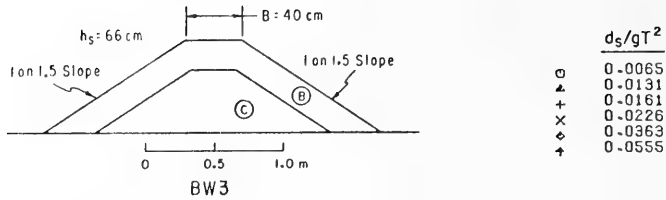


Figure 30. Wave transmission coefficients for a subaerial and a submerged breakwater.

predict coefficients for any size breakwater, useful when designing or assessing scale effects in small-scale physical models (see Sec. V).

The Madsen and White model was designed for manual use, but because of the many calculations and iterations necessary, manual calculation is tedious. The model was automated as a part of this study in a FORTRAN computer program, MADSEN (App. G) to simplify use of the model. Advantages of the computer program are that only a few input cards are required to model even a breakwater with complex geometry and the program computer cost is very low. The program includes all the generality in the original model, and the wave transmission by overtopping model developed in Section IV,1 is also incorporated. Since the Madsen and White (1976) technique is complex, reference is made to their publication for details of the model. A brief summary of the major steps in the model and computer program is given below; additional information on the computer program is given in Appendix G.

(1) Determine the breakwater cross-sectional geometry and material characteristics of diameter and porosity.

(2) Estimate the energy dissipation on the seaward face of the breakwater assuming it is rough and impermeable. This is done by solving Madsen and White's equation (127) implicitly using their Figures 15, 16, and 17 and applying a correction factor from their Table 2.

(3) Assume as a first approximation that the head across the breakwater is equal to runup determined from step 2 above.

(4) Transform the trapezoidal breakwater into a hydraulically equivalent rectangular breakwater (see Sec. 4.2 of Madsen and White).

(5) Estimate the coefficient of transmission through the structure,  $K_{Tt}$ , using Madsen and White's Figures 2 and 3 and implicitly solving their equation (57).

(6) Obtain a revised estimate of the head across the breakwater using Madsen and White's equation (161). (Repeat steps 4, 5, and 6 until a converged solution is obtained.)

(7) Estimate wave runup on the breakwater using the method of Ahrens and McCartney (1975) and the coefficients given in Table 3 of this study.

(8) Calculate the transmission by overtopping coefficient,  $K_{TO}$ , using equations (14) and (15) in this study.

(9) Calculate the transmission coefficient,  $K_T$ , using  $K_{Tt}$  from step 5 and  $K_{TO}$  from step 8 and

$$K_T = \sqrt{K_{Tt}^2 + K_{TO}^2}$$

Madsen and White compared the model predictions to physical model results from Keulegan (1973) for rectangular breakwaters composed of one rock type, and from Sollitt and Cross (1976) for a multilayered trapezoidal breakwater made of riprap. There was good agreement between analytical and physical model results for predicting the wave transmission coefficient for long nonbreaking waves. However, the following questions need to be answered to determine the range of usefulness of the Madsen and White model:

(1) How useful is the model for predicting transmission coefficients for relatively short waves?

(2) Can the model be used if waves are breaking?

(3) Can the model be used for breakwaters with concrete armor units?

(4) Can the model be used for irregular waves?

(5) How sensitive is the model to porosity of the materials?

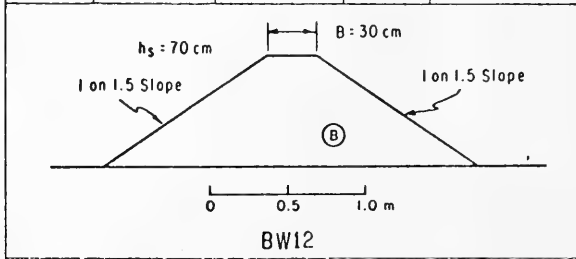
(Porosity is an input parameter and although it probably does not vary over a very wide range, its value will probably not be known accurately in a design situation.)

Each of these areas is discussed below.

(1) The case of the relative wavelength. In many of the laboratory tests the wave period was varied to cover the range from shallow-water long waves to deepwater short waves. Comparison of laboratory data and MADSEN computer program predictions shows excellent correspondence for shallow-water waves; e.g., at  $d/gT^2 = 0.0065$  (Table 4). As the relative depth becomes larger (the wavelength becomes shorter), the computer program slightly overpredicts the observed transmission coefficient (Fig. 31). This means that the prediction method is conservative. Although the absolute value of the overprediction is small, the percent overprediction may be large (Table 4).

Table 4. Effect of relative depth on prediction of  $K_{Tt}$ .

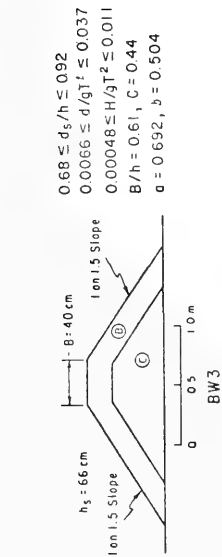
$\frac{d}{gT^2}$	$K_{Tt}$		Pct. error	Relative depth
	Observed	Predicted		
0.0065	0.34	0.33	-3	Shallow
0.016	0.46	0.44	-4	Transitional
0.055	0.13	0.21	+60	Deep



<sup>1</sup>BW12,  $d_g/h = 0.64$ ,  $H/gT^2 \approx 0.0015$ .

The ability of the model to predict wave transmission coefficients for a breakwater constructed entirely of armor stone is shown in Figure 32; wave transmission coefficients for a breakwater with a front-face slope of 1 on 2.6 are shown in Figure 33.

(2) The case of waves breaking on the breakwater. It was difficult in the laboratory to generate long waves that would break on a rough permeable structure without any overtopping. However, several tests that met these conditions were run using nonsurging, breaking waves (Galvin, 1968). These laboratory tests show that for breaking and nonbreaking waves the coefficient of transmission decreases gradually as the incident steepness increases (Fig. 34); no difference was evident between  $K_{Tt}$  for breaking and nonbreaking waves. The same trend is observed in Bottin, Chatham, and Carver's (1976) data for a breakwater with dolos armor units. Comparison of observed and predicted coefficients of transmission through the structure shows good agreement for the few breaking wave conditions tested (Fig. 34). These few tests suggest that the Madsen and White (1976) model can be used for breaking as well as nonbreaking waves.



$0.69 \leq d_s/h \leq 0.92$   
 $0.0066 \leq d/gT^2 \leq 0.037$   
 $0.00048 \leq H/gT^2 \leq 0.011$   
 $B/h = 0.61, C = 0.44$   
 $a = 0.692, b = 0.504$

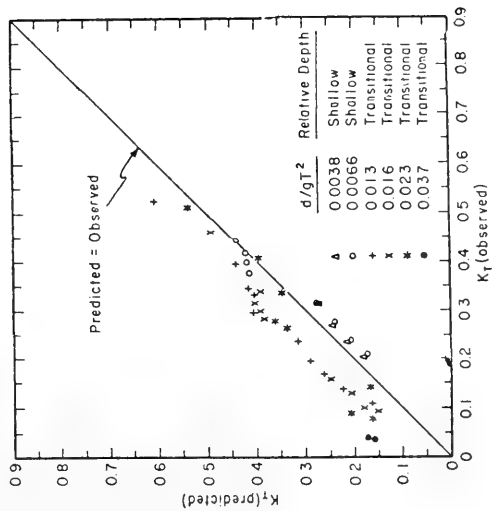
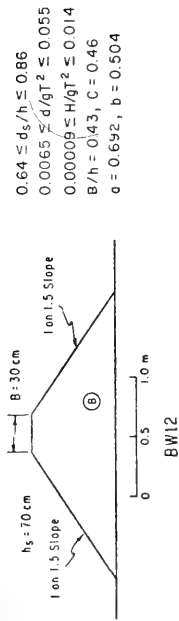


Figure 31. Observed and predicted transmission coefficients for BW3.



$0.64 \leq d_s/h \leq 0.86$   
 $0.0065 \leq d/gT^2 \leq 0.055$   
 $0.00009 \leq H/gT^2 \leq 0.014$   
 $B/h = 0.43, C = 0.46$   
 $a = 0.692, b = 0.504$

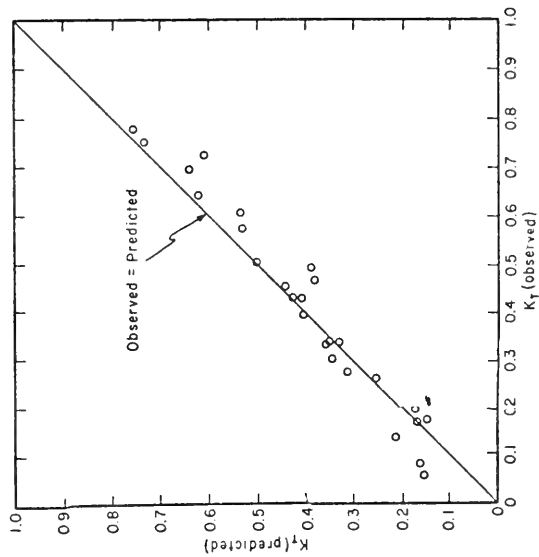


Figure 32. Observed and predicted transmission coefficients for BW12.

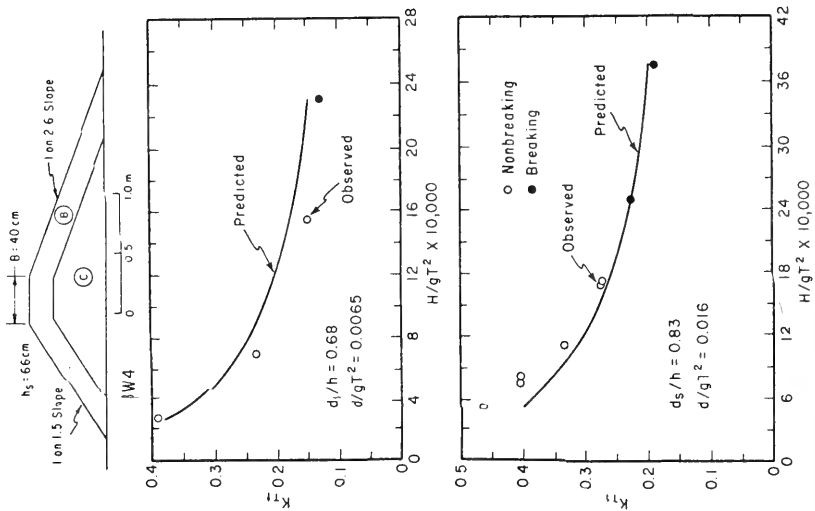


Figure 34. Observed and predicted transmission coefficients for breaking and non-breaking conditions (BW4).

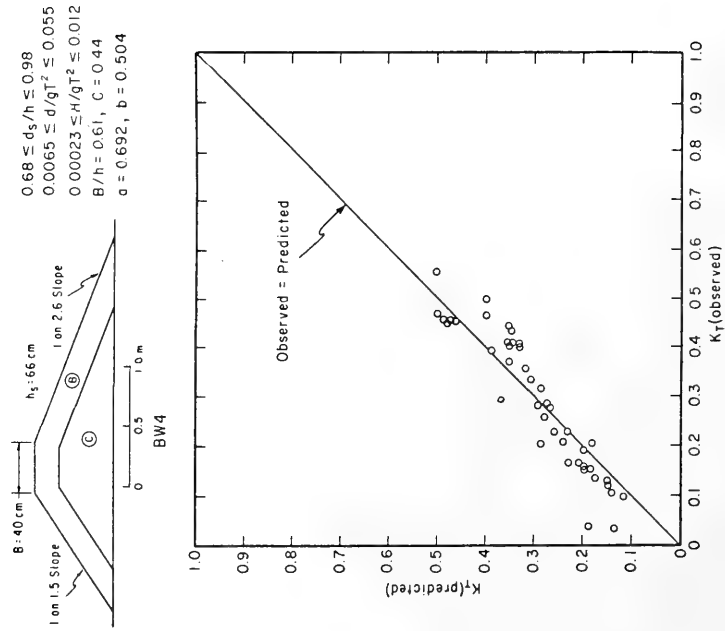


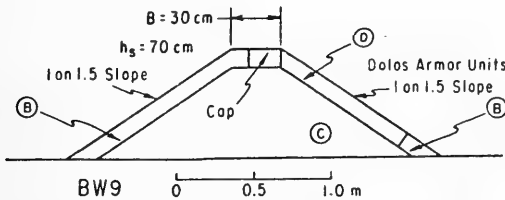
Figure 35. Observed and predicted transmission coefficients for BW4.



(3) The case of breakwaters with concrete armor units. The friction factor and porous media flow factors for concrete armor units are unknown, but they are assumed to be similar to the properties of stone with an effective median diameter,  $d_{50}$ , of

$$d_{50} = \left( \frac{W_{50}}{\gamma} \right)^{1/3} \quad (17)$$

Figure 35 shows observed and predicted transmission coefficients for a breakwater with two layers of dolos armor units. There is excellent prediction of transmission coefficients for long shallow-water waves with the Madsen and White (1976) model overpredicting transmission coefficients for waves with greater relative depth. This is the same trend found in prediction of transmission coefficients for rubble-mound breakwaters.



$0.64 \leq d_s/h \leq 0.86$   
 $0.0065 \leq d/gT^2 \leq 0.055$   
 $0.0001 \leq H/gT^2 \leq 0.012$   
 $B/h = 0.43, C = 0.46$   
 $a = 0.692, b = 0.504$

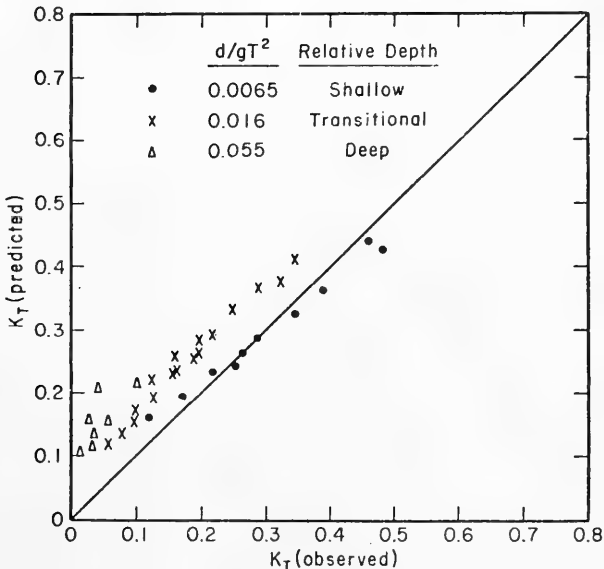


Figure 35. Observed and predicted transmission coefficients for a breakwater with dolos armor units (BW9).

The model also does a good job of predicting the coefficient of transmission through a permeable breakwater armored with tribars tested by Davidson (1969) (Fig. 36). However, the effective transmission by overtopping coefficient,  $C$ , is larger than would be expected from Figure 15 for  $B/h = 0.30$ . Fortunately, the observed transmission coefficient appears to be approaching a value of approximately 0.48, the limiting value of the overtopping wave transmission coefficient for this breakwater predicted from equations (14) and (15). The relatively high porosity of artificial armor units apparently increases the size of the wave transmission by overtopping coefficient over a limited range of wave heights for this case where the stillwater level is above the core and close to the breakwater crest (D. Davidson, Chief, Wave Research Branch, U.S. Army Waterways Experiment Station, personal communication, 1979).

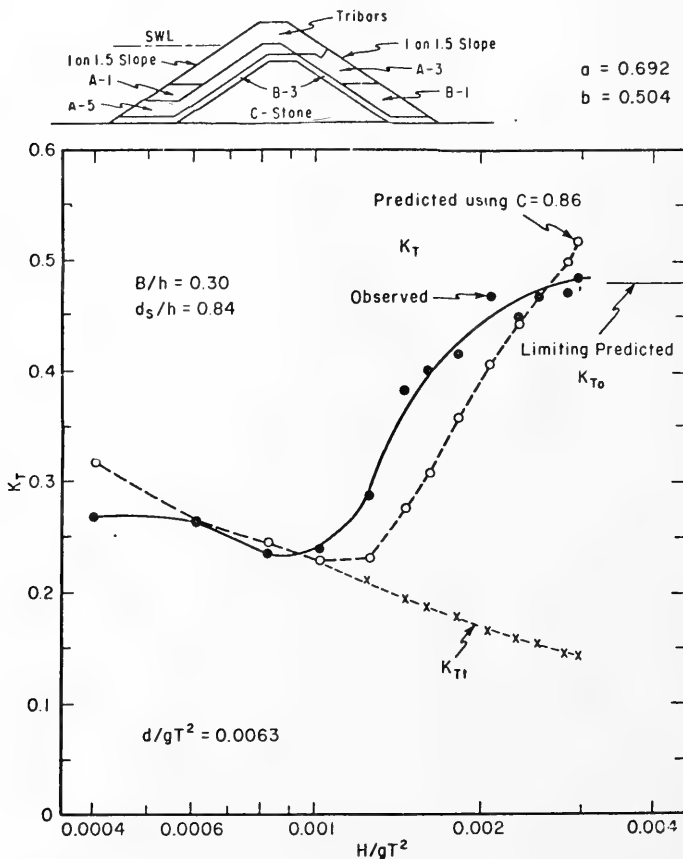


Figure 36. Wave transmission past a heavily overtopped breakwater with tribar armor units (laboratory data from Davidson, 1969).

(4) The case of irregular waves. Laboratory tests with a wide variety of spectral shapes suggest that there is little difference in the transmission coefficient from one spectral type to another. The overall transmission coefficient,  $K_T$ , is approximately the same for a monochromatic test as for an equivalent irregular wave test with the period of peak energy density,  $T_p$ , and mean incident wave height,  $\bar{H}$ , used to characterize the irregular wave conditions. Figure 37 shows observed and predicted transmission coefficients for a rubble-mound breakwater tested with monochromatic and irregular waves. The ability of the computer program MADSEN to predict transmission coefficients for irregular waves is at the same level as for monochromatic waves for the conditions tested.

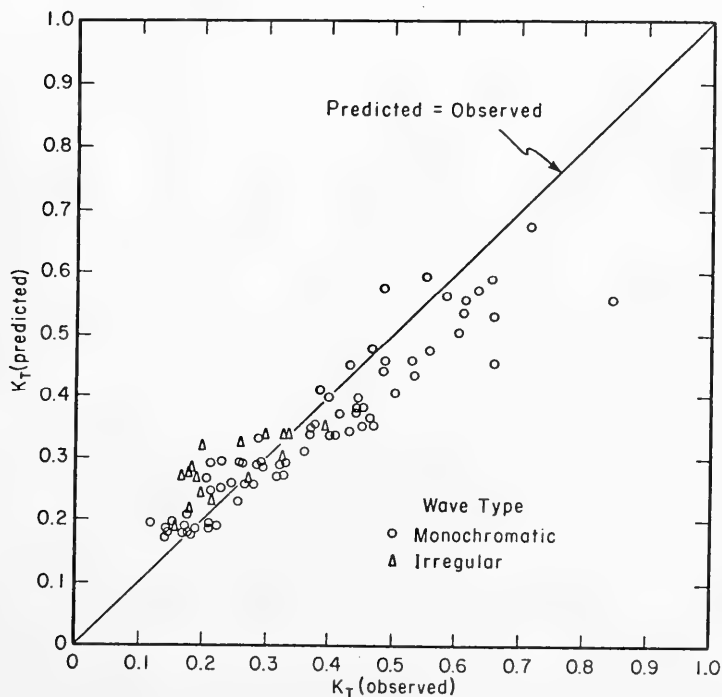
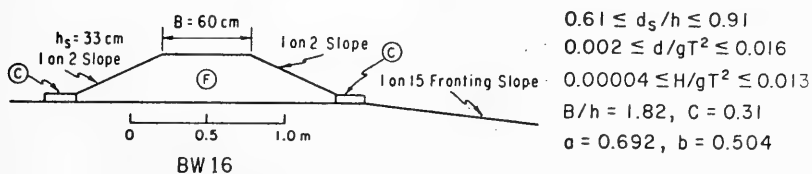


Figure 37. Observed and predicted transmission coefficients for BW16.

(5) The case of porosity of the breakwater. Porosity of each of the materials must be known in order to use the computer program MADSEN. However, in many design situations the value of porosity may be poorly known. Typical values of porosity, P, are given in Table 5. The recommended method of determining the influence of porosity on the predicted transmission coefficient is to run the program MADSEN at various values of porosity keeping all other parameters fixed. Figure 38 shows predicted transmission coefficients over a range of wave steepnesses for three different values of porosity. For this example, the absolute change in  $K_{Tt}$  produced by a given change in P is largest for waves of small steepness. The largest percent change in  $K_{Tt}$  for a given change in P occurs for the steepest waves tested. In general, the same trend will be observed for any breakwater; the value of  $K_{Tt}$  will increase as porosity increases for a given set of conditions. However, the magnitude of change of  $K_{Tt}$  is a complex function of all of the parameters in a design (breakwater geometry, water depth, wave height and period, etc.). A sensitivity analysis with the use of the program MADSEN, similar to the analysis shown in Figure 38, is recommended if the porosity of proposed materials is poorly known.

Table 5. Porosity of various armor units (from U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977).

Armor unit	No. of layers	Placement	Porosity (P)
Quarrystone (smooth)	2	Random	0.38
Quarrystone (rough)	2	Random	0.37
Quarrystone (rough)	>3	Random	0.40
Cube (modified)	2	Random	0.47
Tetrapod	2	Random	0.50
Quadripod	2	Random	0.49
Hexapod	2	Random	0.47
Tribar	2	Random	0.54
Dolos	2	Random	0.63
Tribar	1	Uniform	0.47
Quarrystone	Graded	Random	0.37

c. Wave Transmission for Submerged Permeable Breakwaters. The coefficient of wave transmission over a submerged permeable breakwater,  $K_{TO}$ , may be estimated by the methods given in Section IV,2. However, no generalized model is currently available for determining the coefficient of wave transmission through the structure,  $K_{Tt}$ . Saville's (1963) data for similar permeable and impermeable structures show that the total coefficient,  $K_T$ , approaches the transmission by overtopping coefficient,  $K_{TO}$ , and transmission through the breakwater becomes less important as the structure becomes more submerged and the incident wave height increases (Fig. 39). At  $d_s/h \geq 1.2$ , the data from breakwaters BW3, BW3W, BW4, and BW4W show that the coefficients of transmission through the structure are approximately zero, so that  $K_{TO}/K_T = 1.0$ . An upper estimate of the coefficient of transmission through the structure,  $K_{Tt}$ , for a submerged breakwater

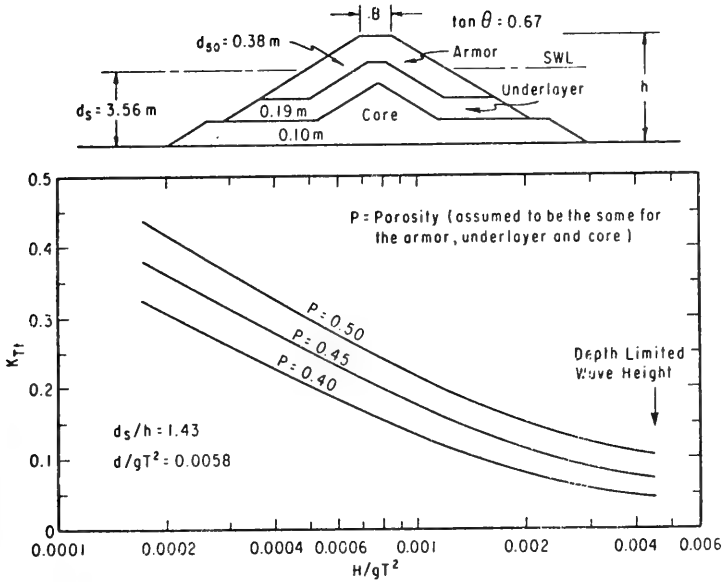


Figure 38. Example of the influence of porosity on the predicted coefficient of transmission for a rubble-mound breakwater.

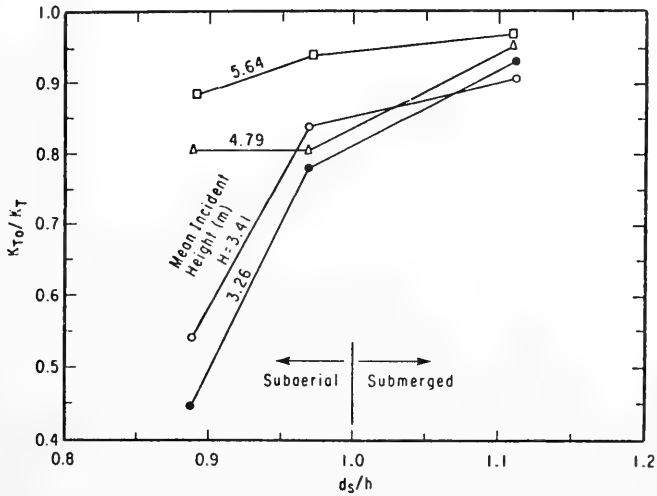


Figure 39. The relative importance of transmission by overtopping as a function of the incident wave height and the water depth-to-structure height ratio (after Saville, 1963).

can be made using the program MADSEN with  $d_g/h = 1.0$ . As a lower estimate,  $K_{Tt} = 0.0$  can be assumed. Laboratory results from BW13, BW15, BW15W, and BW16 show that even using  $K_{Tt} = 0$ , methods in Section IV.1,b tend to give conservative estimates of the transmission coefficient for submerged permeable breakwaters (Fig. 40).

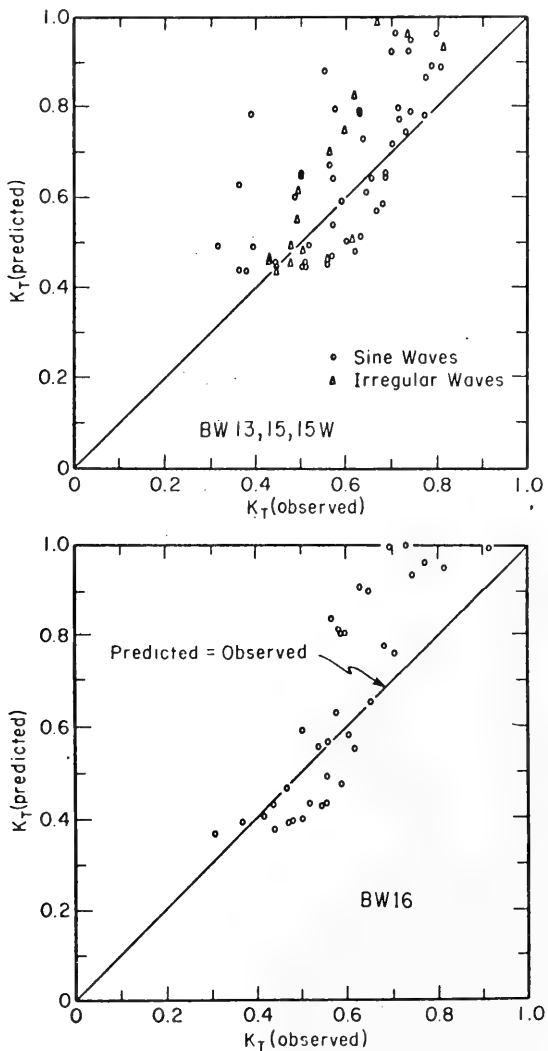


Figure 40. Observed and predicted transmission coefficients for submerged permeable structures assuming  $K_{Tt} = 0$ .

d. Influence of a Permeable Breakwater on Other Wave Characteristics. Wave energy shifts to higher harmonics are found in the transmitted wave records for monochromatic wave tests, as determined for overtopped impermeable breakwaters (Fig. 41). The energy shift is primarily a function of incident wave steepness and the ratio of the water depth to structure height. The largest shifts of energy to higher harmonics occur for steep waves where the structure crest is near to the stillwater level (Fig. 41).

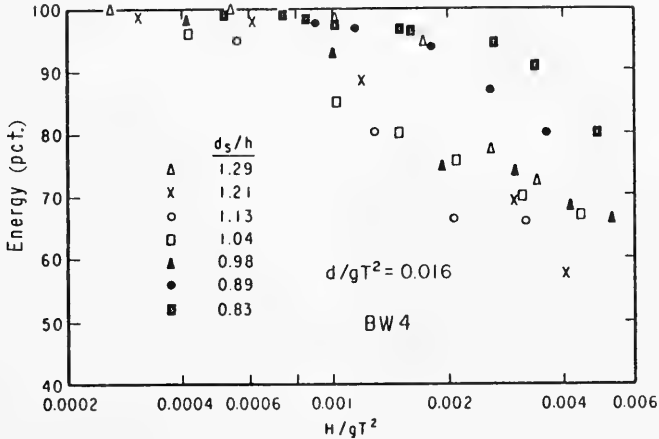


Figure 41. Percent of wave energy at the forcing period for waves transmitted past a permeable breakwater (monochromatic waves).

In the case of irregular waves the higher frequency parts of the reflected and transmitted spectra tend to be dampened out, so relatively more wave energy is found at lower frequencies than in the incident spectrum (Fig. 42). This means that on the average the spectral peakedness,  $Q_p$ , of reflected and transmitted spectra is greater than or equal to the spectral peakedness of incident spectra (Fig. 43).

A zero up-crossing analysis of wave records shows that on the average the wave height distribution shape is approximately the same for incident and transmitted waves for the irregular conditions tested for a permeable breakwater (Fig. 44).

The amount of wave grouping or the tendency of large waves to follow large waves and small waves to follow small waves is characterized by the autocorrelation of zero up-crossing wave heights,  $\rho$  (see Sec. III,4). Results from BW16 show that the autocorrelation transmitted waves is less than or equal to that for incident waves in the case of irregular waves incident on a permeable breakwater (Fig. 45).

The joint distribution of transmitted wave heights and periods for an irregular wave condition is similar to that found for smooth impermeable breakwaters. There is a tendency for lower transmitted waves to have average periods less than found in the incident joint height-period distribution (Fig. 46). Both the incident and transmitted larger wave heights have average periods approximately equal to the period of peak energy density.

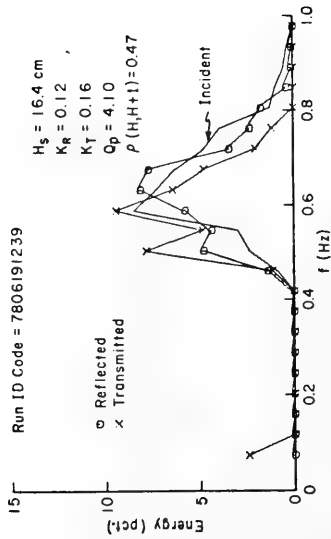
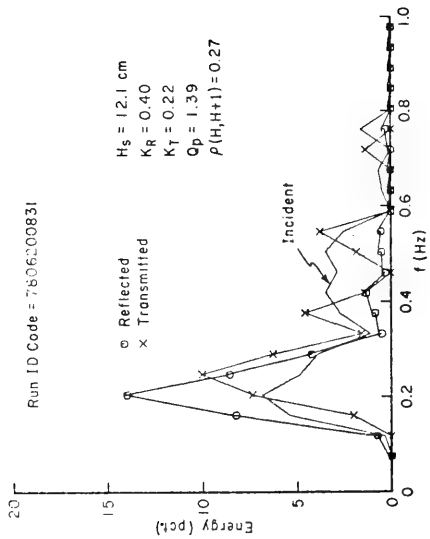


Figure 42. Sample incident, reflected, and transmitted wave spectra for BW16 ( $d_g/h = 0.76$ ).

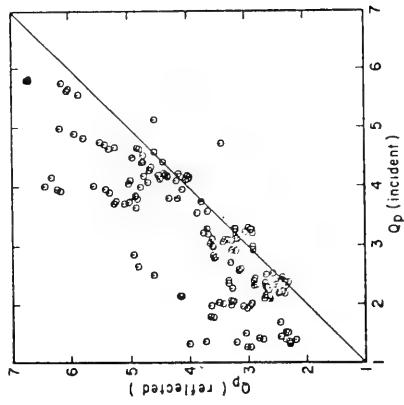
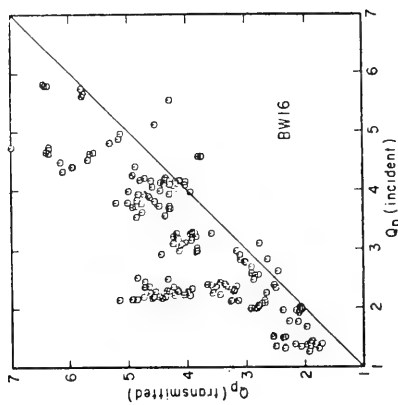


Figure 43. Spectral peakedness of transmitted and reflected wave spectra versus incident spectral peakedness for a permeable breakerwater.



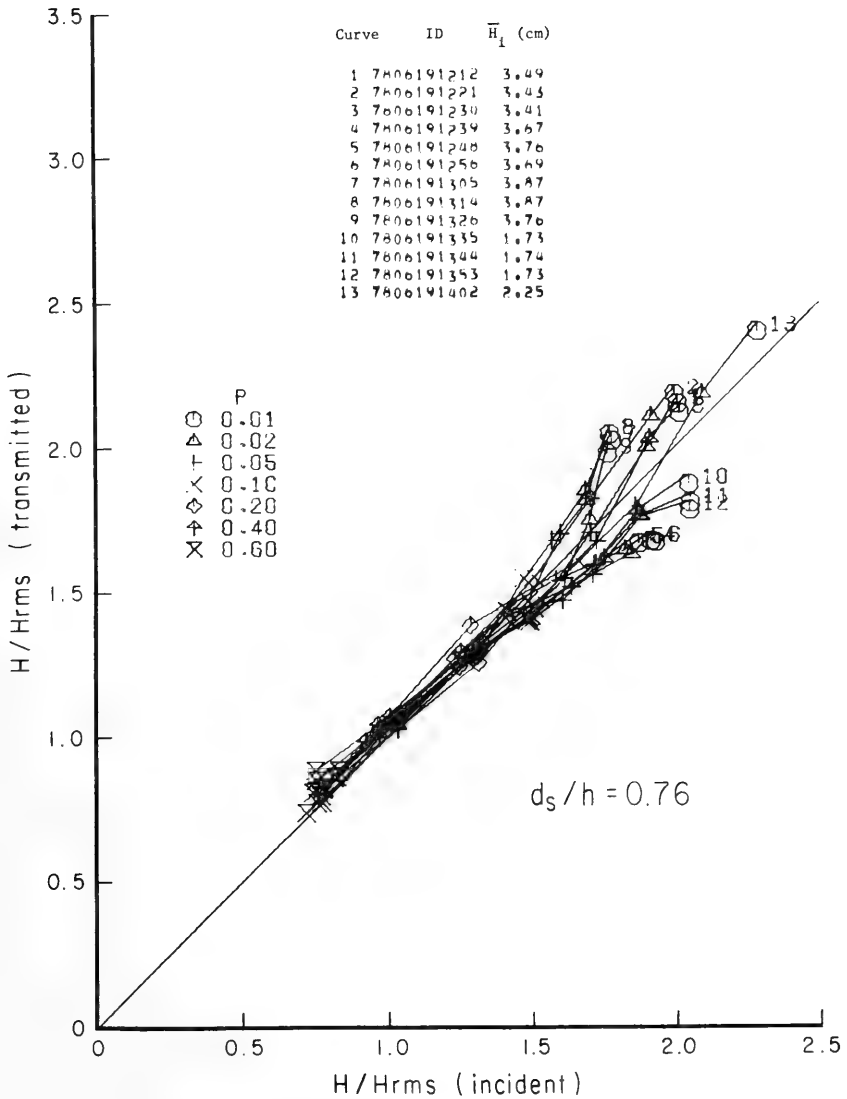


Figure 44. Comparison between incident and transmitted wave height distribution for a permeable breakwater (BW16).

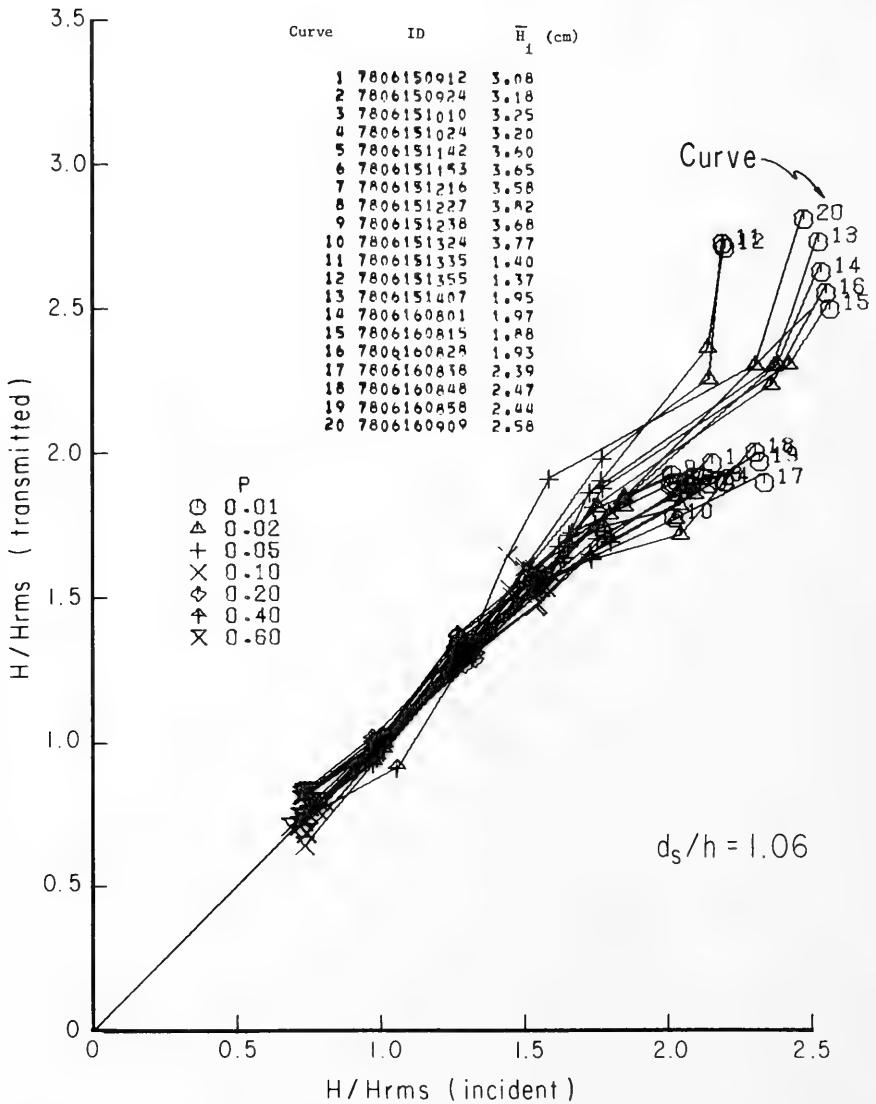


Figure 44. Comparison between incident and transmitted wave height distribution for a permeable breakwater (BW16).--Continued

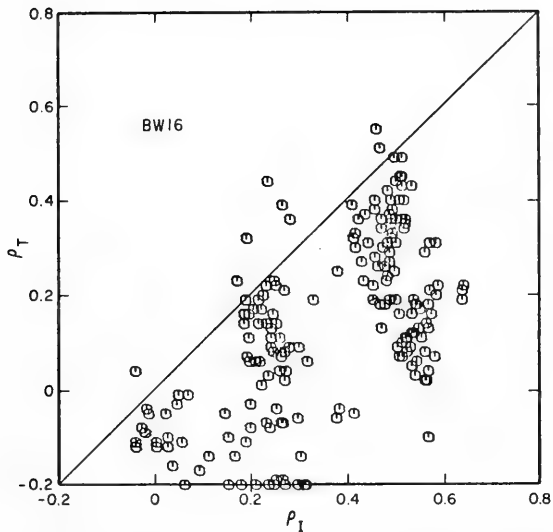


Figure 45. Autocorrelation of zero up-crossing wave heights for transmitted and incident wave records for a permeable breakwater.

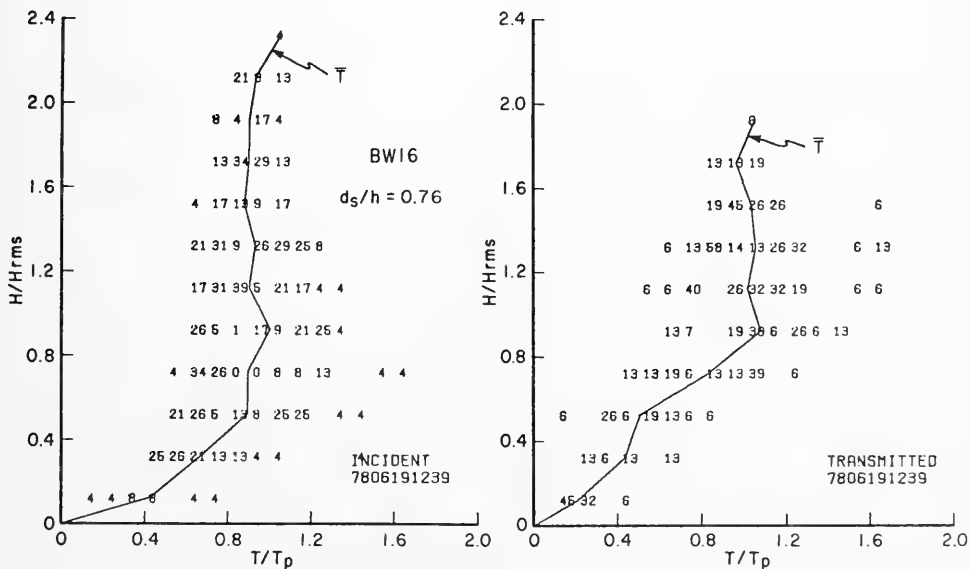


Figure 46. Sample joint distributions of wave height and period for an irregular wave condition and a permeable breakwater.

1. Causes of Physical Model Scale Effects.

Wave energy dissipation and resulting reduction of wave height produced by a breakwater are due to a combination of laminar and turbulent energy loss as well as wave modification. Little information is available on scale effects of wave transmission by overtopping, but scale effects are probably small. This is illustrated by Saville (1963) who tested wave transmission by overtopping for similar breakwaters that differed by a scale of 10. There was little systematic difference between the results of tests run at the two scales, with the small-scale tests being slightly conservative.

Wave transmission through permeable breakwaters is controlled primarily by laminar and turbulent energy loss of flow through the structure (Wilson and Cross, 1972; Keulegan, 1973; Madsen and White, 1976). In the prototype the wave height reduction is due largely to turbulent effects, but in a model laminar and turbulent losses may be important so that a model underpredicts the coefficient of transmission through a breakwater. The size of the scale effect is a complex function of model design, water depth, and wave height and period.

2. Interpreting and Applying Laboratory Results to Prototype Conditions.

The recommended method of estimating scale effects of transmission through permeable breakwaters is to use the computer program MADSEN to predict transmission coefficients for the model and prototype. The physical model correction factor, CF, is defined as the expected coefficient of wave transmission through the structure in the prototype divided by the coefficient of wave transmission through the structure at the model scale. CF is determined by first running the program MADSEN with prototype conditions to determine  $K_{Tt}$  (MADSEN prototype). The program is then run at the model scale to determine  $K_{Tt}$  (MADSEN scale model). CF is defined as

$$CF = \frac{K_{Tt} \text{ (MADSEN prototype)}}{K_{Tt} \text{ (MADSEN scale model)}} \quad (18)$$

The coefficient for wave transmission through the structure measured in the physical scale model should then be multiplied by CF to estimate the prototype coefficient.

For example, assume that the laboratory breakwater tested by Sollitt and Cross (1976) is a 1 on 10-scale Froude model of a prototype structure (Fig. 47). There was no transmission by overtopping. The program MADSEN was run at both model and prototype scales and the results together with the physical model measurements are shown in Figure 48. The MADSEN program output shows that the physical model was probably underpredicting the prototype coefficient because the scale model has proportionally more laminar energy loss than the prototype. Even in this large 1 on 10-scale Froude physical model, the prototype  $K_{Tt}$  is expected to be as much as 20 percent higher than in the scale model over the range of conditions tested.

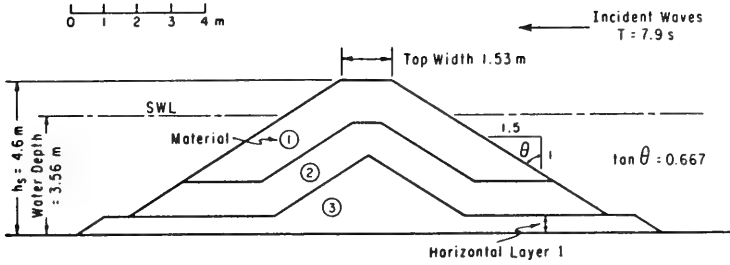


Figure 47. Trapezoidal multilayered breakwater tested by Sollitt and Cross (1976) (prototype).

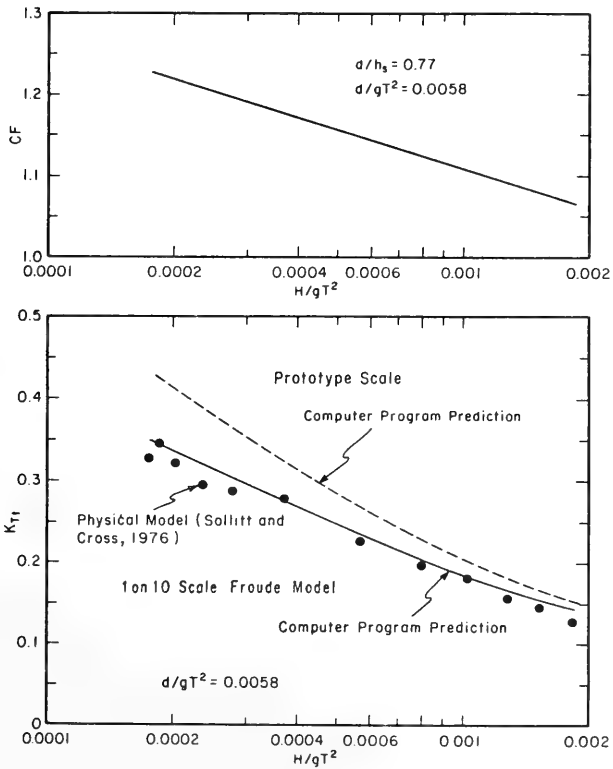


Figure 48. Physical model results and correction factors determined from the analytical model of Madsen and White (1976).

## VI. EXAMPLE OF ESTIMATING WAVE TRANSMISSION COEFFICIENTS

\*\*\*\*\* EXAMPLE PROBLEM \*\*\*\*\*

GIVEN: T = 7.9 seconds

$d_s = 3.56$  meters

Breakwater top width, B = 1.53 meters

Breakwater seaward slope,  $\tan \theta = 0.667$  (1 on 1.5)

FIND: The influence of incident wave height and structure height on the transmission coefficient for the permeable breakwater shown in the upper part of Figure 49 (change the structure height by varying the thickness of horizontal layer 1). Also, compare the predicted transmitted wave heights to heights for a similar smooth impermeable structure (lower part of Fig. 49).

SOLUTION: The computer program MADSEN (App. G) is used to predict wave transmission coefficients for the permeable structure and the program OVER (App. F) is used to predict coefficients for the smooth impermeable breakwater. The transmission coefficient for the permeable structure decreases as wave steepness increases, until overtopping occurs when the transmission coefficient increases with steepness (Fig. 50). The transmission coefficient decreases as structure height increases and the initiation of overtopping occurs at a larger value of the incident wave height as the structure height increases. The similar shaped smooth impermeable breakwater has larger values of the transmission coefficient for the steeper waves examined (Fig. 50) because the runup is higher on the smooth structure. However, there is no transmission for the impermeable structure for the small waves where the runup does not reach the breakwater crest. The predicted transmitted wave height as a function of breakwater crest height is given in Figure 51 for two values of the incident wave height.

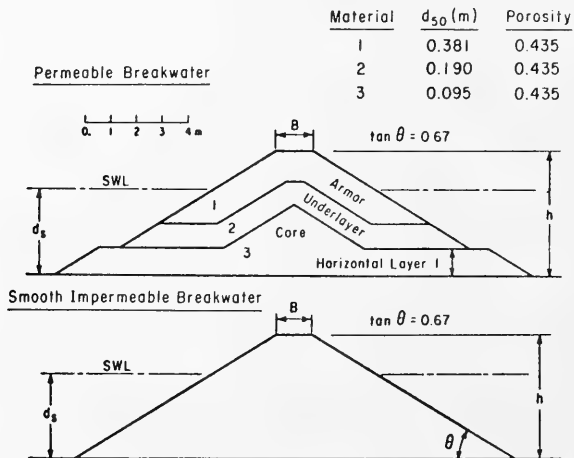


Figure 49. Breakwater cross sections used in the example for estimating wave transmission coefficients.

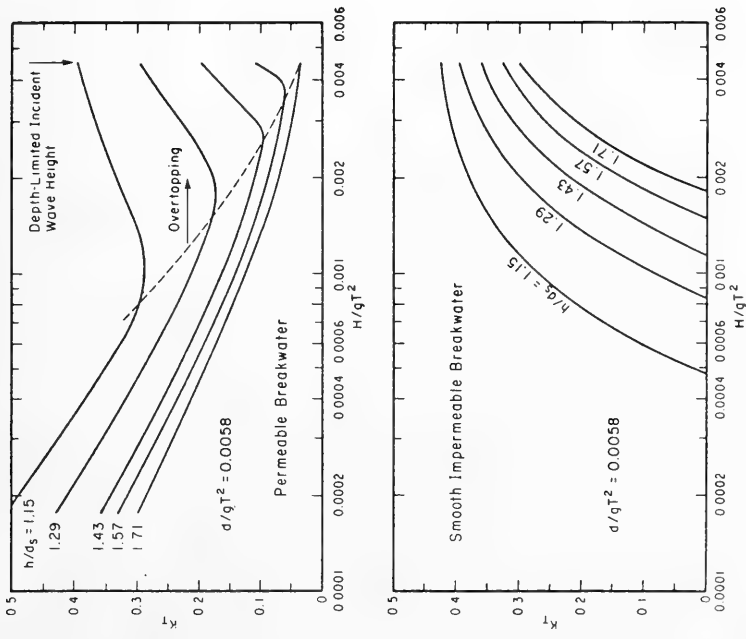


Figure 50. Predicted wave transmission coefficients.

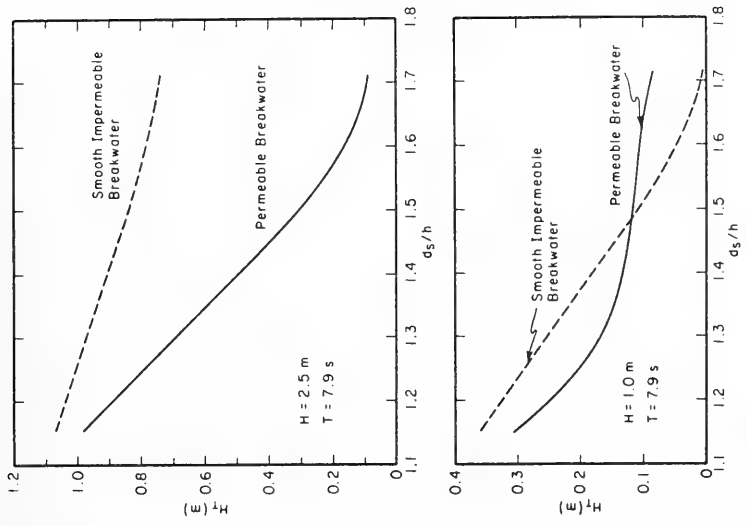


Figure 51. Predicted transmitted wave height as a function of breakwater crest height.

## VII. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The primary conclusions from the tests of wave transmission and reflection of laboratory breakwaters conducted for this study are:

1. A simple formula for predicting wave transmission by overtopping coefficients together with the model of Madsen and White (1976) for transmission through permeable structures can be used to obtain estimates of wave transmission coefficients.

2. Limited tests with breaking waves suggest that the methods can be used for breaking or nonbreaking conditions.

3. Tests with irregular waves show that the transmission coefficient for irregular waves is approximately the same as for a similar monochromatic wave test. The mean wave height and period of peak energy density are the parameters recommended to describe irregular waves.

4. Irregular wave tests indicate that for permeable or submerged breakwaters the incident and transmitted wave height distributions have similar shape. However, smooth impermeable subaerial breakwaters have height distributions biased toward the larger heights for irregular waves because large waves transmit more efficiently than small waves.

5. Transmitted and reflected spectra for irregular waves generally have equal or higher spectral peakedness than incident spectra.

6. Joint wave height-period distributions have similar dimensionless shapes for incident and transmitted wave records.

7. There is a tendency for wave heights to be less grouped after they have transmitted past a breakwater.

8. Transmitted wave energy may appear at higher order harmonics of the incident waves for monochromatic wave tests. However, the tendency for energy shifts decreases as the wave transmission coefficient increases.

9. Additional work is necessary to develop generalized models for predicting wave reflection coefficients and wave transmission through the crests of breakwaters armored with relatively porous materials, such as concrete armor units.

The recommended steps for design of a breakwater for wave transmission are:

1. Use the computer programs MADSEN and OVER to estimate transmission coefficients for preliminary breakwater design. Alternative designs can be tested by varying parameters such as:

- (a) structure height
- (b) crest width
- (c) seaward and landward breakwater slopes
- (d) water depth
- (e) number, thickness, location, and diameter of materials
- (f) porosity
- (g) permeability
- (h) wave height
- (i) wave period



2. A sensitivity analysis is recommended on those input parameters that are poorly known. For example, if there is some uncertainty in the value of the design water level, predictions should be made over the range of expected water levels keeping all other factors fixed. Comparison between the predictions at different levels will indicate the importance of water level.

3. Estimate reflection coefficients from model results.

4. If possible, final breakwater design should be made with the use of physical models. The program MADSEN can be used to assist in designing and interpreting physical laboratory models and results for permeable breakwaters.

Copies of the program decks for the program MADSEN and OVER described in Appendixes F and G may be obtained from the Automatic Data Processing Coordinator, Coastal Engineering Research Center, Fort Belvoir, Virginia 22060.

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## APPENDIX A

### BREAKWATER GEOMETRIES

Each of the breakwaters tested is assigned an identifying code (e.g., BW1). This appendix includes a cross-section drawing and a brief description of each of the breakwaters. Note that breakwaters 1 to 12 (Figs. A-1 to A-14) were tested on a flat tank bottom; breakwaters 13 to 17 (Figs. A-15 to A-19) had a 1 on 15 fronting slope 3.75 meters long. Materials used in construction of the structures are identified by a circled letter; material characteristics are discussed in Appendix B.

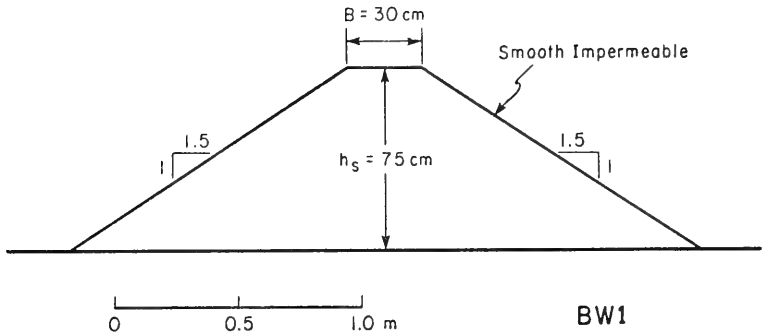


Figure A-1. Breakwater 1 cross section.

BW1 is a smooth impermeable structure tested for wave transmission by overtopping and reflection. Note that simultaneous measurements of wave runup were being made on a smooth 1 on 1.5 slope in an adjacent flume by Ahrens (1978) while the breakwater tests were underway (see Fig. 1).

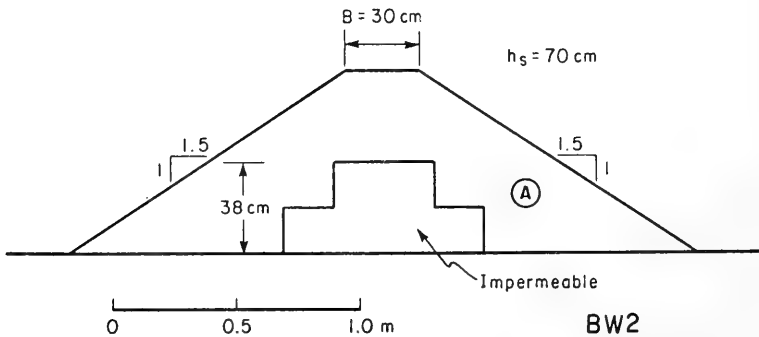


Figure A-2. Breakwater 2 cross section.

BW2 is similar to a caisson breakwater that has been rehabilitated by adding rock armor units. The major emphasis of these tests was to examine the effects of wave period and height on transmission and reflection. Armor material was randomly placed.

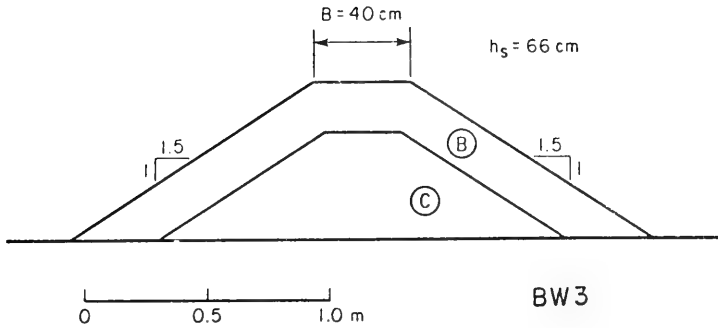


Figure A-3. Breakwater 3 cross section.

BW3 has an armor two units thick of angular stone. A moderate amount of fitting was used in placing the armor, especially near the crest. Core material was placed by dumping.

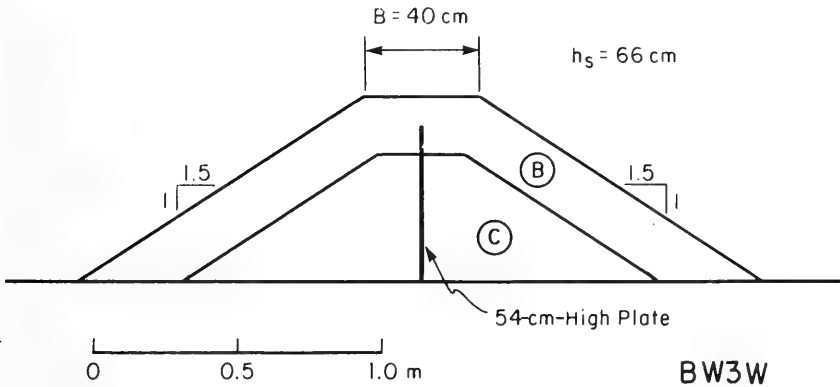


Figure A-4. Breakwater 3W cross section.

BW3W is similar to BW3, except that a 5-millimeter-thick metal plate was installed in the center of the structure. The caulked plate extended from the bottom to within one armor unit of the crest (54 centimeters high).

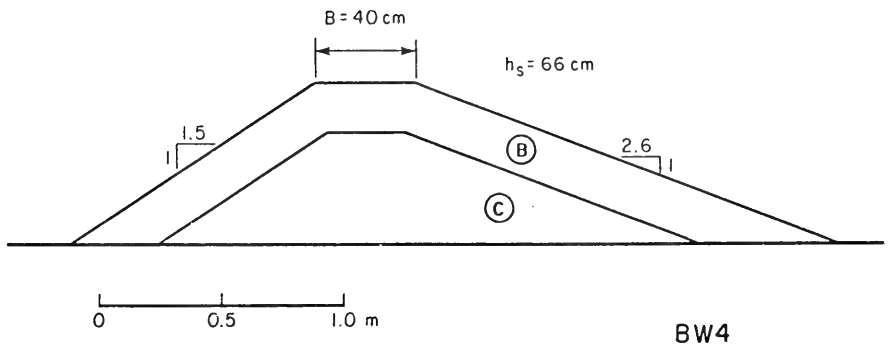


Figure A-5. Breakwater 4 cross section.

BW4 is similar to BW3, except with a 1 on 2.6 front-face slope.

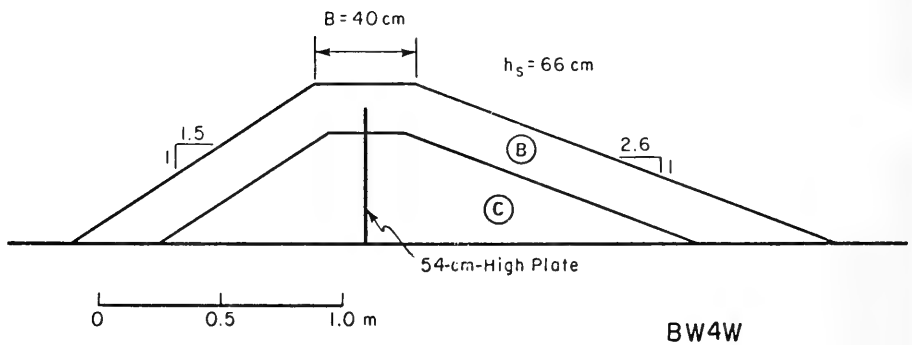


Figure A-6. Breakwater 4W cross section.

BW4W is similar to BW4, but includes a 54-centimeter-high impermeable plate in the center of the structure.



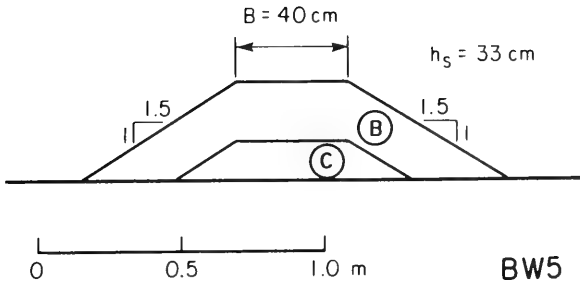


Figure A-7. Breakwater 5 cross section.

BW5, geometrically similar to the upper part of BW3, is typical of a breakwater built in relatively shallow water. The armor unit size is large compared to the structure height and the core size relatively small.

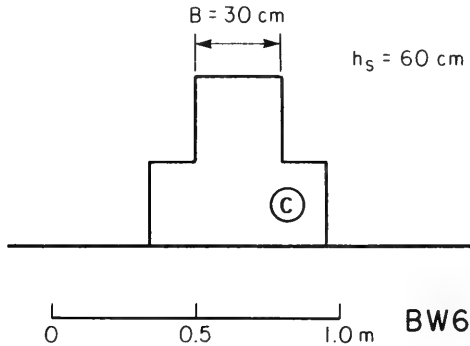


Figure A-8. Breakwater 6 cross section.

BW6 was made of three triangular, fine wire containers filled with core material.

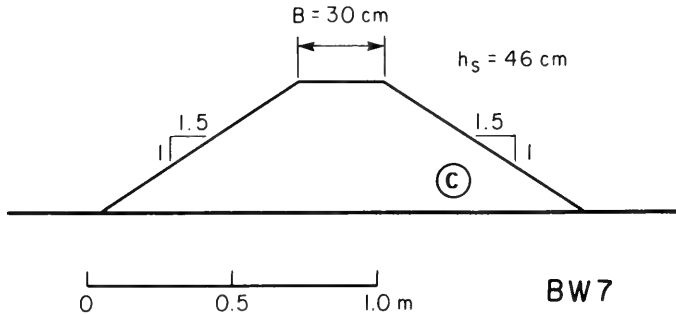


Figure A-9. Breakwater 7 cross section.

BW7 is geometrically similar to the core of BW3. The material was held in a fine wire structure to prevent motion of the stone.

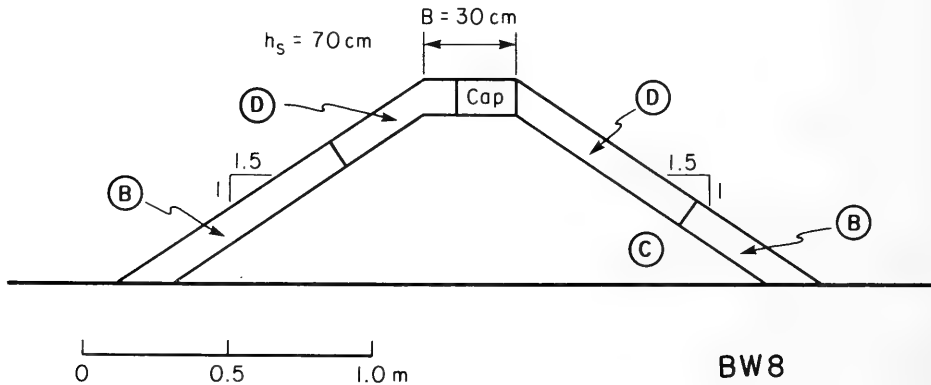


Figure A-10. Breakwater 8 cross section.

BW8 uses dolos artificial units as part of the armor material on both the front and back of the structure near the crest. Stone was used in the lower parts of the armor. A moderate amount of fitting was used in placing the armor units. An impermeable cap was installed toward the seaward side of the crest.

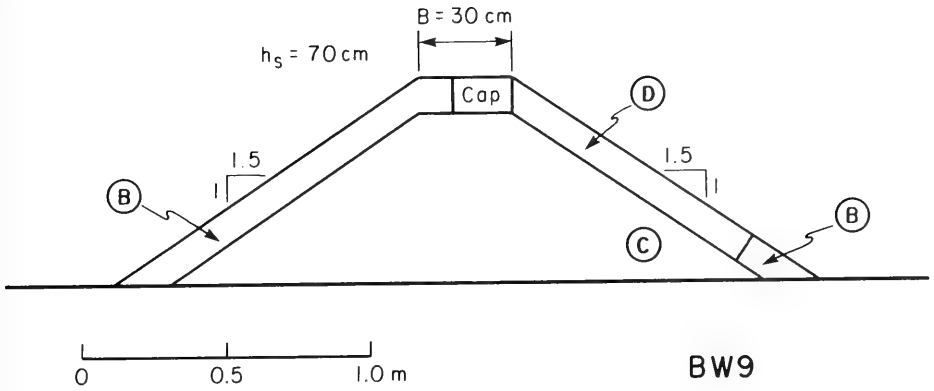


Figure A-11. Breakwater 9 cross section.

BW9 is similar to BW8, except that armor units have been arranged so that all of the dolos units are on the seaward side of the structure.

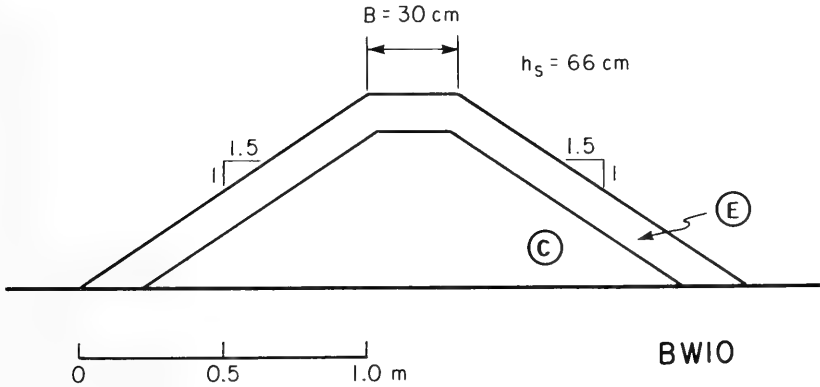


Figure A-12. Breakwater 10 cross section.

BW10 was made with an armor one unit thick of well-fitted rectangular rock. The material was placed with one surface parallel to the structure face.

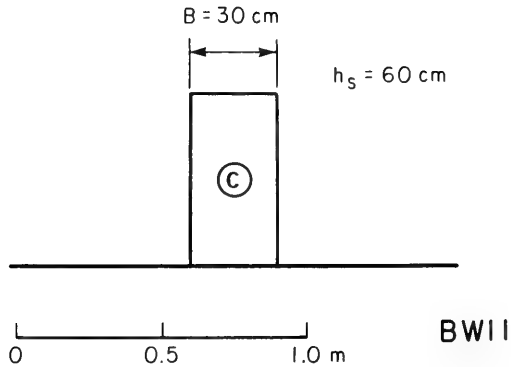


Figure A-13. Breakwater 11 cross section.

BW11 was made of two fine-wire rectangular baskets that enclosed core-type stone. The primary purpose of this structure was to examine the wave transmission and reflection characteristics of permeable material.

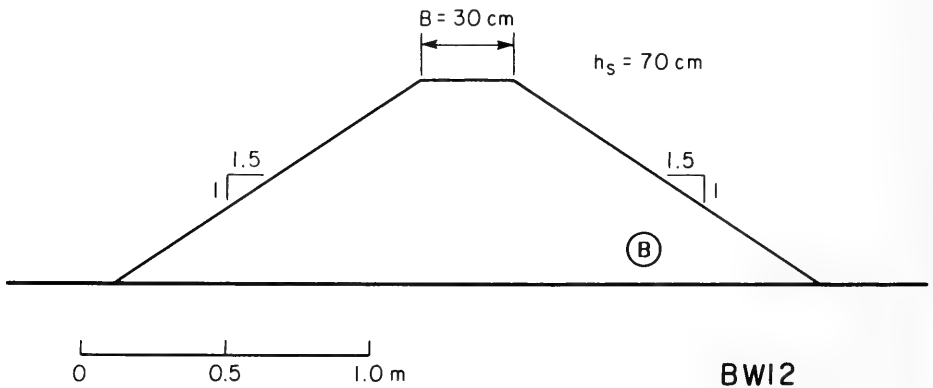


Figure A-14. Breakwater 12 cross section.

BW12 is a structure with no core similar in geometry to breakwaters 8 and 9.

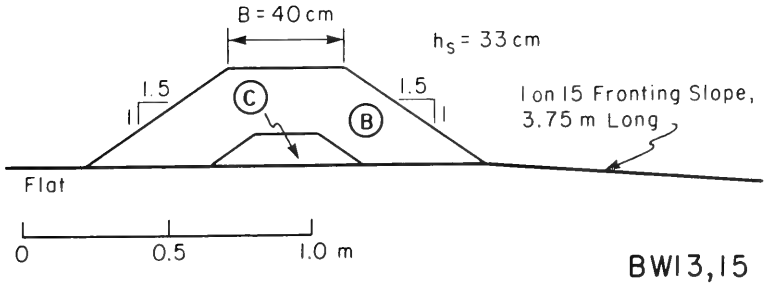


Figure A-15. Breakwaters 13 and 15 cross section.

BW13 and BW15 were tested with a 1 on 15 fronting slope 3.75 meters. Note that these structures are the same geometry as BW5 (built on a flat tank bottom).

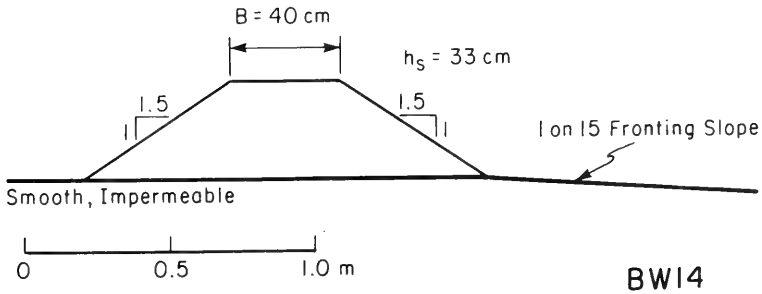


Figure A-16. Breakwater 14 cross section.

BW14, a smooth impermeable structure, has the same outside dimensions as permeable breakwaters BW5, BW13, and BW15.

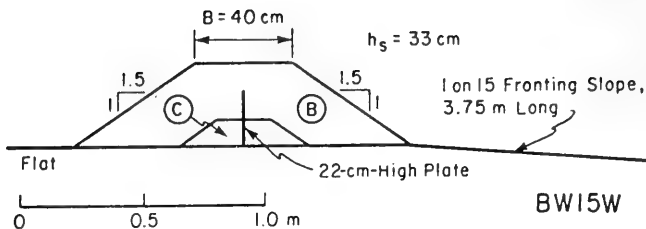


Figure A-17. Breakwater 15W cross section.

BW15W has the same dimensions and materials as BW13 and BW15, except that a 22-centimeter-high metal plate 5 millimeters thick has been installed in the center of the structure. This plate prevents transmission through the lower part of the structure.

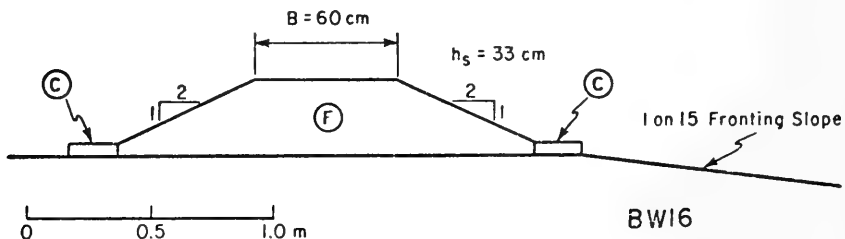


Figure A-18. Breakwater 16 cross section.

BW16 is a one-ninth scale Froude model of a proposed submerged breakwater for Imperial Beach, California.

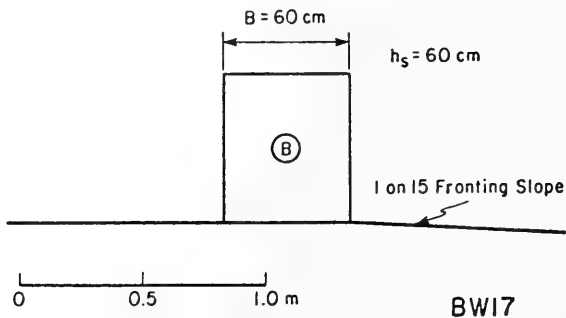


Figure A-19. Breakwater 17 cross section.

BW17 is a vertical permeable structure, similar to BW11, with the rock retained by a thin wire mesh.

## APPENDIX B

### MATERIAL CHARACTERISTICS

Materials used to construct permeable breakwaters are discussed in this appendix. Each material is identified by a circled letter and shown on the breakwaters where it was used in Appendix A. Figure B-1 includes photos of samples of the various materials (material F, not shown, is similar to A and B). Some basic parameters, such as weights, diameters, and porosities, are shown in Table B-1. The weight distribution of each of the materials is given in Figure B-2.

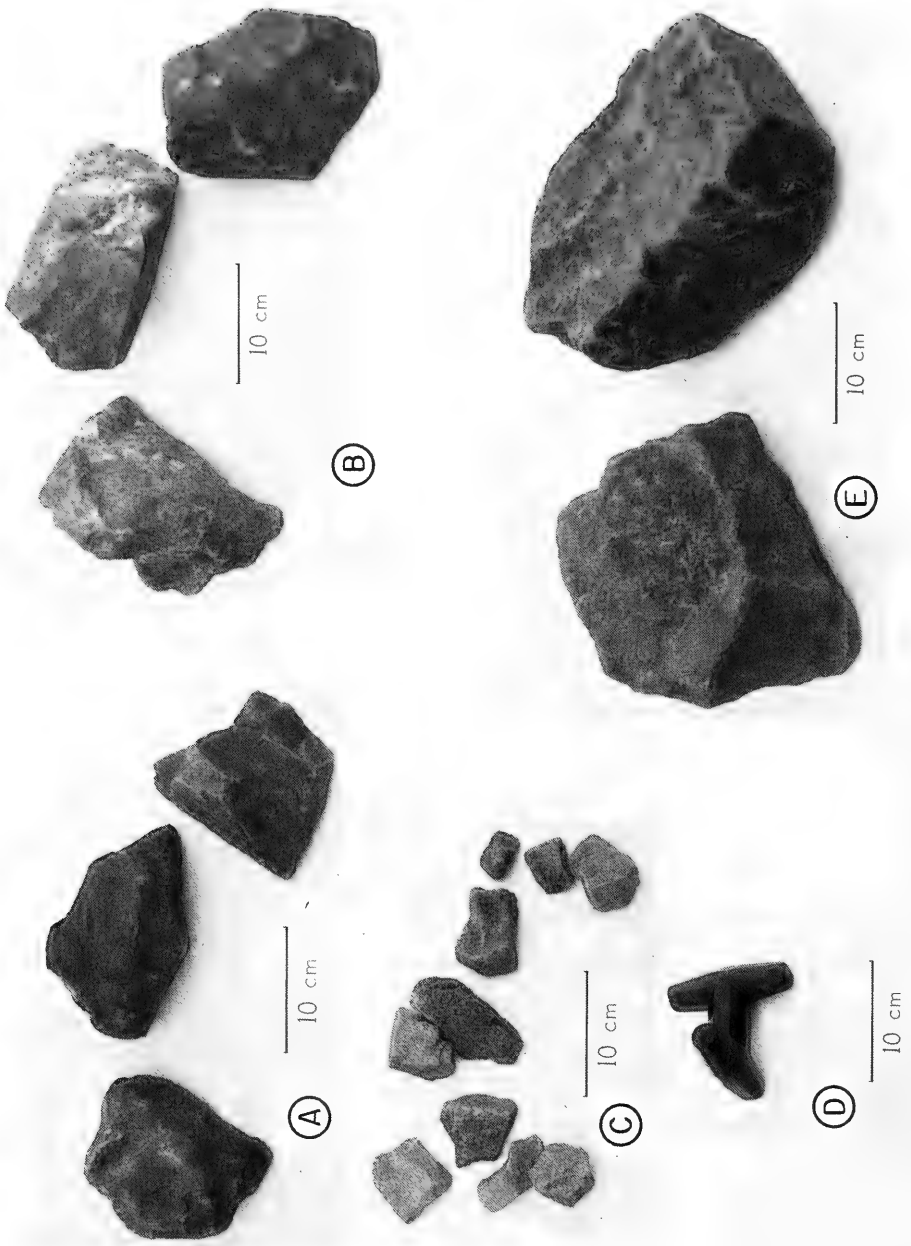


Figure B-1. Photos of construction materials.



Table B-1. Material characteristics.

Material	Description	W <sub>85</sub> <sup>1</sup> (g)	W <sub>50</sub> <sup>2</sup> (g)	W <sub>15</sub> <sup>3</sup> (g)	d <sub>50</sub> <sup>4</sup> (cm)
A	Angular stone	2,520	1,530	990	8.3
B	Angular stone	4,680	3,690	2,900	11.1
C	Angular stone	180	63	31	2.9
D	Dolos	405	390	390	----
E	Flat stone	13,200	11,200	8,100	16.1
F	Angular stone	7,600	4,900	2,500	12.2

<sup>1</sup>Weight at which 85 percent by weight of the material is heavier than.

<sup>2</sup>Weight at which 50 percent by weight of the material is heavier than.

<sup>3</sup>Weight at which 15 percent by weight of the material is heavier than.

<sup>4</sup>Representative diameter corresponding to W<sub>50</sub>.

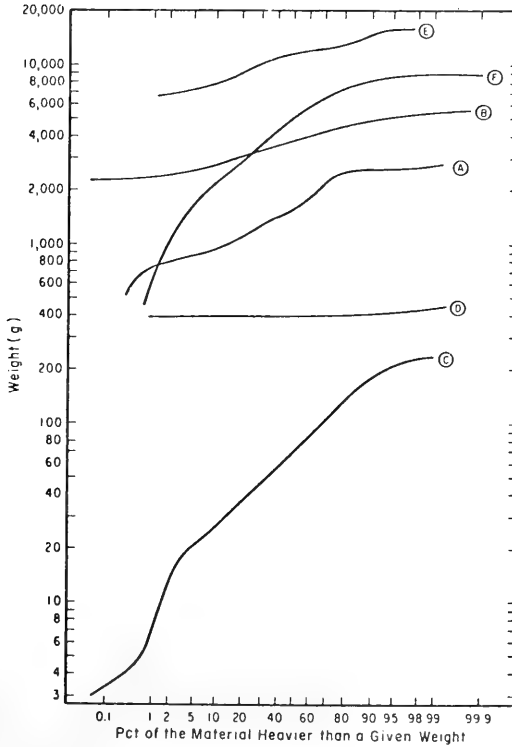


Figure B-2. Weight distribution of the construction materials.







SINE BLADE MOTION

BREAKWATER 4W

Table with 8 columns: ID, D(CM), T(S), H(CM), KY, KR, D/GT2, H/GT2. Rows contain data for breakwater 4W.

Table with 8 columns: ID, D(CM), T(S), H(CM), KY, KR, D/GT2, H/GT2. Rows contain data for breakwater 4W.

BREAKWATER 5

Table with 8 columns: ID, D(CM), T(S), H(CM), KY, KR, D/GT2, H/GT2. Rows contain data for breakwater 5.

Table with 8 columns: ID, D(CM), T(S), H(CM), KY, KR, D/GT2, H/GT2. Rows contain data for breakwater 5.

BREAKWATER 6

Table with 8 columns: ID, D(CM), T(S), H(CM), KY, KR, D/GT2, H/GT2. Rows contain data for breakwater 6.

Table with 8 columns: ID, D(CM), T(S), H(CM), KY, KR, D/GT2, H/GT2. Rows contain data for breakwater 6.

BREAKWATER 7

Table with 8 columns: ID, D(CM), T(S), H(CM), KY, KR, D/GT2, H/GT2. Rows contain data for breakwater 7.

Table with 8 columns: ID, D(CM), T(S), H(CM), KY, KR, D/GT2, H/GT2. Rows contain data for breakwater 7.

SINE BLADE MOTION  
KH R D/GT2 H/GT2

ID D(CM) T(S) H(CM) KT

ID D(CM) T(S) H(CM) KT KH R D/GT2 H/GT2

BREAKWATER 7

7802130922. 75. 2.18 2.6 894 .914 .016 .0006  
7802130943. 75. 2.18 10.5 .844 .845 .016 .0023  
7802131041. 75. 1.18 2.8 .855 .855 .055 .0016  
7802131056. 75. 1.18 14.9 .884 .894 .055 .0109

7802130912. 75. 2.18 5.2 .867 .867 .016 .0011  
7802130954. 75. 2.18 14.3 .870 .870 .016 .0031  
7802131048. 75. 1.18 5.7 .861 .861 .055 .0042

BREAKWATER 8

7802141416. 45. 1.69 1.5 .270 .270 .016 .0005  
7802141438. 45. 1.69 6.7 .181 .181 .016 .0024  
7802141455. 45. 1.69 13.8 .071 .071 .016 .0049  
7802151043. 60. 1.95 3.8 .251 .251 .016 .0010  
7802151051. 60. 1.95 15.8 .159 .159 .016 .0042

7802141429. 45. 1.69 3.1 .193 .193 .016 .0011  
7802141447. 45. 1.69 9.7 .094 .094 .016 .0035  
7802151024. 60. 1.95 1.9 .334 .334 .016 .0005  
7802151033. 60. 1.95 8.0 .188 .188 .016 .0021  
7802151058. 60. 1.95 20.9 .205 .205 .016 .0056

BREAKWATER 9

7802161313. 45. 2.65 .7 .464 .460 .007 .0001  
7802161329. 45. 2.65 3.1 .285 .285 .007 .0005  
7802161346. 45. 2.65 11.8 .117 .117 .007 .0017  
7802161006. 45. 1.69 1.4 .784 .284 .016 .0005  
7802281017. 45. 1.69 4.0 .196 .196 .016 .0014  
7802161022. 45. 1.69 6.6 .122 .122 .016 .0024  
7802281448. 45. 1.69 12.6 .096 .096 .016 .0045  
7802281513. 45. 1.69 24.6 .057 .057 .016 .0088  
7802161501. 45. .91 2.0 .028 .028 .055 .0025  
7802211014. 60. 3.06 1.8 .480 .480 .007 .0002  
7802211029. 60. 3.06 7.9 .254 .250 .007 .0009  
7802211044. 60. 3.06 15.2 .261 .261 .007 .0017  
7802210924. 60. 1.95 3.7 .247 .247 .016 .0010  
7802210938. 60. 1.95 7.7 .182 .182 .016 .0021  
7802211006. 60. 1.95 15.8 .154 .154 .016 .0042  
7802211059. 60. 1.05 4.6 .054 .054 .056 .0043  
7802211114. 60. 1.05 12.1 .030 .030 .056 .0112  
7802220954. 75. 3.42 2.9 .650 .630 .007 .0003  
7802221009. 75. 3.42 13.7 .487 .487 .007 .0012  
7802220916. 75. 2.18 2.6 .741 .741 .016 .0006  
7802220931. 75. 2.18 10.7 .583 .583 .016 .0023  
7802221017. 75. 1.18 3.1 .633 .633 .055 .0023  
7802221034. 75. 1.18 14.0 .413 .413 .055 .0103

7802161321. 45. 2.65 1.5 .391 .391 .007 .0002  
7802161337. 45. 2.65 7.2 .169 .169 .007 .0010  
7802281407. 45. 1.69 1.3 .322 .322 .016 .0005  
78021610914. 45. 1.69 3.1 .197 .197 .016 .0011  
7802281427. 45. 1.69 5.7 .159 .159 .016 .0020  
7802281438. 45. 1.69 8.4 .125 .125 .016 .0030  
7802281458. 45. 1.69 17.8 .075 .075 .016 .0064  
7802161353. 45. .91 1.7 .040 .040 .055 .0009  
7802161138. 45. .91 9.5 .007 .007 .055 .0117  
7802211021. 60. 3.06 3.5 .345 .345 .007 .0004  
7802211036. 60. 3.06 11.2 .216 .216 .007 .0012  
7802210916. 60. 1.95 1.8 .349 .349 .016 .0005  
7802210931. 60. 1.95 5.3 .214 .214 .016 .0014  
7802210946. 60. 1.95 11.1 .157 .157 .016 .0030  
7802210510. 60. 1.05 1.5 .113 .113 .056 .0014  
7802211107. 60. 1.05 7.6 .032 .032 .056 .0070  
7802210946. 75. 3.42 1.4 .624 .624 .007 .0001  
7802210011. 75. 3.42 6.3 .528 .528 .007 .0005  
7802220909. 75. 2.18 1.3 .775 .775 .016 .0003  
7802220924. 75. 2.18 5.3 .660 .660 .016 .0011  
7802220938. 75. 2.18 13.7 .555 .555 .016 .0034  
7802221024. 75. 1.18 7.3 .526 .526 .055 .0053

BREAKWATER 10

7803061141. 75. 3.42 1.3 .643 .643 .007 .0001  
7803061157. 75. 3.42 6.2 .584 .584 .007 .0009  
7803061173. 75. 3.42 20.4 .475 .475 .007 .0018  
7803061105. 75. 2.18 2.7 .785 .785 .016 .0006  
7803061114. 75. 2.18 11.5 .675 .675 .016 .0025  
7803061126. 75. 2.18 22.8 .535 .535 .016 .0049  
7803061231. 75. 1.18 7.9 .642 .642 .055 .0058  
7803031322. 60. 3.06 3.8 .361 .361 .007 .0004  
7803031340. 60. 3.06 19.5 .438 .438 .007 .0021  
7803031016. 60. 1.95 4.2 .302 .302 .016 .0011  
7803031032. 60. 1.95 16.0 .304 .304 .016 .0043  
7803031225. 60. 1.05 2.1 .184 .184 .056 .0019  
7803031248. 60. 1.05 8.1 .118 .118 .056 .0075  
7803031206. 45. 2.65 .7 .393 .393 .007 .0001  
7803021150. 45. 2.65 3.2 .253 .253 .007 .0005  
7803021224. 45. 2.65 14.6 .106 .106 .007 .0021  
7803021124. 45. 1.69 4.3 .165 .165 .016 .0015  
7803021140. 45. 1.69 13.8 .074 .074 .016 .0049

7803061149. 75. 3.42 2.9 .630 .630 .007 .0003  
7803061205. 75. 3.42 13.6 .498 .498 .007 .0012  
7803061047. 75. 2.18 1.3 .630 .630 .016 .0003  
7803061103. 75. 2.18 5.5 .733 .733 .016 .0012  
7803061118. 75. 2.18 17.1 .632 .632 .016 .0037  
7803061222. 75. 1.18 3.1 .726 .726 .055 .0023  
7803031308. 60. 3.06 1.1 .498 .498 .007 .0001  
7803031330. 60. 3.06 11.1 .340 .340 .007 .0012  
7803031348. 60. 3.06 24.9 .451 .451 .007 .0027  
7803031025. 60. 1.95 8.3 .249 .249 .016 .0022  
7803031208. 60. 1.95 21.8 .406 .406 .016 .0059  
7803031241. 60. 1.05 3.6 .145 .145 .056 .0031  
7803031255. 60. 1.05 14.1 .181 .181 .056 .0151  
7803021203. 45. 2.65 1.5 .343 .343 .007 .0002  
7803021217. 45. 2.65 7.2 .157 .157 .007 .0010  
7803021059. 45. 1.69 1.0 .337 .337 .016 .0004  
7803021133. 45. 1.69 9.6 .100 .100 .016 .0034  
7803021147. 45. 1.69 17.0 .060 .060 .016 .0061

BREAKWATER 11

7803131303. 45. 2.65 .8 .676 .676 .007 .0001  
7803131319. 45. 2.65 3.2 .506 .506 .007 .0005  
7803131334. 45. 2.65 13.3 .297 .297 .007 .0019  
7803131531. 45. 1.69 5.1 .429 .429 .016 .0018  
7803131247. 45. 1.69 14.1 .324 .324 .016 .0050  
7803131427. 45. .91 1.7 .286 .286 .055 .0021  
7803131356. 45. .91 7.8 .153 .153 .055 .0096  
7803131440. 31. 1.94 .8 .707 .707 .008 .0002  
7803131453. 31. 1.94 3.8 .449 .449 .008 .0010  
7803131510. 31. 1.93 1.1 .472 .472 .013 .0015  
7803131424. 31. 1.53 5.2 .345 .345 .013 .0023  
7803141278. 31. 1.41 .8 .387 .387 .016 .0004  
7803141145. 31. 1.41 3.1 .338 .338 .016 .0016  
7803141100. 31. 1.16 6.6 .375 .375 .023 .0005

7803131311. 45. 2.65 1.5 .607 .607 .007 .0002  
7803131327. 45. 2.65 6.8 .398 .398 .007 .0010  
7803131146. 45. 1.69 2.4 .499 .499 .016 .0009  
7803131239. 45. 1.69 10.9 .336 .336 .016 .0039  
7803131254. 45. 1.69 15.7 .309 .309 .016 .0056  
7803131349. 45. .91 5.0 .182 .182 .055 .0062  
7803131404. 45. .91 8.6 .145 .145 .055 .0106  
7803131448. 31. 1.94 1.7 .605 .605 .008 .0005  
7803131503. 31. 1.94 10.5 .315 .315 .008 .0028  
7803131517. 31. 1.53 2.4 .400 .400 .010 .0013  
7803141028. 31. 1.53 13.1 .228 .228 .013 .0057  
7803141131. 31. 1.41 1.6 .367 .367 .016 .0008  
7803141052. 31. 1.41 7.0 .273 .273 .016 .0036  
7803141107. 31. 1.16 1.4 .317 .317 .023 .0011

SINE BLADE MOTION  
ID D(CM) T(S) H(CM) KT KR D/GT2 H/GT2

BREAKWATER 11

7803141114. 31. 1.16 3.0 .278 .278 .023 .0023  
7803141130. 31. 1.00 .6 .284 .284 .031 .0006  
7803141144. 31. 1.00 3.6 .205 .205 .031 .0037

BREAKWATER 12

7803171001. 75. 3.42 1.3 .751 .751 .007 .0001  
7803170910. 75. 3.42 2.8 .738 .738 .007 .0002  
7803170927. 75. 3.42 13.5 .569 .569 .007 .0012  
7803170932. 75. 2.18 2.7 .864 .864 .016 .0006  
7803170947. 75. 2.18 11.4 .712 .712 .016 .0024  
7803170937. 75. 1.18 3.5 .732 .732 .055 .0026  
7803170951. 75. 1.18 14.4 .509 .509 .055 .0106  
7803171255. 60. 3.06 9.7 .430 .430 .007 .0011  
7803171311. 60. 3.06 25.2 .493 .493 .007 .0027  
7803171935. 60. 1.95 3.9 .507 .507 .016 .0010  
7803171049. 60. 1.95 10.6 .341 .341 .016 .0045  
7803171106. 60. 1.05 .9 .266 .266 .056 .0008  
7803170913. 60. 1.05 7.4 .170 .170 .056 .0068  
7803160923. 45. 2.65 .6 .753 .753 .007 .0001  
7803160945. 45. 2.65 6.0 .433 .433 .007 .0009  
7803160842. 45. 1.69 .9 .727 .727 .016 .0003  
7803160858. 45. 1.69 3.7 .455 .455 .016 .0013  
7803160913. 45. 1.69 10.6 .280 .280 .016 .0038  
7803161010. 45. .91 3.1 .079 .079 .055 .0038

BREAKWATER 13

7804211154. 60. 3.06 .9 .932 .932 .007 .0001  
7804211138. 60. 3.06 4.2 .870 .870 .007 .0005  
7804211120. 60. 3.06 13.6 .885 .885 .007 .0015  
7804211052. 60. 1.95 3.2 .947 .947 .016 .0009  
7804211100. 60. 1.95 13.8 .859 .859 .016 .0036  
7804211203. 60. 1.05 1.8 .884 .884 .056 .0015  
7804211219. 60. 1.05 6.4 .898 .898 .056 .0059  
7804201436. 45. 3.31 2.5 .866 .866 .004 .0002  
7804201357. 45. 3.31 11.1 .704 .704 .004 .0010  
7804201403. 45. 2.65 4.5 .915 .915 .007 .0007  
7804201090. 45. 2.65 18.8 .769 .769 .007 .0027  
7804201320. 45. 2.11 4.5 .849 .849 .010 .0010  
7804201341. 45. 2.11 11.8 .836 .836 .010 .0027  
7804201304. 45. 1.69 2.9 .844 .844 .016 .0010  
7804201320. 45. 1.69 12.8 .705 .705 .016 .0046  
7804201336. 45. 1.14 1.5 .805 .805 .035 .0012  
7804201927. 45. .91 2.1 .881 .881 .055 .0026  
7804201099. 45. .91 7.8 .687 .687 .055 .0096  
7804201057. 35. 3.06 1.5 .737 .737 .004 .0002  
7804201130. 35. 3.06 3.9 .569 .569 .004 .0009  
7804201054. 35. 1.95 1.1 .791 .791 .009 .0003  
7804201015. 35. 1.95 4.8 .655 .655 .009 .0013  
7804201034. 35. 1.95 19.8 .404 .404 .009 .0053  
7804201157. 35. 1.25 4.6 .497 .497 .023 .0030  
7804201149. 35. 1.25 11.5 .360 .360 .023 .0075  
7804201224. 35. 1.05 5.1 .358 .358 .032 .0047

BREAKWATER 14

7804240807. 65. 2.03 2.7 .964 .964 .016 .0007  
7804240825. 65. 2.03 8.3 .987 .987 .016 .0021  
7804241007. 60. 3.06 .9 .946 .946 .007 .0001  
7804241024. 60. 3.06 8.9 .900 .900 .007 .0010  
7804240909. 60. 1.95 1.1 .961 .961 .016 .0003  
7804240926. 60. 1.95 4.6 .974 .974 .016 .0012  
7804240902. 60. 1.95 9.4 .991 .991 .016 .0025  
7804240958. 60. 1.95 18.9 .992 .992 .016 .0051  
7804241051. 60. 1.95 4.0 .939 .939 .056 .0037  
7804241145. 55. 1.87 1.3 .889 .889 .016 .0004  
7804241252. 55. 1.87 5.4 .934 .934 .016 .0018  
7804250802. 55. 1.87 15.0 .860 .860 .016 .0044  
7804250846. 50. 1.78 .7 .861 .861 .016 .0002  
7804250904. 50. 1.78 3.5 .954 .954 .016 .0011  
7804250926. 50. 1.78 11.6 .924 .924 .016 .0037  
7804251122. 45. 2.65 4.9 .922 .922 .007 .0007  
7804251141. 45. 2.65 14.1 .713 .713 .007 .0020  
7804251131. 45. 1.69 1.0 .934 .934 .016 .0004  
7804251030. 45. 1.69 4.4 .981 .981 .016 .0018  
7804251068. 45. 1.69 12.9 .669 .669 .016 .0048

ID D(CM) T(S) H(CM) KT KR D/GT2 H/GT2

7803141121. 31. 1.16 7.8 .225 .225 .023 .0059  
7803141137. 31. 1.00 1.8 .213 .213 .031 .0006  
7803141152. 31. 1.00 5.4 .195 .195 .031 .0055

7803170902. 75. 3.42 1.3 .762 .762 .007 .0001  
7803170919. 75. 3.42 6.2 .659 .659 .007 .0005  
7803170824. 75. 2.18 1.4 .890 .890 .016 .0003  
7803170839. 75. 2.18 5.6 .793 .793 .016 .0012  
7803170854. 75. 2.18 16.3 .684 .684 .016 .0035  
7803170944. 75. 1.18 7.5 .656 .656 .055 .0055  
7803171240. 60. 3.06 8. .779 .779 .007 .0001  
7803171303. 60. 3.06 19.2 .468 .468 .007 .0021  
7803171028. 60. 1.95 1.3 .643 .643 .016 .0003  
7803171042. 60. 1.95 8.2 .398 .398 .016 .0022  
7803171057. 60. 1.95 22.4 .335 .335 .016 .0030  
7803170005. 60. 1.05 4.4 .192 .192 .056 .0038  
7803171153. 60. 1.05 14.8 .164 .164 .056 .0038  
7803160930. 45. 2.65 1.3 .697 .697 .007 .0002  
7803160954. 45. 2.65 11.7 .340 .340 .007 .0017  
7803160849. 45. 1.69 1.8 .608 .608 .016 .0008  
7803160906. 45. 1.69 8.2 .306 .306 .016 .0029  
7803161003. 45. .91 1.1 .134 .134 .055 .0014  
7803161017. 45. .91 8.0 .057 .057 .055 .0099

7804211146. 60. 3.06 2.0 .893 .893 .007 .0002  
7804211129. 60. 3.06 9.1 .860 .860 .007 .0010  
7804211024. 60. 1.95 1.5 .951 .951 .016 .0004  
7804211047. 60. 1.95 6.4 .912 .912 .016 .0017  
7804211109. 60. 1.95 26.5 .712 .712 .016 .0071  
7804211211. 60. 1.05 3.0 .895 .895 .056 .0028  
7804211227. 60. 1.05 11.9 .903 .903 .056 .0110  
7804201407. 45. 3.31 5.3 .756 .756 .004 .0005  
7804210830. 45. 2.65 2.0 .979 .979 .007 .0003  
7804210851. 45. 2.65 9.6 .903 .903 .007 .0014  
7804201311. 45. 2.11 28.2 .881 .881 .010 .0025  
7804201329. 45. 2.11 6.3 .856 .856 .010 .0019  
7804201454. 45. 1.69 1.4 .850 .850 .016 .0005  
7804201512. 45. 1.69 6.0 .793 .793 .016 .0021  
7804201528. 45. 1.69 18.1 .572 .572 .016 .0065  
7804201544. 45. 1.14 4.3 .773 .773 .035 .0034  
7804201970. 45. .91 3.5 .844 .844 .055 .0043  
7804201047. 35. 3.06 7. .828 .828 .004 .0001  
7804201119. 35. 3.06 3.6 .635 .635 .004 .0004  
7804201140. 35. 3.06 17.1 .507 .507 .004 .0019  
7804201004. 35. 1.95 2.3 .734 .734 .009 .0006  
7804201025. 35. 1.95 10.3 .600 .600 .009 .0028  
7804201210. 35. 1.25 2.5 .549 .549 .023 .0016  
7804201203. 35. 1.25 4.7 .497 .497 .023 .0031  
7804201217. 35. 1.05 3.1 .384 .384 .032 .0009  
7804201231. 35. 1.05 11.1 .311 .311 .032 .0103

7804240816. 65. 2.03 5.8 .979 .979 .016 .0014  
7804240835. 65. 2.03 11.8 .997 .997 .016 .0029  
7804241015. 60. 3.06 2.8 .900 .900 .007 .0003  
7804241030. 60. 3.06 13.4 .939 .939 .007 .0015  
7804240918. 60. 1.95 2.3 .964 .964 .016 .0006  
7804240930. 60. 1.95 6.5 .984 .984 .016 .0017  
7804240951. 60. 1.95 15.7 .968 .968 .016 .0037  
7804241004. 60. 1.05 1.5 .921 .921 .056 .0014  
7804241059. 60. 1.05 9.7 .888 .888 .056 .0090  
7804241240. 55. 1.87 2.7 .927 .927 .016 .0008  
7804241304. 55. 1.87 10.8 .961 .961 .016 .0032  
7804250812. 55. 1.87 20.5 .732 .732 .016 .0060  
7804250855. 50. 1.78 1.6 .913 .913 .016 .0005  
7804250917. 50. 1.78 7.4 .889 .889 .016 .0024  
7804250918. 50. 1.78 15.2 .693 .693 .016 .0049  
7804251032. 45. 2.65 10.0 .806 .806 .006 .0015  
7804251120. 45. 2.65 19.7 .652 .652 .007 .0029  
7804251039. 45. 1.69 2.1 .952 .952 .016 .0008  
7804251039. 45. 1.69 8.9 .713 .713 .016 .0032  
7804251058. 45. 1.69 18.3 .510 .510 .016 .0065

## SINE BLADE MOTION

JD	D(CM)	T(S)	M(CM)	KT	KR	D/GT2	H/GT2	JD	D(CM)	T(S)	M(CM)	KT	KR	D/GT2	H/GT2
BREAKWATER 14															
7804251236	45	.91	1.9	.879	.879	.055	.0023	7804251244	45	.91	4.3	.820	.820	.055	.0053
7804251254	45	.91	5.6	.729	.729	.055	.0069	7804251305	45	.91	7.8	.684	.684	.055	.0086
7804251316	45	.91	8.9	.530	.530	.055	.0110	7804251349	40	1.59	2.1	.852	.852	.016	.0088
7804251350	40	1.59	4.0	.670	.670	.016	.0016	7804251357	40	1.59	7.1	.564	.564	.016	.0029
7804251407	40	1.59	9.6	.509	.509	.016	.0039	7804251415	40	1.59	13.1	.473	.473	.016	.0053
7804251505	35	1.49	11.7	.419	.419	.016	.0054	7804251426	40	1.59	17.6	.438	.438	.016	.0071
7804251537	35	1.49	17.2	.363	.363	.016	.0079	7804251448	35	1.49	23.9	.280	.280	.016	.0110
7804251631	35	5.06	12.2	3.390	3.390	.004	.0013	7804261000	35	3.06	17.0	.452	.452	.004	.0019
7804261049	35	3.06	21.2	.437	.437	.004	.0023	7804261056	35	1.95	9.9	.683	.683	.009	.0027
7804261005	35	1.95	14.1	.477	.477	.009	.0038	7804261133	35	1.49	1.8	.417	.417	.016	.0088
7804261111	35	1.49	8.3	.397	.397	.016	.0024	7804261210	35	1.30	11.5	.382	.382	.021	.0069
7804261022	35	1.30	14.8	.354	.354	.021	.0089	7804261236	30	2.17	7.7	.246	.246	.007	.0017
7804261229	30	2.17	13.7	.439	.439	.007	.0030	7804261221	30	2.17	17.5	.440	.440	.007	.0038
7804261213	30	2.17	20.1	.429	.429	.007	.0044	7804261150	30	1.38	6.3	.229	.229	.016	.0034
7804261158	30	1.38	11.2	.330	.330	.016	.0060	7804261205	30	1.38	14.8	.326	.326	.016	.0079

## BREAKWATER 15

7805021015	45	2.80	4.7	.903	.903	.006	.0006	7805021026	45	2.80	7.1	.863	.863	.006	.0009
7805021036	45	2.80	10.3	.833	.833	.006	.0013	7805021045	45	2.80	14.8	.805	.805	.006	.0019
7805021058	45	2.80	19.4	.739	.739	.006	.0024	7805021108	45	1.69	1.0	.908	.908	.016	.0044
7805021116	45	1.69	2.1	.908	.908	.016	.0044	7805021124	45	1.69	4.2	.890	.890	.016	.0015
7805021136	45	1.69	6.0	.858	.858	.016	.0021	7805021145	45	1.69	8.7	.821	.821	.016	.0031
7805021155	45	1.69	12.9	.795	.795	.016	.0046	7805021204	45	1.69	18.3	.627	.627	.016	.0065
7805021311	45	.91	1.8	.865	.865	.055	.0022	7805021321	45	.91	2.4	.850	.850	.055	.0030
7805021330	45	.91	3.1	.851	.851	.055	.0038	7805021339	45	.91	3.9	.866	.866	.055	.0048
7805021247	45	.91	8.2	.594	.594	.055	.0101	7805021349	40	2.80	5.9	.788	.788	.005	.0008
7805021337	40	2.80	8.6	.785	.785	.005	.0011	7805021394	40	2.80	12.1	.729	.729	.005	.0016
7805021358	40	2.80	16.6	.685	.685	.005	.0022	780503732	40	2.50	20.8	.588	.588	.005	.0027
7805030854	40	2.50	.7	.931	.931	.007	.0001	7805030905	40	2.50	1.5	.864	.864	.007	.0002
7805030930	40	2.50	3.1	.826	.826	.007	.0005	7805030939	40	2.50	6.3	.810	.810	.007	.0010
7805030947	40	2.50	9.0	.772	.772	.007	.0015	7805030956	40	2.50	13.0	.700	.700	.007	.0021
7805031007	40	2.50	19.1	.641	.641	.007	.0031	7805030845	40	1.59	1.3	.861	.861	.016	.0005
7805030827	40	1.59	2.8	.813	.813	.016	.0011	7805030816	40	1.59	5.6	.718	.718	.016	.0023
7805030756	40	1.59	10.8	.627	.627	.016	.0044	7805030744	40	1.59	15.0	.561	.561	.016	.0061
7805030740	40	1.59	20.0	.484	.484	.016	.0081	7805031143	40	.86	2.2	.772	.772	.055	.0030
7805031052	40	.86	3.2	.755	.755	.055	.0044	7805031044	40	.86	4.2	.726	.726	.055	.0058
7805031037	40	.86	5.6	.730	.730	.055	.0077	7805031026	40	.86	6.0	.521	.521	.055	.0083
7805031018	40	.86	7.4	.516	.516	.055	.0102	7805040935	35	2.80	1.5	.789	.789	.005	.0002
7805030945	35	2.80	3.0	.713	.713	.005	.0004	7805040953	35	2.80	6.1	.679	.679	.005	.0008
7805041002	35	2.80	12.6	.619	.619	.005	.0016	7805041012	35	2.80	17.7	.557	.557	.005	.0023
7805041027	35	2.80	20.6	.561	.561	.005	.0027	7805041157	35	2.34	5	.889	.889	.007	.0001
7805041206	35	2.34	1.1	.819	.819	.007	.0002	7805042135	35	2.34	2.2	.739	.739	.007	.0004
7805041226	35	2.34	3.2	.714	.714	.007	.0006	7805040135	35	2.34	4.6	.685	.685	.007	.0009
7805040109	35	2.34	6.6	.669	.665	.007	.0012	7805040120	35	2.34	9.6	.630	.630	.007	.0018
7805040129	35	2.34	14.3	.567	.567	.007	.0027	7805040137	35	2.34	20.3	.506	.506	.007	.0038
7805041149	35	1.49	1.1	.796	.796	.016	.0005	7805041138	35	1.49	2.3	.696	.696	.016	.0011
7805041114	35	1.49	4.8	.569	.569	.016	.0022	7805041102	35	1.49	11.1	.516	.516	.016	.0051
7805041053	35	1.49	16.7	.440	.440	.016	.0077	7805040146	35	1.49	22.3	.359	.359	.016	.0102
7805041042	35	1.49	23.0	.374	.374	.016	.0106	7805040203	30	2.80	2.6	.538	.538	.004	.0003
7805040211	30	2.80	5.1	.480	.480	.004	.0007	7805040119	30	2.80	10.6	.637	.637	.004	.0014
7805051228	30	2.17	1.6	.673	.673	.007	.0003	7805051222	30	2.17	1.7	.674	.674	.007	.0004
7805051215	30	2.17	3.3	.602	.602	.007	.0007	7805051155	30	2.17	6.3	.543	.543	.007	.0014
7805051003	30	2.17	12.1	.551	.551	.007	.0026	7805050944	30	2.17	15.9	.510	.510	.007	.0034
7805050933	30	2.17	21.0	.436	.436	.007	.0046	7805050840	30	1.38	1.1	.566	.566	.016	.0006
7805050848	30	1.38	2.2	.501	.501	.016	.0012	7805050857	30	1.38	4.9	.425	.425	.016	.0026
7805050906	30	1.38	9.6	.408	.408	.016	.0051	7805050916	30	1.38	12.0	.362	.362	.016	.0064
7805050924	30	1.38	16.9	.303	.303	.016	.0091	7805081048	25	1.98	.7	.767	.767	.007	.0002
7805081040	25	1.98	1.4	.692	.692	.007	.0004	7805081032	25	1.98	3.1	.573	.573	.007	.0008
7805081024	25	1.98	6.5	.437	.437	.007	.0017	7805081012	25	1.98	9.5	.417	.417	.007	.0025
7805081004	25	1.98	13.6	.366	.366	.007	.0035	7805080858	25	1.26	1.4	.609	.609	.016	.0009
7805080907	25	1.26	3.0	.460	.460	.016	.0019	7805080919	25	1.26	6.3	.346	.346	.016	.0040
7805080928	25	1.26	9.3	.311	.311	.016	.0060	7805080941	25	1.26	13.7	.297	.297	.016	.0088
7805080956	25	1.26	14.9	.256	.256	.016	.0096	7805091024	20	1.77	5.5	.405	.405	.007	.0018
7805091036	20	1.77	8.0	.341	.341	.007	.0026	7805091044	20	1.77	11.9	.309	.309	.007	.0039
7805090845	20	1.13	.7	.371	.371	.016	.0006	7805090837	20	1.13	1.2	.335	.335	.016	.0010
7805090855	20	1.13	2.7	.271	.271	.016	.0022	7805090923	20	1.13	3.8	.233	.233	.016	.0030
7805090913	20	1.13	5.6	.198	.198	.016	.0045	7805090923	20	1.13	7.8	.176	.176	.016	.0062

## BREAKWATER 15W

7804270921	50	2.18	.9	***	***	.011	.0002	7804270932	50	2.18	1.8	.955	.955	.011	.0004
7804270942	50	2.18	3.6	.918	.918	.011	.0008	7804270955	50	2.18	7.5	.897	.897	.011	.0016
7804271003	50	2.18	10.7	.877	.877	.011	.0023	7804271018	50	1.78	2.3	.868	.868	.016	.0007
7804271055	50	1.78	1.1	.868	.868	.016	.0004	7804271032	50	1.78	11.8	.851	.851	.016	.0038
7804271040	50	1.78	5.6	.824	.824	.016	.0018								



## SINE BLADE MOTION

ID	D(CM)	T(S)	H(CM)	KT	KR	D/GT2	H/GT2
BREAKWATER 15W							
7804271023.	50.	1.7A	14.7	.783	.783	.016	.0047
7804271210.	45.	2.03	4.5	.860	.860	.007	.0007
7804271227.	45.	2.03	13.6	.811	.811	.007	.0020
7804271119.	45.	1.69	3.0	.859	.859	.016	.0011
7804271135.	45.	1.69	0.9	.802	.802	.016	.0032
7804271151.	45.	1.69	16.9	.815	.815	.016	.0060
7804271252.	45.	.91	1.3	.859	.859	.055	.0043
7804281251.	40.	1.59	1.9	.835	.835	.016	.0008
7804281327.	40.	1.59	7.2	.664	.664	.016	.0029
7804281304.	40.	1.59	10.7	.491	.491	.016	.0075
7804281256.	35.	3.06	17.6	.476	.476	.004	.0019
7804281242.	35.	1.93	14.9	.558	.558	.009	.0040
7804281230.	35.	1.49	3.4	.594	.594	.016	.0016
7804281247.	35.	1.49	16.7	.430	.430	.016	.0077
7804281125.	30.	1.30	15.0	.428	.428	.021	.0091
7804271417.	30.	2.17	4.4	.464	.464	.007	.0010
7804271432.	30.	2.17	16.2	.47A	.478	.007	.0035
7804271324.	30.	1.38	1.4	.453	.453	.016	.0008
7804271341.	30.	1.38	7.1	.332	.332	.016	.0038
7804271357.	30.	1.38	13.0	.31A	.31A	.016	.0070

## BREAKWATER 16

ID	D(CM)	T(S)	H(CM)	KT	KR	D/GT2	H/GT2
BREAKWATER 15W							
7804271207.	45.	2.65	.9	.975	.975	.007	.0001
7804271219.	45.	2.65	9.7	.871	.871	.007	.0014
7804271111.	45.	1.69	1.4	.880	.880	.016	.0005
7804271127.	45.	1.69	6.2	.810	.810	.016	.0022
7804271143.	45.	1.69	12.9	.732	.732	.016	.0046
7804271259.	45.	.91	1.9	.937	.937	.055	.0023
7804271244.	45.	.91	8.1	.600	.600	.055	.0100
7804281259.	40.	1.59	3.8	.754	.754	.016	.0015
7804281316.	40.	1.59	13.7	.561	.561	.016	.0055
7804281151.	35.	3.06	12.5	.502	.502	.004	.0014
7804281305.	35.	3.06	22.5	.444	.444	.004	.0025
7804281222.	35.	1.49	1.6	.675	.675	.016	.0007
7804281239.	35.	1.49	7.4	.489	.489	.016	.0034
7804281116.	35.	1.30	11.3	.476	.476	.021	.0068
7804271409.	30.	2.17	2.2	.555	.555	.007	.0005
7804271425.	30.	2.17	6.6	.463	.463	.007	.0019
7804271442.	30.	2.17	20.7	.438	.438	.007	.0045
7804271332.	30.	1.38	3.1	.355	.355	.016	.0017
7804271349.	30.	1.38	9.6	.342	.342	.016	.0051

ID	D(CM)	T(S)	H(CM)	KT	KR	D/GT2	H/GT2
BREAKWATER 16							
7805110706.	60.	4.83	.8	.826	.826	.003	.0000
7805110723.	60.	4.83	6.0	.766	.766	.003	.0003
7805110746.	60.	4.83	17.8	.793	.793	.003	.0008
7805110031.	60.	3.06	2.8	.917	.917	.007	.0003
7805110051.	60.	3.06	8.9	.908	.908	.007	.0010
7805110056.	60.	1.95	1.7	.959	.959	.016	.0005
7805110924.	60.	1.95	6.7	.915	.915	.016	.0018
7805111010.	60.	1.95	26.4	.766	.766	.016	.0071
7805111201.	60.	1.05	4.1	.953	.953	.056	.0038
7805111038.	60.	1.05	9.3	.869	.869	.056	.0086
7805111232.	55.	4.69	1.2	.786	.786	.003	.0001
7805111252.	55.	4.69	8.3	.764	.764	.003	.0004
7805111313.	55.	4.69	21.5	.624	.624	.003	.0010
7805120022.	55.	2.93	3.5	.972	.972	.007	.0004
7805111318.	55.	2.93	11.1	.949	.949	.007	.0013
7805111326.	55.	2.93	22.2	.909	.909	.007	.0026
7805120057.	55.	1.87	3.3	.860	.860	.016	.0010
7805120935.	55.	1.87	13.6	.823	.823	.016	.0040
7805120955.	55.	1.87	25.7	.643	.643	.016	.0075
7805121023.	55.	1.01	3.8	.940	.940	.055	.0038
7805121014.	55.	1.01	4.8	.897	.897	.055	.0048
7805121205.	50.	4.54	4.0	.715	.715	.002	.0002
7805121225.	50.	4.54	11.2	.762	.762	.002	.0006
7805121247.	50.	4.54	23.7	.591	.591	.002	.0012
7805121319.	50.	2.80	9.8	.908	.908	.007	.0012
7805121259.	50.	2.80	16.1	.923	.923	.007	.0021
7805140942.	50.	1.78	2.4	.846	.846	.016	.0008
7805141015.	50.	1.78	6.5	.849	.849	.016	.0027
7805141042.	50.	1.78	17.1	.688	.688	.016	.0055
7805141241.	45.	4.38	1.3	.694	.694	.002	.0001
7805141306.	45.	4.38	6.1	.671	.671	.002	.0003
7805141329.	45.	4.38	12.7	.78A	.788	.002	.0007
7805141411.	45.	2.65	12.9	.81A	.810	.007	.0019
7805141350.	45.	2.65	25.7	.574	.574	.007	.0037
7805170830.	35.	4.06	5.4	.555	.555	.002	.0003
7805170857.	35.	4.06	15.4	.499	.499	.002	.0010
7805220937.	35.	3.10	.9	.871	.871	.004	.0001
7805221003.	35.	3.10	5.1	.601	.601	.004	.0005
7805221022.	35.	3.10	11.1	.516	.516	.004	.0012
7805170921.	35.	2.34	1.0	.799	.799	.007	.0002
7805170939.	35.	2.34	4.0	.650	.650	.007	.0007
7805170957.	35.	2.34	8.3	.587	.587	.007	.0015
7805171022.	35.	2.34	16.9	.468	.468	.007	.0031
7805221049.	35.	1.65	1.4	.673	.673	.013	.0005
7805221145.	35.	1.65	5.6	.534	.534	.013	.0021
7805221203.	35.	1.65	14.4	.414	.414	.013	.0054
7805171043.	35.	1.69	2.3	.624	.624	.016	.0011
7805171154.	35.	1.69	11.5	.435	.435	.016	.0053
7805171214.	35.	1.49	23.2	.365	.365	.016	.0107
7805171243.	30.	3.89	3.0	.468	.468	.002	.0002
7805171303.	30.	3.89	10.3	.417	.417	.002	.0007
7805180937.	30.	2.87	1.8	.616	.616	.004	.0002
7805180959.	30.	2.87	7.2	.484	.484	.004	.0009
7805181241.	30.	2.87	14.7	.483	.483	.004	.0018

SINE BLADE MOTION  
KR D/GT2 H/GT2

ID	D(CM)	T(S)	H(CM)	KT	BREAKWATER 16	ID	D(CM)	T(S)	H(CM)	KT	BREAKWATER 17
7805171321.	30.	2.17	2.0	.660	.660 .007 .0004	7805171330.	30.	2.17	4.1	.536	.536 .007 .0009
7805171338.	30.	2.17	8.1	.444	.444 .007 .0018	7805171347.	30.	2.17	14.9	.434	.434 .007 .0032
7805171355.	30.	2.17	19.1	.411	.411 .007 .0041	7805180832.	30.	1.53	.7	.636	.636 .013 .0003
7805180900.	30.	1.53	4.5	.762	.362 .013 .0020	7805180910.	30.	1.53	12.4	.330	.330 .013 .0054
7805180920.	30.	1.53	18.2	.264	.264 .013 .0079	7805180928.	30.	1.53	24.1	.213	.213 .013 .0105
7805180933.	30.	1.38	1.3	.490	.490 .016 .0007	7805180741.	30.	1.38	2.7	.377	.377 .016 .0014
7805180950.	30.	1.38	5.9	.292	.292 .016 .0032	7805180759.	30.	1.38	8.3	.298	.298 .016 .0044
7805180970.	30.	1.38	10.7	.288	.288 .016 .0057	7805180815.	30.	1.38	15.0	.261	.261 .016 .0080
7805190923.	25.	3.70	18.6	.228	.228 .016 .0100	7805190910.	25.	3.70	1.1	.487	.487 .002 .0001
7805190946.	25.	3.70	2.4	.434	.434 .002 .0002	7805190945.	25.	3.70	3.1	.387	.387 .002 .0002
7805191111.	25.	3.70	12.7	.245	.245 .002 .0009	7805191021.	25.	3.70	18.6	.267	.267 .002 .0014
7805191131.	25.	2.62	1.2	.565	.565 .004 .0002	7805181323.	25.	2.62	2.7	.487	.487 .004 .0004
7805191315.	25.	2.62	5.6	.371	.371 .004 .0008	7805181340.	25.	2.62	8.0	.324	.324 .004 .0012
7805191348.	25.	2.62	11.6	.282	.282 .004 .0017	7805181357.	25.	2.62	16.7	.283	.283 .004 .0025
7805191747.	25.	1.40	2.6	.288	.288 .013 .0014	7805190801.	25.	1.40	5.3	.211	.211 .013 .0028
7805191909.	25.	1.40	9.8	.171	.171 .013 .0051	7805190818.	25.	1.40	18.1	.144	.144 .013 .0094
7805191926.	25.	1.26	4.4	.206	.206 .016 .0028	7805190834.	25.	1.26	9.9	.150	.150 .016 .0064
7805191943.	25.	1.26	13.9	.147	.147 .016 .0089	7805190851.	25.	1.26	17.5	.140	.140 .016 .0112
7805191990.	25.	1.26	20.4	.118	.118 .016 .0131	7805191225.	20.	3.51	4	.717	.717 .002 .0000
7805191234.	20.	3.51	.7	.658	.658 .002 .0001	7805191251.	20.	3.51	10	.612	.612 .002 .0001
7805191301.	20.	3.51	1.5	.559	.559 .002 .0001	7805191311.	20.	3.51	3.0	.444	.444 .002 .0002
7805191322.	20.	3.51	6.3	.328	.328 .002 .0005	7805191331.	20.	3.51	13.5	.225	.225 .002 .0011
7805191340.	20.	3.51	20.0	.187	.187 .002 .0017	7805220820.	20.	2.34	.9	.845	.845 .004 .0002
7805220812.	20.	2.34	1.8	.662	.662 .004 .0003	7805220831.	20.	2.34	3.6	.472	.472 .004 .0007
7805191405.	20.	2.34	7.0	.317	.317 .004 .0013	7805220854.	20.	2.34	7.1	.316	.316 .004 .0013
7805220766.	20.	2.34	9.9	.257	.257 .004 .0018	7805191356.	20.	2.34	13.5	.209	.209 .004 .0025
7805220736.	20.	2.34	14.3	.210	.210 .004 .0027	7805191394.	20.	2.34	20.7	.169	.169 .004 .0039
7805220727.	20.	2.34	19.9	.180	.180 .004 .0037	7805220829.	20.	1.77	1.2	.605	.605 .007 .0004
7805220938.	20.	1.77	2.5	.447	.447 .007 .0008	7805220846.	20.	1.77	5.4	.293	.293 .007 .0018
7805220855.	20.	1.77	8.1	.229	.229 .007 .0026	7805220904.	20.	1.77	12.4	.175	.175 .007 .0040
7805220912.	20.	1.77	18.1	.138	.138 .007 .0059						

7807070834.	50.	6.99	2.1	.780	.780 .001 .0000	7807070844.	50.	6.99	4.3	.692	.692 .001 .0001
7807070854.	50.	6.99	8.5	.586	.586 .001 .0002	7807070904.	50.	6.99	8.5	.559	.559 .001 .0002
7807070937.	50.	6.99	16.4	.457	.457 .001 .0003	7807010135.	50.	6.34	4	.934	.934 .001 .0000
7808151017.	50.	6.34	1.5	.742	.742 .001 .0003	7808151025.	50.	6.34	2.8	.671	.671 .001 .0001
7808151033.	50.	6.34	3.9	.648	.648 .001 .0001	7808102008.	50.	6.34	4.1	.682	.682 .001 .0001
7808151049.	50.	6.34	8.9	.529	.529 .001 .0002	7808010155.	50.	6.34	9.1	.561	.561 .001 .0002
7808151057.	50.	6.34	14.8	.435	.435 .001 .0004	7808010145.	50.	6.34	14.9	.458	.458 .001 .0004
7807070823.	50.	5.17	1.0	.709	.709 .002 .0000	7807070814.	50.	5.17	2.0	.670	.670 .002 .0001
7807070830.	50.	5.17	4.0	.598	.598 .002 .0002	7807070755.	50.	5.17	5.9	.543	.543 .002 .0002
7807070746.	50.	5.17	8.8	.491	.491 .002 .0003	7808151133.	50.	4.54	2.3	.546	.546 .002 .0001
7808151127.	50.	4.54	7.1	.427	.427 .002 .0004	7808151119.	50.	4.54	10.5	.377	.377 .002 .0005
7808151112.	50.	4.54	15.7	.330	.330 .002 .0008	7808151105.	50.	4.54	23.3	.296	.296 .002 .0012
7807071114.	50.	3.70	2.8	.565	.565 .004 .0008	7807071105.	50.	3.70	5.7	.501	.501 .004 .0004
7807070956.	50.	3.70	11.0	.419	.419 .004 .0008	7807070947.	50.	3.70	14.8	.387	.387 .004 .0011
7807071440.	50.	2.80	1.6	.765	.765 .007 .0002	7807071031.	50.	2.80	3.4	.689	.689 .007 .0004
7808020709.	50.	1.87	2.3	.508	.508 .015 .0007	7808020719.	50.	1.87	4.7	.467	.467 .015 .0014
7808020727.	50.	1.87	6.7	.433	.433 .015 .0020	7808020735.	50.	1.87	9.7	.409	.409 .015 .0028
7808151151.	50.	1.87	14.0	.339	.339 .015 .0041	7808151145.	50.	1.87	18.8	.311	.311 .015 .0055
7808151139.	50.	1.87	26.4	.265	.265 .015 .0077	7807071129.	50.	1.78	6.0	.472	.472 .016 .0019
7807071122.	50.	1.78	12.7	.370	.370 .016 .0041	7807071047.	50.	1.78	23.2	.294	.294 .016 .0075
7807071144.	50.	1.50	8.8	.437	.437 .023 .0031	7807071136.	50.	1.50	11.7	.352	.352 .023 .0053
7807081508.	45.	6.90	2.8	.760	.760 .001 .0001	7807051458.	45.	6.90	5.8	.660	.660 .001 .0001
7807081509.	45.	6.90	6.6	.586	.586 .001 .0002	7807051441.	45.	6.90	13.7	.475	.475 .001 .0003
7807081408.	45.	4.91	2.1	.579	.579 .002 .0001	7807051116.	45.	4.91	3.1	.553	.553 .002 .0001
7807081326.	45.	4.91	4.7	.519	.519 .002 .0002	7807051330.	45.	4.91	6.9	.471	.471 .002 .0003
7807081347.	45.	4.91	10.3	.426	.426 .002 .0004	7807051354.	45.	4.91	15.1	.364	.364 .002 .0006
7807081358.	45.	3.51	1.4	.689	.689 .004 .0001	7807051405.	45.	3.51	2.9	.624	.624 .004 .0002
7807081416.	45.	3.51	6.0	.534	.534 .004 .0005	7807051424.	45.	3.51	12.4	.443	.443 .004 .0010
7807081432.	45.	3.51	18.2	.386	.386 .004 .0015	7807051515.	45.	2.65	1.2	.734	.734 .007 .0002
7807081521.	45.	2.65	2.7	.664	.664 .007 .0004	7807051528.	45.	2.65	6.2	.553	.553 .007 .0009
7807081536.	45.	2.65	13.6	.424	.424 .007 .0020	7807051543.	45.	2.65	18.5	.361	.361 .007 .0027
7807081608.	45.	1.88	2.8	.544	.544 .013 .0008	7807051601.	45.	1.88	5.4	.492	.492 .013 .0016
7807081555.	45.	1.88	10.6	.407	.407 .013 .0031	7807051549.	45.	1.88	21.0	.317	.317 .013 .0061
7807081614.	45.	1.69	.6	.552	.552 .016 .0002	7807051620.	45.	1.69	1.5	.551	.551 .016 .0005
7807081626.	45.	1.69	2.8	.523	.523 .016 .0010	7807051632.	45.	1.69	6.2	.453	.453 .016 .0022
7807071430.	35.	6.09	1.6	.836	.836 .001 .0000	7807071437.	35.	6.09	3.3	.728	.728 .001 .0001
7807071444.	35.	6.09	6.9	.589	.589 .001 .0002	7807071453.	35.	6.09	10.1	.523	.523 .001 .0003
7807071218.	35.	4.33	3.0	.471	.471 .002 .0002	7807071226.	35.	4.33	8.7	.370	.370 .002 .0005
7807071244.	35.	4.33	14.8	.345	.345 .002 .0008	7807071315.	35.	3.10	1.2	.707	.707 .004 .0001
7807071308.	35.	3.10	3.9	.766	.766 .004 .0004	7807071300.	35.	3.10	5.6	.596	.596 .004 .0006
7807071252.	35.	3.10	8.5	.501	.501 .004 .0009	7807071322.	35.	2.34	1.5	.637	.637 .007 .0003
7807071330.	35.	2.34	4.4	.557	.557 .007 .0008	7807071338.	35.	2.34	9.5	.460	.460 .007 .0018
7807071347.	35.	2.34	14.7	.390	.390 .007 .0027	7807071419.	35.	1.49	1.4	.603	.603 .016 .0006
7807071411.	35.	1.49	2.8	.523	.523 .016 .0013	7807071404.	35.	1.49	6.3	.425	.425 .016 .0029
7807071355.	35.	1.49	18.6	.304	.304 .016 .0067						

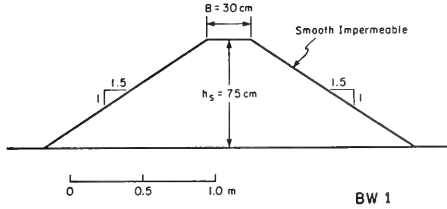






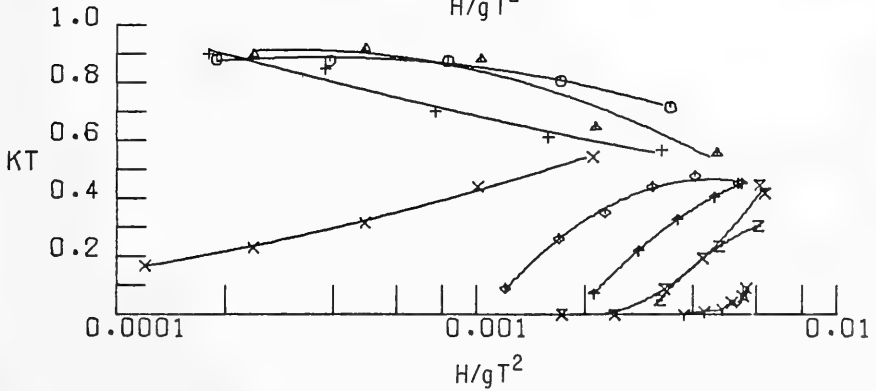
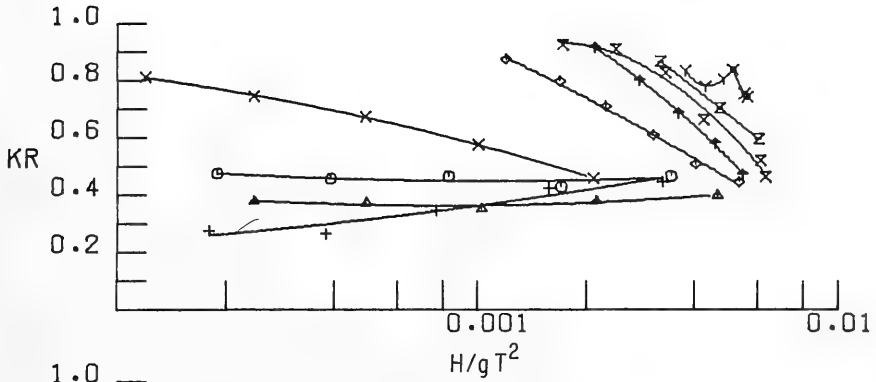


APPENDIX E  
TEST RESULTS (GRAPHICAL FORM)



SYMBOL DS/HS

○	1.20
△	1.13
+	1.07
×	1.00
◇	0.93
†	0.87
×	0.80
Z	0.73
Y	0.67
×	0.60



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

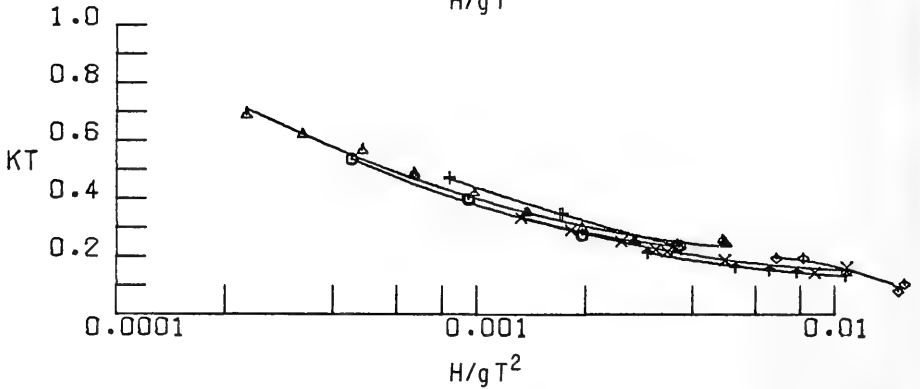
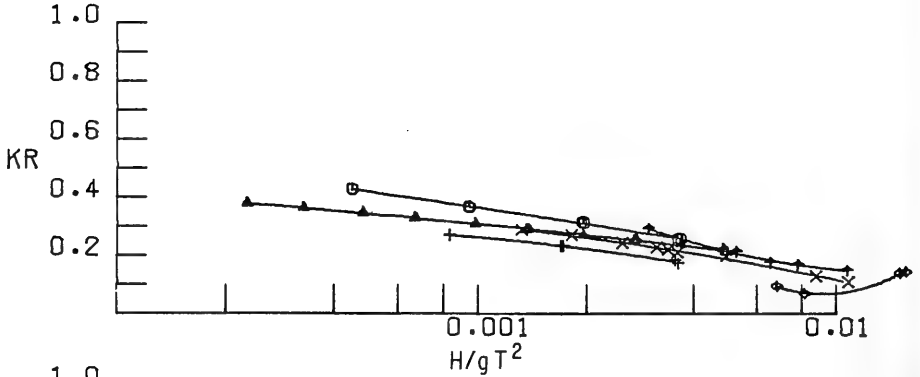
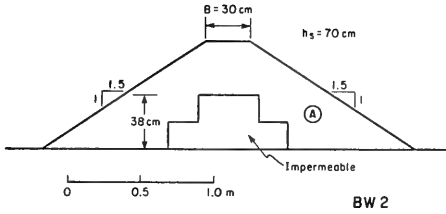
BREAKWATER

1

$D/(GT^2) = 0.016$

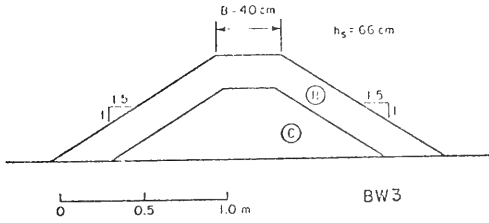
SYMBOL D/QT2

- 0.0131
- △ 0.0161
- + 0.0227
- × 0.0364
- ◇ 0.0556
- † 0.0788



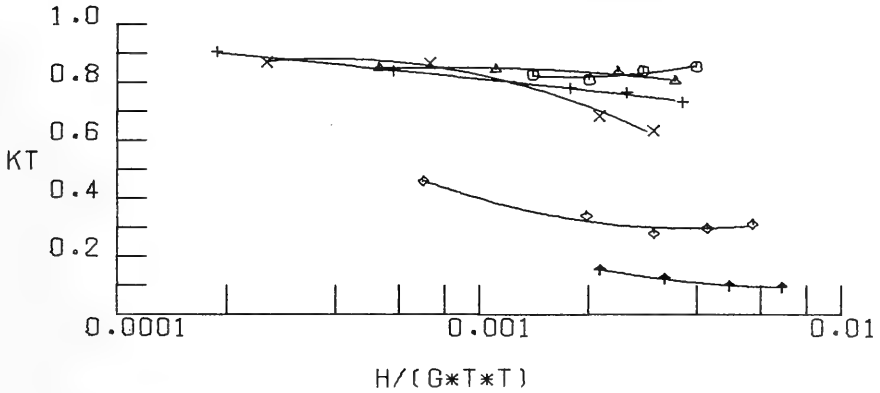
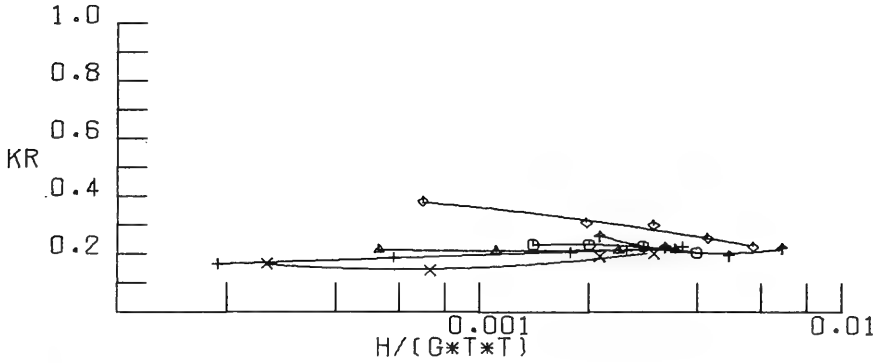
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS  
 BREAKWATER 2 DS/HS= 0.87





SYMBOL DS/HS

□	1.44
△	1.38
+	1.29
×	1.14
◇	0.92
†	0.69



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

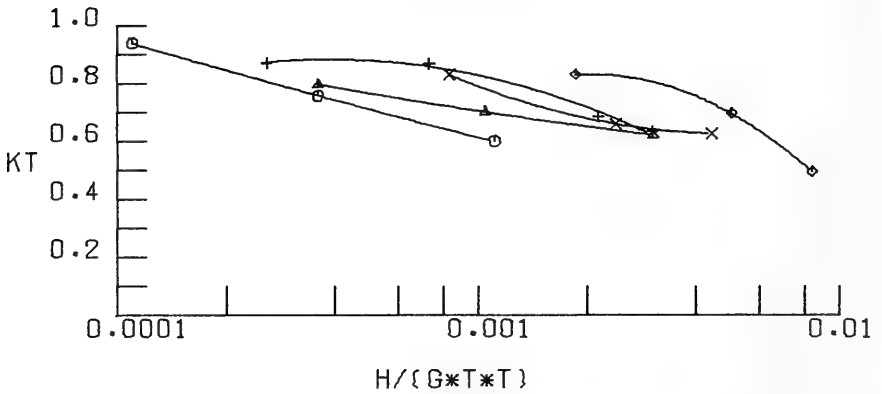
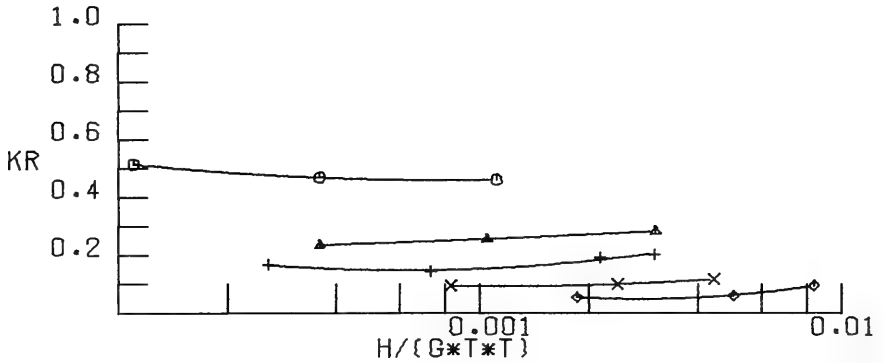
BREAKWATER

3

$D/(GT^2) = 0.016$

SYMBOL D/GT2

○	0.0065
△	0.0131
+	0.0161
×	0.0226
◇	0.0364

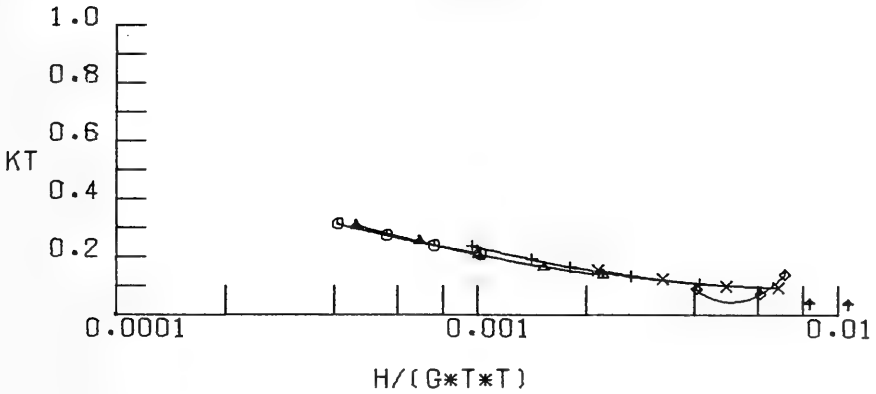
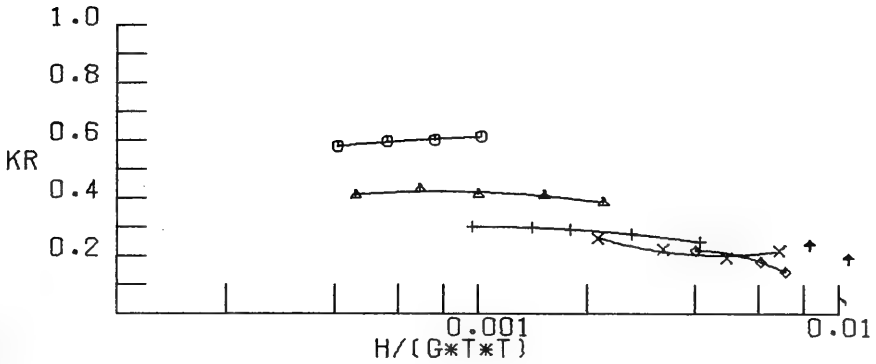


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 3 DS/HS= 1.14

SYMBOL D/GT2

○	0.0038
△	0.0066
+	0.0131
×	0.0162
◇	0.0229
†	0.0368



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

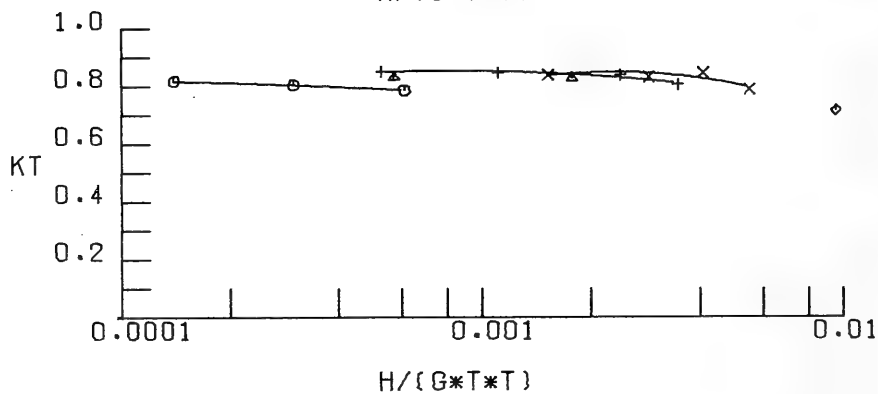
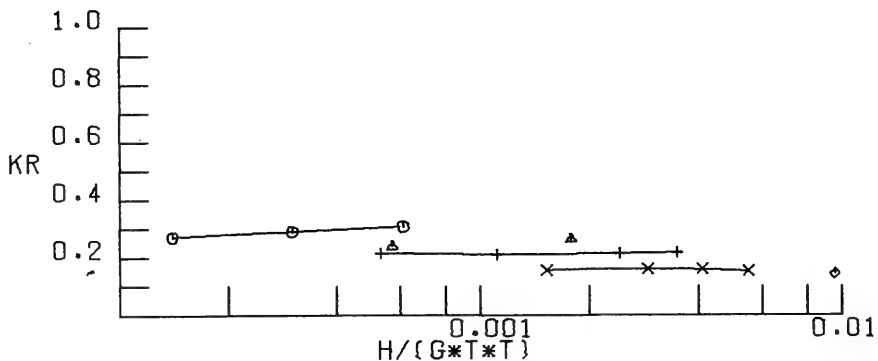
BREAKWATER

3

DS/HS= 0.69

SYMBOL D/GT2

○	0.0065
△	0.0130
+	0.0161
×	0.0227
◇	0.0362



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

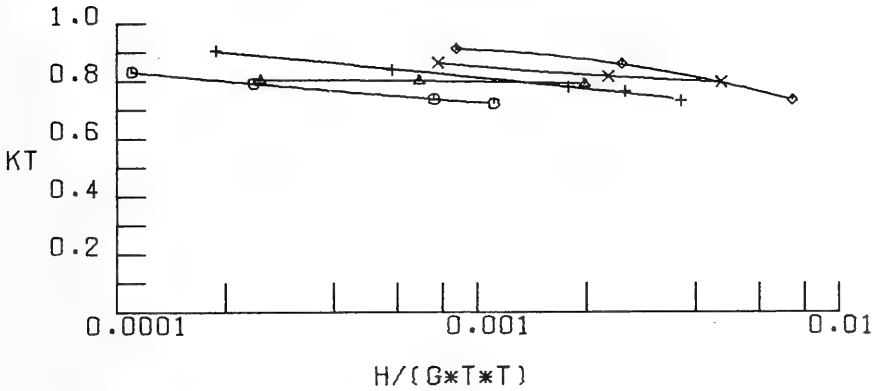
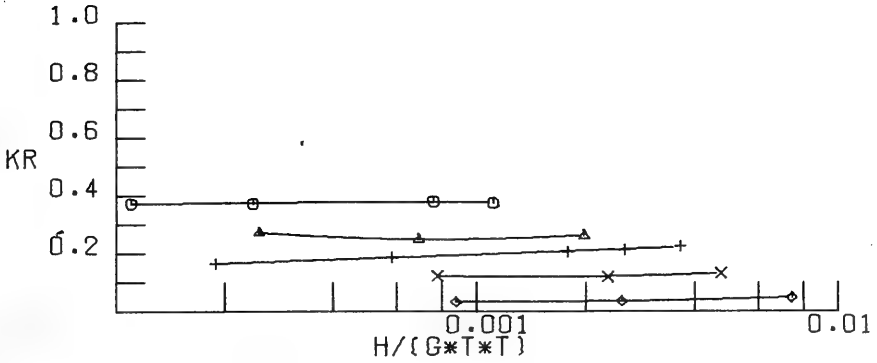
BREAKWATER 3

3

DS/HS= 1.38

SYMBOL D/GT2

- 0.0065
- △ 0.0130
- + 0.0161
- × 0.0226
- ◇ 0.0366

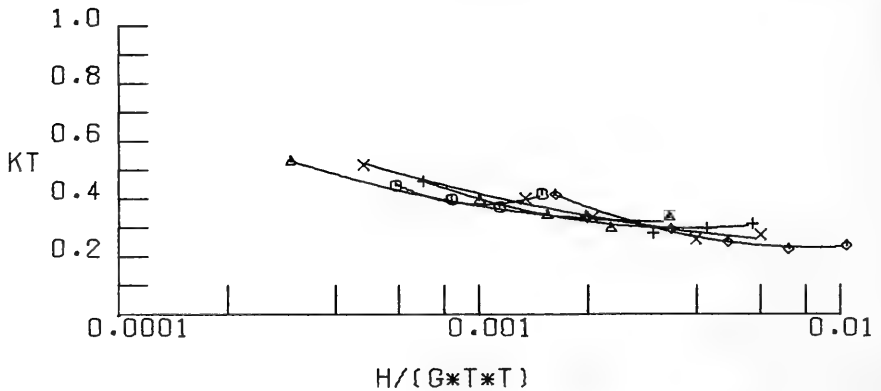
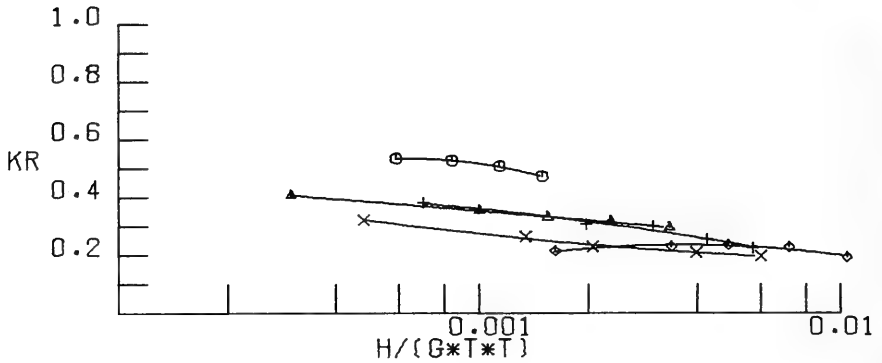


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 3 DS/HS= 1.29

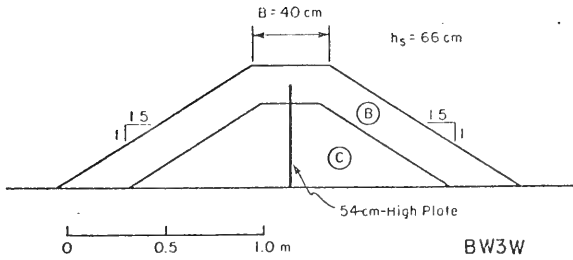
SYMBOL D/GT2

○	0.0066
△	0.0131
+	0.0162
×	0.0230
◇	0.0365



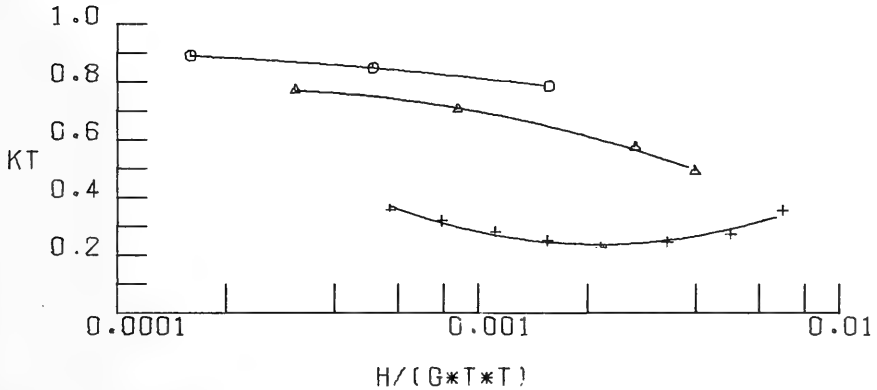
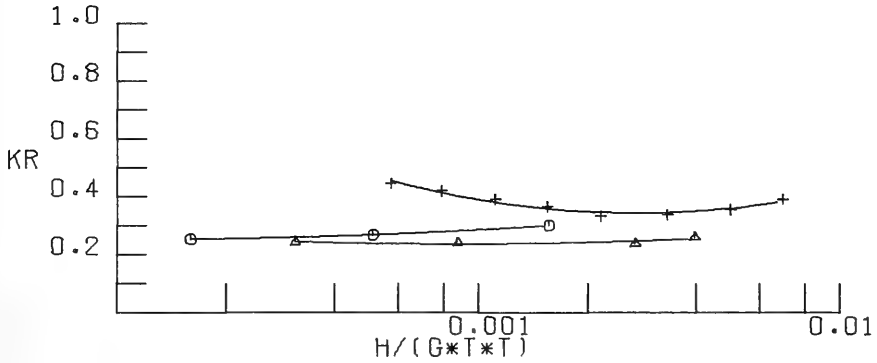
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 3 DS/HS= 0.92



SYMBOL DS/HS

○	1.29
△	1.15
+	0.93
×	0.69



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

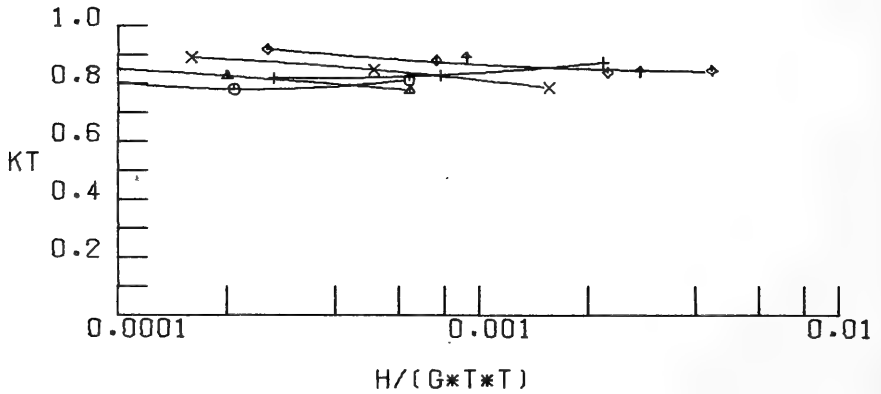
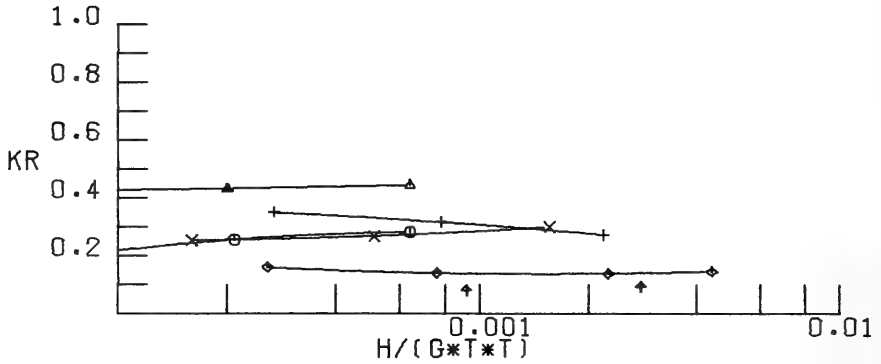
BREAKWATER

3W

$D/(GT^2) = 0.016$

SYMBOL D/GT2

○	0-0037
△	0-0065
+	0-0130
x	0-0161
◇	0-0226
†	0-0366



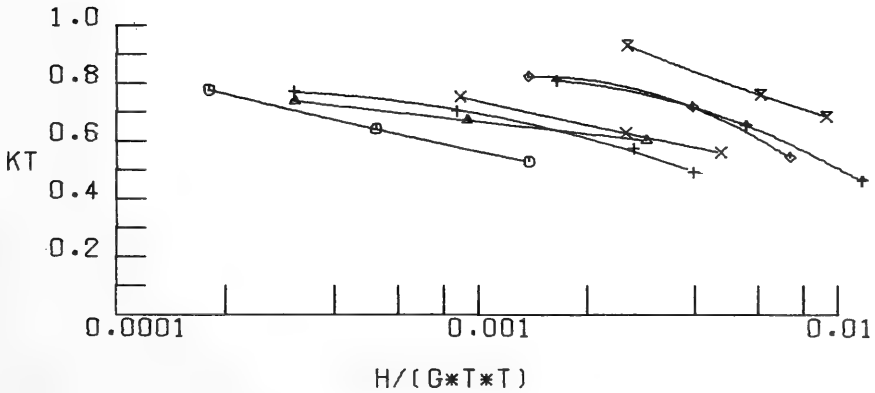
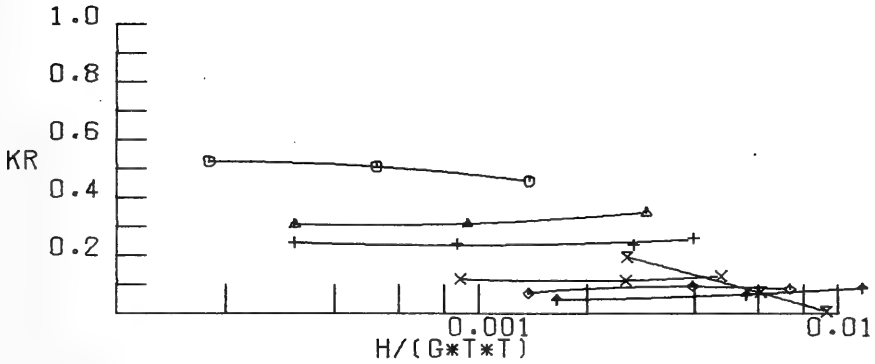
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 3W DS/HS= 1.29



SYMBOL D/GT2

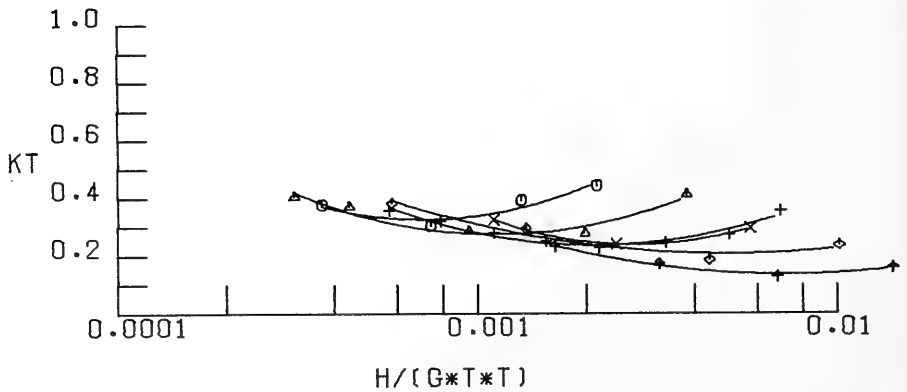
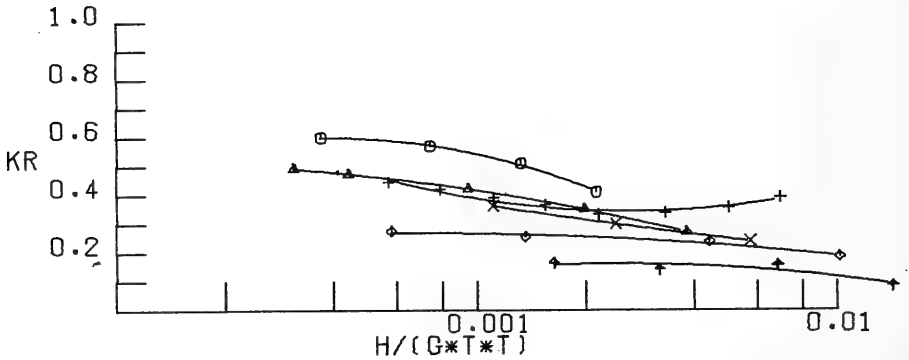
○	0.0066
△	0.0132
+	0.0163
×	0.0228
◇	0.0368
†	0.0555
×	0.0805



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS  
 BREAKWATER 3W DS/HS= 1.15

SYMBOL D/GT2

□	0.0065
△	0.0131
+	0.0161
×	0.0226
◇	0.0363
†	0.0555

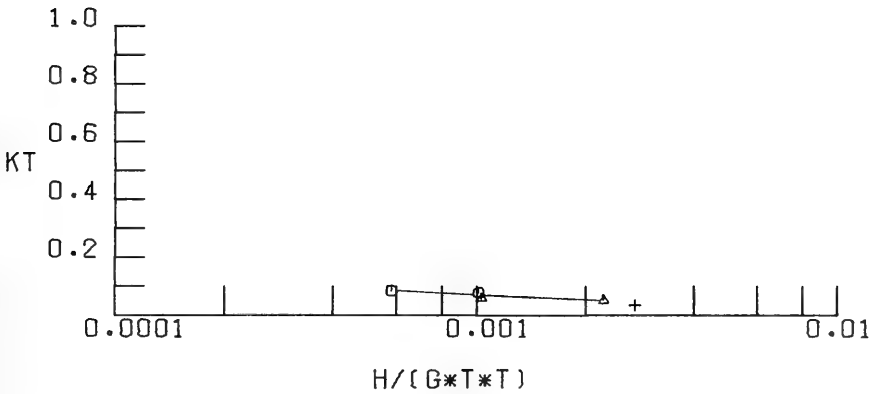
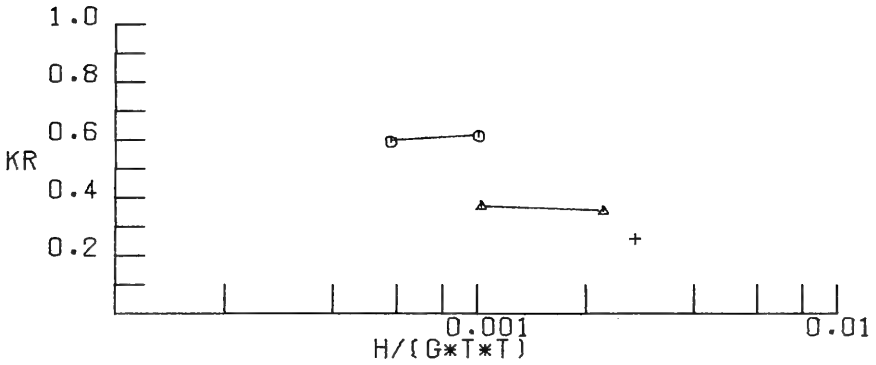


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 3W DS/HS= 0.93

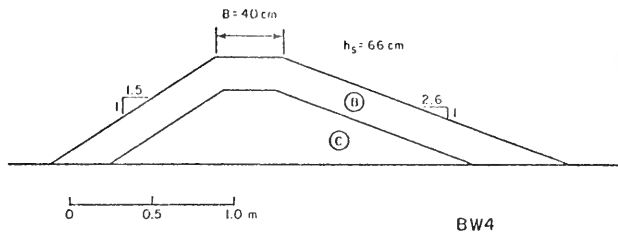
SYMBOL D/GT2

○ 0.0038  
△ 0.0066  
+ 0.0131



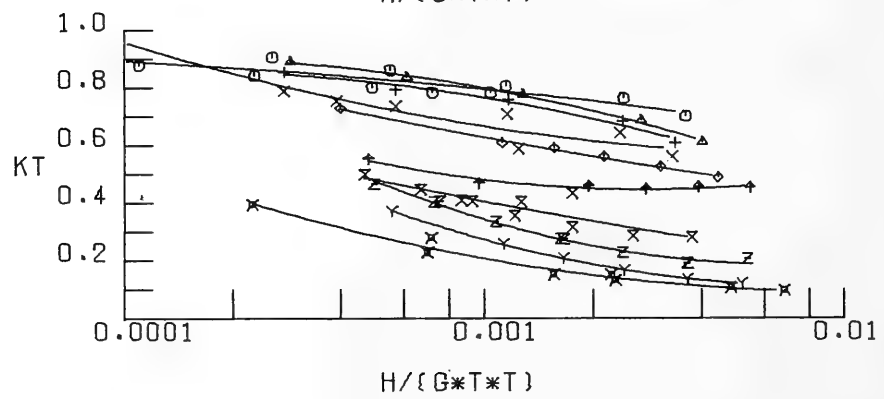
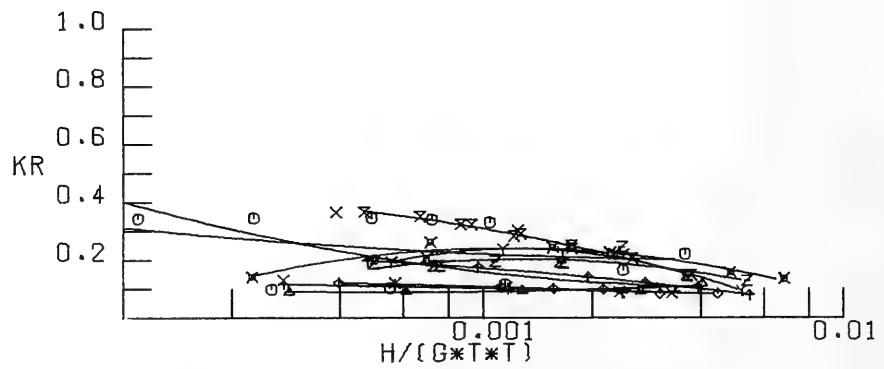
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 3W DS/HS= 0.69



SYMBOL DS/HS

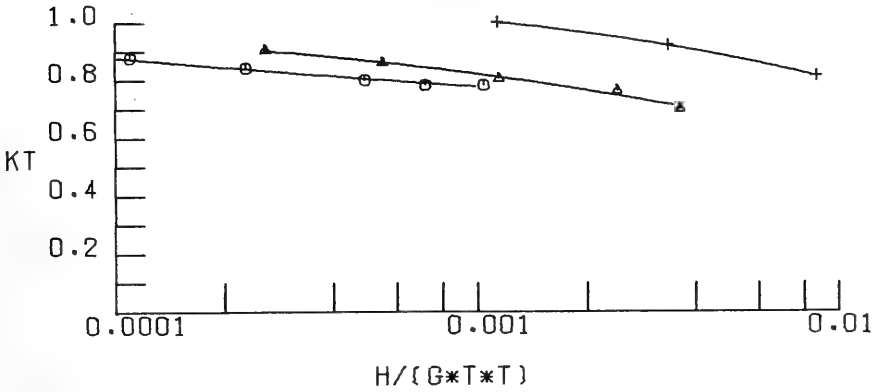
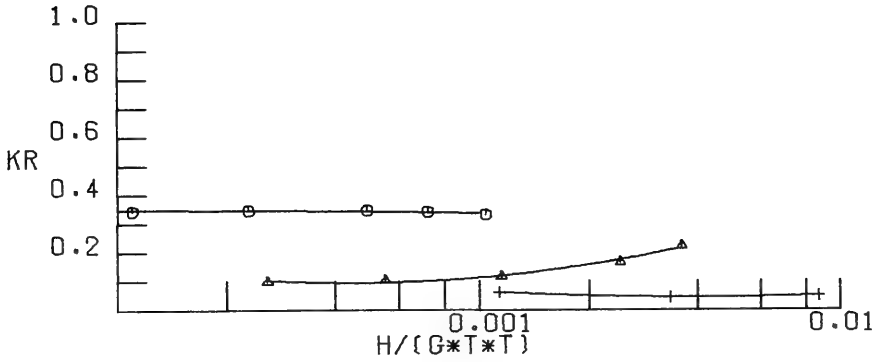
⊙	1.29
△	1.21
+	1.14
×	1.11
◇	1.09
+	0.98
×	0.90
Z	0.84
Y	0.74
X	0.68



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS  
 BREAKWATER 4       $D/(GT^2)=0.016$

SYMBOL D/GT2

□ 0.0065  
△ 0.0161  
+ 0.0546



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

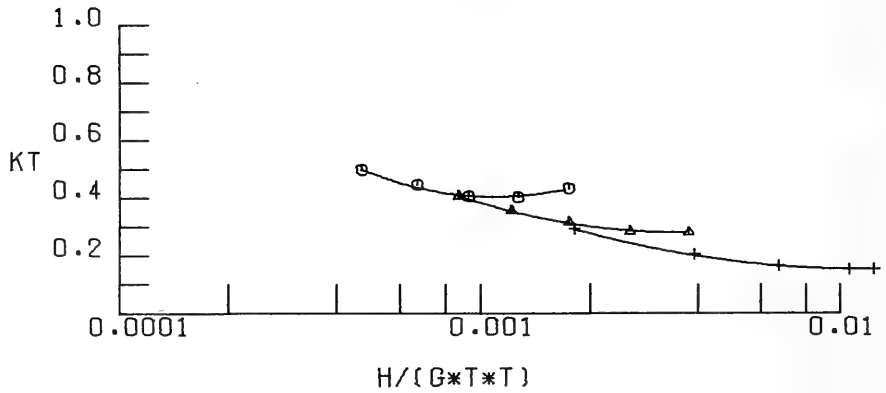
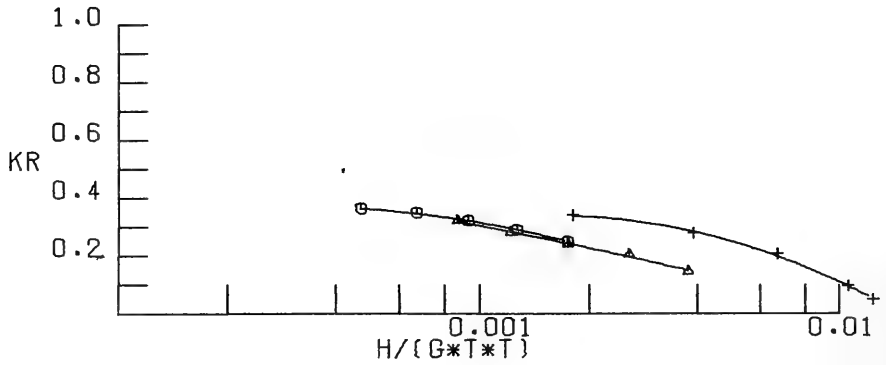
BREAKWATER

4

DS/HS= 1.29

SYMBOL D/GT2

○ 0.0065  
 ▲ 0.0160  
 + 0.0553



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

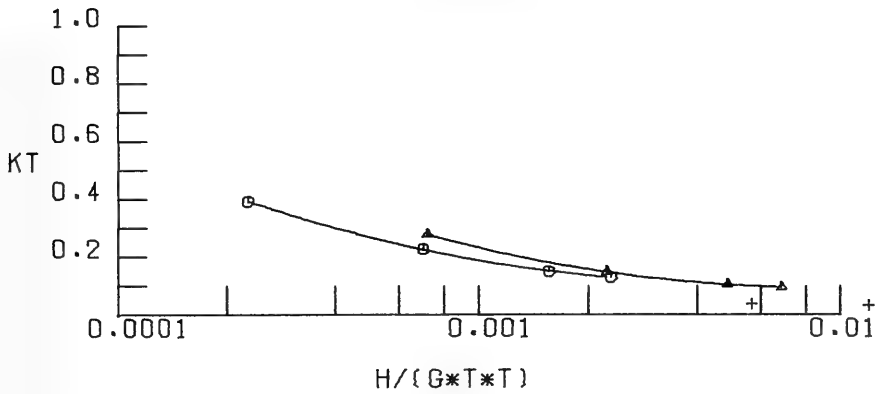
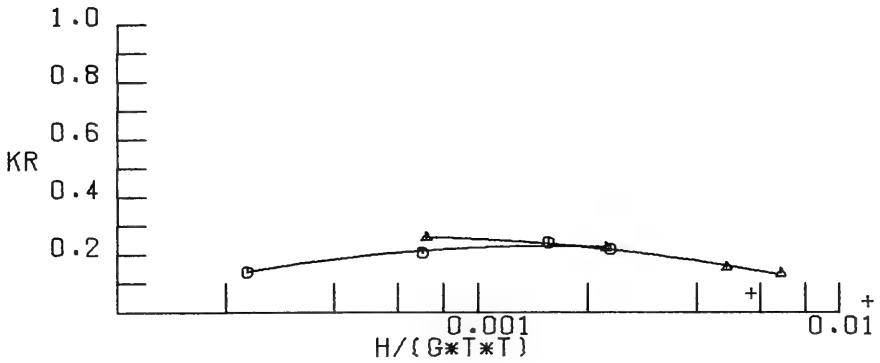
BREAKWATER 4 DS/HS= 0.90

SYMBOL  $D/GT^2$

○ 0.0065

△ 0.0161

+ 0.0555

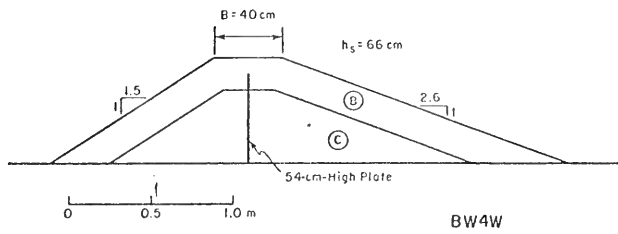


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER

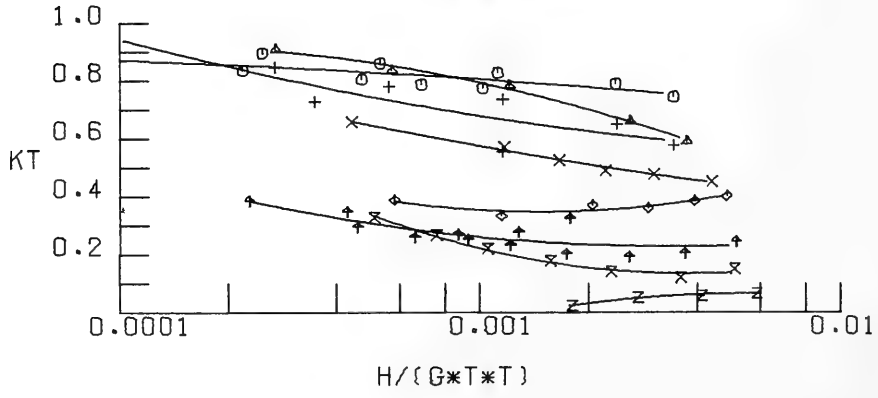
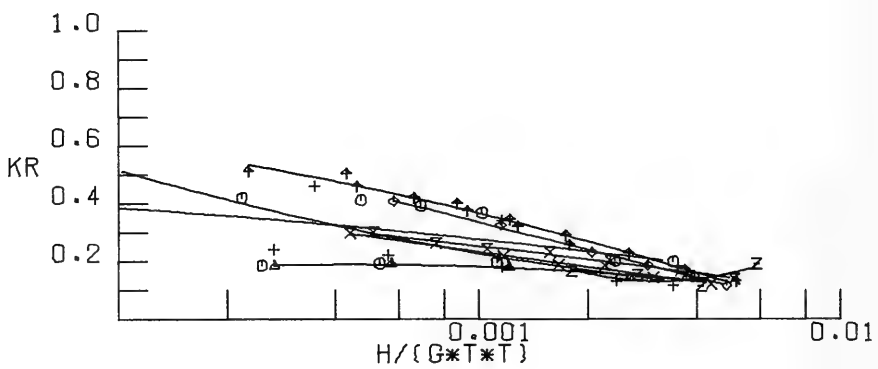
4

$DS/HS = 0.68$



SYMBOL DS/HS

□	1.29
△	1.21
+	1.14
×	1.06
◇	0.98
†	0.91
×	0.85
Z	0.76

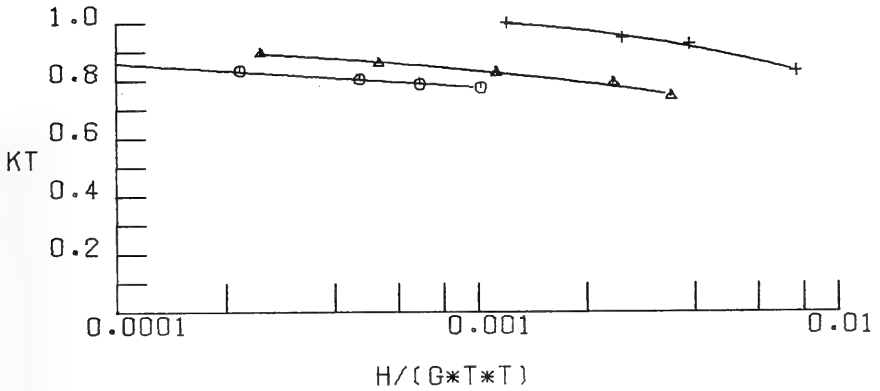
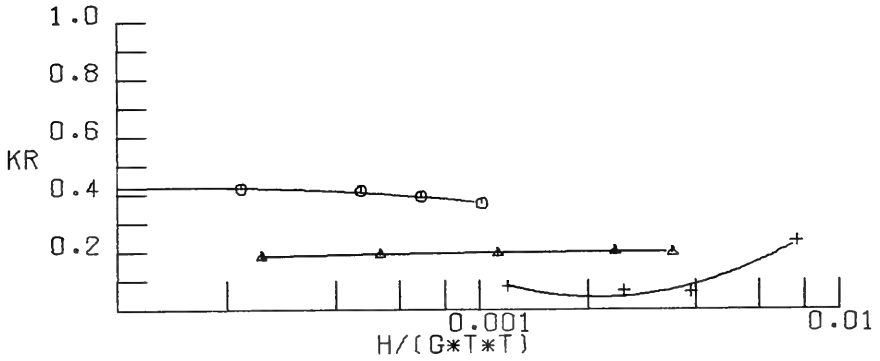


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS  
 BREAKWATER 4W  $D/((G*T^2))=0.016$



SYMBOL D/GT<sup>2</sup>

○ 0.0065  
△ 0.0161  
+ 0.0546



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

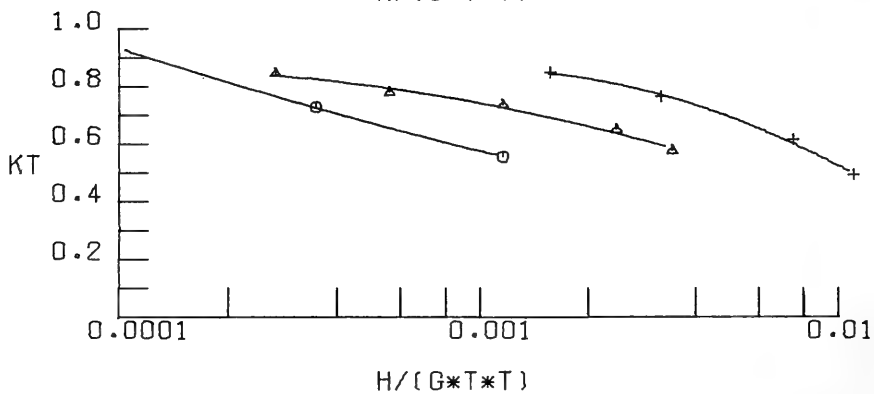
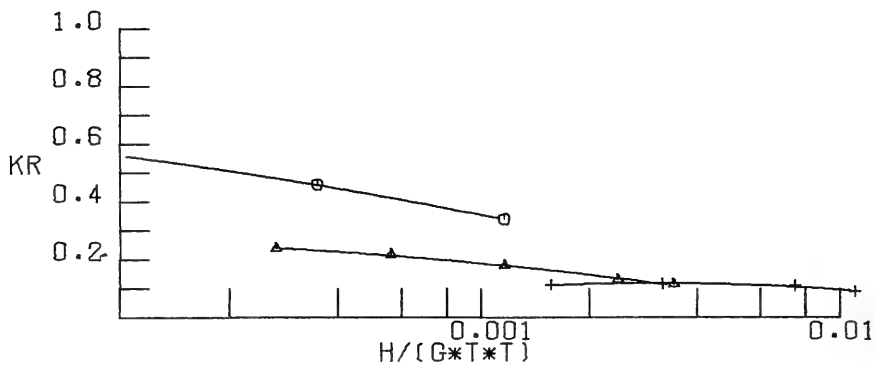
BREAKWATER

4W

DS/HS= 1.29

SYMBOL D/GT2

○ 0.0066  
 ▲ 0.0162  
 + 0.0553

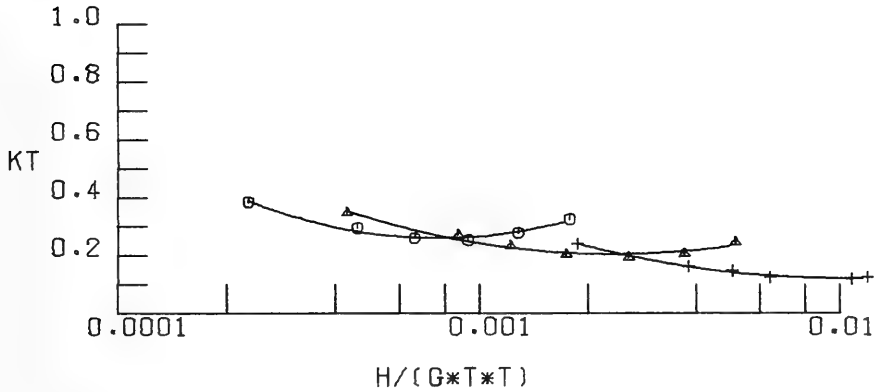
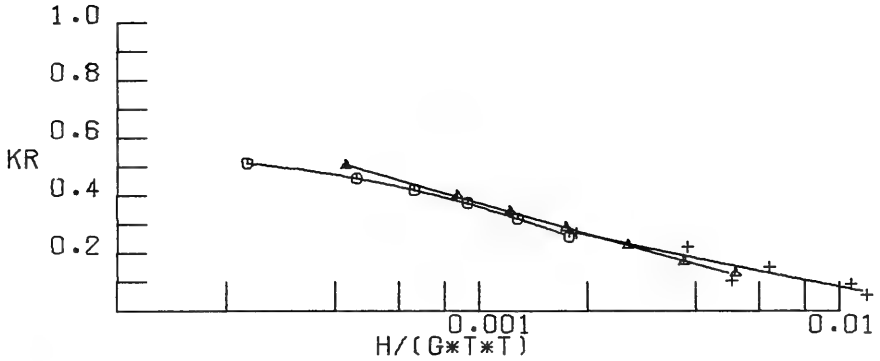


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 4W DS/HS= 1.14

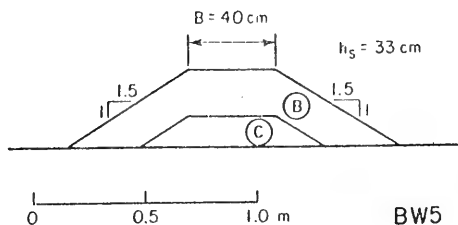
SYMBOL D/GT2

○ 0.0065  
 ▲ 0.0161  
 + 0.0555



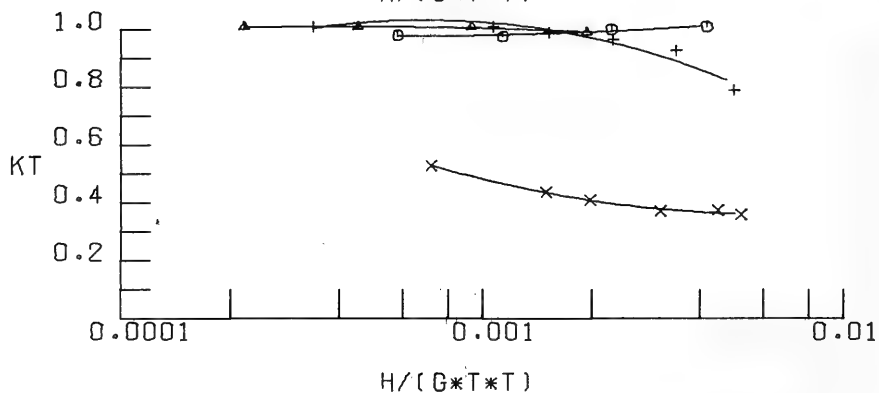
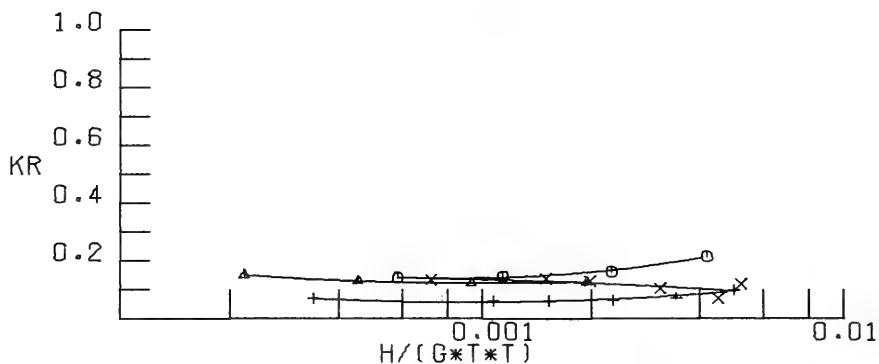
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 4W DS/HS= 0.91



SYMBOL DS/HS

○	2.27
△	1.82
+	1.36
×	0.92



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

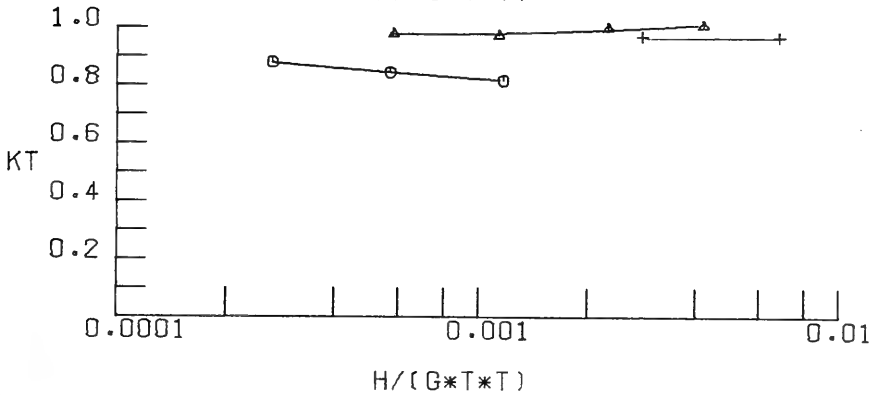
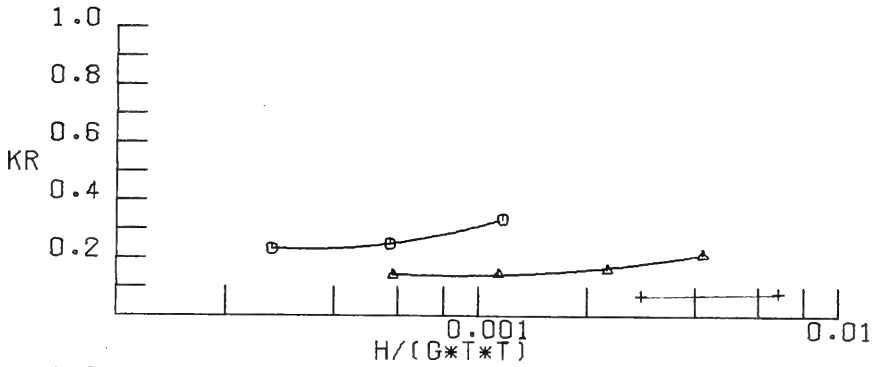
BREAKWATER

5

$D/((GT^2))=0.016$

SYMBOL D/GT2

○ 0.0065  
 △ 0.0161  
 + 0.0550



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

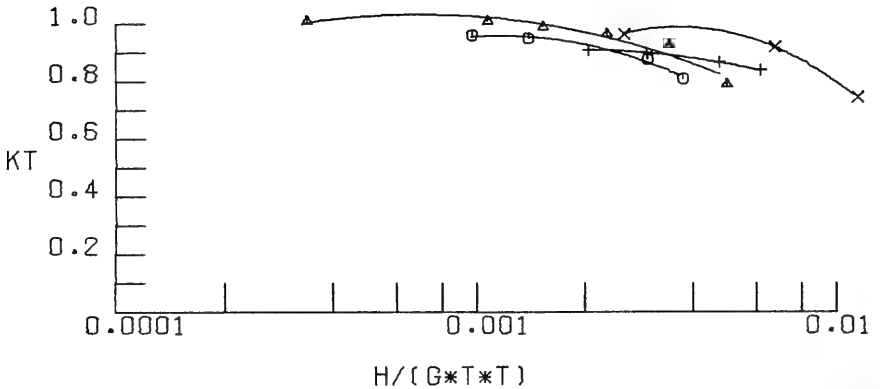
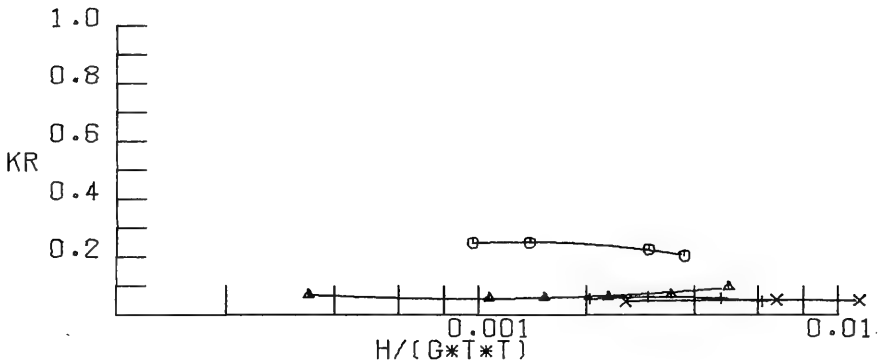
BREAKWATER

5

DS/HS= 2.27

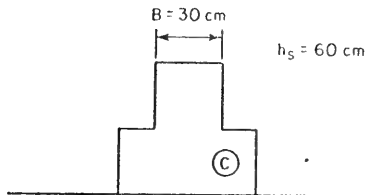
SYMBOL D/GT2

○	0.0114
△	0.0161
+	0.0330
x	0.0555



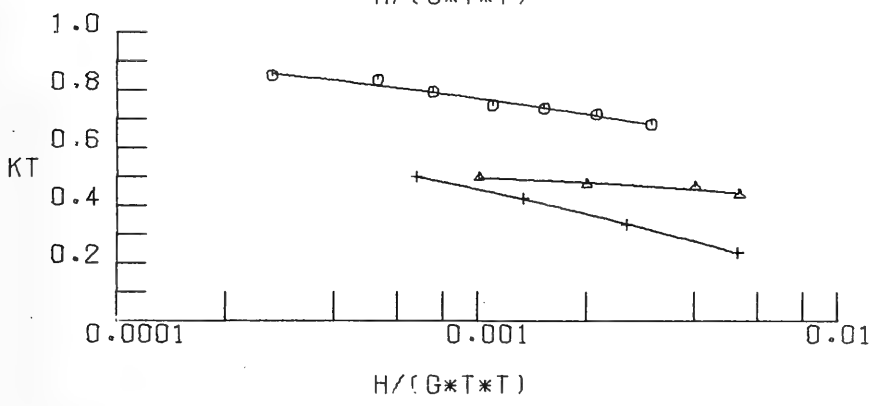
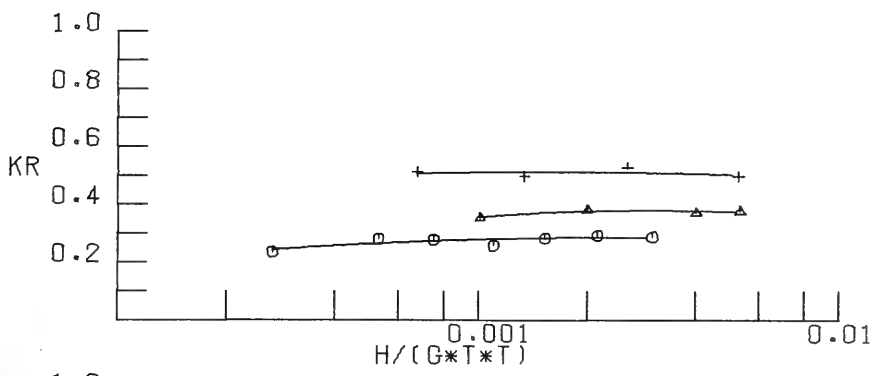
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 5 DS/HS= 1.36



SYMBOL DS/HS

○	1.25
△	1.00
+	0.75

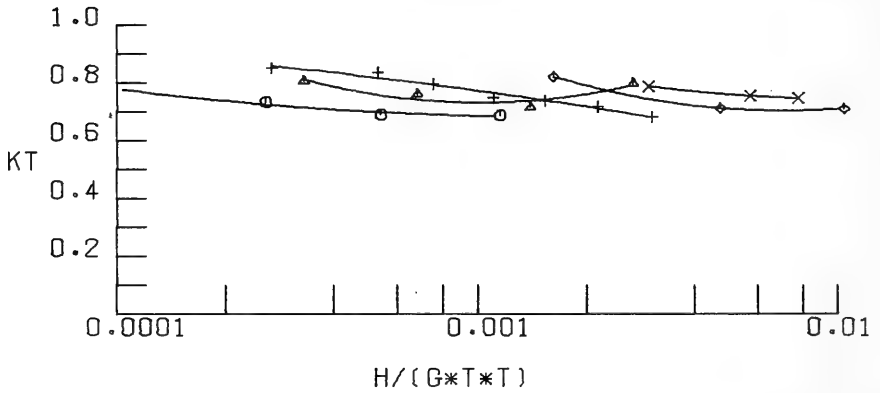
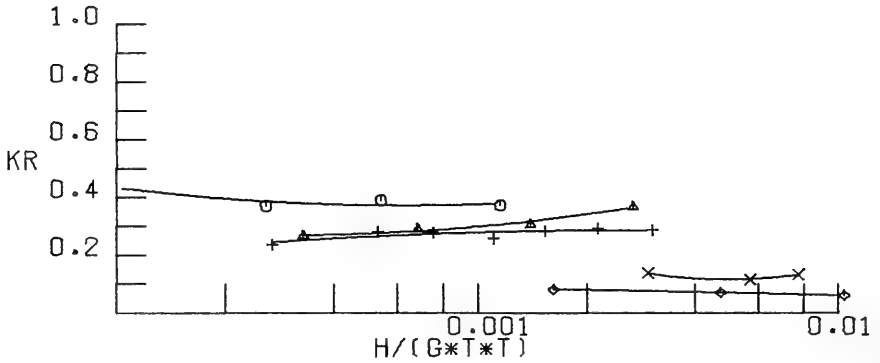


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 6 D/(GT<sup>2</sup>)=0.016

SYMBOL D/GT2

○ 0.0065  
 △ 0.0113  
 + 0.0161  
 × 0.0390  
 ◇ 0.0549



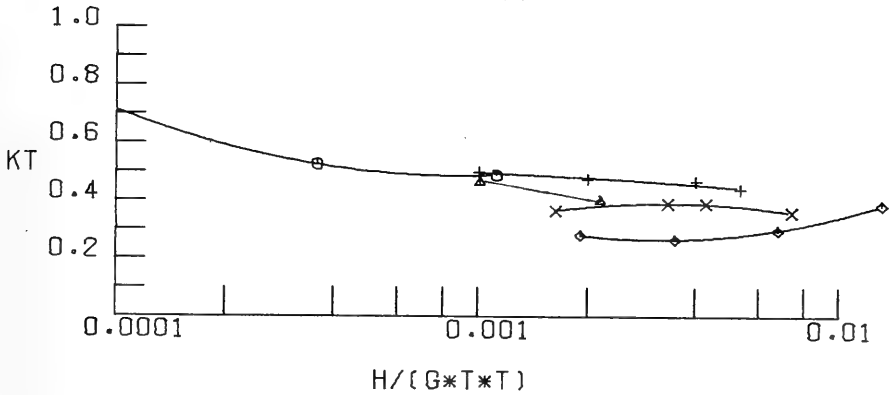
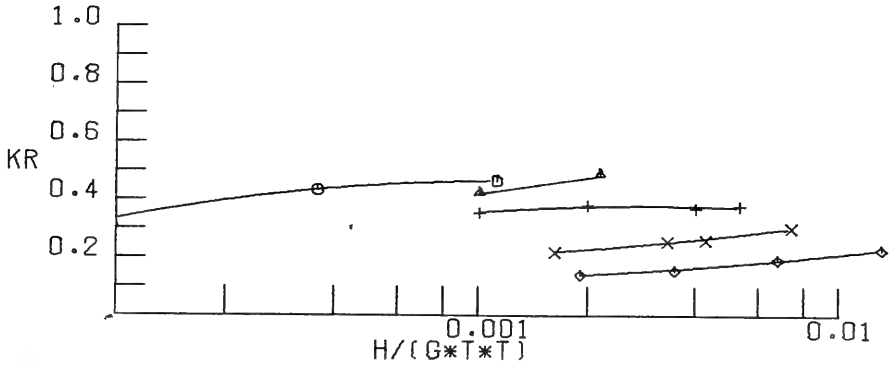
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 6 DS/HS= 1.25



SYMBOL D/GT2

○	0.0065
△	0.0114
+	0.0161
×	0.0392
◇	0.0555

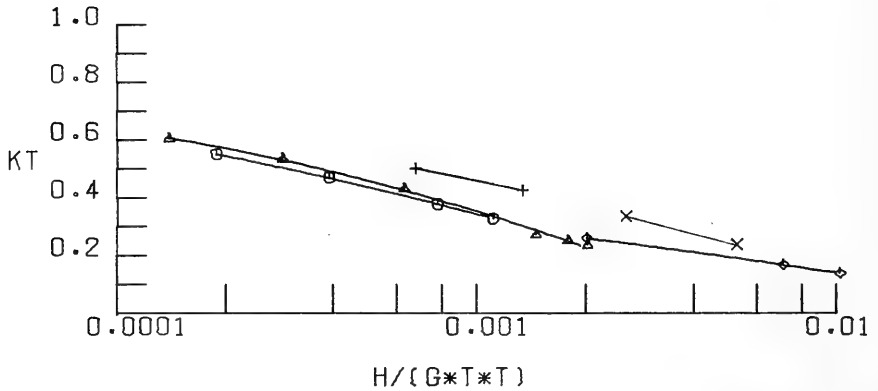
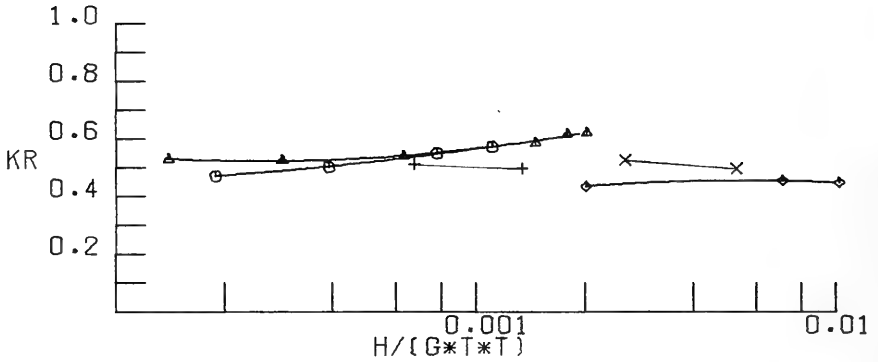


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 6 DS/HS= 1.00

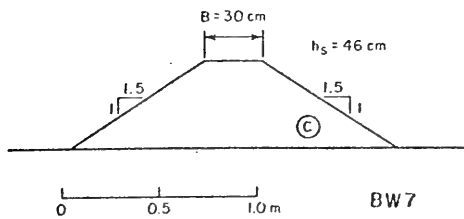
SYMBOL D/GT<sup>2</sup>

- 0.0056
- △ 0.0065
- + 0.0171
- × 0.0161
- ◇ 0.0555



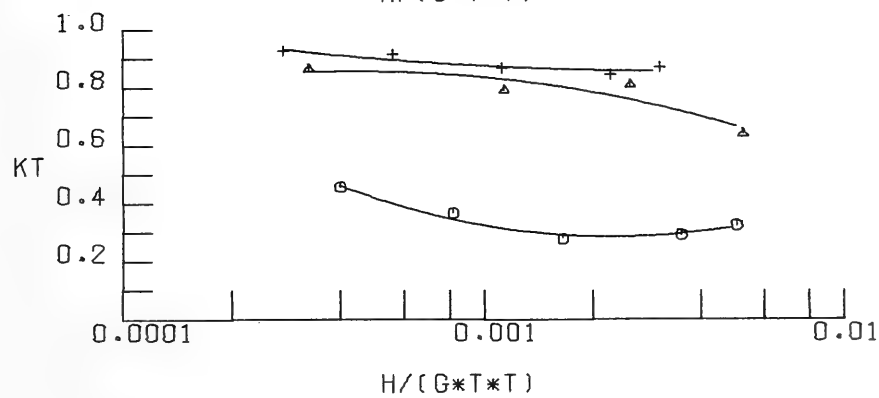
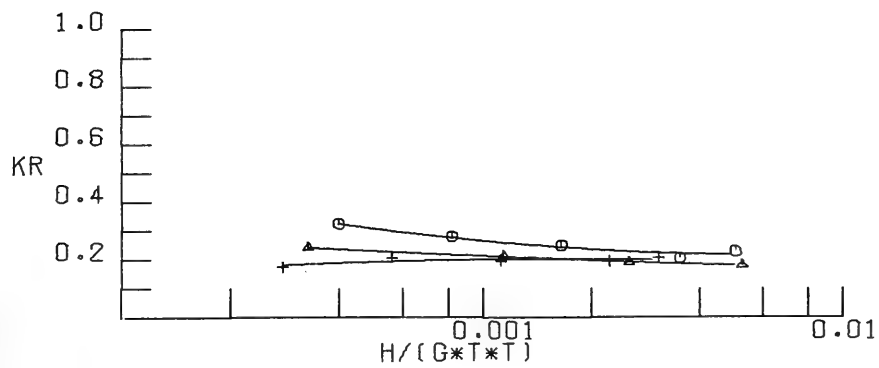
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 6 DS/HS= 0.75



SYMBOL DS/HS

- 0.98
- △ 1.30
- +

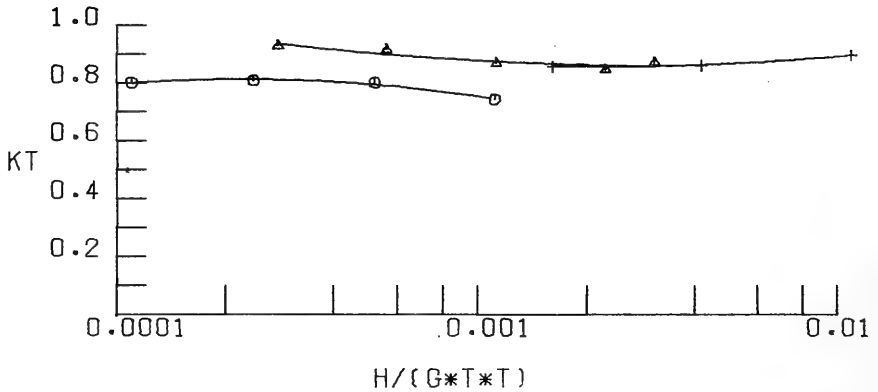
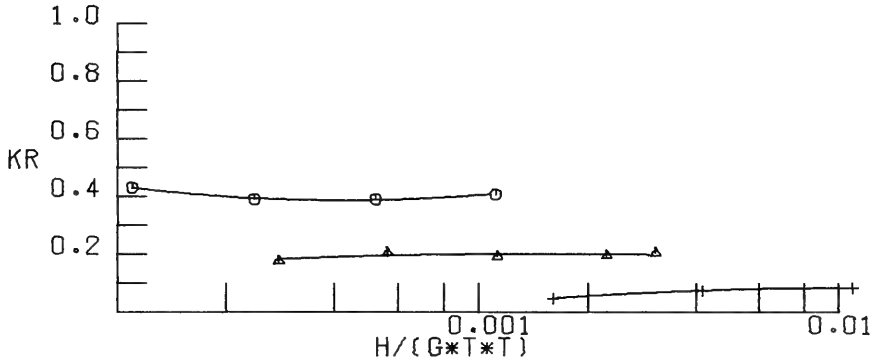


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 7 D/(GT<sup>2</sup>)=0.016

SYMBOL D/GT2

○ 0.0065  
 ▲ 0.0161  
 + 0.0550

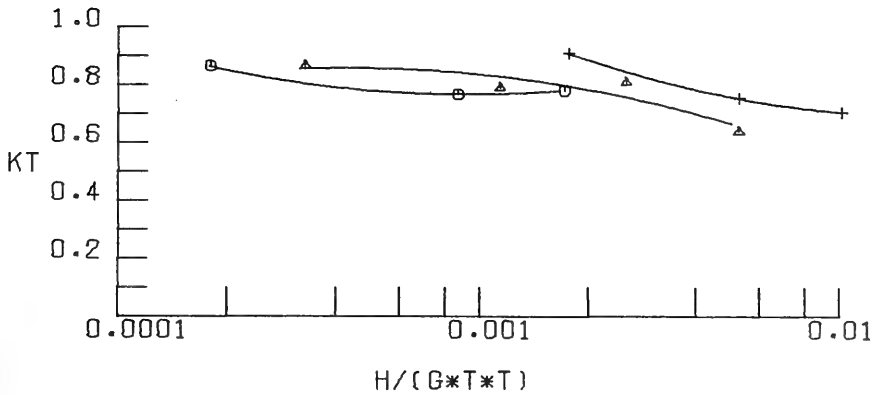
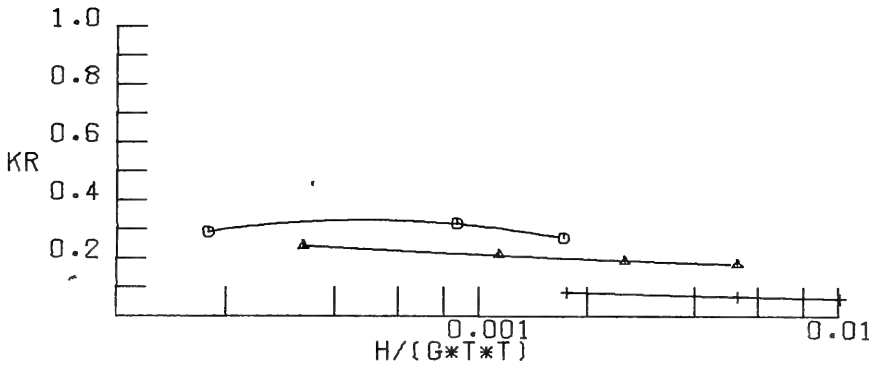


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 7 DS/HS= 1.63

SYMBOL D/OT2

○ 0.0065  
 △ 0.0161  
 + 0.0555



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

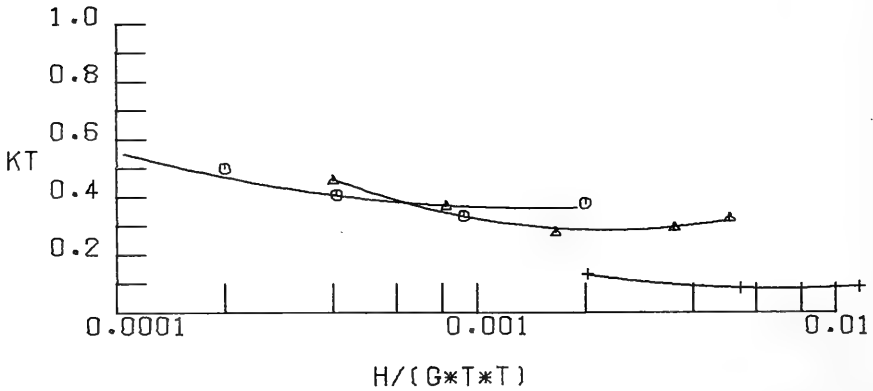
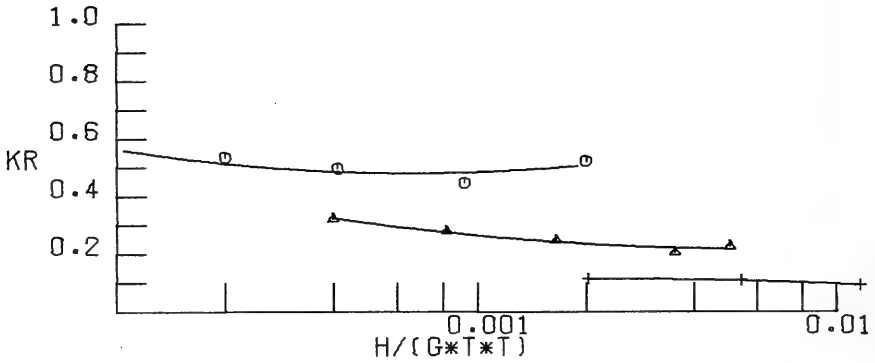
BREAKWATER

7

DS/HS= 1.30

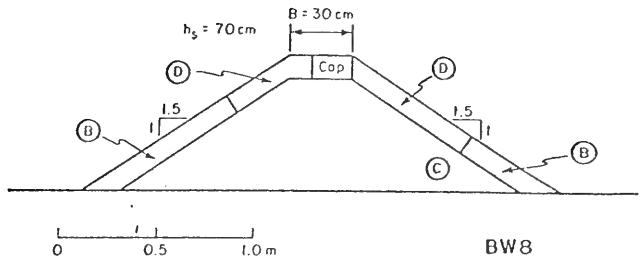
SYMBOL  $D/GT^2$

○ 0.0065  
 ▲ 0.0161  
 + 0.0555

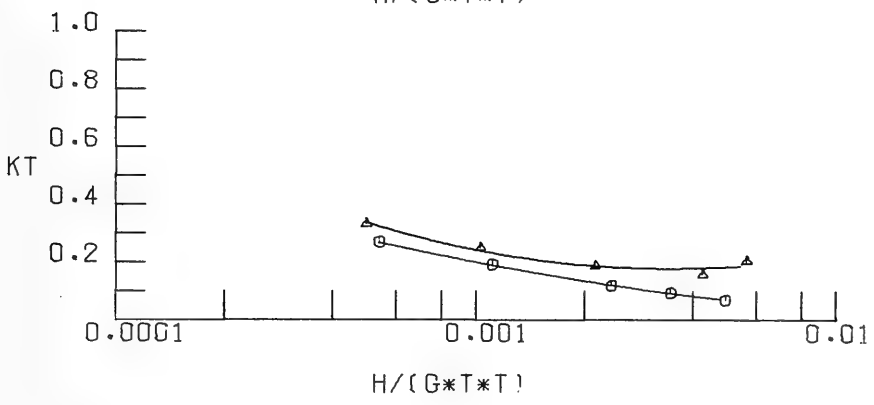
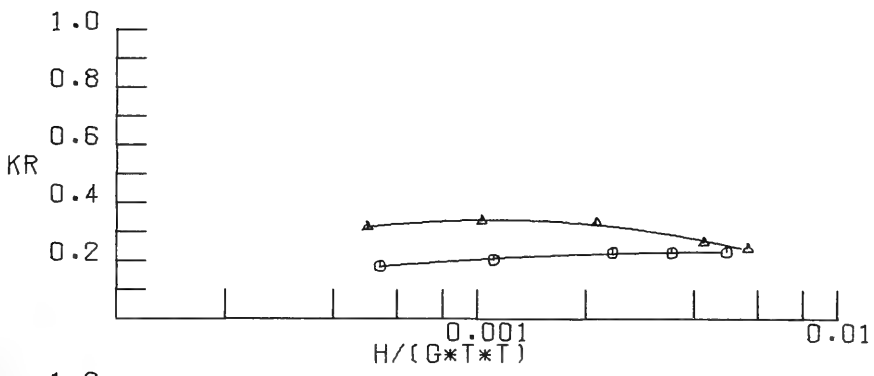


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

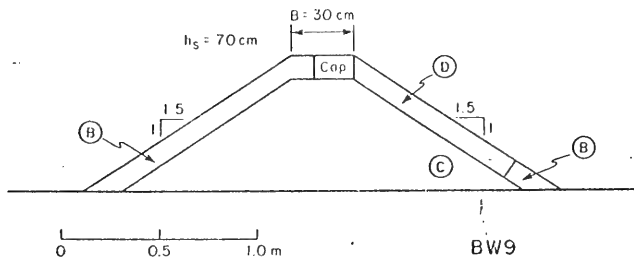
BREAKWATER 7 DS/HS= 0.98



SYMBOL DS/HS  
 □ 0.64  
 ▲ 0.86

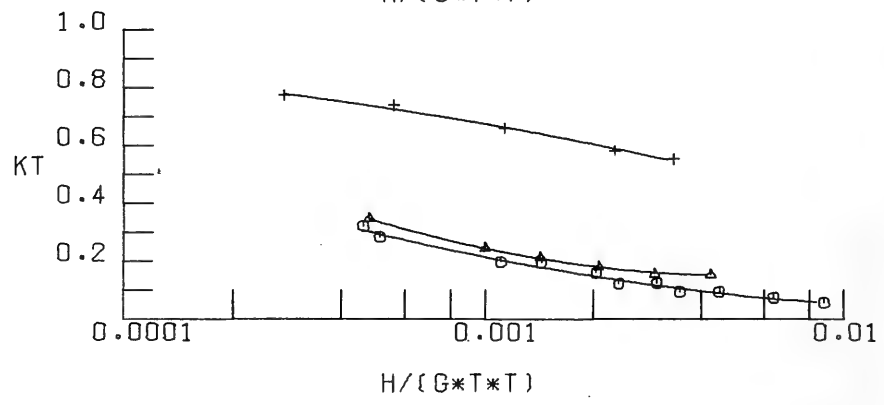
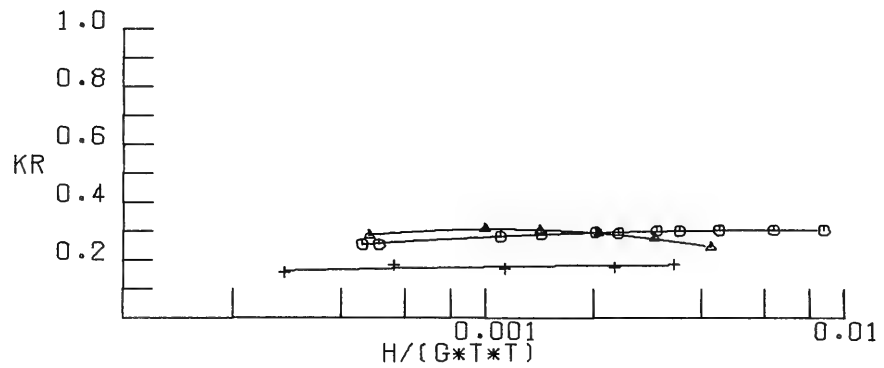


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS  
 BREAKWATER 8 D/(GT<sup>2</sup>)=0.016



SYMBOL DS/HS

□	0.64
△	0.86
+	1.07



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 9 D/(GT<sup>2</sup>)=0.016

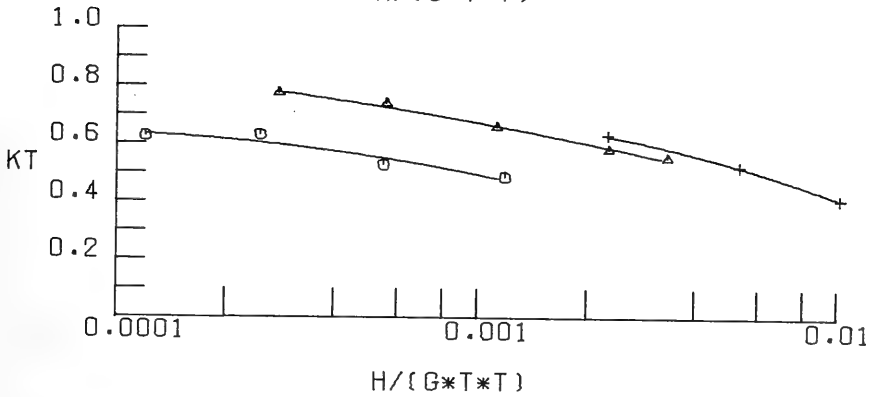
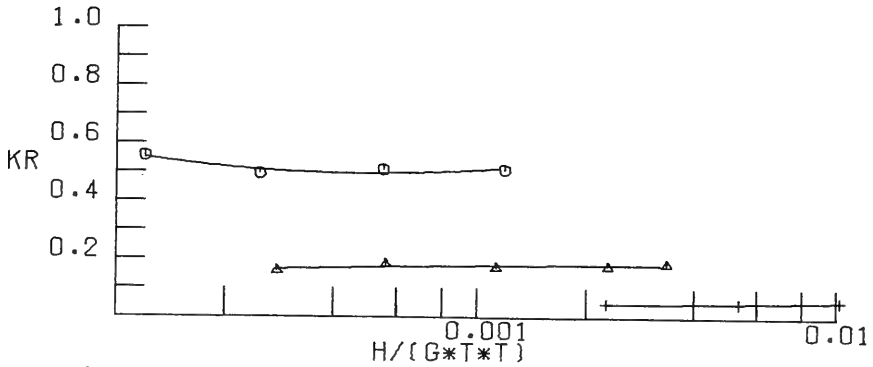


SYMBOL  $D/GT^2$

○ 0.0065

△ 0.0161

+ 0.0550



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

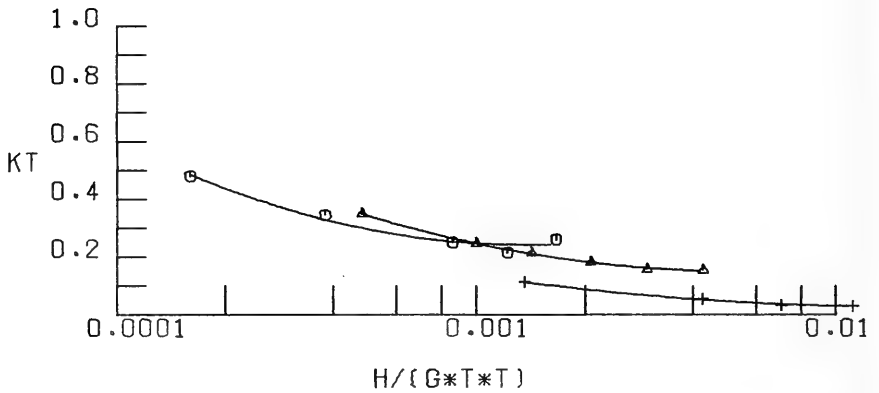
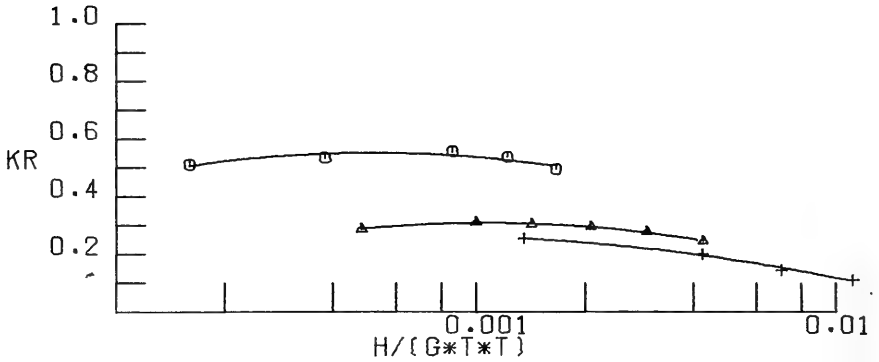
BREAKWATER

9

DS/HS= 1.07

SYMBOL D/GT2

□ 0.0065  
 ▲ 0.0161  
 + 0.0555

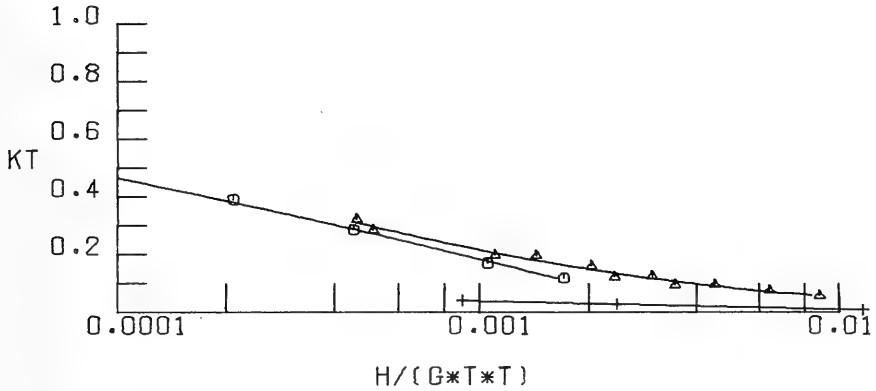
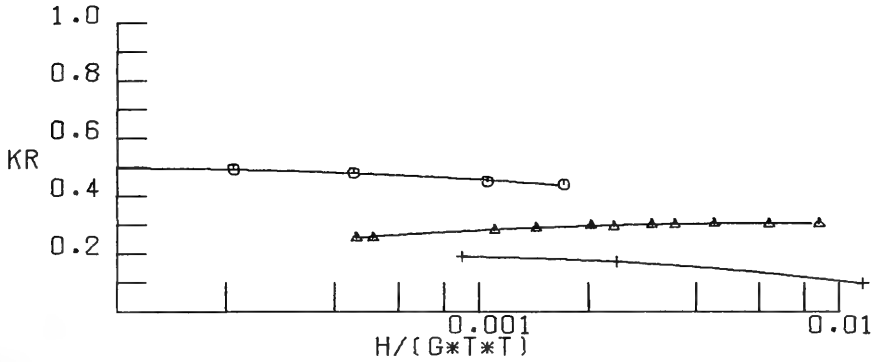


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

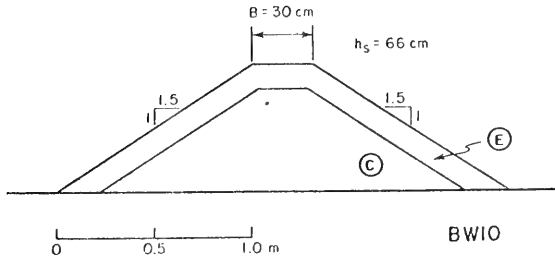
BREAKWATER 9 DS/HS= 0.86

SYMBOL D/GT2

○ 0.0065  
 ▲ 0.0162  
 + 0.0555

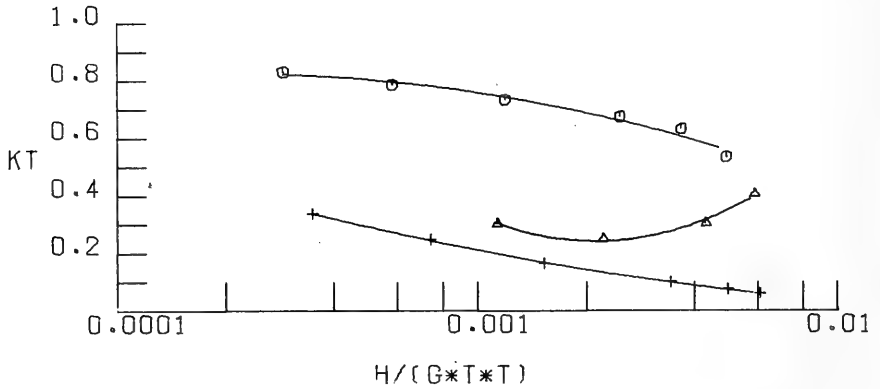
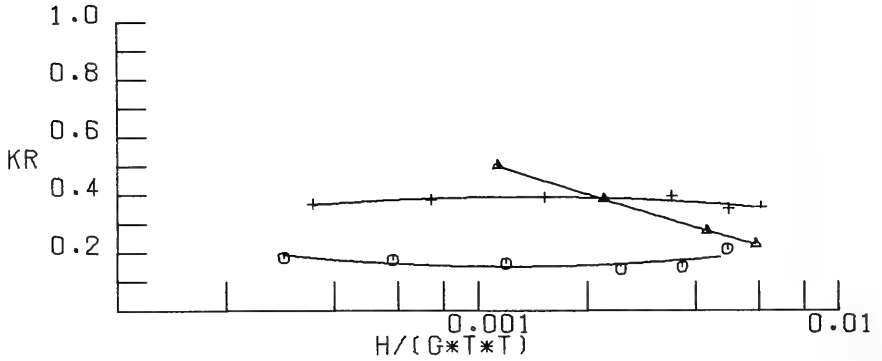


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS  
 BREAKWATER 9 DS/HS= 0.64



SYMBOL DS/HS

○	1.14
△	0.91
+	0.6



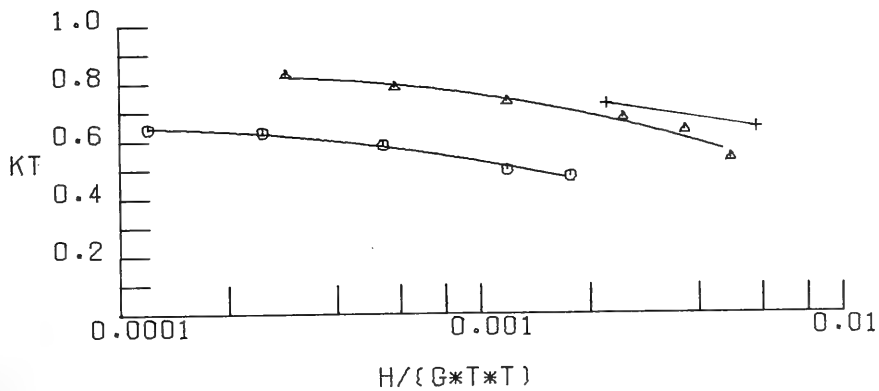
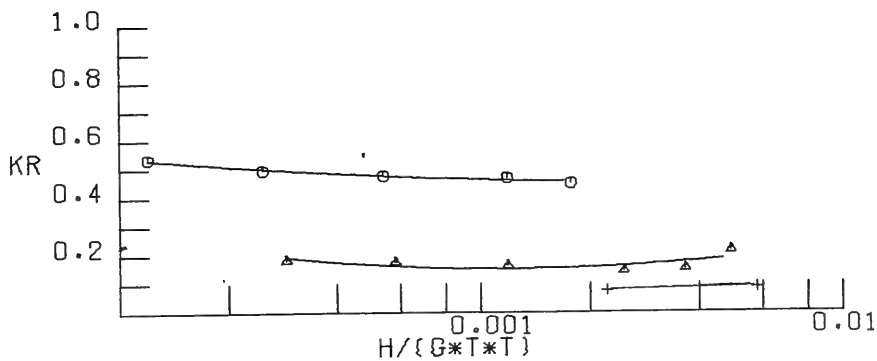
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 10

$D/(GT^2) = 0.016$

SYMBOL D/GT<sup>2</sup>

○ 0.0065  
 △ 0.0161  
 + 0.0550



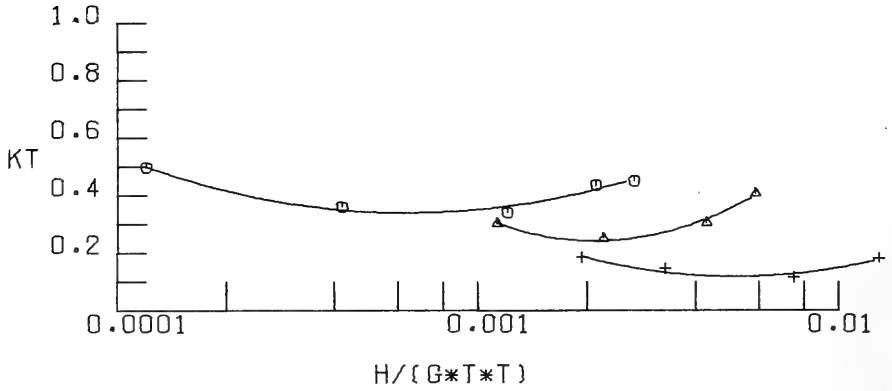
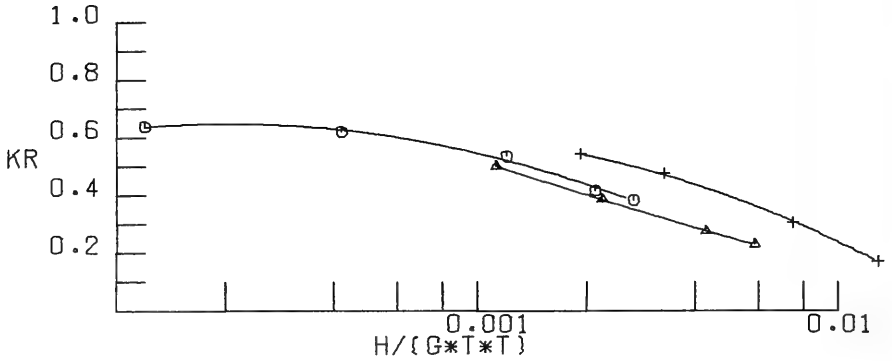
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 10

DS/HS= 1.14

SYMBOL D/GT2

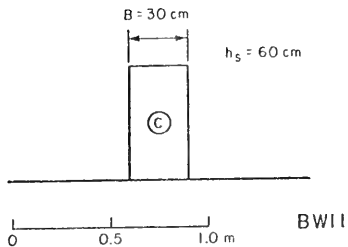
□ 0.0065  
 ▲ 0.0161  
 + 0.0555



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

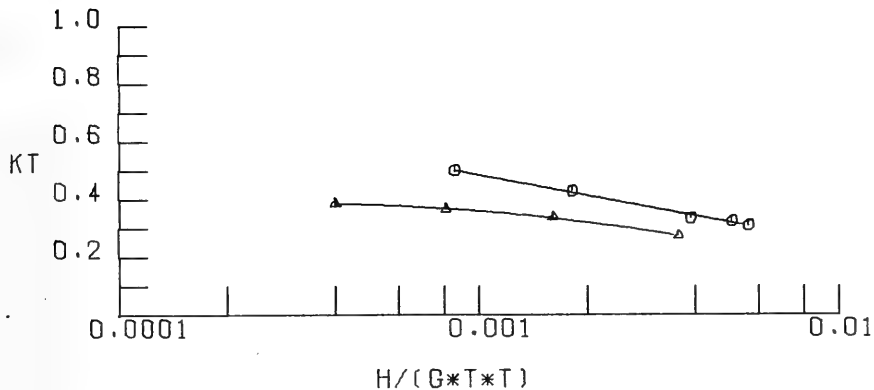
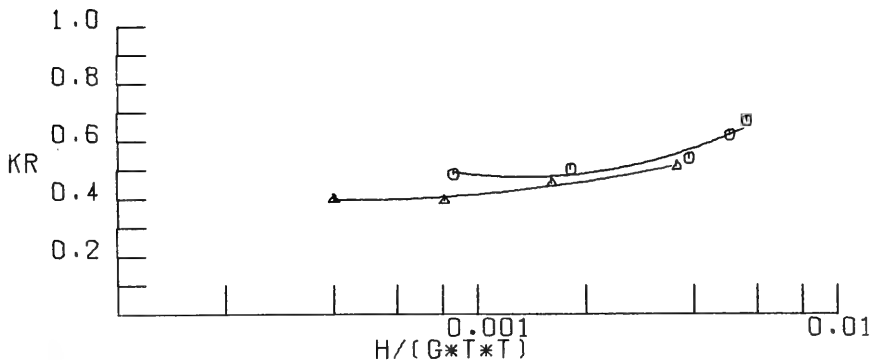
BREAKWATER 10

DS/HS= 0.91



SYMBOL DS/HS

□ 0.75  
 △ 0.51



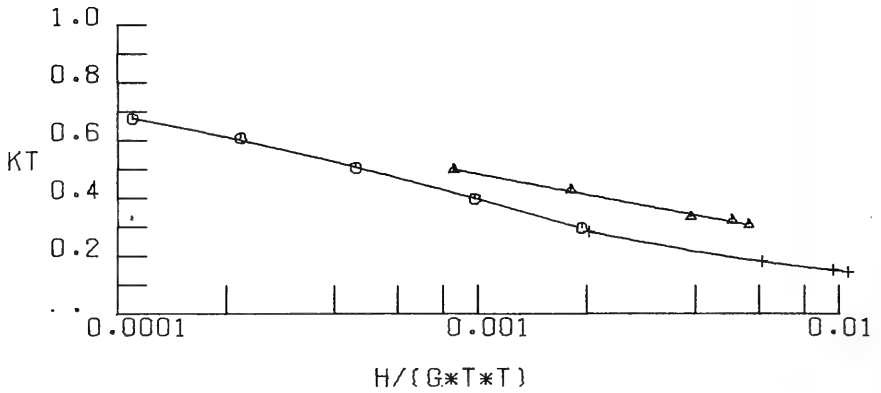
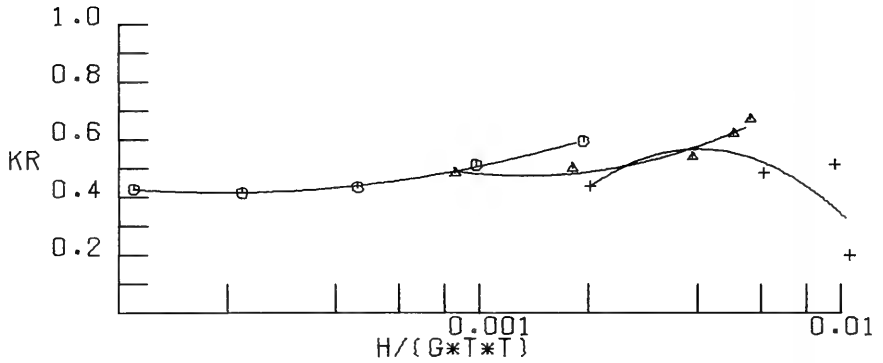
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 11

$D/(GT^2) = 0.016$

SYMBOL D/GT2

○ 0.0065  
 ▲ 0.0161  
 + 0.0555



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

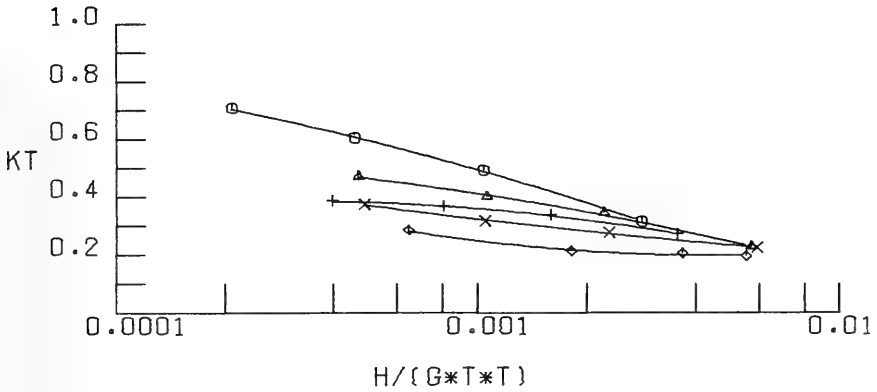
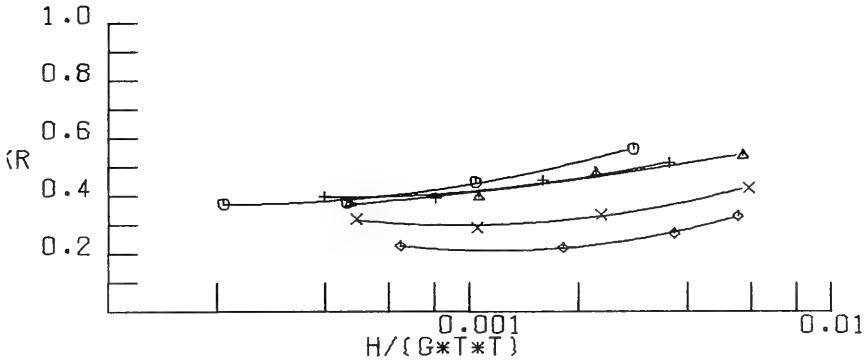
BREAKWATER 11

DS/HS= 0.75



SYMBOL D/GT2

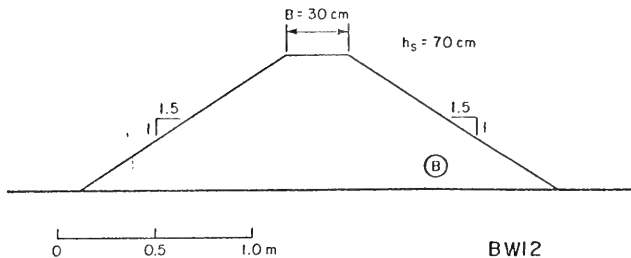
○ 0.0083  
 ▲ 0.0133  
 + 0.0157  
 × 0.0231  
 ◇ 0.0311



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 11

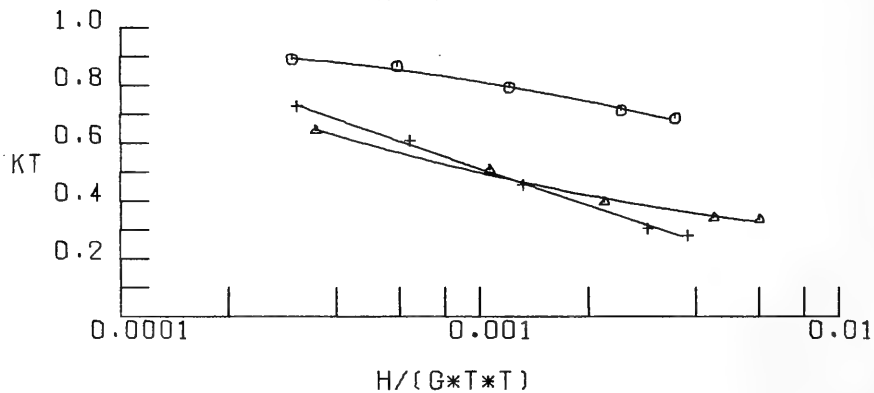
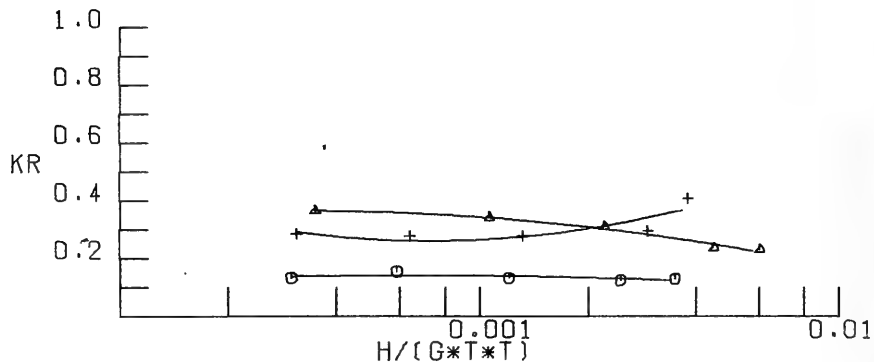
DS/HS= 0.51



SYMBOL DS/HS

○	1.07
△	0.86
+	0.64

BW12



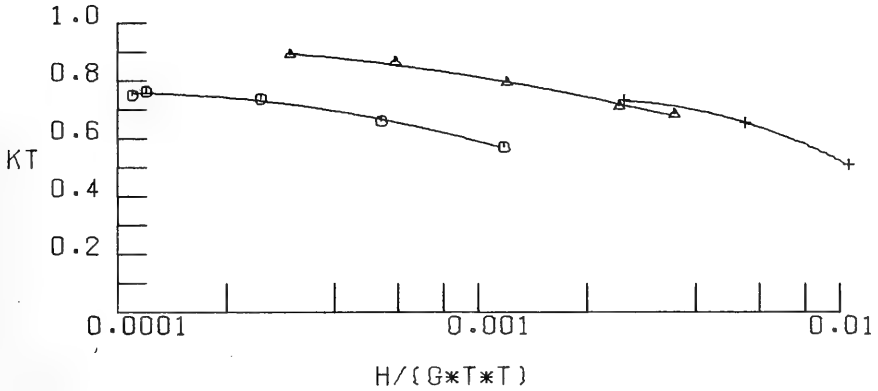
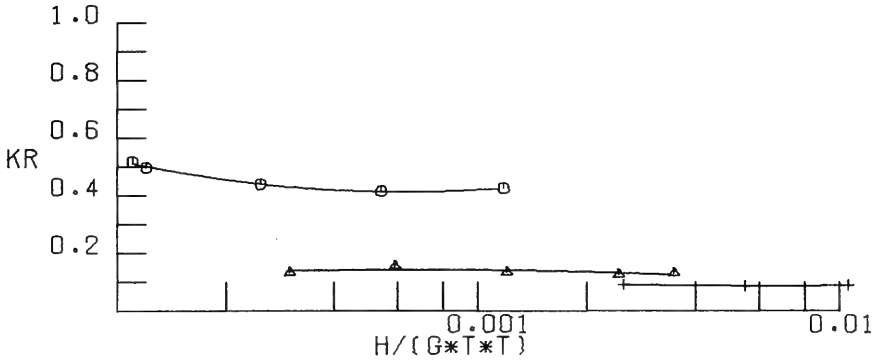
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 12

$D/(GT^2) = 0.016$

SYMBOL D/GT<sup>2</sup>

□ 0.0065  
 ▲ 0.0161  
 + 0.0550

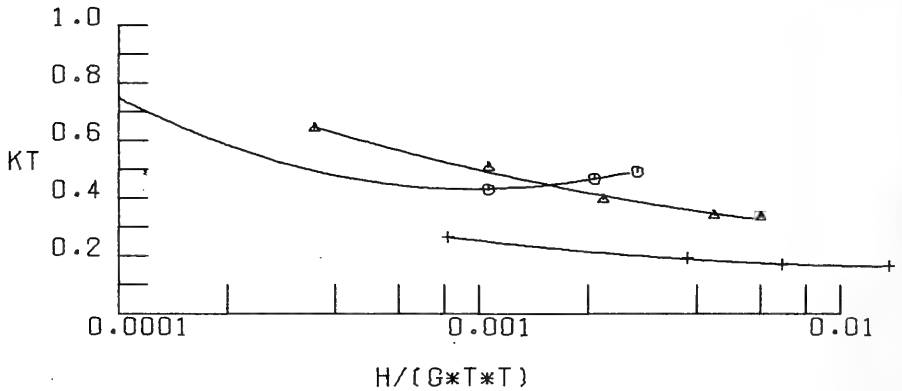
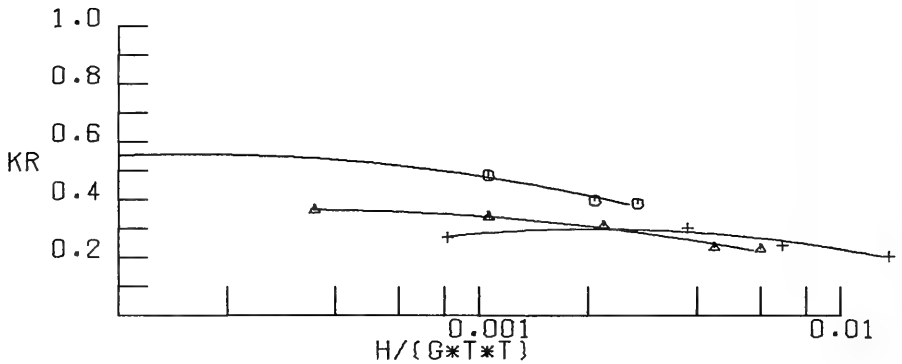


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 12 DS/HS= 1.07

SYMBOL D/GT2

○ 0.0065  
 ▲ 0.0161  
 + 0.0555



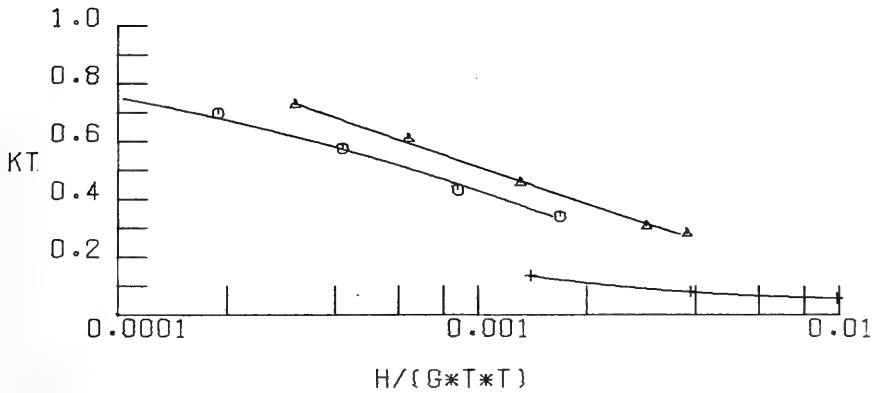
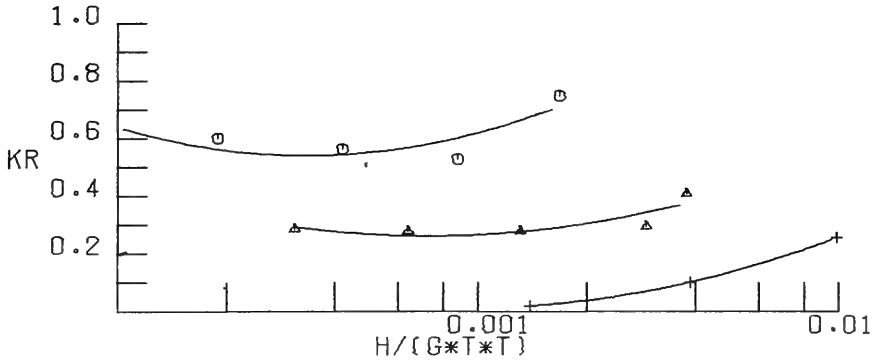
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 12

DS/HS= 0.86

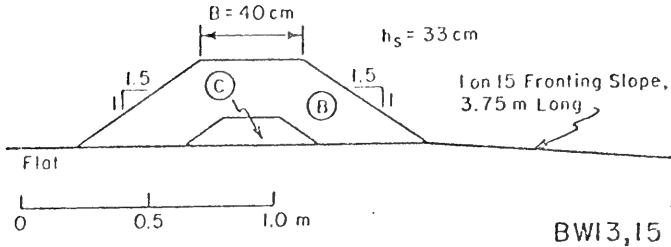
SYMBOL D/GT2

○ 0.0065  
 ▲ 0.0161  
 + 0.0555

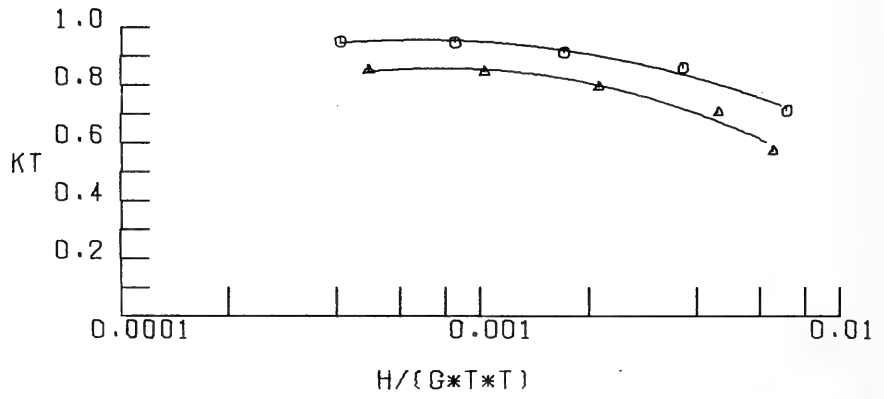
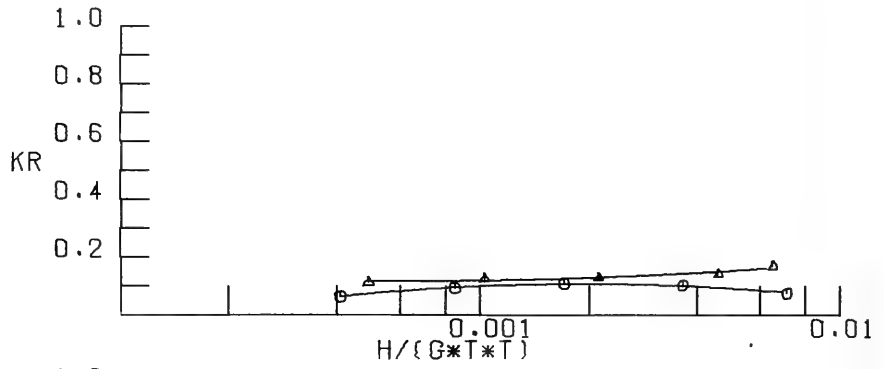


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 12 DS/HS= 0.64



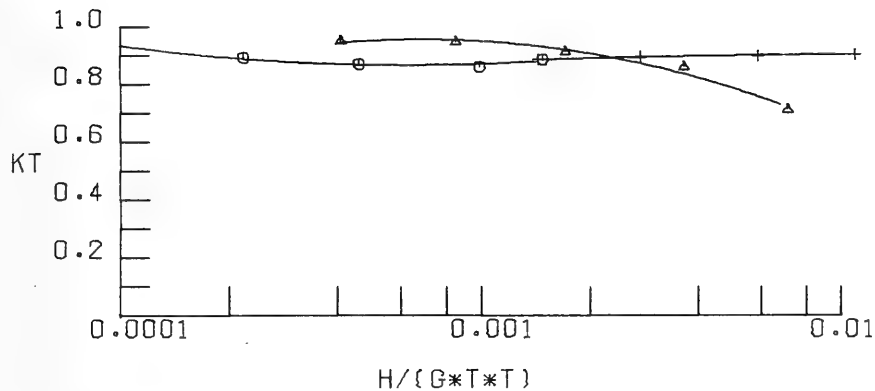
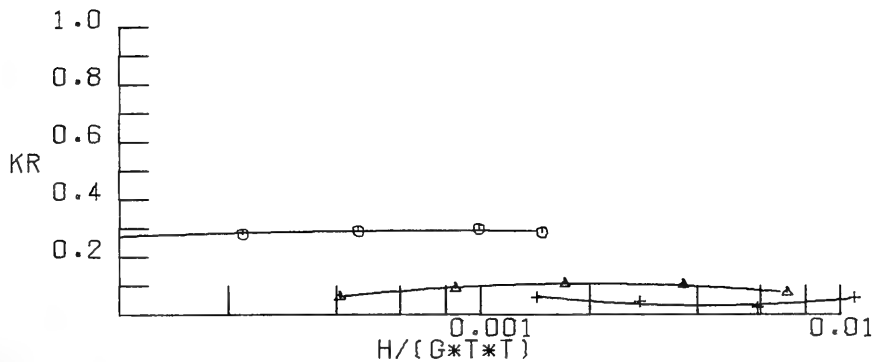
SYMBOL	DS/HS
○	1.82
△	1.36
+	1.06



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS  
 BREAKWATER 13  $D/(GT^2) = 0.016$

SYMBOL D/GT2

○ 0.0065  
 △ 0.0161  
 + 0.0555

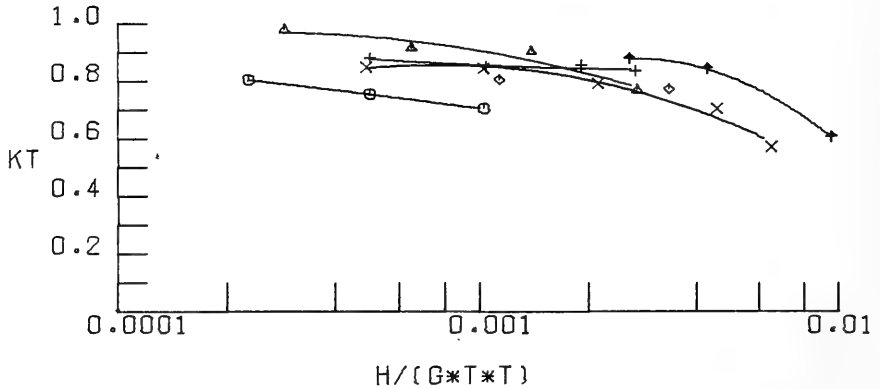
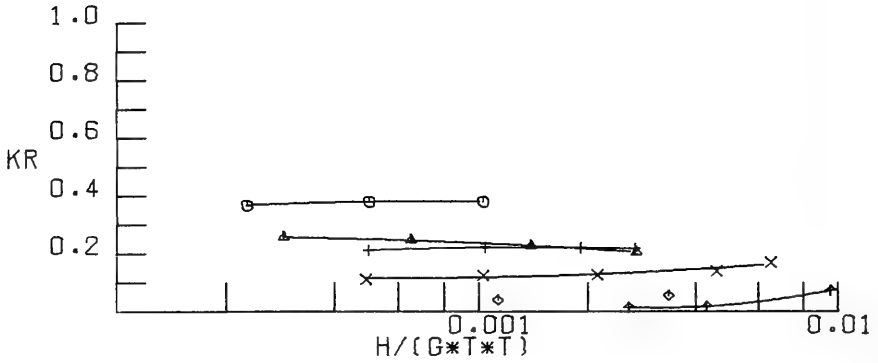


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 13 DS/HS= 1.82

SYMBOL D/GT2

○	0.0042
△	0.0065
+	0.0103
×	0.0161
◇	0.0353
†	0.0555



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

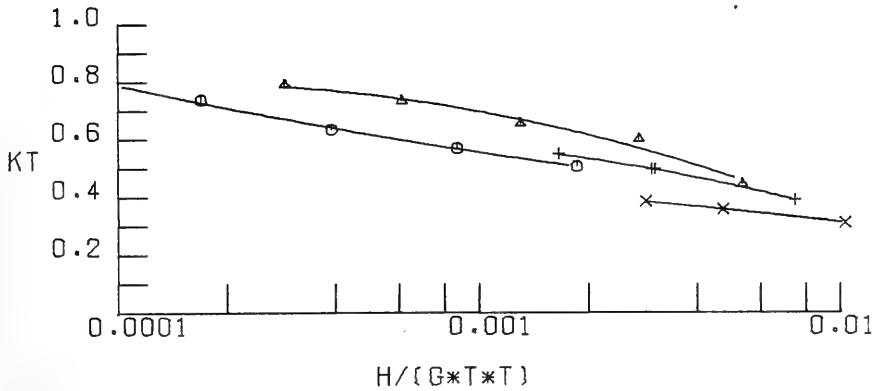
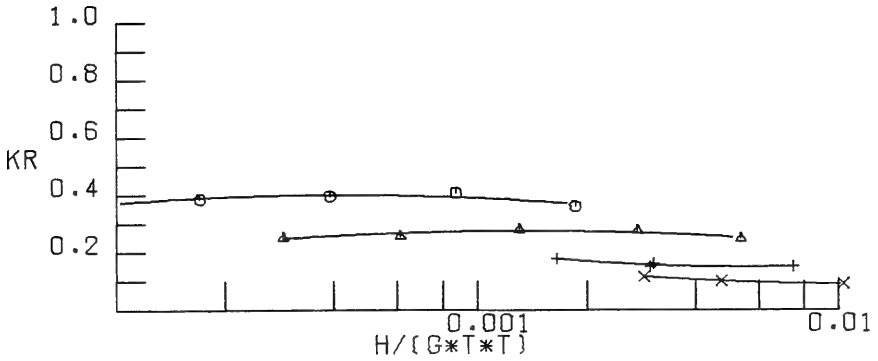
BREAKWATER 13

DS/HS= 1.36



SYMBOL D/GT2

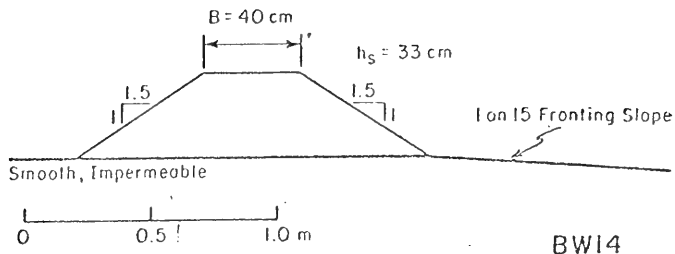
□ 0.0038  
 ▲ 0.0094  
 + 0.0229  
 × 0.0324



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

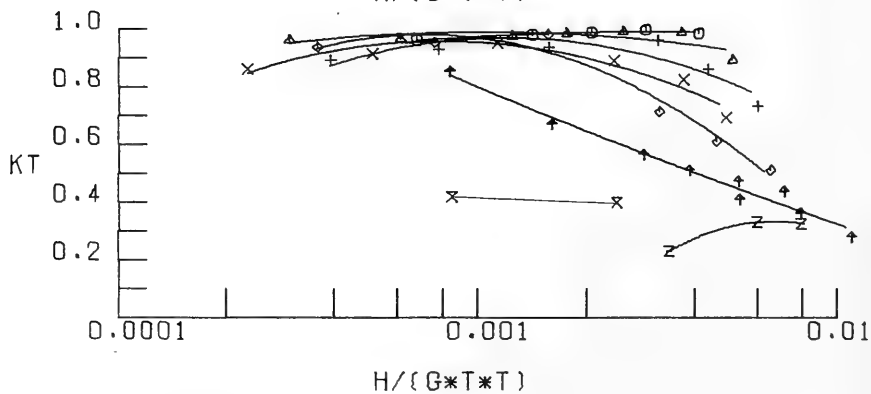
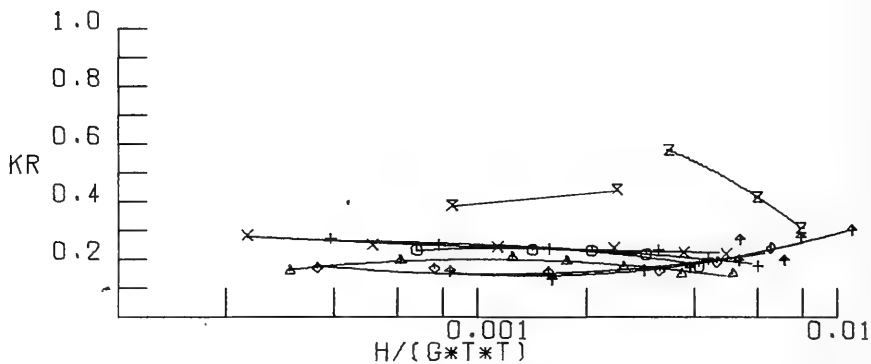
BREAKWATER 13

DS/HS= 1.06



SYMBOL DS/HS

□	1.97
△	1.82
+	1.67
x	1.52
◇	1.36
↑	1.21
x	1.06
Z	0.91



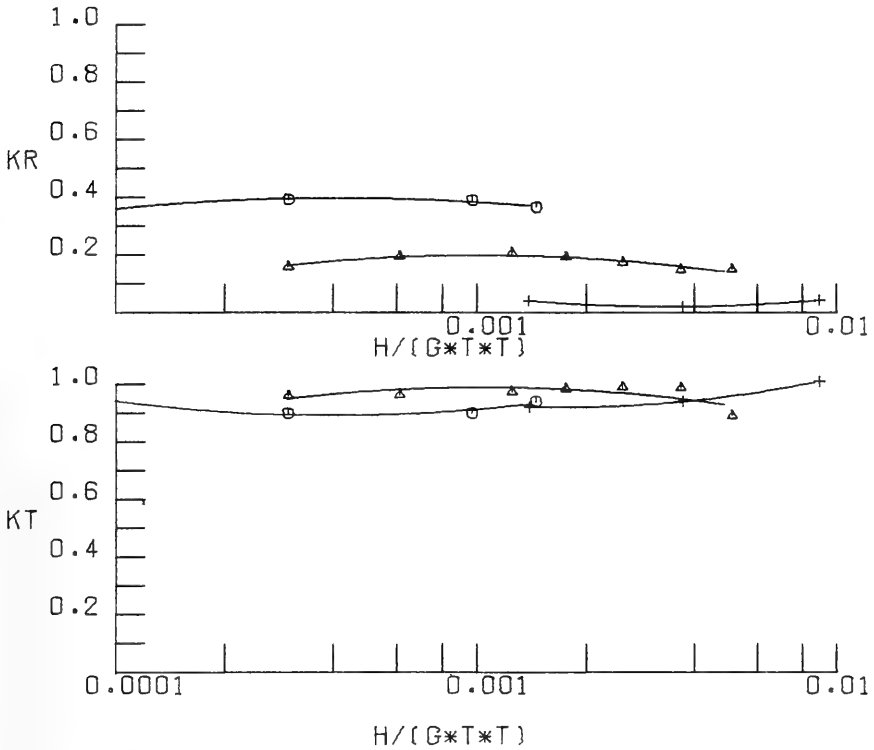
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 14

$D/(GT^2) = 0.016$

SYMBOL D/GT2

○ 0.0065  
 ▲ 0.0161  
 + 0.0555

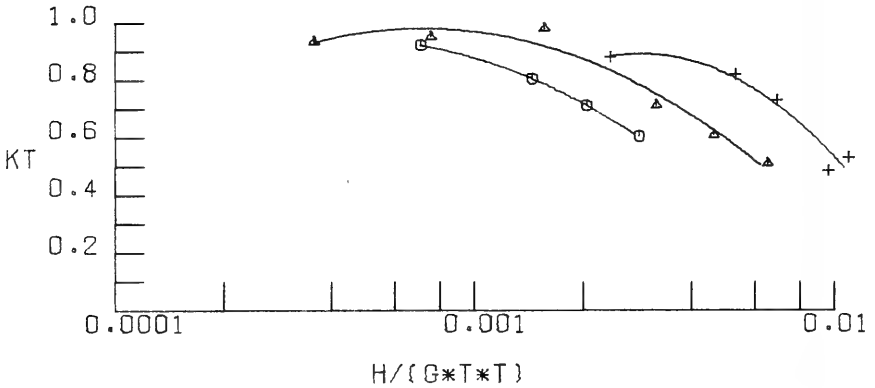
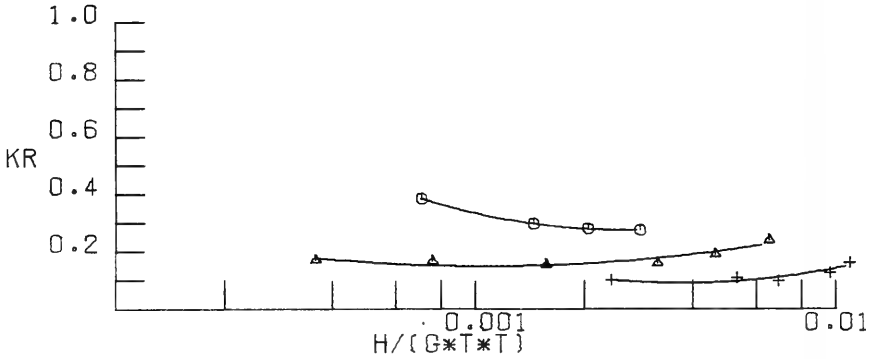


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 14 DS/HS= 1.82

SYMBOL D/GT2

○ 0.0065  
 ▲ 0.0161  
 + 0.0555



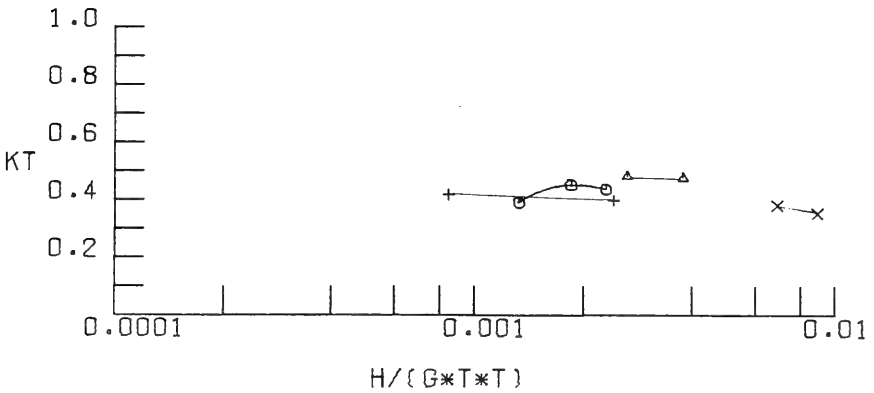
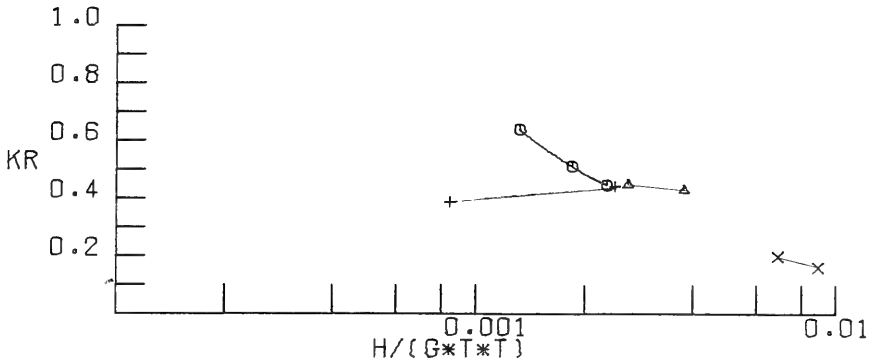
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 14

DS/HS= 1.36

SYMBOL D/GT2

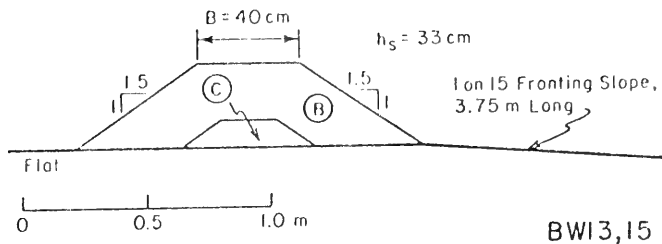
○	0.0038
△	0.0094
+	0.0161
x	0.0211



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

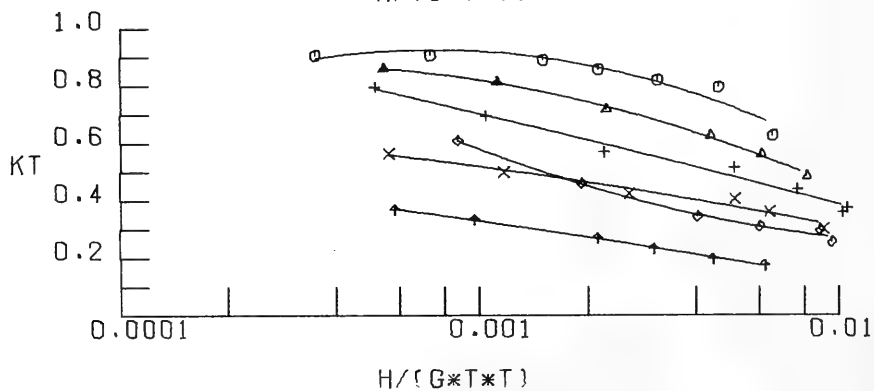
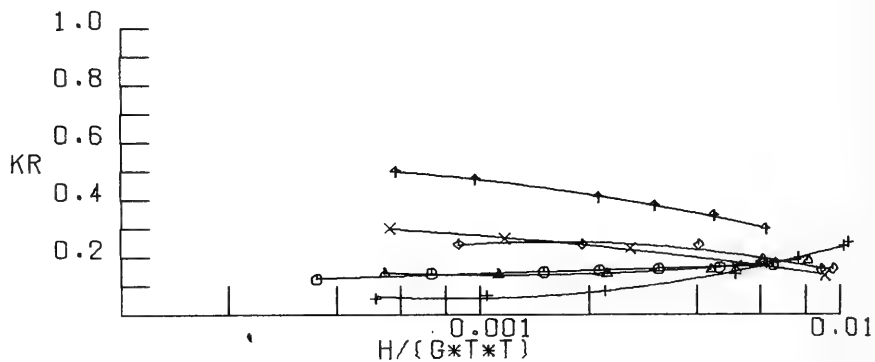
BREAKWATER 14

DS/HS= 1.06



SYMBOL  $D_s/H_s$

○	1.36
△	1.21
+	1.06
×	0.91
◇	0.76
†	0.61



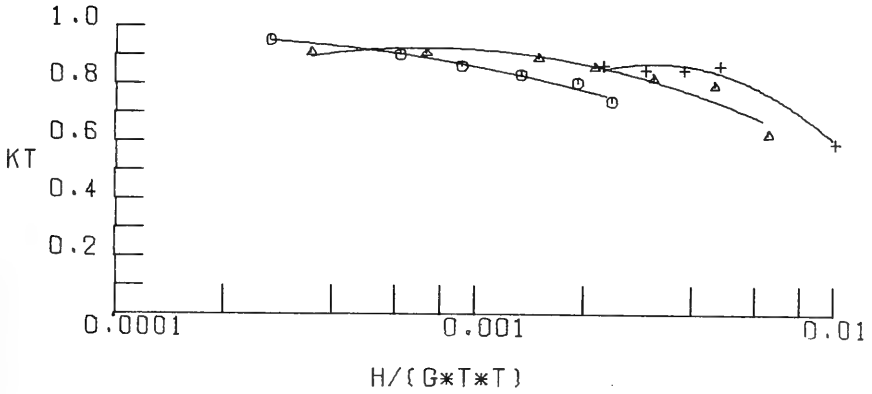
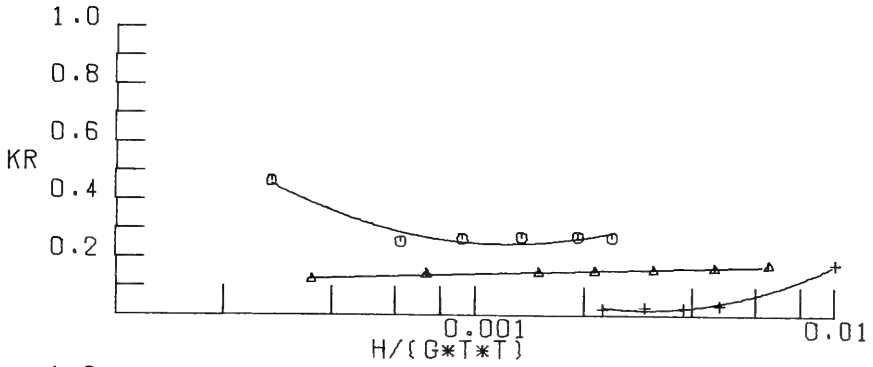
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 15

$D/(GT^2) = 0.016$

SYMBOL D/GT2

○	0.0059
△	0.0161
+	0.0555

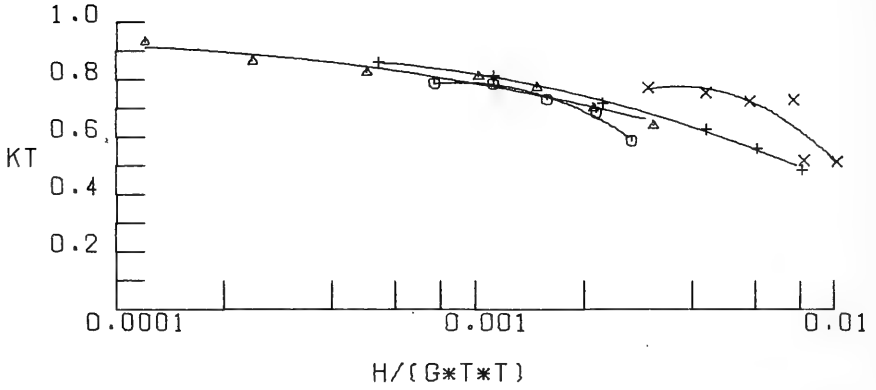
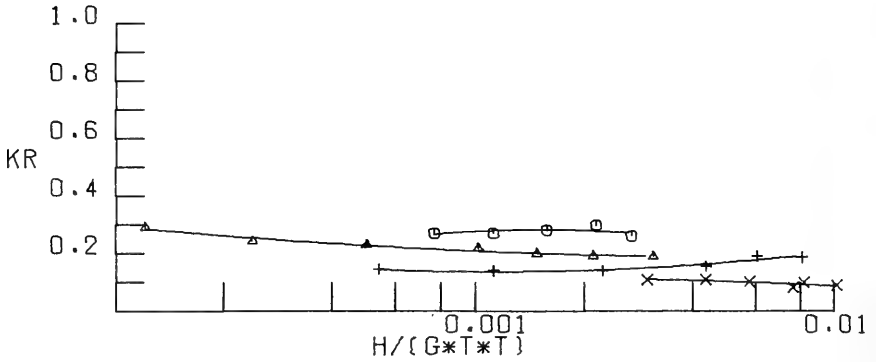


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 15 DS/HS= 1.36

SYMBOL D/GT2

○	0.0052
△	0.0065
+	0.0161
x	0.0552



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

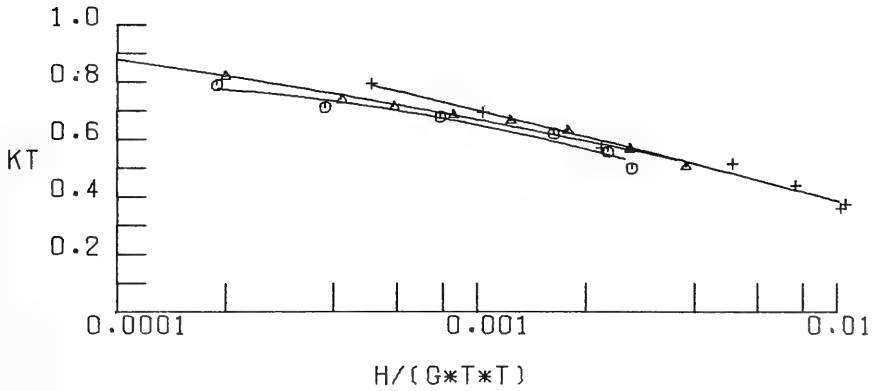
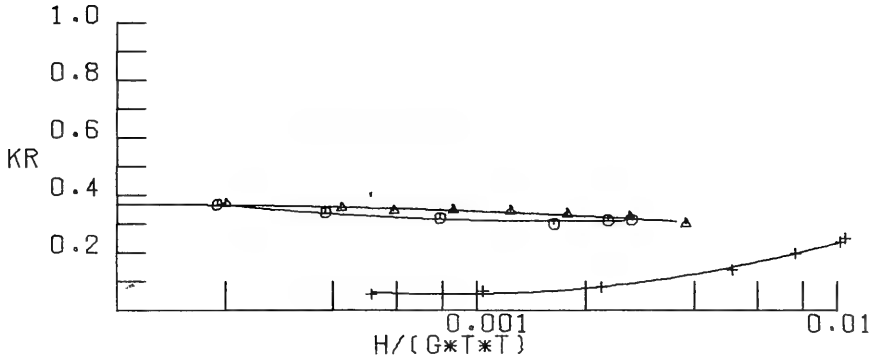
BREAKWATER 15

DS/HS= 1.21



SYMBOL D/GT<sup>2</sup>

○ 0.0046  
 ▲ 0.0065  
 + 0.0161

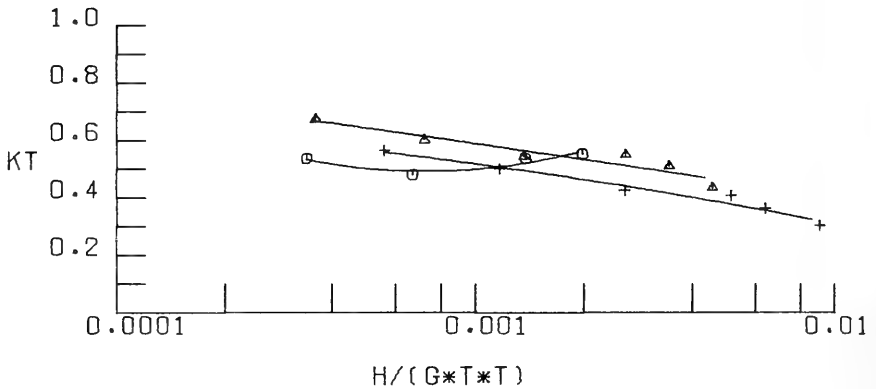
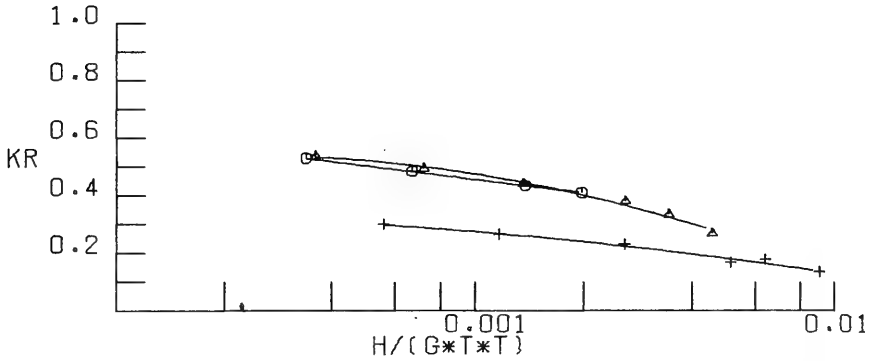


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 15 DS/HS= 1.06

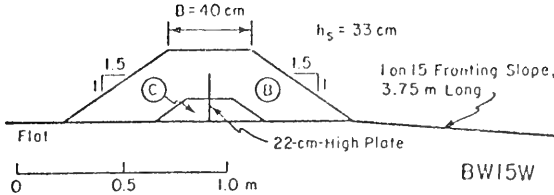
SYMBOL D/GT2

○ 0.0039  
△ 0.0065  
+ 0.0161



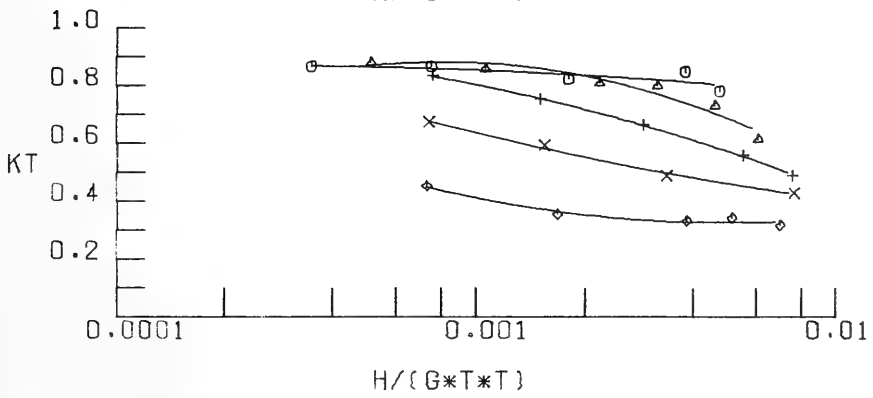
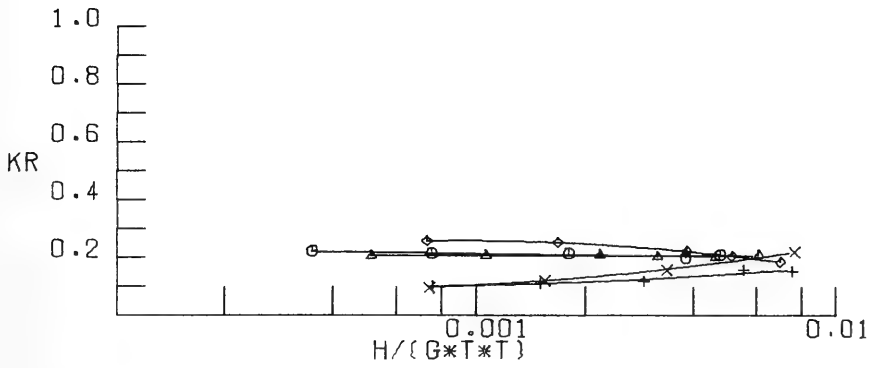
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 15 DS/HS= 0.91



SYMBOL DS/HS

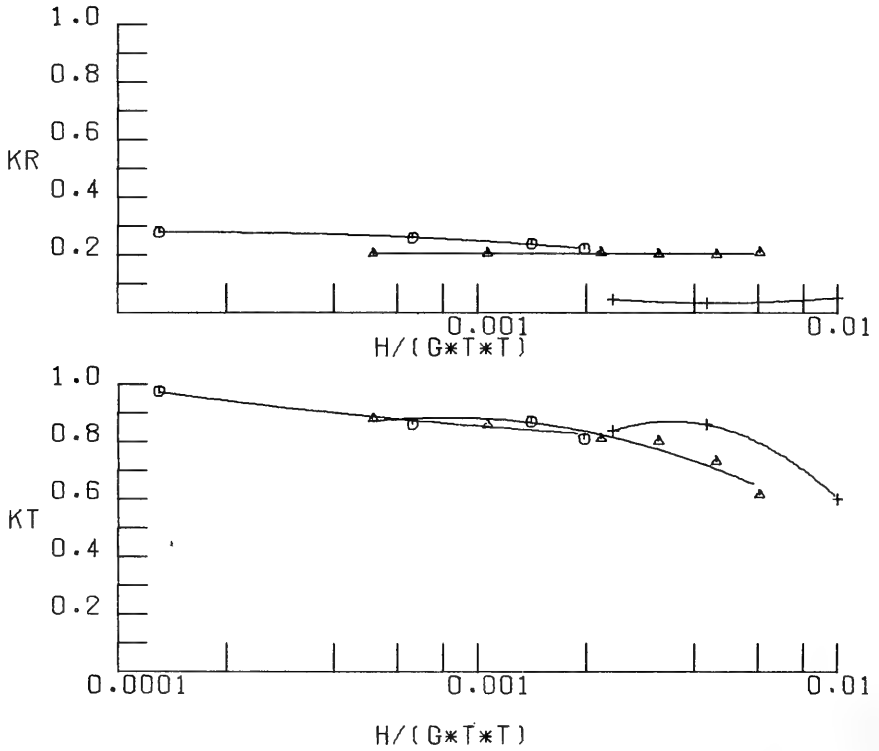
○	1.52
△	1.36
+	1.21
×	1.06
◇	0.91



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS  
 BREAKWATER 15W  $D/((GT^2))=0.016$

SYMBOL D/GT<sup>2</sup>

○ 0.0065  
 ▲ 0.0161  
 + 0.0555



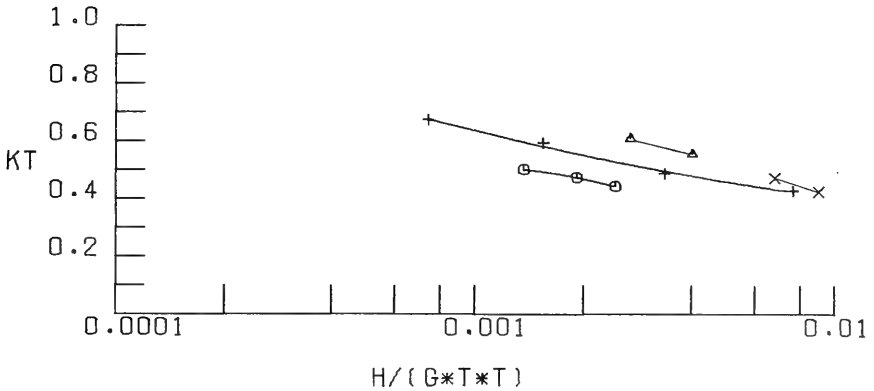
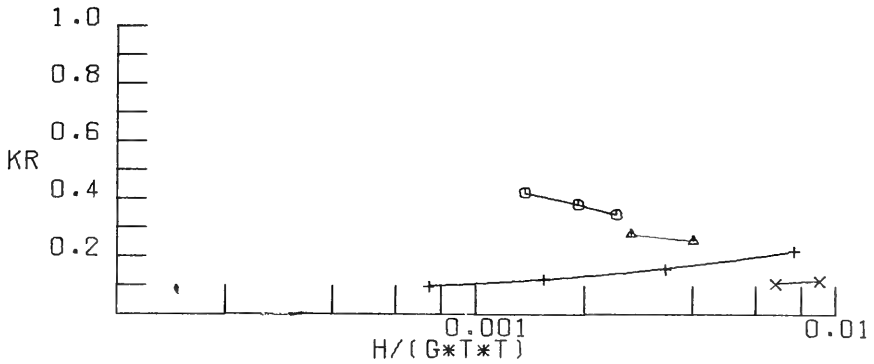
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 15W

DS/HS= 1.36

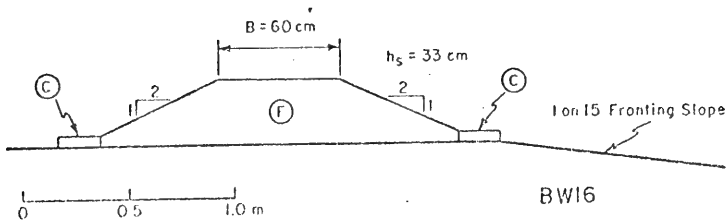
SYMBOL D/GT2

○	0.0038
△	0.0094
+	0.0161
×	0.0211



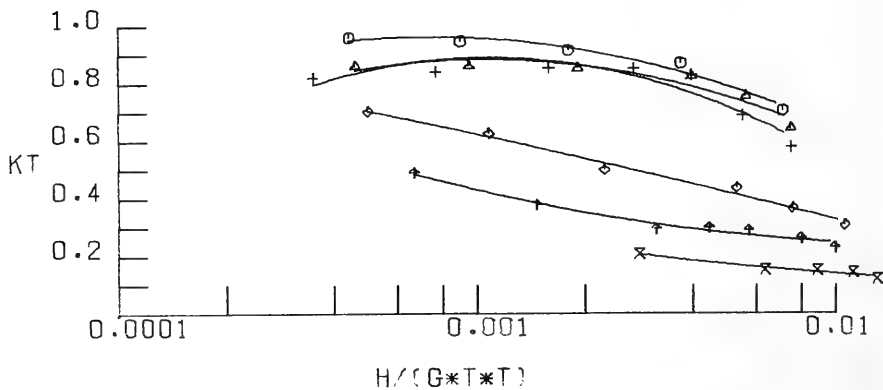
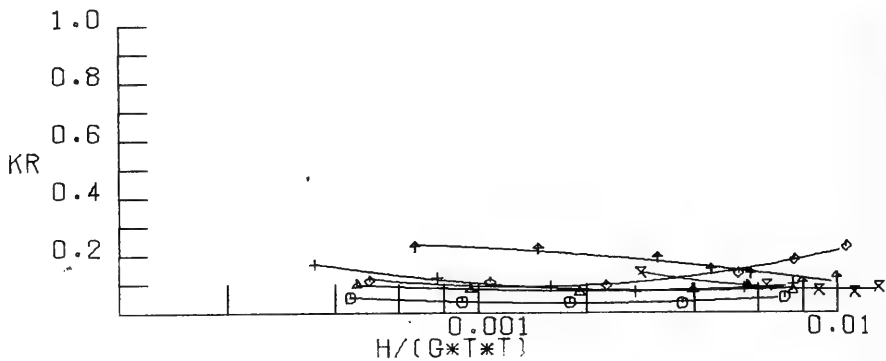
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 1SW DS/HS= 1.06



SYMBOL DS/HS

○	1.82
△	1.67
+	1.52
×	1.36
◇	1.06
†	0.91
×	0.76
z	0.61



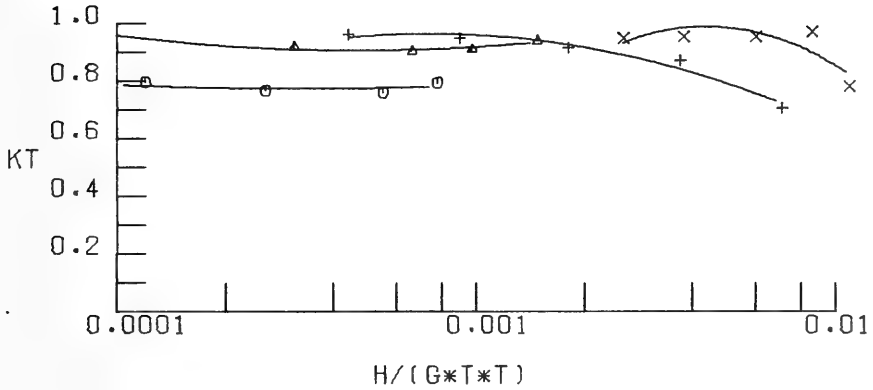
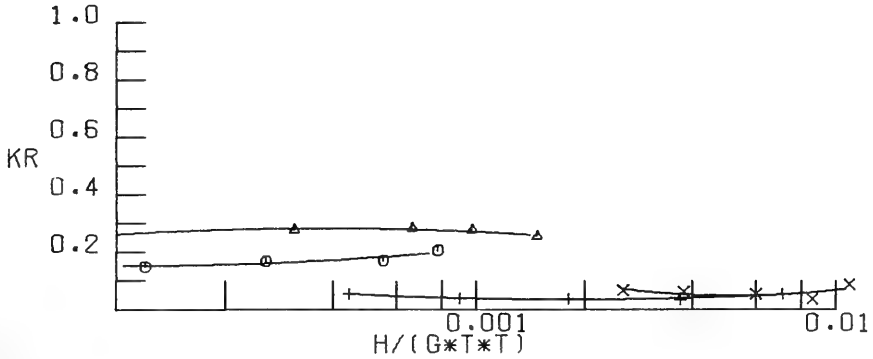
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 16

$D/(GT^2) = 0.016$

SYMBOL D/GT<sup>2</sup>

○ 0.0026  
 ▲ 0.0065  
 + 0.0161  
 × 0.0555

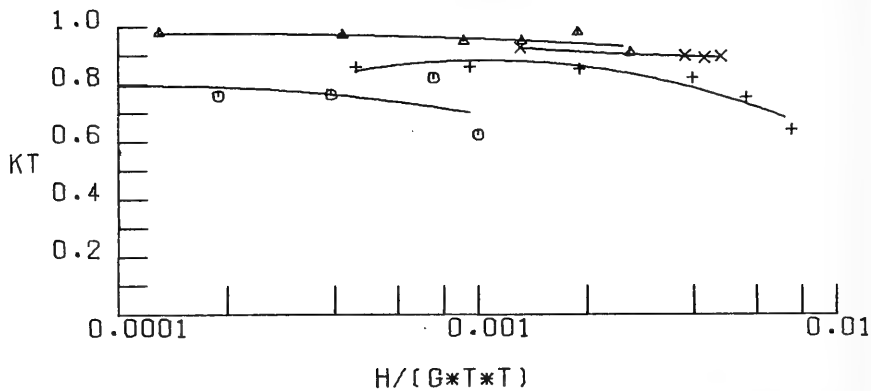
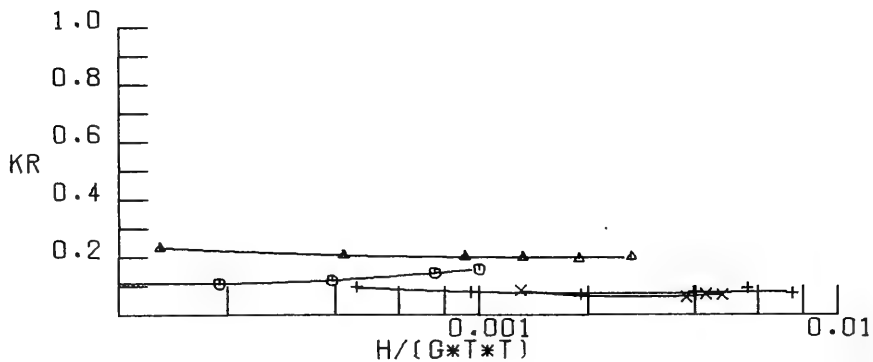


WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 16 DS/HS= 1.82

SYMBOL D/GT2

□	0.0026
△	0.0065
+	0.0160
x	0.0550



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

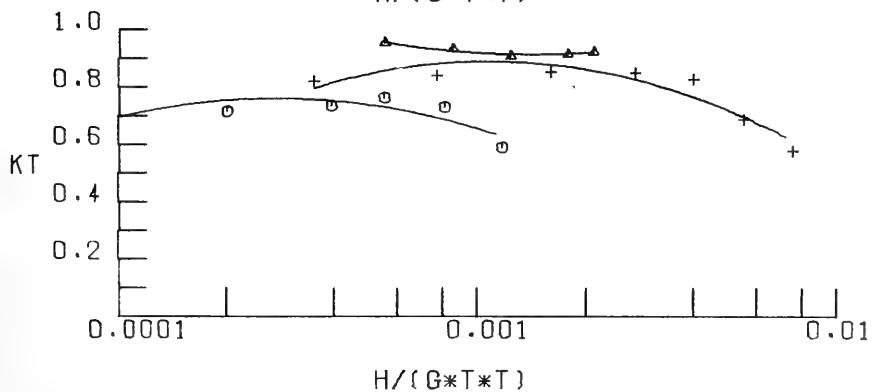
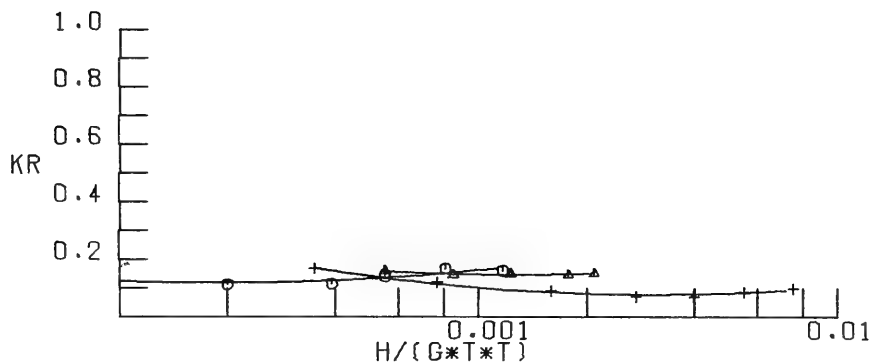
BREAKWATER 16

DS/HS= 1.67



SYMBOL D/GT2

○ 0.0025  
 △ 0.0065  
 + 0.0161



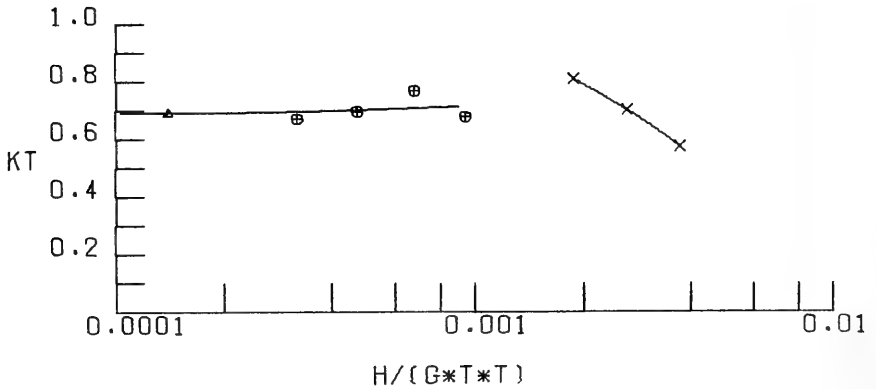
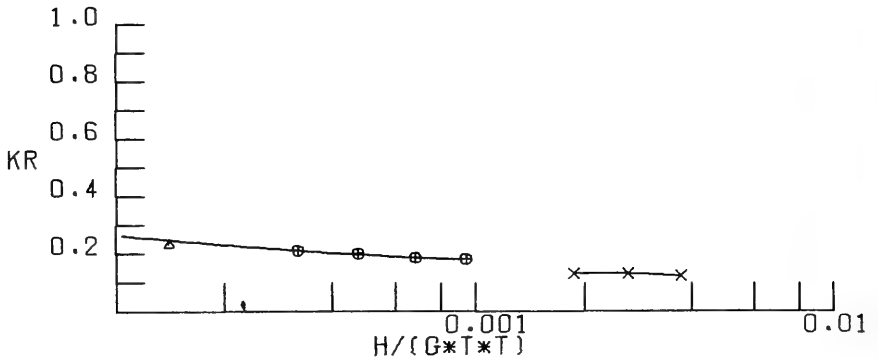
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 16

DS/HS= 1.52

SYMBOL D/GT2

⊙	0.0024
▲	0.0022
+	0.0024
×	0.0065



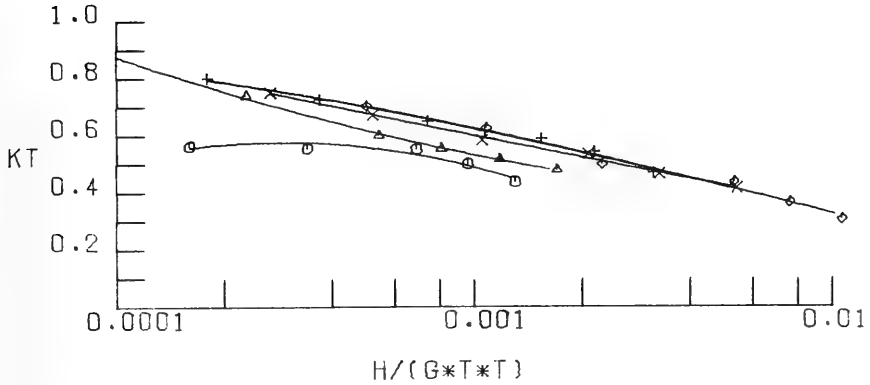
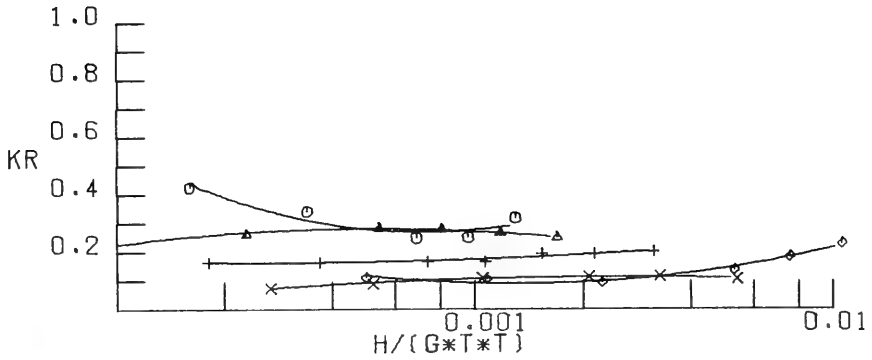
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 16

DS/HS= 1.36

SYMBOL  $D/GT^2$

○	0.0022
△	0.0037
+	0.0065
x	0.0131
◇	0.0161



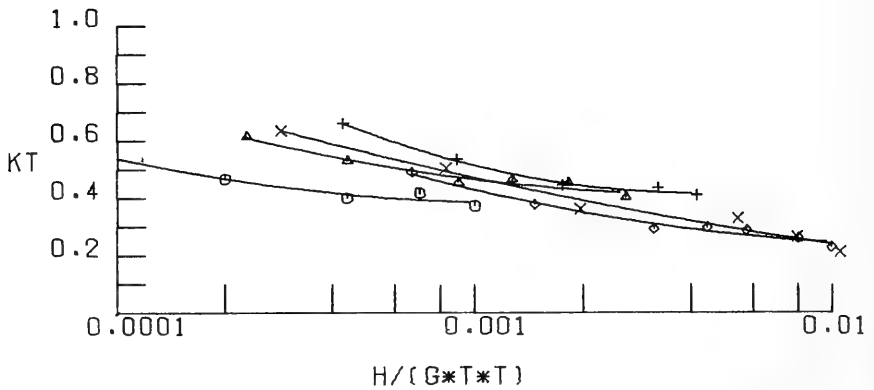
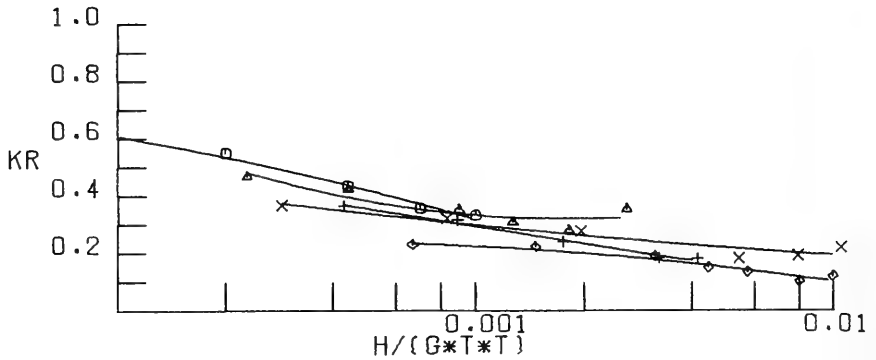
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 16

DS/HS= 1.06

SYMBOL  $D/GT^2$

□	0.0020
△	0.0037
+	0.0065
x	0.0131
◇	0.0161



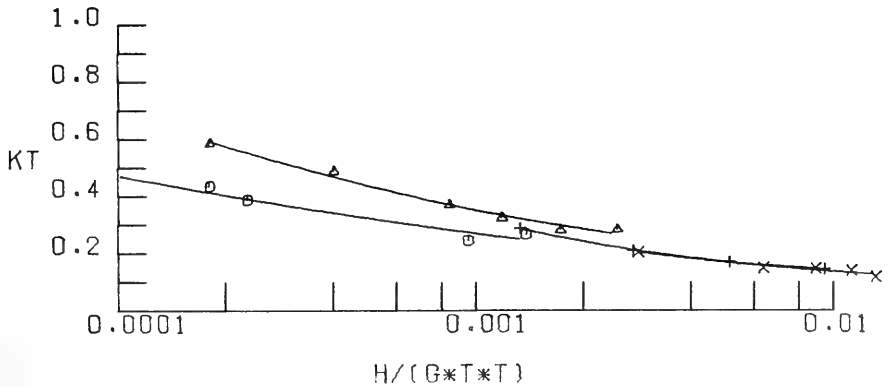
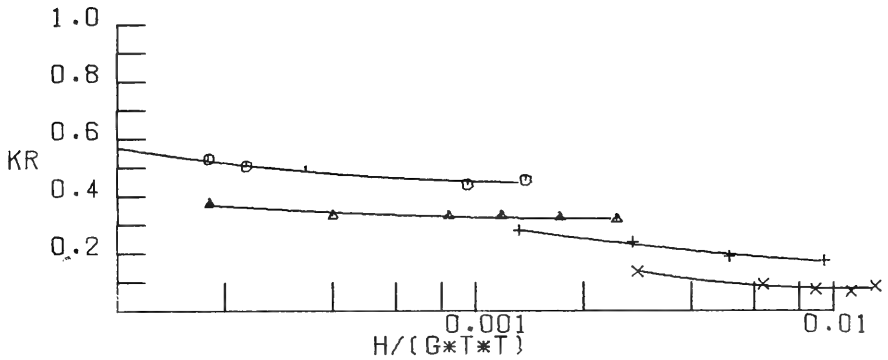
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 16

DS/HS= 0.91

SYMBOL D/GT2

○	0.0019
△	0.0037
+	0.0130
x	0.0161



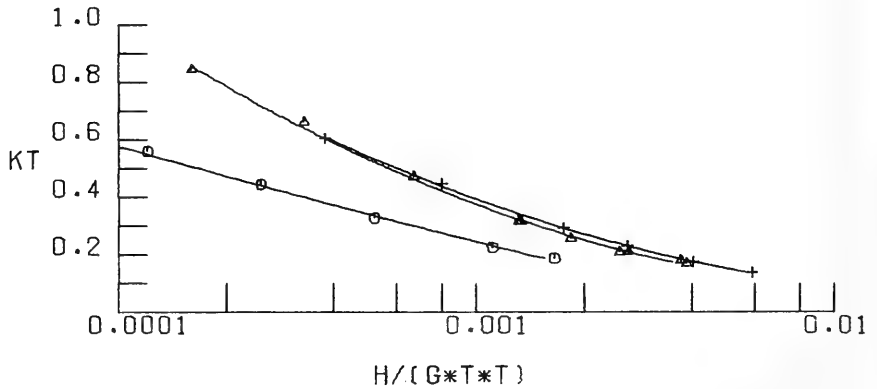
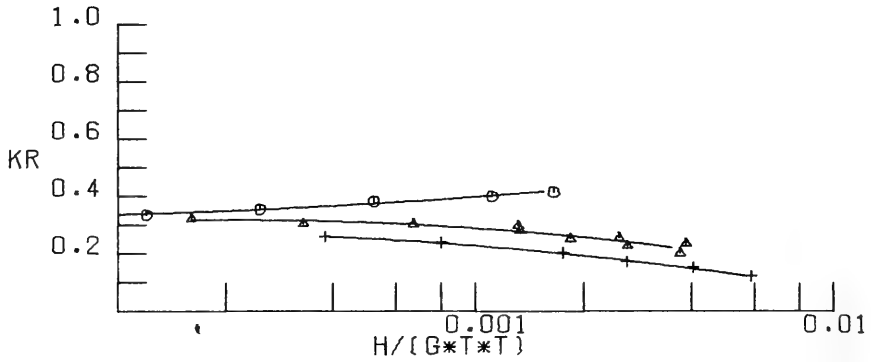
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 16

DS/HS= 0.76

SYMBOL D/GT2

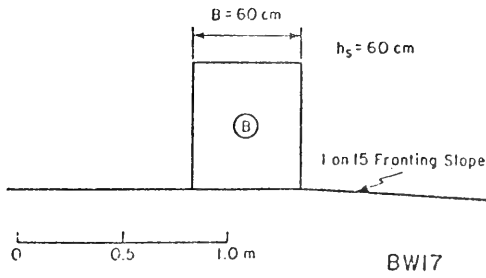
○ 0.0017  
 ▲ 0.0037  
 + 0.0065



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

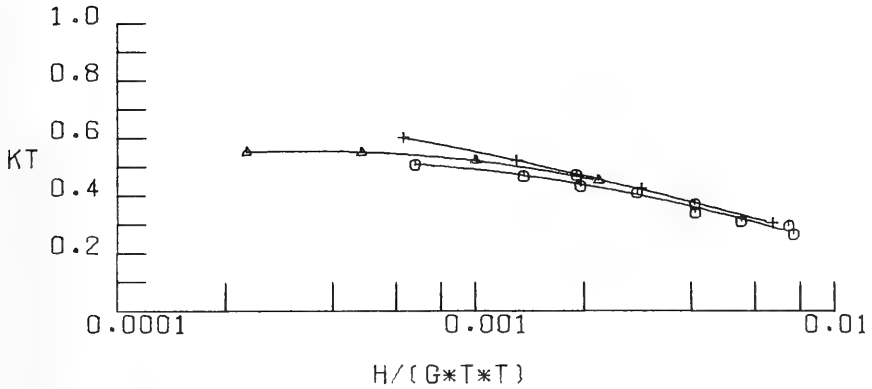
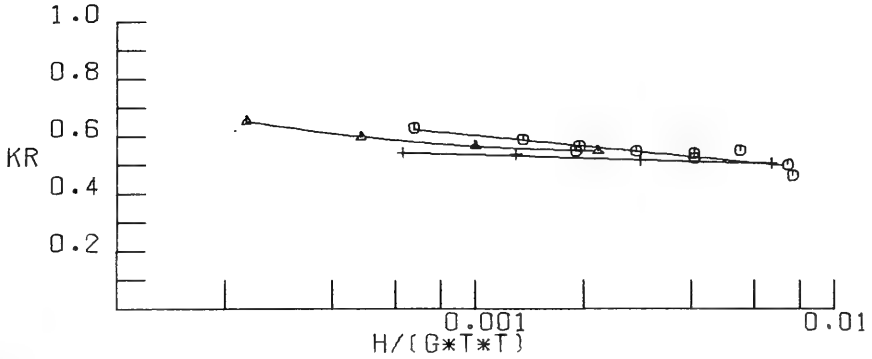
BREAKWATER 16

DS/HS= 0.61



SYMBOL DS/HS

- 0.83
- △ 0.75
- + 0.58



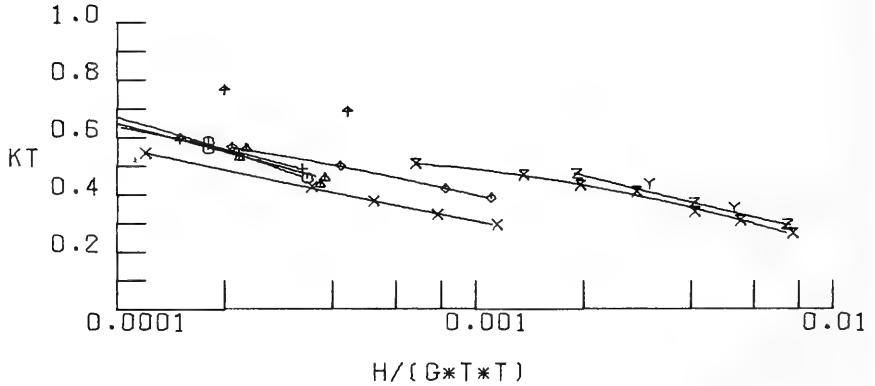
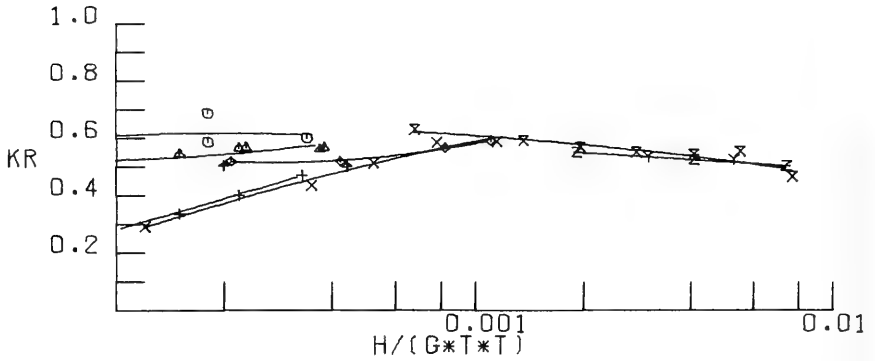
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 17

$D / (GT^2) = 0.016$

SYMBOL D/GT2

○	0.0010
△	0.0013
+	0.0019
×	0.0025
◇	0.0037
†	0.0065
×	0.0146
×	0.0161
Y	0.0227



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

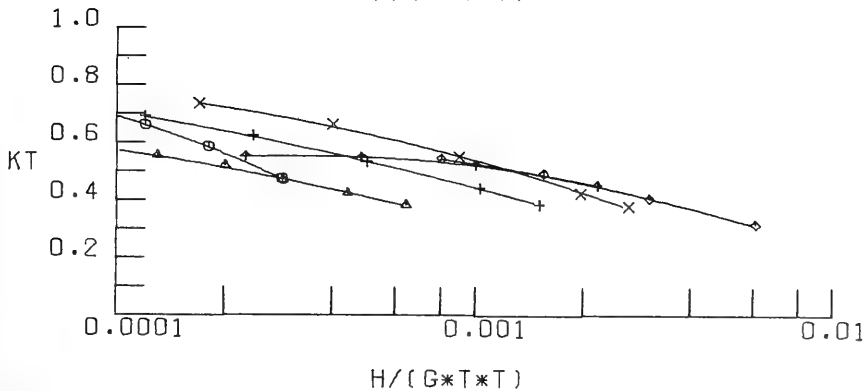
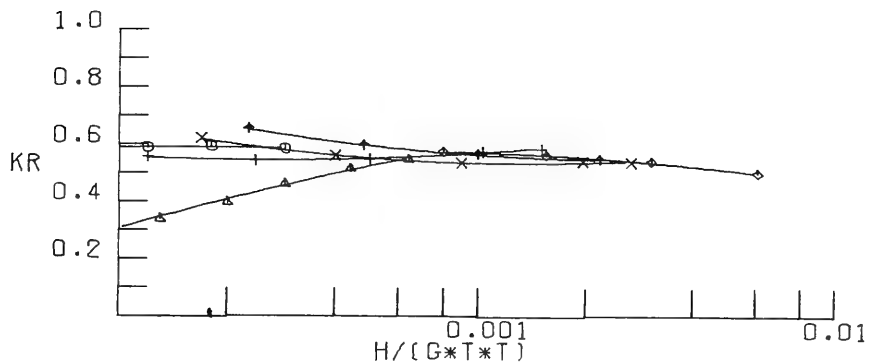
BREAKWATER 17

DS/HS= 0.83



SYMBOL D/GT2

○	0.0010
△	0.0019
+	0.0037
×	0.0065
◇	0.0130
†	0.0161



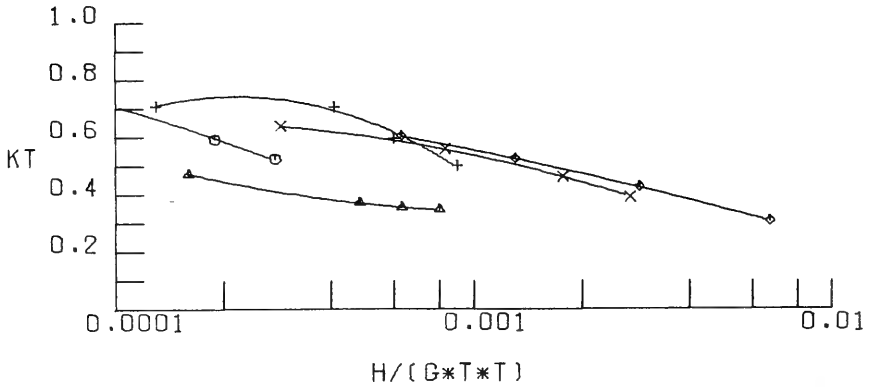
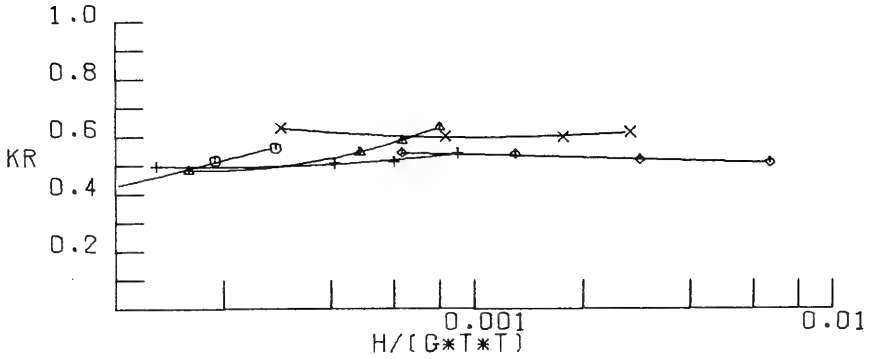
WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 17

DS/HS= 0.75

SYMBOL D/GT2

□	0.0010
△	0.0019
+	0.0037
×	0.0065
◇	0.0161



WAVE TRANSMISSION AND REFLECTION COEFFICIENTS

BREAKWATER 17

DS/HS= 0.58

APPENDIX F

DOCUMENTATION OF THE PROGRAM OVER (752X6R1CY0)

1. Purpose. This FORTRAN program estimates wave transmission by overtopping coefficients and transmitted wave heights for smooth impermeable breakwaters. The method can be used for subaerial and submerged breakwaters with structure seaward-face slopes from vertical to 1 on 3. It is recommended for values of  $d_g/(gT^2) \leq 0.03$ .

2. Mathematical Method and Procedure. The program uses the methods developed in this report. The procedure is to estimate wave runup on smooth impermeable slopes,  $R$ , using the equation

$$R = HC_1 \left( \frac{0.123 L}{H} \right) (C_2 \sqrt{H/d} + C_3)$$

where  $C_1$ ,  $C_2$ , and  $C_3$  are empirical coefficients related to the structure slope,  $H$  is incident wave height,  $d$  is water depth, and  $L$  is the local wavelength. Runup on rough slopes is estimated using

$$R = \frac{Ha\xi}{(1 + b\xi)}$$

where  $a$  and  $b$  are empirical coefficients and  $\xi$  is the surf parameter given by

$$\xi = \frac{\tan \theta}{\sqrt{\frac{H}{L_0}}}$$

where  $\theta$  is the angle of the front face of the breakwater and  $L_0$  is the deepwater wavelength.

A wave transmission by overtopping coefficient,  $C$ , is estimated from

$$C = 0.51 - \frac{0.11 B}{h}$$

where  $B$  is the breakwater crest width and  $h$  the structure height. The transmission by overtopping coefficient,  $K_{TO}$ , is determined from

$$K_{TO} = C \left( 1 - \frac{F}{R} \right)$$

where  $F$  is the breakwater freeboard. For submerged breakwaters with a 1 on 15 fronting slope the equation

$$K_{TO} = C \left( 1 - \frac{F}{R} \right) - (1 - 2C) \left( \frac{F}{R} \right)$$

is used.

The transmitted wave height,  $H_T$ , is given by

$$H_T = K_{TO} H$$

3. Program Variables. A description of all program variables is presented in Table F-1.

4. Input. A description and an example of the input parameters are given in Table F-2. Note that all measurements are in metric units.

5. Output. Program output includes a summary table of input information together with the predicted ratio of the breakwater freeboard to wave runup, the wave transmission by overtopping coefficient, and the predicted transmitted wave height. An example output corresponding to the input is shown in Table F-3.

6. Program Listing. A listing of the program is shown in Table F-4. The subroutine LENGTH finds the value of  $d/L$  given  $d/L_0$  by using linear wave theory.

Table F-1. Variables used in the program OVER.

Variable	Description
AC	a; rough-slope runup coefficient
BC	b; rough-slope runup coefficient
B	breakwater crest width (meter)
BH	B/h
C	transmission by overtopping coefficient = $0.51 - 0.11 B/h$
CA, CB, CC	runup coefficient lookup tables
C1, C2, C3	smooth-slope runup coefficients (a function of slope) $R/H = C_1(0.123 L/H) (C_2 \sqrt{H/d} + C_2)$
DGT2	$d_g/(gT^2)$
DL	$d_g/L$
DLO	$d_g/L_0$
DS	structure water depth, $d_g$
F	breakwater freeboard = $h - d_g$
FR	F/R
H	incident wave height, H
HGT2	$H/(gT^2)$
HMAX	depth-limited maximum wave height = $0.78 d_g$
HS	structure height, $h_g$
HT	transmitted wave height
I	counter index
IFRONT	flag to indicate the presence of a fronting slope (IFRONT = 1 for fronting slope of 1 on 15)
KTO	wave transmission by overtopping coefficient
L	wavelength
N	number of wave conditions of interest
P	linear interpolation factor to find C1, C2, C3
R	predicted smooth-slope runup
RH	R/H
SURF	the surf parameter = $\tan \theta / \sqrt{H/L_0}$
T	wave period (second)
TANA	lookup table of structure slopes corresponding to CA, CB, CC
TANT	tangent of the seaward face of the breakwater = $\tan \theta$

Table F-2. Input to the program OVER.

Card	Format	Description
1	I2	number of breakwaters
2	I2	number of wave conditions of interest <ul style="list-style-type: none"> <li>● equals 1 if breakwater has a 1 on 15 fronting slope seaward of the structure</li> </ul>
	4X	
	F10.5	tangent of breakwater seaward slope <ul style="list-style-type: none"> <li>● breakwater crest width (m)</li> <li>● breakwater structure height (m)</li> <li>● water depth at toe of the structure (m)</li> <li>● rough-slope runup parameter, a (a = 0 for smooth slopes)</li> <li>● rough-slope runup parameter, b</li> </ul>
3	F10.5	wave period (s) <ul style="list-style-type: none"> <li>● incident wave height (in)</li> </ul>
(one card per wave condition)		
(repeat card types 2 and 3 for each breakwater)		

Sample input

14.0	0.667	1.53	4.6	3.56	0.	0.
7.9	0.2					
7.9	0.4					
7.9	0.6					
7.9	0.8					
7.9	1.0					
7.9	1.2					
7.9	1.4					
7.9	1.6					
7.9	1.8					
7.9	2.0					
7.9	2.2					
7.9	2.4					
7.9	2.6					
7.9	2.8					

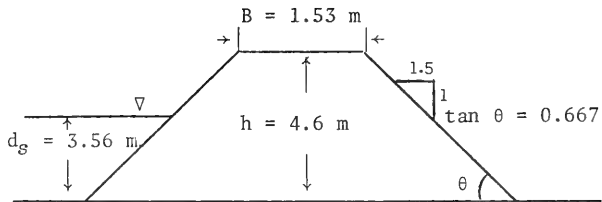


Table F-3. Sample output from the program OVER.

PREDICTION OF WAVE TRANSMISSION COEFFICIENTS FOR  
AN IMPERMEABLE BREAKWATER

NUMBER OF WAVE CONDITIONS = 14  
 IFRONT = 0  
 TAN(SLOPE) = .667  
 BREAKWATER TOP WIDTH(M) = 1.530  
 STRUCTURE HEIGHT(M) = 4.600  
 WATER DEPTH(M) = 3.560  
 FREEBOARD(M) = 1.040  
 COEFFICIENT OF OVERTOPPING C<sub>0</sub> = .473

C<sub>1</sub> = 1.9910  
 C<sub>2</sub> = .4980  
 C<sub>3</sub> = .1850

T (SEC)	D/GT2	H (M)	H/GT2	H/H	F/R	K <sub>TU</sub>	HT (M)
7.900	.0058	.200	.00033	1.594	3.261	0.000	0.000
7.900	.0058	.400	.00065	1.899	1.369	0.000	0.000
7.900	.0058	.600	.00098	2.079	.834	.079	.047
7.900	.0058	.800	.00131	2.197	.592	.193	.155
7.900	.0058	1.000	.00164	2.278	.456	.257	.257
7.900	.0058	1.200	.00196	2.334	.371	.298	.357
7.900	.0058	1.400	.00229	2.371	.313	.325	.455
7.900	.0058	1.600	.00262	2.394	.272	.345	.552
7.900	.0058	1.800	.00294	2.406	.240	.360	.648
7.900	.0058	2.000	.00327	2.410	.216	.371	.743
7.900	.0058	2.200	.00360	2.407	.196	.380	.837
7.900	.0058	2.400	.00392	2.399	.181	.388	.931
7.900	.0058	2.600	.00425	2.386	.168	.394	1.025
7.900	.0058	2.800	.00456	2.370	.157	.399	1.118

Table F-4. Listing of the program OVER.

```

1  PROGRAM OVER(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
   REAL L,KTO
   DIMENSION TANA(6),CA(6),CB(6),CC(6)
   DATA TANA/10.,2.,1.,.6671,444,0.333/
5  DATA CA/0.958,1.280,1.469,1.991,1.811,1.366/
   DATA CB/.228,1.390,1.346,1.498,1.469,1.512/
   DATA CC/.0578,1.091,1.105,1.185,1.080,1.040/
   READ(5,1) NBW
   DO 100 IBW=1,NBW
10  READ(5,1) N,IFRONT,TANT,B,HS,DS,AC,BC
   I
   I  FUMMAT(212,0X,7F10,5)
   C N = NUMBER OF WAVE CONDITIONS
   C IFRONT = 1 FOR 1/16 FRONTING SLOPE
   C TANT = TANGENT OF FRONT BREAKWATER SLOPE ANGLE
15  C B = STRUCTURE WIDTH AT THE CREST (M)
   C HS = STRUCTURE HEIGHT (M)
   C DS = WATER DEPTH AT TOE OF STRUCTURE (M)
   C AC = AHRENS ROUGH SLOPE RUNUP COEFFICIENT (=0 FOR SMOOTH SLOPES)
   C BC = AHRENS ROUGH SLOPE RUNUP COEFFICIENT
20  F=HS*DS
   BHR=HS
   C=0.51+0.11*BH
   WRITE(6,2) N,IFRONT,TANT,B,HS,DS,F,C
2  FORMAT(1H1,2X,(PREDICTION OF WAVE TRANSMISSION COEFFICIENTS FOR (, /
25  *2X, [AN IMPERMEABLE BREAKWATER (, //, 1X, (NUMBER OF WAVE CONDIT
   * IUNS = [1,3, /, 1X, (IFRONT = [1,2, //, 1X, (TAN(SLOPE) = [F6,3, //, 1X, (BREAK
   * KWATER TOP WIDTH(M) = [F6,3, //, 1X, (STRUCTURE HEIGHT(M) = [F6,3, //, 1X
   * [WATER DEPTH(M) = [F6,3, //, 1X, (FREEBOARD(M) = [F6,3, //, 1X,
30  * [COEFFICIENT OF OVERTIPPING C = [F6,3, //)
   IF(AC.LT.0.001) GO TO 21
   WRITE(6,22) AC,BC
22  FORMAT(1X, (RUNUP COEFFICIENTS FOR ROUGH SLOPE RUNUP AC=[F6,2,
   * ( BC=[F6,2)
   GO TO 23
35  21  DO 3 I=1,5
   IF(TANT.GT.TANA(I).OR.TANT.LT.TANA(I+1)) GO TO 3
   P=(TANA(I)-TANT)/(TANA(I)+TANA(I+1))
   C1=CA(I)=(CA(I)+CA(I+1))*P
   C2=CB(I)=(CB(I)+CB(I+1))*P
   C3=CC(I)=(CC(I)+CC(I+1))*P
40  3  CONTINUE
   IF(TANT.GT.10.) C1=CA(1)
   IF(TANT.GT.10.) C2=CB(1)
   IF(TANT.GT.10.) C3=CC(1)
45  IF(TANT.LT.0.333) C1=CA(6)
   IF(TANT.LT.0.333) C2=CB(6)
   IF(TANT.LT.0.333) C3=CC(6)
   WRITE(6,7) C1,C2,C3
7  FORMAT(1X, (C1=[F6,4, //, 1X, (C2=[F6,4, //, 1X, (C3=[F6,4, //)
50  23  WRITE(6,14)
14  FORMAT(/, 1X, ( T(SEC) D/GT2 H(M) H/GT2 R/H F/R KTO HT(M) (,
   */)
   DO 4 I=1,N
55  READ(5,5) T,H
   5  FUMMAT(2F10,5)
   DLO=US/(1.56*T*H)
   CALL LENGTH(DLO,DL)

```

Table F-4. Listing of the program OVER.--Continued

```

L=DS/DL
MGT2=H/(9.8*T*T)
60  DGT2=DS/(4.8*T*T)
    HM=C1*(0.123*L/H)**(C2*SQR(T/H/DS)+C3)
    SURF=TANT/SQR(T/H/(1.56*T*T))
    IF (AC.GT.0.001) HM=AC*SURF/(1.+BC*SURF)
    R=HM*H
    F=H/R
    KTO=C*(1.=FR)
    IF (IFRONT,60,1,AND,F,LT,0.) KTO=C*(1.=FR)=(1.=2.+C)*FR
    IF (FM.GT.1.) KTO=0.
    HT=H*KTO
70  *WRITE (6,12) T,DGT2,H,MGT2,HH,FR,KTO,HT
    12  FORMAT(1X,F6.3,P7.4,F6.3,F7.5,4F6.3)
    4   CONTINUE
    100 CONTINUE
    STGP
75  END

1   SUBROUTINE LENGTH(DLO,DL)
    REAL LD,LDNEW,LD
    LD=1.0/DLO
    LOD=1.0/DLU
    5   N=1
    PI=3.14159
    1   ARG=D.0*PI/LD
    LDNEW=LOD*TANH(ARG)
    N=N+1
    10  DIFF=ABS(LDNEW-LD)
    IF (N=200) 3,4,4
    3   IF (DIFF=0.0005) 2,2,5
    5   LD=(LDNEW+LD)/2.0
    GO TO 1
    15  4   DL=1.0/LDNEW
    *WRITE (6,100) DLO,DL
    100  FORMAT(44H SUBROUTINE LENGTH DID NOT CONVERGE, D/LO = ,F10.5)
    1   1   BHD/L = ,F10.5)
    2   DL=1.0/LDNEW
    20  RETURN
    END

```



APPENDIX G

DOCUMENTATION OF THE COMPUTER PROGRAM MADSEN

The computer program MADSEN (CERC program number 752X1R1CPO) is used to predict wave transmission through rubble-mound breakwaters using methods developed by Madsen and White (1976). (Note: Equations and figures referenced from that publication are identified by the symbol MW.) A wave transmission by overtopping model is also included as discussed in the text of this report. The program is organized as shown in Figure G-1. Whenever possible the variable names used are a close approximation to the symbols used by Madsen and White (1976). Table G-1 lists important variable names, corresponding symbols used in Madsen and White, and gives a description including references to defining equations in Madsen and White (1976). A description of each of the program subroutines is given below:

**SUBROUTINE READI** - This routine reads standard lookup tables corresponding to MW Figures 2, 3, 15, 16, and 17 from Madsen and White (1976). Lookup tables with a combination linear and logarithmic interpolation were selected to avoid having to use Bessel functions with complex arguments. The 53 standard lookup table cards are given in Table G-2.

**SUBROUTINE REFL** - This routine determines reflection coefficients from rough impermeable slopes to account for energy dissipation on the breakwater face (see Ch. III of Madsen and White, 1976). MW equation (127) is solved iteratively and the final result corrected by the corresponding correction factor from MW Table 2 (a linear fit to these points is used). Lookup tables from MW Figures 15, 16, and 17 are employed in this routine.

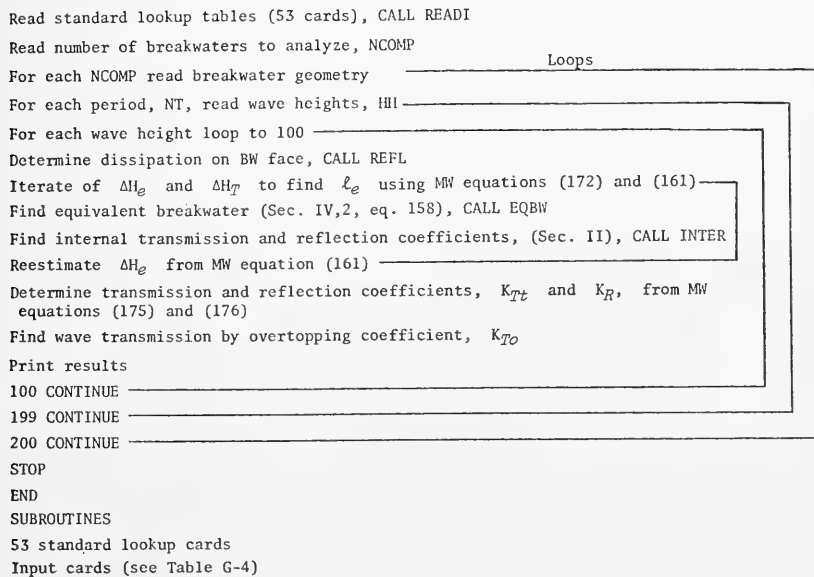


Figure G-1. General program organization.

Table G-1. Program variables.

Symbol (Madsen and White, 1976)	Variables	Description
$a_i$	A	incident wave amplitude
RII	RII	reflection coefficient (Sec. III)
$\Delta H_T$	DHT	head (MW eq. 160)
$\Delta H_e$	DHE	equivalent head (MW eq. 159)
$d_r$	DR	reference diameter
$\beta_r$	BETAR	reference beta
$\nu$	NU	kinematic viscosity
d	D	diameter (cm)
$a_I$	AI	equals RII $a_i$ (MW eq. 146)
RI	RI	internal reflection coefficient (Sec. II)
TI	TI	internal transmission coefficient (Sec. II)
T	KTT	coefficient of wave transmission for transmission through the structure (MW eq. 175)
	KTO	transmission by overtopping coefficient
	KT	total wave transmission coefficient equals $\sqrt{KTT^2 + KTO^2}$
R	KR	reflection coefficient (eq. 176)
$\eta$	N	porosity
$S_*$	SS	$(n/0.45)^2$
$nk_0 \ell$	NKL	equivalent
$\ell_e$	LE	equivalent BW width (eq. 158)
$h_0$	HO	water depth
T	T	wave period
$f/S_*$	FS	
$\lambda$	LAMBDA	
$k_0$	KO	$2\pi/L$
	TS	lookup tables

Table G-1. Program variables.--Continued

Symbol (Madsen and White, 1976)	Variables	Description
	RS	lookup tables
	FST	lookup tables
	RUT	lookup tables
	RT	lookup tables
	GSS	lookup tables
	FUS	lookup tables
	TX	lookup tables
	RX	lookup tables
$F_s$	FS	(Fig. 17)
$l_s$	LS	slope length
L	L	wavelength
	NM	number of materials (maximum of 10)
	NL	number of layers (maximum of 10)
$\Delta h_j$	TH	level thickness
$\frac{\Delta h_j}{h_o}$	DH	relative thickness
	NR	reference porosity = 0.45
$\frac{\Delta h_j}{h_o} \frac{1}{\left(\sum \frac{\beta_i}{P_r} l_i\right)^{1/2}}$	SUM2	
$\sum \frac{\beta_i}{\beta_r} l_i$	SUM1	
	TOPW	width of top of structure
$l_n$	LL	length of materials in horizontal layers
	F	breakwater freeboard
	R	wave runup

Table G-2. Standard lookup tables to be read by READ1.

1	.85	.83	.901	.502	.192	.333	.233	.463	.96
2	.85	.83	.901	.492	.192	.503	.193	.423	.90
3	.85	.83	.901	.492	.162	.293	.103	.283	.70
4	.85	.83	.901	.472	.102	.222	.943	.073	.40
5	.85	.83	.901	.462	.052	.142	.742	.803	.00
6	.85	.63	.901	.451	.982	.032	.502	.502	.60
7	.85	.83	.901	.441	.891	.922	.282	.222	.20
8	.85	.83	.901	.421	.801	.792	.021	.911	.83
9	.85	.83	.901	.401	.701	.681	.791	.631	.60
10	.85	.83	.901	.361	.611	.521	.571	.381	.24
11	.85	.83	.901	.301	.501	.401	.371	.171	.00
12	1.001	.242	.032	.492	.693	.283	.353	.744	.00
13	1.001	.231	.942	.322	.502	.682	.973	.203	.34
14	1.001	.221	.852	.162	.312	.562	.632	.732	.80
15	1.001	.201	.762	.032	.142	.282	.322	.342	.36
16	1.001	.191	.701	.901	.982	.042	.042	.021	.97
17	1.001	.191	.611	.781	.821	.821	.791	.731	.65
18	1.001	.181	.541	.681	.671	.651	.581	.491	.38
19	1.001	.181	.481	.571	.541	.471	.371	.271	.18
20	1.001	.171	.431	.481	.421	.321	.211	.08	.97
21	1.001	.161	.371	.381	.311	.181	.05	.93	.80
22	1.001	.161	.321	.291	.191	.06	.43	.80	.67
23	1.001	.001	.001	.001	.001	.001	.001	.001	.001
24	1.001	.00	.98	.96	.92	.87	.87	.88	.87
25	1.001	.00	.98	.93	.83	.75	.76	.78	.75
26	1.001	.00	.97	.90	.75	.65	.66	.69	.65
27	1.001	.00	.97	.87	.68	.55	.58	.62	.56
28	1.001	.00	.95	.83	.62	.46	.52	.55	.48
29	1.00	.99	.94	.79	.57	.40	.45	.50	.43
30	1.00	.99	.93	.75	.51	.34	.40	.45	.38
31	1.00	.99	.92	.72	.44	.28	.36	.42	.33
32	1.00	.99	.91	.70	.40	.23	.33	.38	.30
33	1.00	.98	.90	.67	.35	.18	.31	.35	.27
34	.80	.66	.57	.50	.46	.42	.38	.36	.34
35	.67	.50	.41	.34	.30	.26	.22	.18	.16
36	.58	.41	.32	.26	.21	.17	.13	.11	.08
37	.50	.33	.26	.19	.16	.12	.99	.07	.05
38	.45	.30	.22	.16	.12	.08	.07	.04	.03
39	.41	.26	.18	.13	.09	.07	.05	.03	.02
40	.37	.23	.16	.11	.08	.05	.03	.02	.02
41	.33	.21	.13	.09	.06	.04	.03	.02	.01
42	.31	.18	.12	.08	.05	.03	.03	.02	.01
43	.29	.17	.11	.07	.04	.03	.02	.01	.01
44	.25	.40	.49	.56	.58	.59	.58	.56	.53
45	.35	.52	.60	.65	.66	.65	.63	.62	.60
46	.44	.60	.68	.71	.71	.69	.67	.67	.66
47	.50	.67	.73	.74	.73	.72	.71	.70	.70
48	.57	.71	.75	.77	.76	.74	.73	.73	.73
49	.60	.73	.78	.78	.77	.76	.76	.76	.76
50	.63	.76	.80	.79	.78	.78	.77	.77	.77
51	.66	.78	.81	.80	.79	.79	.79	.79	.79
52	.68	.80	.82	.81	.80	.80	.80	.80	.80
53	.71	.81	.83	.82	.81	.81	.81	.81	.81

SUBROUTINE INTER - Internal wave transmission and reflection coefficients for the equivalent breakwater found in EQBW are solved in this routine. MW equations (57) and (37) are solved implicitly using  $R_c = 170$  and interpolation of MW Figures 2 and 3, when  $nk_1$  is greater than 0.1. If  $nk_1$  is greater than 0.9 the coefficients cannot be solved, so another equivalent breakwater with smaller reference diameter stone is determined.

SUBROUTINE EQBW - This routine determines the rectangular breakwater corresponding to the multilayered trapezoidal breakwater using the methods described in MW Section IV,2. The initial reference diameter is taken as one-half the armor diameter and reference porosity is defined as 0.435.

SUBROUTINE LENGTH - Finds the relative depth given the ratio of water depth to deepwater wavelength.

1. Program Use. The following steps are required to use the program MADSEN:

(a) Assign each of the materials used in the various layers of the breakwater a consecutive number making the armor "material number 1." Determine the diameter of each material from

$$d_{50} = \left( \frac{W_{50}}{\gamma} \right)^{1/3}$$

where  $W_{50}$  is the median weight and  $\gamma$  the specific weight. Also estimate the material porosity.

(b) Divide the breakwater into horizontal layers. A new layer occurs any time there is a change vertically in any material type of slope (see Fig. G-2 for an example problem). Make the layer next to the seabed "layer number 1." Find the thickness of each layer and determine the average horizontal length of each material in each layer. Remove the outer layer of armor from the seaward face of the breakwater before making length calculations, because energy dissipation on the front face is determined separately in the program.

(c) Estimate the kinematic viscosity of water as a function of water temperature (Table G-3).

(d) Estimate breakwater water runup parameters,  $a$  and  $b$ . At the present time the values of  $a = 0.692$  and  $b = 0.504$  are recommended based on the laboratory data of Hudson (1958).

(e) Put the information into the required input format (Table G-4). Input cards for the example breakwater (Fig. G-2) are shown in Table G-5.

(f) Sample output for the example problem is shown in Table G-6.

2. Computer Program. A listing of the computer program MADSEN is given in Table G-7.



Table G-3. Kinematic viscosity of water.

Water temperature (C°)	Kinematic viscosity of water (m <sup>2</sup> /s)
0	0.0000018
10	0.0000013
20	0.0000010
30	0.0000008

Table G-4. Format of input information.

Card type	Format	Description
standard		53 standard input cards (see Table G-3)
1	I2	number of breakwater configurations or water depths to test
2	20A4	title card
3	3I2, 4X, 7F10.5	number of wave conditions to test number of materials number of horizontal layers structure height (m) water depth (m) kinematic viscosity (m <sup>2</sup> /s) width of top of breakwater (m) front slope of breakwater = tan (θ) wave runup parameter a = 0.692 wave runup parameter b = 0.504
4	10X, 2F10.5 (one card per material)	material diameter (m) (armor 1st) material porosity
5	10X, 7F10.5 (one card per horizontal layer)	layer thickness (m) mean length of each material type in the layer (put in consecutive order, material 1 (armor 1st), etc.)
6	2F10.5 (wave condition card; one card per wave condition)	wave period (s) wave heights (m)

NOTE.--Repeat card types 2 to 6 for each water depth or breakwater configuration to be tested.





Table G-6. Sample output.

EXAMPLE PROBLEM

COMPUTATIONS OF WAVE TRANSMISSION THROUGH A POROUS BREAKWATER

NUM OF WAVE CONDITIONS 18  
 NUM OF MATERIALS= 3  
 NUM OF HORIZONTAL LAYERS= 3  
 STRUCTURE HEIGHT (M)= 6.000  
 WATER DEPTH (M)= 4.800  
 KINEMATIC VISCOSITY (M<sup>2</sup>/SEC)= .00000930  
 RW TOP WIDTH (M)= 2.520  
 TANH OF FRONT SLOPE= .6670  
 RUNUP COEFFICIENTS A= .692 B= .504  
 MATERIAL CHARACTERISTICS (MAKE ARMOR MATERIAL NUMBER 1)

MATERIAL= 1 DIAMETER (M)= .729 POROSITY= .370  
 MATERIAL= 2 DIAMETER (M)= .538 POROSITY= .370  
 MATERIAL= 3 DIAMETER (M)= .092 POROSITY= .370

HORIZONTAL LAYER CHARACTERISTICS  
 (MAKE LAYER NEXT TO SEALED LAYER NUMBER 1)

			MATERIAL=	1	2	3
HORIZONTAL LAYER=	1 THICKNESS (M)=	3.550	LENGTHS (M)=	4.5	2.8	6.4
HORIZONTAL LAYER=	2 THICKNESS (M)=	.780	LENGTHS (M)=	4.5	2.5	0.0
HORIZONTAL LAYER=	3 THICKNESS (M)=	.470	LENGTHS (M)=	5.3	0.0	0.0

H(M)	T(SEC)	H/(G*T*T)	H/L	D/(G*T*T)	KTT	KTO	KT	KR	HT(M)
.100	5.00	.000408	.00335	.0196	.392	0.000	.392	.26	.039
.500	5.00	.002041	.01674	.0196	.213	0.000	.213	.28	.106
1.000	5.00	.004082	.03349	.0196	.151	0.000	.151	.27	.151
1.500	5.00	.006122	.05023	.0196	.131	0.00	.131	.27	.205
1.750	5.00	.007143	.05860	.0196	.122	.080	.149	.26	.262
2.000	5.00	.008163	.06697	.0196	.115	.125	.169	.26	.339
.100	10.00	.000162	.00151	.0049	.401	0.000	.401	.50	.040
.500	10.00	.000510	.00753	.0049	.202	0.000	.202	.59	.101
1.000	10.00	.001520	.01507	.0049	.135	0.000	.135	.62	.135
1.500	10.00	.001531	.02260	.0049	.100	.115	.152	.63	.229
1.750	10.00	.001786	.02837	.0049	.088	.159	.182	.64	.318
2.000	10.00	.002041	.035013	.0049	.080	.193	.209	.64	.413
.100	20.00	.000076	.00073	.0012	.381	0.000	.381	.53	.038
.500	20.00	.000128	.00367	.0012	.186	0.000	.186	.66	.093
1.000	20.00	.000255	.00735	.0012	.127	.010	.127	.70	.127
1.500	20.00	.000323	.01102	.0012	.098	.154	.182	.71	.214
1.750	20.00	.000440	.01286	.0012	.087	.196	.214	.72	.375
2.000	20.00	.000510	.01470	.0012	.081	.227	.241	.72	.482

KTT = WAVE TRANSMISSION THROUGH THE STRUCTURE  
 KTO = WAVE TRANSMISSION BY OVERTOPPING COEFFICIENT  
 KT = TOTAL WAVE TRANSMISSION COEFFICIENT  
 KR = WAVE REFLECTION COEFFICIENT  
 HT = TRANSMITTED WAVE HEIGHT

Table G-7. Listing of the computer program MADSEN.

```

1      PROGRAM MADSEN(INPUT,OUTPUT,TAPES=INPUT,TAPE6=OUTPUT,TAPE3)
COMMON/MAD81/NM,NL,D(1),N(1),LL(1,1),TH(1)
COMMON/SEEL/NKL,P8
2      REAL NKL
5      DIMENSION IBUF(1),TITLE(20),NUM(10)
REAL L,NU,KT,KR,N,LE,NR,LL,KTO,KTT
DATA NUM/1,2,3,4,5,6,7,8,9,10/
PI=3.14159
CALI READI
10     READ(5,590) NCOMP
590    FORMAT(3I2,4X,7F10,5)
DO 200 JJ=1,NCOMP
C READ INPUT INFORMATION
15     READ(5,171) (TITLE(JJM),JJM=1,20)
171    FORMAT(20A4)
WRITE(6,172) (TITLE(JJM),JJM=1,20)
172    FORMAT(1M1,10X,20A4)
READ(5,590) NT,NM,NL,HS,HO,NU,TOPW,TANB,RA,RB
F=HS*HO
20     IF(PA,LE,0.) RA=0.692
IF(OB,LE,0.) RB=504
WRITE(6,971) NT,NM,NL,HS,HO,NU,TOPW,TANB,RA,RB
971    FORMAT(/,10X,1COMPUTATIONS OF WAVE TRANSMISSION THROUGH A POROUS
* BHPAKWATER(,/,/,5X, INUM OF WAVE CONDITIONS(,12X,13,/,5X,
25     * INUM OF MATERIALS(,17X,13,/,5X,
* INUM OF HORIZONTAL LAYERS(,6X,15,/,5X,(STRUCTURE HEIGHT (M)
* (,4X,F10,3,/,5X, (WATER DEPTH (M) (,11X,F10,3,/,5X,
* (KINEMATIC VISCOSITY (M2/SEC) (,F11,9, /,5X, (BW TOP WIDTH (M) (,
* 10X,F10,3,/,5X, (TANB OF FRONT SLOPE (,9X,F3,4,/,5X, (RUNUP COEFFICI
30     * ENTS A=(,F6,3,1 B=(,F6,3)
DO 99 I=1,11
DO 98 J=1,11
98     LL(I,J)=0.
99     CONTINUE
35     WRITE(6,283)
283    FORMAT(5X, (MATERIAL CHARACTERISTICS (MAKE ARMOR MATERIAL NUMBER 1)
* (,/)
DO 7 I=1,NM
40     READ(5,7) D(I),N(I)
7      FORMAT(10X,7F10,5)
WRITE(6,177) I,D(I),N(I)
177    FORMAT(5X, (MATERIAL=(,13, ( DIAMETER (M) (,F 6,3, ( POROSITY=(,F6,3)
6      CONTINUE
WRITE(6,284) (NUM(JM),JM=1,NM)
45     284    FORMAT(/,5X, (HORIZONTAL LAYER CHARACTERISTICS(,/,5X,
* (MAKE LAYER NEXT TO SEABED LAYER NUMBER 1) (,/,
* 52X, (MATERIAL= (,7(11,5X),/,63X,6(12,4X),/)
DO 33 J=1,NL
50     READ(5,7) TH(J),(LL(I,J),I=1,NM)
WRITE(6,178) J,TH(J),(LL(I,J),I=1,NM)
178    FORMAT(5X, (HORIZONTAL LAYER=(,13, ( THICKNESS (M) (,F 6,3, ( LENGTH
* S (M) (,7F6,1,/,60X,7F6,1)
33     CONTINUE
NM=NM+1
55     D(NM)=D(1)
N(NM)=0.01
NL=NL+1
TH(NL)=10000000.
LL(NM,NL)=3.*D(1)
WRITE(6,942)
60     942    FORMAT(/,6X, (M) T(SEC) H/(G*T*T) H/L D/(G*T*T/) KTT
* KTU KT KR HT(M) I)
DO 199 IK=1,NT
READ(5,8) T,H
65     8      FORMAT(2F10,5)
A=H*0.5
DR=D(1)*0.5

```

Table G-7. Listing of the computer program MADSEN.--Continued

```

IF(A,LT,0,00001) GO TO 100
IF(TANB,LE,0,0) GO TO 37
CALL REFL(A,MS,D(1),HO,TANB,T,RII,RII,L)
70   AI=RII*A
22   DHT=2,*RU*A
      IFLAG=0
C ASSUME DMF=DHT AND ITERATE ON THE EQUIVALENT BM
75   ICOUNT=0
      DHE=DHT
10   ICOUNT=ICOUNT+1
      CALL EWBW(DHE,DHT,LF,HO,MS,TANB,NR,DR,TOPW)
80   CALL INTER(NR,T,LE,HO,AI,NU,DR,TI,RI,L,IFLAG)
      IF(TFLAG,EQ,1) DR=DR*0,95
      IF(TFLAG,EQ,1) GO TO 22
      DHE=(1,0+RI)*RII*A
      IF(TCOUNT,LT,4) GO TO 10
      KR=RI*RII
85   KTT=TI*RII
37   IF(TANB,LF,0,0) CALL INTER(N(1),T,TOPW,HO,A,NU,D(1),KTT,KR,L,IFLAG)
      IF(TFLAG,EQ,1) DR=DR*0,5
      IF(TFLAG,EQ,1) GO TO 37
      SUMF=TANB/SQRT(W/(1,56*T*T))
90   WM=0*A*SIIRF/(1,0+RB*SUMF)
      RM=MRH
      FR=F/R
      C=0,91-0,11*TOPW/MS
      KTO=C*(1,0+FR)
95   IF((TOPW/MS),GT,0,8A,AND,F,LT,0,0) KTO=C*(1,0+FR)=(1,0+2,0*C)*FR
      IF(KTO,GT,1,0) KTO=1,0
      IF(FM,GT,1,0) KTO=0,0
      HGT=A*2,0/(9,80*T*T)
100  HL=A/L
      DGT=HD/(9,80*T*T)
      FLAG=3H
      KT=SQRT(KTT**2+KTO**2)
      IF(KT,GT,1,0) KT=1,0
      HT=A*KT
105  WRITE(6,9R1) H,T,HGT,HL,DGT,KT,KTO,KT,KR,HT
9R1  FORMAT(5X,F6,3,F10,2,F10,6,F10,5,F10,4,3F6,3,F6,2,F7,3)
100  CONTINUE
199  CONTINUE
      WRITE(6,201)
110  201  FORMAT(//,2X, [KT] = WAVE TRANSMISSION THROUGH THE STRUCTURE[1,0/
      * 2X, [KTO] = WAVE TRANSMISSION BY OVERTOPPING COEFFICIENT[1,0/
      * 2X, [KT] = TOTAL WAVE TRANSMISSION COEFFICIENT[1,0/2X,
      * [KR] = WAVE REFLECTION COEFFICIENT[1,
      *//,2X, [HT] = TRANSMITTED WAVE HEIGHT[1)
115  200  CONTINUE
      STOP
      END
1   SUBROUTINE REFL(A,MS,D,HO,TANB,T,RII,RII,L)
      COMMON/MADS/FST(9,11),RUT(9,11),RT(17,11),TX(9,10),RX(9,10)
      DIMENSION FSS(11),RUS(11),MS(11)
      REAL I,LSL,LS
5   C CF = MODEL CORRECTION FACTOR TO ACCOUNT FOR MODEL SLOPE EFFECTS
      CF=1,28-0,578*TANB
      IF(TANB,LT,0,4) CF=1,02
      IF(TANB,GT,0,68) CF=0,89
10  C FIND WAVE LENGTH L
      HOLO=HO/(1,56*T*T)
      CALL LENGT(HOLO,HOL)
      L=HO/HOL
      LS=HU/TANB
      IF(MS,LT,HO) LS=MS/TANB
15  LSL=LS/L
      IF(LSL,LT,0,8) GO TO 105
      TMN=SQRT(6,283*(LS/0,8)/(9,8*TANH(6,283*HO/(LS/0,8))))
      WRITE(6,101) TMN
101  FORMAT(//,1X, [WARNING=THE MINIMUM WAVE PERIOD TO BE ANALYZED BY T

```

Table G-7. Listing of the computer program MADSEN.--Continued

```

20      *THIS PROGRAM IS (,F6,2,I SEC FOR THIS CONDITION)
      LSL=0.799
105     I=(1,LSL*10,+1)
C INTERPOLATE INPUT TABLE FOR THIS LSL VALUE
      II=LSL*20,+1
25     DO 3 J=1,11
      FSS(J)=FST(I,J)+(PST(I+1,J)-FST(I,J))*(LSL=(I-1)*0.1)/0.1
      RUS(J)=RUT(I,J)+(RUT(I+1,J)-RUT(I,J))*(LSL=(I-1)*0.1)/0.1
3       RS(J)=RT(I,J)+(RT(II+1,J)-RT(II,J))*(LSL=(II-1)*0.05)/0.05
C GUESS PHI AND ITERATE
30     PHI=5.0
      M=0
6       J=PHI
      FAC=(ALOG(PHI+1.)-ALOG(J+1.))/(ALOG(J+2.)-ALOG(J+1.))
      FS=FSS(J+1)+ FAC*(FSS(J+2)-FSS(J+1))
35     RI=RUS(J+1)+ FAC*(RUS(J+2)-RUS(J+1))
      RI1=RS(J+1)+(RS(J+2)-RS(J+1))*FAC
      ARG=0.29*(D/HO)**0.2*(RU*2.*A/(HO*TANB))**0.3*FS
      PHIN=0.5*ATAN(ARG)*57.29578
40     M=M+1
      DEL=ARS(PHIN-PHI)
      IF (M,GT,20) GO TO 9
      PHI=PHIN
      IF (PHI,LT,0.01) PHI=0.01
      IF (PHI,GT,9.99) PHI=9.99
45     IF (DEL,GT,0.05) GO TO 6
9       RI1=RI*CF
      RETURN
      END
1       SUBROUTINE READI
      COMMON/MADSEN/FST(9,11),RUT(9,11),RT(17,11),TX(9,10),RX(9,10)
177     FORMAT(3X,17F4.2)
5       DO 1 M=1,11
1         READ(5,177) (FST(N,M),N=1,9)
      DO 2 M=1,11
2         READ(5,177) (RUT(N,M),N=1,9)
10        DO 3 M=1,11
3         READ(5,177) (RT(N,M),N=1,17)
      DO 4 M=1,10
4         READ(5,177) (TX(N,M),N=1,9)
      DO 5 M=1,10
5         READ(5,177) (RX(N,M),N=1,9)
15        RETURN
      END
1       SUBROUTINE EBRW(DHE,DHT,LE,HO,HS,TANB,NR,DM,TOPW)
      COMMON/MADSEN/NM,NL,D(11),N(11),L(11,11),TH(11)
      DIMENSION BETA(11),DH(11)
      REAL N,L,LE,NR
5         NR=N*.435
      BETAR=2.7*(1,=NR)/(NR**3*DR)
      DO 2 I=1,NM
21        BETA(I)=2.7*(1,=N(I))/(N(I)**3*D(I))
10         TH1=0.
      TH2=0.
      DO 4 J=1,NL
4         TH1=TH1+TH(J)
      NYL=J
15         DH(J)=TH(J)/HO
      IF (TH1,GT,HO) DH(J)=(HO-TH2)/HO
      IF (TH1,GT,HO) GO TO 5
4         TH2=TH2+TH(J)
5         SUM2=0.
      DO 16 J=1,NYL
17         SUM1=SUM1+BETA(I)/BETAR*L(I,J)
16         SUM2=SUM2+DH(J)/(SQRT(SUM1))
      LE=1./((SUM2**2)*DHE/DHT

```

Table G-7. Listing of the computer program MADSEN.--Continued

```

25      RETURN
      END
1      SUBROUTINE INTER(N,T,L,HU,A,NU,D,TI,RI,WL,IFLAG)
      COMMON/SEFL/NKL,FS
      COMMON/MADS/FST(9,11),RUT(9,11),RT(17,11),TX(9,10),RX(9,10)
      DIMENSION TS(10),RS(10)
5      RFAI=NKL,L,NU,KO,LAMBDA,N
      SS=(N/0.45)**2
      KO=2.*3.14159/WL
      NKL=7.*KO*L
      BETA=2.7*(1.+N)/(N**3*D)
      LAMBDA=1.
      F=0.
      RC=170.
      IC=0
      P      FNF
15      IC=IC+1
      U=ASQRT(9.80/HN)/(1.+LAMBDA)
      RO=11*D/NU
      F=N*(KO*L)*(SQRT(1.+(1.+RC/RO)**16.*BETA**4/L/(3.*3.14159*HO)))-1.)
      LAMBDA=KO*L*F/(2.*N)
20      IF(TC,GT,10) GO TO 5
      IF(ABS(FN-F)/F,GT,0.02) GO TO 2
5      TI=1./(1.+LAMBDA)
      RT=LAMBDA/(1.+LAMBDA)
      FS=F/SS
25      C
      WRITE(6,397) F,FS,U,KO
397      FORMAT(2UX,(F,FS,U,RO=1.4E13,5)
      IF(NKL,GT,0.9) IFLAG=1
      IF(NKL,GT,0.9) RETURN
      IF(NKL,LT,0.1) RETURN
      IF(FS,GT,35.) FS=35.
30      J=NKL*10.
      J=FS
      C INTERPOLATE MADSEN CURVES 2 AND 3
      M=1,10
35      RS(M)=RX(J,M)+(RX(J+1,M)-RX(J,M))*(NKL=N,1*J)/0.1
      TS(M)=TX(J,M)+(TX(J+1,M)-TX(J,M))*(NKL=N,1*J)/0.1
      IF(FS,LF,1.0) TI=TS(1)+ALOG10(FS)*(TS(10)-TS(1))
      IF(FS,LF,1.0) RT=RS(1)+ALOG10(FS)*(RS(10)-RS(1))
      IF(FS,GF,10.) TI=TS(10)*(35.-FS)/25.
      IF(FS,GF,10.) RT=RS(10)+(1.-RS(10))*(FS-10.)/25.
40      IF(FS,LF,1.0,OR,RT,GE,10.0) RETURN
      TI=RS(I)+(RS(I+1)-RS(I))*(ALOG(FS)=ALOG(I*1.))/(ALOG(I+1.)=ALOG(I*
*1.))
      TI=TS(I)+(TS(I+1)-TS(I))*(ALOG(FS)=ALOG(I*1.))/(ALOG(I+1.)=ALOG(I*
*1.))
45      RETURN
      END
1      SUBROUTINE LENGT(DLO,DL)
      REAL LD,LDNEW,LOD
      LD=1.0/DLO
      LOD=1.0/DLO
5      N=1
      PI=3.14159
      ARG=2.0*PI/LOD
      LDNEW=LOD*TANH(ARG)
      N=N+1
10      DIFF=ABS(LDNEW-LD)
      IF(N=200) 3,4,4
      IF(DIFF=0.0005) 2,2,5
5      LD=(LDNEW+LD)/2.0
      GO TO 1
15      4      DL=1.0/LDNEW
      WRITE(6,100) DLO,DL
100     FORMAT(4H SUBROUTINE LENGTH DID NOT CONVERGE, D/LO = ,F10.5)
      1      BWD/L = ,F10.5)
2      DL=1.0/LDNEW
      RETURN
20      END

```



<p>Seelig, William N.</p> <p>Two-dimensional tests of wave transmission and reflection characteristics of laboratory breakwaters / by William N. Seelig - Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1980. [187] p. : ill. : 27 cm. - (Technical report - U.S. Coastal Engineering Research Center ; no. 80-1)</p> <p>Includes bibliographical references.</p> <p>Appendixes.</p> <p>This report presents the results of research conducted to develop methods for estimating wave transmission past submerged, subaerial, permeable, and impermeable breakwaters. The final prediction techniques are given in the form of computer programs; laboratory data used to develop and test the methods are included as appendixes.</p> <p>1. Breakwaters. 2. Wave reflection. 3. Wave transmission.</p> <p>I. Title. II. Series: U.S. Coastal Engineering Research Center. Technical report no. 80-1. .U581tr</p> <p>TC203 no. 80-1 627</p>	<p>Seelig, William N.</p> <p>Two-dimensional tests of wave transmission and reflection characteristics of laboratory breakwaters / by William N. Seelig - Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1980. [187] p. : ill. : 27 cm. - (Technical report - U.S. Coastal Engineering Research Center ; no. 80-1)</p> <p>Includes bibliographical references.</p> <p>Appendixes.</p> <p>This report presents the results of research conducted to develop methods for estimating wave transmission past submerged, subaerial, permeable, and impermeable breakwaters. The final prediction techniques are given in the form of computer programs; laboratory data used to develop and test the methods are included as appendixes.</p> <p>1. Breakwaters. 2. Wave reflection. 3. Wave transmission.</p> <p>I. Title. II. Series: U.S. Coastal Engineering Research Center. Technical report no. 80-1. .U581tr</p> <p>TC203 no. 80-1 627</p>
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