CETA 79-6

Estimation of Wave Transmission Coefficients for Permeable Breakwaters

by

William N. Seelig

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The Madsen and White (1976) analytical model of wave transmission through permeable breakwaters is combined with a wave transmission by overtopping formula to provide a method of predicting wave transmission coefficients for permeable breakwaters. Comparison of this combined prediction technique with physical model laboratory tests shows that the technique is useful for estimating transmission coefficients for design. A computer program was found the most convenient method of making predictions. The computer program and an example showing program use are included in an Appendix.

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PREFACE

This report describes methods for predicting wave transmission coefficients for permeable breakwaters using a transmission by overtopping equation together with the analytical model of Madsen and White (1976). This technique has been tested with physical model results for nonbreaking and some breaking waves, for monochromatic and irregular wave conditions, and for riprap and some concrete armor unit breakwaters (Seelig, in preparation, 1979). The technique was found to give useful predictions of transmission coefficients for design. The work was carried out under the offshore breakwaters for shore stabilization program of the U.S. Army Coastal Engineering Research Center (CERC).

This report was prepared by William N. Seelig, Hydraulic Engineer, under the general supervision of Dr. R.M. Sorensen, Chief, Coastal Processes and Structures Branch.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

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

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

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

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

---

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

To obtain Kelvin (K) readings, use formula: K = (5/9) (F -32) + 273.15.

ESTIMATION OF WAVE TRANSMISSION COEFFICIENTS FOR PERMEABLE BREAKWATERS

by
William N. Seelig

I. INTRODUCTION

The primary purpose of a breakwater is to reduce wave energy in an area to be sheltered. One of the important characteristics of a breakwater is the magnitude of the wave transmission coefficient, defined as the ratio of the transmitted wave height to the incident wave height.

Two basic types of wave transmission are: (a) by overtopping that occurs when wave runup exceeds the crest elevation of the breakwater, overtops the breakwater, and generates waves in the lee; and (b) through a permeable structure that occurs because some of the wave energy is not dissipated by the breakwater and is transmitted through the breakwater. The total wave transmission coefficient, K_T, is given by:

$$K_T = \sqrt{(K_{To})^2 + (K_{Tt})^2} = H_T/H_I \qquad (1)$$

where

K_{To} = transmission by overtopping coefficient

K_{Tt} = coefficient of transmission through the structure

H_I = incident wave height

H_T = transmitted wave height

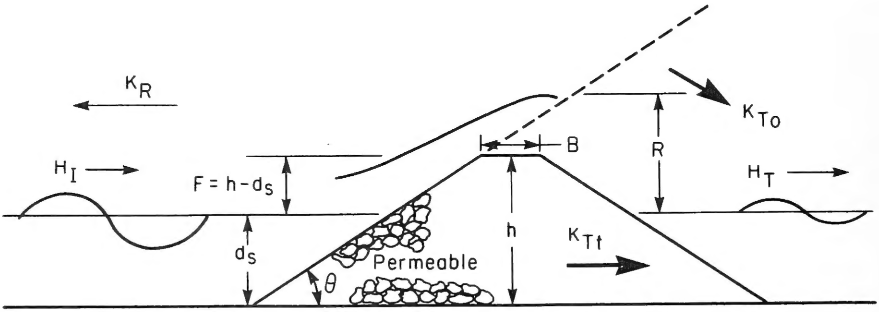
These and other symbols are defined in Figure 1.

Since the prediction method is complex, particularly for transmission through the structure, a computer program is presented in an Appendix to this report. The program incorporates the analytical model to determine K_{Tt} by Madsen and White (1976)[1] and an empirical equation to determine K_{To} developed by Seelig (in preparation, 1979)[2].

---

[1] MADSEN, O.S., and WHITE, S.M., "Reflection and Transmission Characteristics of Porous Rubble-Mound Breakwaters," MR 76-5, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., Mar. 1976.

[2] SEELIG, W.N., "Two-Dimensional Tests of Wave Transmission and Reflection of Laboratory Breakwaters," U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va. (in preparation, 1979).



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

Figure 1. Definition of terms for wave transmission for permeable breakwaters.

II. WAVE TRANSMISSION BY OVERTOPPING

Wave transmission by overtopping occurs when wave energy is transmitted by flow over the top of a structure. The transmission by overtopping coefficient can be estimated using (Seelig, in preparation, 1979)[3]:

$$K_{To} = C\ (1 - F/R) \tag{2}$$

$$= 0 \text{ for } F/R \text{ greater than } 1.0$$

where

R = wave runup

F = breakwater freeboard, defined as the structure height, h, minus the water depth, d_s

C = an empirical coefficient

$(K_{To})\max$ = 1.0

Laboratory tests show that the value of C is related to the crest width of the structure, B:

$$C = 0.51 - 0.11\ B/h\ . \tag{3}$$

Thus, a slight decrease in the transmission by overtopping occurs as the structure crest width increases.

---

[3] SEELIG, W.N., op. cit., p. 7.

Wave runup is estimated using the formula (Ahrens and McCartney, 1975)[4]:

$$\frac{R}{H_I} = \frac{a\xi}{1 + b\xi} \tag{4}$$

where a = 0.692 and b = 0.504 are recommended for rubble-mound breakwaters and a = 0.988 and b = 0.703 are recommended for a breakwater armored with two layers of dolos. ξ is the surf parameter given by

$$\xi = \frac{\tan\theta}{\sqrt{H_I/L_0}} \tag{5}$$

where θ is the angle of the seaward face of the breakwater, and L_o is the deepwater wavelength obtained from linear wave theory. Calculations of wave transmission by overtopping are performed automatically in the program MADSEN (see App.).

III. WAVE TRANSMISSION THROUGH PERMEABLE BREAKWATERS

The coefficient of wave transmission through permeable breakwaters, K_{Tt}, is estimated using the analytical model of Madsen and White (1976)[5]. In this model the transmission coefficient is related to a complex function of the size and porosity of the materials used in building the breakwater (Table 1), the breakwater geometry, the seaward

Table 1. Porosity of various armor units (after U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977)[6].

Armor unit	No. of layers	Placement	Porosity
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

---

[4] AHRENS, J., and McCARTNEY, B.L., "Wave Period Effect on the Stability of Riprap," *Proceedings of Civil Engineering in the Oceans/III*, June 1975, pp. 1019-1034 (also Reprint 76-2, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., June 1976, NTIS A029 739.

[5] MADSEN, O.S., and WHITE, S.M., op. cit., p. 7.

[6] U.S. ARMY, CORPS OF ENGINEERS, COASTAL ENGINEERING RESEARCH CENTER, *Shore Protection Manual*, 3d ed., Vols. I, II, and III, Stock No. 008-022-00077-1, U.S. Government Printing Office, Washington, D.C., 1977.

slope of the structure, water depth, wave height and period, and the kinematic viscosity of water (Table 2). To use this method, waves should have

$$\frac{d}{L} < \frac{1.25}{\sqrt{H_I \cot^2 \theta}} \qquad (6)$$

where L is local wavelength.

Table 2. Kinematic viscosity of water.

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

The Madsen and White model was tested against laboratory data for permeable breakwaters (Seelig, in preparation, 1979)[7] and was shown to give useful estimates for both monochromatic and irregular waves. For irregular wave conditions, the wave input to the program should be the mean wave height and period of peak energy density. A few tests with breaking waves suggest that the prediction method can also be used with breaking waves. The Madsen and White model appears to effectively account for breaking wave energy losses, although it does not explicitly include breaking. Tests of breakwaters armored with dolos units suggest that the program can also be used for artificial armor units. Comparison with laboratory data shows that the model gives the best predictions for shallow-water waves. Predictions of transmission coefficients tend to be conservative for transitional or deepwater waves. Refer to Seelig (in preparation, 1979)[7] or Madsen and White (1976)[8] for more information. Figure 2 shows a comparison between wave transmission coefficients observed in a laboratory model and predicted using the methods described in this CETA.

IV. EXAMPLE

Use of the computer program (MADSEN) in the Appendix can best be illustrated by an example. The format of required input information is given in Table 3. Any number of breakwater geometries, water depths or wave conditions can be analyzed in a single run. The first 53 cards are a standard deck of look-up (input) tables (see Table A-1); card type 1 provides the number of breakwater configurations or water depths to analyze. Card types 2 to 6 give required input information for each breakwater of interest; however, a separate set of these card types is required when the breakwater geometry or water depth is changed.

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[7] SEELIG, W.N., op. cit., p. 7.

[8] MADSEN, O.S., and WHITE, S.M., op. cit., p. 7.

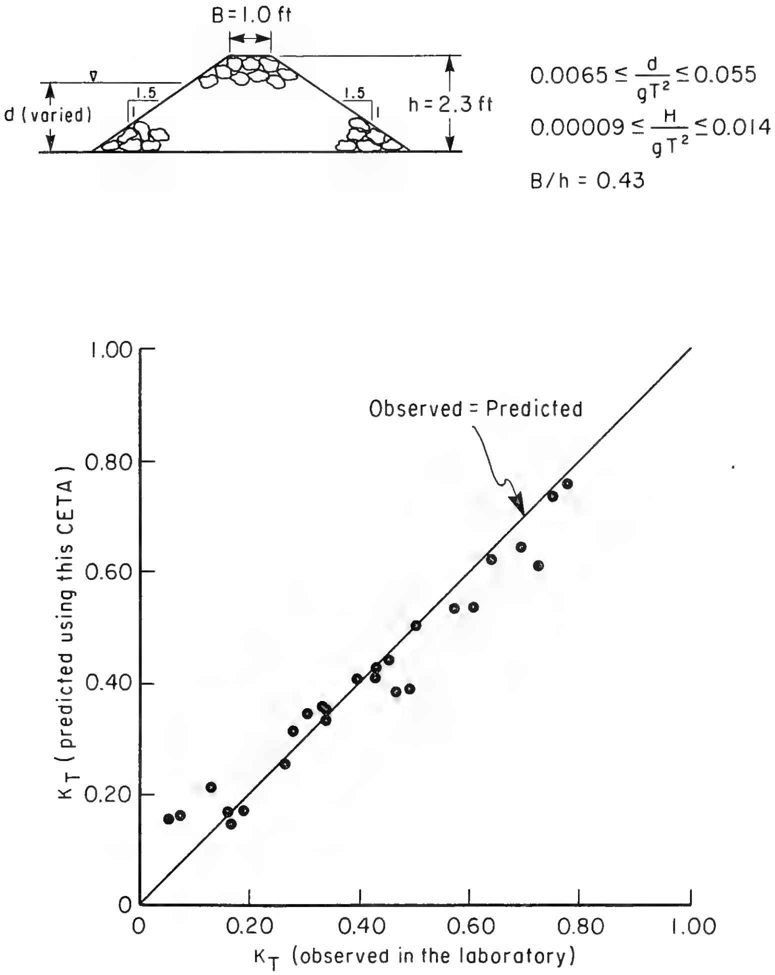


Figure 2. Observed and predicted transmission coefficients for a rubble-mound breakwater.

Table 3. Format of input information.

Card type	Format	Description
Standard		53 standard input cards
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^2/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 (1 card per material)	Material diameter (m) (armor 1st) Material porosity
5	10x,7F10.5 (1 card per horizontal layer)	Layer thickness (m) Mean length of each material type in the layer (put in consecutive order; e.g., material 1 (armor) 1st, etc.)
6	2F10.5 (wave condition card; one card per wave condition)	Wave period (s) Wave heights (m)

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

Card type 3 gives the number of wave conditions to analyze and summarizes general input information (Table 3). For the example breakwater (Fig. 3), 18 wave conditions with periods of 5, 10, and 20 seconds and with heights that range from 0.1 to 2.0 meters, are analyzed.

Card type 4 gives material characteristics, one card per material and the first card should describe the armor material. The example gives three materials (armor, underlayer, and core); diameter and porosity of the materials are shown in Figure 3.

Card type 5 is used to input the mean horizontal length of various materials in various horizontal layers of the breakwater. A new horizontal layer occurs when there is a change vertically in material type or slope and the layer next to the seabed should be designated as "layer number 1." In the case of the example breakwater, three horizontal layers

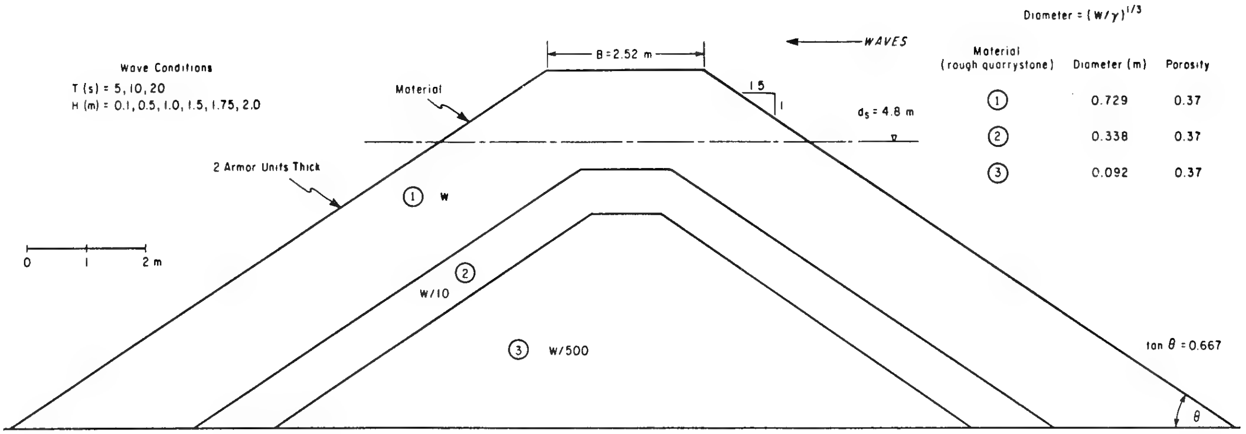


Figure 3. Example breakwater.

are shown in Figure 4. Sample horizontal length calculations are also included. Note that when determining horizontal lengths of the armor material, the outer layer of the armor on the seaward side of the breakwater should be "removed" first because dissipation of the seaward face is determined in a separate part of the computer program.

Table 4 gives the computer program input information required for the example; Table 5 is the resulting program output. The output shows that predicted transmitted wave height for this example is a complex function of incident wave height and period.

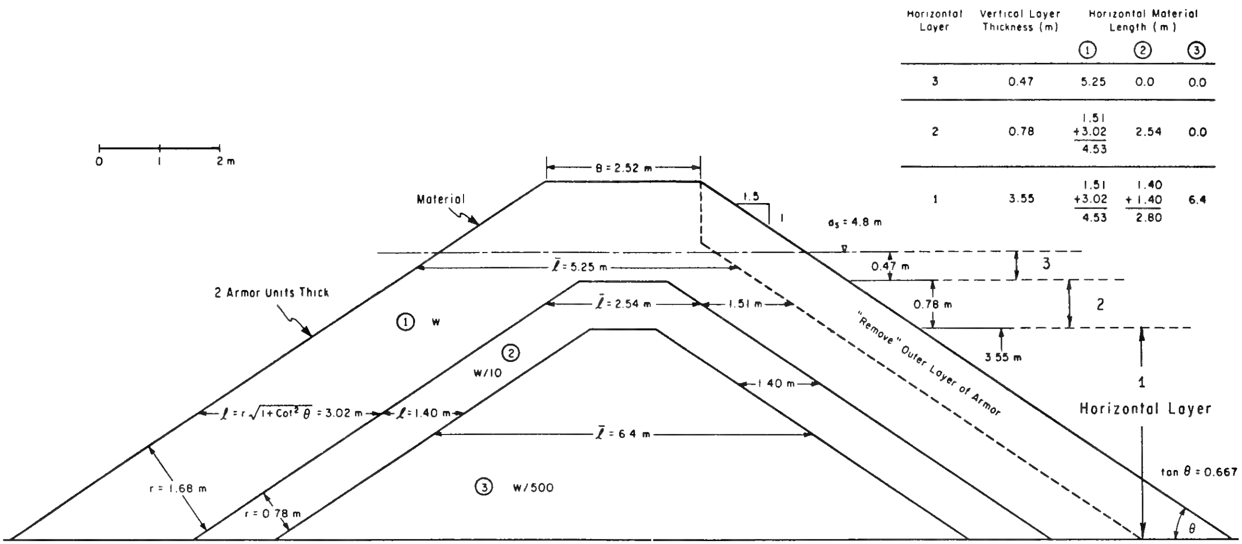
Table 4. Sample input.

```
 1
EXAMPLE PROBLEM
18 3 3        6.0        4.8        00000093   2.52       0.667      0.692      0.504
MAT 1         0.729      0.37
MAT 2         0.338      0.37
MAT 3         0.092      0.37
LAY 1         3.55       4.53       3.80       6.40
LAY 2         0.78       4.53       2.54       0.0
LAY 3         0.47       5.25       0.0        0.0
 5.0          0.1
 5.0          0.5
 5.0          1.0
 5.0          1.5
 5.0          1.75
 5.0          2.0
 10.0         0.1
 10.0         0.5
10.0          1.0
 10.0         1.5
 10.0         1.75
 10.0         2.0
 20.0         0.1
 20.0         0.5
 20.0         1.0
 20.0         1.5
 20.0         1.75
 20.0         2.0
```

V. SUMMARY

A computer program is presented for estimation of wave transmission coefficients for permeable breakwaters. Extensive testing of the program with laboratory data has shown that the program can be used to estimate transmission coefficients for monochromatic or irregular waves and for rubble-mound or other types of permeable breakwaters. A limited amount of testing suggests that it can also be used for breaking and nonbreaking waves.

A copy of the card deck and more extensive program documentation for the computer program MADSEN (CERC Program Number 752X6R1CPO) are available from the ADP Coordinator at CERC. The cost of running the program on a CDC 6600 computer is only a few cents for each wave condition of interest.



Horizontal Layer	Vertical Layer Thickness (m)	Horizontal Material Length (m)		
		①	②	③
3	0.47	5.25	0.0	0.0
2	0.78	1.51 +3.02 4.53	2.54	0.0
1	3.55	1.51 +3.02 4.53	1.40 + 1.40 2.80	6.4

Figure 4. Information required for (horizontal layer) example breakwater.

Table 5. Sample output.

```
      EXAMPLE PROBLEM

     COMPUTATIONS OF WAVE TRANSMISSION THROUGH A POROUS BREAKWATER


  NUM OF WAVE CONDITIONS                18
  NUM OF MATERIALS=                      3
  NUM OF HORIZONTIAL LAYERS=             3
  STRUCTURE HEIGHT (M)=              6.000
  WATER DEPTH (M)=                   4.800
  KINEMATIC VISCOSITY (M2/SEC)= .000000930
  BW TOP WIDTH (M)=                  2.520
  TANB 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)=  .338 POROSITY=  .370
  MATERIAL=  3 DIAMETER (M)=  .092 POROSITY=  .370


  HORIZONTIAL LAYER CHARACTERISTICS
  (MAKE LAYER NEXT TO SEABED LAYER NUMBER 1)
                                                 MATERIAL=   1     2     3
  HORIZONTIAL LAYER=  1 THICHNESS (M)= 3.550 LENGTHS (M)=   4.5   3.8   6.4
  HORIZONTIAL LAYER=  2 THICHNESS (M)=  .780 LENGTHS (M)=   4.5   2.5   0.0
  HORIZONTIAL LAYER=  3 THICHNESS (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 .391 0.000   .391   .26   .039
   .500     5.00   .002041   .01674      .0196 .211 0.000   .211   .28   .105
  1.000     5.00   .004082   .03349      .0196 .149 0.000   .149   .28   .149
  1.500     5.00   .006122   .05023      .0196 .129  .036   .134   .27   .201
  1.750     5.00   .007143   .05860      .0196 .121  .086   .148   .27   .260
  2.000     5.00   .008163   .06697      .0196 .113  .125   .168   .26   .337
   .100    10.00   .000102   .00151      .0049 .397 0.000   .397   .51   .040
   .500    10.00   .000510   .00753      .0049 .199 0.000   .199   .60   .099
  1.000    10.00   .001020   .01507      .0049 .135 0.000   .135   .62   .135
  1.500    10.00   .001531   .02260      .0049 .099  .115   .152   .64   .228
  1.750    10.00   .001786   .02637      .0049 .088  .159   .182   .64   .318
  2.000    10.00   .002041   .03013      .0049 .080  .193   .209   .64   .418
   .100    20.00   .000026   .00073      .0012 .379 0.000   .379   .53   .038
   .500    20.00   .000128   .00367      .0012 .184 0.000   .184   .66   .092
  1.000    20.00   .000255   .00735      .0012 .125  .010   .125   .70   .125
  1.500    20.00   .000383   .01102      .0012 .096  .154   .182   .71   .273
  1.750    20.00   .000446   .01286      .0012 .086  .196   .214   .72   .374
  2.000    20.00   .000510   .01470      .0012 .080  .227   .241   .72   .481

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
```

APPENDIX

LISTING OF THE COMPUTER PROGRAM MADSEN

```
EOR
      PROGRAM MADSEN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3)
      COMMON/MADS1/NM,NL,D(11),N(11),LL(11,11),TH(11)
      COMMON/SEEL/NKL,FS
      REAL NKL
      DIMENSION IBUF(1),TITLE(20),NUM(10)
      REAL L,NU,KT,KR,N,LF,NQ,LL,KTO,KTT
      DATA NUM/1,2,3,4,5,6,7,8,9,10/
      PI=3.14159
      CALL READ1
      READ(5,590) NCOMP
 590  FORMAT(5I2,4X,7F10.5)
      DO 200 IJ=1,NCOMP
C READ INPUT INFORMATION
      READ(5,171) (TITLE(JJM),JJM=1,20)
 171  FORMAT(20A4)
      WRITE(6,172) (TITLE(JJM),JJM=1,20)
 172  FORMAT(1H1,10X,20A4)
      READ(5,590) NT,NM,NL,HS,HO,NU,TOPW,TANB,RA,RB
      F=HS-HO
      IF(RA.LE.0.) RA=0.692
      IF(RB.LE.0.) RB=.504
      WRITE(6,971) NT,NM,NL,HS,HO,NU,TOPW,TANB,RA,RB
 971  FORMAT(/  ,10X,'COMPUTATIONS OF WAVE TRANSMISSION THROUGH A POROUS
     * BREAKWATER',///,5X, 'NUM OF WAVE CONDITIONS',12X,I3,/,5X,
     * 'NUM OF MATERIALS=',17X,I3,/,5X,
     *       'NUM OF HORIZONTIAL LAYERS=',6X,I5,/,5X,'STRUCTURE HEIGHT (M)
     *=',6X,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,F8.4,/,5X,'RUNUP COEFFICI
     *ENTS  A=',F6.3,' B=',F6.3)
      DO 99 I=1,11
      DO 98 J=1,11
 98   LL(I,J)=0.
 99   CONTINUE
      WRITE(6,283)
 283  FORMAT(5X,'MATERIAL CHARACTERISTICS (MAKE ARMOR MATERIAL NUMBER 1)
     *',/)
      DO 6 I=1,NM
      READ(5,7) D(I),N(I)
 7    FORMAT(10X,7F10.5)
      WRITE(6,177) I,D(I),N(I)
 177  FORMAT(5X,'MATERIAL=',I3,' DIAMETER (M)=',F 6.3,' POROSITY=',F6.3)
 6    CONTINUE
      WRITE(6,284) (NUM(JM),JM=1,NM)
 284  FORMAT(//,5X,'HORIZONTIAL LAYER CHARACTERISTICS',/,5X,
     *'(MAKE LAYER NEXT TO SEABED LAYER NUMBER 1)',/,
     * 52X,'MATERIAL=    ',7(I1,5X),/,63X,6(I2,4X),/)
      DO 33 J=1,NL
      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,'HORIZONTIAL LAYER=',I3,' THICHNESS (M)=', F6.3,' LENGTH
```

```
     *S (M)=',7F6.1,/,60X,7F6.1)
 33   CONTINUE
      NM=NM+1
      D(NM)=D(1)
      N(NM)=0.01
      NL=NL+1
      TH(NL)=10000000.
      LL(NM,NL)=3.*D(1)
      WRITE(6,942)
 942  FORMAT(//, 6X,'H(M)    T(SEC)    H/(G*T*T)    H/L       D/(G*T*T/) KTT
     *  KTO     KT     KR    HT(M)')
      DO 199 IK=1,NT
      READ(5,8) T,H
 8    FORMAT(2F10.5)
      A=H*0.5
      DR=D(1)*0.5
      IF(A.LT.0.00001) GO TO 100
      IF(TANB.LE.0.) GO TO 37
      CALL REFL(A,HS,D(1),HO,TANB,T,RII,RU,L)
      AI=RII*A
 22   DHT=2.*RU*A
      IFLAG=0
C ASSUME DHE=DHT AND ITERATE ON THE EQUILIVANT BW
      ICOUNT=0
      DHE=DHT
 10   ICOUNT=ICOUNT+1
      CALL EQBW(DHE,DHT,LE,HO,HS,TANB,NR,DR,TOPW)
      CALL INTER(NR,T,LE,HO,AI,NU,DR,TI,RI,L,IFLAG)
      IF(IFLAG.EQ.1) DR=DR*0.95
      IF(IFLAG.EQ.1) GO TO 22
      DHE=(1.+RI)*RII*A
      IF(ICOUNT.LT.4) GO TO 10
      KR=RI*RII
      KTT=TI*RII
 37   IF(TANB.LE.0.) CALL INTER(N(1),T,TOPW,HO,A,NU,D(1),KTT,KR,L,IFLAG)
      IF(IFLAG.EQ.1) DR=DR*0.5
      IF(IFLAG.EQ.1) GO TO 37
      SURF=TANB/SQRT(H/(1.56*T*T))
      RH=RA*SURF/(1.+RB*SURF)
      R=H*RH
      FR=F/R
      C=0.51 -0.11*TOPW/HS
      KTO=C*(1.-FR)
      IF((TOPW/HS).GT.0.88.AND.F.LT.0.) KTO=C*(1.-FR)-(1.-2.*C)*FR
      IF(KTO.GT.1.) KTO=1.
      IF(FR.GT.1.0) KTO=0.
      HGT2=A*2./(9.80*T*T)
      HL=2.*A/L
      DGT2=HO/(9.80*T*T)
      FLAG=5H
      KT=SQRT(KTT**2+KTO**2)
      IF(KT.GT.1.0) KT=1.0
      HT=H*KT
      WRITE(6,981) H,T,HGT2,HL,DGT2,KTT,KTO,KT,KR,HT
 981  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)
```

```
 201  FORMAT(//,2X,'KTT = WAVE TRANSMISSION THROUGH THE STRUCTURE',/,
     *2X,'KTO = WAVE TRANSMISSION BY OVERTOPPING COEFFICIENT',/,
     * 2X,'KT  = TOTAL WAVE TRANSMISSION COEFFICIENT',/,2X,
     * 'KR  = WAVE REFLECTION COEFFICIENT',
     */,2X,'HT  = TRANSMITTED WAVE HEIGHT')
 200  CONTINUE
      STOP
      END
      SUBROUTINE REFL(A,HS,D,HO,TANB,T,RTI,RII,L)
      COMMON/MAUS/FST(9,11),RUT(9,11),RT(17,11),TX(9,10),RX(9,10)
      DIMENSION FSS(11),RUS(11),RS(11)
      REAL L,LSL,LS
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
C FIND WAVE LENGTH L
      HOLO=HO/(1.56*T*T)
      CALL LENGT(HOLO,HOL)
      L=HO/HOL
      LS=HO/TANB
      IF(HS.LT.HO) LS=HS/TANB
      LSL=LS/L
      IF(LSL.LT.0.8) GO TO 105
      TMIN=SQRT(6.283*(LS/0.8)/(9.8*TANH(6.283*HO/(LS/0.8))))
      WRITE(6,101) TMIN
 101  FORMAT(///,1X,'WARNING-THE MINIMUM WAVE PERIOD TO BE ANALYZED BY T
     *HIS PROGRAM IS',F6.2,' SEC FOR THIS CONDITION')
      LSL=0.799
 105  I=(LSL*10.+1.)
C INTERPOLATE INPUT TABLE FOR THIS LSL VALUE
      II=LSL*20.+1.
       DO 3 J=1,11
      FSS(J)=FST(I,J)+(FST(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(II,J)+(RT(II+1,J)-RT(II,J))*(LSL-(II-1)*0.05)/0.05
C GUESS PHI AND ITERATE
      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))
      RU=RUS(J+1)+             FAC*(RUS(J+2)-RUS(J+1))
      RII=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
      M=M+1
      DEL=ABS(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
      IF(DEL.GT.0.05) GO TO 6
 9    RII=RII*CF
      RETURN
      END
      SUBROUTINE READI
      COMMON/MAUS/FST(9,11),RUT(9,11),RT(17,11),TX(9,10),RX(9,10)
```

```
177   FORMAT(3X,17F4.2)
      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)
      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)
      RETURN
      END
      SUBROUTINE LENGT( DLO,DL)
      REAL LD,LDNEW,LOD
      LD=1.0/DLO
      LOD=1.0/DLO
      N=1
      PI=3.14159
1     ARG=2.0*PI/LD
      LDNEW=LOD*TANH(ARG)
      N=N+1
      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
4     DL=1.0/LDNEW
      WRITE(6,100) DLO,DL
100   FORMAT(44H SUBROUTINE LENGTH DID NOT CONVERGE, D/LO =    ,F10.5,
     1  8HD/L =    ,F10.5)
2     DL=1.0/LDNEW
      RETURN
      END
      SUBROUTINE EQBW(DHE,DMT,LE,HO,HS,TANB,NR,DR,TOPW)
      COMMON/MADS1/NM,NL,D(11),N(11), L(11,11),TH(11)
      DIMENSION BETA(11),DH(11)
      REAL N,L,LE,NR
      NR=0.035
      BETAR=2.7*(1.-NR)/(NR**3*DR)
      DO 21 I=1,NM
21    BETA(I)=2.7*(1.-N(I))/(N(I)**3*D(I))
      TH1=0.
      TH2=0.
      DO 4 J=1,NL
      TH1=TH1+TH(J)
      NYL=J
      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
      SUM1=0.
      DO 17 I=1,NM
17    SUM1=SUM1+BETA(I)/BETAR*L(I,J)
```

```
16    SUM2=SUM2+DH(J)/(SQRT(SUM1))
      LE=1./(SUM2**2)*DHF/DMT
      RETURN
      END
      SUBROUTINE INTER(N,T,L,HO,A,NU,D,TI,RI,WL,IFLAG)
      COMMON/SFEL/NKL,FS
      COMMON/MADS/FST(9,11),RUT(9,11),RT(17,11),TX(9,10),RX(9,10)
      DIMENSION TS(10),RS(10)
      REAL NKL,L,NU,KO,LAMBDA,N
      SS=(N/0.45)**2
      KO=2.*3.14159/WL
      NKL=N*KO*L
      BETA=2.7*(1.-N)/(N**3*D)
      LAMBDA=1.
      F=0.
      RC=170.
      IC=0
 2    FN=F
      IC=IC+1
      U=A*SQRT(9.80/HO)/(1.+LAMBDA)
      RD=U*D/NU
      F=N/(KO*L)*(SQRT(1.+(1.+RC/RD)*(16.*BETA*A*L/(3.*3.14159*HO)))-1.)
      LAMBDA=KO*L*F/(2.*N)
      IF(IC.GT.10) GO TO 5
      IF((ABS(FN-F)/F).GT.0.02) GO TO 2
 5    TI=1./(1.+LAMBDA)
      RI=LAMBDA/(1.+LAMBDA)
      FS=F/SS
C     WRITE(6,397) F,FS,U,RD
 397  FORMAT(20X,'F,FS,U,RD=',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.
      J=NKL*10.
      I=FS
C INTERPOLATE MADSEN CURVES 2 AND 3
      DO 1 M=1,10
      RS(M)=RX(J,M)+(RX(J+1,M)-RX(J,M))*(NKL-0.1*J)/0.1
 1    TS(M)=TX(J,M)+(TX(J+1,M)-TX(J,M))*(NKL-0.1*J)/0.1
      IF(FS.LE.1.0) TI=TS(1)+ALOG10(FS)*(TS(10)-TS(1))
      IF(FS.LE.1.0) RI=RS(1)+ALOG10(FS)*(RS(10)-RS(1))
      IF(FS.GE.10.) TI=TS(10)*(35.-FS)/25.
      IF(FS.GE.10.) RI=RS(10)+(1.-RS(10))*(FS-10.)/25.
      IF(FS.LE.1.0.OR.FS.GE.10.0) RETURN
      RI=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.))
      RETURN
      END
```

Table A-1. Standard look-up tables to be read by subroutine REDI.

```
 1  .85 .83 .901.502.192.333.233.463.96
 2  .85 .83 .901.492.192.303.193.423.90
 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 .83 .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 1.001.231.942.322.502.882.973.203.34
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 .93 .80 .67
23 1.001.001.001.001.001.001.001.001.001.001.001.001.001.001.001.001.00
24 1.001.00 .98 .96 .92 .87 .87 .88 .87 .81 .76 .78 .79 .77 .72 .69 .70
25 1.001.00 .98 .93 .83 .75 .76 .78 .75 .66 .60 .61 .66 .60 .54 .48 .48
26 1.001.00 .97 .90 .75 .65 .66 .69 .65 .53 .46 .48 .50 .47 .38 .32 .34
27 1.001.00 .97 .87 .68 .55 .58 .62 .56 .42 .34 .38 .40 .37 .27 .21 .24
28 1.001.00 .95 .83 .62 .46 .52 .55 .48 .33 .25 .30 .33 .29 .18 .12 .18
29 1.00 .99 .94 .79 .57 .40 .45 .50 .43 .26 .18 .24 .28 .24 .13 .06 .14
30 1.00 .99 .93 .75 .51 .34 .40 .45 .38 .21 .12 .20 .24 .20 .08 .02 .13
31 1.00 .99 .92 .72 .44 .28 .36 .42 .33 .16 .07 .17 .22 .18 .07 .02 .13
32 1.00 .99 .91 .70 .40 .23 .33 .38 .30 .12 .05 .17 .20 .18 .07 .02 .13
33 1.00 .98 .90 .67 .35 .18 .31 .35 .27 .10 .05 .17 .20 .18 .07 .02 .13
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 .15 .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
```

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