Additional Computer Programs in Ocean Engineering

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Ocean Engineering Program

TAMU-SG-77-209
COE Report No. 201
August 1977

TEXAS A&M UNIVERSITY SEA GRANT COLLEGE

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IN OCEAN ENGINEERING

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Partially supported through Institutional Grant 04-6-158-44012
to Texas A&M University
by the National Oceanic and Atmospheric
Administration's Office of Sea Grants
Department of Commerce

$4.00

Order from:

Department of Marine Resources Information
Center for Marine Resources
Texas A&M University
College Station, Texas 77843

ABSTRACT

In response to a need in Ocean Engineering for additional computational aids, widely used computer solution programs were assembled in this report. The computer programs were developed or adapted for the AMDAHL 470 V/6 computer available on the College Station campus of Texas A&M University.

The computer programs appear as follows:

(1) Stokes Fifth Order Wave Theory

(2) Horizontal Wave Force on a Large Submerged Rectangular Body

  (a) Using Stokes Third Order Wave Theory

  (b) Using Stokes Fifth Order Wave Theory

(3) Wave Forces and Moments on a Circular Cylindrical Pile

  (a) Using Cnoidal Wave Theory

  (b) Using Stokes Third Order Wave Theory

(4) Wave Forces and Moments Produced on a Vertical Pile Using the Stream Function Theory

(5) Red Sea Revisions - Program to Estimate the Combined Effects of Refraction, Diffraction of Water Waves and of Bottom Friction.

PREFACE

Development of computer programs was conducted as part of the general research program in Coastal and Ocean Engineering at Texas A&M University.

Various portions of the report were prepared by different authors and assembled by Wei Yih Chow.

The study was partially supported by the Sea Grant College Program of the National Oceanic and Atmospheric Administration through Institutional Grant 04-6-158-44012 made to Texas A&M University.

The manuscript was edited by Dr. Gisela Mahoney and typed for publication by Joyce McCabe and Debi Brendel.

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I. INTRODUCTION

Computer programs are a very useful aid in determining wave characteristics in coastal and ocean engineering. The programs presented in this report were developed, or adapted, in the course of continuing investigations conducted within the Ocean Engineering Program at Texas A&M University. Each program includes a description of the computational technique involved. Notation and reference sources are given. Finally, the main program is issued statement by statement and followed by a concise, illustrative output using sample data.

II. STOKES' FIFTH ORDER WAVE THEORY

General Comment

Stokes' fifth order wave theory is best applicable in the region of intermediate water waves to deep-water waves, with d/T^2 larger than 0.2 and H/T^2 larger than 0.04. This computer program initially calculates the actual wavelength, if unknown. The main object of the program is to calculate the water particle velocities and accelerations at different intervals of depth and at different intervals along the wavelength. It also computes the wave profile.

Program Description

Main Program

Purpose: To calculate the water particle velocities and accelerations given wave height, water depth, wave period or wavelength.

Equations: Wave profile

$$y = 1/\beta \sum_{n=1}^{n=5} yn \cdot \cos(n\theta)$$

Water Particle Velocities

Horizontal:

$$u = \overline{C} \sum_{n=1}^{n=5} n \cdot U_n \cdot \cosh(n\beta s) \cdot \cos(n\theta)$$

Vertical:

$$v = \overline{C} \sum_{n=1}^{n=5} n \cdot U_n \cdot \sinh(n\beta S) \cdot \sin(n\theta)$$

Water Particle Accelerations

Horizontal:

$$A_x = \beta \cdot \overline{C}^2 \sum_{n=1}^{n=5} n^2 \cdot U_n \sinh(n\beta S) \cdot \cos(n\theta)$$

Vertical:

$$A_y = -\beta \cdot \overline{C}^2 \sum_{n=1}^{n=5} n^2 U_n \sinh(n\beta S) \cdot \cos(n\theta)$$

Wave speed

$$\overline{C} = L/T$$

Subroutine SOLVEL

This subroutine calculates λ, a constant for each wave and the wavelength. The two following equations are solved simultaneously to obtain the unique solution of λ and wavelength.

$$\frac{\pi H}{d} = \frac{L}{d} \{ \lambda + \lambda^3 B_{33} + \lambda^5 (B_{35} + B_{55})\} \quad . . . . (1)$$

$$\frac{d}{Lo} = (\frac{d}{L}) \cdot \tanh(\beta d) \cdot (1 + \lambda^2 C_1 + \lambda^4 C_2) \quad . . . . (2)$$

The Newton-Raphson method is used to calculate the value of λ from Equation 1. A value of $\lambda = 0.2$ is initially assumed to start the iterative process. The value of λ obtained in the subroutine is used to check the validity of Equation 2 which is in the main program. This process proceeds until the wavelength and λ converge to their respective unique values.

For brevity in listing the coefficients let $s = \sinh \frac{2\pi d}{L}$ and $c = \cosh \frac{2\pi d}{L}$

i $y_1 = \lambda = \beta a,$ $\quad y_2 = \lambda^2(B_{22} + \lambda^2 B_{24})$

$y_3 = \lambda^3(B_{33} + \lambda^2 B_{35}),$ $\quad y_4 = \lambda^4 B_{44}$

$y_5 = \lambda B_{55}$

ii $u_1 = \lambda(A_{11} + \lambda^2 A_{13} + \lambda^4 A_{15}),$ $\quad u_2 = \lambda^2(A_{22} + \lambda^2 A_{24})$

$u_3 = \lambda^3(A_{33} - \lambda^2 A_{35}),$ $\quad u_4 = \lambda^4 A_{44}$

$u_5 = \lambda^5 A_{55}$

iii $A_{11} = 1/s$

$$A_{13} = \frac{-c^2(5c^2 + 1)}{8s^5}$$

$$A_{15} = \frac{-(1184c^{10} - 1440c^8 - 1992c^6 + 2641c^4 - 249c^2 + 18)}{1536s^{11}}$$

$$A_{22} = \frac{3}{8s^4}$$

$$A_{24} = \frac{(192c^8 - 424c^6 - 312c^4 + 480c^2 - 17)}{768s^{10}}$$

$$A_{33} = \frac{(13 - 4c^2)}{64s^7}$$

$$A_{35} = \frac{(512c^{12}+4224c^{10}-6800c^8-12,808c^6+16,704c^4-3154c^2+107)}{4096s^{13}(6c^2-1)}$$

$$A_{44} = \frac{(80c^6 - 816c^4 + 1338c^2 - 197)}{1563s^{10}(6c^2-1)}$$

$$A_{55} = \frac{-(2880c^{10}-72,480c^8+324,000c^6-432,000c^4\ 163,470c^2-16,245)}{61,440s^{11}(6c^2-1)(8c^4-11c^2+3)}$$

iv $$B_{22} = \frac{(2c^2+1)}{4s^3}\ c$$

$$B_{24} = \frac{c(272c^8 - 504c^6 - 192c^4 + 322c^2 + 21)}{384s^9}$$

$$B_{33} = \frac{3(8c^6 + 1)}{64s^6}$$

$$B_{35} = \frac{(88{,}128c^{14} - 208{,}224c^{12} + 70{,}848c^{10} + 54{,}000c^8 - 21{,}816c^6)}{12{,}288s^{12}(6c^2-1)} + \frac{(6264c^4 - 54c^2 - 81)}{12{,}288s^{12}(6c^2 - 1)}$$

$$B_{44} = \frac{c(768c^{10} - 448c^8 - 48c^6 + 48c^4 + 106c^2 - 21)}{384s^9(6c^2 - 1)}$$

$$B_{55} = \frac{(192{,}000c^{16} - 262{,}720c^{14} + 83{,}680c^{12} + 20{,}160c^{10} - 7280c^8)}{12{,}288s^{10}\ (6c^2 - 1)(8c^4 - 11c^2 + 3)} + \frac{(7160c^6 - 1800c^4 = 1050c^2 + 225)}{12{,}288s^{10}(6c^2 - 1)(8c^4 - 11c^2 + 3)}$$

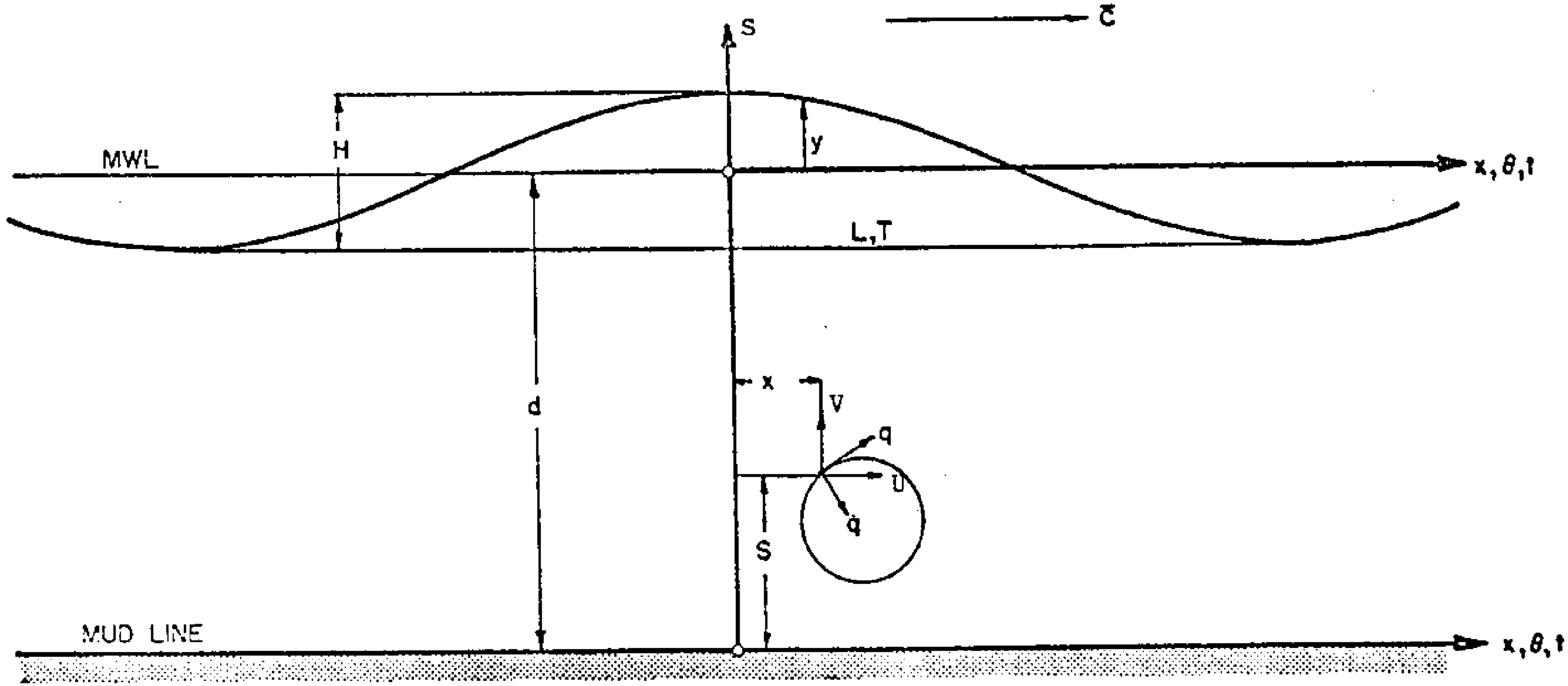
v $$C_0^2 = g(\tanh \beta d)$$

$$C_1 = \frac{(8c^4 - 8c^2 + 9)}{8s^4}$$

$$C_2 = \frac{(3840c^{12} - 4096c^{10} + 2592c^8 - 1008c^6 + 5944c^4 - 1830c^2 + 147)}{512s^{10}\ (6c^2 - 1)}$$

$$C_3 = -\frac{1}{4sc}$$

$$C_4 = \frac{(12c^8 + 36c^6 - 162c^4 + 141c^2 - 27)}{192cs^9}$$



$\overline{C}$	WAVE VELOCITY
d	DEPTH OF WATER
H	WAVE HEIGHT
T	WAVE PERIOD
L	WAVELENGTH
U	HORIZONTAL PARTICLE VELOCITY
V	VERTICAL PARTICLE VELOCITY
X	HORIZONTAL CO-ORDINATE DISTANCE MEASURED FROM CREST
S	VERTICAL CO-ORDINATE DISTANCE MEASURED POSITIVELY UPWARDS FROM MUD LINE
θ	PHASE ANGLE
t	TIME

FIGURE 1. CO-ORDINATE SYSTEM AND SYMBOLS

3. Notation

Symbol	FORTRAN Name	Description
A_x	AU	Water particle acceleration in the horizontal direction
A_y	AV	Water particle acceleration in the vertical direction
$\overline{C}$	CEL	Wave speed
d	D	Stillwater depth
H	H	Wave height
L	WL	Wavelength
S	SD	Elevation above mudline
T	T	Wave period
U	UP	Water particle velocity in the horizontal direction
V	VP	Water particle velocity in the vertical direction
t		Time
y	YP	Wave profile elevation above mean waterline
β	BETA	$2\pi/L$
θ	THETA	Phase angle = $\beta(x - Ct)$
λ	LAMBDA	A constant to be determined for each wave

4. Bibliography

1. Skjelbreia, L., and Hendrickson, J.A., "Fifth Order Gravity Wave Theory with Tables of Functions", National Engineering Science Co., Pasadena, California, 1962.

2. Dean, Robert G., "Relative Validities of Water Wave Theories", Civil Engineering in the Oceans, Nov. 1967.

3. Carnahan, B., Luther, H.A., and Wilkes, J.O., "Applied Numerical Methods", John Wiley & Sons Inc., 1969.

COMPUTER INPUT

The input sequence for Stokes V Order wave theory is in accordance with the Fortran watfiv language used in the main program. The data are read into the program on two cards.

Card 1 -

The first card is used to enter program commands and incrementation constants for the iterative schemes are used in the main program. The data values on the first card are Num, Depinc, and Xlinc. Num is an integer value either 1 or 2. If wavelength (L), wave height (H), and water depth (D), are given then Num should be set equal to one by typing 1 in the first column of the first data card. If wave period (T), wave height, and water depth are given the Num equals 2. Depinc is the depth incrementation in feet, measured from the bottom to the wave surface, at which the particle velocities and accelerations are calculated. This value is a floating decimal point number and in accordance with format 5 should be entered in columns 2-11. Xlinc initializes the incrementation along the wavelength and should be entered in columns 12-21 as a dividend of X (the horizontal distance along the wavelength) and L (the wavelength).

Card 2 -

The second card is used to enter either wavelength, wave height, and water depth or period, wave height, and water depth depending upon the value of Num. Format statement number 10 is used and given as:

```
10 FORMAT (3 F 10.4)
```

The computer expects then to read these data values, the first of these values, either wavelength or period, should be typed in columns 1-10; similarly wave height in columns 11-20; and water depth in columns 21-30.

PROGRAM LIMITATIONS

This Stokes V order wave theory program is set up to operate under certain limitations or constraints. These constraints are in accordance with experimental verification of where Stokes V order wave theory is most applicable and best describes the natural phenomenon. The limitations tested are:

(1) $D/L > 0.039$

(2) $H/D > 0.2$

(3) $D/T^2 > 0.2$

If any of these conditions is not satisfied the program is directed to halt computation and output the fact that Stokes V wave theory is not applicable to the input wave characteristics.

```
//$OPTIONS
C
C
C   *****************************************************************
C       STCKES FIFTH ORCER WAVE THEORY
C   *****************************************************************
C       H= WAVE HEIGHT
C       T = WAVE PERICD
C       D = STILL WATER DEPTH
C       NUM=1,  WHEN L,H,D, ARE KNOWN; ; NUM=2, WHEN T,H,D, ARE KNOWN
C       DEPINC DEPTH INCREMENTS AT WHICH THE PARTICLE VELOCITIES AND
C       ACCELERATIONS ARE CALCULATED
C       XLINC INCREMENTS ALONG WAVELENGTH AT WHICH THE VELOCITIES AND
C       ACCELERATIONS ARE CALCULATED
C       S IS MEASURED POSITIVELY UPWARDS FROM THE MUDLINE
C
C       LIMITATIONS :  D/L> 0.039,  H/D>0.2  AND D/T*T > 0.2
C
        DIMENSICN U(10),Y(10),YF(100)
        CHK=0.
        N=0
        PI=3.1416
        G=32.2
        READ(5,5) NUM,DEPINC,XLINC
        GO TO (7,8),NUM
      7 READ(5,10) WL,H,D
        PRINT,WL,H,D
C
C       CHECK THE LIMITATIONS
C
        SHA1=D/WL
        SHA2=H/D
        IF(SHA1.LT.0.039) GO TO 2000
        IF(SHA2.LT.0.20) GO TO 2000
        GO TO 30
      8 READ(5,10) T,H,D
        PRINT,T,H,D
        WL=G*T**2/(2.*PI)
C
C       CHECK THE LIMITATIONS
C
        SHA1=D/WL
        SHA2=H/D
        IF(SHA1.LT.0.039) GO TO 2000
        IF(SHA2.LT.0.20) GO TO 2000
        WLO=WL
     30 CALL SOLVEL(WL,AMDA,H,T,D,PI,G,B33,B35,B55)
C
C       CHECK VALUE OF LAMDA AND WAVELENGTH
C
        BETA=2.*PI/WL
        S=SINH(2.*PI*D/WL)
        C=COSH(2.*PI*D/WL)
        C1=(8.*C**4-8.*C**2+9.)/(8.*S**4)
        C2=(3840.*C**12-4096.*C**10+2592.*C**8-1008.*C**6+5944.*C**4-1830.
       .*C**2+147.)/(512.*S**10*(6.*C**2-1.))
        AMDA2=AMDA**2
        AMDA4=AMDA**4
        GO TO (21,22),NUM
     21 WLO=WL/(TANH(BETA*D)*(1.+AMDA2*C1+AMDA4*C2))
```

```
      T=SQRT(WLO*2.*PI/G)
      GO TO 50
   22 CONTINUE
      WLT=WLO*TANH(BETA*D)*(1.+AMDA2*C1+AMDA4*C2)
      DIFF=WL-WLT
      WL=(WL+WLT)/2.
      N=N+1
      WRITE(6,20) WLT,AMDA
      IF(N.GT.50) GO TO 990
      CDIFF=CHK-AMDA
      IF(ABS(CDIFF).LT..1E-06) GO TO 50
      CHK=AMDA
      IF(ABS(DIFF).GT.0.0001) GO TO 30
   50 CONTINUE
C
      CEL=WL/T
      WRITE(6,200) WL,H,D,CEL,T,AMDA
C
C     CALCULATE COEFFICIENTS
C
      A11=1./S
      A13=-C**2*(5.*C**2+1.)/(8.*S**5)
      A15=-(1184.*C**10-1440.*C**8-1992.*C**6+2641.*C**4-249.*C**2+18.)
     ./(1536.*S**11)
      A22=3./(8.*S**4)
      A24=(192.*C**8-424.*C**6-312.*C**4+480.*C**2-17.)/(768.*S**10)
      A33=(13.-4.*C**2)/(64.*S**7)
      A35=(512.*C**12+4224.*C**10-6800.*C**8-12808.*C**6+16704.*C**4
     .-3154.*C**2+107.)/(4096.*S**13*(6.*C**2-1.))
      A44=(80.*C**6-816.*C**4+1338.*C**2-197.)/(1536.*S**10*(6.*C**2-1.)
     .)
      A55=-(2880.*C**10-72480.*C**8+324000.*C**6-432000.*C**4+163470.*
     .C**2-16245.)/(61440.*S**11*(6.*C**2-1.)*(8.*C**4-11.*C**2+3.))
      B22=(2.*C**2+1.)*C/(4.*S**3)
      B24=C*(272.*C**8-504.*C**6-192.*C**4+322.*C**2+21.)/(384.*S**9)
      B33=3.*(8.*C**6+1.)/(64.*S**6)
      B44=C*(768.*C**10-448.*C**8-48.*C**6+48.*C**4+106.*C**2-21.)/
     .(384.*S**9*(6.*C**2-1.))
      C0=SQRT(G*(TANH(BETA*D)))
      C3=-1./(4.*S*C)
      C4=(12.*C**8+36.*C**6-162.*C**4+141.*C**2-27.)/(192.*C*S**9)
      AMDA3=AMDA**3
      AMDA5=AMDA**5
      Y(1)=AMDA
      Y(2)=AMDA2*(B22+AMDA2*B24)
      Y(3)=AMDA3*(B33+AMDA2*B35)
      Y(4)=AMDA4*B44
      Y(5)=AMDA5*B55
      U(1)=AMDA*(A11+AMDA2*A13+AMDA4*A15)
      U(2)=AMDA2*(A22+AMDA2*A24)
      U(3)=AMDA3*(A33+AMDA2*A35)
      U(4)=AMDA4*A44
      U(5)=AMDA5*A55
      WRITE(6,250) A11,A13,A15,A22,A24,A33,A35,A44,A55,B22,B24,B33,B35,
     1B44,B55,C0,C1,C2,C3,C4
C
      WRITE(6,260)
      KKK=0.5/XLINC+1.
C
C     COMPUTE THE WAVE PROFILE
```

```
C
      XDL=0.
      DO 410 J=1,KKK
      THETA=2.*PI*XDL
      WSUM=0.0
      DO 400 I=1,5
      WF=Y(I)*COS(I*THETA)
      WSUM=WSUM+WF
  400 CONTINUE
      YP(J)=WSUM/BETA
      WRITE(6,270) XDL,YP(J)
      XDL=XDL+XLINC
  410 CONTINUE
      KKK=0.5/XLINC+1.
      XDL=0.
C
C     BEGIN DO LOOP TO CALCULATE VELOCITIES AND ACCELERATIONS
C
      DO 320 MM=1,KKK
      WRITE(6,280) XDL
      THETA=2.*PI*XDL
      DEP=D+YP(MM)
      IDP=DEP/DEPINC+2.
      FP=DEP/DEPINC
      IP=FP
      DP=FP-FLOAT(IP)
      IF(DP.EQ.0.0) IDP=IDP-1
      SD=0.
      DO 310 K=1,IDP
      USUM=0.
      VSUM=0.
      UASUM=0.
      VASUM=0.
      DO 300 I=1,5
      UPU=I*U(I)*COSH(I*BETA*SD)*COS(I*THETA)
      VPV=I*U(I)*SINH(I*BETA*SD)*SIN(I*THETA)
      USUM=USUM+UPU
      VSUM=VSUM+VPV
      UAU=I**2*U(I)*COSH(I*BETA*SD)*SIN(I*THETA)
      VAV=I**2*U(I)*SINH(I*BETA*SD)*COS(I*THETA)
      UASUM=UASUM+UAU
      VASUM=VASUM+VAV
  300 CONTINUE
      UP=USUM*CEL
      VP=VSUM*CEL
      AU=UASUM*CEL**2*BETA
      AV=-VASUM*CEL**2*BETA
      WRITE(6,500) SD,UP,VP,AU,AV
      SD=SD+DEPINC
      IF(SD.GT.DEP) SD=DEP
  310 CONTINUE
      XDL=XDL+XLINC
  320 CONTINUE
      WRITE(6,850)
      GO TO 999
  990 WRITE(6,800)
  999 WRITE(6,900)
      GO TO 1000
 2000 WRITE(6,3000)
    5 FORMAT(I1,2F10.5)
```

```
   10 FORMAT(3F10.5)
   20 FORMAT(5X,2(F10.4,5X))
  200 FORMAT(1H1,////////,T05,'VALUES DERIVED USING STOKES FIFTH ORDER ',
     6'WAVE THEORY',
     1////////,T17,'WAVE LENGTH    =',F10.4,///,T17,'WAVE HEIGHT    =',
     2F10.4,///,T17,'WATER DEPTH    =',F10.4,///,T17,'WAVE CELERITY =',
     4F10.4,///,T17,'WAVE PERIOD    =',F10.4,///,T17,'LAMBDA         =',
     5F10.4)
  250 FORMAT(////,T12,' VALUES OF COEFFICIENTS ',///,T07,'A11  = ',
     1F10.4,5X,' A13 = ',F10.4,5X,' A15 = ',F10.4,///,T07,' A22 = ',
     2F10.4,5X,'A24 = ',F10.4,5X,                        ' A33 = ',F10.4,
     3///,T07,' A35 = ',F10.4,5X,' A44 = ',F10.4,5X,' A55 = ',F10.4,///,
     4T07,' B22 = ',F10.4,5X,' B24 = ',F10.4,5X,' B33 = ',F10.4,///,
     5T07,' B35 = ',F10.4,5X,' B44 = ',F10.4,5X,' B55 = ',F10.4,///,
     6T07,' C0 = ',F10.4,5X,'C1 = ',F10.4,5X,' C2 = ',F10.4,///,T07,
     7' C3 = ',F10.4,5X,' C4 = ',F10.4)
  260 FORMAT(1H1,/////,T30,'WAVE  PROFILE'////,T20,'X/L',5X,'DISTANCE AB
     1OVE MWL',/)
  270 FORMAT(      T15,F10.4,T28,F10.4)
  280 FORMAT(1H1,9(/),T34,'X/L =',F7.4,///,T10,'S',T18,'HORIZONTAL',T34,
     1'VERTICAL',T50,'HORIZONTAL',T67,'VERTICAL',/,T19,'VELOCITY',T34,
     2'VELOCITY',T49,'ACCELERATION',T65,'ACCELERATION',/)
 500   FORMAT(     F13.4,4F16.6)
 800   FORMAT(1H1,////,' DOES NOT CONVERGE')
  850 FORMAT(//,T20,'ALL DIMENSIONS IN FEET, POUNDS, SECONDS.')
900    FORMAT(1H1)
 3000 FORMAT(////,T10,'**********  STOKES V WAVE THEORY IS NOT APPLICABL
     1E FOR THIS PROBLEM  **********',////)
 1000 STOP
      END
C    *****************************************************************

      SUBROUTINE SOLVEL(WL,AMDA,H,T,D,PI,G,B33,B35,B55)
C   THIS SUBROUTINE CALCULATES VALUE OF LAMDA
      C=COSH(2.*PI*D/WL)
      S=SINH(2.*PI*D/WL)
      BETA=2.*PI/WL
      B33=3.*(8.*C**6+1.)/(64.*S**6)
      B35=(88128.*C**14-208224.*C**12+70848.*C**10+54000.*C**8-21816.
     .*C**6+6264.*C**4-54.*C**2-81.)/(12288.*S**12*(6.*C**2-1.))
      B55=(192000.*C**16-262720.*C**14+83680.*C**12+20160.*C**10-7280.
     .*C**8+7160.*C**6-1800.*C**4-1050.*C**2+225.)/(
     .12288.*S**10*(6.*C**2-1.)*(8.*C**4-11.*C**2+3.))
      ITMAX=50
      X=.2
      CK2=B35+B55
      CST=PI*H/WL
      DO 25 I=1,ITMAX
      ROOT=X-(B33*X**3+CK2*X**5-CST+X)/(1.+3*B33*X**2+5*CK2*X**4)
      RDIFF=ROOT-X
      IF(ABS(RDIFF).LE..0001) GO TO 100
      X=ROOT
   25 CONTINUE
      WRITE(6,200) ROOT
      STOP
  100 AMDA=X
  200 FORMAT(2X,'DOESNT CONVERGE AFTER  50  ITERATIONS',3X,'ROOT= ',
     1F10.4)
      RETURN
      END
```

```
      //$DATA
0.1000000E 02     0.2000000E 02     0.1000000E 03
     441.7771          0.1206
     455.2107          0.1296
     459.3921          0.1326
     460.6853          0.1336
     461.0850          0.1339
     461.2087          0.1340
     461.2468          0.1340
     461.2590          0.1340
     461.2625          0.1340
     461.2637          0.1340
     461.2642          0.1340
     461.2642          0.1340
```

VALUES DERIVED USING STOKES FIFTH ORDER WAVE THEORY

WAVE LENGTH	=	461.2642
WAVE HEIGHT	=	20.0000
WATER DEPTH	=	100.0000
WAVE CELERITY	=	46.1264
WAVE PERIOD	=	10.0000
LAMBDA	=	0.1340

VALUES OF COEFFICIENTS

A11 =	0.5482	A13 =	-0.6062	A15 =	-1.0312
A22 =	0.0339	A24 =	0.0932	A33 =	-0.0010
A35 =	0.0263	A44 =	-0.0002	A55 =	0.0000
B22 =	0.8272	B24 =	1.2685	B33 =	0.8261
B35 =	3.0304	B44 =	0.9760	B55 =	1.2701
C0 =	5.3138	C1 =	1.4021	C2 =	3.8226
C3 =	-0.0659	C4 =	0.0523		

WAVE PROFILE

X/L	DISTANCE ABOVE MWL
0.0000	11.1445
0.1000	8.2367
0.2000	2.0190
0.3000	-3.8189
0.4000	-7.5812

X/L = 0.0000

S	HORIZONTAL VELOCITY	VERTICAL VELOCITY	HORIZONTAL ACCELERATION	VERTICAL ACCELERATION
0.0000	0.337858E 01	0.000000E 00	0.000000E 00	-0.000000E 00
1.5000	0.337932E 01	0.000000E 00	0.000000E 00	-0.456267E-01
3.0000	0.338155E 01	0.000000E 00	0.000000E 00	-0.912760E-01
4.5000	0.338526E 01	0.000000E 00	0.000000E 00	-0.136971E 00
6.0000	0.339046E 01	0.000000E 00	0.000000E 00	-0.182734E 00
7.5000	0.339715E 01	0.000000E 00	0.000000E 00	-0.228588E 00
9.0000	0.340532E 01	0.000000E 00	0.000000E 00	-0.274557E 00
10.5000	0.341500E 01	0.000000E 00	0.000000E 00	-0.320663E 00
12.0000	0.342618E 01	0.000000E 00	0.000000E 00	-0.366928E 00
13.5000	0.343887E 01	0.000000E 00	0.000000E 00	-0.413377E 00
15.0000	0.345307E 01	0.000000E 00	0.000000E 00	-0.460033E 00
16.5000	0.346879E 01	0.000000E 00	0.000000E 00	-0.506920E 00
18.0000	0.348604E 01	0.000000E 00	0.000000E 00	-0.554059E 00
19.5000	0.350483E 01	0.000000E 00	0.000000E 00	-0.601476E 00
21.0000	0.352517E 01	0.000000E 00	0.000000E 00	-0.649195E 00
22.5000	0.354706E 01	0.000000E 00	0.000000E 00	-0.697239E 00
24.0000	0.357052E 01	0.000000E 00	0.000000E 00	-0.745634E 00
25.5000	0.359556E 01	0.000000E 00	0.000000E 00	-0.794403E 00
27.0000	0.362219E 01	0.000000E 00	0.000000E 00	-0.843572E 00
28.5000	0.365043E 01	0.000000E 00	0.000000E 00	-0.893166E 00
30.0000	0.368028E 01	0.000000E 00	0.000000E 00	-0.943210E 00
31.5000	0.371178E 01	0.000000E 00	0.000000E 00	-0.993730E 00
33.0000	0.374492E 01	0.000000E 00	0.000000E 00	-0.104475E 01
34.5000	0.377973E 01	0.000000E 00	0.000000E 00	-0.109630E 01
36.0000	0.381623E 01	0.000000E 00	0.000000E 00	-0.114841E 01
37.5000	0.385443E 01	0.000000E 00	0.000000E 00	-0.120110E 01
39.0000	0.389435E 01	0.000000E 00	0.000000E 00	-0.125440E 01
40.5000	0.393602E 01	0.000000E 00	0.000000E 00	-0.130834E 01
42.0000	0.397945E 01	0.000000E 00	0.000000E 00	-0.136294E 01
43.5000	0.402467E 01	0.000000E 00	0.000000E 00	-0.141824E 01
45.0000	0.407170E 01	0.000000E 00	0.000000E 00	-0.147427E 01
46.5000	0.412056E 01	0.000000E 00	0.000000E 00	-0.153105E 01
48.0000	0.417129E 01	0.000000E 00	0.000000E 00	-0.158862E 01
49.5000	0.422389E 01	0.000000E 00	0.000000E 00	-0.164701E 01
51.0000	0.427841E 01	0.000000E 00	0.000000E 00	-0.170624E 01
52.5000	0.433488E 01	0.000000E 00	0.000000E 00	-0.176635E 01
54.0000	0.439331E 01	0.000000E 00	0.000000E 00	-0.182738E 01
55.5000	0.445374E 01	0.000000E 00	0.000000E 00	-0.188935E 01
57.0000	0.451620E 01	0.000000E 00	0.000000E 00	-0.195231E 01
58.5000	0.458072E 01	0.000000E 00	0.000000E 00	-0.201629E 01
60.0000	0.464734E 01	0.000000E 00	0.000000E 00	-0.208131E 01
61.5000	0.471610E 01	0.000000E 00	0.000000E 00	-0.214743E 01
63.0000	0.478703E 01	0.000000E 00	0.000000E 00	-0.221467E 01
64.5000	0.486015E 01	0.000000E 00	0.000000E 00	-0.228308E 01
66.0000	0.493553E 01	0.000000E 00	0.000000E 00	-0.235269E 01

67.5000	0.501319E 01	0.000000E 00	0.000000E 00	-0.242354E 01
69.0000	0.509316E 01	0.000000E 00	0.000000E 00	-0.249567E 01
70.5000	0.517552E 01	0.000000E 00	0.000000E 00	-0.256913E 01
72.0000	0.526027E 01	0.000000E 00	0.000000E 00	-0.264396E 01
73.5000	0.534748E 01	0.000000E 00	0.000000E 00	-0.272020E 01
75.0000	0.543720E 01	0.000000E 00	0.000000E 00	-0.279790E 01
76.5000	0.552947E 01	0.000000E 00	0.000000E 00	-0.287710E 01
78.0000	0.562435E 01	0.000000E 00	0.000000E 00	-0.295785E 01
79.5000	0.572187E 01	0.000000E 00	0.000000E 00	-0.304020E 01
81.0000	0.582209E 01	0.000000E 00	0.000000E 00	-0.312420E 01
82.5000	0.592508E 01	0.000000E 00	0.000000E 00	-0.320989E 01
84.0000	0.603088E 01	0.000000E 00	0.000000E 00	-0.329733E 01
85.5000	0.613955E 01	0.000000E 00	0.000000E 00	-0.338658E 01
87.0000	0.625116E 01	0.000000E 00	0.000000E 00	-0.347768E 01
88.5000	0.636576E 01	0.000000E 00	0.000000E 00	-0.357071E 01
90.0000	0.648342E 01	0.000000E 00	0.000000E 00	-0.366570E 01
91.5000	0.660420E 01	0.000000E 00	0.000000E 00	-0.376272E 01
93.0000	0.672816E 01	0.000000E 00	0.000000E 00	-0.386184E 01
94.5000	0.685539E 01	0.000000E 00	0.000000E 00	-0.396310E 01
96.0000	0.698594E 01	0.000000E 00	0.000000E 00	-0.406659E 01
97.5000	0.711990E 01	0.000000E 00	0.000000E 00	-0.417236E 01
99.0000	0.725733E 01	0.000000E 00	0.000000E 00	-0.428049E 01
100.5000	0.739832E 01	0.000000E 00	0.000000E 00	-0.439103E 01
102.0000	0.754295E 01	0.000000E 00	0.000000E 00	-0.450407E 01
103.5000	0.769129E 01	0.000000E 00	0.000000E 00	-0.461967E 01
105.0000	0.784343E 01	0.000000E 00	0.000000E 00	-0.473791E 01
106.5000	0.799946E 01	0.000000E 00	0.000000E 00	-0.485888E 01
108.0000	0.815947E 01	0.000000E 00	0.000000E 00	-0.498264E 01
109.5000	0.832356E 01	0.000000E 00	0.000000E 00	-0.510928E 01
111.0000	0.849182E 01	0.000000E 00	0.000000E 00	-0.523889E 01
111.1445	0.850825E 01	0.000000E 00	0.000000E 00	-0.525154E 01

X/L = 0.1000

S	HORIZONTAL VELOCITY	VERTICAL VELOCITY	HORIZONTAL ACCELERATION	VERTICAL ACCELERATION
0.0000	0.270410E 01	0.000000E 00	0.129615E 01	-0.000000E 00
1.5000	0.270467E 01	0.421532E-01	0.129646E 01	-0.354267E-01
3.0000	0.270649E 01	0.843269E-01	0.129740E 01	-0.708695E-01
4.5000	0.270928E 01	0.126541E 00	0.129897E 01	-0.106344E 00
6.0000	0.271332E 01	0.168817E 00	0.130118E 01	-0.141867E 00
7.5000	0.271851E 01	0.211175E 00	0.130401E 01	-0.177454E 00
9.0000	0.272486E 01	0.253635E 00	0.130747E 01	-0.213121E 00
10.5000	0.273237E 01	0.296218E 00	0.131157E 01	-0.248884E 00
12.0000	0.274105E 01	0.338945E 00	0.131631E 01	-0.284760E 00
13.5000	0.275089E 01	0.381836E 00	0.132169E 01	-0.320764E 00
15.0000	0.276191E 01	0.424913E 00	0.132772E 01	-0.356913E 00
16.5000	0.277411E 01	0.468197E 00	0.133439E 01	-0.393224E 00
18.0000	0.278749E 01	0.511708E 00	0.134172E 01	-0.429713E 00
19.5000	0.280206E 01	0.555468E 00	0.134971E 01	-0.466396E 00
21.0000	0.281783E 01	0.599498E 00	0.135835E 01	-0.503291E 00
22.5000	0.283479E 01	0.643821E 00	0.136767E 01	-0.540413E 00
24.0000	0.285298E 01	0.688457E 00	0.137766E 01	-0.577780E 00
25.5000	0.287238E 01	0.733429E 00	0.138833E 01	-0.615410E 00
27.0000	0.289300E 01	0.778760E 00	0.139969E 01	-0.653318E 00
28.5000	0.291486E 01	0.824471E 00	0.141175E 01	-0.691523E 00
30.0000	0.293797E 01	0.870585E 00	0.142450E 01	-0.730042E 00
31.5000	0.296235E 01	0.917126E 00	0.143797E 01	-0.768893E 00
33.0000	0.298799E 01	0.964117E 00	0.145216E 01	-0.808094E 00
34.5000	0.301491E 01	0.101158E 01	0.146708E 01	-0.847662E 00
36.0000	0.304313E 01	0.105954E 01	0.148275E 01	-0.887617E 00
37.5000	0.307264E 01	0.110802E 01	0.149916E 01	-0.927976E 00
39.0000	0.310348E 01	0.115705E 01	0.151633E 01	-0.968758E 00
40.5000	0.313566E 01	0.120665E 01	0.153427E 01	-0.100998E 01
42.0000	0.316918E 01	0.125685E 01	0.155300E 01	-0.105167E 01
43.5000	0.320406E 01	0.130767E 01	0.157253E 01	-0.109384E 01
45.0000	0.324032E 01	0.135913E 01	0.159287E 01	-0.113651E 01
46.5000	0.327798E 01	0.141127E 01	0.161403E 01	-0.117969E 01
48.0000	0.331706E 01	0.146412E 01	0.163603E 01	-0.122342E 01
49.5000	0.335756E 01	0.151769E 01	0.165888E 01	-0.126772E 01
51.0000	0.339951E 01	0.157202E 01	0.168260E 01	-0.131259E 01
52.5000	0.344294E 01	0.162713E 01	0.170721E 01	-0.135808E 01
54.0000	0.348785E 01	0.168306E 01	0.173272E 01	-0.140418E 01
55.5000	0.353427E 01	0.173984E 01	0.175915E 01	-0.145094E 01
57.0000	0.358222E 01	0.179749E 01	0.178652E 01	-0.149836E 01
58.5000	0.363173E 01	0.185604E 01	0.181484E 01	-0.154648E 01
60.0000	0.368281E 01	0.191553E 01	0.184414E 01	-0.159532E 01
61.5000	0.373549E 01	0.197599E 01	0.187443E 01	-0.164489E 01
63.0000	0.378980E 01	0.203745E 01	0.190575E 01	-0.169523E 01
64.5000	0.384576E 01	0.209995E 01	0.193810E 01	-0.174636E 01
66.0000	0.390339E 01	0.216352E 01	0.197152E 01	-0.179831E 01

67.5000	0.396273E 01	0.222819E 01	0.200603E 01	-0.185109E 01
69.0000	0.402379E 01	0.229400E 01	0.204164E 01	-0.190474E 01
70.5000	0.408662E 01	0.236098E 01	0.207840E 01	-0.195928E 01
72.0000	0.415123E 01	0.242918E 01	0.211631E 01	-0.201475E 01
73.5000	0.421766E 01	0.249864E 01	0.215542E 01	-0.207116E 01
75.0000	0.428594E 01	0.256938E 01	0.219574E 01	-0.212855E 01
76.5000	0.435611E 01	0.264146E 01	0.223731E 01	-0.218694E 01
78.0000	0.442819E 01	0.271491E 01	0.228016E 01	-0.224637E 01
79.5000	0.450223E 01	0.278977E 01	0.232432E 01	-0.230686E 01
81.0000	0.457824E 01	0.286609E 01	0.236983E 01	-0.236845E 01
82.5000	0.465628E 01	0.294392E 01	0.241671E 01	-0.243117E 01
84.0000	0.473637E 01	0.302328E 01	0.246499E 01	-0.249504E 01
85.5000	0.481856E 01	0.310425E 01	0.251473E 01	-0.256012E 01
87.0000	0.490289E 01	0.318685E 01	0.256595E 01	-0.262641E 01
88.5000	0.498940E 01	0.327115E 01	0.261869E 01	-0.269398E 01
90.0000	0.507812E 01	0.335719E 01	0.267299E 01	-0.276284E 01
91.5000	0.516911E 01	0.344502E 01	0.272890E 01	-0.283303E 01
93.0000	0.526239E 01	0.353469E 01	0.278645E 01	-0.290459E 01
94.5000	0.535803E 01	0.362626E 01	0.284569E 01	-0.297757E 01
96.0000	0.545607E 01	0.371979E 01	0.290667E 01	-0.305199E 01
97.5000	0.555655E 01	0.381533E 01	0.296943E 01	-0.312791E 01
99.0000	0.565952E 01	0.391294E 01	0.303402E 01	-0.320535E 01
100.5000	0.576503E 01	0.401268E 01	0.310049E 01	-0.328438E 01
102.0000	0.587315E 01	0.411461E 01	0.316889E 01	-0.336502E 01
103.5000	0.598391E 01	0.421880E 01	0.323928E 01	-0.344732E 01
105.0000	0.609737E 01	0.432531E 01	0.331172E 01	-0.353133E 01
106.5000	0.621360E 01	0.443421E 01	0.338624E 01	-0.361710E 01
108.0000	0.633264E 01	0.454557E 01	0.346294E 01	-0.370467E 01
108.2367	0.635169E 01	0.456338E 01	0.347524E 01	-0.371866E 01

X/L = 0.2000

S	HORIZONTAL VELOCITY	VERTICAL VELOCITY	HORIZONTAL ACCELERATION	VERTICAL ACCELERATION
0.0000	0.978780E 00	0.000000E 00	0.202758E 01	-0.000000E 00
1.5000	0.978554E 00	0.659404E-01	0.202803E 01	-0.107396E-01
3.0000	0.979077E 00	0.131910E 00	0.202938E 01	-0.214807E-01
4.5000	0.979951E 00	0.197938E 00	0.203164E 01	-0.322248E-01
6.0000	0.981174E 00	0.264055E 00	0.203480E 01	-0.429732E-01
7.5000	0.982746E 00	0.330289E 00	0.203886E 01	-0.537275E-01
9.0000	0.984668E 00	0.396670E 00	0.204383E 01	-0.644889E-01
10.5000	0.986940E 00	0.463227E 00	0.204972E 01	-0.752591E-01
12.0000	0.989562E 00	0.529991E 00	0.205651E 01	-0.860393E-01
13.5000	0.992536E 00	0.596991E 00	0.206423E 01	-0.968308E-01
15.0000	0.995861E 00	0.664256E 00	0.207286E 01	-0.107635E 00
16.5000	0.999537E 00	0.731818E 00	0.208243E 01	-0.118453E 00
18.0000	0.100356E 01	0.799705E 00	0.209292E 01	-0.129287E 00
19.5000	0.100795E 01	0.867948E 00	0.210434E 01	-0.140137E 00
21.0000	0.101268E 01	0.936579E 00	0.211671E 01	-0.151004E 00
22.5000	0.101777E 01	0.100563E 01	0.213003E 01	-0.161890E 00
24.0000	0.102321E 01	0.107512E 01	0.214431E 01	-0.172795E 00
25.5000	0.102901E 01	0.114510E 01	0.215954E 01	-0.183721E 00
27.0000	0.103516E 01	0.121559E 01	0.217575E 01	-0.194668E 00
28.5000	0.104167E 01	0.128662E 01	0.219294E 01	-0.205638E 00
30.0000	0.104853E 01	0.135822E 01	0.221111E 01	-0.216629E 00
31.5000	0.105576E 01	0.143044E 01	0.223029E 01	-0.227645E 00
33.0000	0.106334E 01	0.150329E 01	0.225047E 01	-0.238684E 00
34.5000	0.107128E 01	0.157682E 01	0.227168E 01	-0.249748E 00
36.0000	0.107958E 01	0.165105E 01	0.229391E 01	-0.260836E 00
37.5000	0.108824E 01	0.172602E 01	0.231719E 01	-0.271948E 00
39.0000	0.109727E 01	0.180177E 01	0.234152E 01	-0.283086E 00
40.5000	0.110666E 01	0.187832E 01	0.236692E 01	-0.294247E 00
42.0000	0.111641E 01	0.195572E 01	0.239341E 01	-0.305434E 00
43.5000	0.112652E 01	0.203400E 01	0.242099E 01	-0.316644E 00
45.0000	0.113700E 01	0.211319E 01	0.244967E 01	-0.327877E 00
46.5000	0.114785E 01	0.219334E 01	0.247949E 01	-0.339133E 00
48.0000	0.115906E 01	0.227447E 01	0.251045E 01	-0.350411E 00
49.5000	0.117064E 01	0.235663E 01	0.254257E 01	-0.361709E 00
51.0000	0.118258E 01	0.243985E 01	0.257587E 01	-0.373026E 00
52.5000	0.119490E 01	0.252417E 01	0.261036E 01	-0.384362E 00
54.0000	0.120758E 01	0.260963E 01	0.264607E 01	-0.395712E 00
55.5000	0.122064E 01	0.269628E 01	0.268301E 01	-0.407078E 00
57.0000	0.123406E 01	0.278415E 01	0.272121E 01	-0.418455E 00
58.5000	0.124785E 01	0.287328E 01	0.276068E 01	-0.429842E 00
60.0000	0.126201E 01	0.296371E 01	0.280145E 01	-0.441235E 00
61.5000	0.127655E 01	0.305549E 01	0.284355E 01	-0.452633E 00
63.0000	0.129145E 01	0.314866E 01	0.288698E 01	-0.464031E 00
64.5000	0.130673E 01	0.324327E 01	0.293179E 01	-0.475426E 00
66.0000	0.132237E 01	0.333936E 01	0.297799E 01	-0.486814E 00

67.5000	0.133839E 01	0.343697E 01	0.302561E 01	-0.498190E 00
69.0000	0.135476E 01	0.353616E 01	0.307468E 01	-0.509552E 00
70.5000	0.137153E 01	0.363696E 01	0.312522E 01	-0.520891E 00
72.0000	0.138865E 01	0.373943E 01	0.317727E 01	-0.532206E 00
73.5000	0.140614E 01	0.384362E 01	0.323085E 01	-0.543488E 00
75.0000	0.142400E 01	0.394958E 01	0.328600E 01	-0.554733E 00
76.5000	0.144222E 01	0.405735E 01	0.334275E 01	-0.565932E 00
78.0000	0.146081E 01	0.416700E 01	0.340113E 01	-0.577080E 00
79.5000	0.147975E 01	0.427857E 01	0.346117E 01	-0.588169E 00
81.0000	0.149906E 01	0.439213E 01	0.352292E 01	-0.599191E 00
82.5000	0.151872E 01	0.450772E 01	0.358640E 01	-0.610137E 00
84.0000	0.153874E 01	0.462540E 01	0.365166E 01	-0.620997E 00
85.5000	0.155911E 01	0.474524E 01	0.371874E 01	-0.631764E 00
87.0000	0.157983E 01	0.486729E 01	0.378766E 01	-0.642425E 00
88.5000	0.160089E 01	0.499161E 01	0.385850E 01	-0.652970E 00
90.0000	0.162230E 01	0.511826E 01	0.393127E 01	-0.663387E 00
91.5000	0.164404E 01	0.524731E 01	0.400602E 01	-0.673664E 00
93.0000	0.166611E 01	0.537883E 01	0.408281E 01	-0.683788E 00
94.5000	0.168851E 01	0.551288E 01	0.416167E 01	-0.693744E 00
96.0000	0.171123E 01	0.564952E 01	0.424266E 01	-0.703519E 00
97.5000	0.173426E 01	0.578884E 01	0.432584E 01	-0.713096E 00
99.0000	0.175760E 01	0.593090E 01	0.441124E 01	-0.722461E 00
100.5000	0.178125E 01	0.607576E 01	0.449893E 01	-0.731594E 00
102.0000	0.180518E 01	0.622353E 01	0.458897E 01	-0.740479E 00
102.0190	0.180549E 01	0.622542E 01	0.459012E 01	-0.740590E 00

X/L = 0.3000

S	HORIZONTAL VELOCITY	VERTICAL VELOCITY	HORIZONTAL ACCELERATION	VERTICAL ACCELERATION
0.0000	-0.107371E 01	0.000000E 00	0.194051E 01	-0.000000E 00
1.5000	-0.107396E 01	0.631061E-01	0.194088E 01	0.156367E-01
3.0000	-0.107473E 01	0.126241E 00	0.194201E 01	0.312831E-01
4.5000	-0.107600E 01	0.189422E 00	0.194391E 01	0.469488E-01
6.0000	-0.107778E 01	0.252678E 00	0.194656E 01	0.626435E-01
7.5000	-0.108007E 01	0.316032E 00	0.194996E 01	0.783769E-01
9.0000	-0.108288E 01	0.379510E 00	0.195413E 01	0.941588E-01
10.5000	-0.108620E 01	0.443135E 00	0.195905E 01	0.109999E 00
12.0000	-0.109003E 01	0.506932E 00	0.196474E 01	0.125907E 00
13.5000	-0.109439E 01	0.570927E 00	0.197119E 01	0.141893E 00
15.0000	-0.109926E 01	0.635145E 00	0.197841E 01	0.157968E 00
16.5000	-0.110466E 01	0.699609E 00	0.198639E 01	0.174140E 00
18.0000	-0.111059E 01	0.764345E 00	0.199514E 01	0.190421E 00
19.5000	-0.111705E 01	0.829379E 00	0.200467E 01	0.206820E 00
21.0000	-0.112404E 01	0.894735E 00	0.201496E 01	0.223348E 00
22.5000	-0.113157E 01	0.960438E 00	0.202604E 01	0.240016E 00
24.0000	-0.113966E 01	0.102651E 01	0.203790E 01	0.256834E 00
25.5000	-0.114828E 01	0.109299E 01	0.205055E 01	0.273813E 00
27.0000	-0.115746E 01	0.115989E 01	0.206398E 01	0.290964E 00
28.5000	-0.116721E 01	0.122724E 01	0.207821E 01	0.308298E 00
30.0000	-0.117752E 01	0.129506E 01	0.209323E 01	0.325627E 00
31.5000	-0.118840E 01	0.136339E 01	0.210905E 01	0.343561E 00
33.0000	-0.119986E 01	0.143224E 01	0.212568E 01	0.361513E 00
34.5000	-0.121192E 01	0.150165E 01	0.214312E 01	0.379695E 00
36.0000	-0.122456E 01	0.157164E 01	0.216137E 01	0.398119E 00
37.5000	-0.123781E 01	0.164223E 01	0.218045E 01	0.416797E 00
39.0000	-0.125167E 01	0.171346E 01	0.220035E 01	0.435741E 00
40.5000	-0.126615E 01	0.178535E 01	0.222108E 01	0.454966E 00
42.0000	-0.128127E 01	0.185792E 01	0.224265E 01	0.474484E 00
43.5000	-0.129702E 01	0.193122E 01	0.226506E 01	0.494308E 00
45.0000	-0.131342E 01	0.200525E 01	0.228832E 01	0.514453E 00
46.5000	-0.133046E 01	0.208005E 01	0.231244E 01	0.534933E 00
48.0000	-0.134821E 01	0.215566E 01	0.233742E 01	0.555762E 00
49.5000	-0.136663E 01	0.223209E 01	0.236327E 01	0.576956E 00
51.0000	-0.138574E 01	0.230937E 01	0.238999E 01	0.598528E 00
52.5000	-0.140556E 01	0.238754E 01	0.241760E 01	0.620496E 00
54.0000	-0.142610E 01	0.246662E 01	0.244609E 01	0.642875E 00
55.5000	-0.144738E 01	0.254664E 01	0.247549E 01	0.665682E 00
57.0000	-0.146940E 01	0.262763E 01	0.250578E 01	0.688934E 00
58.5000	-0.149219E 01	0.270962E 01	0.253700E 01	0.712648E 00
60.0000	-0.151576E 01	0.279264E 01	0.256913E 01	0.736842E 00
61.5000	-0.154012E 01	0.287672E 01	0.260219E 01	0.761535E 00
63.0000	-0.156529E 01	0.296189E 01	0.263619E 01	0.786746E 00
64.5000	-0.159129E 01	0.304819E 01	0.267113E 01	0.812495E 00
66.0000	-0.161814E 01	0.313563E 01	0.270703E 01	0.838801E 00

67.5000	-0.164585E 01	0.322426E 01	0.274390E 01	0.865685E 00
69.0000	-0.167445E 01	0.331410E 01	0.278173E 01	0.893169E 00
70.5000	-0.170395E 01	0.340518E 01	0.282054E 01	0.921275E 00
72.0000	-0.173438E 01	0.349755E 01	0.286034E 01	0.950026E 00
73.5000	-0.176575E 01	0.359123E 01	0.290115E 01	0.979445E 00
75.0000	-0.179809E 01	0.368625E 01	0.294295E 01	0.100956E 01
76.5000	-0.183142E 01	0.378264E 01	0.298577E 01	0.104039E 01
78.0000	-0.186576E 01	0.388045E 01	0.302963E 01	0.107196E 01
79.5000	-0.190114E 01	0.397970E 01	0.307451E 01	0.110431E 01
81.0000	-0.193759E 01	0.408042E 01	0.312044E 01	0.113745E 01
82.5000	-0.197513E 01	0.418266E 01	0.316743E 01	0.117142E 01
84.0000	-0.201379E 01	0.428644E 01	0.321547E 01	0.120624E 01
85.5000	-0.205359E 01	0.439180E 01	0.326459E 01	0.124196E 01
87.0000	-0.209457E 01	0.449878E 01	0.331479E 01	0.127859E 01
88.5000	-0.213676E 01	0.460741E 01	0.336608E 01	0.131618E 01
90.0000	-0.218019E 01	0.471772E 01	0.341847E 01	0.135475E 01
91.5000	-0.222488E 01	0.482975E 01	0.347198E 01	0.139434E 01
93.0000	-0.227088E 01	0.494355E 01	0.352659E 01	0.143499E 01
94.5000	-0.231822E 01	0.505913E 01	0.358233E 01	0.147673E 01
96.0000	-0.236694E 01	0.517654E 01	0.363922E 01	0.151961E 01
96.1811	-0.237292E 01	0.519085E 01	0.364616E 01	0.152486E 01

X/L = 0.4000

S	HORIZONTAL VELOCITY	VERTICAL VELOCITY	HORIZONTAL ACCELERATION	VERTICAL ACCELERATION
0.0000	-0.266769E 01	0.000000E 00	0.115539E 01	-0.000000E 00
1.5000	-0.266823E 01	0.375745E-01	0.115558E 01	0.335530E-01
3.0000	-0.266987E 01	0.751619E-01	0.115617E 01	0.671189E-01
4.5000	-0.267260E 01	0.112775E 00	0.115716E 01	0.100710E 00
6.0000	-0.267642E 01	0.150426E 00	0.115853E 01	0.134340E 00
7.5000	-0.268134E 01	0.188128E 00	0.116030E 01	0.168022E 00
9.0000	-0.268735E 01	0.225895E 00	0.116246E 01	0.201768E 00
10.5000	-0.269446E 01	0.263738E 00	0.116502E 01	0.235590E 00
12.0000	-0.270267E 01	0.301670E 00	0.116797E 01	0.269504E 00
13.5000	-0.271199E 01	0.339705E 00	0.117132E 01	0.303520E 00
15.0000	-0.272242E 01	0.377856E 00	0.117505E 01	0.337652E 00
16.5000	-0.273395E 01	0.416134E 00	0.117918E 01	0.371913E 00
18.0000	-0.274661E 01	0.454552E 00	0.118371E 01	0.406317E 00
19.5000	-0.276038E 01	0.493125E 00	0.118863E 01	0.440875E 00
21.0000	-0.277528E 01	0.531864E 00	0.119394E 01	0.475601E 00
22.5000	-0.279132E 01	0.570782E 00	0.119965E 01	0.510510E 00
24.0000	-0.280849E 01	0.609852E 00	0.120575E 01	0.545612E 00
25.5000	-0.282681E 01	0.649207E 00	0.121225E 01	0.580922E 00
27.0000	-0.284627E 01	0.688740E 00	0.121914E 01	0.616454E 00
28.5000	-0.286690E 01	0.728503E 00	0.122643E 01	0.652220E 00
30.0000	-0.288868E 01	0.768509E 00	0.123410E 01	0.688233E 00
31.5000	-0.291166E 01	0.808772E 00	0.124218E 01	0.724508E 00
33.0000	-0.293581E 01	0.849303E 00	0.125065E 01	0.761059E 00
34.5000	-0.296116E 01	0.890116E 00	0.125951E 01	0.797897E 00
36.0000	-0.298771E 01	0.931224E 00	0.126876E 01	0.835038E 00
37.5000	-0.301547E 01	0.972640E 00	0.127841E 01	0.872495E 00
39.0000	-0.304446E 01	0.101437E 01	0.128846E 01	0.910281E 00
40.5000	-0.307468E 01	0.105644E 01	0.129889E 01	0.948411E 00
42.0000	-0.310615E 01	0.109886E 01	0.130972E 01	0.986899E 00
43.5000	-0.313887E 01	0.114163E 01	0.132094E 01	0.102576E 01
45.0000	-0.317286E 01	0.118477E 01	0.133255E 01	0.106500E 01
46.5000	-0.320814E 01	0.122830E 01	0.134455E 01	0.110465E 01
48.0000	-0.324472E 01	0.127223E 01	0.135694E 01	0.114471E 01
49.5000	-0.328260E 01	0.131656E 01	0.136972E 01	0.118520E 01
51.0000	-0.332180E 01	0.136131E 01	0.138289E 01	0.122613E 01
52.5000	-0.336235E 01	0.140650E 01	0.139644E 01	0.126752E 01
54.0000	-0.340424E 01	0.145214E 01	0.141038E 01	0.130938E 01
55.5000	-0.344752E 01	0.149824E 01	0.142470E 01	0.135173E 01
57.0000	-0.349217E 01	0.154461E 01	0.143940E 01	0.139459E 01
58.5000	-0.353822E 01	0.159186E 01	0.145448E 01	0.143796E 01
60.0000	-0.358577E 01	0.163941E 01	0.146994E 01	0.148186E 01
61.5000	-0.363466E 01	0.168747E 01	0.148577E 01	0.152631E 01
63.0000	-0.368497E 01	0.173604E 01	0.150198E 01	0.157132E 01
64.5000	-0.373681E 01	0.178516E 01	0.151855E 01	0.161692E 01
66.0000	-0.379014E 01	0.183481E 01	0.153548E 01	0.166310E 01

67.5000	-0.384498E 01	0.188503E 01	0.155278E 01	0.170990E 01
69.0000	-0.390135E 01	0.193581E 01	0.157044E 01	0.175732E 01
70.5000	-0.395929E 01	0.198717E 01	0.158845E 01	0.180538E 01
72.0000	-0.401878E 01	0.203912E 01	0.160681E 01	0.185410E 01
73.5000	-0.407988E 01	0.209168E 01	0.162551E 01	0.190349E 01
75.0000	-0.414259E 01	0.214485E 01	0.164455E 01	0.195358E 01
76.5000	-0.420694E 01	0.219864E 01	0.166393E 01	0.200436E 01
78.0000	-0.427296E 01	0.225307E 01	0.168363E 01	0.205587E 01
79.5000	-0.434066E 01	0.230814E 01	0.170365E 01	0.210812E 01
81.0000	-0.441007E 01	0.236387E 01	0.172398E 01	0.216112E 01
82.5000	-0.448123E 01	0.242027E 01	0.174462E 01	0.221490E 01
84.0000	-0.455414E 01	0.247734E 01	0.176555E 01	0.226946E 01
85.5000	-0.462884E 01	0.253510E 01	0.178677E 01	0.232482E 01
87.0000	-0.470535E 01	0.259356E 01	0.180827E 01	0.238101E 01
88.5000	-0.478371E 01	0.265272E 01	0.183004E 01	0.243804E 01
90.0000	-0.486393E 01	0.271259E 01	0.185206E 01	0.249592E 01
91.5000	-0.494605E 01	0.277317E 01	0.187432E 01	0.255467E 01
92.4187	-0.499729E 01	0.281064E 01	0.188807E 01	0.259110E 01

ALL DIMENSIONS IN FEET, POUNDS, SECONDS.

III. HORIZONTAL WAVE FORCE ON A LARGE SUBMERGED RECTANGULAR BODY

(a) By Stokes' Third Order Wave Theory
(b) By Stokes' Fifth Order Wave Theory

1. General Comment

These two programs compute the horizontal wave force on a large submerged rectangular body whose length is a significant fraction of the wavelength. When the volume of the body is large enough, then practically all of the entire force on the object can be considered inertial. The inertial force in this case is computed directly from the pressure distribution beneath the wave. It is assumed that the height of the submerged object is only a small fraction of the depth, otherwise the reflection of surface waves by the object must be taken into the computation of the pressure.

2. Program Description

Purpose: To calculate horizontal wave force on a large submerged rectangular body, given the dimensions of the body, the coefficient of mass and wave parameters, i.e., wave period, water depth, wave height. The depth at which the body is placed should also be given.

Equations: The general expression for horizontal wave force, F, acting on a rectangular body due to a wave is given by

$$F = C_M \cdot L_1 \cdot L_2 \cdot L_3 \cdot (\Delta p_1 - \Delta p_2)$$

where, C_M = coefficient of mass

L_1 = length of the body

L_2 = width of the body

L_3 = height of the body

Δp_1 and Δp_2 are the values of the pressure anomaly at either end of the body, i.e., at X_1 and $X_1 + L_1$.

$\Delta p = p - wd$

p = actual gage pressure

wd = hydrostatic pressure

From Bernoulli's equation the pressure anomaly is expressed as

$$\Delta p = -\rho[-\bar{C}\,u + (\frac{u^2+v^2}{2}) + g(S-d)]$$

where, S = elevation above mudline

u = horizontal particle velocity

v = vertical particle velocity

ρ = density

g = acceleration due to gravity

d = still water depth

$\bar{C}$ = wave speed

The forces are calculated at elemental depths and summed over the height of the body using Simpson's 1/3 rule. The body is placed at different intervals along the wavelength. The length L_1 of the body is parallel to the direction of wave travel.

3. Notation

Symbol	FORTRAN Name	Description
$\overline{C}$	CEL	Wave velocity
d	D	Stillwater depth
C_M	CM	Coefficient of mass
F	THF	Horizontal wave force
H	H	Wave height
L_1	SL_1	Length of body
L_2	SL_2	Width of body
L_3	SL_3	Height of body
L	WL	Wavelength
T	T	Wave period
u	UP	Horizontal particle velocity
v	VP	Vertical particle velocity
ρ	RHO	Density of seawater

4. Bibliography

1. McClenan, C.M., Kindel, C.M., Ross, H.E., and Worthington, H.W., "Computer Programs in Ocean Engineering", Sea Grant Publication, TAMU-SG-71-405, COE Report No. 131, July 1971.

2. Ippen, Arthur T., "Estuary and Coastline Hydrodynamics", New York, McGraw-Hill Book Co. Inc. 1964.

3. Reid, R.O., and Bretschneider, C.L., "Surface Waves and Offshore Structures: The Design Wave in Deep or Shallow Water, Storm Tide, and Forces on Vertical Piles and Large Submerged Objects", Technical Report, Texas A&M Research Foundation.

4. Shank, George E., "Forces Due to Waves on Submerged Structures", M.S. Thesis, May 1970, Dept. of Civil Engineering, Texas A&M University, College Station, Tx. 77840.

COMPUTER INPUT

The input data for horizontal wave force calculations on a submerged rectangular body is read into the main program on three data cards.

Card 1 -

The first data card is used to input wave characteristics. Wave period (T) should be typed in columns 1-10; wave height (H) in columns 11-20; and water depth (D) in columns 21-30.

Card 2 -

The second data card is used to input the physical characteristics of the body under consideration. The coefficient of mass (C_M) should be typed in columns 1-10, the body length (SL1) in columns 11-20, the body width (SL2) in columns 21-30, the body height in columns 31-40, and Depth (depth of body above mudline; at mudline = 0.0) in columns 41-50.

Card 3 -

The last data card is used to input iteration constants. In the first two columns Idep, number of increments along the height of the body (must be an even number), should be typed as an integer value. Remember, that if Idep is a 1 digit even number it must be right justified in column 2. The other value Xlinc, the increments along the wavelength at which one end of the body is placed, should be typed in columns 3-12 as a floating decimal quantity. Xlinc is the dividend of x, the horizontal distance, and L the wavelength.

```
//$OPTIONS
C
C
C  ******************************************************************
C  ******************************************************************
C  E. J. CHACKO, COASTAL AND OCEAN ENGINEERING DIV.,
C  CIVIL ENGINEERING DEPARTMENT          CE 685  PROBLEMS
C  ******************************************************************
C     HORIZONTAL WAVE FORCE ON SUBMERGED RECTANGULAR BODY BY
C     STOKES THIRD ORDER WAVE THEORY
C  ******************************************************************
C     D = STILL WATER DEPTH
C     H= WAVE HEIGHT
C     T = WAVE PERIOD
C     DEPTH= DEPTH OF BODY ABOVE MUDLINE; AT MUDLINE,DEPTH=0.0
C     SL1=LENGTH;SLI=WIDTH;SL3=HEIGHT
C     IDEP = NUMBER OF INCREMENTS ALONG THE HEIGHT OF THE BODY
C     IDEP MUST BE EVEN INTEGER
C     XLINC = INCREMENTS ALONG WAVELENGTH AT WHICH ONE END OF THE
C     BODY IS PLACED
C
      DIMENSION FP(10),YP(10),SV(100)
      READ(5,10) T,H,D
      READ(5,10) CM,SL1,SL2,SL3,DEPTH
      READ(5,5)     IDEP,XLINC
      L=0
      G=32.2
      PI=3.141593
      RHO=64./G
      WL =5.12*T*T
   12 X=2.*PI*D/WL
      CF31=COSH(X)*COSH(X)*COSH(X)*COSH(X)*COSH(X)*COSH(X)
      CF32=SINH(X)*SINH(X)*SINH(X)*SINH(X)*SINH(X)*SINH(X)
      F3=(3./16.)*(1.+(8.*CF31))/CF32
      A1=WL*WL/(PI*PI*F3)
      B1=-H*WL*WL/(2.*PI*PI*F3)
      A=(-.5*B1+SQRT(.25*B1*B1+A1*A1*A1/27.))**(1./3.)
      B=(-.5*B1-SQRT(.25*B1*B1+A1*A1*A1/27.))
      BB=B
      B=ABS(B)**(1./3.)
      SIGN = 1.
      IF(BB.LT.0.) SIGN = -1.
      A=A+SIGN*B
      C1=14.+4.*COSH(2.*X)*COSH(2.*X)
      C2=16.*SINH(X)*SINH(X)*SINH(X)*SINH(X)
      C=1.+((2.*PI*A/WL)**2.)*C1/C2
      WLT=(.5*G*T*T/PI)*(TANH(X))*C
      WRITE(6,111)WL,WLT
  111 FORMAT(5X,2E16.8)
      DIFF=WL-WLT
      WL=(WL+WLT)/2.
      IF(ABS(DIFF).GT.0.01)GO TO 12
C
C     END OF ITERATIVE RROCESS TO SOLVE FOR ACTUAL WAVELENGTH
C
      CF2=(2.+COSH(2.*X))*COSH(X)
      CF21=2.*SINH(X)*SINH(X)*SINH(X)
      F2=CF2/CF21
      CEL=WL/T
      A1=A/WL
```

```
      A2=PI*A1*A1*F2
      A3=PI*PI*A1*A1*A1*F3
      F1=2.*PI*A/(WL*SINH(X))
      F2=3.*PI*PI*A*A/(WL*WL*SINH(X)*SINH(X)*SINH(X)*SINH(X))
      F3=(((3./16.)*PI*PI*A*A/(WL*WL))*(11.-2.*COSH(2.*X))/(SINH(X)**7.)
     1)*2.*PI*A/WL
      YC=(A1+A2+A3)*WL
      YT=YC-H
      WRITE(6,200) WL,H,D,YC,YT,CEL,T,A1,A2,A3,F1,F2,F3,A
      WRITE (6,210)
      WRITE(6,270) SL1,SL2,SL3,CM,DEPTH
      XINC=SL1/WL
      DELTA=SL3/IDEP
      CON=CM*SL2
      MM=IDEP+1
C
C     GENERATE SIMPSON'S VECTORS
C
      SV(1)=1.0
      DO 45 KL=2,MM,2
      SV(KL)=4.0
   45 SV(KL+1)=2.0
      SV(KL+1)=1.0
C
C     END
C
      KKK=0.5/XLINC+1.
      XDL=0.
      WRITE(6,260)
C
C     BEGIN DO LOOP TO CALCULATE THE WAVE FORCES
C
      DO 410 JJJ=1,KKK
      SD=DEPTH
      XML=XDL
      DO 400 JJ=1,2
      FP(JJ)=0.0
      THETA=2.*PI*XML
      TH=THETA
      DO 310 K=1,MM
      YS=WL*(A1*COS(TH)+A2*COS(2.*TH)+A3*COS(3.*TH))
      YP(JJ)=YS
      XY=2.*PI*SD/WL
      U=(F1*COSH(XY)*COS(TH)+F2*COSH(2*XY)*COS(2.*TH)+F3*COSH(3.*XY)*COS
     1(3.*TH))*CEL
      V=(F1*SINH(XY)*SIN(TH)+F2*SINH(2.*XY)*SIN(2.*TH)+F3*SINH(3.*XY)*SI
     2N(3.*TH))*CEL
      UP=U
      VP=V
      UPS=UP**2
      VPS=VP**2
      DP=-RHO*((-CEL)*UP+(UPS+VPS)/2.)
      FP(JJ)=FP(JJ)+DP*SV(K)
      SD=SD+DELTA
  310 CONTINUE
      XML=XML+XINC
  400 CONTINUE
      FL=(DELTA/3.)*(FP(1)-FP(2))
      DHF=(YP(1)-YP(2))*G*SL3*(-RHO)
      THF=CON*(FL+DHF)
```

```
      WRITE(6,500) XDL,THF
      XDL=XDL+XLINC
  410 CCNTINUE
      WRITE(6,850)
      GC TO 999
  999 WRITE(6,900)
    5 FORMAT(I2,F10.5)
   10 FORMAT(5F10.5)
  200 FCRMAT(1H1,/////,T15,'     STOKES THIRD ORDER WAVE THEORY      ',
     1  /////,T20,'WAVE LENGTH    =',F10.3,///,T20,'WAVE HEIGHT    =',
     2F10.3,///,T20,'WATER DEPTH    =',F10.3,///,T20,'YC             =',
     3F10.3,///,T20,'YT             =',F10.3,///,T20,'WAVE CELERITY =',
     4F10.3,///,T20,'WAVE PERIOD    =',F10.3,///,T20,'A1             =',
     5E14.7,///,T20,'A2             =',E14.7,///,T20,'A3             =',
     6E14.7,///,T20,'F1             =',E14.7,///,T20,'F2             =',
     7E14.7,///,T20,'F3             =',E14.7,///,T20,'A              =',
     8E14.7)
  210 FORMAT(1H1)
  270 FORMAT(10(/),T20,' DIMENSIONS OF THE BODY ',///,T20,' LENGTH = '
     1,F10.5,//,T20,' WIDTH  = ',F10.5,//T20,' HEIGHT = ',F10.5,///
     2,T20,' COEFFICIENT OF MASS = ',F10.5,///,T20,'ELEVATION ABOVE MUDL
     3INE = ',F10.5)
  260 FORMAT(1H1,10(/),T20,' X/L ',T30,' HORIZONTAL WAVE FORCE ',//)
  500 FORMAT(T19,F6.4,T33,E16.6)
  850 FORMAT(//,T20,'ALL DIMENSIONS IN FEET, PCUNDS, SECONDS.')
 900  FORMAT(1H1)
      STOP
      END

//$CATA
 0.51199570E 03  0.44147460E 03
 0.47673700E 03  0.45485270E 03
 0.46579490E 03  0.45901610E 03
 0.46240550E 03  0.46030540E 03
 0.46135540E 03  0.46070500E 03
 0.46103020E 03  0.46082860E 03
 0.46092940E 03  0.46086710E 03
 0.46089810E 03  0.46087890E 03
 0.46088840E 03  0.46088280E 03
```

STOKES THIRD ORDER WAVE THEORY

WAVE LENGTH	=	460.885
WAVE HEIGHT	=	20.000
WATER DEPTH	=	100.000
YC	=	11.094
YT	=	-8.906
WAVE CELERITY	=	46.089
WAVE PERIOD	=	10.000
A1	=	0.2137926E-01
A2	=	0.2373039E-02
A3	=	0.3181179E-03
F1	=	0.7354176E-01
F2	=	0.1215773E-02
F3	=	-0.7278398E-05
A	=	0.9853394E 01

DIMENSIONS OF THE BODY

LENGTH = 100.00000

WIDTH = 150.00000

HEIGHT = 10.00000

COEFFICIENT OF MASS = 1.50000

ELEVATION ABOVE MUDLINE = 0.00000

X/L	HORIZONTAL WAVE FORCE
0.0000	-0.900264E 06
0.1000	-0.980430E 06
0.2000	-0.592653E 06
0.3000	-0.224642E 06
0.4000	0.321549E 05

ALL DIMENSIONS IN FEET, POUNDS, SECONDS.

COMPUTER INPUT

The computer input data in the horizontal wave force prediction by Stokes Fifth Order Wave Theory is divided between 3 cards.

Card 1 -

The first data card is used to input the physical characteristics of the rectangular body. They include the coefficient of mass (C_m), body length (SL1), body width (SL2), body height (SL3), and the depth of the body above mudline (depth). The format referenced by this read statement requires 5 floating point quantities to appear on the card each with a maximum character field of 10 spaces. Therefore, the coefficient of mass should be a floating point number entered in columns 1-10, body length in columns 11-20, body width in columns 21-30, body height in columns 31-40, and for this program depth equals 0.0 in columns 41-50.

Card 2 -

Card number two is used to input program commands and iteration constants. Num, Idep, and Xlinc. Num is an integer value used in the program to determine which wave characteristics are to be entered. If wavelength (L), wave height (H), and water depth (D) are to be used then Num should be set equal to 1 by typing 1 in the first column of the second card. If wave period (T), wave height, and water depth are to be used then Num should be set equal to 2. Idep is also an integer value representing the number of iteration increments along the height of the body. It should be typed in columns 2 and 3 (remember, however, that if Idep is a one-digit integer it must be right justified in column 3). The next ten spaces, columns 4-13, are reserved for Xlinc. This value is a floating point number which denotes the station increments along the wavelength at which the force is calculated. Hence, Xlinc equals .1 if 10 stations are desired, etc.

Card 3 -

Card number 3 is used to input wave characteristics. If Num is equal to 1, then wavelength, wave height and water depth are initialized. Conversely, if Num is equal to 2, wave period, wave height and water depth should be used. The format (5F10.5) requires that wavelength or wave period be typed in columns 1-10, wave height is columns 11-20, and water depth in columns 21-30.

PROGRAM LIMITATIONS

This program was set up to operate under certain limiting conditions which will necessarily require Stokes Fifth Order validity. If these conditions are not met then the program is directed to halt computation and output: "Stokes V Order Wave Theory is not applicable for this problem". These conditions are as follows:

$$\frac{D}{L} > .039 \; ; \qquad \frac{H}{D} > 0.2 \text{ and if}$$

Le Méhauté's conditions are used,

$$\frac{D}{T^2} > 0.2 \quad \text{and} \quad \frac{H}{T^2} > 1.0.$$

```
//$OPTIONS
C
C
C   ******************************************************************
C      HORIZONTAL WAVE FORCE ON SUBMERGED RECTANGULAR BODY BY
C      STOKES FIFTH ORDER WAVE THEORY
C   ******************************************************************
C      D = STILL WATER DEPTH
C      T = WAVE PERIOD
C      H= WAVE HEIGHT
C      NUM=1,  WHEN L,H,D, ARE KNOWN: : NUM=2, WHEN T,H,D, ARE KNOWN
C      DEPTH= DEPTH OF BODY ABOVE MUDLINE; AT MUDLINE,DEPTH=0.0
C      SL1=LENGTH;SL2=WIDTH;SL3=HEIGHT
C      IDEP = NUMBER OF INCREMENTS ALONG THE HEIGHT OF THE BODY
C      IDEP MUST BE EVEN INTEGER
C      XLINC = INCREMENTS ALONG WAVELENGTH AT WHICH ONE END OF THE
C      BODY IS PLACED
C      S IS MEASURED POSITIVELY UPWARDS FROM THE MUDLINE
C
C      LIMITATIONS :  D/L> 0.039,  H/D>0.2  AND D/T*T > 0.2
C
       DIMENSION U(10),Y(10),YF(10),FP(10),SV(100)
       CHK=0.
       N=0
       READ(5,10) CM,SL1,SL2,SL3,DEPTH
       READ(5,5) NUM,IDEP,XLINC
       GO TO (7,8),NUM
     7 READ(5,10) WL,H,D
       PRINT,WL,H,D
C
C      CHECK THE LIMITIONS
C
       SHA1=D/WL
       SHA2=H/D
       IF(SHA1.LT.0.039) GO TO 2000
       IF(SHA2.LT.0.20) GO TO 2000
       GO TO 30
     8 READ(5,10) T,H,D
       PRINT,T,H,D
       PI=3.1416
       G=32.2
       RHO=64./G
       WL=G*T**2/(2.*PI)
C
C      CHECK THE LIMITIONS
C
       SHA1=D/WL
       SHA2=H/D
       IF(SHA1.LT.0.039) GO TO 2000
       IF(SHA2.LT.0.20) GO TO 2000
       WLO=WL
    30 CALL SOLVEL(WL,AMDA,H,T,D,PI,G,B33,B35,B55)
       BETA=2.*PI/WL
       S=SINH(2.*PI*D/WL)
       C=COSH(2.*PI*D/WL)
       C1=(8.*C**4-8.*C**2+9.)/(8.*S**4)
       C2=(3840.*C**12-4096.*C**10+2592.*C**8-1008.*C**6+5944.*C**4-1830.
      .*C**2+147.)/(512.*S**10*(6.*C**2-1.))
       AMDA2=AMDA**2
       AMDA4=AMDA**4
```

```
      GO TO (21,22),NUM
   21 WLO=WL/(TANH(BETA*D)*(1.+AMDA2*C1+AMDA4*C2))
      T=SQRT(WLO*2.*PI/G)
      GO TO 50
   22 CONTINUE
      WLT=WLO*TANH(BETA*D)*(1.+AMDA2*C1+AMDA4*C2)
      DIFF=WL-WLT
      WL=(WL+WLT)/2.
      N=N+1
      WRITE(6,20) WLT,AMDA
      IF(N.GT.50) GO TO 990
      CDIFF=CHK-AMDA
      IF(ABS(CDIFF).LT..1E-06) GO TO 50
      CHK=AMDA
      IF(ABS(DIFF).GT.0.0001) GO TO 30
   50 CONTINUE
      CEL=WL/T
      WRITE(6,200) WL,H,D,CEL,T,AMDA
C
C     CALCULATE COEFFICIENTS
C
      A11=1./S
      A13=-C**2*(5.*C**2+1.)/(8.*S**5)
      A15=-(1184.*C**10-1440.*C**8-1992.*C**6+2641.*C**4-249.*C**2+18.)
     ./(1536.*S**11)
      A22=3./(8.*S**4)
      A24=(192.*C**8-424.*C**6-312.*C**4+480.*C**2-17.)/(768.*S**10)
      A33=(13.-4.*C**2)/(64.*S**7)
      A35=(512.*C**12+4224.*C**10-6800.*C**8-12808.*C**6+16704.*C**4
     .-3154.*C**2+107.)/(4096.*S**13*(6.*C**2-1.))
      A44=(80.*C**6-816.*C**4+1338.*C**2-197.)/(1536.*S**10*(6.*C**2-1.)
     .)
      A55=-(2880.*C**10-72480.*C**8+324000.*C**6-432000.*C**4+163470.*
     .C**2-16245.)/(61440.*S**11*(6.*C**2-1.)*(8.*C**4-11.*C**2+3.))
      B22=(2.*C**2+1.)*C/(4.*S**3)
      B24=C*(272.*C**8-504.*C**6-192.*C**4+322.*C**2+21.)/(384.*S**9)
      B33=3.*(8.*C**6+1.)/(64.*S**6)
      B44=C*(768.*C**10-448.*C**8-48.*C**6+48.*C**4+106.*C**2-21.)/
     .(384.*S**9*(6.*C**2-1.))
      C0=SQRT(C*(TANH(BETA*D)))
      C3=-1./(4.*S*C)
      C4=(12.*C**8+36.*C**6-162.*C**4+141.*C**2-27.)/(192.*C*S**9)
      AMDA3=AMDA**3
      AMDA5=AMDA**5
      Y(1)=AMDA
      Y(2)=AMDA2*(B22+AMDA2*B24)
      Y(3)=AMDA3*(B33+AMDA2*B35)
      Y(4)=AMDA4*B44
      Y(5)=AMDA5*B55
      U(1)=AMDA*(A11+AMDA2*A13+AMDA4*A15)
      U(2)=AMDA2*(A22+AMDA2*A24)
      U(3)=AMDA3*(A33+AMDA2*A35)
      U(4)=AMDA4*A44
      U(5)=AMDA5*A55
      WRITE(6,250) A11,A13,A15,A22,A24,A33,A35,A44,A55,B22,B24,B33,B35,
     1B44,B55,C0,C1,C2,C3,C4
      WRITE(6,900)
      WRITE(6,270) SL1,SL2,SL3,CM,DEPTH
      XINC=SL1/WL
      DELTA=SL3/IDEP
```

```
      CON=CN*SL2
      MM=IDEP+1
C
C     GENERATE SIMPSON'S VECTORS
C
      SV(1)=1.0
      DO 45 KL=2,MM,2
      SV(KL)=4.0
   45 SV(KL+1)=2.0
      SV(KL+1)=1.0
C
C     END
C
      KKK=0.5/XLINC+1.
      XDL=0.
      WRITE(6,260)
C
C     BEGIN DO LOOP TO CALCULATE WAVE FORCES
C
      DO 410 JJJ=1,KKK
      SD=DEPTH
      XML=XDL
      DO 400 JJ=1,2
      FP(JJ)=0.0
      THETA=2.*PI*XML
      DO 310 K=1,MM
      WSUM=0.0
      USUM=0.
      VSUM=0.
      DO 300 I=1,5
      UPU=I*U(I)*COSH(I*BETA*SD)*COS(I*THETA)
      VPV=I*U(I)*SINH(I*BETA*SD)*SIN(I*THETA)
      WP=Y(I)*COS(I*THETA)
      USUM=USUM+UPU
      VSUM=VSUM+VPV
      WSUM=WSUM+WP
  300 CONTINUE
      YP(JJ)=WSUM/BETA
      UP=USUM*CEL
      VP=VSUM*CEL
      UPS=UP**2
      VPS=VP**2
      DP=-RHO*((-CEL)*UP+(UPS+VPS)/2.)
      FP(JJ)=FP(JJ)+DP*SV(K)
      SD=SD+DELTA
  310 CONTINUE
      XML=XML+XINC
  400 CONTINUE
      FL=(DELTA/3.)*(FP(1)-FP(2))
      DHF=(YP(1)-YP(2))*G*SL3*(-RHO)
      THF=CON*(FL+DHF)
      WRITE(6,500) XDL,THF
      XDL=XDL+XLINC
  410 CONTINUE
      WRITE(6,850)
      GO TO 999
  990 WRITE(6,800)
  999 WRITE(6,900)
      GO TO 1000
 2000 WRITE(6,3000)
```

```
    5 FORMAT(I1,I2,F10.5)
   10 FORMAT(5F10.5)
   20 FORMAT(5X,2(F10.4,5X))
  200 FORMAT(1H1,////////,T05,'VALUES DERIVED USING STOKES FIFTH ORDER ',
     6'WAVE THEORY',
     1////////,T17,'WAVE LENGTH    =',F10.4,///,T17,'WAVE HEIGHT    =',
     2F10.4,///,T17,'WATER DEPTH    =',F10.4,///,T17,'WAVE CELERITY =',
     4F10.4,///,T17,'WAVE PERIOD    =',F10.4,///,T17,'LAMBDA          =',
     5F10.4)
  250 FORMAT(////,T12,' VALUES OF COEFFICIENTS ',///,T07,'A11  = ',
     1F10.4,5X,' A13 = ',F10.4,5X,' A15 = ',F10.4,///,T07,' A22 = ',
     2F10.4,5X,'A24 = ',F10.4,5X,                     ' A33 = ',F10.4,
     3///,T07,' A35 = ',F10.4,5X,' A44 = ',F10.4,5X,' A55 = ',F10.4,///,
     4T07,' B22 = ',F10.4,5X,' B24 = ',F10.4,5X,' B33 = ',F10.4,///,
     5T07,' B35 = ',F10.4,5X,' B44 = ',F10.4,5X,' B55 = ',F10.4,///,
     6T07,' C0 = ',F10.4,5X,'C1 = ',F10.4,5X,' C2 = ',F10.4,///,T07,
     7' C3 = ',F10.4,5X,' C4 = ',F10.4)
  270 FORMAT(10(/),T20,' DIMENSIONS OF THE BODY ',///,T20,' LENGTH = '
     1,F10.5,//,T20,' WIDTH  = ',F10.5,//T20,' HEIGHT = ',F10.5,///
     2,T20,' COEFFICIENT OF MASS = ',F10.5,///,T20,'ELEVATION ABOVE MUDL
     3INE = ',F10.5)
  260 FORMAT(1H1,10(/),T20,' X/L ',T30,' HORIZONTAL WAVE FORCE ',//)
  500 FORMAT(T19,F6.4,T33,F16.6)
  910  FORMAT(1H1,////,' DOES NOT CONVERGE')
  450 FORMAT(//,T20,'ALL DIMENSIONS IN FEET, POUNDS, SECONDS.')
 900    FORMAT(1H1)
 3000 FORMAT(////,T10,'**********  STOKES V WAVE THEORY IS NOT APPLICABL
     1E FOR THIS PROBLEM  **********',////)
 1000 STOP
      END
C   ****************************************************************

      SUBROUTINE SOLVEL(WL,AMDA,H,T,D,PI,G,B33,B35,B55)
C     THIS SUBROUTINE SOLVES FOR LAMBDA
C
      C=COSH(2.*PI*D/WL)
      S=SINH(2.*PI*D/WL)
      BETA=2.*PI/WL
      B33=3.*(8.*C**6+1.)/(64.*S**6)
      B35=(88128.*C**14-208224.*C**12+70848.*C**10+54000.*C**8-21816.
     .*C**6+6264.*C**4-54.*C**2-81.)/(12288.*S**12*(6.*C**2-1.))
      B55=(192000.*C**16-262720.*C**14+83680.*C**12+20160.*C**10-7280.
     .*C**8+7160.*C**6-1800.*C**4-1050.*C**2+225.)/(
     .12288.*S**10*(6.*C**2-1.)*(8.*C**4-11.*C**2+3.))
      ITMAX=50
      X=0.2
      CK2=B35+B55
      CST=PI*H/WL
      DO 25 I=1,ITMAX
      ROOT=X-(B33*X**3+CK2*X**5-CST+X)/(1.+3*B33*X**2+5*CK2*X**4)
      RDIFF=ROOT-X
      IF(ABS(RDIFF).LE..0001) GO TO 100
      X=ROOT
   25 CONTINUE
      WRITE(6,200) ROOT
      STOP
  100 AMDA=X
  200 FORMAT(2X,' DOESNT CONVERGE AFTER  50 ITERATIONS',3X,' ROOT =   ',
     1F10.4)
      RETURN
```

```
171          END

     //$DATA
0.1000000E 02     0.2000000E 02     0.1000000E 03
   441.7771           0.1206
   455.2107           0.1296
   459.3921           0.1326
   460.6853           0.1336
   461.0850           0.1339
   461.2097           0.1340
   461.2468           0.1340
   461.2590           0.1340
   461.2625           0.1340
   461.2637           0.1340
   461.2640           0.1340
   461.2640           0.1340
```

VALUES DERIVED USING STOKES FIFTH ORDER WAVE THEORY

WAVE LENGTH = 461.2642

WAVE HEIGHT = 20.0000

WATER DEPTH = 100.0000

WAVE CELERITY = 46.1264

WAVE PERIOD = 10.0000

LAMBDA = 0.1340

VALUES OF COEFFICIENTS

A11 =	0.5492	A13 =	-0.6062	A15 =	-1.0312
A22 =	0.0330	A24 =	0.0932	A33 =	-0.0010
A35 =	0.0263	A44 =	-0.0002	A55 =	0.0000
B22 =	0.8272	B24 =	1.2685	B33 =	0.8261
B35 =	3.0304	B44 =	0.9760	B55 =	1.2701
C0 =	5.3136	C1 =	1.4021	C2 =	3.8226
C3 =	-0.0659	C4 =	0.0523		

DIMENSIONS OF THE BODY

LENGTH = 100.00000

WIDTH = 150.00000

HEIGHT = 10.00000

COEFFICIENT OF MASS = 1.50000

ELEVATION ABOVE MUDLINE = 0.00000

Y/L	HORIZONTAL WAVE FORCE
0.0000	-0.917629E 06
0.1000	-0.993710E 06
0.2000	-0.605234E 06
0.3000	-0.228577E 06
0.4000	0.315924E 05

ALL DIMENSIONS IN FEET, POUNDS, SECONDS.

IV. WAVE FORCES AND MOMENTS ON A CIRCULAR CYLINDRICAL PILE

(a) By Cnoidal Wave Theory
(b) By Stokes Third Order Wave Theory

1. General Comment

The two programs included here calculate the wave forces and moments on a circular cylindrical pile. The first program uses the Cnoidal wave theory which is best applicable within the range of $1/50 < d/L < 1/10$. The second program uses Stokes third order wave theory which is best applicable for relative water depth, d/L greater than 1/8.

Programs developed for the two theories have been modified to obtain wave forces and moments. The forces and moments are calculated at different positions along the wavelength.

2. Program Description

Purpose: To calculate forces and moments on a circular cylindrical pile, given wave height, wave period, water depth, size of pile, coefficient of mass and coefficient of drag.

Equations: Morison's equation is used to compute the total force, F_T, given by

$$F_T = F_D + F_M$$

where, F_D = drag force / unit length

F_M = inertia force / unit length

$$F_D = 1/2\ \rho \cdot C_D \cdot D \cdot U^2$$

$$F_M = 1/4\ \pi\ \rho\ C_M\ D^2 \frac{du}{dt}$$

where, D = diameter of pile

C_D = coefficient of drag

C_M = coefficient of mass

ρ = density of seawater

u = horizontal particle velocity

$\frac{du}{dt}$ = horizontal particle acceleration

The total moment about the mudline is given by

$$M_T = M_D + M_m$$

where, M_D = moment due to drag force

M_m = moment due to inertia force

$$M_D = \int_o^{n+d} f_D \cdot s \cdot ds$$

$$M_m = \int_o^{n+d} f_M \cdot s \cdot ds$$

where, s = elevation above mudline

n+d = water surface elevation above mudline

The velocities and accelerations are calculated at elemental depth increments and elemental forces and moments are computed at these depths. The forces and moments are obtained by summing their elemental components using Simpon's 1/3 rule.

3. Notation

Symbol	FORTRAN Name Cnoidal	FORTRAN Name Stokes Third	Description
a_x	AX	UDOT	Horizontal particle acceleration
c	CEL	WAVEV	Wave speed
C_D	CD	CD	Coefficient of drag
C_M	CM	CM	Coefficient of mass
D	DIA	PDIA	Pile diameter
d	D	D	Stillwater depth
F_T	TFORCE	FAREA	Total force
F_D	TFCD	FARE1	Drag force
F_M	TFCM	FARE2	Inertia force
H	H	H	Wave height
k	TK	---	Elliptic modulus
L	WL	WAVEL	Wavelength
M_T	TMOM	BAREA	Total moment
M_D	TMCD	BARE1	Drag moment
M_m	TMCM	BARE2	Inertia moment
T	T	T	Wave period
u	U	UVEL	Horizontal particle velocity
ρ	RHO	RHO	Density of seawater

4. Bibliography

1. Janke, Eugene and Emde, Frity, "Tables of Functions with Formulae and Curves", 4th ed., Dover Publications, Inc. 1945.

2. McClenan, C.M., Kindel, C.M., Ross, H.E., Worthington, H.W., "Computer Programs in Ocean Engineering", Sea Grant Publication, TAMU-SG-71-405, COE Report No. 131, July 1971.

3. Wiegel, Robert L., "Oceanographical Engineering", Englewood Cliffs, Prentice-Hall, Inc., 1964.

COMPUTER INPUT

Data is input into Cnoidal wave theoretical prediction of forces and moments on a cylindrical pile on four cards.

Card 1 -

Data card number 1 is used to enter interval iteration variables and commands. The only parameter that need be specified on this card is Num. Again, Num is used to discriminate between different sets of input data with which the computer is able to work with. If Num is set equal to one, the program is set up to work with wavelength (L), wave height (H), and water depth (D). If Num is set equal to 2, the program is ready to utilize wave period (T), wave height, and water depth. Num is an integer value and should be typed in column 2 of the first data card. The other program parameters on the first card need to be initialized as a zero value. The simplest way to do this, in this case, is by leaving the rest of the data card blank.

Card 2 -

The second data card inputs either the wavelength or wave period, wave height, and water depth depending upon the value of Num on the first data card. All numbers on this card are floating decimal point numbers and should be typed in as follows: wavelength or wave period in columns 1-10, wave height columns 11-20, and water depth, columns 21-30. Format statement 100 is used for this input sequence.

Card 3 -

This data card is used to enter the physical characteristics of the pile under consideration. Format statement 100 is also used denoting each value as a floating decimal point number. The values are coefficient of mass (C_M) in columns 1-10, coefficient of drag in columns 11-20, and diameter of pile in columns 21-30.

Card 4 -

The fourth data card is used to enter the incrementation constants. These constants are Depinc, Xlinc, and Ncode. Ncode has a special significance if it is set equal to 1, the pile top must be below the crest of the wave and Topht, the distance from bottom to top of pile, must be entered on the 5th data card. Depinc must be an even floating decimal point number and entered in columns 1-10. This value gives the depth increments at which forces and moments are calculated. Xlinc increments of X/L at which forces and moments are calculated. It also should be a floating decimal point number and entered in columns 11-20. In column 21, Ncode should be entered; 1, pile top is below crest and blank if pile top exceeds wave crest.

Card 5 -

Topht, the distance from the pile bottom to top, should be entered in columns 1-10 if Ncode is equal to 1.

```
//$OPTIONS
C
C
C     ****************************************************************
C     ****************************************************************
C     T. J. CHACKO, COASTAL AND OCEAN ENGINEERING DIV.,
C     CIVIL ENGINEERING DEPARTMENT           CE 685  PROBLEMS
C     ****************************************************************
C        CALCULATION OF WAVE FORCE AND MOMENTS ON A CYLINDRICAL PILE BY
C        CNOIDAL WAVE THEORY
C     ****************************************************************
C        THIS WAVE THEORY IS APPLICABLE OVER THE RANGE OF
C        1/50 < D/L < 1/10
C        H= WAVE HEIGHT
C        D = STILL WATER DEPTH
C        T = WAVE PERIOD
C        ON FIRST DATA CARD X,XL,WLSAVE,T,EIK,EIE,XK,TKPS=BLANK OR 0.0
C        NUM=1, WHEN L,H,D ARE GIVEN; NUM=2, WHEN T,H,D ARE GIVEN
C        CM= COEFF. OF MASS ; CD = COEFF. OF DRAG ; DIA = DIAMETER OF PILE
C        WHEN PILE TOP BELOW CREST NCODE=1 AND INPUT TOPHT= DISTANCE FROM
C        BOTTOM TO TOP OF PILE
C        XLINC= INCREMENTS OF X/L AT WHICH FORCES AND MOMENTS ARE
C        CALCULATED.
C        DEPINC= DEPTH INCREMENTS AT WHICH FORCES AND MOMENTS ARE
C        CALCULATED. DEPINC MUST BE AN EVEN NUMBER
C
C
         DIMENSION SV(100)
         READ(5,90) NUM,X,XT,WLSAVE,T,EIK,EIE,XK,TKPS
         IF(NUM.EQ.1) READ(5,100) WL,H,D
         IF(NUM.EQ.2) READ(5,100) T,H,D
         READ(5,100) CM,CD,DIA
         READ(5,110) DEPINC,XLINC,NCODE
         IF(NCODE.EQ.1) READ(5,100) TOPHT
         IF (NUM.EQ.1) GO TO 1
         WL=  8.0*SQRT(D*D*D/H)
       1 SAVE=0.0
         TK=1.0
         G=32.2
         PI=3.1416
         RHO=64./G
         C=WL**2.*H/D**3.
       5 SUM=0.0
         A=1.0
         DO 10 N=1,99,2
         IF(A.LT..1E-35)GO TO 11
         Q=N
         EIK=((Q/(Q+1))**2)*(TK**2)*A
         SUM=SUM+EIK
      10 A=EIK
      11 EIK=(PI/2.)*(1.+SUM)
         DIFF=C-((16./3.)*(TK**2)*(EIK**2))
         IF(ABS(DIFF).LT.0.001)GO TO 20
      15 IF(DIFF)16,20,17
      16 X=TK
         TK=(TK+SAVE)/2.
         GO TO 5
      17 SAVE=TK
         IF(X.EQ.0.0)CALL SOLVEK(NUM,WL,H,D,WLSAVE,T,EIK,EIE,TKPS,XK,YC,YT,
        1CEL,WL,XT,TK)
```

```
      IF(X.EQ.0.0)GO TO 180
      TK=(X+TK)/2.
      GO TO 5
   20 SUM=0.0
      A=1.0
      DO 30 N=2,98,2
      IF(A.LT..1E-35)GO TO 31
      C=N
      EIE=(((C-1)/C)**2.)*TK*TK*A/(C-1)
      SUM=SUM-EIE
   30 A=EIE*(C-1)
   31 EIE=(PI/2.)*(1.+SUM)
      YC=((16./(3.*C))*H*(EIK*(EIK-EIE)))+D
      YT=YC-H
      CEL=(SQRT(G*YT))*(1+((H/(YT*(TK*TK)))*(.5-(EIE/EIK))))
      IF(NUM.EQ.1)GO TO 180
      TT=WL/CEL
      TDIFF=T-TT
      IF(ABS(TDIFF).LT..001) GO TO 190
      IF(TDIFF)18,190,19
   18 XT=WL
      WL=(WL+WLSAVE)/2.
      GO TO 1
   19 WLSAVE=WL
      IF(XT.EQ.0.0)CALL SOLVEK(NUM,T,H,D,WLSAVE,T,EIK,EIE,TKPS,XK,YC,YT
     1,CEL,WL,XT,TK)
      IF(XK.GT.0.0)GO TO 190
      WL=(WL+XT)/2.
      GO TO 1
  180 T=WL/CEL
  190 TK2=TK*TK
      TSGD=T*SQRT(G/D)
      WRITE(6,200) WL,H,D,YC,YT,CEL,T,TK2,EIK,EIE
      WRITE(6,210) TSGD,DIA,CM,CD
      IF(XK.GT.0.0)GO TO 55
      A=1.0
      SUM=0.0
      TKP=SQRT(1.-TK**2.)
      DO 50 N=1,99,2
      IF(A.LT..1E-35)GO TO 51
      C=N
      EIKP=((C/(C+1))**2)*(TKP**2)*A
      SUM=SUM+EIKP
   50 A=EIKP
   51 EIKP=(PI/2.)*(1.+SUM)
      Q=2.718282**(-PI*EIKP/EIK)
C
C     GENERATE SIMPSONS VECTORS
C
      KKK=DEFINC+1
      SV(1)=1.0
      DO 45 JJ=2,KKK,2
      SV(JJ)=4.0
   45 SV(JJ+1)=2.0
      SV(JJ+1)=1.0
C
C     END
C
      C1=CD*RHO*DIA*0.5
      C2=CM*RHO*PI*DIA*DIA*0.25
```

```
   55 XDL=0.0
      TOT=0.0
      L=0
      WRITE(6,215)
      ITER=0.5/XLINC+1.
C
C     BEGIN DO LOOP TO CALCULATE THE WAVE FORCES
C
      DO 70 NN=1,ITER
      IF(XK.GT.0.0)GO TO 65
      SUM=0.0
      DO 60 N=1,20
      S=N-1
      THETA=(2.*S+1.)*PI*(XDL-TOT)/(2*TK)
      CN1=(Q**(S+.5))*COS(THETA)/(1.+(Q**(2.*S+1.)))
      IF(CN1.LT..1E-35)GO TO 61
   60 SUM=SUM+CN1
   61 CN1=(2.*PI/(TK*PIK))*SUM
      CN2=CN1*CN1
      SN2=1.-CN2
      DN2=1.-TK*TK*SN2
      GO TO 66
   65 XU=2.*PIK*(XDL-TOT)
      SN2=(TANH(XU)+.25*TKPS/COSH(XU)**2.*(SINH(XU)*COSH(XU)-XU))**2.
      CN2=(1./COSH(XU)-.25*TKPS*TANH(XU)/COSH(XU)*(SINH(XU)*COSH(XU)-XU)
     1)**2.
      DN2=(1./COSH(XU)+.25*TKPS*TANH(XU)/COSH(XU)*(SINH(XU)*COSH(XU)+XU)
     1)**2.
   66 IF(SN2.LT..1E-20)SN2=0.0
      IF(CN2.LT..1E-20)CN2=0.0
      IF(DN2.LT..1E-20)DN2=0.0
      YS=H*CN2+YT
      CU=SQRT(G*D)
      CU1= (-1.25)+(1.5*YT/D)-(.25*YT*YT/(D*D))+(((1.5*H/D)-(.5*YT*H/(D*
     1D)))*CN2)-(.25*H*H*CN2*CN2/(D*D))
      CU2=-8.*H*PIK*PIK/(WL*WL)
      CU3=(-TK2*SN2*CN2)+(CN2*DN2)-(SN2*DN2)
      CAX=(SQRT(G*D*SN2*CN2*DN2))*4.*H*PIK/(T*D)
      CAX1=(1.5-(.5*YT/D))-(.5*H*CN2/D)
      CAX2=(16.*PIK*PIK/(WL*WL))*((TK2*SN2)-(TK2*CN2)-DN2)
      DELTA=YS/DEPINC
      IF(NCODE.EQ.1) DELTA=TOPHT/DEPINC
      SDIST=0.
      DFCM=0.
      DMCM=0.
      DFCD=0.0
      DMCD=0.0
      DO 40 K=1,KKK
      Y=SDIST
      U=CU*(CU1+(CU2*CU3*((D/3.)-(.5*Y*Y/D))))
      AX=CAX*(CAX1+(CAX2*((D*D/3.)-(Y*Y))))
      USQRD=U*ABS(U)
      DFCD=DFCD+SV(K)*USQRD
      DFCM=DFCM+SV(K)*AX
      DMCD=DMCD+SV(K)*SDIST*USQRD
      DMCM=DMCM+SV(K)*SDIST*AX
      SDIST=SDIST+DELTA
   40 CONTINUE
      TFCD=DFCD*DELTA*C1*(1./3.)
      TFCM=DFCM*DELTA*C2*(1./3.)
```

```
      TFORCE=TFCD+TFCM
      TMCM=CMCM*DELTA*C2*(1./3.)
      TMCD=CMCD*DELTA*C1*(1./3.)
      TMOM=TMCD+TMCM
C
      WRITE(6,220) XDL,TFCD,TFCM,TMCD,TMCM,TFORCE,TMOM
      XDL=XDL+XLINC
   70 CONTINUE
      WRITE(6,225)
      WRITE(6,230)
   99 FORMAT(1X,1I1,20F2.1)
  100 FORMAT(8F10.4)
  110 FORMAT(2F10.5,I1)
  200 FORMAT(1H1,///////,T10,'VALUES DERIVED USING CNOIDAL WAVE THEORY',
     1///////,T15,'WAVE LENGTH    =',F10.3,///,T15,'WAVE HEIGHT    =',
     2F10.3,///,T15,'WATER DEPTH    =',F10.3,///,T15,'YC             =',
     3F10.3,///,T15,'YT             =',F10.3,///,T15,'WAVE CELERITY =',
     4F10.3,///,T15,'WAVE PERIOD    =',F10.3,///,T15,'K**2           =',
     5F10.3,///,T15,'K(K)           =',F10.3,///,T15,'E(K)           =',
     6F10.3)
  210 FORMAT(// ,T14,' T*SQRT(G/D)    =',F10.3,////,T22,'INPUT DATA',
     1///,T10,'DIAMETER OF PILE  = ',F10.3,'FT',///,T24,'CM  = ',F10.3,
     2///,T24,'CD  = ',F10.3)
  215 FORMAT(1H1,///,T13,'X/L',T22,'DRAG FORCE',T36,'INERTIA FORCE',
     1T53,'DRAG MOMENT',T67,'INERTIA MOMENT',T85,'TOTAL FORCE',T100,
     2'TOTAL MOMENT',//)
  220 FORMAT(T8,F7.4,6F16.7)
  225 FORMAT(/,T12,' ALL UNITS IN FEET, POUNDS, SECONDS ')
  230 FORMAT(1H1)
  999 STOP
      END
C
C   *********************************************************************

      SUBROUTINE SOLVEK(NUM,DUM,H,D,WLSAVE,T,EIK,EIE,TKPS,XK,YC,YT,CEL,
C     THIS SUBROUTINE CALCULATES THE ELLIPTIC MODULUS
C
     1WL,XT,TK)
      XK=1.0
      IF(NUM.EQ.1)WL=DUM
      IF(NUM.EQ.2)T=DUM
      IF(NUM.EQ.1)GO TO 1
      WL =200.*SQRT(D*D*D/H)
    1 SAVE=.1E-25
      X=.2
      PI=3.1416
      C=WL*WL*H/(D*D*D)
      TK2=1.0
      TKPS = .199
    5 TKP=SQRT(TKPS)
      G=ALOG(4./TKP)
      EIK=G+(G-1.)*TKPS/4.
      IF(TKPS.LT..1E-36)GO TO 10
      EIK=EIK+(G-7./6.)*9.*TKPS*TKPS/64.
      IF(TKPS.LT..1E-24)GO TO 10
      EIK=EIK+(G-37./30.)*25.*TKPS*TKPS*TKPS/256.
   10 TK2=1.-TKPS
      DIFF=C-16.*TK2*EIK*EIK/3.
      IF(ABS(DIFF).LT..001) GO TO 25
      IF(DIFF)15,25,20
```

```
   15 SAVE=TKPS
      TKPS=10.**((ALOG10(TKPS)+ALOG10(X))/2.)
      GO TO 5
   20 X=TKPS
      TKPS=10.**((ALOG10(TKPS)+ALOG10(SAVE))/2.)
      GO TO 5
   25 FIE=1.+.5*(G-.5)*TKPS
      IF(TKPS.LT..1E-36)GO TO 30
      FIE=FIE+3./16.*(G-13./12.)*TKPS*TKPS
      IF(TKPS.LT..1E-24)GO TO 30
      FIE=FIE+15./128.*(G-6./5.)*TKPS*TKPS*TKPS
   30 YC=((16./(3.*C))*H*(FIK*(FIK-FIE)))+D
      YT=YC-H
      CEL=(SQRT(G*YT))*(1+((H/(YT*(TK*TK)))*(.5-(FIE/FIK))))
      IF(NUM.EQ.1)GO TO 180
      TT=WL/CEL
      TDIFF=T-TT
      IF(ABS(TDIFF).LT..001) GO TO 190
      IF(TDIFF)18,190,19
   18 XT=WL
      WL=(WL+WLSAVE)/2.
      GO TO 1
   19 WLSAVE=WL
      WL=(WL+XT)/2.
      GO TO 1
  180 T=WL/CEL
  190 RETURN
      END

//$DATA
```

VALUES DERIVED USING CNOIDAL WAVE THEORY

WAVE LENGTH	=	768.273
WAVE HEIGHT	=	30.000
WATER DEPTH	=	100.000
YC	=	117.424
YT	=	87.424
WAVE CELERITY	=	51.219
WAVE PERIOD	=	15.000
K**2	=	0.733
K(K)	=	2.128
E(K)	=	1.221
T*SQRT(G/D)	=	8.512

INPUT DATA

DIAMETER OF PILE	=	4.000FT
CM	=	1.400
CD	=	1.050

X/L	DRAG FORCE	INERTIA FORCE	DRAG MOMENT	INERTIA MOMENT	TOTAL FORCE	TOTAL MOMENT
0.0000	0.3805525E 05	0.1229929E 03	0.2929226E 07	0.1038827E 05	0.3817824E 05	0.2939614E 07
0.0500	0.3593493E 05	0.5994207E 04	0.2734059E 07	0.4932816E 06	0.4182914E 05	0.3227340E 07
0.1000	0.3026510E 05	0.1076888E 05	0.2224687E 07	0.8769443E 06	0.4103398E 05	0.3101631E 07
0.1500	0.2273610E 05	0.1401107E 05	0.1580610E 07	0.1091593E 07	0.3674717E 05	0.2672203E 07
0.2000	0.1529654E 05	0.1556198E 05	0.9884959E 06	0.1145146E 07	0.3085852E 05	0.2133641E 07
0.2500	0.8893875E 04	0.1583882E 05	0.5240616E 06	0.1089247E 07	0.2473270E 05	0.1613308E 07
0.3000	0.4441492E 04	0.1531223E 05	0.2341531E 06	0.9838249E 06	0.1975373E 05	0.1217978E 07
0.3500	0.2046017E 04	0.1456112E 05	0.9471425E 05	0.8859229E 06	0.1660714E 05	0.9806372E 06
0.4000	0.5385632E 03	0.1353810E 05	0.1858254E 05	0.7772306E 06	0.1407666E 05	0.7958131E 06
0.4500	-0.5664319E 02	0.1229724E 05	-0.6614586E 04	0.6655973E 06	0.1224060E 05	0.6589826E 06

ALL UNITS IN FEET, POUNDS, SECONDS

COMPUTER INPUT

The input format for Stokes III order theoretical predictions of forces and moments on a cylindrical pile is in accordance with the fortran watfive language wiht which the main program was written. The input sequence is divided into four cards.

Card 1 -

The first card is used to enter the wave period (T), wave height, and water depth (D). The format card corresponding to this input sequence is given as: 999 FORMAT (8 F 18.4). This means the computer can expect 8 quantities having 10 total digits including the decimal point and 4 digits to the right of the decimal point. The computer will read the card expecting the first value in columns 1-10, the second value in columns 11-20, etc. Thus, the wave period should be entered in columns 1-10, wave height in columns 11-20, and water depth in columns 21-30. Care should be taken in placing the decimal point. Do not leave these quantities as integers, each column left unpunched will be read as a zero. Thus, if you simply enter 10 for wave period instead of 10., the value read by the computer will be 1,000,000,000. The same reasoning applies to the wave heigth and water depth.

Card 2 -

The second data card contains the limiting values for the iterative schemes employed in the main program. Format card 600 which is used to read the second data card is given as: 600 FORMAT (2I5, 7 F 10.0). This means the computer expects to read 9 values (in this case only 4 are used), the first two of which are integer values containing a total of 5 digits and the last 7 real numbers containing 10 digits with the number of decimal places unspecified.

The quantities to be read in to the program respectively then are Numinc, Numthe, Theta, and Vincrm. Numinc and Numthe, are integer values; Theta and Vincrm are floating decimal point numbers. In the first five spaces, Numinc is typed. It must be right justified, that is, if Numinc equals 10, 10 must be typed in columns 4 and 5. The same reasoning applied to Numthe in columns 6-10. Theta and Vincrm should then be entered in columns 11-20 and 21-30, respectively, with the appropriate decimal points. No right justification is required in this case.

Card 3 -

Data card 3 is used to enter PDia (Pile Diameter), C_M (Coefficient of mass), and C_D (Coefficient of drag). Format 601 is used, denoting all numbers as floating decimal point numbers. Hence, pile diameter should be entered in columns 1-10, C_M in columns 11-20, and C_D in columns 21-30.

Card 4 -

Data card 4 is used to input Ncode (code designation: 0 if pile top is above wave crest and 1 if pile top is below wave trough. Note here that pile top cannot be between crest and trough for this program.) and Topht (distance from bottom to pile top). Topht is entered only if Ncode equals 1. FORMAT 502 is referenced and given as: 602 FORMAT (I5, 5X, F 10.0). This means that Ncode should be an integer value containing no more than 5 digits and right justified in columns 1-5. If Ncode equals 1, Topht is required and should be entered as a floating point value in columns 11-20.

```
//$OPTIONS
C
C
C   *********************************************************************
C   *********************************************************************
C   E. J. CHACKO, COASTAL AND OCEAN ENGINEERING DIV.,
C   CIVIL ENGINEERING DEPARTMENT           CE 685   PROBLEMS
C   *********************************************************************
C       PROGRAM TO COMPUTE FORCES AND MOMENTS ON A CYLINDRICAL PILE
C       USING STOKES III ORDER THEORY
C   *********************************************************************
C
C
C
C       CALCULATION OF SMALLA AND WAVELENGTH
C
C
C       READ DATA
C
C       T = PERIOD
C       H = WAVE HEIGHT
C       D = DEPTH
C
      DIMENSION SV(50)
      READ(5,999)T,H,D
  999 FORMAT(8F10.4)
      G=32.2
      PI=3.141593
      WL =5.12*T*T
   10 X=2.*PI*D/WL
      CE31=COSH(X)*COSH(X)*COSH(X)*COSH(X)*COSH(X)*COSH(X)
      CE32=SINH(X)*SINH(X)*SINH(X)*SINH(X)*SINH(X)*SINH(X)
      F3=(3./16.)*(1.+(8.*CE31))/CE32
      A1=WL*WL/(PI*PI*F3)
      B1=-H*WL*WL/(2.*PI*PI*F3)
      A=(-.5*B1+SQRT(.25*B1*B1+A1*A1*A1/27.))**(1./3.)
      B=(-.5*B1-SQRT(.25*B1*B1+A1*A1*A1/27.))
      B=ABS(B)**.3333333
      BB=(-.5*B1-SQRT(.25*B1*B1+A1*A1*A1/27.))
      SIGN = 1.
      IF(BB.LT.0.) SIGN = -1.
      A=A+SIGN*B
      C1=14.+4.*COSH(2.*X)*COSH(2.*X)
      C2=16.*SINH(X)*SINH(X)*SINH(X)*SINH(X)
      C=1.+((2.*PI*A/WL)**2.)*C1/C2
      WLT=(.5*G*T*T/PI)*(TANH(X))*C
      DIFF=WL-WLT
      WRITE(6,122)WL,WLT
  122 FORMAT(5X,2F16.8)
      WL=(WL+WLT)/2.
      IF(ABS(DIFF).GT.0.01) GO TO 10
      SMALLA=A
      DEPTH=D
      WAVEL=WL
      WAVEP=T
C
C
C
C       READ DATA
C
```

```
C       NUMINC = NO. OF INCREMENTS TO USE IN THE 'SIMPSON' NUMERICAL
C       INTEGRATION SCHEME.  TWENTY (20) INCREMENTS WILL GIVE SUFFICIENTLY
C       ACCURATE RESULTS.  IT IS IMPORTANT TO NOTE THAT 'NUMINC' MUST
C       BE AN EVEN NUMBER.
C       NUMTHE = NO. OF THETA'S AT WHICH FORCES AND MOMENTS ARE TO BE
C       CALCULATED.
C       THETA = INITIAL PHASE ANGLE AT WHICH FORCES AND MOMENTS ARE TO
C       BE CALCULATED (RADIANS).
C       VINCRM = ANGLE BY WHICH THETA IS INCREMENTED AT EACH STEP (RADIANS).
C       SMALLA = 'A' USED IN THE STOKES THIRD ORDER FORMULAS (FEET).
C       DEPTH = DISTANCE FROM BOTTOM TO SWL (FEET).
C       WAVEL = WAVE LENGTH (FEET).
C       WAVEP = WAVE PERIOD (SECONDS).
C       PDIA = PILE DIAMETER (FEET).
C       CM = COEFFICIENT OF MASS (UNITLESS).
C       CD = COEFFICIENT OF DRAG (UNITLESS).
C       RHO = MASS DENSITY OF WATER (LB.-SEC.(SQ.)/FT.).
C       NCODE = CODE DESIGNATION
C             = 0 IF PILE TOP IS ABOVE CREST
C             = 1 IF PILE TOP IS BELOW TROUGH
C             NOTE THAT PILE TOP CANNOT BE BETWEEN CREST AND TROUGH
C             FOR THIS PROGRAM.
C       TOPHT = DISTANCE FROM BOTTOM TO PILE TOP.  INPUT ONLY IF NCODE = 1
C
        READ(5,600) NUMINC,NUMTHE,THETA,VINCRM
        READ(5,601) PDIA,CM,CD
        READ(5,602) NCODE,TOPHT
C
C       DEFINE CONSTANTS
C
        GRAV = 32.2
        PI = 3.14159
        RHO=64./G
        C1 = 2.*PI*DEPTH/WAVEL
        C2 = 2.*PI/WAVEL
        C3 = PI/WAVEL
        C4 = CD*RHO*PDIA*0.5
        C5 = CM*RHO*PI*PDIA*PDIA*0.25
        CO1 = COSH(C1)
        SO1 = SINH(C1)
        SF2 = CO1*(COSH(2.*C1) + 2.)/(2.*SO1**3)
        SF3 = (24.*CO1**6 + 3.)/(16.*SO1**6)
        F1 = C2*SMALLA/SO1
        F2 = 0.75*(C2*SMALLA)**2/SO1**4
        F3 = (3./64.)*(C2*SMALLA)**3*(11. - 2.*COSH(2.*C1))/SO1**7
C
C       DETERMINE WAVE VELOCITY
C
        WAVEV = WAVEL/WAVEP
C
C       WRITE INPUT
C
        WRITE(6,500)
        WRITE(6,501)
        WRITE(6,502) WAVEL,WAVEP,WAVEV,SMALLA
        WRITE(6,503) DEPTH,H
        WRITE(6,504) PDIA,CD,CM
        WRITE(6,509)
        WRITE(6,505)
        WRITE(6,506)
        WRITE(6,507)
```

```
      WRITE(6,506)
      WRITE(6,507)
C
C     DETERMINE SIMPSON'S VECTOR
C
      KKK = NUMINC + 1
      SV(1) = 1.0
      DO 50 JJ = 2,NUMINC,2
      SV(JJ) = 4.0
   50 SV(JJ+1) = 2.0
      SV(JJ+1) = 1.0
C
C     BEGIN LOOP TO DETERMINE FORCES AND MOMENTS
C
      INUM=NUMTHE+1
      DO 100 J=1,INUM
      SIN1 = SIN(THETA)
      SIN2 = SIN(2.*THETA)
      SIN3 = SIN(3.*THETA)
      COS1 = COS(THETA)
      COS2 = COS(2.*THETA)
      COS3 = COS(3.*THETA)
      Y = SMALLA*COS1 + C2*SMALLA*SMALLA*SF2*COS2 + C3*C3*SMALLA*
     1 SMALLA*SMALLA*SF3*COS3
      IF(NCODE.EQ.1) GO TO 60
      YDIST = Y + DEPTH
      GO TO 70
   60 YDIST = TOPHT
   70 DELTA = YDIST/NUMINC
      SDIST = 0.0
      FARE1 = 0.0
      FARE2 = 0.0
      BARE1 = 0.0
      BARE2 = 0.0
      DO 200 K = 1,KKK
      CON = C2*SDIST
      U1 = F1*COSH(CON)
      U2 = F2*COSH(2.*CON)
      U3 = F3*COSH(3.*CON)
      UVEL = (U1*COS1 + U2*COS2 + U3*COS3)*WAVEV
      USQRD = UVEL*ABS(UVEL)
      UDOT =  (U1*SIN1 + U2*SIN2 + U3*SIN3)*C2*WAVEV*WAVEV
      FARE1 = FARE1 + SV(K)*USQRD
      FARE2 = FARE2 + SV(K)*UDOT
      BARE1 = BARE1 + SV(K)*SDIST*USQRD
      BARE2 = BARE2 + SV(K)*SDIST*UDOT
      SDIST = SDIST + DELTA
  200 CONTINUE
      RMS = (FARE1/ABS(FARE1))*SQRT(ABS(FARE1)/YDIST)
      FARE1 = FARE1*DELTA*C4*0.333333
      FARE2 = FARE2*DELTA*C5*0.333333
      BARE1 = BARE1*DELTA*C4*0.333333
      BARE2 = FARE2*DELTA*C5*0.333333
      FAREA = FARE1 + FARE2
      BAREA = BARE1 + BARE2
C
C     WRITE OUTPUT
C
      WRITE(6,508) THETA,Y,RMS,FARE1,FARE2,BARE1,BARE2,FAREA,BAREA
      THETA = THETA + VINCRM
```

```
    100 CONTINUE
        WRITE(6,509)
C
C       FORMAT STATEMENTS
C
    500 FORMAT(1H1,15(/))
    501 FORMAT(5X,'---- FORCES & MOMENTS ON PILE BY STOKES THIRD ORDER THE
       1ORY ----')
    502 FORMAT(////,10X,'WAVE CHARACTERSTICS = '//,10X,'LENGTH = ',F6.1,
       1 ' FT.'/,10X,'PERIOD = ',F4.1,' SEC.'/,10X,'VELOCITY = ',F5.1,
       2 ' FT./SEC.'/,10X,'A = ',F5.1,' FT.')
    503 FORMAT(///,10X,'WATER DEPTH = ',F5.1,' FT.',/10X,'WAVE HEIGHT = ',
       1F5.1,' FT.')
    504 FORMAT(///,10X,'PILE PROPERTIES = '//,10X,'DIAMETER = ',F5.1,
       1 ' FT.',/,10X,'DRAG COEFFICIENT = ',F4.2,/,10X,'MASS COEFFICIENT =
       2 ',F4.2)
    505 FORMAT(///,5X,'THETA WAVE HT.  RMS PARTICLE        DRAG             INE
       *RTIA             DRAG             INERTIA             TOTAL             TOTAL')
    506 FORMAT(11X,'ABOVE SWL   VELOCITY          FORCE             FORCE
       *    MOMENT             MOMENT             FORCE             MOMENT')
    507 FORMAT(5X,'(RD.)   (FT.)    (FT./SEC.)          (LBS.)            (LBS.)
       *          (FT.-LBS.)       (FT.-LBS.)        (LBS.)         (FT.-LBS.)'//)
    508 FORMAT(5X,F5.2,F7.1,7X,F5.2,4X,6F15.6)
    509 FORMAT(1H1)
    600 FORMAT(2I5,7F10.0)
    601 FORMAT(8F10.0)
    602 FORMAT(I5,5X,F10.0)
        STOP
        END

 //$DATA
 0.11519990E 04  0.61626260E 03
 0.88413110E 03  0.74526730E 03
 0.81469920E 03  0.78702050E 03
 0.80085980E 03  0.79582950E 03
 0.79934470E 03  0.79744840E 03
 0.79789640E 03  0.79773770E 03
 0.79781710E 03  0.79778880E 03
 0.79780290E 03  0.79779780E 03
```

---- FORCES & MOMENTS ON PILE BY STOKES THIRD ORDER THEORY ----

WAVE CHARACTERSTICS -

LENGTH = 797.8 FT.
PERIOD = 15.0 SEC.
VELOCITY = 53.2 FT./SEC.
A = 14.2 FT.

WATER DEPTH = 100.0 FT.
WAVE HEIGHT = 30.0 FT.

PILE PROPERTIES -

DIAMETER = 4.0 FT.
DRAG COEFFICIENT = 1.05
MASS COEFFICIENT = 1.40

THETA (RD.)	WAVE HT. ABOVE SWL (FT.)	RMS PARTICLE VELOCITY (FT./SEC.)	DRAG FORCE (LBS.)	INERTIA FORCE (LBS.)	DRAG MOMENT (FT.-LBS.)	INERTIA MOMENT (FT.-LBS.)	TOTAL FORCE (LBS.)	TOTAL MOMENT (FT.-LBS.)
0.00	18.6	6.93	0.469673E 05	0.000000E 00	0.339021E 07	0.000000E 00	0.469673E 05	0.339021E 07
0.07	18.5	6.90	0.465277E 05	0.139084E 04	0.335394E 07	0.939028E 05	0.479185E 05	0.344784E 07
0.14	18.2	6.82	0.452327E 05	0.275798E 04	0.324739E 07	0.185647E 06	0.479907E 05	0.343304E 07
0.21	17.8	6.59	0.431510E 05	0.407876E 04	0.307722E 07	0.273193E 06	0.472297E 05	0.335041E 07
0.28	17.2	6.50	0.403896E 05	0.533251E 04	0.285364E 07	0.354736E 06	0.457222E 05	0.320837E 07
0.35	16.5	6.27	0.370847E 05	0.650137E 04	0.258941E 07	0.428787E 06	0.435861E 05	0.301819E 07
0.42	15.6	5.99	0.333894E 05	0.757084E 04	0.229554E 07	0.494233E 06	0.409602E 05	0.279278E 07
0.49	14.6	5.58	0.294624E 05	0.853012E 04	0.199509E 07	0.550360E 06	0.379925E 05	0.254545E 07
0.56	13.5	5.33	0.254567E 05	0.937218E 04	0.169204E 07	0.596851E 06	0.348288E 05	0.228889E 07
0.63	12.3	4.95	0.215112E 05	0.100936E 05	0.140052E 07	0.633748E 06	0.316048E 05	0.203427E 07
0.70	11.1	4.55	0.177444E 05	0.106943E 05	0.112936E 07	0.661404E 06	0.284388E 05	0.179077E 07
0.77	9.9	4.12	0.142507E 05	0.111771E 05	0.884862E 06	0.680412E 06	0.254278E 05	0.156527E 07
0.84	8.4	3.68	0.110997E 05	0.115469E 05	0.670918E 06	0.691543E 06	0.226466E 05	0.136246E 07
0.91	7.1	3.23	0.833708E 04	0.118105E 05	0.489293E 06	0.695668E 06	0.201475E 05	0.118496E 07
0.98	5.8	2.77	0.598692E 04	0.119759E 05	0.339996E 06	0.693706E 06	0.179628E 05	0.103370E 07
1.05	4.5	2.31	0.405521E 04	0.120516E 05	0.221699E 06	0.686569E 06	0.161068E 05	0.908268E 06
1.12	3.2	1.85	0.253304E 04	0.120466E 05	0.132146E 06	0.675125E 06	0.145796E 05	0.807270E 06
1.19	2.0	1.39	0.140030E 04	0.119695E 05	0.685043E 05	0.660169E 06	0.133699E 05	0.728673E 06
1.26	0.8	0.94	0.625583E 03	0.118290E 05	0.276649E 05	0.642410E 06	0.124579E 05	0.670075E 06
1.33	-0.3	0.52	0.185416E 03	0.116327E 05	0.645291E 04	0.622460E 06	0.118181E 05	0.628913E 06
1.40	-1.3	0.07	0.322238E 01	0.113850E 05	-0.101513E 04	0.600832E 06	0.113912E 05	0.599817E 06
1.47	-2.3	-0.43	-0.135866E 03	0.111013E 05	-0.107894E 05	0.577550E 06	0.109654E 05	0.567160E 06
1.54	-3.2	-0.84	-0.455023E 03	0.107784E 05	-0.308217E 05	0.554156E 06	0.103234E 05	0.523335E 06
1.61	-4.0	-1.22	-0.954998E 03	0.104246E 05	-0.595305E 05	0.529721E 06	0.946957E 04	0.470191E 06
1.68	-4.7	-1.59	-0.160167E 04	0.100442E 05	-0.946402E 05	0.504854E 06	0.844250E 04	0.410014E 06
1.74	-5.4	-1.95	-0.236329E 04	0.964117E 04	-0.134944E 06	0.479716E 06	0.727788E 04	0.344771E 06
1.81	-6.0	-2.29	-0.321080E 04	0.921499E 04	-0.178285E 06	0.454425E 06	0.600819E 04	0.276141E 06
1.88	-6.6	-2.60	-0.411795E 04	0.878055E 04	-0.223535E 06	0.429077E 06	0.466270E 04	0.205542E 06
1.95	-7.1	-2.90	-0.506134E 04	0.832878E 04	-0.269570E 06	0.403740E 06	0.326744E 04	0.134170E 06
2.02	-7.6	-3.18	-0.602041E 04	0.786572E 04	-0.315452E 06	0.378470E 06	0.184531E 04	0.630180E 05
2.09	-8.0	-3.44	-0.697728E 04	0.739351E 04	-0.360407E 06	0.353310E 06	0.416227E 03	-0.709663E 04
2.16	-8.4	-3.68	-0.791670E 04	0.691398E 04	-0.403905E 06	0.328296E 06	-0.100273E 04	-0.755086E 05
2.23	-8.8	-3.91	-0.882673E 04	0.642859E 04	-0.445141E 06	0.303456E 06	-0.239704E 04	-0.141685E 06
2.30	-9.2	-4.11	-0.969366E 04	0.593908E 04	-0.484027E 06	0.278816E 06	-0.375458E 04	-0.205211E 06
2.37	-9.5	-4.30	-0.105119E 05	0.544636E 04	-0.520166E 06	0.254396E 06	-0.506541E 04	-0.265771E 06
2.44	-9.8	-4.46	-0.112730E 05	0.495155E 04	-0.553348E 06	0.230209E 06	-0.632146E 04	-0.323139E 06
2.51	-10.1	-4.61	-0.119719E 05	0.445555E 04	-0.583426E 06	0.206267E 06	-0.751634E 04	-0.377160E 06
2.58	-10.4	-4.73	-0.126042E 05	0.395904E 04	-0.610321E 06	0.182573E 06	-0.864515E 04	-0.427748E 06
2.65	-10.5	-4.87	-0.131667E 05	0.346255E 04	-0.633982E 06	0.159124E 06	-0.970416E 04	-0.474859E 06
2.72	-10.8	-4.97	-0.136572E 05	0.296649E 04	-0.654407E 06	0.135910E 06	-0.106907E 05	-0.518497E 06
2.79	-11.0	-5.05	-0.140740E 05	0.247109E 04	-0.671608E 06	0.112916E 06	-0.116029E 05	-0.558692E 06
2.86	-11.1	-5.12	-0.144151E 05	0.197646E 04	-0.685513E 06	0.901169E 05	-0.124397E 05	-0.595496E 06
2.93	-11.3	-5.18	-0.146829E 05	0.148261E 04	-0.696462E 06	0.674833E 05	-0.132003E 05	-0.628979E 06
3.00	-11.4	-5.22	-0.148738E 05	0.989425E 03	-0.704189E 06	0.449793E 05	-0.138844E 05	-0.659209E 06
3.07	-11.4	-5.24	-0.149837E 05	0.496735E 03	-0.708824E 06	0.225646E 05	-0.144919E 05	-0.685255E 06
3.14	-11.4	-5.25	-0.150274E 05	0.430330E 01	-0.710384E 06	0.195432E 03	-0.150231E 05	-0.710189E 06

V. A COMPUTER PROGRAM USING THE STREAM FUNCTION TO PREDICT THE FORCE AND MOMENT OF A VERTICAL PILE

1. General Comment

This program was developed based on the stream function as presented by Robert G. Dean in his publication "Stream Function Wave Theory: Validity and Application". The mathematical functions for the wave represented here are the Stokes III and Stokes V Theories. Other functions can be substituted. Once the wave function is chosen, the water particle velocity and acceleration must be computed. These parameters as well as the input constants of the problem, e.g. pile diameter, water density, constants, etc. can be used to compute the force and moment on a pile.

2. Program Description

Main Program

Purpose: To calculate forces and moments on a vertical pile, given wave height, wave period, water depth, size of pile, coefficients of mass and drag.

Equations: To use the wave and piling constants to compute dimensionless coefficients of force and moment, the following equations are used:

$$\phi = F/\gamma C_D H^2 D = \frac{1}{2}\int_0^{1+\eta(\theta)/h} \frac{u(\theta)}{\sqrt{gH}} \frac{|u(\theta)|}{\sqrt{gH}} \frac{h}{H}\, d\,\frac{S}{h} + \frac{\pi}{4}\frac{C_m}{C_D}\cdot\frac{D}{H}\int_0^{1+\eta(\theta)/h} \frac{\dot{u}(\theta)}{gH}\frac{h}{H}\, d\,\frac{S}{h} \qquad (1)^*$$

$$\alpha = M/\gamma C_d H^2 Dh = \tfrac{1}{2} \int_0^{1+n(\theta)/h} \frac{u(\theta)}{\sqrt{gH}} \frac{u(\theta)}{\sqrt{gH}} \frac{h}{H} \frac{S}{h} \, d \frac{S}{h} + \tag{2}$$

$$\frac{\pi}{4} \frac{C_M}{C_D} \cdot \frac{D}{H} \int_0^{1+n(\theta)/h} \frac{\dot{u}(\theta)}{gH} \frac{h}{H} \frac{S}{h} \, d \frac{S}{h}$$

where: ϕ = Dimensionless force coefficient

F = Total force on pile

γ = Water density

C_D = Drag coefficient

H = Wave height

D = Piling diameter

n = Wave shape function

$u(\ )$ = particle velocity at a given level

g = Gravitational constant = 32.2

π = Constant = 3.1415927

C_M = Inertia Coefficient

$\dot{u}(\theta)$ = Particle acceleration at a given level

S = Vertical component with original bottom and positive upwards

α = Dimensionless moment coefficient

3. DEFINITION OF TERMS

A ALPHA - Dimensionless moment coefficient on a single verticle pile

AXM( ) - Horizontal component of water particle acceleration

C

CD - Drag coefficient (optional input variable)

CM - Inertia coefficient (optional input variable)

D

D - Depth from stillwater level to bottom in feet

DENOMF - Denominator term used to create dimensionless force coefficient

DENOMM - Denominator term used to create dimensionless moment coefficient

DEPIMC - Depth of increments, i.e. number of feet/increment (ft) (input variable)

DIA - Pile Diameter (ft) (input variable)

F

F - Force on pile at a given water level (lbs)

FSUM - Summation of force on pile (lbs)

G

G - Gravitational constant = 32.2 ft/sec^2

GAMMA - Water density (optional input variable)

H

HEIGHT - Wave height (ft) (input variable)

I

ITIMES - Number of steps in summation internally computed

M

M - Moment at base due to acceleration at a given level (ft-lbs)

MSUM - Summation of moments about base (ft-lbs)

N

NWRITE - Print option

0 implies force and moment output

1 implies 0 and wave function

P

PHI - Dimensionless total force on single verticle pile

PI - Constant = 3.1415927

S

S - Vertical component with origin at bottom and positive upwards

SDH - S/D

SDHE - S/height

SUMIF - Temporary variable in F computation first term

SUM2F - Temporary variable in F computation second term

SUMIM - Temporary variable in M computation first term

SUM2M - Temporary variable in M computation second term

T

T - Wave period (secs) (input variable)

TERMIF - First term in F equation

TERM2F - Second term in F equation

U

UM( ) - Horizontal component of velocity of water particle

X

XDL - Distance wave divided by wavelength

XDLINC - Increment which XDL will be incremented by in solution

XDLF - Final value that XDL can have in solution

Y

YM( ) - Level at which UM( ) and AXM( ) are computed, origin at SWL positive upwards, negative downwards (ft)

4. BIBLIOGRAPHY

1. Robert G. Dean, "Stream Function Wave Theory; Validity and Application". Coastal Engineering, Santa Barbara Specialty Conference, October 1965.

2. Cecil M. McClenan, Charles M. Kindel, Hayes, E. Ross and Henry W. Worthington, "Computer Programs in Ocean Engineering", TAMU-SG-71-405, COE Report No. 131, Texas A&M University, July 1971.

COMPUTER INPUT

Input data for forces and moments on wave-loaded vertical piles using the Stream Function Theory is read into the main program via 2 data cards. The input sequence is formated in accordance with the fortran watfiv language utilized in the main program.

Card 1 -

Data card number 1 contains 8 parameters. The format corresponding to this data card is given in statement 100 as: FORMAT (8E10.3). This means the computer expects to read 8 different quantities each containing a maximum of 10 characters and formated on the card in exponential notation. The quantities to be read on the first data card are wave height columns 1-10, water depth (D) columns 11-20, wave period (T) columns 21-30, XDL (the initial X/L interval usually 0.0) in columns 31-40, SDLINC (the incrementation by which XDL is to be increased) in columns 41-50, XDLIF (final value of X/L to which program should iterate, usually 1.0) in columns 51-60, Dia (pile diameter in feet) in columns 61-70, Depinc (increments in feet of iteration along pile length) in columns 71-80.

Card 2 -

Card 2 optionally initializes several constants in the main program and carries the instructions for particular output formats available in the program. The card corresponding format is given as: 101 Format (3E10.2, 2I5). C_D (the drag coefficient) should be typed in columns 1-10, C_M (the mass coefficient) in columns 11-20, and Gamma (the specific weight of water) in columns 21-30. All of these values should be given in exponential notation. If the columns corresponding to each value are left blank the computer will read this as a zero and automatically set C_D equal to 1.05, C_M equal to 1.4, and Gamma equal to 64.0, respectively. The final two values on the card activate optional output and denote method of solution. In column 35 type either zero or one. Zero will write all the input data and the forces and moments calculated in the program; one writes zero stream function level plus velocity and acceleration from the wave function. In column 40 type either zero or one, zero corresponds to solution by Stokes V Order Wave Theory, and 1 implies solution by Stokes Third Order Wave Theory.

PROGRAM LIMITATIONS

Program limitations are the same as those incorporated into the Stokes V Order and Stokes III Order Wave Theory programs.

```
//$OPTIONS
C-----------------------------------------------------------------------
C       FORCE AND MOMENT ON WAVE LOADED VERTICAL PILE
C                                         BY THE STREAM FUNCTION
C
C            INPUT DATA
C              CARD 1    (8E10.3)
C                COLS
C                1-10  HEIGHT      = WAVE HEIGHT
C                11-20   D         = WATER DEPTH
C                21-30   T         = WAVE PERIOD
C                31-40   XDL       = INITIAL X/L INTERVAL
C                41-50  XDLINC     = INCREMENT WHICH XDL IS TO BE INCREASED BY
C                51-60  XDLF       = FINAL X/L INTERVAL
C                61-70   DIA       = DIAMETER OF PILE(FT)
C                71-80  DEPINC     = INCREMENT WHICH  PILE WILL BE DIVIDED
C                                                          INTO (FT)
C              CARD 2   OPTIONAL CONSTANTS  (3E10.3,I5)
C                1-10    CD        = DRAG COEFF.      IF 0 WILL BE SET =1.05
C                11-20  CM         = INERTIA COEFF.    IF 0 WILL BE SET =1.40
C                21-30  GAMMA      = UNIT WEIGHT OF WATER (LBS/FT**3) IF 0
C                                                            WILL BE SET = 64
C                31-35 NWRITE      = WRITE OPTION
C                                        0 IMPLIES ALL INPUT AND FORCE AND MOME
C                                        1 IMPLIES 0 LEVEL PLUS VELOCITY AND
C                                          ACCELERATION FROM THE WAVE FUNCTION
C                35-40 NMETH       = METHOD OF SOLUTION
C                                           0 IMPLIES STOKES V
C                                           1 IMPLIES STOKES III
C        MULTIPLE SETS ( CARD 1  + CARD 2 ) ALLOWED
C
C-----------------------------------------------------------------------
          REAL M,MUSM
          COMMON/WRITO/XDLINC,XDLF,DIA,CM,CD,NWRITE
          COMMON/RESULT/UM(100),AXM(100) ,YM(100)
10000     READ(5,100,END=999) HEIGHT,D,T,XDL,XDLINC,XDLF,DIA,DEPINC
          PRINT,HEIGHT,D,T,XDL,XDLINC,XDLF,DIA,DEPINC
  100     FORMAT(8E10.3)
          READ(5,101) CD,CM,GAMMA,NWRITE,NMETH
          PRINT,CD,CM,GAMMA,NWRITE,NMETH
  101     FORMAT(3E10.2,2I5)
          IF (CD.EQ.0) CD=1.05
          IF (CM.EQ.0) CM=1.40
          IF (GAMMA.EQ.0) GAMMA=64.0
          G=32.2
          PI=3.1415927
          DENOMF=GAMMA*CD*HEIGHT*HEIGHT*DIA
          DENOMM=DENOMF*D
    1     CONTINUE
          IF(NMETH.EQ.0) CALL STOKEV (T,HEIGHT,D,DEPINC,XDL,ITIMES)
          IF(NMETH.EQ.1) CALL STOKES (T,HEIGHT,D,DEPINC,XDL,ITIMES)
          WRITE(6,1000)
          FSUM=0
          MSUM=0
          DO 10 I=1,ITIMES
          S=D+YM(I)
          IF(I.EQ.1) SDH=(YM(1)-YM(2))/D
          IF(I.NE.1) SDH=DEPINC/D
          IF(I.EQ.1) SDHE=(YM(1)-YM(2))/HEIGHT
          IF(I.NE.1) SDHE=DEPINC/HEIGHT
```

```
      SUM1F=UM(I)*ABS(UM(I))*SDH
      TERM1F=SUM1F*(D/HEIGHT)*(1/(G*HEIGHT))*.5
      SUM2F=AXM(I)/(G*HEIGHT)*D/HEIGHT*SDH
      TERM2F=PI/4.*CM/CD*DIA/HEIGHT*SUM2F
      F=DENOMF*(TERM1F+TERM2F)
      FSUM=F+FSUM
      SUM1M=TERM1F*S/D
      SUM2M=AXM(I)*D/HEIGHT*S/D*SDHF*PI/4.*CM/CD*DIA/HEIGHT
      M=DENOMM*(SUM1M+SUM2M)
      MSUM=M+MSUM
      WRITE(6,1100)YM(I),F,M
   10 CONTINUE
      WRITE(6,1101) FSUM,MSUM
      ALPHA=MSUM/DENOMM
      PHI=FSUM/DENOMF
      WRITE(6,1102) PHI,ALPHA
      WRITE(6,950)
  950 FORMAT(//,T26,'ALL DIMENSIONS IN FEET, POUNDS,SECONDS.')
      XDL=XDL+XDLINC
      IF(XDLINC.EQ.0) GO TO 10000
      IF(XDL.GT.XDLF) GO TO 10000
      GO TO 1
  999 WRITE(6,998)
      RETURN
  998 FORMAT(1H1,20X,'END OF DATA')
 1000 FORMAT(//,T40,'FORCE ON PILE',//,T30,'DEPTH (FT)',T50,'FORCE ',
     *T70,'MOMENT',/)
 1101 FORMAT(/,T40,'TOTAL',T45,G15.7,T65,G15.7)
 1102 FORMAT(////,T40,'THE COMPUTED DIMENSIONLESS COEFFICIENTS FOR THIS
     *CASE ARE:',//,T50,'FORCE = ',G10.3,T70,'MOMENT = ',G10.3)
 1100 FORMAT(T30,F10.2,T45,1PE15.7,T65,1PE15.7)
      END
C**********************************************************************

      SUBROUTINE STOKES (T,H,D,DEPINC,XDL,ITIMES)
      COMMON/WRITE/XDLINC,XDLF,DIA,CM,CD,NWRITE
      COMMON/RESULT/UM(100),AXM(100),YM(100)
C
C     STOKES THIRD ORDER WAVE THEORY
C
C     FOR WAVE CONDITIONS WHERE D/L GREATER THAN 1/10
C
C     'T' IS THE WAVE PERIOD
C     'H' IS THE WAVE HEIGHT
C     'D' IS THE DEPTH
C     'DEPINC' IS THE DEPTH INCREMENTATION DESIRED(SHOULD BE AN INTERGER)
C
      DIMENSION YSD(50),XHEAD(5),YHEAD(5),TITLE(10),XHEADA(5),XHEADB(5),
     1YHEADC(5),XHEADD(5),YHEADA(5),YHEADB(5),YHEADC(5),YHEADD(6),TITLEA
     2(10),TITLEB(10),TITLEC(10),TITLED(10),YP(999),XDLP(50),NAME(20,20)
      SYMBOL=0
      NPRINT=0
      L=0
      G=32.2
      PI=3.141593
      WL=5.12*T*T
   10 X=2.*PI*D/WL
      CE31=COSH(X)**6
      CE32=SINH(X)**6
      C3=(3./16.)*(1.+(8.*CE31))/CE32
```

```
      A1=WL*WL/(PI*PI*F3)
      B1=-H*WL*WL/(2.*PI*PI*F3)
      A=(-.5*B1+SQRT(.25*B1*B1+A1*A1*A1/27.))**(1./3.)
      B=(-.5*B1-SQRT(.25*B1*B1+A1*A1*A1/27.))
      BB=B
      B=ABS(B)**(1./3.)
      SIGN= 1.
      IF(BB.LT.0.) SIGN = -1.
      A=A+SIGN*B
      C1=14.+4.*COSH(2.*X)**2
      C2=16.*SINH(X)**4
      C=1.+((2.*PI*A/WL)**2  )*C1/C2
      WLT=(.5*G*T*T/PI)*(TANH(X))*C
      DIFF=WL-WLT
      WL=(WL+WLT)/2.
      IF(ABS(DIFF).GT.0.01) GO TO 10
C
C     END OF ITERATIVE PROCESS TO SOLVE FOR ACTUAL WAVELENGTH
C
      CF2=(2.+COSH(2.*X))*COSH(X)
      CF21=2.*SINH(X)*SINH(X)*SINH(X)
      F2=CF2/CF21
      CEL=WL/T
      A1=A/WL
      A2=PI*A1*A1*F2
      A3=PI*PI*A1*A1*A1*F3
      F1=2.*PI*A/(WL*SINH(X))
      F2=3.*PI*PI*A*A/(WL*WL*SINH(X)*SINH(X)*SINH(X)*SINH(X))
      F3=(((3./16.)*PI*PI*A*A/(WL*WL))*(11.-2.*COSH(2.*X))/(SINH(X)**7.)
     1)*2.*PI*A/WL
      YC=(A1+A2+A3)*WL
      YT=YC-H
      WRITE(6,200) WL,H,D,YC,YT,CEL,T
      W=CM/CD*DIA/H
      HEIGT2=H/(T*T)
      DEPT2=D/(T*T)
      WRITE(6,201)  XDLINC,XDLF,DIA,CM,CD,W,DEPT2,HEIGT2
      TEST=D/WL
      IF(TEST.LT..1) WRITE(6,500)
      TOT=0.0
      WRITE(6,300)XDL
      IF(NWRITE.EQ.0) GO TO 1002
      WRITE(6,301)
 1002 CONTINUE
      TH=2.*PI*(XDL-TOT)
      YS=WL*(A1*COS(TH)+A2*COS(2.*TH)+A3*COS(3.*TH))
      I=(YS+D)/DEPINC+2
      KY=YS+2.*DEPINC
      KY=KY/DEPINC
      KY=KY*DEPINC
      Y=KY
      ITIMES=I
      DO 40 N=1,I
      Y=KY-DEPINC*N
      IF(N.EQ.1) Y=YS
      IF(Y.GT.YS)KY=KY-DEPINC
      IF(Y.GT.YS)Y=Y-DEPINC
      XY=2.*PI*(Y+D)/WL
      U=(F1*COSH(XY)*COS(TH)+F2*COSH(2*XY)*COS(2.*TH)+F3*COSH(3.*XY)*COS
     1(3.*TH))*CEL
```

```
      C=2.*PI*CEL/T
      AX=C*F1*COSH(XY)*SIN(TH)+2.*C*F2*COSH(2.*XY)*SIN(2.*TH)+3.*C*F3*CO
     1SH(3.*XY)*SIN(3.*TH)
      L=L+1
      UM(N)=U
      AXM(N)=AX
      YM(N)=Y
      IF(NWRITE.EQ.0) GO TO 1001
      WRITE(6,400) Y,U,AX
 1001 CONTINUE
   40 CONTINUE
  200 FORMAT(1H1,/////,T45,'      STOKES THIRD ORDER WAVE THEORY      ',
     1  /////,T50,'WAVE LENGTH    =',F10.3,///,T50,'WAVE HEIGHT    =',
     2F10.3,///,T50,'WATER DEPTH    =',F10.3,///,T50,'YC             =',
     3F10.3,///,T50,'YT             =',F10.3,///,T50,'WAVE CELERITY =',
     4F10.3,///,T50,'WAVE PERIOD    =',F10.3)
  201 FORMAT( //,T50,'X/L INCREMENT',T64,'=',F10.4,///,T50,'LAST X/L VAL
     $UE',T64,'=',F10.4,///,T50,'DIA. OF PILE',T64,'=',F10.2,///,T50,
     $'CM',T64,'=',F10.4,///,T50,'CD',T64,'=',F10.4,///,T50,'W',T64,'=',
     $F10.4,///,T50,'DEPTH/T**2',T64,'=',F10.4,///,T50,'HEIGHT/T**2',
     $T64,'=',F10.4)
  300 FORMAT(1H1,T60,'X/L =',F4.2,3(/))
  301 FORMAT(T36,'Y',T44,'HORIZONTAL',T60,'HORIZONTAL',/,T45,'VELOCITY',
     $T60,'ACCELERATION')
  400 FORMAT(T26,F13.2,4F16.6)
  500 FORMAT(20X,'***** WARNING D/L IS LESS THAN 1/10 - SUBROUTINE STOKE
     *S LIMIT IS EXCEEDED.  EXERCISE GREAT CARE WITH USE OF DATA',/,
     *30X,'EXECUTION CONTINUES *****')
      RETURN
      END
C***********************************************************************
      SUBROUTINE STOKEV (T,H,D,DEPINC,XDL,ITIMES)
      COMMON/WRITE/XDLINC,XDLF,DIA,CM,CD,NWRITE
      COMMON/RESULT/UM(100),AXM(100),YM(100)
C     STOKES FIFTH ORDER WAVE THEORY
C     NUM=1,  WHEN L,H,D  ARE KNOWN; NUM=2, WHEN T,H,D ARE KNOWN
C     DEPINC DEPTH INCREMENTS AT WHICH THE PARTICLE VELOCITY AND
C     ACCELERATIONS ARE CALCULATED
C     XLINC INCREMENTS ALONG WAVE LENGTH AT WHICH THE VELOCITY AND
C     ACCELERATIONS ARE CALCULATED
C     Y IS MEASURED POSITIVELY UPWARDS FROM THE MUDLINE
      DIMENSION U(10),Y(10),YP(100)
      CHK=0.
      N=0
      PI=3.1416
      G=32.2
      WL=G*T**2/(2.*PI)
      WLF=WL
   30 CALL SOLVEL(WL,AMDA,H,T,D,PI,G,F22,F35,B55)
      BETA=2.*PI/WL
      S=SINH(2.*PI*D/WL)
      C=COSH(2.*PI*D/WL)
      C1=(8.*C**4-8.*C**2+9.)/(8.*S**4)
      C2=(3840.*C**12-4096.*C**10+2592.*C**8-1008.*C**6+5944.*C**4-1830.
     .*C**2+147.)/(512.*S**10*(6.*C**2-1.))
      AMDA2=AMDA**2
      AMDA4=AMDA**4
   20 WLO=WL/(TANH(BETA*D)*(1.+AMDA2*C1+AMDA4*C2))
      T=SQRT(WLO*2.*PI/G)
```

```
      CEL=WL/T
      WRITE(6,200) WL,H,D,CEL,T,AMDA
      W=CM/CD*DIA/H
      HEIDT2=H/(T*T)
      DEPT2=D/(T*T)
      WRITE(6,201) XDLINC,XDLF,DIA,CM,CD,W,DEPT2,HEIDT2
  201 FORMAT( //,T50,'X/L INCREMENT',T64,'=',F10.4,///,T50,'LAST X/L VAL
     $UE',T64,'=',F10.4,///,T50,'DIA. OF PILE',T64,'=',F10.2,///,T50,
     $'CM',T64,'=',F10.4,///,T50,'CD',T64,'=',F10.4,///,T50,'W',T64,'=',
     $F10.4,///,T50,'DEPTH/T**2',T64,'=',F10.4,///,T50,'HEIGHT/T**2',
     $T64,'=',F10.4)
      A11=1./S
      A13=-C**2*(5.*C**2+1.)/(8.*S**5)
      A15=-(1184.*C**10-1440.*C**8-1992.*C**6+2641.*C**4-249.*C**2+18.)
     ./(1536.*S**11)
      A22=3./(8.*S**4)
      A24=(192.*C**8-424.*C**6-312.*C**4+480.*C**2-17.)/(768.*S**10)
      A33=(13.-4*C**2)/(64.*S**7)
      A35=(512.*C**12+4224.*C**10-6800.*C**8-12808.*C**6+16704.*C**4
     .-3154.*C**2+107.)/(4096.*S**13*(6.*C**2-1.))
      A44=(80.*C**6-816.*C**4+1338.*C**2-197.)/(1536.*S**10*(6.*C**2-1.
     .))
      A55=-(2880.*C**10-72480.*C**8+324000.*C**6-432000.*C**4+163470.*
     .C**2-16245.)/(61440.*S**11*(6.*C**2-1.)*(8.*C**4-11.*C**2+3.))
      B22=(2.*C**2+1.)*C/(4.*S**3)
      B24=C*(272.*C**8-504.*C**6-192.*C**4+322.*C**2+21.)/(384.*S**9)
      B33=3.*(8.*C**6+1.)/(64.*S**6)
      B44=C*(768.*C**10-448.*C**8-48.*C**6+48.*C**4+106.*C**2-21.)/
     .(384.*S**9*(6.*C**2-1.))
      C0=SQRT(G*(TANH(BETA*D)))
      C3=-1./(4.*S*C)
      C4=(12.*C**8+36.*C**6-162.*C**4+141.*C**2-27.)/(192.*C*S**9)
      AMDA3=AMDA**3
      AMDA5=AMDA**5
      Y(1)=AMDA
      Y(2)=AMDA2*(B22+AMDA2*B24)
      Y(3)=AMDA3*(B33+AMDA2*B35)
      Y(4)=AMDA4*B44
      Y(5)=AMDA5*B55
      U(1)=AMDA*(A11+AMDA2*A13+AMDA4*A15)
      U(2)=AMDA2*(A22+AMDA2*A24)
      U(3)=AMDA3*(A33+AMDA2*A35)
      U(4)=AMDA4*A44
      U(5)=AMDA5*A55
      THETA=2.*PI*XDL
      WSUM=0.0
      DO 400 I=1,5
      WE=Y(I)*COS(I*THETA)
      WSUM=WSUM+WE
  400 CONTINUE
      YDC=WSUM/BETA
      IF(NWRITE.EQ.0) GO TO 21
      WRITE(6,280) XDL
   21 CONTINUE
      IF (NWRITE.EQ.0) WRITE(6,290) XDL
      THETA=2.*PI*XDL
      DEE=D+YDC
      IDD=DEE/DEPINC+2.
      DE=DEE/DEPINC
      ID=DE
```

```
      DP=FP-FLOAT(IP)
      IF(DP.EQ.0.0) IDP=IDP-1
      SP=0.
      DO 310 K=1,IDP
      USUM=0.
      VSUM=0.
      UASUM=0.
      VASUM=0.
      DO 300 I=1,5
      UPU=I*U(I)*COSH(I*BETA*SP)*COS(I*THETA)
      VPV=I*U(I)*SINH(I*BETA*SP)*SIN(I*THETA)
      USUM=USUM+UPU
      VSUM=VSUM+VPV
      UAU=I**2*U(I)*COSH(I*BETA*SP)*SIN(I*THETA)
      VAV=I**2*U(I)*SINH(I*BETA*SP)*COS(I*THETA)
      UASUM=UASUM+UAU
  300 VASUM=VASUM+VAV
      SO=SP-D
      UP=USUM*CEL
      VP=VSUM*CEL
      AU=UASUM*CEL**2*BETA
      AV=-VASUM*CEL**2*BETA
      IF(NWRITE.EQ.0) GO TO 65
      WRITE(6,500) SO,UP,AU
   65 CONTINUE
      YM(K)=SO
      UM(K)=UP
      AYM(K)=AU
      ITIMES=K
      SP=SP+DEPINC
      IF(SP.GT.DEP) SP=DEP
  310 CONTINUE
  320 CONTINUE
      IF(NWRITE.EQ.0) GO TO 67
   67 CONTINUE
  200 FORMAT(1H1,////////,T28,' VALUES DERIVED USING STOKES FIFTH ORDER '
     6'WAVE THEORY',
     1////////,T50,'WAVE LENGTH    =',F10.4,///,T50,'WAVE HEIGHT    =',
     2F10.4,///,T50,'WATER DEPTH    =',F10.4,///,T50,'WAVE CELERITY  =',
     3F10.4,///,T50,'WAVE PERIOD    =',F10.4,///,T50,'LAMBDA            =',
     4F10.4)
  290 FORMAT(1H1,T60,'X/L=',F7.4,///,T26,'Y',T44,'HORIZONTAL',T60,
     $'HORIZONTAL',/,T45,'VELOCITY',T60,'ACCELERATION',/)
  200 FORMAT(1H1,T50,'X/L=',F10.4,///)
  500 FORMAT(T26,F13.4,4F16.6)
      RETURN
      END
C    ***************************************************************
      SUBROUTINE SOLVEL(WL,AMDA,H,T,D,PI,C,B33,B35,B55)
C    THIS SUBROUTINE CALCULATES VALUE OF LAMDA
      G=32.2
      PI=3.1416
      C=COSH(2.*PI*D/WL)
      S=SINH(2.*PI*D/WL)
      BETA=2.*PI/WL
      B33=3.*(8.*C**6+1.)/(64.*S**6)
      B35=(88128.*C**14-208224.*C**12+70848.*C**10+54000.*C**8-21816.
     .*C**6+6264.*C**4-54.*C**2-81.)/(12288.*S**12*(6.*C**2-1.))
      B55=(192000.*C**16-262720.*C**14+83680.*C**12+20160.*C**10-7280.
```

```
     .*C**8+7160.*C**6-1800.*C**4-1050.*C**2+225.)/(
     .12288.*S**10*(6.*C**2-1.)*(8.*C**4-11.*C**2+3.))
      ITMAX=50
      X=.2
      CK2=B35+B55
      CST=PI*H/WL
      DO 25 I=1,ITMAX
      ROOT=X-(B33*X**3+CK2*X**5-CST+X)/(1.+3*B33*X**2+5*CK2*X**4)
      DIFF=ROOT-X
      IF(ABS(DIFF).LE..0001) GO TO 100
      X=ROOT
   25 CONTINUE
      WRITE(6,200) ROOT
      STOP
  100 ANDA=X
  200 FORMAT(2X,'DOESNT CONVERGE AFTER  50  ITERATIONS',3X,'ROOT= ',
     1F10.4,'*******>THAT MEANS FOR THIS PROBLEM STOKES V THEORY IS NOT
     * APPLICABLE')
      RETURN
      END

//$DATA
0.55000000E 02    0.12000000E 03    0.13000000E 02    0.20000000E 00    0.10000000E 00
0.10000000E 02
0.00000000E 00    0.00000000E 00    0.10000000E 00             1                 1
```

STOKES THIRD ORDER WAVE THEORY

WAVE LENGTH	=	751.254
WAVE HEIGHT	=	65.000
WATER DEPTH	=	120.000
YC	=	42.181
YT	=	-22.819
WAVE CELERITY	=	57.789
WAVE PERIOD	=	13.000
X/L INCREMENT	=	0.1000
LAST X/L VALUE	=	0.2000
DIA. OF PILE	=	6.00
CM	=	1.4000
CD	=	1.0500
W	=	0.1231
DEPTH/T**2	=	0.7101
HEIGHT/T**2	=	0.3846

X/L =0.00

Y	HORIZONAL VELOCITY	HORIZONTAL ACCELERATION
42.18	0.359927E 02	0.000000E 00
40.00	0.351800E 02	0.000000E 00
30.00	0.317551E 02	0.000000E 00
20.00	0.287763E 02	0.000000E 00
10.00	0.261852E 02	0.000000E 00
-0.00	0.239328E 02	0.000000E 00
-10.00	0.219778E 02	0.000000E 00
-20.00	0.202856E 02	0.000000E 00
-30.00	0.188271E 02	0.000000E 00
-40.00	0.175778E 02	0.000000E 00
-50.00	0.165173E 02	0.000000E 00
-60.00	0.156290E 02	0.000000E 00
-70.00	0.148988E 02	0.000000E 00
-80.00	0.143157E 02	0.000000E 00
-90.00	0.138709E 02	0.000000E 00
-100.00	0.135577E 02	0.000000E 00
-110.00	0.133716E 02	0.000000E 00
-120.00	0.133099E 02	0.000000E 00

FORCE ON PILE

DEPTH (FT)	FORCE	MOMENT
42.18	1.7686560E 04	2.8684160E 06
40.00	7.7486500E 04	1.2397840E 07
30.00	6.3133650E 04	9.4700470E 06
20.00	5.1844500E 04	7.2582290E 06
10.00	4.2928440E 04	5.5806970E 06
-0.00	3.5860890E 04	4.3033060E 06
-10.00	3.0241560E 04	3.3265710E 06
-20.00	2.5763850E 04	2.5763840E 06
-30.00	2.2192140E 04	1.9972910E 06
-40.00	1.9344680E 04	1.5475740E 06
-50.00	1.7081040E 04	1.1956720E 06
-60.00	1.5293110E 04	9.1758600E 05
-70.00	1.3897530E 04	6.9487700E 05
-80.00	1.2830980E 04	5.1323920E 05
-90.00	1.2045560E 04	3.6137880E 05
-100.00	1.1598200E 04	2.3016410E 05
-110.00	1.1194460E 04	1.1194450E 05
-120.00	1.1091350E 04	0.0000000E-01
TOTAL	491425.0	55351120

THE COMPUTED DIMENSIONLESS COEFFICIENTS FOR TH

FORCE = 0.288 MOMENT = 0.271

ALL DIMENSIONS IN FEET, POUNDS, SECONDS.

STOKES THIRD ORDER WAVE THEORY

```
WAVE LENGTH    =    751.254

WAVE HEIGHT    =     65.000

WATER DEPTH    =    120.000

YC             =     42.181

YT             =    -22.819

WAVE CELERITY  =     57.789

WAVE PERIOD    =     13.000

X/L INCREMENT  =     0.1000

LAST X/L VALUE =     0.2000

DIA. OF PILE   =       6.00

CM             =     1.4000

CD             =     1.0500

K              =     0.1271

DEPTH/T**2     =     0.7101

HEIGHT/T**2    =     0.3846
```

X/L =0.10

Y	HORIZONAL VELOCITY	HORIZONTAL ACCELERATION
25.56	0.198560E 02	0.143686E 02
20.00	0.190085E 02	0.133727E 02
10.00	0.176128E 02	0.117975E 02
-0.00	0.163652E 02	0.104620E 02
-10.00	0.152656E 02	0.933017E 01
-20.00	0.142908E 02	0.837245E 01
-30.00	0.134353E 02	0.756435E 01
-40.00	0.126907E 02	0.688568E 01
-50.00	0.120497E 02	0.631989E 01
-60.00	0.115061E 02	0.585346E 01
-70.00	0.110547E 02	0.547545E 01
-80.00	0.106911E 02	0.517715E 01
-90.00	0.104119E 02	0.495177E 01
-100.00	0.102143E 02	0.479428E 01
-110.00	0.100965E 02	0.470115E 01
-120.00	0.100573E 02	0.467034E 01

FORCE ON PILE

DEPTH (FT)	FORCE	MOMENT
25.56	1.3831260E 04	5.6428640E 07
20.00	2.2783670E 04	9.0728800E 07
10.00	1.9564550E 04	7.4254720E 07
-0.00	1.6902730E 04	6.0729740E 07
-10.00	1.4703230E 04	4.9605800E 07
-20.00	1.2887620E 04	4.0436540E 07
-30.00	1.1397790E 04	3.2857680E 07
-40.00	1.0166530E 04	2.6570090E 07
-50.00	9.1669410E 03	2.1326970E 07
-60.00	8.3596560E 03	1.6923290E 07
-70.00	7.7174640E 03	1.3186890E 07
-80.00	7.2188390E 03	9.9716540E 06
-90.00	6.8471400E 03	7.1514480E 06
-100.00	6.5900740E 03	4.6152110E 06
-110.00	6.4391440E 03	2.2625510E 06
-120.00	6.3897860E 03	0.0000000E-01
TOTAL	180960.8	507048704

THE COMPUTED DIMENSIONLESS COEFFICIENTS FOR

FORCE = 0.106 MOMENT = 2.48

ALL DIMENSIONS IN FEET, POUNDS, SECONDS.

VI. RED SEA REVISIONS

1. General Comment

This program was developed at Texas A&M University to trace waves entering a harbor. The phenomena of refraction, diffraction, and shoaling are all included. This program was presented in an earlier publication, A Computer Program to Estimate the Combined Effect of Refraction and Diffraction of Water Waves, by Henry W. Worthington and John B. Herbich[4] The program presented here has been updated, however, to conform more closely with Coastal and Ocean Engineering needs.

2. Program Description

INPUT, OUTPUT

The input to the program has been rewritten.

The first card still inputs M, N, NOP and SP. The second input card type, the depth cards, have been changed. Now the depths are input in FORMAT (16F5.0) by rows. Each new row starts on a new card. This change was made to allow fewer cards as input and to allow keypunching in the reading position.

The original program was designed to read depths in columns. This means that the depths as read are in the transpose of the way in which they are needed. For this reason, the depths are read into the TM (25, 25) matrix and then the DO 70 loop transposes the data and places it into the D(25, 25) matrix.

The third input card type contains a new variable, FE which is the bottom friction coefficient.

The output of the depths has been rewritten so that any number of columns of data can be printed wihtout changing FORMAT statements. If 13 or less columns of data are in a row, they will be printed row by row. If 14 or more columns of data are in a row, a heading ROW= is printed and the data follows on the following lines with 13 data points per line.

The Friction Coefficient

In a paper by Skovgaard, Jonsson and Bertelson[5], a method for computing the effect of bottom friction is outlined. The formula for this effect is as follows:

$$d/dt\, K_f' = \frac{1}{-T}\,\frac{4\pi}{3}\,\frac{H}{L_0}\,st\,\sqrt{n_{st}c_{st}}\;\frac{f_e}{n\sqrt{nc}\,\sinh^3 kh}\;\frac{K_f'}{\sqrt{\beta}}$$

T = Wave period

π = Constant = 3.1415926

H_{st} = Wave height at starting position

L_0 = Deepwater wavelength

n_{st} = Dimensionless quantity at start

n = Dimensionless quantity at time t

c_{st} = Wave celerity at start

c = Wave celerity at time t

f_e = Wave energy loss factor (bottom friction coefficient)

K_f = Modified friction coefficient

β = Wave orthogonal separation factor

New quantities computed in RED SEA are:

L_0 = LO = 5.12T**2

$$n = P = \frac{2kh}{.5(1 + \sinh 2kh)}$$

all variables that require the st subscript are initialized at the beginning of each orthogonal.

The numerical method used to solve the nonlinear differential equation is as follows:

Given K_f at time t

K_f at time t + 1 =

$K_{f \text{ at } t}$ + DEL t (Const*$K_{f \text{ at } t}$ **2)

and const = all terms in d/dt K_f' equation except K_f'

K_f at time = 1 is 1

The H/H_{st} ratio is equal to $K_{refraction}$*$K_{shoaling}$*$K_{friction}$. The RED SEA program was originally programmed to handle refraction and shoaling coefficients. The friction coefficient has simply been multiplied in.

The friction coefficient is displayed in the output. The height coefficient displayed now includes all factors.

3. BIBLIOGRAPHY

1. Cecil M. McClenan, Charles M. Kindel, Hayes, E. Ross and Henry W. Worthington, "Computer Programs in Ocean Engineering", TAMU-SG-71-405, COE Report No. 131, Texas A&M University, July 1971.

2. Fan, S., J.E. Cumming, and R.L. Weigle, "Computer Solution of Wave Diffraction by Semi-Infinite Breakwater", HEL 1-8, University of California, Berkeley, 1967.

3. Herbich, J.B. and Orr, T.E., "Numerical Calculation of Wave Diffraction by Digital Computer", Sea Grant Publication No. 209, Texas A&M University, 1969.

4. Worthington, H.W., and Herbich, J.B., "A Computer Program to Estimate the Combined Effects of Refraction and Diffraction of Water Waves", Sea Grant Publication No. 219, Texas A&M University, 1970.

5. Skovgaard, Jonsson and Bertelson, "Calculation of Wave Heights Due to Refraction and Friction", Technical University of Denmark, June 1973, pp. 1-19.

COMPUTER INPUT

The Redsea program has been previously published by Texas A&M University but is now being re-released with a new program input sequence. For a description of the current input technique, see the program description part 2 of this section.

```
//$OPTIONS
C                                                                        R
C........................................................................ R
C   RECSEA PROGRAM                                                       R
C      REVISED JULY 1974                                                 R
C                                                                        R
C                                                                        R
C   THIS PROGRAM WILL EVALUATE THE EFFECTS OF A SEMI-INFINITE BREAK-     R
C   WATER AND AN IRREGULAR BOTTOM TOPOGRAPHY ACTING SIMULTANEOUSLY TO    R
C   CHANGE THE HEIGHT AND DIRECTION OF WATER WAVES                       R
C                                                                        R
C   NECESSARY INPUT DATA IS                                              R
C   CARD 1                                                               R
C     M=NUMBER OF POINTS IN GRID HORIZONTALLY (COL 1-5, I FORMAT)        R
C     N=NUMBER OF POINTS IN GRID VERTICALLY (COL 6-10, I FORMAT)         R
C     NOP= NUMBER OF PROBLEMS TO BE SOLVED (COL 11-15, I FORMAT)         R
C     SP=GRID LINE SPACING IN FEET (COL 16-25)                           R
C   WATER DEPTH CARDS                                                    R
C     DEPTH IN FEET  FORMAT(16F5.0)   16 POINTS PER CARD BY ROW          R
C          NEW ROW STARTS ON A NEW CARD                                  R
C   PROBLEM DATA CARDS (NOP CARDS REQUIRED)                              R
C     ALPH(2)=WAVE ANGLE W/ HORIZ IN DEGREES (COL 1-5)                   R
C     TH=WAVE PERIOD IN SEC (COL 6-10)                                   R
C     DELT=ORTHGNL POINT TIME INCREMENT IN SEC (COL 11-15)               R
C     X(1)=INITIAL ORTHGNL ORIGIN HORIZ GRID COORD (COL 16-20)           R
C     Y(1)=INITIAL ORTHGNL ORIGIN VERT GRID COORD (COL 21-25)            R
C     QM=ORTHGNL ORIGIN LIMIT GRID COORD (COL 26-30)                     R
C     UK=DIST BETWEEN ORTHGNLS AT ORIGIN IN GRID SPACINGS (COL 31-35)    R
C     BWTX=BKWTR TIP HORIZ GRID COORD (COL 36-40)                        R
C     BWTY=BKWTR TIP VERT GRID COORD (COL 41-45)                         R
C     BWBX=BKWTR BUTT HORIZ GRID COORD (COL 46-50)                       R
C     BWBY=BKWTR BUTT VERT GRID COORD (COL 51-55)                        R
C     CREL=REFLECTION COEF FROM BKWTR (COL 56-60)                        R
C     FF=WAVE ENERGY LOSS FACTOR  (COL 61-65)                            R
C                                                                        R
C   ALL FORMATS ARE 'F' FORMATS UNLESS OTHERWISE INDICATED               R
C       DIMENSIONS ARE (NROWS,NCOLS) IN SIZE                             R
C                                                                        R
C      WRITTEN BY H. W. WORTHINGTON                                      R
C      REFERENCE: SEA GRANT PUBLICATION 219, COE REPORT NO. 127-COE      R
C      TEXAS A & M UNIVERSITY, AUGUST 1970                               R
C                                                                        R
C........................................................................ R
C                                                                        R
C   RECSEA MAIN PROGRAM                                                  R
C                                                                        R
C   SPECIFICATION STATEMENTS                                             R
1         DIMENSION D(25,25),C(25,25),CX(25,25),CY(25,25),C2X(25,25),    R
         $C2Y(25,25),C2XY(25,25),TM(25,25)                               R
2         DIMENSION ALPH(200),X(200),Y(200),IX(200),IY(200),F(200),E(200),  R
         1CXL(200),CYL(200),C2XL(200),C2YL(200),C2XYL(200),GAMA(200),    R
         2PE(200),Q(200),BETA(200),T(200),V(200),W(200)                  R
3         INTEGER RSW, JT, NP, IR                                        R
4         COMMON PI                                                      R
5         REAL LO                                                        R
6         REAL KF                                                        R
7         REAL LANG                                                      R
8         KF=1                                                           R
C   READ DATA AND CONDITIONS                                             R
9         READ(5,17) M,N,NOP,SP                                          R
```

```
   17 FORMAT (3I5,F10.7)
      DO 60 I=1,N
   60 READ(5,10)(TM(I,J),J=1,M)
   10 FORMAT(16F5.0)
      IGC=1
   44 READ (5,30) ALPH(2),TH,DELT,X(1),Y(1),OM,UK,BWTX,BWTY,BWBX,BWBY,CR
     1EL,FF
   30 FORMAT (13F5.3)
C  DEFINE VARIABLES
      G=32.17398
      PI=3.141592654
      RSW=0
      A=(G*TH)/(6.28*SP)
      B=(6.28/TH)
C  PRINT DATA, CONDITIONS, AND HEADINGS
      IF (IGC.NE.1) GO TO 888
      WRITE (6,38) M,N,NOP,SP
   38 FORMAT (1H1,2X,'WATER DEPTH DATA',///,3X,'NUMBER OF HORIZONTAL GRI
     1D LINES', I6,//,3X,'NUMBER OF VERTICAL GRID LINES ',2X,I5,//3X, 'N
     2UMBER OF PROBLEMS ',13X,I5,//,3X, 'GRID INTERVAL',19X,F5.1,1X,'FT'
     3,////,57X,'D E P T H    S O U N D I N G S',//)
      DO 50 I=1,N
      WRITE(6,51)
   51 FORMAT(/)
      IF(M.LE.13) GO TO 52
      WRITE(6,53) I
   53 FORMAT(' ROW',I3,'=')
      WRITE(6,29)(TM(I,J),J=1,M)
      GO TO 50
   52 WRITE(6,29)(TM(I,J),J=1,M)
   50 CONTINUE
   29 FORMAT(13(3X,F7.1))
      DO 70 I=1,M
      DO 70 J=1,N
   70 D(I,J)=TM(J,I)
  888 WRITE (6,33) IGC,ALPH(2),TH,DELT,X(1),Y(1),OM,UK,BWTX,BWTY,BWBX,BW
     1BY,CREL ,FF
   33 FORMAT (1H1,2X,'PROBLEM DATA',///,2X,'PROBLEM NUMBER',16X,I5,//,2X
     1,'ANGLE OF INCIDENCE',12X,F7.2,1X,'DEGREES',//,2X,'WAVE PERIOD',
     219X,F7.2,1X,'SECONDS',// ,2X,'TIME INCREMENT',16X,F7.2,1X,'SECONDS
     3'//,2X,'INITIAL ORTHOGONAL ORIGIN',5X,2F7.1,1X,'(HORIZ,VERT)',
     4                                                //, 2X, 'MAX HORIZ
     5ORTHOGONAL ORIGIN' , 3X, F7.1, //, 2X, 'ORTHOGONAL ORIGIN INTERVAL
     6', 4X, F7.1, //, 2X, 'BREAKWATER  TIP', 15X, 2F7.1,1X, '(HORIZ, VE
     7RT)' //, 2X, 'BREAKWATER BUTT', 15X, 2F7.1,1X,'(HORIZ,VERT)',
     8//,2X,'COEFFICIENT OF REFLECTION',/,4X, 'FROM BREAKWATER',13X,F7.2
     9,//2X,'BOTTOM FRICTION COEFFICIENT',T33,F7.3)
C  CALCULATE BREAKWATER ANGLE W/ HORIZ GRID
      ALCH (2)=(PI*ALPH(2))/180.0
      BWDX=BWBX-BWTX
      BWDY=BWTY-BWBY
      BWANG=ATAN2(BWDY,BWDX)
C  CALCULATE WAVE ANGLE FOR DIFFRACTION COORD SYSTEM
      WVANG=ALCH(2)+BWANG
      IP=0
C  CALCULATE CELERITY
      I=1
   15 J=1
      RC=A
   47 1F(IGP.EQ. 1) GO TO 14
```

```
C  RECORD DEPTH IN GRID SPACING UNITS
      D(I,J)=D(I,J)*SF
   14 IF (D(I,J)-0.001*SP) 11,11,922
  922 D(I,J)=D(I,J)/SP
   13 P1=A*TANH((B*D(I,J))/PO)
      IF(ABS(P1-PO)-(0.001*PO).LE.0.0) GO TO 12
      PO=P1
       GO TO 13
   12 C(I,J)=P1
      PO=P1
      GO TO 34
   11 C(I,J)=0.0
      D(I,J)=D(I,J)/SP
   34 J=J+1
      IF ((N-J).GE.0) GO TO 47
      I=I+1
      IF ((M-I).GE.0) GO TO 15
C  CALCUALTE CELERITY DERIVITIVES
      I=2
   19 J=2
   18 CX(I,J)=(C(I+1,J)-C(I-1,J))/2.0
      CY(I,J)=(C(I,J+1)-C(I,J-1))/2.0
      C2X(I,J)=(C(I+1,J)-2*C(I,J)+C(I-1,J))
      C2Y(I,J)=(C(I,J+1)-2*C(I,J)+C(I,J-1))
      C2XY(I,J)=(C(I+1,J+1)-C(I-1,J+1)-C(I+1,J-1)+C(I-1,J-1))/4.0
      J=J+1
      IF((N-J).GT.0) GO TO 18
      I=I+1
      IF ((M-I).GT.0) GO TO 19
C  TRACE OF ORTHOGONALS
      WRITE(6,63)
   63 FORMAT(1H ,///,4X,'ORTHGNL',3X,'POINT',6X,'TIME',2X,'COORDINATES'
     1, 2X, ' DEPTH ',1X, 'REFRACTION',1X,'SHOALING',1X,'DIFFRACTION', 2
     $X,'FRICTION',2
     2X,'HEIGHT',4X, 'WAVE', /, 4X, 'NUMBER', 4X, 'NUMBER', 5X, '(SEC)',
     34X,'X', 4X, 'Y', 4X, ' (FT) ' , 5X, 'COEF', 6X, 'COEF', 6X, 'COEF'
     4, 6X, ' COEF ',6X,'COEF',2X,'DIRECTION',/,6X,'1')
      X(2)=X(1)
      Y(2)=Y(1)
      K=1
C  INITIALIZE HEIGHT AND ANGLE @ BKWTR TIP FOR DIFFRACTION CALCULATIONS
      TWVANG = WVANG
      THTIP=0.0
      PHTIP=1.0
   28 L=2
      NC=1
      T(2)=0.0
      IROW=IFIX(X(2))
      ICOL=IFIX(Y(2))
      DST=D(IROW,ICOL)/SF
      CST=C(IROW,ICOL)
      WRITE (6,909) X(2),Y(2)
  909 FORMAT(1H ,11X,5H    1,2X,10H      0.00,2X,2F5.1,2X,'ORTHOGONAL
     1ORIGIN')
      JT=0
      IR=0
C  RECORD THE HEIGHT OF THE LAST ORTHOGONAL TO PASS BKWTR
      IF(THTIP.NE.0.0) PHTIP=THTIP
      THTIP=0.0
      BETA(1)=1.0
```

```
      BETA(2)=1.0
C   INTERPOLATE F(L),E(L) AND DERIVITIVES
   25 IX(L)=X(L)
      IY(L)=Y(L)
      GF=X(L)-IX(L)
      G5=Y(L)-IY(L)
      G1=GF*G5
      G2=G1-GF
      G3=G1-G5
      G4=G2-G5+1
      I=IX(L)
C   TERMINATE ORTHGNL REACHING EDGE OF GRID
      IF(I.GE.M-1.OR.I.LT.2) GO TO 21
      J=IY(L)
      IF(J.GE.N-2.OR.J.LT.2) GO TO 21
      F(L)=G4*D(I,J)-G3*D(I,J+1)+G1*D(I+1,J+1)-G2*D(I+1,J)
C   TERMINATE ORTHGNL REACHING SHORE
      IF(F(L)-.01*A.LE.0.0) GO TO 21
      E(L)=G4*C(I,J)-G3*C(I,J+1)+G1*C(I+1,J+1)-G2*C(I+1,J)
      CXL(L)=G4*CX(I,J)-G3*CX(I,J+1)+G1*CX(I+1,J+1)-G2*CX(I+1,J)
      CYL(L)=G4*CY(I,J)-G3*CY(I,J+1)+G1*CY(I+1,J+1)-G2*CY(I+1,J)
      C2XL(L)=G4*C2X(I,J)-G3*C2X(I,J+1)+G1*C2X(I+1,J+1)-G2*C2X(I+1,J)
      C2YL(L)=G4*C2Y(I,J)-G3*C2Y(I,J+1)+G1*C2Y(I+1,J+1)-G2*C2Y(I+1,J)
      C2XYL(L)=G4*C2XY(I,J)-G3*C2XY(I,J+1)+G1*C2XY(I+1,J+1)-
     1G2*C2XY(I+1,J)
      GAMA(L)=(CXL(L)*SIN(ALPH(L)))-(CYL(L)*COS(ALPH(L)))
   27 IF(JT.EQ.1) GO TO 22
      IF(JT.GT.1) GO TO 23
      DEL=GAMA(L)
      TAU=E(L)
      GO TO 24
   23 DEL=(GAMA(L-1)+GAMA(L))/2.0
      TAU=(E(L-1)+E(L))/2.0
      L=L-1
   24 DALPH=DEL*DELT
      GCOS=ALPH(L)+(DALPH/2.0)
      ALPH(L+1)=ALPH(L)+DALPH
C   DETERMINE COORD OF NEXT POINT ON ORTHGNL
      X(L+1)=X(L)+(TAU*DELT*COS(GCOS))
      Y(L+1)=Y(L)+(TAU*DELT*SIN(GCOS))
      L=L+1
      JT=JT+1
      GO TO 25
   22 DYBR=Y(L)-BWRY
      DXBR=BWRX-X(L)
      LANG = ATAN2(DYBR, DXBR)
C   TERMINATE ORTHGNL INTERCEPTING BRKWTR
      IF(X(L)-BWTX) 905,905,900
  900 IF(LANG.GE.BWANG.AND.BSW.EQ.0) GO TO 21
      IF(LANG.LT.BWANG.AND.BSW.GT.0) GO TO 21
  905 IF(BSW.GT.0) GO TO 921
      IF(LANG.GE.BWANG.AND.IR.EQ.1) IR=IR+1
C   RECORD ANGLE OF FIRST POINT ON PRIMARY ORTHGNL PAST BRKWTR LINE
      IF(IR.EQ.1) TWVANG=ALPH(L) + BWANG
  921 T(L)=T(L-1)+DELT
C   CALCULATE COEFFICIENTS OF REFRACTION AND SHOALING
      L=L-1
      DE(L)=-CXL(L)*COS(ALPH(L))+CYL(L)*SIN(ALPH(L))
      Q(L)=E(L)*((C2YL(L)*SIN(ALPH(L))**2   )-2.0*C2XYL(L)*SIN(ALPH(L))*
     1COS(ALPH(L))+C2YL(L)*(COS(ALPH(L))*COS(ALPH(L))))
```

```
      BETA(L+1)=((PP(L)*DELT-2.0)*BETA(L-1)+(4.0-2.0*Q(L)*(DELT**2.0))
     1*BETA(L))/(PP(L)*DELT+2.0)
      L=L+1
      BAFFLE=(P*F(L))/E(L)
      BACK=EXP(BAFFLE)
      BACKX=1.0/BACK
      COSHX=(BACK+BACKX)/2.0
      SINHX=(BACK-BACKX)/2.0
C  CALCULATE SHOALING COEFFICIENT
      W(L)=(COSHX)/(SQRT(SINHX*COSHX+BAFFLE))
C  CALCULATE REFRACTION COEFFICIENT
      CR=1.0/SQRT(ABS(BETA(L)))
C  RECORD REFRACTION COEFFICIENT IF WAVE PASSES BRKWTR
      IF(IR.EQ.1.AND.RSW.EQ.0) THTIP=CR
C  CONVERT ORTHGNL ANGLE TO DEGREES FOR PRINTOUT
      ALPHLD=ALPH(L)*180.0/PI
C  COMPUTE WAVE LENGTH AND X-Y COORDINATES FOR DIFFRACTION COORD SYSTEM
      WLX=E(L)*TH
      XD=(X(L)-BWTX)*COS( BWANG)-(Y(L)-BWTY)*SIN( BWANG)
      YD=(X(L)-BWTX)*SIN( BWANG)+(Y(L)-BWTY)*COS( BWANG)
      CALL DIFFR (WLX,XD,YD,WVANG,CRFL,RG,CD)
C  RECOMPUTE ACTUAL DEPTH FOR PRINTOUT
      DEP= F(L)*SP
C       COMPUTE EFFECT OF FRICTION
      WLX=E(L)*TH*SP
      IF(L.EQ.3) DEPST=DEP
      IF(L.EQ.3) WLXST=WLX
      RK=2.*PI/WLX
      HST=1
      LO=5.12*TH*TH
      TKH=  2*PI/WLX*DEP
      THKST=  2*PI/WLXST*DEPST
      QST=.5*(1+THKST/SINH(THKST))
      P=.5*(1+TKH/SINH(TKH))
      Z=C(I,J)
      TEMP1=QST*CST
      TEM=P*Z
      RKD=RK*DEP
      BET=BETA(L)
      DENOM=(P*SQRT(TEM)*(SINH(RKD)**3))
      IF(BET.EQ.0.OR.DENOM.EQ.0) GO TO 181
      CF=-1/TH*4*PI/3*HST/LO*SQRT(TEMP1   )*FF/DENOM*1/SQRT(ABS(BET))
      KF=KF+DELT*(CF*KF**2)
  181 CONTINUE
      WLX=E(L)*TH
      NC=NC+1
C  WAVE HT OF RADIAL ORTHGNLS
      IF(RSW.EQ.0) GO TO 950
      V(L)=W(L)*CR*CD*THTIP
      GO TO 960
C  WAVE HT OF PRIMARY ORTHGNLS
  950 V(L)=W(L)*CR*CD
      V(L)=V(L)*KF
  960 WRITE (6,26) NC,T(L),X(L),Y(L),DEP,CR,W(L),CD,KF,V(L),ALPHLD
   26 FORMAT(1H ,11X, I5,2X,F10.2,2X,2F5.1,F8.2,6F10.2)
      JT=0
      GO TO 27
   21 K=K+1
      WRITE (6,37) K
   37 FORMAT(1H ,/,4X,I3)
```

```
C   MOVE TO NEXT ORTHGNL ORIGIN
        X(2)=X(2) + ABS(UK/SIN(ALPH(2)))
        IF(QM-X(2).GE.0.0) GO TO 28
C   BEGIN RADIAL ORTHGNLS
        IF(RSW.EQ.0) WVANG=TWVANG
        RSW=RSW+1
C   ESTABLISH ORTHGNL DIRECTION FROM BRKWTR TIP
        ALPH(2)=(15.0*PI/180.0)*RSW - BWANG
C   TERMINATE PROB IF ORTHGNL LEAVES LEE
        IF(ALPH(2).GT.WVANG) GO TO 930
C   ESTABLISH RADIAL ORTHGNL ORIGIN AT BKWTR TIP
        X(2)=BWTX
        Y(2)=BWTY
C   LIMIT RADIAL ORTHGNLS TO ONE AT EACH ANGLE
        QM=BWTX + 1.0
        UK=2.0
        IF(RSW.GT.1) GO TO 940
C   CONVERT TO DEGREES FOR PRINTOUT
        WVANGD=WVANG*180.0/PI
        WRITE(6,920) BHTIP,WVANGD
  920 FORMAT(1H ,//,2X,'ORTHOGONALS IN LEE OF BREAKWATER',/, 15X,
     1'WAVE HT PASSING BREAKWATER TIP TAKEN AS', F14.2,2X, 'X  DEEP WAT
     2R HEIGHT', /, 15X, 'WAVE ANGLE (THETAO FOR DIFFRACTION) TAKEN AS',
     3F8.1,2X,'DEGREES', //)
  940 GO TO 28
C   TERMINATE COMPUTER RUN IF THIS IS LAST PROBLEM
  930 IF(NCP-ICP.EQ.0) GO TO 46
        ICP=ICP+1
        GO TO 44
   46 STOP
        END
C   EVALUATE COEFFICIENT OF DIFFRACTION

        SUBROUTINE DIFFR (WLX,X,Y,ANG,CREL,RG,CD)
        COMMON PI
        REAL K
        DATA RGQ/4H  Q /, RGR/4H  R /, RGS/4H  S /
        THETAO=ANG
C   ASSIGN CD AND THETA AT BKWTR TIP
        IF (X.NE.0.0.OR.Y.NE.0.0) GO TO 200
        CD=1.0
        THETA=0.0
        RG=RGQ
        RETURN
C   EVALUATE PARAMETERS FOR DIFFRACTION CALCULATIONS
  200 K=2.0*PI/WLX
        THETA=ATAN2(Y,X)
        R=SQRT(X**2 + Y**2)
        SIGMA=2.0*SQRT(K*R/PI)*SIN(0.5*(THETA-THETAO))
        SIGPRM=-2.0*SQRT(K*R/PI)*SIN(0.5*(THETA + THETAO))
        U=PI*SIGMA**2/2.0
        CALL CS(C,S,U)
        U1=0.5*(1.0-C-S)
        W1=0.5*(S-C)
        U=PI*SIGPRM**2/2.0
        CALL CS(C,S,U)
        U2=0.5*(1.0-C-S)
        W2=0.5*(S-C)
        ALPHA=K*R*COS(THETA-THETAO)
        BETA=K*R*COS(THETA+THETAO)
```

```
      A = U1*COS(ALPHA) + W1*SIN(ALPHA) + (U2*COS(BETA) + W2*SIN(BETA))
     1*CREL
      B = -U1*SIN(ALPHA) + W1*COS(ALPHA) - (U2*SIN(BETA) + W2*COS(BETA)
     1)*CREL
      D = COS(ALPHA) - U1*COS(ALPHA) - W1*SIN(ALPHA) +(U2*COS(BETA) +
     1W2*SIN(BETA))*CREL
      E = -SIN(ALPHA) - W1*COS(ALPHA) + U1*SIN(ALPHA) + (W2*COS(BETA) -
     1U2*SIN(BETA)) *CREL
      G = COS(ALPHA) - U1*COS(ALPHA) - W1*SIN(ALPHA) +(COS(BETA) - U2*C
     1OS(BETA) - W2*SIN(BETA))*CREL
      H = -SIN(ALPHA) -W1*COS(ALPHA) + U1*SIN(ALPHA) + (-SIN(BETA)
     1- W2*SIN(BETA) + U2*SIN(BETA))*CREL
C  DETERMINE REGION P,S, OR Q
      IF(X.LE.R*COS(THETAO)) GO TO 210
      IF(Y.LT.0.0.AND.X.GT.R*COS(THETAO)) GO TO 220
      IF(Y.GE.0.0.AND.X.GT.R*COS(THETAO)) GO TO 230
  210 CD     =SQRT(D**2+E**2)
      RG=RGQ
      GO TO 250
  220 CD     =SQRT(G**2+H**2)
      RG=RGS
      GO TO 250
  230 CD     =SQRT(A**2+B**2)
      RG=RGS
  250 RETURN
      END
C
C  EVALUATE FRESNEL INTEGRAL

      SUBROUTINE CS(C,S,X)
      Z=ABS(X)
      IF(Z-4.)1,1,2
    1 C=SQRT(Z)
      S=Z*C
      Z=(4.-Z)*(4.+Z)
      C=C*((((((5.100785E-11*Z+5.244297E-9)*Z+5.451182E-7)*Z
     1+3.273708E-5)*Z+1.020418E-3)*Z+1.102544E-2)*Z+1.840965E-1)
      S=S*(((((6.677681E-10*Z+5.883158E-8)*Z+5.051141E-6)*Z
     1+2.441816E-4)*Z+6.121320E-3)*Z+8.026490E-2)
      RETURN
    2 D=COS(Z)
      S=SIN(Z)
      Z=4./Z
      A=((((((((8.768258E-4*Z-4.169289E-3)*Z+7.970943E-3)*Z-6.792801E-3)
     1*Z-3.095341E-4)*Z+5.972151E-3)*Z-1.606428E-5)*Z-2.493322E-2)*Z
     2-4.444091E-9
      B=((((((-6.633926E-4*Z+3.401409E-3)*Z-7.271690E-3)*Z+7.428246E-3)
     1*Z-4.027145E-4)*Z-9.314910E-3)*Z-1.207998E-6)*Z+1.994711E-1
      Z=SQRT(Z)
      C=0.5+Z*(D*A+S*B)
      S=0.5+Z*(S*A-D*B)
      RETURN
      END

//*DATA
```

WATER DEPTH DATA

NUMBER OF HORIZONTAL GRID LINES 16

NUMBER OF VERTICAL GRID LINES 14

NUMBER OF PROBLEMS 2

GRID INTERVAL 50.0 FT

D E P T H   S O U N D I N G

ROW 1=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 2=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 3=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 4=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 5=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 6=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 7=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 8=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 9=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0

20.0 20.0 20.0

ROW 10=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 11=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 12=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 13=
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0

ROW 14=
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0

PROBLEM DATA

PROBLEM NUMBER	1	
ANGLE OF INCIDENCE	60.00 DEGREES	
WAVE PERIOD	8.00 SECONDS	
TIME INCREMENT	2.00 SECONDS	
INITIAL ORTHOGONAL ORIGIN	1.0	1.0 (HORIZ,VERT)
MAX HORIZ ORTHOGONAL ORIGIN	16.0	
ORTHOGONAL ORIGIN INTERVAL	1.0	
BREAKWATER TIP	6.0	3.0 (HORIZ, VERT)
BREAKWATER BUTT	16.0	3.0 (HORIZ,VERT)
COEFFICIENT OF REFLECTION FROM BREAKWATER	0.22	
BOTTOM FRICTION COEFFICIENT	0.001	

ORTHGNL NUMBER	POINT NUMBER	TIME (SEC)	COORDINATES X	Y	DEPTH (FT)	REFRACTION COEF	SHOALING COEF	DIFFRACTION COEF
1								
	1	0.00	1.0	1.0	ORTHOGONAL	ORIGIN		
2								
	1	0.00	2.2	1.0	ORTHOGONAL	ORIGIN		
3								
	1	0.00	3.3	1.0	ORTHOGONAL	ORIGIN		
4								
	1	0.00	4.5	1.0	ORTHOGONAL	ORIGIN		
5								
	1	0.00	5.6	1.0	ORTHOGONAL	ORIGIN		
6								
	1	0.00	6.8	1.0	ORTHOGONAL	ORIGIN		
7								
	1	0.00	7.9	1.0	ORTHOGONAL	ORIGIN		
8								
	1	0.00	9.1	1.0	ORTHOGONAL	ORIGIN		
9								
	1	0.00	10.2	1.0	ORTHOGONAL	ORIGIN		
10								
	1	0.00	11.4	1.0	ORTHOGONAL	ORIGIN		

11								
	1	0.00	12.5	1.0	ORTHOGONAL	ORIGIN		
12								
	1	0.00	13.7	1.0	ORTHOGONAL	ORIGIN		
13								
	1	0.00	14.9	1.0	ORTHOGONAL	ORIGIN		
14								

ORTHOGONALS IN LEE OF BREAKWATER
WAVE HT PASSING BREAKWATER TIP TAKEN AS 1.00 X DEEP WATER H
WAVE ANGLE (THETAC FOR DIFFRACTION) TAKEN AS 60.0 DEGREES

	1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
	2	2.00	6.9	3.2	20.00	1.00	0.99	0.27
	3	4.00	7.8	3.5	20.00	1.00	0.99	0.29
	4	6.00	8.8	3.7	20.00	1.00	0.99	0.23
	5	8.00	9.7	4.0	20.00	1.00	0.99	0.22
	6	10.00	10.6	4.2	20.00	1.00	0.99	0.20
	7	12.00	11.5	4.5	20.00	1.00	0.99	0.17
	8	14.00	12.4	4.7	20.00	1.00	0.99	0.16
	9	16.00	13.3	5.0	20.00	1.00	0.99	0.15
	10	18.00	14.3	5.2	20.00	1.00	0.99	0.13
15								
	1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
	2	2.00	6.8	3.5	20.00	1.00	0.99	0.32
	3	4.00	7.6	3.9	20.00	1.00	0.99	0.32
	4	6.00	8.5	4.4	20.00	1.00	0.99	0.26
	5	8.00	9.3	4.9	20.00	1.00	0.99	0.26
	6	10.00	10.1	5.4	20.00	1.00	0.99	0.23
	7	12.00	10.9	5.8	20.00	1.00	0.99	0.23
	8	14.00	11.8	6.3	20.00	1.00	0.99	0.20
	9	16.00	12.6	6.8	20.00	1.00	0.99	0.20
	10	18.00	13.4	7.3	20.00	1.00	0.99	0.19
	11	20.00	14.2	7.7	20.00	1.00	0.99	0.18
16								
	1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
	2	2.00	6.7	3.7	20.00	1.00	0.99	0.41
	3	4.00	7.3	4.3	20.00	1.00	0.99	0.40
	4	6.00	8.0	5.0	20.00	1.00	0.99	0.39
	5	8.00	8.7	5.7	20.00	1.00	0.99	0.37
	6	10.00	9.4	6.4	20.00	1.00	0.99	0.34
	7	12.00	10.0	7.0	20.00	1.00	0.99	0.34
	8	14.00	10.7	7.7	20.00	1.00	0.99	0.30
	9	16.00	11.4	8.4	20.00	1.00	0.99	0.31
	10	18.00	12.0	9.0	20.00	1.00	0.99	0.30
	11	20.00	12.7	9.7	20.00	1.00	0.99	0.29
	12	22.00	13.4	10.4	20.00	1.00	0.99	0.29
	13	24.00	14.1	11.1	20.00	1.00	0.99	0.28
	14	26.00	14.7	11.7	20.00	1.00	0.99	0.27
17								
	1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
	2	2.00	6.5	3.8	20.00	1.00	0.99	0.52

3	4.00	6.9	4.6	20.00	1.00	0.99	0.52
4	6.00	7.4	5.5	20.00	1.00	0.99	0.49
5	8.00	7.9	6.3	20.00	1.00	0.99	0.52
6	10.00	8.4	7.1	20.00	1.00	0.99	0.51
7	12.00	8.8	7.9	20.00	1.00	0.99	0.51
8	14.00	9.3	8.8	20.00	1.00	0.99	0.49
9	16.00	9.8	9.6	20.00	1.00	0.99	0.51
10	18.00	10.3	10.4	20.00	1.00	0.99	0.51
11	20.00	10.7	11.2	20.00	1.00	0.99	0.51

18

PROBLEM DATA

PROBLEM NUMBER	2	
ANGLE OF INCIDENCE	120.00 DEGREES	
WAVE PERIOD	8.00 SECONDS	
TIME INCREMENT	2.00 SECONDS	
INITIAL ORTHOGONAL ORIGIN	1.0	1.0 (HORIZ,VERT)
MAX HORIZ ORTHOGONAL ORIGIN	16.0	
ORTHOGONAL ORIGIN INTERVAL	1.0	
BREAKWATER TIP	6.0	3.0 (HORIZ, VERT)
BREAKWATER BUTT	16.0	3.0 (HORIZ,VERT)
COEFFICIENT OF REFLECTION FROM BREAKWATER	0.22	
BOTTOM FRICTION COEFFICIENT	0.001	

ORTHGNL NUMBER	POINT NUMBER	TIME (SEC)	COORDINATES X	Y	DEPTH (FT)	REFRACTION COEF	SHOALING COEF	DIFFRACTION COEF
1								
	1	0.00	1.0	1.0	ORTHOGONAL	ORIGIN		
2								
	1	0.00	2.2	1.0	ORTHOGONAL	ORIGIN		
3								
	1	0.00	3.3	1.0	ORTHOGONAL	ORIGIN		
4								
	1	0.00	4.5	1.0	ORTHOGONAL	ORIGIN		
5								
	1	0.00	5.6	1.0	ORTHOGONAL	ORIGIN		
6								
	1	0.00	6.8	1.0	ORTHOGONAL	ORIGIN		
7								
	1	0.00	7.9	1.0	ORTHOGONAL	ORIGIN		
8								
	1	0.00	9.1	1.0	ORTHOGONAL	ORIGIN		
9								
	1	0.00	10.2	1.0	ORTHOGONAL	ORIGIN		
10								
	1	0.00	11.4	1.0	ORTHOGONAL	ORIGIN		

11

1	0.00	12.5	1.0	ORTHOGONAL	ORIGIN

12

1	0.00	13.7	1.0	ORTHOGONAL	ORIGIN

13

1	0.00	14.9	1.0	ORTHOGONAL	ORIGIN

14

ORTHOGONALS IN LEE OF BREAKWATER
WAVE HT PASSING BREAKWATER TIP TAKEN AS 1.00 X DEEP WATER H
WAVE ANGLE (THETAO FOR DIFFRACTION) TAKEN AS 120.0 DEGREES

1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
2	2.00	6.9	3.2	20.00	1.00	0.99	0.23
3	4.00	7.8	3.5	20.00	1.00	0.99	0.17
4	6.00	8.8	3.7	20.00	1.00	0.99	0.12
5	8.00	9.7	4.0	20.00	1.00	0.99	0.11
6	10.00	10.6	4.2	20.00	1.00	0.99	0.09
7	12.00	11.5	4.5	20.00	1.00	0.99	0.08
8	14.00	12.4	4.7	20.00	1.00	0.99	0.09
9	16.00	13.3	5.0	20.00	1.00	0.99	0.08
10	18.00	14.3	5.2	20.00	1.00	0.99	0.08

15

1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
2	2.00	6.8	3.5	20.00	1.00	0.99	0.24
3	4.00	7.6	3.9	20.00	1.00	0.99	0.17
4	6.00	8.5	4.4	20.00	1.00	0.99	0.15
5	8.00	9.3	4.9	20.00	1.00	0.99	0.13
6	10.00	10.1	5.4	20.00	1.00	0.99	0.11
7	12.00	10.9	5.8	20.00	1.00	0.99	0.11
8	14.00	11.8	6.3	20.00	1.00	0.99	0.09
9	16.00	12.6	6.8	20.00	1.00	0.99	0.09
10	18.00	13.4	7.3	20.00	1.00	0.99	0.07
11	20.00	14.2	7.7	20.00	1.00	0.99	0.08

16

1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
2	2.00	6.7	3.7	20.00	1.00	0.99	0.26
3	4.00	7.3	4.3	20.00	1.00	0.99	0.18
4	6.00	8.0	5.0	20.00	1.00	0.99	0.17
5	8.00	8.7	5.7	20.00	1.00	0.99	0.13
6	10.00	9.4	6.4	20.00	1.00	0.99	0.13
7	12.00	10.0	7.0	20.00	1.00	0.99	0.11
8	14.00	10.7	7.7	20.00	1.00	0.99	0.11
9	16.00	11.4	8.4	20.00	1.00	0.99	0.10
10	18.00	12.0	9.0	20.00	1.00	0.99	0.10
11	20.00	12.7	9.7	20.00	1.00	0.99	0.09
12	22.00	13.4	10.4	20.00	1.00	0.99	0.09
13	24.00	14.1	11.1	20.00	1.00	0.99	0.08
14	26.00	14.7	11.7	20.00	1.00	0.99	0.08

17

1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
2	2.00	6.5	3.8	20.00	1.00	0.99	0.29

3	4.00	6.9	4.6	20.00	1.00	0.99	0.21
4	6.00	7.4	5.5	20.00	1.00	0.99	0.19
5	8.00	7.9	6.3	20.00	1.00	0.99	0.16
6	10.00	8.4	7.1	20.00	1.00	0.99	0.15
7	12.00	8.8	7.9	20.00	1.00	0.99	0.13
8	14.00	9.3	8.8	20.00	1.00	0.99	0.13
9	16.00	9.8	9.6	20.00	1.00	0.99	0.11
10	18.00	10.3	10.4	20.00	1.00	0.99	0.12
11	20.00	10.7	11.2	20.00	1.00	0.99	0.10
18							
1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
2	2.00	6.2	3.9	20.00	1.00	0.99	0.33
3	4.00	6.5	4.8	20.00	1.00	0.99	0.26
4	6.00	6.7	5.8	20.00	1.00	0.99	0.24
5	8.00	7.0	6.7	20.00	1.00	0.99	0.20
6	10.00	7.2	7.6	20.00	1.00	0.99	0.19
7	12.00	7.5	8.5	20.00	1.00	0.99	0.17
8	14.00	7.7	9.4	20.00	1.00	0.99	0.17
9	16.00	8.0	10.3	20.00	1.00	0.99	0.15
10	18.00	8.2	11.3	20.00	1.00	0.99	0.15
19							
1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
2	2.00	6.0	3.9	20.00	1.00	0.99	0.39
3	4.00	6.0	4.9	20.00	1.00	0.99	0.32
4	6.00	6.0	5.8	20.00	1.00	0.99	0.30
5	8.00	6.0	6.8	20.00	1.00	0.99	0.27
6	10.00	6.0	7.7	20.00	1.00	0.99	0.24
7	12.00	6.0	8.7	20.00	1.00	0.99	0.24
8	14.00	6.0	9.6	20.00	1.00	0.99	0.21
9	16.00	6.0	10.6	20.00	1.00	0.99	0.21
10	18.00	6.0	11.5	20.00	1.00	0.99	0.18
20							
1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
2	2.00	5.8	3.9	20.00	1.00	0.99	0.45
3	4.00	5.5	4.8	20.00	1.00	0.99	0.41
4	6.00	5.3	5.8	20.00	1.00	0.99	0.36
5	8.00	5.0	6.7	20.00	1.00	0.99	0.36
6	10.00	4.8	7.6	20.00	1.00	0.99	0.33
7	12.00	4.5	8.5	20.00	1.00	0.99	0.33
8	14.00	4.3	9.4	20.00	1.00	0.99	0.33
9	16.00	4.0	10.3	20.00	1.00	0.99	0.31
10	18.00	3.8	11.3	20.00	1.00	0.99	0.30
21							
1	0.00	6.0	3.0	ORTHOGONAL	ORIGIN		
2	2.00	5.5	3.9	20.00	1.00	0.99	0.53
3	4.00	5.1	4.6	20.00	1.00	0.99	0.52
4	6.00	4.6	5.5	20.00	1.00	0.99	0.52
5	8.00	4.1	6.3	20.00	1.00	0.99	0.52
6	10.00	3.6	7.1	20.00	1.00	0.99	0.51
7	12.00	3.2	7.9	20.00	1.00	0.99	0.51
8	14.00	2.7	8.8	20.00	1.00	0.99	0.51
9	16.00	2.2	9.6	20.00	1.00	0.99	0.51
22							