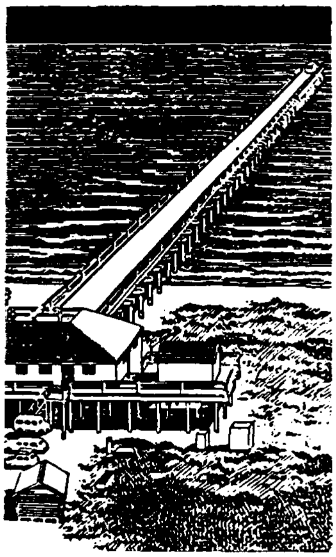
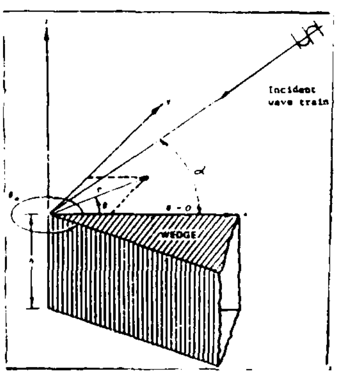
US Army Corps of Engineers





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TECHNICAL REPORT CERC-88-9

COMBINED DIFFRACTION AND REFLECTION BY A VERTICAL WEDGE: PCDFRAC USER'S MANUAL

by

James M. Kaihatu, H. S. Chen

Coastal Engineering Research Center

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This report discusses a method for determining the combined diffraction and reflection of monochromatic incident water waves by a vertical wedge of arbitrary wedge angle. The mathematical formulation of the physical problem is briefly presented as well as the analytical solution, although details of the solution are omitted. In addition, the computer program PCDFRAC, which is a PC version of WEDGE, is outlined. The program, which is designed for use with an IBM or IBM-compatible personal computer, calculates the wave height amplification factors necessary for the modification of incident wave heights due to diffraction and reflection. It also calculates the phase of the amplified wave as well as the wave length (based on the Pade approximation of the linear dispersion relation). Program inputs are incident wave period and direction, water depth near the wedge, the internal angle of the wedge (or wedge angle), and the locations where amplification factors and phase are required.

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Bessel function	Semi-infinite breakwater	Wave reflection
Interactive operation	Vertical wedge	Wedge angle

PREFACE

The work in this report was authorized by the US Army Corps of Engineers (USACE), Coastal Engineering Functional Area of Civil Works Research and Development, under Waves at Entrances Work Unit 31673, Harbor Entrances and Coastal Channels Program, at the Coastal Engineering Research Center (CERC) of the US Army Engineer Waterways Experiment Station (WES). Messrs. John H. Lockhart, Jr., John G. Housley, James Crews, and Charles W. Hummer were USACE Technical Monitors. Dr. Charles L. Vincent is CERC Program Manager.

This report was prepared by Mr. James M. Kaihatu, Research Hydraulic Engineer, and Dr. H. S. Chen, Research Hydraulic Engineer, Coastal Oceanography Branch (CR-O), Research Division (CR), CERC. Work was performed under direct supervision of Dr. Edward F. Thompson, Chief, CR-O, and Mr. H. Lee Butler, Chief, CR, CERC. Chief and Assistant Chief, CERC, are Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., respectively. This report was edited by Ms. Shirley A. J. Hanshaw, Information Products Division, Information Technology Laboratory, WES.

During publication of this report, COL Dwayne G. Lee, EN, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
feet per second squared	0.3048	metres per second squared
inches	2.54	centimetres

COMBINED DIFFRACTION AND REFLECTION BY A VERTICAL WEDGE

PCDFRAC USER'S MANUAL

PART I: INTRODUCTION

Background

1. In coastal/ocean engineering practice it is often important to be able to determine the wave heights near such marine structures as jetties, breakwaters, platforms, and docks. Such information aids engineers in evaluating their marine structure designs, especially in the areas of energy transmissibility, sediment transport, and structural strength. Wave heights in the near field have usually been presented in the form of dimensionless wave amplification factors which are defined as the ratio of near field wave height to incident wave height.

2. Early studies (Wiegel 1962) presented a dimensionless graphical solution for diffraction by a semi-infinite breakwater. Subsequently, these diagrams have been incorporated into every edition of the Shore Protection Manual (SPM) (1984), and they remain useful tools for preliminary engineering design. However, the diagrams cannot account for wave reflection from the breakwater.

3. Chen (1987) has recently presented an analytical solution for the total wave field due to combined diffraction and reflection by a vertical wedge of arbitrary wedge angle, as well as the FORTRAN program WEDGE, which calculates the amplification factors and the phases of the waves in the near field. Solutions for 0- and 90-deg wedge angle, presented in amplification factor diagrams, are also included. WEDGE was designed to operate on a conventional mainframe computer.

4. The FORTRAN program PCDFRAC is a version of WEDGE which is operable on an IBM or IBM-compatible personal computer (PC). It can be used to calculate wave amplification factors due to combined diffraction and reflection near jettied harbor entrances, quay walls, and other such structures. Jetties and breakwaters can be approximated by a semi-infinite breakwater in which the wedge angle is equal to zero. Corners of docks and quay walls can be represented by setting the wedge angle equal to 90 deg. Additionally, such natural

diffracting and reflecting obstacles as rocky headlands can be approximated by setting a particular value for the wedge angle.

Objective

5. The problem of determining wave heights near marine structures has been recognized for some time, and it is made more complex by the combination of water wave diffraction and reflection effects present near such structures. Consequently, a method must be developed to not only solve the physical problem but also accommodate the needs of various users in a flexible and effective manner. This report addresses this problem by summarizing an analytical solution for the diffraction and reflection of monochromatic incident waves caused by a vertical wedge. It also presents PCDFRAC which calculates the analytical solution to the combined diffraction and reflection problem. The PC code makes the solution much more available to users than did the mainframe version.

6. The objectives of this report are to:

a. Document the program PCDFRAC.

b. Instruct the user (Corps or non-Corps) in the proper application of the program in field situations and in the interpretation of results.

c. Instruct the user in setting up PCDFRAC in a personal computer and to run the code.

d. Present the user with relevant examples of program execution.

Report Organization

7. The report herein is organized as follows:

a. Part I - introduction containing background, objectives, and program availability.

b. Part II - brief theoretical outline of the basis of the model.

c. Part III - details of the model, including program convention and required equipment for proper program execution.

d. Part IV - procedures for installing the program onto a personal computer.

e. Part V - program execution and usage examples.

Program Availability

8. The program PCDFRAC calculates wave heights due to diffraction and reflection by a vertical wedge of arbitrary wedge angle in constant water depth, including the zero wedge angle (semi-infinite breakwater) case. It also calculates the wavelength from the linear dispersion relation by using a Pade approximation (Chen and Thompson 1985). It can be used on an IBM or IBM-compatible personal computer and is available on 5-1/4-in.* floppy diskette in Microsoft FORTRAN 77. The diskette contains the source code PCDFRAC.FOR and the executable file PCDFRAC.EXE as well as sample input and output files. It can be obtained directly from the authors at the following address: Coastal Oceanography Branch, Research Division, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, PO Box 631, Vicksburg, MS 39180-0631.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

PART II: THEORETICAL BACKGROUND

9. This part of the report summarizes the linear formulation and solution of water wave diffraction and reflection by a vertical wedge of arbitrary wedge angle, with a semi-infinite breakwater considered a special case in which the wedge angle is zero. Water depth h* is constant, the bottom is rigid and impermeable, and the monochromatic incident waves of infinitesimal amplitude come from infinity at an angle α. The cylindrical coordinate system (r, θ, z) is chosen, with $z = 0$ representing the undisturbed free surface and the positive z-axis positioned vertically upward. The tip of the wedge is chosen to be the origin of the coordinate system, and the two rigid walls of the wedge are at $\theta = 0$ and $\theta = \theta_o$, respectively, as shown in Figure 1. Cartesian coordinates (x, y, z), corresponding to the cylindrical coordinates, are also used on occasion and are shown in the same figure. The wedge angle is thus defined as $2\pi - \theta_o$, while the water domain is defined as $0 \leqq \theta \leqq \theta_o$ and $0 \geqq z \geqq -h$.

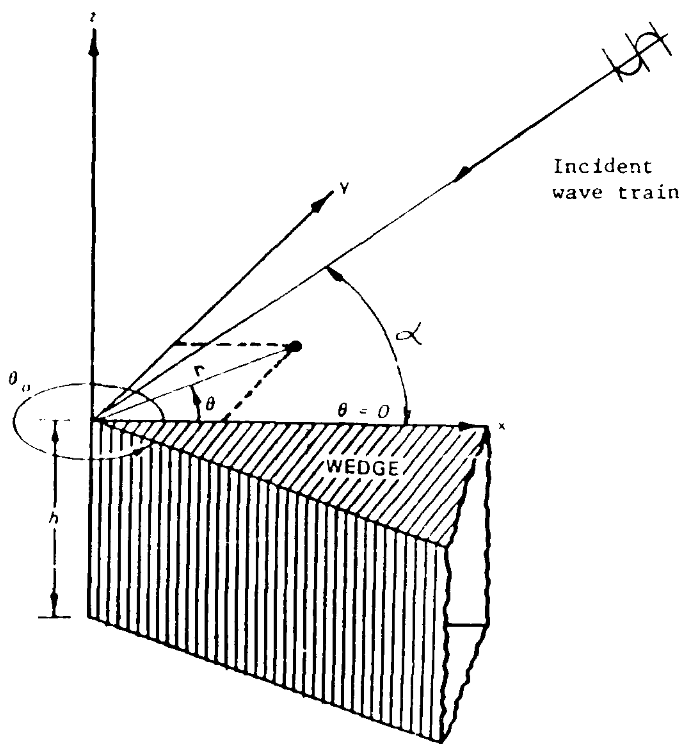

Figure 1. A vertical wedge of arbitrary angle

* For convenience, symbols and abbreviations are listed in the Notation (Appendix C).

10. For the problem at hand, the velocity field for wave motion in an ideal fluid may be represented by the velocity potential $\Phi(r,\theta,z,t)$ and is expressed as follows:

$$\Phi(r,\theta,z,t) = A_o \frac{\cosh k(z + h)}{\cosh kh} \phi(r,\theta) e^{i\omega t} \qquad (1)$$

where

$A_o = -iga_o/\omega$

$i = \sqrt{-1}$

g = gravitational acceleration

a_o = incident wave amplitude

ω = radian frequency

k = wave number

$\phi(r,\theta)$ = velocity potential function in the horizontal plane

t = time variable

The wave number k must be real and satisfy the following linear dispersion relation:

$$\omega^2 = gk \tanh kh \qquad (2)$$

11. Several properties of wave mechanics are dependent on the velocity potential component $\phi(r,\theta)$. For example, the free surface elevation η may be expressed in terms of $\phi(r,\theta)$ as follows:

$$\eta = a_o \phi(r,\theta) e^{i\omega t} \qquad (3)$$

The flow velocity u is also dependent on $\phi(r,\theta)$. This quantity is important in the area of sediment transport and may be expressed in polar coordinates as follows:

$$u_r = \frac{\partial\Phi}{\partial r} = A_o \frac{\cosh k(z + h)}{\cosh kh} \frac{\partial\phi}{\partial r} e^{i\omega t} \qquad (4)$$

$$u_\theta = \frac{1}{r} = \frac{\partial\Phi}{\partial\theta} = A_o \frac{\cosh k(z + h)}{\cosh kh} \frac{1}{r} \frac{\partial\phi}{\partial r} e^{i\omega t} \qquad (5)$$

where the subscripts r and θ refer to the r- and θ-directions. The absolute values of u_r and u_θ are the maximum flow velocities for each component direction, while the phases of u_r and u_θ contain the wave phase information. It is clear, then, that the solution to Equation 1, as well as to Equations 3 through 5, lies in finding $\phi(r,\theta)$.

12. For an incident plane wave train coming from the α direction (as shown in Figure 1) where the free surface elevation of the incident wave may be described by:

$$\eta_i = a_o e^{i(kr \cos \alpha + \omega t)} \tag{6}$$

the analytical solution for a wave field by a vertical wedge of arbitrary wedge angle (based on the linearized wave theory) may be written as follows (Chen 1987):

$$\varphi(r,\theta) = \frac{2}{\nu}\left[J_o(kr) + 2 \sum_{n=1}^{\infty} e^{in\pi/2\nu} J_{n/\nu} \cos \frac{n\alpha}{\nu} \cos \frac{n\theta}{\nu}\right] \tag{7}$$

where

$$\nu = \theta_o/\pi \tag{8}$$

J_o = zeroth order Bessel function of the first kind

$J_{n/\nu}$ = n/ν order Bessel function of the first kind

The semi-infinite breakwater is a special case of the diffraction and reflection problem where the wedge angle is equal to zero and $\nu = 2$. The solution of Equation 1 for this case is

$$\phi(r,\theta) = J_o(kr) + 2 \sum_{n=1}^{\infty} e^{in\pi/4} \frac{Jn}{2} \cos \frac{n\alpha}{2} \cos \frac{n\theta}{2} \tag{9}$$

The velocity potential function $\phi(r,\theta)$ in Equations 7 and 9 is a complex function and may be expressed as

$$\phi = |\phi| e^{i\beta} \tag{10}$$

where

$$|\phi| = \left[Im(\phi)\right]^2 + \left[Re(\phi)\right]^2 = amplitude\ of\ \ \phi \tag{11}$$

$$\beta = \tan^{-1}\left[\frac{Im(\phi)}{Re(\phi)}\right] = \text{phase of } \ \phi \tag{12}$$

and where

Im ϕ = imaginary part of ϕ

Re ϕ = real part of ϕ

Substituting Equation 10 into Equation 3, the following is obtained:

$$\eta = a_o |\phi| e^{i(\beta + \omega t)} \tag{13}$$

This expression represents the actual water surface elevation at a point in the water domain bounded by a vertical wedge of arbitrary wedge angle. Since the incident wave train is expressed in Equation 6, the normalized water surface elevation in the near field may be expressed as

$$\frac{\eta}{\eta_i} = |\phi| e^{i(\beta - kr \cos \alpha)} \tag{14}$$

where η_i is the incident free surface elevation. It is clear that the term $|\phi| e^{i(\beta - kr \cos \alpha)}$ is a factor which modifies the incident wave elevation to account for reflection and diffraction effects; thus, the amplitude of the normalized surface elevations may be expressed as the following wave amplitude factor:

$$\left|\frac{\eta}{\eta_i}\right| = |\phi| \tag{15}$$

The phase of Equation 14 is the following phase difference between incident and amplified waves:

$$\text{Phase of } \frac{\eta}{\eta_i} = \beta - kr \cos \alpha \tag{16}$$

13. Output of the program PCDFRAC is comprised of $|\phi|$ and β. The amplification factor $|\phi|$ would then be multiplied by the incident wave height to obtain the actual wave height. The phase of the amplified wave β is a quantity not usually required in engineering practice; however, it may be useful on some occasions.

PART III: PCDFRAC OPERATIONAL DETAILS

Program Characteristics

14. The program PCDFRAC has been developed specifically for the problem of water wave diffraction and reflection from a vertical wedge of arbitrary wedge angle. It has been designed for operation on an IBM or IBM-compatible PC. A thin, rigid, impermeable semi-infinite breakwater is a special case in which the wedge angle is equal to zero. The program language is FORTRAN 77. The source code, PCDFRAC.FOR, requires 114 Kb of space, while the executable file, PCDFRAC.EXE, uses 74 Kb.

Input and Output

15. The program is divided into several parts. The first part is the main program PCDFRAC, with which the user works directly. It calls the solving subroutines and prints the answers in usable form. It also calculates wavelength from the input wave period by the Pade approximation to the linear dispersion relation (Chen and Thompson 1985). The subroutine PCWEDGES solves the actual problem and uses the mathematical subroutines BESJ, JAIRY, and GAMLN which are borrowed from the Naval Surface Weapons Center (NSCW) Library of Mathematics Subroutines (Morris 1984). Only the main program PCDFRAC and the subroutine PCWEDGES are listed in Appendix B. The main code of PCDFRAC is similar to that of WEDGE (See Chen 1987).

16. Inputs into the program are as follows:

- a. Constant water depth D, in feet.
- b. Period T of the incident wave, in seconds.
- c. Approach angle WAVEA of the incident wave, in degrees counter-clockwise from the positive X-axis.
- d. Wedge angle WEDGEA of the obstacle, in degrees. A default of the program allows the semi-infinite breakwater case (WEDGEA = 0.0 deg) to be run.
- e. Location X,Y of the desired calculation, in feet from the tip of the wedge.

Figure 2 shows the preceding input conventions.

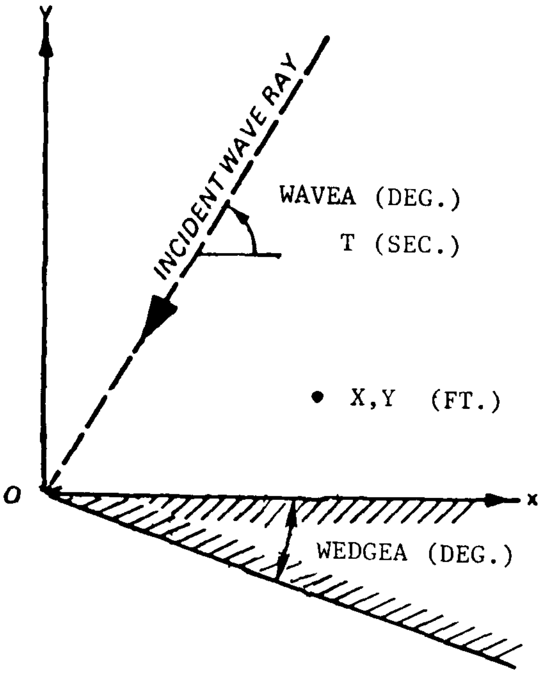

Figure 2. Input conventions for program PCDFRAC

17. The program outputs are:

   a. Wavelength L , in feet.

   b. Wave amplification factor $|\phi|$ as given in Equation 11, which is the ratio of wave height to incident wave height.

   c. Wave phase β as given in Equation 12, in radians.

18. The program may be run either interactively (i.e., working directly with the user), or as a batch job (where the data is read from a file). These features will be discussed in further detail in Part V.

19. Equations 7 and 9 showed a summation of an infinite number of terms. This summation has been accommodated in the program by carrying the summation out to a term followed by eight successive terms in which the absolute value of the Bessel function is 10^{-8} or less. If the value of the solution is of the order of one, this corresponds to a truncation error of 10^{-8} or less.

20. For values of R/L (radial distance to point of calculation divided by wavelength) greater than 16, the statement "NO. OF TERMS FOR SUMMATION IS INSUFFICIENT" may appear. This statement indicates that the number of terms in the summation is insufficient to ensure the 10^{-8} truncation error and that the NN value in the PARAMETER statement in the subroutine PCWEDGES needs to be greater than the present value of 200 if accuracy is to be

maintained. In this case, the user should change NN from 200 to a larger value.

21. A program of this length would require a certain amount of run time on a PC. Tables A1 and A2 (located in Appendix A) give run times (in seconds) for various values of the truncation error and R/L ratio. The times indicated are the lengths of time the computer would require to process one set of (x,y) coordinates for one incident wave angle and one incident wave period (on the order of seconds). It follows that the greater the truncation error allowed, the less time the computer would need to process one set of coordinates. It also follows that the greater the R/L ratio, the longer the computer would take to finish processing one set of coordinates, as more terms in the summation are required to ensure proper accuracy. Table A1 is a collection of run times using an IBM AT-class computer, while Table A2 is comprised of run times on an IBM XT computer.

Required Equipment

22. The source code PCDFRAC.FOR and the executable file PCDFRAC.EXE are contained on a floppy diskette which may be obtained upon user request. Additionally, the following equipment is either required or recommended:

a. An IBM or IBM-compatible personal computer with a hard disk and disk operating system (DOS).

b. A FORTRAN compiler (installed in the computer). Major differences between various brands of compilers are not expected; however, the compiler must accept the Fortran 77 language.

c. One 5-1/4 in. disk drive.

d. Printer (optional).

e. Text editor.

PART IV: START-UP PROCEDURES

Copying Program onto Hard Disk

23. As mentioned earlier in this report, an IBM or IBM-compatible personal computer with DOS is required to use this program. Although Microsoft DOS Version 2.10 was used for this copying procedure, major deviations among various brands of DOS are not expected. To perform this procedure the user must:

a. Insert the floppy disk into a particular disk drive, and switch the operating drive of the computer to the drive and directory containing the Fortran compiler. For Microsoft DOS this is done by typing

```
C:  CD/FORTRAN            <CR>
```

if the Fortran compiler were located in drive C and in directory FORTRAN. (The symbol <CR> denotes carriage return.)

b. Copy the program PCDFRAC.FOR onto the hard disk. For Microsoft DOS Version 2.10 this is done by typing

```
COPY A:  PCDFRAC.FOR      <CR>
```

if the disk were in drive A. Now the program PCDFRAC.FOR is copied onto the same disk and into the same directory as the FORTRAN compiler.

Compilation of Program

24. Compilation of a program translates the language in which the program is written (in this case, FORTRAN) into the internal machine language of the computer. The procedure here is that of the Ryan-McFarland Version 1.00 Fortran compiler; however, major discrepancies among various compilers are not expected. To compile the program, the user should type

```
PROFORT PCDFRAC/E         <CR>
```

and compilation will begin. With the Ryan-McFarland Version 1.00 compiler, the /E option added to the end of the file name will list any syntactical errors as they occur. There should be no errors.

25. Compiling the program on an IBM XT or XT-compatible computer takes about 12 min, primarily because of the length of the program. On an IBM AT or AT-compatible personal computer, compilation requires just over 4 min. When the compilation process is complete, the following message:

Compilation Complete: 0 Errors, 0 Warnings

should appear on the screen. An object file, PCDFRAC.OBJ, has been created as a result.

Linkage of Program

26. Linkage of the program with any external subroutines is done next. This is a necessary step with all programs, regardless whether any external subroutines are specified within the program. Linkage is done by typing

```
LINK PCDFRAC                 <CR>
```

The following will then print to the screen, one at a time (each to be answered with a carriage return):

```
RUN FILE [PCDFRAC.EXE]       <CR>
LIST FILE [NUL.MAP]          <CR>
LIBRARIES [.LIB]             <CR>
```

The above options actually refer to specific options in the linking process. These options are not directly involved with PCDFRAC and are not required for program execution. Linkage takes about 30-40 sec, regardless of the type of computer. After linkage, the usual computer prompt will appear, and an executable file, PCDFRAC.EXE, will have been created.

Execution of Program

27. The executable file, PCDFRAC.EXE, actually runs the program. If the user wished to use PCDFRAC without any intent to modify it, this file would be used exclusively. Additionally, no FORTRAN compiler is required to use PCDFRAC.EXE. To perform any modifications, however, the file PCDFRAC.FOR would be needed. If the program were modified in any way, it would need to be recompiled and relinked after the changes were completed. To execute the program the user should type

PCDFRAC <CR>

and the program will begin running.

PART V: PROGRAM EXECUTION

28. The program will offer the option of either operating directly with the user (interactive operation) or of reading and processing the data directly from an existing file (batch operation).

Interactive Option

29. The interactive option is recommended for users with a small amount of data. It is sequenced as follows:

   a. The program will first ask whether a written output is desired. If so, the user will input the file name to be used. The program contains a feature which will alert the user if the file name specified matches that of an existing file. If this occurs, the program will offer the user the option of either entering a new file name or of overwriting the existing file. (Note: Limited to a maximum of an eight-character string, the file name can have fewer characters. Some examples of eight-character strings include: FAST.DAT, DIFRACT1, and WAVES-10.)

   b. The program will then ask if the input data are stored in a file. Because the interactive option is to be used here, the answer is "no".

   c. The program will then ask if the user would require a particular value for the wedge angle or the semi-infinite breakwater case. If a value for the wedge angle is needed, it would be input (in degrees) during this step.

   d. The program will then request the following:

      Water depth, in feet.
      Incident wave period, in seconds.
      Incident wave angle, in degrees counter-clockwise from the positive x-axis.

   e. Next the program will ask for the number of points to be input on the present run.

   f. It will then ask for the (x,y) coordinates (in feet) of the desired points of calculation, one at a time.

   g. After all the points have been entered, it will then give the information in tabular form, including the input information. If the output were also written to a file, the user would be reminded of the file name.

30. In the example problem shown in Figure 3, it is desired to calculate the wave amplification factors at the locations shown, with the obstacle being a semi-infinite breakwater (wedge angle = 0.00). The interactive run for the example in Figure 3 is shown in Figure 4 with user input underlined. The resulting output is then sent to both the screen and any output file specified. It appears in Figure 5.

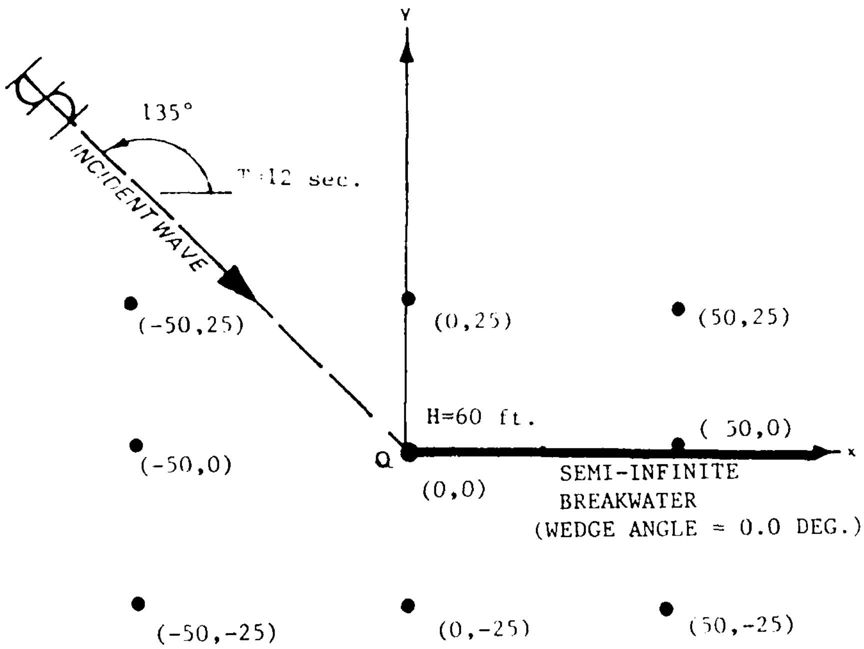

Figure 3. Example problem for semi-infinite breakwater

Explanation of Output

31. In the interactive output shown in Figure 5, the first three columns, as well as the fifth, sixth, and seventh columns, consist of user input which require no further explanation. The fourth column is the calculated wavelength. The last two columns comprise the primary solution, as given in Equations 11 and 12. AMP is the amplification factor for the incident wave. This number would be multiplied by the incident wave height to obtain the actual wave height at that particular (X,Y) location. PHA is the wave phase (in radians). This information is not usually required in most engineering applications but may be of use at times.

```
**********************************************************************
*                                                                    *
* "PCDFRAC" - A PROGRAM WHICH CALCULATES WAVE AMPLIFICATION FACTORS  *
* BASED ON THE COMBINED DIFFRACTION AND REFLECTION OF WAVES BY A     *
* VERTICAL WEDGE OF ARBITRARY WEDGE ANGLE. THE PROGRAM ALSO CALCU-   *
* LATES THE PHASE OF THE AMPLIFIED WAVE. THE PROGRAM WILL DEFAULT TO *
* ZERO WEDGE ANGLE (SEMI-INFINITE BREAKWATER CASE) IF NO WEDGE ANGLE *
* IS SPECIFIED.                                                      *
*                                                                    *
**********************************************************************

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

DO YOU WANT OUTPUT IN A FILE ? (0="NO", 1="YES") = 1

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

ENTER NAME OF OUTPUT FILE  = TESTI.OP

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

IS INPUT DATA LOCATED IN A FILE ? (0="NO",1="YES") = 0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

OPTION TO SET WEDGE ANGLE (DEFAULT VALUE = 0.00 DEG.)

SET WEDGE ANGLE ? (0="NO",1="YES") = 0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

SET INITIAL VALUES

INPUT WATER DEPTH (FT.) = 20

INPUT INCIDENT WAVE PERIOD (SEC.) = 8

INPUT INCIDENT WAVE ANGLE
(DEG. CCW FROM POSITIVE X - AXIS) = 135

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

HOW MANY POINTS DO YOU WISH TO ENTER (UP TO 99)? = 9

AT EACH PROMPT, DO THE FOLLOWING :
   1) TYPE IN X - COORDINATE
   2) TYPE A COMMA
   3) TYPE IN Y - COORDINATE
   4) PRESS "ENTER"

(X,Y) COORDINATES FOR POINT NO.  1  (FT.) = -50,25

(X,Y) COORDINATES FOR POINT NO.  2  (FT.) = 0,25

(X,Y) COORDINATES FOR POINT NO.  3  (FT.) = 50,25

(X,Y) COORDINATES FOR POINT NO.  4  (FT.) = -50,0

(X,Y) COORDINATES FOR POINT NO.  5  (FT.) = 0,0

(X,Y) COORDINATES FOR POINT NO.  6  (FT.) = 50,0

(X,Y) COORDINATES FOR POINT NO.  7  (FT.) = -50,-25

(X,Y) COORDINATES FOR POINT NO.  8  (FT.) = 0,-25

(X,Y) COORDINATES FOR POINT NO.  9  (FT.) = 50,-25
```

Figure 4. Interactive execution for problem in Figure 3

SEMI-INFINITE BREAKWATER (WEDGE ANGLE = 0.00 DEGREES)

DEPTH (FT)	PERIOD (SEC)	WAV.ANGLE (DEG)	WAVLNG. (FT)	WDG.ANG. (DEG)	X (FT)	Y (FT)	AMP	PHA (RAD)
20.00	8.00	135.00	190.00	0.00				
					-50.00	25.00	0.98	1.77
					0.00	25.00	1.04	0.45
					50.00	25.00	1.44	-0.81
					-50.00	0.00	1.00	1.17
					0.00	0.00	1.00	0.00
					50.00	0.00	1.69	-0.90
					-50.00	-25.00	1.03	0.59
					0.00	-25.00	0.86	-0.55
					50.00	-25.00	0.60	-2.18

YOUR OUTPUT IS IN TESTI.OP
Execution terminated : 0

C>

Figure 5. Solution to problem in Figure 3

32. Figure 6 is an example problem in which the diffracting obstacle is a dock with a 90-deg wedge angle. It is desired to calculate the wave amplification factors at the locations shown. The interactive run and the output are both similar to those of the example shown in Figure 3 and require no

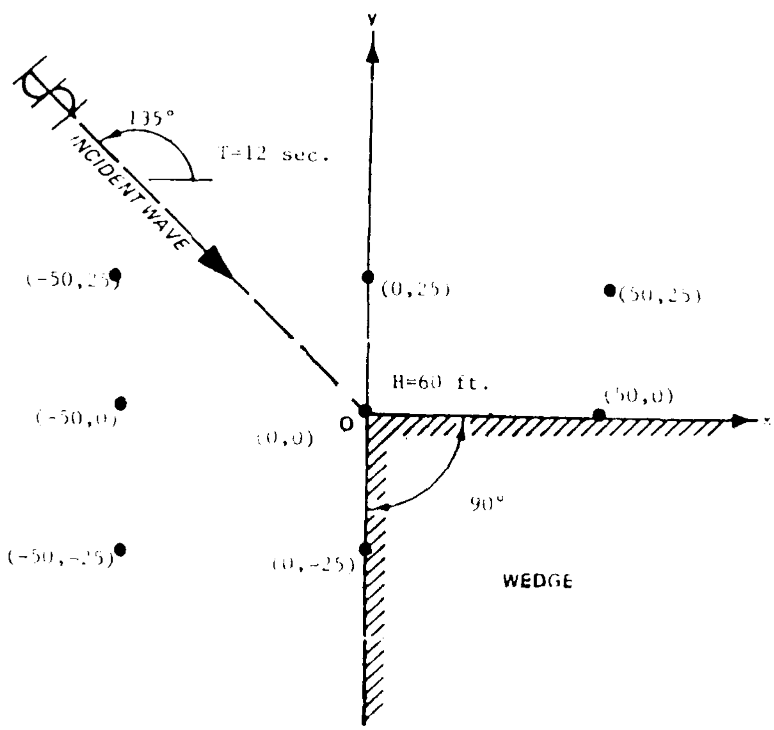

Figure 6. Example problem, 90-deg wedge

further explanation. The interactive run is shown in Figure 7, while the corresponding output is shown in Figure 8.

Batch Option

33. The batch operation is recommended for calculation of a large number of points or if the user requires calculatiors with several values of wave period, incident wave angle, and/or wedge angle. The batch operation is sequenced as follows:

a. The user will first create the file. An example appears in a following subsection. (Note: The file name must be kept to a maximum of eight characters, as before.)

b. The program will ask if a written output file is desired. If it is, the user will enter the name of the output file. As before, the program will alert the user if the chosen output file name matches that of an existing file. If so, the user will have tne option of either overwriting the file, or enter a new file name.

c. It will then ask if the data are located in a file. Because batch operation is desired, the answer input by the user would be "yes".

d. It will then request the input file name.

e. As it calculates, it will print the results to the screen in tabular form. If a written file was requested, it will write to the file in the same format.

f. When completed, it will ask the user if any additional files need to be processed. If so, the user will input the name of the file.

g. The entire sequence is then repeated until there are no more input files left to process.

34. The input file for the batch job requires a specific format and can be created with any compatible text editor. The input file in Figure 9 contains data for the example problems in Figures 3 and 6. There is a limit of 300 values of X and Y which can be processed in one batch job. However, a greater number of values can be processed by changing the value of 300 in the DIMENSION statement in program PCDFRAC.FOR to a higher value. To create an input file, the following information is used:

a. Line 1 - D,T,WAVFA,WEDGEA

The water depth, incident wave period, incident wave angle and wedge angle are input here. D appears in columns 1-10, T in columns 11-20, WAVEA in columns 21-30, and WEDGEA in

```
**********************************************************************
*                                                                    *
* "PCDFRAC" - A PROGRAM WHICH CALCULATES WAVE AMPLIFICATION FACTORS  *
* BASED ON THE COMBINED DIFFRACTION AND REFLECTION OF WAVES BY A     *
* VERTICAL WEDGE OF ARBITRARY WEDGE ANGLE. THE PROGRAM ALSO CALCU-   *
* LATES THE PHASE OF THE AMPLIFIED WAVE. THE PROGRAM WILL DEFAULT TO *
* ZERO WEDGE ANGLE (SEMI-INFINITE BREAKWATER CASE) IF NO WEDGE ANGLE *
* IS SPECIFIED.                                                      *
*                                                                    *
**********************************************************************

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
DO YOU WANT OUTPUT IN A FILE ? (0="NO", 1="YES") = 1

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
ENTER NAME OF OUTPUT FILE  = TESTI.OP

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
IS INPUT DATA LOCATED IN A FILE ? (0="NO",1="YES") = 0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
OPTION TO SET WEDGE ANGLE (DEFAULT VALUE = 0.00 DEG.)

SET WEDGE ANGLE ? (0="NO",1="YES") = 1

ENTER WEDGE ANGLE (DEG.) = 90

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
SET INITIAL VALUES

INPUT WATER DEPTH (FT.) = 20

INPUT INCIDENT WAVE PERIOD (SEC.) = 8

INPUT INCIDENT WAVE ANGLE
(DEG. CCW FROM POSITIVE X - AXIS) = 135

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

HOW MANY POINTS DO YOU WISH TO ENTER (UP TO 99)? = 8

AT EACH PROMPT, DO THE FOLLOWING :
   1) TYPE IN X - COORDINATE
   2) TYPE A COMMA
   3) TYPE IN Y - COORDINATE
   4) PRESS 'ENTER'

 (X,Y) COORDINATES FOR POINT NO.  1  (FT.) = -50,25

 (X,Y) COORDINATES FOR POINT NO.  2  (FT.) = 0,25

 (X,Y) COORDINATES FOR POINT NO.  3  (FT.) = 50,25

 (X,Y) COORDINATES FOR POINT NO.  4  (FT.) = -50,0

 (X,Y) COORDINATES FOR POINT NO.  5  (FT.) = 0,0

 [illegible]

 (X,Y) COORDINATES FOR POINT NO.  7  (FT.) = -50,-25

 (X,Y) COORDINATES FOR POINT NO.  8  (FT.) = 0,-25
```

Figure 7. Interactive execution for problem in Figure 6

```
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
OBSTACLE IS A VERTICAL WEDGE OF ANGLE  90.00 DEGREES

  DEPTH   PERIOD  WAV.ANGLE WAVLNG.WDG.ANG.    X        Y      AMP     PHA
  (FT)    (SEC)    (DEG)     (FT)   (DEG)     (FT)     (FT)            (RAD)
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  20.00    8.00   135.00   190.00  90.00
                                            -50.00    25.00   0.90    1.94
                                              0.00    25.00   1.01    0.30
                                             50.00    25.00   1.43   -0.87
                                            -50.00     0.00   0.75    1.18
                                              0.00     0.00   1.33    0.00
                                             50.00     0.00   1.71   -0.95
                                            -50.00   -25.00   0.75    0.35
                                              0.00   -25.00   1.53   -0.41

YOUR OUTPUT IS IN TESTI.OP
Execution terminated : 0


C>
```

Figure 8. Solution to problem in Figure 6

```
   20.00      8.00    135.00    90.00
    0.00    -25.00
  -50.00    -25.00
   50.00      0.00
    0.00      0.00
  -50.00      0.00
   50.00     25.00
    0.00     25.00
   50.00     25.00                              1
   20.00      8.00    135.00
   50.00    -25.00
    0.00    -25.00
  -50.00    -25.00
   50.00      0.00
    0.00      0.00
  -50.00      0.00
   50.00     25.00
    0.00     25.00
  -50.00     25.00                              1
```

Figure 9. Sample input data file for Figures 3 and 6

columns 31-40. If the semi-infinite breakwater case is to be run, the input field for WEDGEA can be left blank.

b. <u>Line 2 - X,Y,END</u>

The location of the calculation is input on each line. X is input in columns 1-10, Y in columns 11-20, and END in column 50. END is an end-of-file marker alerting the computer that that particular line is the last line of X,Y data for the particular values of D, T, WAVEA, and WEDGEA. To denote the end of X,Y data, the user should enter 1 for END. Otherwise, the input field may be left blank. Successive sets of D, T, WAVEA, and WEDGEA data can then be entered, along with their corresponding sets of X,Y data.

35. The execution of the data file in Figure 9 is shown in Figure 10 with the user input underlined. Figure 11 shows the resultant output.

```
***********************************************************************
*                                                                     *
* "PCDFRAC" - A PROGRAM WHICH CALCULATES WAVE AMPLIFICATION FACTORS   *
* BASED ON THE COMBINED DIFFRACTION AND REFLECTION OF WAVES BY A      *
* VERTICAL WEDGE OF ARBITRARY WEDGE ANGLE. THE PROGRAM ALSO CALCU-    *
* LATES THE PHASE OF THE AMPLIFIED WAVE. THE PROGRAM WILL DEFAULT TO  *
* ZERO WEDGE ANGLE (SEMI-INFINITE BREAKWATER CASE) IF NO WEDGE ANGLE  *
* IS SPECIFIED.                                                       *
*                                                                     *
***********************************************************************

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
DO YOU WANT OUTPUT IN A FILE ? (0="NO", 1="YES") = 1

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
ENTER NAME OF OUTPUT FILE  = TESTB.OP

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
IS INPUT DATA LOCATED IN A FILE ? (0="NO",1="YES") = 1

ENTER NAME OF INPUT FILE = TESTB.IP
```

Figure 10. User input for execution of file in Figure 9

```
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
INPUT FILE = TESTB.IP
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 DEPTH    PERIOD   WAV.ANGLE  WAVLNG.WDG.ANG.    X         Y       AMP      PHA
 (FT)     (SEC)     (DEG)      (FT)   (DEG)    (FT)      (FT)              (RAD)
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 20.00     3.00     135.00    190.00  90.00
                                                0.00    -25.00    1.53    -0.41
                                              -50.00    -25.00    0.75     0.35
                                               50.00      0.00    1.71    -0.95
                                                0.00      0.00    1.33     0.00
                                              -50.00      0.00    0.75     1.18
                                               50.00     25.00    1.43    -0.87
                                                0.00     25.00    1.01     0.30
                                              -50.00     25.00    0.90     1.94
 20.00     8.00     135.00    190.00   0.00
                                               50.00    -25.00    0.60    -2.18
                                                0.00    -25.00    0.86    -0.55
                                              -50.00    -25.00    1.03     0.59
                                               50.00      0.00    1.69    -0.90
                                                0.00      0.00    1.00     0.00
                                              -50.00      0.00    1.00     1.17
                                               50.00     25.00    1.44    -0.81
                                                0.00     25.00    1.0[illegible]  0.45
                                              -50.00     25.00    0.98     1.77

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
YOUR OUTPUT IS IN TESTB.OP

DO YOU HAVE ANOTHER INPUT FILE ? (0="NO",1="YES") = 0

Execution terminated : 0

C>
```

Figure 11. Output for execution of sample input file in Figure 9

PART VI: SUMMARY

36. A brief theoretical outline of wave diffraction and reflection by a vertical wedge of arbitrary wedge angle has been presented. A personal computer code, PCDFRAC, which is a PC version of WEDGE (Chen 1987), has been implemented for calculating the wave amplification factors necessary to obtain wave heights in the near field of the vertical wedge due to diffraction and reflection.

37. The necessary procedures for setting up PCDFRAC on a personal computer have been documented in detail. Input and output files have also been described in detail. Possible applications of the program in field situations have been discussed and the execution of the program outlined in sequential order. Instructive examples of the execution of PCDFRAC have also been presented.

REFERENCES

Chen, H. S. 1987. "Combined Reflection and Diffraction by a Vertical Wedge," Technical Report CERC-87-16, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

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Morris, A. H., Jr. 1984 (Jun). "NSWC Library of Mathematics Subroutines," NSWC TR 84-143, Strategic Systems Department, Naval Surface Weapons Center, Dahlgren, Va.

Shore Protection Manual. 1984. 4th ed., 2 vols, US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, US Government Printing Office, Washington, DC.

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APPENDIX A: RUN TIMETABLES

Table A1

Run Time* Versus Summation Truncation Error

IBM AT-Class

R/L Ratio	Truncation Error E-08	E-06	E-04
1.0	0.82	0.70	0.59
2.0	2.42	2.26	1.98
3.0	2.56	2.28	2.06
4.0	2.72	2.31	2.10
5.0	3.29	2.85	2.46
6.0	3.41	3.06	2.71
7.0	3.91	3.46	3.08
8.0	4.29	3.88	3.37
9.0	4.84	4.28	3.83
10.0	5.20	4.70	4.10

* In seconds.

Table A2

Run Time* Versus Summation Truncation Error

IBM XT

R/L Ratio	Truncation Error E-08	E-06	E-04
1.0	2.15	1.65	1.49
2.0	4.20	4.11	3.03
3.0	4.85	4.76	4.29
4.0	5.65	5.08	4.32
5.0	5.85	5.10	4.38
6.0	6.04	5.65	4.50
7.0	7.04	6.04	5.50
8.0	7.25	6.60	5.97
9.0	8.14	6.87	6.10
10.0	8.95	7.66	7.17

* In seconds.

APPENDIX B: PARTIAL LISTING OF PROGRAM PCDFRAC

```
      PROGRAM PCDFRAC
C     ***************************************************
C     *This program calculates wave amplification factors*
C     *for the combined diffraction and reflection of    *
C     *monochromatic incident waves of infinitesimal     *
C     *amplitude coming from infinity by a vertical wedge*
C     *of arbitrary wedge angle. It also calculates the  *
C     *phase of the amplified wave. The program will     *
C     *default to a zero wedge angle (semi-infinite      *
C     *breakwater) if no wedge angle is specified.       *
C     ***************************************************
C
C     Initialize and dimension variables
C
      COMPLEX F
      REAL L,PI,PI2
      INTEGER END
      CHARACTER*8 OUTFILE
      CHARACTER*8 INFILE
      LOGICAL EXST
      DIMENSION X(300),Y(300),FABS(300),FPHA(300)
      PI=3.14159
      PI2=2.*PI
      WEDGEA=0.0
      ICOUNT = 0.0
C
C     Program introduces itself
C
      WRITE (*,*)'                              '
      PRINT 8001
8001  FORMAT(1X,70('*'))
      PRINT 8002
8002  FORMAT (1X,'*',68X,'*')
      PRINT 8003
8003  FORMAT (1X,'* "PCDFRAC" - A PROGRAM WHICH CALCULATES WAVE'
     1 ,1X,'AMPLIFICATION FACTORS  *')
      PRINT 8004
8004  FORMAT (1X,'* BASED ON THE COMBINED DIFFRACTION AND REFLECTION'
     1 ,1X,'OF WAVES BY A      *')
      PRINT 8005
8005  FORMAT (1X,'* VERTICAL WEDGE OF ARBITRARY WEDGE ANGLE. THE'
     1 ,1X,'PROGRAM ALSO CALCU-    *')
      PRINT 8006
8006  FORMAT (1X,'* LATES THE PHASE OF THE AMPLIFIED WAVE. THE PROGRAM'
     1 ,1X,'WILL DEFAULT TO *')
      PRINT 8007
8007  FORMAT (1X,'* ZERO WEDGE ANGLE (SEMI-INFINITE BREAKWATER CASE)'
     1 ,1X,'IF NO WEDGE ANGLE *')
      PRINT 8008
8008  FORMAT (1X,'* IS SPECIFIED.',54X,'*')
      PRINT 8002
      PRINT 8001
      WRITE(*,*)'                               '
C
C     Set option for writing output into file
```

```
C
991   PRINT 2199
2199  FORMAT (36(' -'))
      PRINT *,'DO YOU WANT OUTPUT IN A FILE ? (0="NO", 1="YES") = '
      READ *, MM
      IF (MM .NE. 1 .AND. MM .NE. 0) GOTO 991
      IF (MM .EQ. 0) GOTO 993
      PRINT 2199
614   PRINT *,'ENTER NAME OF OUTPUT FILE  = '
      READ (*,'(A)') INFILE
      INQUIRE (FILE=INFILE,EXIST=EXST)
      IF (EXST .EQV. .TRUE.) THEN
613   PRINT *,'FILE ALREADY EXISTS; SELECT ONE OF THE FOLLOWING:'
      PRINT *,'               '
      PRINT 615
615   FORMAT(1X,'0=ENTER ANOTHER FILE NAME ; 1=OVERWRITE OLD'
     1 ,1X,'FILE WITH NEW DATA')
      PRINT *,'              '
      PRINT *,'OPTION ? = '
      READ *,ANS
      IF (ANS .NE. 0 .AND. ANS .NE. 1) GOTO 613
      IF (ANS .EQ. 1) THEN
      OPEN (2,FILE=INFILE,STATUS='UNKNOWN')
      ELSE
      GOTO 614
      END IF
      END IF
      OPEN (2,FILE=INFILE,STATUS='NEW')
      WRITE (2,2201) INFILE
2201  FORMAT (1X,'OUTPUT OF PROGRAM "PCWEDGE" - FILENAME IS ',A8)
993   IF (ICOUNT .NE. 0.00) GOTO 998
C
C     Set Option for Interactive or Batch operation
C
      PRINT 2199
      PRINT *,'IS INPUT DATA LOCATED IN A FILE ? (0="NO",1="YES") = '
      READ *, NN
      IF (NN .NE. 0 .AND. NN .NE. 1) GOTO 993
      IF (NN .EQ. 0) GOTO 600
C
C     Batch Operation Option
C
      PRINT*,'ENTER NAME OF INPUT FILE = '
      READ (*,'(A)')OUTFILE
      OPEN (1,FILE=OUTFILE,STATUS='OLD')
998   KCOUNT=0.00
      PRINT 2199
      WRITE (2,2199)
      PRINT 2143,OUTFILE
      WRITE (2,2143) OUTFILE
2143  FORMAT(1X,'INPUT FILE = ',A8)
C
C     Read the file - can have multiple values of h,t,wavea, and wedgea
C
      K=1
```

```
1001  READ (1,2100,END=999) D,T,WAVEA,WEDGEA
2100  FORMAT(4F10.2)
      IF (D .LT. 0.00) THEN
      PRINT*,'WATER DEPTH CANNOT BE NEGATIVE. EXECUTION STOPPED.'
      PRINT*,'PLEASE CORRECT INPUT FILE AND RE - RUN.'
      GOTO 700
      ELSE
      END IF
      IF (T .LT. 0.00) THEN
      PRINT*,'WAVE PERIOD CANNOT BE NEGATIVE. EXECUTION STOPPED.'
      PRINT*,'PLEASE CORRECT INPUT FILE AND RE - RUN.'
      GOTO 700
      ELSE
      END IF
      IF (WEDGEA .LT. 0.00 .OR. WEDGEA .GT. 180.00) THEN
      PRINT *,'WEDGE ANGLE MUST BE BETWEEN 0.0 AND 180.0 DEGREES.'
      PRINT *,'EXECUTION STOPPED.'
      PRINT *,'PLEASE CORRECT INPUT FILE AND RE - RUN.'
      GOTO 700
      ELSE
      END IF
      IF (KCOUNT .NE. 0.00) GO TO 6551
      WRITE (2,2199)
      PRINT 2199
      PRINT 2049
      WRITE (2,2049)
2049  FORMAT('                    ')
      WRITE(2,2050)
      PRINT 2050
2050  FORMAT(3X,'DEPTH',3X,'PERIOD',2X,'WAV.ANGLE',1X,'WAVLNG.',
     1 'WDG.ANG.',3X,'X',7X,'Y',5X,'AMP',4X,'PHA')
      WRITE(2,2051)
      PRINT 2051
2051  FORMAT(4X,'(FT)',4X,'(SEC)',4X,'(DEG)',4X,'(FT)',3X,'(DEG)',4X,
     1 '(FT)',4X,'(FT)',9X,'(RAD)'/ 36(' -')/)
C
C     Call subroutine PADES to calculate wavelength
C
6551  CALL PADES(L,D,T)
      WRITE(2,2150) D,T,WAVEA,L,WEDGEA
2150  FORMAT(F8.2,2X,F6.2,4X,F6.2,2X,F7.2,1X,F6.2)
      PRINT 2150,D,T,WAVEA,L,WEDGEA
      J=1
98    READ (1,2200,END=99) X(J),Y(J),END
2200  FORMAT(2F10.2,25X,I5)
C
C     Call subroutine MAIN to solve problem and deliver
C     solution
C
      CALL MAIN (F,FABS(J),FPHA(J),X(J),Y(J),L,WEDGEA,WAVEA)
      WRITE(2,2250) X(J),Y(J),FABS(J),FPHA(J)
2250  FORMAT(42X,2F8.2,2X,F4.2,2X,F5.2)
      PRINT 2250,X(J),Y(J),FABS(J),FPHA(J)
      X(J)=0.00
      Y(J)=0.00
```

```
      FABS(J)=0.00
      FPHA(J)=0.00
      IF (END .EQ. 1) GOTO 99
      J=J+1
      GOTO 98
99    CONTINUE
      KCOUNT = KCOUNT + 1.00
      K=K+1
      GOTO 1001
999   CONTINUE
      CLOSE(1,STATUS='KEEP')
      CLOSE(2,STATUS='KEEP')
      PRINT *,'                    '
      PRINT 2199
      IF (MM .EQ. 0) GOTO 994
      PRINT 222,INFILE
222   FORMAT(1X,'YOUR OUTPUT IS IN ',A8)
C
C     Option to process additional input files
C
      PRINT *,'                    '
994   PRINT *,'DO YOU HAVE ANOTHER INPUT FILE ? (0="NO",1="YES") = '
      READ *,II
      IF (II .NE. 1 .AND. II .NE. 0) GOTO 994
      IF (II .EQ. 0) GOTO 700
      PRINT *,'ENTER NEW INPUT FILE NAME = '
      READ (*,'(A)') OUTFILE
      OPEN (1,FILE=OUTFILE, STATUS='OLD')
      ICOUNT = ICOUNT+1.0
      GOTO 991
C
C     Interactive option
C
600   PRINT 2199
      PRINT *,'OPTION TO SET WEDGE ANGLE (DEFAULT VALUE = 0.00 DEG.)'
      PRINT 2049
15    PRINT *,'SET WEDGE ANGLE ? (0="NO",1="YES") = '
      READ *, LOGIC
      IF (LOGIC .NE. 1 .AND. LOGIC .NE. 0) GOTO 15
      IF (LOGIC .EQ. 1) THEN
702   PRINT *,'ENTER WEDGE ANGLE (DEG.) = '
      READ *,WEDGEA
      IF (WEDGEA .GT. 180.0 .OR. WEDGEA .LT. 0.00) THEN
      PRINT *,'WEDGE ANGLE MUST BE BETWEEN 0.0 AND 180.0 DEGREES.'
      PRINT 2049
      GOTO 702
      ELSE
      END IF
      ELSE
      WEDGEA = 0.0
      END IF
C
C     Get the facts: Initial values input in this step
C
120   PRINT 2199
```

```
      PRINT *,'SET INITIAL VALUES'
      PRINT 2049
602   PRINT *,'INPUT WATER DEPTH (FT.) = '
      READ *,D
      IF (D .LT. 0.00) THEN
      PRINT *,'WATER DEPTH CANNOT BE NEGATIVE.'
      PRINT 2049
      GOTO 602
      ELSE
      END IF
603   PRINT *,'INPUT INCIDENT WAVE PERIOD (SEC.) = '
      READ *,T
      IF (T .LT. 0.00) THEN
      PRINT *,'INCIDENT WAVE PERIOD CANNOT BE NEGATIVE'
      PRINT 2049
      GOTO 603
      ELSE
      END IF
701   PRINT *,'INPUT INCIDENT WAVE ANGLE'
      PRINT *,'(DEG. CCW FROM POSITIVE X - AXIS) = '
      READ *,WAVEA
      PRINT 2199
      WRITE (2,2199)
C
C     Call subroutine PADES to calculate wavelength
C
730   CALL PADES(L,D,T)
      IF (WEDGEA .NE. 0.00) THEN
      WRITE (2,2001) WEDGEA
2001  FORMAT (1X,'OBSTACLE IS A VERTICAL WEDGE OF ANGLE ',F6.2
     1 ,' DEGREES')
      ELSE
      WRITE (2,2002)
2002  FORMAT(1X,'SEMI-INFINITE BREAKWATER (WEDGE ANGLE'
     1 ,1X,'= 0.00 DEGREES)')
      END IF
      PRINT 2049
      WRITE (2,2049)
      WRITE (2,2050)
      WRITE (2,2051)
      WRITE (2,2150) D,T,WAVEA,L,WEDGEA
710   PRINT *,'HOW MANY POINTS DO YOU WISH TO ENTER (UP TO 99)? = '
      READ *,KK
      PRINT 667
667   FORMAT(1X,'AT EACH PROMPT, DO THE FOLLOWING :',/
     1 ,4X,'1) TYPE IN X - COORDINATE',/,4X,'2) TYPE A COMMA'
     2 ,/,4X,'3) TYPE IN Y - COORDINATE',/,4X,'4) PRESS "ENTER"',/)
      DO 10 I=1,KK
      PRINT 2000,I
2000  FORMAT (1X,'(X,Y) COORDINATES FOR POINT NO. ',I2
     1 ,1X,' (FT.) = ')
      READ *,X(I),Y(I)
C
C     Call subroutine MAIN to solve problem and deliver
C     solution
```

```
C
      CALL MAIN (F,FABS(I),FPHA(I),X(I),Y(I),L,WEDGEA,WAVEA)
      WRITE (2,2250) X(I),Y(I),FABS(I),FPHA(I)
10    CONTINUE
      CLOSE(2,STATUS='KEEP')
      PRINT 2199
      IF (WEDGEA .NE. 0.00) THEN
      PRINT 2001,WEDGEA
      PRINT 2049
      ELSE
      PRINT 2002
      PRINT 2049
      END IF
      PRINT 2050
      PRINT 2051
      PRINT 2150,D,T,WAVEA,L,WEDGEA
C
C     Screen Output
C
      DO 20 N=1,KK
      PRINT 2250,X(N),Y(N),FABS(N),FPHA(N)
20    CONTINUE
      PRINT *,'         '
      IF (MM .EQ. 0) GOTO 700
      PRINT 222,INFILE
700   STOP
      END
C
C     Subroutine PADES, to calculate wavelength .
C     Based on Pade's approximation solution for the linear
C     dispersion relation
C
      SUBROUTINE PADES(L,D,T)
      REAL L
      PI=3.14159
      PI2=2.*PI
      OMGA=PI2/T
      OMGG=OMGA**2./32.2
      A=OMGG*D
      BB=A*(A+1./(1.+A*(0.66667+A*(0.35550+A*(0.16084+A*(0.06320+A*
     1   (0.02174+A*(0.00654+A*(0.00171+A*(0.00039+A*0.00011))))))))))
      B=SQRT(BB)
      PK=B/D
      L=PI2/PK
      RETURN
      END
C
C     Subroutine MAIN, which normalizes the input and calls
C     Subroutine WEDGES, which solves the actual problem.
C
      SUBROUTINE MAIN(F,FABS,FPHA,X,Y,L,WEDGEA,WAVEA)
      REAL L
      PI=3.14159
      PI2=2.*PI
      XX=ABS(X/L)
```

```
      YY=ABS(Y/L)
      XRL=SQRT((XX**2.0)+(YY**2.0))
      IF (X .EQ. 0.00 .AND. Y .LT. 0.00) THEN
      XTH=1.5*PI
      GOTO 351
      ELSE
      IF (X .EQ. 0.00 .AND. Y .GT. 0.00) THEN
      XTH = 0.5*PI
      GOTO 351
      ELSE
      GOTO 428
      END IF
      END IF
428   IF (XX .EQ. 0.00 .AND. YY .EQ. 0.00) THEN
      XTH = 0.00
      GOTO 351
      ELSE
      XTH=ATAN(YY/XX)
      END IF
      IF (X .LT. 0.00)GOTO 100
      IF (Y .LT. 0.00) GOTO 300
      GOTO 400
100   IF (Y .LT. 0.00) GOTO 200
      XTH=PI-XTH
      GOTO 400
200   XTH=PI+XTH
      GOTO 400
300   XTH=PI2-XTH
400   IDX=0.0
351   CALL FCWEDGES(F,FABS,FPHA,XRL,XTH,WEDGEA,WAVEA,IDX)
      RETURN
      END
      SUBROUTINE FCWEDGES(F.FABS,FPHA,XRL,XTH,WEDGEA,WAVEA,IDX)
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C  * THIS COMPUTER PROGRAM WAS PREPARED UNDER THE EFFORT OF CIVIL WORK
C  * R&D PROGRAM OF COE.  NEITHER ANY OF AGENCIES NOR ANYONE ASSUMES
C  * ANY LEGAL LIABILITY OR RESPONSIBILITY FOR THE ACCURACY OF THE
C  * PROGRAM.
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C  WAVE SCATTERING BY A WEDGE OBSTACLE.  NUMBER OF SUMMATION TERMS IS
C  NN.  IDX=0 TO CALL BESJ.
C  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      PARAMETER NN=200
      DIMENSION BJ(NN),W(NN).XM(NN)
      COMPLEX F.TM
      DATA TOLR/1.E-8/,ITER/8/
      IF (IDX .NE. 0) GOTO 4
      DO 5 I=1,NN
5     BJ(I)=0.00
4     CONTINUE
      PI=3.141592654
      DPI=PI/180.
      XKR=XRL*2.0*PI
      TH=XTH
```

```
      WA=WAVEA*CPI
      XNU=(360.-WEDGEA)/180.
      XM(1)=1.0
      IF(IDX.NE.0) GOTO 14
      CALL BESJ(XKR,0.0,1,W,NZ)
      BJ(1)=W(1)
      ICOUNT=0
      DO 10 N=1,NN
      N1=N+1
      ICOUNT=ICOUNT+1
      IF(ICOUNT.LE.ITER) GOTO 8
      NNN=N
      GOTO 14
    8 XM(N1)=FLOAT(N)/XNU
      M=INT(XM(N1))
      ALPHA=XM(N1)-M
      M1=M+1
      CALL BESJ(XKR,ALPHA,M1,W,NZ)
      IF(N1.EQ.NN) WRITE(6,9) XKR,ALPHA,M1,W(M1),NZ
    9 FORMAT(/' **** NO. OF TERMS FOR SUMMATION IS INSUFFICIENT ****',
     1 /' XKR,ALPHA,M1,W(M1),NZ =',2F10.4,I5,E15.6,I5/)
      BJ(N1)=W(M1)
      IF(ABS(BJ(N1)).GT.TOLR) ICOUNT=0
   10 CONTINUE
   14 CONTINUE
      F=BJ(1)/2.
      DO 20 N=1,NNN
      N1=N+1
      XMN=XM(N1)
      TM=(0.0,1.0)**XMN*BJ(N1)*COS(XMN*WA)*COS(XMN*TH)
      F=F+TM
   20 CONTINUE
      F=4./XNU*F
      FR=REAL(F)
      FI=AIMAG(F)
      FABS=SQRT(FR*FR+FI*FI)
      IF(WA.LE.1.E-8) FABS=FABS/2.
      IF(FABS.LT.TOLR) GOTO 30
      FPHA=ATAN2(FI,FR)
      RETURN
   30 FPHA=0.0
      RETURN
      END
      SUBROUTINE BESJ(X,ALPHA,N,Y,NZ)
C
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```

APPENDIX C: NOTATION

A_o	$-iga_o/\omega$
a_o	Incident wave amplitude
e	2.71828....; base for natural logarithm
g	Gravitational acceleration
h	Water depth
i	$\sqrt{-1}$
J_o	Zeroth order Bessel function of the first kind
$J_{\eta/\nu}$	$\frac{\eta}{\nu}$ order Bessel function of the first kind
k	Wave number
(r,θ,z)	Cylindrical coordinate system
r	Radial coordinate
u	Flow velocity
z	Vertical coordinate
α	Approach angle of incident wave train
β	Phase of $\phi(r,\theta)$
η	Water surface elevation
η_i	Incident water surface elevation
θ	Angular coordinate
θ_o	Angular coordinate for water domain
ν	$\theta_o/2\pi$
π	3.14159.......
$\Phi(r,\theta,z,t)$	Three-dimensional, time-dependent velocity potential
$\phi(r,\theta)$	Velocity potential in horizontal plane
ω	Radian frequency

Subscripts:

r	Denotes r-coordinate variable
θ	Denotes θ-coordinate variable

Mathematical symbols:

∂	Partial differentiation
Σ	Summation
$\lvert\,\rvert$	Absolute value
Im( )	Imaginary part
Re( )	Real part