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The Construction of Wave Refraction Diagrams by Computer

P. E. Vandall, Jr.

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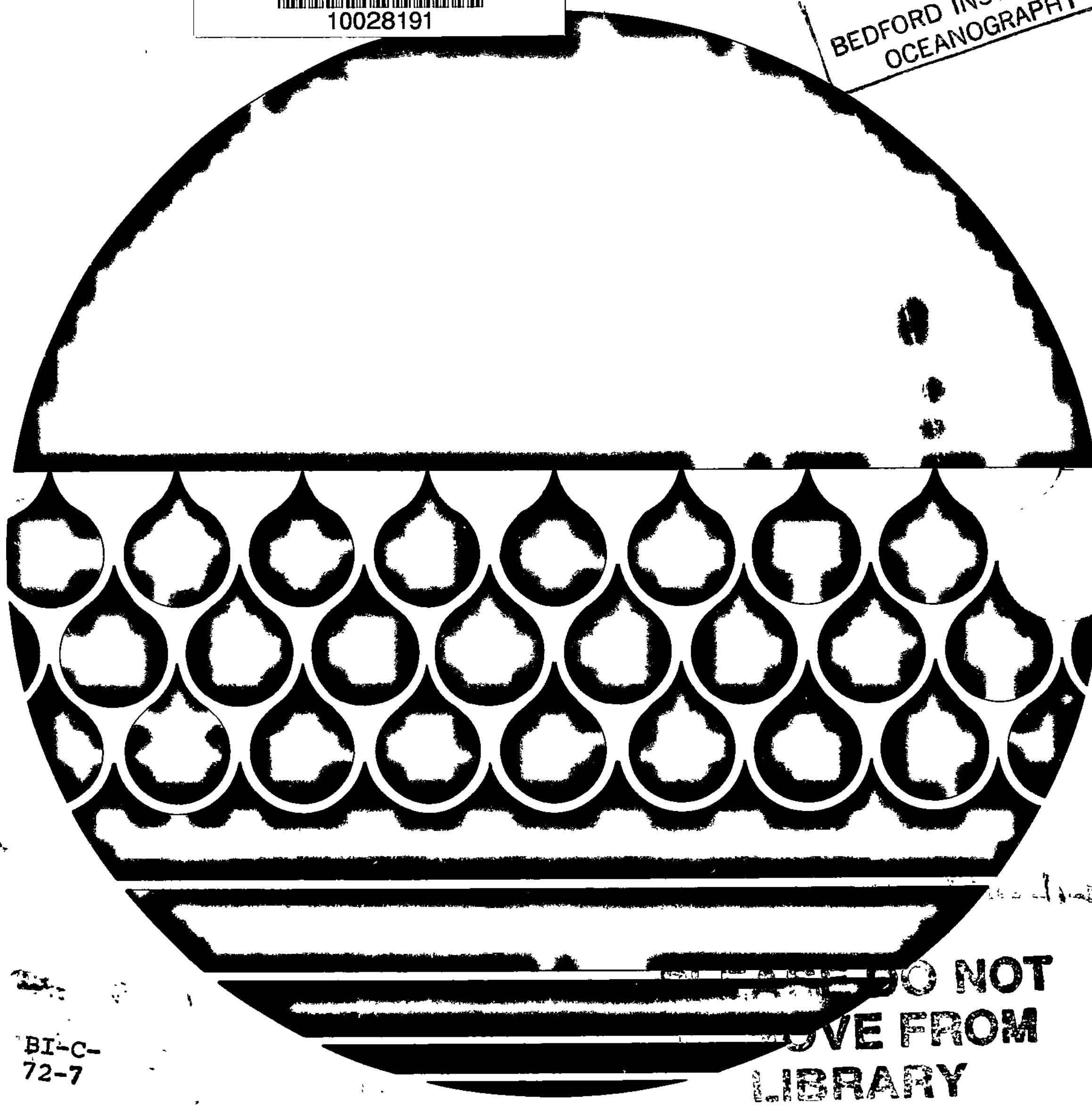

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THE CONSTRUCTION OF WAVE REFRACTION DIAGRAMS BY COMPUTER

by

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Marine Sciences Directorate
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ABSTRACT

The computer program for ocean wave refraction described estimates and constructs wave refraction diagrams which are graphical representations of changes in direction of wave fronts as they move over relatively shallow areas with varying depths. The rays or orthogonals calculated indicate the direction of travel of the wave energy from a given initial position.

For each point along the ray, water depth and bottom slope are estimated from the depth grid by linear interpolation; wave speed and curvature are computed according to the first order wave theory; the location of the next successive point is approximated by an iterative procedure. Sample data and their results are included.

All subroutines, with the exception of NUMBER, SYMBØL and DATE (which is written in binary) are written in FORTRAN 32 and together are designed for use only on the Bedford Institute CDC 3150 computer.

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ACKNOWLEDGEMENTS

This program is a modification of a program developed by W.S. Wilson under the auspices of the Coastal Engineering Center, U.S. Army Corps of Engineers, and in its original form is described in a Technical Memorandum (No. 17) entitled "A Method for Calculating and Plotting Surface Wave Rays" by W.S. Wilson (February 1966). This report describes the modifications made and is meant to be a guide to the users at BIO only.

I wish to thank R. Richards (former Head of Computer Section at BIO) and G. Seibert (Coastal Oceanography) for their assistance in preparing some of the subroutines required for this program.

1.0 INTRODUCTION

A wave refraction diagram is a graphical representation of the change in direction of a wave front as it moves from deep water to shallow water. A straight wave front of a wave propagating over shallow areas (depth less than half the wavelength) starts to bend as its velocity becomes a function of depth. When progressing over increasing depths wave orthogonals tend to diverge and when progressing over shoals or ridges they tend to converge.

The refraction theory applied to this program is based upon the following assumptions: (1) that the waves are long-crested, sinusoidal, progressive gravity waves for which the linear wave theory applies; (2) that the wave period is constant throughout the shoaling process; (3) that the wave velocity depends only upon the wavelength and still water depth; (4) that the elements of the wave crest advance in a direction perpendicular to the wave front; (5) that the amount of wave energy between orthogonals remains constant; (6) that the effect of friction and currents on the refraction process is negligible. These last two assumptions make it possible to estimate variations in wave height with variations in depth and orthogonal spacing.

Refraction diagrams are constructed in two ways. The first, known as the 'wave-front method', is essentially the illustration of successive wave front positions (at given time intervals), found by using Huygen's principle, on a chart of the region of interest. The second method, known as the 'orthogonal method', illustrates the path of the wave orthogonals. This second method is employed in the program described.

This program was designed to replace the manual construction of wave rays particularly when a multiple number of periods and angles of approach are to be considered. However, it should be noted that the preparation of the depth grid and ray cards will exceed in time and effort that required for the manual construction of two or three refraction diagrams.

Comparisons of manually and computer constructed refraction plots will show slight differences, due to the finite grid spacing and lack of an integrating effect over an area around each point in the computer product. These differences may be made smaller by using a smaller grid spacing (if possible) and by visually integrating the area around each grid point and using the integrated depth as the grid depth at any point.

The refraction principle is quite useful and can be employed in a wide variety of applications. Of particular importance is its identification of areas of convergence and divergence of wave rays. For example, when establishing a wave climate for a certain area through direct wave measurements observations should be confined to regions of non-convergence and non-divergence. This is one important application for which this technique has been used. Other uses may be found in Pierson, Neumann, and James (1955) and Pierson, Tuttell, and Wooley (1953).

2.0 METHOD

2.1 Initial Requirements

A hydrographic chart with sufficient depth detail is the basic requirement. This chart must cover the shoreline of interest and extend out into water that is considered 'deep', i.e. where the depth is at least equal to half the wave length of the longest wave to be considered.[1] Under these circumstances 'deep water' conditions prevail; i.e. no refraction is occurring and the initial wave front can be assumed to be a straight line. A set of periods and angles for which wave rays are to be drawn must be chosen and the 'deep water' wave front fitted into the area of interest. Since the maximum plotting dimensions of the PDP-8 plotting system are 22 x 28 inches, the area of interest on the chart should not exceed these dimensions if the ratio between the size of the resultant wave ray plots to the chart size is to be equal to one. There is a provision made to scale the plot down but unless shorelines and contours are indicated in the output plot the results cannot be easily referenced to the original chart. To plot shorelines major alterations must be made to the depth grid and will be described later. These alterations are manually time-consuming and the additional plotting of shorelines and contours requires a considerable amount of computer time and memory space as will be seen. For these reasons it is most advantageous to make the ratio of the refraction plot to chart size, one to one. Clear plastic overlays of the shore line and contours on the resultant wave ray plots will relate the refraction diagram to the chart.

2.2 Selection of Grid Boundaries

A rectangular (right-handed) X-Y coordinate system, whose boundaries form the boundaries of the depth grid, is imposed on the area of interest. The boundaries of the plot are specified by the lines X = 0, X = AMM, Y = 0 and Y = ANN (AMM and ANN are expressed in grid units). Care must be exercised in selecting these boundaries. As indicated before some criteria must be kept in mind: (a) all rays must start in deep water for all angles of approach (if a 'deep water' wave front is required), (b) no shoals should be left in the seaward direction, and (c) the angles of approach should be adequately covered by the depth grid, so as to ensure realistic approaches to the shoreline of interest. For example, if the shoreline of interest is on an island the depth grid must surround the island since the waves which arrive at any point on the shore could originate from almost any point around the island.

Generally (and for the program presented here) the Y-axis is set parallel to the coast (or to the contour defining the boundary of 'deep water'); the X-axis increases positively seaward. If another orientation is desired changes must be made in the main program. The shoreline and the 'deep water' contour must lie at least one grid unit from the grid boundaries since any ray which comes within one-half grid unit of the boundary is stopped at that point.

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1. Wavelength $L = 5.12\ T^2$ where T is the period of the wave in seconds.

(A)

2.3 Selection of Grid Interval

The depth grid is a two-dimensional array of integer depths, all equally spaced. The selection of the grid interval is dependent on opposing criteria. The first requires that each grid cell be so small that its bottom topography may be approximated by a plane. Of course, the smaller the cell the better the approximation and the better the resolution of the wave rays. The number of depths in the grid, however, is limited by the size of the computer core. For the BIO computer the maximum dimensions of the depth grid are 25 x 30 (i.e. 25 in X direction and 30 in Y direction) - see Memory Requirements, Section 6.1. Along with these criteria some consideration of the size of the area must also be made. For instance, since the Y axis can only be 28 inches long (i.e. $HT \leq 28$) and can only have 30 equally spaced points, the points then will be spaced 0.932 inch apart. This is an odd figure. It is certainly easier to use a distance of one inch so that inch- lined paper or plastic can be laid on top of the hydrographic chart to interpolate the depths at the grid points. If one inch is used then 28 points are sufficient. The grid interval will then be equal to one inch times map scale factor to yield actual separation between depths in feet. This factor is determined by the scale of the hydrographic chart used. If this grid interval does not yield sufficient resolution the area of interest should be subdivided into overlapping areas that are small enough to yield adequate resolution and whose orthogonals are made to match in the overlapped regions.

2.4 Selection of Depth Values

The depths used in the depth grid may be expressed in any units. The depths used, however, must be converted to units of feet to be useful for this program. For this reason the program requires a conversion factor called DCØN which when multiplied by the depth unit used yields depths in feet. For example, if the depths are in fathoms DCØN = 6.0 (ft/fm) and if the depths are in metres DCØN = 3.28 (ft/m).

The depth at each grid point is most easily determined by first drawing contour lines on the hydrographic chart at convenient intervals. This may appear time-consuming but it saves on the interpolation time required to establish the depth at each grid point. Depths indicated should be a visual integration of depths within an area of one-half grid unit square.

To obtain a plot of the shoreline the depths overland are not set equal to zero (as they would be if no shoreline is to be drawn) but are set equal to negative values which are generated, as indicated below. Depth contours are drawn in a strip extending at least *three* grid units seaward from the shoreline. On the land the reflections of these contours about the shoreline are drawn. The depth assigned to each reflected contour is the negative water depth associated with the contour being reflected. Successive reflections should be made to obtain the depths further inland. Once within two grid units of the boundary the remaining depths may be set equal to zero (see Figure 1).

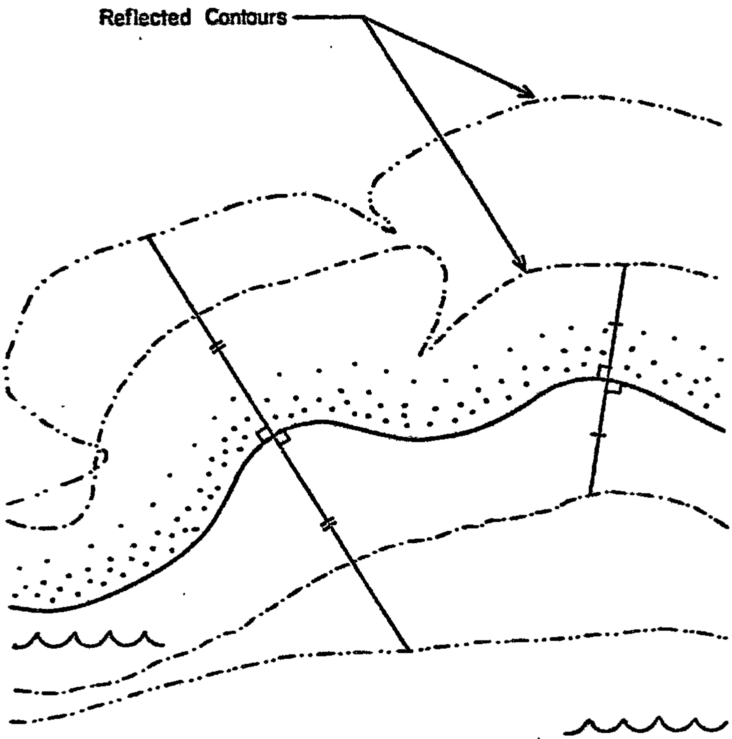

FIGURE 1: Depth Grid used to draw Shoreline

2.5 Selection of Ray Origins

To determine the wave ray paths, the starting points (ray origins) of each ray must be specified, along with the angle at which the rays are to set out from these points. If the rays are originated in deep water then all the initial points may lie on the same straight line and all the angles for the rays are the same. For example on Figure 2 a wave front is indicated with the starting points of the wave rays. The rays originate in deep water (i.e. beyond deep water contour DW) so their origins may lie on a straight line. The starting points are given by their X and Y coordinates. The angles or angle (for this example denoted as A) are measured in degrees with respect to the increasing X-axis, as shown in Figure 3. This method of selecting ray origins is used if the refraction of a particular wave front for a particular wave period is desired.

If instead it is desired to see from which direction and location waves are refracted into a point then all possible angles of approach are specified for that point for a particular wave period. These rays then radiate from that point. When these rays reach deep water, their directions yield the angles at which wave rays should be initially started in deep water in the case of the first application mentioned above.

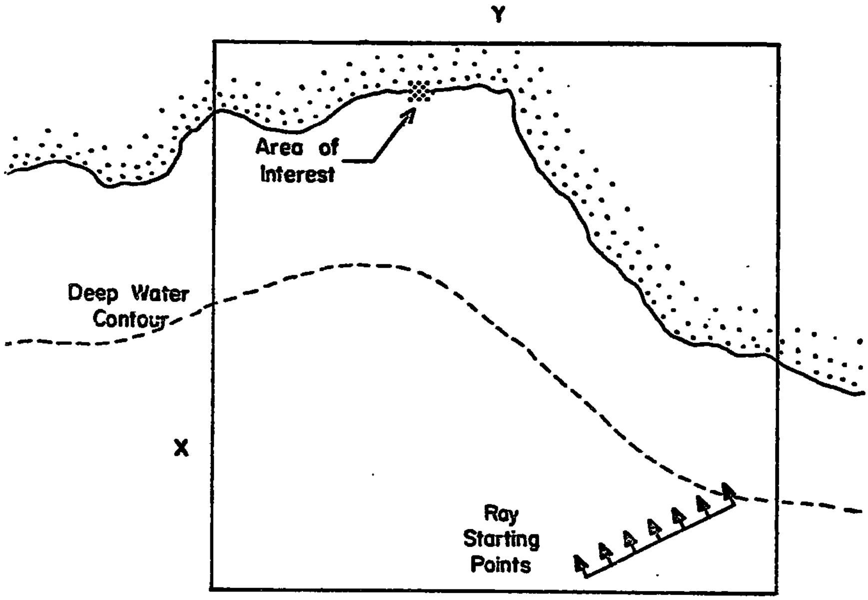

FIGURE 2: Initial Wave Front Positions on Depth Grid

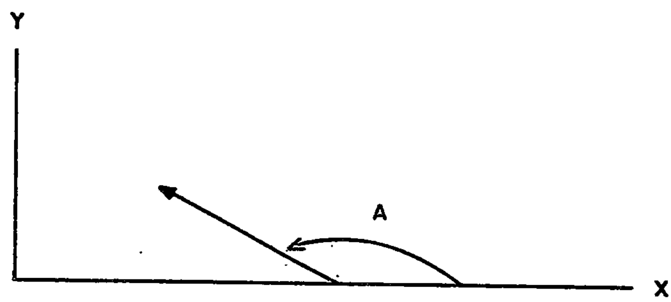

FIGURE 3: Selection of Initial Ray Angle

3.0 COMPUTER OPERATIONS (quoted from Wilson)

The computer starts with a ray origin and approximates the path by calculating successive points. For this calculation the computer needs the array of depth values (KMAT), the wave period (TT), the direction of travel (A), and the coordinates of the initial position (X,Y). At each point a first order plane is fitted by least-squares to the four closest depth values. Water depth (h) and the gradients $\partial h/\partial x$ and $\partial h/\partial y$ are obtained from the plane. The change in depth normal to the ray ($\partial h/\partial n$) is found from

$$\frac{\partial h}{\partial n} = -\frac{\partial h}{\partial x}\sin A + \frac{\partial h}{\partial y}\cos A \qquad (1)$$

Wave speed (C) and $\frac{\partial C}{\partial n}$ are calculated with

$$C = \frac{gT}{2\pi}\tanh\frac{(2\pi h)}{(CT)} \qquad (2)$$

where T = wave period

and

$$\frac{\partial C}{\partial n} = \frac{\partial h}{\partial n}\cdot W \qquad (3)$$

where

$$W = \frac{1}{k'}\,\frac{1}{\frac{Ck''}{1+k''C} + \frac{Ck''}{1-k''C} + \ln(1+k''C) - \ln(1-k''C)} \qquad (4)$$

and

$$k' = \frac{T}{4} \qquad \text{and } k'' = \frac{2}{gT} \qquad \text{(see Harrison and Wilson, 1964)} \qquad (5)\ \&\ (6)$$

Ray curvature (K) is computed with

$$K = \frac{1}{C}\frac{(-\partial C)}{(\partial n)} \qquad (7)$$

Denoting the current point (P_n) and the next succeeding point (P_{n+1}) P_{n+1} is reached from P_n by iterating with

$$\Delta A = (K_n + K_{n+1})\, D_n/2 \tag{8}$$

$$A_{n+1} = A_n + \Delta A \tag{9}$$

$$\bar{A} = (A_n + A_{n+1})/2 \tag{10}$$

$$X_{n+1} = X_n + D_n \cos \bar{A} \tag{11}$$

and

$$Y_{n+1} = Y_n + D_n \sin \bar{A} \tag{12}$$

where D_n, the incremental distance between points, is given by the ratio h_n/L_d (Griswold and Nagle, 1962; Griswold, 1963).

Computations stop when the rays reach the shore, a border of the grid, when the number of the points along a ray exceeds 1799 or when the bottom slope increases very sharply. The coordinates of the points defining the ray path, just completed, are then stored and subsequently written on tape. The process is repeated for each ray origin specified. Later, the information contained on this tape is used by the PDP-8 plotter to draw the rays.

3.1 Optional Operations

The computer may be made to perform any or all of four options provided memory space is available (see Memory Requirements). The first calculates the coordinates along a ray of the positions occupied by a wave crest at equal time intervals (CIN). If the value of CIN is chosen so that CIN/TT = M where M is an integer, the result of the calculation can be interpreted as the positions of every Mth crest in a sinusoidal wave train.

The second operation obtains coordinate values of points on the depth grid where the linearly-interpolated depth equals zero. This option, if exercised, provides the plotter with data with which it can draw an approximate position of the shoreline. The approximation becomes poorer as $\frac{\partial h}{\partial x} \to 0$ at $h = 0$.

The third option enables the plotter to enter selected soundings on the ray diagrams. If a judicious selection of water depths is made, an idea of the bathymetry of the region of analysis can be formed directly from the ray plot without referring to the chart of the region. These soundings should also verify the accuracy of the computed ray paths.

The fourth option causes the computer to calculate the points along a straight line wave front if NØFRNT ≠ 0. Only the initial point (XST, YST) and the final point (XEND,YEND) need to be specified. The front is divided up into NØR equally spaced points and these points are taken to be the starting points of the rays originating on that wave front. This option is not exercised if NØFRNT = 0.

3.2 Plotter Operations

The PDP-8 computer is used to transform the data on the CDC 3150 output tape into the plots desired by means of the CALCOMP plotter and the PLØTLS or PLTLS plotting routine. The choice is determined by the mode of output; paper or magnetic tape. Each plot shows ray paths and is bordered and labelled. If the options have been exercised, the plot will also show travel-time marks, the shoreline, and soundings.

The maximum dimensions of the plotting surface are 120 feet by 29.5 inches.[2] The position of the border and label of each plot is controlled by AMM, ANN and HT (the height of the plot in inches). AMM and ANN are determined from the dimensions of the depth grid. HT must be fed in and may be no greater than 28 inches. The value of HT, however, may be chosen so as to produce a specific scale of plot (SCL). This may be done by setting HT = GRID•SCL•ANN•12, where GRID equals the number of feet per grid interval.

Before beginning a series of plots, the plotter pen is set (15.0 - HT/2) inches from the bottom of the roll of paper where HT is the height selected for the first plot. This establishes the origin. Subsequent plots are spaced by 6 inches from the previous plot.

4.0 DESCRIPTION OF COMPUTER PROGRAM (SWAVE)

This program consists of a main program, 17 subroutines (one of these is a binary program) and 4 function routines. The description of the main and subprograms follows in Figure 3 which is *a diagram* depicting the sequence in which the various subroutines are called. Program variables will be discussed later.

MAIN Program

This part of the program called MAIN controls the rest of the program and receives the data input. This data which is to be described later is read in on cards. MAIN calls (in order) the following subroutines: TITLE, NUMCØN, SHØRE and RAYN. RAYN is called for each ray but the other subroutines are only called once (for each plot).

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2. These are the maximum dimensions of the roll of plotting paper.

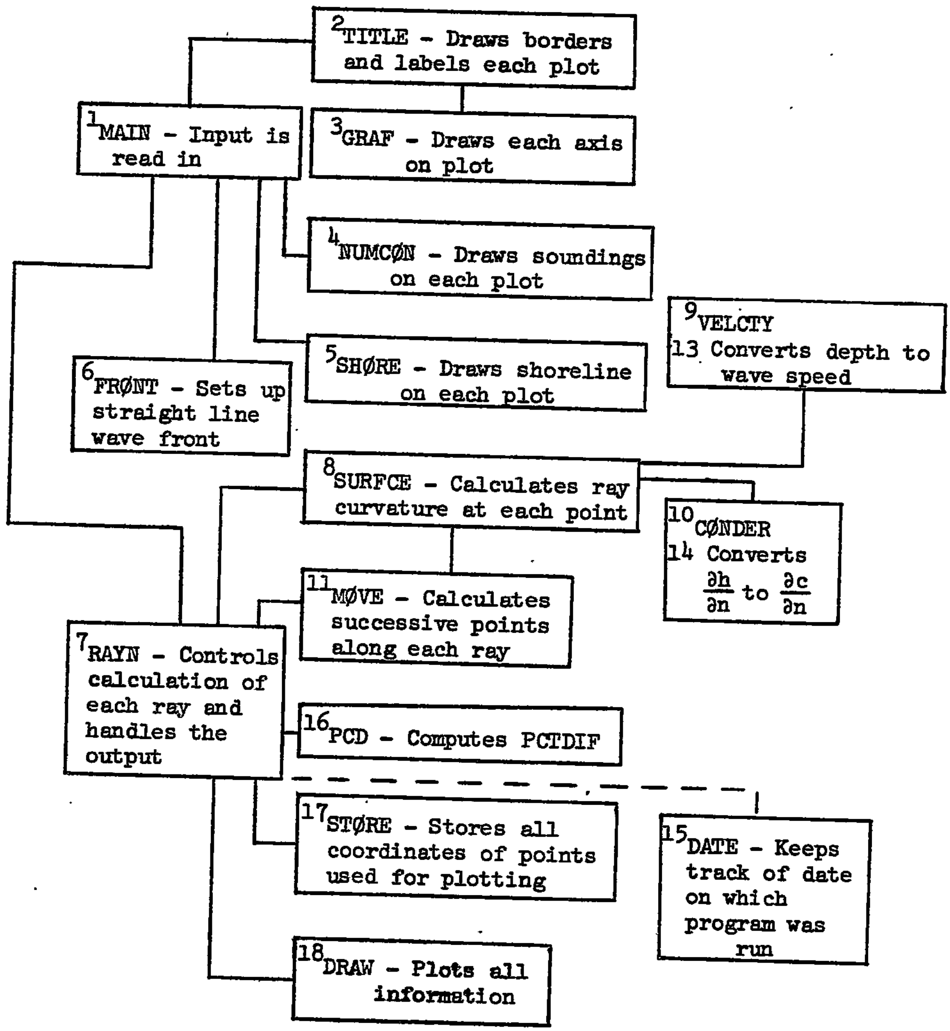

FIGURE 4: Generalized Flow Chart of SWAVE

TITLE

This subroutine produces all the information necessary for plotting the borders of and the labelling of each plot. The label contains the project number, date, plot number, wave period, and time between crest marks. Depending on the value of NAX, TITLE may or may not call GRAF which prepares instructions for drawing calibrated X and Y axis.

GRAF

This subroutine calibrates X and Y axes and prepares the instructions for the resulting plot. Calibrations are located at integral values along the axes. The product DY·SIZE must be integer.

NUMCØN

This subroutine (which is optionally called) draws specified sounding values on a particular plot. NCØ specifies the number of sounding values, and these values are stored in the array CTØUR. For each integral value of Y where $1 \leq Y \leq$ ANN - 1 and for each value of CTØUR, NUMCØN prepares the necessary plotting instructions for the plotter to draw this value of CTØUR.

This subroutine cannot be used unless $\frac{\partial h}{\partial x} \geq 0$ at h = 0 for the entire depth grid. When NCØ $\leq$ 0 NUMCØN is not called, and no sounding card is read.

SHØRE

This subroutine (which is optionally called) is only called if NSH $\neq$ 0. When called it prepares plotting instructions for drawing the shoreline on a plot. Coordinates of points, where the linearly-interpolated value of KMAT equals zero, are calculated. When plotted, the shoreline consists of a line joining all these points. This subroutine cannot be used when $\frac{\partial h}{\partial x} < 0$ at h = 0 for the entire depth grid.

FRØNT

This subroutine is only called if NØFRNT $\neq$ 0. When called it calculates the coordinates of the starting points of each ray if the points all lie on a straight line (i.e. the wave front is straight). For each wave front this subroutine is only called once, subsequent plots use the original starting points if the variable NEWRAY = 0.

RAYN

This subroutine is the heart of the program. RAYN calls, in order, the following subroutines SURFCE, MØVE, DATE, PCD, STØRE and DRAW. RAYN calls SURFCE to obtain the initial curvature of the ray. MØVE then calculates the coordinates of all the points on each ray. DATE calls the date from the computer accounting system. After each point is located on a plot, RAYN calls PCD to obtain PCTDIF and then calls STØRE to store the coordinates of the point. After all points have been generated, RAYN calls DRAW to prepare plotting instructions for the stored points.

The calculation of new points along a ray ceases when one of the following conditions is encountered. Each condition is followed by the message which is printed by the computer when this condition is fulfilled.

1. MIT = 3, CURVATURE APPROXIMATIØNS NØT CØNVERGING

2. NGØ = 2, RAY REACHED GRID BØUNDARY

3. NDP = 2, RAY REACHED SHØRE

4. K (or KMAX + KCIN) > MMAX, DIMENSIØN ØF ØUTPUT ARRAYS EXCEEDED

NOTE: Condition 3 may occur in deep water if the bottom slope is changing too fast.

RAYN also prepares the printed output for the entire program. Two formats are available: first, if NPT $\neq$ 0, MAX, X, Y, ANGLE, TIME PCTDIF, DEP, and D are printed for *each* point along a ray; second, if NPT = 0, X, Y, ANGLE and TIME are output *only* for the initial and final points along a ray.

SURFCE

This subroutine is called by RAYN and MØVE and it in turn calls VELCTY and CØNDER. SURFCE calculates the curvature for a specific point along a wave ray. The four closest KMAT values (depth grid values) i.e. closest to point of interest, are stored in array C and the coefficients found in arrays EM and S are combined with the values in C to obtain the coefficients of the plane fitted to the four depths. DEP is obtained by interpolating on this plane.

If DEP > 0 NDP = 1

If DEP $\leq$ 0 NDP = 2

If NDP = 2, control is transferred back to MØVE. Otherwise, VELCTY is called to obtain CXY.

If DEP/WL > 0.5 NFK = 1 and FK = 0 (curvature)

If DEP/WL $\leq$ 0.5 NFK = 2 and FK is computed after calling CØNDER to obtain the partial derivative of wave speed normal to the ray.

VELCTY

This subroutine is called by SURFCE each time a wave speed CXY is required. If NFK = 1, CXY = CXXØ. If NFK = 2, CXY = equation 2.

CØNDER

This subroutine is called by SURFCE to convert the partial derivative of water depth with respect to the direction normal to a ray into the partial derivative of wave speed with respect to the normal(see equation 3).

MØVE

This subroutine is called by RAYN and in turn calls only SURFCE. MØVE calculates the coordinates of the next point along a wave ray. D is calculated, and the curvature used in getting the present point is used to approximate the location of the next point. MØVE calls SURFCE to obtain the curvature at the approximated position of the next point. The average of the curvatures at the present and new points is taken and is used to obtain a second approximation of the next point. This procedure continues for a maximum of 20 times or until two successive curvature averages differ by a factor less than 0.0009/D. If this convergence occurs, the new point is accepted and MIT = 1. If the average curvatures used on the 18th and 20th trials have converged to less than 0.009/D, the curvatures of the 19th and 20th trials are averaged to obtain the curvature used in calculating the new point. This is done because the curvature approximations have converged to two values, MIT = 2 in this case and, if NPT $\neq$ 0, the message CURVATURE AVERAGED appears on the printer output. If neither convergence condition is satisfied, MIT = 3 and no new point is accepted.

Before returning to RAYN, the coordinates of the new point are checked to see if the new point lies one-half grid unit from the edge of the grid. If this is true, NGØ = 2, otherwise NGØ = 1.

DATE

This subroutine called by RAYN returns the date on which the program is run from the internal accounting system of the BIO computer.

PCD

This subroutine is called by RAYN to calculate the maximum percent difference (PCTDIF) between the depth at a point on the ray and the surrounding four grid depths.

STØRE

This subroutine is called by RAYN after each point along a ray has been computed. The X,Y coordinates are stored in the AX and AY arrays respectively. If CIN > 0, the X,Y coordinates representing the position of a wave crest at equal time intervals along a ray are calculated and similarly stored in AX and AY. If CIN $\leq$ 0, these crest positions are not calculated.

DRAW

This subroutine is called by RAYN after all points have been calculated for a given ray so that coordinates of these points can be transformed into plotting instructions. In order to minimize plotting time, odd-numbered rays are plotted beginning with the initial point; even-numbered rays are plotted beginning with the terminal point. If CIN > 0 marks are placed along a ray to designate crest positions, otherwise there are no marks.

SYMBØL and NUMBER

These subroutines are system plotting subroutines used for plotting characters or numbers and are called by TITLE, GRAF, NUMCØN, and DRAW.

PLØTS

This subroutine is called by MAIN to initialize plotting operations by reserving an output buffer region for plotting information. The limits on the dimension of this region are $120 \leq N \leq 180{,}000$, where it is recommended that N be at least 2000.

PLØT

This subroutine is called by MAIN, TITLE, AXIS, NUMCON, SHORE and DRAW to issue plotting instructions to the pen.

5.0 DESCRIPTION OF PROGRAM VARIABLES

A	- initial ray angle measured in degrees relative to the direction of increasing X. Internally in the program the ray angle in radians for a specific calculation point along a ray.
AMM, ANN	- maximum values of X and Y, respectively, for a particular depth grid.
ANGLE	- ray angle in degrees for a specific point along a ray.
AX, AY	- two arrays used for temporary storage of plotter output information. The dimensions of these arrays is specified by MMAX.
B	- dummy array for starting angles for rays.
BUFFER	- an array used for temporary storage of plotter output information. See discussion of PLØTS.
C	- the array for the four closest points to a specific calculation point along a ray.

CIN	- if CIN > 0: in the input and output, the travel time in seconds between the CIN/TT successive crest marks is given along a ray; internally in program, the same time as above but measured in hours. If CIN = 0: no crest marks are made on the wave rays.
CTØUR	- an array of up to five sounding values in feet. These values are plotted numerically on the resultant plot.
CXXØ	- deep water wave speed in ft/s.
CXY	- wave speed in ft/s at a specific point on a ray.
D	- incremental distance in grid units between successive calculation points along a ray.
DCØN	- conversion factor which will take KMAT values into units of feet.
DEP	- water depth in feet at a specific point on a ray.
DN	- before CØNDER is called: $\partial h/\partial n$ in ft/grid unit; after CØNDER is called: $\partial C/\partial n$ in ft/s/grid unit.
DT	- a dummy argument for subroutine DATE where the date is subsequently stored.
DY	- number of grid units per inch for a specific plot.
E	- array of coefficients of the equation of the plane fitted to the four closest depth values around a point along a ray.
EM	- array used in calculation of coefficients for fitted depth plane (see Harrison and Wilson (1964), Appendix C).
FAN	- FAN ≠ 0 (for rays originating from one point) causes rays to be numbered at their terminal points; FAN = 0 (for rays originating along a front) causes their initial points to be numbered.
FK	- ray curvature (1/grid unit).
GRID	- number of feet per grid unit for a particular depth grid.
HT	- length in inches of Y axis for a specific plot.
I,J	- indices for KMAT: I = X + 1, J = Y + 1.
K	- index specifying the number of rays in straight line wave front.
KCIN	- number of crest marks calculated along a ray which do not correspond to calculation points used for plotting the ray path.

KMAT	- array of grid depth. Dimension is (MM, NN).
KREST	- number of crest marks calculated along a particular ray.
LI	- LI + 5 = number of lines printed per page.
MAX	- serial number of a specific calculation point along a ray.
MIT	- MIT = 1 if the curvature approximations in MØVE have converged to one value; MIT = 2 if they have converged to two values; MIT = 3 if they have not converged.
MM	- X-dimension of the depth grid (number of points on X axis).
MMAX	- dimension of AX and AY arrays.
MXPLØT	- number of plots to be prepared for a given operation of the computer program.
N	- ray number.
NAX	- if NAX = 0, the borders of a given plot will be uncalibrated; if NAX ≠ 0, the borders will be calibrated with integral values of grid units.
NCØ	- this variable specifies the number of sounding values which are to be read in (must be ≤ 5) if NCO ≤ 0 no sounding card is required.
NDP	- if DEP > 0, NDP = 1, if DEP ≤ 0, NDP = 2.
NEWRAY	- if NEWRAY = 0 the starting points for the previous wave front and plot are to be used again; if NEWRAY ≠ 0 these starting points are calculated by calling subroutine FRØNT or read in on cards.
NFK	- if (DEP/WL) > 0.5, NFK = 1; if (DEP/WL) ≤ 0.5, NFK = 2.
NN	- Y-dimension of the depth grid (number of points on Y axis).
NØFRNT	- if NØFRNT = 0 then wave front is not straight and the points on the front must be read from cards and FRØNT is not called. If NØFRNT ≠ 0 then only XST, YST, XEND and YEND need be read in and subroutine FRØNT is called.
NØR	- number of rays to be drawn for a given plot.
NPLØT	- plot number.
NPT	- this determines the format of printed output. See discussion of RAYN in previous section.
NSH	- if NSH ≠ 0 a shoreline is drawn; if NSH = 0 no shoreline.

NXCMAT	- if NXCMAT = 0 a depth grid is read in; if NXCMAT ≠ 0 the depth grid for the previous plot is used again.
PCTDIF	- this is the percent difference between an interpolated depth and a nearby grid depth. See discussion of PCD in previous section.
PROJCT	- six digits of alphanumeric information used to identify the project number.
RT	- width in inches of the plot.
S	- array used for calculating the coefficients of fitted depth plane.
SCL	- scale of plot.
SCL1	- 1/SCL.
TIME	- total time in hours necessary for a wave crest to travel from a ray origin to a specific calculation point of the same ray.
TT	- wave period in seconds.
U	- calculated X coordinates of points on straight line wave front.
V	- calculated Y coordinates of points on straight line wave front.
WL	- deep-water wavelength in feet.
X,Y	- coordinates of a specific calculation point.
XEND,YEND	- coordinates of end point on straight line wave front.
XST,YST	- coordinates of starting point on straight line wave front.

6.0 PROGRAM LISTING

(see following pages)

```
SEQUENCE,708,---------------708
JCE,SNAV-034,166P,005,NC                                    *** MSOS V4.2 EDITION=SC DATE=12/07/72.
FORTRAN,L,X,M

                                MS FORTRAN (4.2)/MSOS          12/07/72

      PROGRAM SWAVE
C     MAIN PROGRAM FOR THE CALCULATION AND PLOTTING OF SURFACE WAVE RAYS
C     ------------------------------------------------------------------
C     THIS PROGRAM NEEDS THE FOLLOWING SUBROUTINES...TITLE,GRAF,
C     NUMCON,SHORE,FRONT,RAYN,MOVE,SURFCE,VELCTY,CONDER,PCD,STORE,
C     DRAW,SYMBOL,NUMBER,PLOTS,PLOT,AXISXY,PLOTXY,AND DATE
C     ------------------------------------------------------------------
C
C     THIS PROGRAM WAS PREPARED BY W.S.WILSON,DEPT OF OCEANOGRAPHY,
C     JOHNS HOPKINS UNIVERSITY, IN PURSUANCE OF CONTRACT DA-49-055-
C     CIV-ENG-64-5 WITH THE COASTAL ENGINEERING RESEARCH CENTER,
C     U.S.ARMY CORPS OF ENGINEERS.     JULY 21,1965.
C
      DIMENSION S(3,3), EM(4,3), E(3), YVW(3), KMAT(25,33), C(4), BUFFER
     $(1), AX(1800), AY(1800), CTOUR(5), U(50), V(50), B(50), IVFT(21)
      COMMON /DATA/ S(3,3)
      COMMON /DATA/ EM(4,3)
      COMMON E,YVW,KMAT,C,BUFFER,AX,AY,CTOUR,PROJCT,D,TT,DXY,MAX,GRID,
     $DCON,DEP,WL,AMM,ANN,DY,FAN,CIN,DT,RT
C     ------------------------------------------------------------------
C     NEW USERS BEWARE OF DIMENSIONS OF KMAT, FORMAT OF KMAT, AND
C     VAUE OF HT, WHICH DETERMINES THE SIZE OF THE PLOTS
C     THE VALUE OF MMAX MAY ALSO HAVE TO BE ADJUSTED IF THERE ARE
C     MORE THAN 1800 POINTS CALCULATED ALONG EACH RAY
C     ------------------------------------------------------------------
      DATA (((S(I,J),J=1,3),I=1,3)=0.75,-0.5,-0.5,-0.5,1.0,0.0,-0.5,0.0,
     $1.0)
      DATA (((EM(L,I),L=1,4),I=1,3)=4(1.00),0.0,2(1.00),3(0.0),2(1.00))
      CALL PLOTS (BUFFER(2000),2000)
      CALL DATE (DT)
      MMAX = 1800
      LI = 57
      LII = (LI-4)/3
      READ 18, MXPLOT,PROJCT
      PRINT 19
      PRINT 20, MXPLOT,PROJCT
      DO 17 NPLOT=1,MXPLOT
        READ 21, TT,NCR,MM,NN,GRID,DCON,NSH,NCO,NXCMAT,NPT,NAX,CIN,HT,
     $  NCFRNT,NEWRAY
        IF(HT.GT.28.)HT = 28.
        PRINT 22
        PRINT 23, TT,NCR,MM,NN,GRID,DCON,NSH,NCO,NXCMAT,NPT,NAX,CIN,HT,
     $  NCFRNT,NEWRAY
        CIN = CIN/3600.
        WL = 32.2*TT**2./6.2831854
        AMM = MM-1
        ANN = NN-1
        DY = ANN/HT
        SCLI = GRID*DY*12.
        KRAYS = NCR
        CALL TITLE (NPLOT,NAX,SCLI,HT)
        IF (NXCMAT) 2,1,2
    1   READ (60,24) (IVFT(I),I=2,21)
        PRINT 25
        PRINT 26, (IVFT(I),I=2,21)
        READ (60,IVFT(2) )((KMAT(I,J),I=1,MM),J=1,NN)
```

```
      PRINT 27
      IVFT(1) = 4H(1X,
      I = 4H
      ENCODE (1,28,IVFT(2) )I
      WRITE (61,IVFT) ((KMAT(I,J),I=1,MM),J=1,NN)
 2    IF (NCO) 4,4,3
 3    READ 29, (CTCLR(KC),KC=1,NCO)
      PRINT 30
      PRINT 31, (CTCLR(I),I=1,NCO)
      CALL NUMCON (MM,NN,NCO)
 4    IF (NSH) 5,6,5
 5    CALL SHORE (MM,NN)
 6    IF (NOFRNT.EQ.0) 7,10
 7    IF (NEWRAY.EQ.0) 14,8
 8    DO 9 N=1,KRAYS
          MAX = 1
          READ 32, A,X,Y,FAN
          PRINT 33
          PRINT 34, A,X,Y,FAN
          U(N) = X
          V(N) = Y
          B(N) = A*0.0174532925
          A = A*0.0174532925
          CALL RAYN (X,Y,A,NPLOT,N,MMAX,LI,NPT,LII)
 9    CONTINUE
      GO TO 16
10    IF (NEWRAY.EQ.0) 12,11
11    READ 35, A,XST,YST,XEND,YEND
      PRINT 36
      PRINT 37, A,XST,YST,XEND,YEND
      FAN = 0.
      CALL FRONT (A,XST,YST,XEND,YEND,NOR,U,V)
12    DO 13 K=1,KRAYS
          B(K) = A
13    CONTINUE
14    DO 15 K=1,KRAYS
          MAX = 1
          X = U(K)
          Y = V(K)
          A = B(K)
          CALL RAYN (X,Y,A,NPLOT,K,MMAX,LI,NPT,LII)
15    CONTINUE
16    CALL PLOTXY (RT+6.,-2.0,0,0)
      CALL ENDPLOT (20)
      CALL AXISXY (20,40.0,20.0,0.0,40.0,20.0,-2.,-2.,-2.0,-2.0)
17 CONTINUE
   CALL PLOT (0.0,0.0,-3)
   PRINT 38
C
18 FORMAT (I3,A6)
19 FORMAT (1X,14HNXPLOT  PROJCT)
20 FORMAT (1X,I6,A6)
21 FORMAT (F5.1,I4,2I4,F7.0,F7.2,5I4,F7.0,F9.3,2X,I1,4X,I1)
22 FORMAT (1H0,83H  TT  NOR  MM  NN   GRID   CCON NSH NCO NXCMAT NPT
  $NAX  CIN      HT   NOFRNT NEWRAY)
23 FORMAT (1X,F5.1,I4,2I4,F7.0,F7.2,2I4,2X,I5,2I4,F7.0,F9.3,I6,1X,I6)
24 FORMAT (20A4)
25 FORMAT (1H0,24HVARIABLE FORMAT FOR KMAT)
26 FORMAT (1X,20A4)
27 FORMAT (1H0,24HDEPTH GRID VALUES (KMAT))
28 FORMAT (A1)
29 FORMAT (5F8.2)
```

```
   30 FORMAT (1H0,31HSOUNDING VALUES TO BE CONTOURED)                       A 123
   31 FORMAT (1X,5F5.0)                                                     A 124
   32 FORMAT (F7.2,2F6.2,F3.0)                                              A 125
   33 FORMAT (1H0,22H ANGLE     X      Y  FAN)                              A 126
   34 FORMAT (1X,F7.2,2F6.2,F3.0)                                           A 127
   35 FORMAT (F7.2,4F6.2)                                                   A 128
   36 FORMAT (1H0,30H ANGLE   XST   YST  XEND  YEND)                        A 129
   37 FORMAT (1X,F7.2,4F6.2)                                                A 130
   38 FORMAT (17H1THIS IS THE END.)                                         A 131
      END                                                                   A 132-

 PROGRAM VARIABLES

01004 R   A          01001 I   KC        01003 I   N         00735 I   NPLCT     01006 R   X
00526 R   B          00772 I   KRAYS     00747 I   NAX       00746 I   NPT       01020 R   XEND
00750 R   HT         00724 I   LI        00744 I   NCC       00743 I   NSH       01014 R   XST
00774 I   I          00726 I   LII       00753 I   NEWRAY    00745 I   NXCPAT    01010 R   Y
03672 I   IVFT       00741 I   MM        00742 I   NN        00770 R   SCLI      01022 R   YEND
00776 I   J          00722 I   MPAX      00752 I   NOFRNT    00216 R   U         01016 R   YST
01024 I   K          00732 I   MXPLOT    00740 I   NOR       00362 R   V

 COMMON VARIABLES

17477 R   ANM        01372 R   C         17471 R   OCCN      17505 R   FAN       17513 R   RT
17501 R   ANN        17507 R   CIN       17473 R   DEP       17467 R   GRID      17462 R   TT
01404 R   AX         17444 R   CTOLR     17511 R   DT        00014 I   KPAT      17475 R   WL
13424 R   AY         17464 R   CXY       17503 R   DY        17466 I   MAX       00006 R   YVW
01402 R   BUFFER     17460 R   D         00000 R   E         17456 R   PROJCT

 DATA VARIABLES

00022 R   EM         00000 R   S

 STATEMENT NUMBERS

  1 01354        8 01620       15 02042       21 00013       27 00114       33 00152
  2 01523        9 01706       16 02052       22 00030       28 00125       34 00162
  3 01527       10 01717       17 02114       23 00057       29 00126       35 00167
  4 01600       11 01723       18 00000       24 00076       30 00130       36 00172
  5 01604       12 01777       19 00002       25 00100       31 00142       37 00204
  6 01610       13 02004       20 00010       26 00111       32 00145       38 00210
  7 01614       14 02014

                 FORTRAN DIAGNOSTIC RESULTS  FOR   SWAVE

  COMPILED LENGTHS OF SWAVE   - P   02160   C   17515   D   00062
NO ERRORS
```

```
      SUBROUTINE TITLE (NFLOT,NAX,SCLI,HT)
C     ----------------------------------------------------------------
C     THIS SLBRCUTINE REQUIRES THE FOLLOWING SUBROUTINES,PLCT,SYMBCL AND
C     NUMBER AND GRAF
C     ----------------------------------------------------------------
      CIMENSION IPRCJNC(21)
      CIMENSION S(3,3), EM(4,3), E(3), YVH(3), KMAT(25,30), C(4), BUFFER
     $(1), AX(1800), AY(1800), CTCUR(5), U(50), V(50), E(50), IVFT(21)
      COMMON /DATA/ S(3,3)
      COMMCN /DATA/ EM(4,3)
      COMMCN E,YVH,KMAT,C,BUFFER,AX,AY,CTOUR,PROJCT,D,TT,CXY,MAX,GRIC,
     $CCON,DEP,HL,AMM,ANN,DY,FAN,CIN,CT,RT
      RT = AMM/CY
      XNPLCT = NPLCT
      ENCODE (81,6,IPROJNC)
      CALL SYMBOL (-1.5,0.0,0.21,IPROJNC(1),90.,81)
      CALL NUMBER (-1.5,16.25,0.21,CIN*3600.,90.,-1)
      CALL NUMBER (-1.5,13.25,0.21,TT,90.,1)
      CALL NUMBER (-1.5,10.25,0.21,SCLI,90.,-1)
      CALL NUMBER (-1.5,07.75,0.21,XNFLCT,90.,-1)
      CALL SYMBOL (-1.5,02.88,0.21,CT,90.,8)
      CALL SYMBCL (-1.5,01.44,0.21,FRCJCT,90.,6)
      IF (NAX) 2,1,2
    1 CALL PLOT (0.0,0.0,3)
      CALL PLOT (0.0,HT,2)
      GO TO 3
    2 CALL GRAF (0.,0.,1RY,1,HT,90.,0.,CY)
      CALL GRAF (0.,0.,1RX,-1,RT,0.,0.,DY)
      CALL PLOT (0.0,HT,3)
    3 CALL PLOT (RT,HT,2)
      CALL PLOT (RT,0.0,2)
      IF (NAX) 5,4,5
    4 CALL PLOT (0.0,0.0,2)
    5 CALL PLOT (0.0,0.0,-3)
      YHT = HT
      RETURN
C
    6 FORMAT (81HIPRCJNC(1)                    , PLOT NO.   , SCL = 1/
     $ , TT =        , CIN =        )
      END
```

PRCGRAM VARIABLES

```
00363 R   B          00527 I   IVFT       00217 R   V          00554 R   XNPLOT     00614 R   YHT
00026 I   IPRCJNO    00053 R   U
```

COMMCN VARIABLES

```
17477 R   AMM        01372 R   C          17471 R   DCCN       17505 R   FAN        17513 R   RT
17501 R   ANN        17507 R   CIN        17473 R   DEP        17467 R   GRID       17462 R   TT
01404 R   AX         17444 R   CTCUR      17511 R   DT         00014 I   KMAT       17475 R   HL
13424 R   AY         17464 R   CXY        17503 R   DY         17466 I   MAX        00006 R   YVH
01402 R   BUFFER     17460 R   D          00000 R   E          17456 R   PRCJCT
```

DATA VARIABLES

```
00022 R   EM         00000 R   S
```

STATEMENT NUMBERS

```
1 00757            2 00772            3 01025            4 01043            5 01050            6 00000

                FCRTRAN CIAGNOSTIC RESLLTS FOR    TITLE

   CCMPILEC LENGTHS OF TITLE    - P   01124   C   17519   D   00052
NC ERRORS
```

```
      SUBROUTINE NUMCON (MM,NN,NCO)
C     ------------------------------------------------------------------
C     THIS SUBROUTINE REQUIRES THE FOLLOWING SUBROUTINES,PLOT,NUMBER
C     AND THE FUNCTION XMLUF.
C     ------------------------------------------------------------------
      DIMENSION S(3,3), EP(4,3), E(3), YVW(3), KMAT(25,30), C(4), BUFFER
     $(1), AX(1800), AY(1800), CTOUR(5), U(50), V(50), B(50), IVFT(21)
      COMMON /DATA/ S(3,3)
      COMMON /DATA/ EP(4,3)
      COMMON E,YVW,KMAT,C,BUFFER,AX,AY,CTOUR,PROJCT,D,T1,CXY,MAX,GRIC,
     $DCON,DEP,FL,ANM,ANN,DY,FAN,CIN,DT,RT
      NCO = NN-1
      MCO = MM-1
      DO 22 J=2,NCO
         YJ = J-1
         KKK = 1
         DO 13 KC=1,NCC
            KWIT = 0
            NDIF = 3
            I = MM-1
            DO 12 II=1,MOD
               XI = I-1
               IL = I+1
               XL = IL-1
               IF (KWIT) 1,1,13
1              IF (KMAT(I,J)) 2,2,3
2              KWIT = 1
3              IF (KMAT(I,J)*DCON-CTOUR(KC)) 5,4,7
4              AX(KKK) = XI
               AY(KKK) = CTOUR(KC)
               KKK = KKK+1
               NDIF = 3
               GO TO 12
5              GO TO (6,9,6), NDIF
6              NDIF = 1
               GO TO 12
7              GO TO (9,8,8), NDIF
8              NDIF = 2
               GO TO 12
9              SLPX = (DCON*(KMAT(IL,J)-KMAT(I,J)))/(XL-XI)
               XP = (CTOUR(KC)-DCON*KMAT(I,J))/SLPX+XI
               AX(KKK) = XP
               AY(KKK) = CTOUR(KC)
               KKK = KKK+1
               GO TO (10,11), NDIF
10             NDIF = 2
               GO TO 12
11             NDIF = 1
12          I = I-1
13       CONTINUE
         KKK = KKK-1
         IF (KKK-1) 22,17,14
14       KKL = KKK-1
         DO 16 IA=1,KKL
            IAD = IA+1
            DO 16 IB=IAD,KKK
               IF (AX(IA)-AX(IB)) 16,16,15
15             XMIN = AX(IA)
               AX(IA) = AX(IB)
               AX(IB) = XMIN
```

```
                XMIN = AY(IA)
                AY(IA) = AY(IB)
                AY(IB) = XMIN
   16     CCNTINUE
   17     IF (XPCDF(J,2)) 19,18,19
   18     KCNE = KKK
          KADC = -1
          LAST = +1
          GO TO 20
   19     KCNE = +1
          KADC = +1
          LAST = KKK
   20     CALL NUMBER (AX(KONE)/DY,YJ/DY,0.10,AY(KONE),0.0,-1)
          IF (KCNE-LAST) 21,22,21
   21     KCNE = KCNE+KACD
          GO TO 20
   22 CONTINLE
      CALL PLOT (0.,0.,-3)
      RETURN
      END

    PRCGRAM VARIABLES

00313 R   B        00522 I  IL      00533 I  KKL     00514 I  NCIF    00520 R  XI
00516 I   I        00454 I  IVFT    00541 I  KONE    00501 I  NCD     00823 R  XL
00534 I   IA       00504 I  J       00512 I  KWIT    00527 R  SLPX    00837 R  XMIN
00535 I   IAD      00542 I  KADC    00543 I  LAST    00000 R  U       00531 R  XP
00536 I   IB       00511 I  KC      00503 I  MOD     00144 R  V       00506 R  YJ
00517 I   II       00510 I  KKK

    CCMMCN VARIABLES

17477 R   AMM      01372 R  C       17471 R  OCCN    17505 R  FAN     17513 R  RT
17501 R   ANN      17507 R  CIN     17473 R  DEP     17467 R  GRIC    17462 R  TT
01404 R   AX       17444 R  CTOUR   17511 R  DT      00014 I  KPAT    17475 R  WL
10424 R   AY       17464 R  CXY     17503 R  DY      17466 I  MAX     00006 R  YVN
01402 R   BUFFER   17460 R  D       00000 R  E       17456 R  PROJCT

    DATA VARIABLES

00022 R   EM       00000 R  S

    STATEMENT NUMBERS

   1 00744      5 01001      9 01025     13 01112     17 01211     20 01236
   2 00751      6 01010     10 01073     14 01133     18 01217     21 01267
   3 00753      7 01013     11 01076     15 01154     19 01227     22 01274
   4 00764      8 01022     12 01103     16 01172

                 FORTRAN CIAGNOSTIC RESULTS  FOR    NUMCCN

   CCMPILED LENGTHS OF NUMCCN   - P   01350   C   17515   D   00052
NC ERRORS
```

```
      SUBROUTINE SHORE (MM,NN)
C     ------------------------------------------------------------------
C     THIS SUBROUTINE REQUIRES THE FOLLOWING SUBROUTINE, PLOT.
C     IT ALSO REQUIRES THE FUNCTION PCNTF
C     ------------------------------------------------------------------
      DIMENSION S(3,3), EM(4,3), E(3), YVH(3), KMAT(25,30), C(4), BUFFER
     $(1), AX(1800), AY(1800), CTOUR(5), U(50), V(50), B(50), IVFT(21)
      COMMON /DATA/ S(3,3)
      COMMON /DATA/ EM(4,3)
      COMMON E,YVH,KMAT,C,BUFFER,AX,AY,CTOUR,PROJCT,D,TT,DXY,MAX,GRID,
     $DCON,DEP,WL,AMM,ANN,DY,FAN,CIN,DT,RT
      IC = 3
      DO 17 J=1,NN
         YJ = J-1
         JL = J-1
         YL = JL-1
         I = MM
         DO 16 II=1,MM
            XI = I-1
            IL = I+1
            XL = IL-1
            IF (KMAT(I,J)) 1,5,13
1           IF (IC-2) 2,2,3
2           XP = PCNTF(XI,XL,KMAT(I,J),KMAT(IL,J))
            CALL PLOT (XP/DY,YJ/DY,IC)
            IC = 2
            GO TO 17
3           IF (J-1) 2,2,4
4           YP = PCNTF(YJ,YL,KMAT(1,J),KMAT(1,JL))
            CALL PLOT (0.,YP/DY,IC)
            IC = 2
            XP = PCNTF(XI,XL,KMAT(I,J),KMAT(IL,J))
            CALL PLOT (XP/DY,YJ/DY,IC)
            GO TO 17
5           IF (II-MM) 9,6,9
6           CALL PLOT (XI/DY,YJ/DY,IC)
            IF (IC-2) 7,7,8
7           IC = 3
            GO TO 17
8           IC = 2
            GO TO 17
9           IF (IC-2) 12,12,10
10          IF (J-1) 12,12,11
11          YP = PCNTF(YJ,YL,KMAT(1,J),KMAT(1,JL))
            CALL PLOT (0.,YP/DY,IC)
            IC = 2
12          CALL PLOT (XI/DY,YJ/DY,IC)
            IC = 2
            GO TO 17
13          IF (II-MM) 16,14,16
14          IF (IC-2) 15,15,17
15          YP = PCNTF(YJ,YL,KMAT(1,J),KMAT(1,JL))
            CALL PLOT (0.,YP/DY,IC)
            IC = 3
            GO TO 17
16       I = I-1
17    CONTINUE
      CALL PLOT (0.0,0.0,-3)
      RETURN
      END
```

```
    PROGRAM VARIABLES

00310 R   B        00916 I   IL       00507 I   JL       00514 R   XI       00505 R   YJ
00512 I   I        00454 I   IVFT     00000 R   U        00517 R   XL       00510 R   YL
00501 I   IC       00503 I   J        00144 R   V        00523 R   XP       00526 R   YP
00513 I   II

    COMMON VARIABLES

17477 R   AMM      01372 R   C        17471 R   OCCN     17505 R   FAN      17513 R   RT
17501 R   ANN      17507 R   CIN      17473 R   DEP      17467 R   GRID     17462 R   TT
01404 R   AX       17444 R   CTOUR    17511 R   DT       00014 I   KMAT     17475 R   WL
10424 R   AY       17464 R   CXY      17503 R   DY       17466 I   MAX      00006 R   YVN
01402 R   BUFFER   17460 R   D        00000 R   E        17456 R   PRC.CT

    DATA VARIABLES

00022 R   EM       00000 R   S

    STATEMENT NUMBERS

    1 00653      4 00717      7 01022     10 01035     13 01106     16 01147
    2 00663      5 00775      8 01025     11 01042     14 01113     17 01161
    3 00712      6 01002      9 01030     12 01070     15 01120

              FORTRAN DIAGNOSTIC RESULTS FOR   SHORE

  COMPILED LENGTHS OF SHORE    - P   01234   C   17515   D   00052
NO ERRORS
```

```
      SUBROUTINE GRAF (X,Y,BCD,NC,SIZE,THETA,YMIN,DY)
C     ----------------------------------------------------------------
C     THIS SUBROUTINE REQUIRES THE FOLLOWING SUBROUTINES,PLOT,SYMBOL AND
C     NUMBER.  IT ALSO REQUIRES THE FUNCTION MODF.
C     ----------------------------------------------------------------
C     MODIFIED FROM A CALCOMP SUBROUTINE OF THE SAME NAME.
C     REPRODUCED WITH PERMISSION FROM
C     CALIFORNIA COMPUTER PRODUCTS, INC.,ANAHEIM,CALIF.
      SIGN = 1.0
      IF (NC) 1,2,2
    1 SIGN = -1.0
    2 NAC = XABSF(NC)
      TH = THETA*0.017453294
      N = DY*SIZE+0.5
      CTH = COSF(TH)
      STH = SINF(TH)
      TN = N
      XB = X
      YB = Y
      XA = X-0.1*SIGN*STH
      YA = Y+0.1*SIGN*CTH
      CALL PLOT (XA,YA,3)
      DO 3 I=1,N
         CALL PLOT (XB,YB,2)
         XC = XB+CTH/DY
         YC = YB+STH/DY
         CALL PLOT (XC,YC,2)
         XA = XA+CTH/DY
         YA = YA+STH/DY
         CALL PLOT (XA,YA,2)
         XB = XC
    3 YB = YC
      ABSV = YMIN+TN
      XA = XB-(.20*SIGN-.05)*STH-.02857*CTH
      YA = YB+(.20*SIGN-.05)*CTH-.02857*STH
      N = N+1
      DO 6 I=1,N
         IF (MODF(ABSV,5.)) 5,4,5
    4    CALL NUMBER (XA,YA,0.1,ABSV,THETA,-1)
    5    ABSV = ABSV-1.
         XA = XA-CTH/DY
    6 YA = YA-STH/DY
      TNC = NAC+7
      XA = X+(SIZE/2.0-.06*TNC)*CTH-(-.07+SIGN*.36)*STH
      YA = Y+(SIZE/2.0-.06*TNC)*STH+(-.07+SIGN*.36)*CTH
      CALL SYMBOL (XA,YA,0.14,BCD,THETA,NAC)
      RETURN
      END
```

PROGRAM VARIABLES

00044	R	ABSV	00006	I	NAC	00011	R	TH	00032	R	XA	00034	R	YA
00016	R	CTH	00002	R	SIGN	00022	R	TN	00024	R	XB	00026	R	YB
00037	I	I	00020	R	STH	00056	R	TNC	00040	R	XC	00042	R	YC
00015	I	N												

STATEMENT NUMBERS

1 00103	2 00105	3 00220	4 00274	5 00306	6 00315

```
              FORTRAN DIAGNOSTIC RESULTS  FOR    GRAP

   COMPILED LENGTHS OF GRAP      = P   00465   C   00000   D   00000
NO ERRORS
```

```
      FUNCTION PONTF (X1,X2,D1,D2)                                      F   1
      PONTF = X1-D1*((X1-X2)/(D1-D2))                                   F   2
      END                                                               F   3-

              FORTRAN DIAGNOSTIC RESULTS  FOR    PONTF

   COMPILED. LENGTHS OF PONTF    - P   00060   C   00000   D   00000
NO ERRORS
```

```
      SUBROUTINE FRCNT (A,XST,YST,XEND,YEND,NOR,U,V)
      DIMENSION S(3,3), EM(4,3), E(3), YVW(3), KMAT(25,30), C(4), BUFFER
     $(1), AX(1800), AY(1800), CTOUR(5), U(50), V(50), B(50), IVFT(21)
      COMMCN /CATA/ S(3,3)
      COMMCN /CATA/ EM(4,3)
      COMMON E,YVW,KMAT,C,BUFFER,AX,AY,CTOUR,PROJCT,D,TT,CXY,MAX,GRIC,
     $CCON,DEP,WL,AMM,ANN,DY,FAN,CIN,DT,RT
      CNR = NOR-1
      KRAYS = NCR
      XINCR = (XENC-XST)/QNR
      YINCR = (YENC-YST)/QNR
      A = A*0.0174532925
      U(1) = XST
      V(1) = YST
      PI = 3.1415926536
      API = PI/2.
      AA = A-API
      DO 1 K=2,KRAYS
         U(K) = U(K-1)+XINCR
         V(K) = V(K-1)+YINCR
         DELX = U(K)-XEND
         DELY = V(K)-YEND
         IF (DELX.GE.0.0001.AND.DELY.GE.0.0001) 2,1
    1 CONTINLE
    2 NDEL = NCR-K+1
      IF (NDEL) 3,4,3
    3 FRINT 5
    4 CONTINLE
      RETURN
C
    5 FORMAT (1X,42HERRCR IN CALCULATION OF RAY STARTING POINT)
      END
```

PROGRAM VARIABLES

```
00233 R  AA        00234 R  DELX      00232 I  K         00222 R  PI        00212 R  XINCR
00226 R  API       00236 R  DELY      00211 I  KRAYS     00206 R  QNR       00214 R  YINCR
00015 R  B         00161 I  IVFT      00242 I  NDEL
```

COMMCN VARIABLES

```
17477 R  AMM       01372 R  C         17471 R  DCCN      17505 R  FAN       17513 R  RT
17501 R  ANN       17507 R  CIN       17473 R  DEP       17467 R  GRIC      17462 R  TT
01404 R  AX        17444 R  CTOUR     17511 R  DT        00014 I  KMAT      17475 R  WL
13424 R  AY        17464 R  CXY       17503 R  DY        17466 I  MAX       00006 R  YVW
01402 R  BUFFER    17460 R  D         00000 R  E         17456 R  PRCJCT
```

DATA VARIABLES

```
00022 R  EM        00000 R  S
```

STATEMENT NUMBERS

```
1 00343      2 00353      3 00363      4 00367      5 00C00
```

FCRTRAN DIAGNOSTIC RESULTS FOR FRONT

```
CCMPILED LENGTHS OF FRONT    - P  00455  C  17515  D  00052
NO ERRORS
```

```
      SUBROUTINE RAYN (X,Y,A,NPLOT,N,MMAX,LI,NPT,LII)
C     ------------------------------------------------------------------
C     THIS SUBROUTINE REQUIRES THE FOLLOWING SUBROUTINES,SURFCE,MOVE,
C     DATE(BINARY),PCD,STORE,AND DRAW
C     IT ALSO REQUIRES THE FUNCTION XMODF.
C     ------------------------------------------------------------------
      DIMENSION S(3,3), EM(4,3), E(3), YVW(3), KMAT(25,30), C(4), BUFFER
     $(1), AX(1800), AY(1800), CTOUR(5), U(50), V(50), B(50), IVFT(21)
      COMMON /DATA/ S(3,3)
      COMMON /LATA/ EM(4,3)
      COMMON E,YVW,KMAT,C,BUFFER,AX,AY,CTOUR,PROJCT,D,TT,CXY,MAX,GRID,
     $CCON,DEP,WL,ANM,ANN,DY,FAN,CIN,CT,RT
      NDP = 1
      NFK = 1
      NGO = 1
      KREST = 0
      KCIN = 0
      CALL SURFCE (X,Y,A,FK,NFK,NDP)
      CALL MOVE (X,Y,A,FK,NGO,MIT,NFK,NDP)
      TIME = 0.0
      ANGLE = A*57.29577951
      IF (NPT) 1,2,1
    1 PRINT 28, PROJCT,DT,NPLOT,TT,N
      PRINT 29
      GO TO 16
    2 IF (N-1) 4,4,3
    3 IF (XMODF(N,LII)) 5,4,5
    4 PRINT 30, PROJCT,CT,NPLOT,TT
      PRINT 31
    5 PRINT 32, N,MAX,X,Y,ANGLE,TIME
      GO TO 16
    6 MAX = 1+MAX
      IF (MAX+KCIN-MMAX) 8,7,7
    7 PRINT 33
      GO TO 25
    8 ZCXY = CXY
      CALL MOVE (X,Y,A,FK,NGO,MIT,NFK,NDP)
      GO TO (10,9), NDP
    9 PRINT 34
      GO TO 25
   10 GO TO (12,12,11), MIT
   11 PRINT 35
      GO TO 25
   12 IF (NPT) 13,15,13
   13 IF (XMODF(MAX,LI)) 15,14,15
   14 PRINT 28, PROJCT,DT,NPLOT,TT,N
      PRINT 29
   15 TIME = TIME+(D*GRID/(1800.*(CXY+ZCXY)))
      ANGLE = A*57.29577951
   16 IF (NPT) 17,18,17
   17 CALL PCD (C,E,PCTDIF)
      PRINT 36, MAX,X,Y,ANGLE,TIME,PCTDIF,DEP,D
   18 KMAX = MAX
      PX = X
      PY = Y
      CALL STORE (X,Y,A,KMAX,TIME,KCIN,KREST,MMAX)
      GO TO (21,19), MIT
   19 IF (NPT) 20,21,20
   20 PRINT 37
   21 IF (MAX-1) 22,22,23
```

```
22 GO TO (6,9), NDP
23 GO TO (0,24), NGO
24 PRINT 38
25 IF (NPT) 27,26,27
26 PRINT 39, N,KMAX,PX,PY,ANGLE,TIME
27 CALL DRAW (N,KMAX,KCIN,KREST)
   RETURN
C
28 FORMAT (1H1,11HPROJECT NO.,A6,2H, ,A8,10H, PLOT NO.,I3,10H, PERIOD
  $ =,F5.1,14H SEC., RAY NO.,I3,1H.//)
29 FORMAT (1H ,3X,3HMAX,6X,1HX,8X,1HY,8X,5HANGLE,6X,4HTIME,4X,
  $6HPCTDIF,5X,5HDEPTH,6X,1HD//)
30 FORMAT (12H1PROJECT NO.,A6,2H, ,A8,10H, PLOT NO.,I3,10H, PERIOD =,
  $F5.1,5H SEC.///)
31 FORMAT (8H RAY NO.,4X,3HMAX,6X,1HX,8X,1HY,8X,5HANGLE,6X,4HTIME//)
32 FORMAT (1H ,I6,1X,I7,2F9.2,F11.2,F10.3)
33 FORMAT (80X,36HDIMENSION OF OUTPUT-ARRAYS EXCEEDED.)
34 FORMAT (80X,18HRAY REACHED SHORE.)
35 FORMAT (80X,40HCURVATURE APPROXIMATIONS NOT CONVERGING.)
36 FORMAT (I7,2F9.2,F11.2,F10.3,F10.1,F10.2,F10.3)
37 FORMAT (1H+,80X,19HCURVATURE AVERAGED.)
38 FORMAT (80X,26HRAY REACHED GRID BOUNDARY.)
39 FORMAT (1H+,I6,1X,I7,2F9.2,F11.2,F10.3,//)
   END
```

PROGRAM VARIABLES

00754 R	ANGLE	00742 I	KCIN	00734 I	NDP	00767 R	PX	00233 R	U		
00543 R	B	00766 I	KMAX	00736 I	NFK	00771 R	PY	00377 R	V		
00743 R	FK	00740 I	KREST	00737 I	NGO	00750 R	TIME	00752 R	ZCXY		
00707 I	IVFT	00745 I	MIT	00764 R	PCTDIF						

COMMON VARIABLES

17477 R	ANM	01372 R	C	17471 R	DCON	17505 R	FAN	17513 R	RT		
17501 R	ANN	17507 R	CIN	17473 R	DEP	17467 R	GRID	17462 R	TT		
01404 R	AX	17444 R	CTCLR	17511 R	DT	00014 I	KMAT	17475 R	WL		
01424 R	AY	17464 R	CXY	17503 R	DY	17466 I	MAX	00006 R	YVN		
01402 R	BUFFER	17460 R	D	00000 R	E	17456 R	PROJCT				

DATA VARIABLES

00022 R	EM	00000 R	S

STATEMENT NUMBERS

1 01042	8 01157	15 01256	22 01374	28 00000	34 00143
2 01065	9 01201	16 01274	23 01402	29 00030	35 00152
3 01072	10 01206	17 01300	24 01410	30 00055	36 00167
4 01100	11 01215	18 01331	25 01414	31 00100	37 00201
5 01120	12 01222	19 01357	26 01420	32 00117	38 00211
6 01141	13 01226	20 01363	27 01440	33 00127	39 00222
7 01152	14 01234	21 01367			

FORTRAN DIAGNOSTIC RESULTS FOR RAYN

COMPILED LENGTHS OF RAYN - P 01553 C 17515 D 00052
NO ERRORS

```
      SUBROUTINE MCVE (X,Y,A,FK,NGC,MIT,NFK,NDP)
C     ----------------------------------------------------------------
C     THIS SUBROUTINE REQUIRED THE FOLLOWING SUBROUTINE,SURFCE.
C     ----------------------------------------------------------------
      DIMENSION S(3,3), EP(4,3), E(3), YVW(3), KMAT(25,30), C(4), BUFFER
     $(1), AX(1800), AY(1800), CTOUR(5), U(50), V(50), B(50), IVFT(21)
      COMMON /DATA/ S(3,3)
      COMMON /DATA/ EP(4,3)
      COMMON E,YVW,KMAT,C,BUFFER,AX,AY,CTOUR,PROJCT,G,TT,CXY,MAX,GRID,
     $CCON,DEP,WL,AMM,ANN,DY,FAN,CIN,DT,RT
      MIT = 1
      GO TO (1,2), NFK
    1 D = 0.5
      GO TO 4
    2 D = DEF/WL
      IF (D/DY-.005) 3,3,4
    3 D = DY*.005
    4 IF (MAX-2) 21,5,6
    5 FKBAR = FK
    6 DO 14 IT=1,20
    7    DELA = FKBAR*D
         AA = A+DELA
         ABAR = A+.5*DELA
         DELX = D*COSF(ABAR)
         DELY = D*SINF(ABAR)
         XX = X+DELX
         YY = Y+DELY
         CALL SURFCE (XX,YY,AA,FKK,NFK,NDP)
         GO TO (8,17), MIT
    8    GO TO (9,21), NDP
    9    FKBAR = 0.5*(FK+FKK)
         IF (IT-10) 11,10,13
   10    FKKPP = FKBAR
   11    IF (MAX-2) 12,12,13
   12    IF (IT-1) 14,14,13
   13    IF (ABSF(FKKP-FKBAR)-(0.00009/D)) 17,17,14
   14 FKKP = FKBAR
      IF (ABSF(FKKPP-FKBAR)-(0.00009/D)) 16,16,15
   15 MIT = 3
      GO TO 21
   16 FKBAR = 0.5*(FKBAR+FKKP)
      MIT = 2
      GO TO 7
   17 IF ((XX-0.5)*((AMM-0.5)-XX)) 19,19,18
   18 IF ((YY-0.5)*((ANN-0.5)-YY)) 19,19,20
   19 NGO = 2
   20 X = XX
      Y = YY
      A = AA
      FK = FKK
   21 RETURN
      END
```

PROGRAM VARIABLES

00517	R	AA	00523	R	DELX	00533	R	FKK	00513	I	IT	00144	R	V
00521	R	ABAR	00525	R	DELY	00542	R	FKKP	00454	I	IVFT	00527	R	XX
00310	R	B	00511	R	FKBAR	00536	R	FKKPP	00000	R	U	00531	R	YY
00515	R	DELA												

```
    COMMON VARIABLES

17477 R    AMM          01372 R    C          17471 R    DOCN         17505 R    FAN          17513 R    RT
17501 R    ANN          17507 R    CIN        17473 R    DEP          17467 R    GRIC         17462 R    TT
01434 R    AX           17444 R    CTOUR      17511 R    DT           00014 I    KMAT         17475 R    NL
10424 R    AY           17464 R    CXY        17503 R    DY           17466 I    MAX          00006 R    YVW
01402 R    BUFFER       17460 R    D          00000 R    E            17456 R    PROJCT

    DATA VARIABLES

00322 R    EM           00000 R    S

    STATEMENT NUMBERS

      1 00556           5 00602           9 00662          13 00707          16 00756          19 01011
      2 00561           6 00604          10 00673          14 00725          17 00765          20 01013
      3 00572           7 00606          11 00675          15 00753          18 00777          21 01023
      4 00575           8 00654          12 00702

                  FORTRAN DIAGNOSTIC RESULTS FOR    MOVE

   COMPILED LENGTHS OF MOVE     - P   01101   C   17515  D   00052
NO ERRORS
```

```
      SUBROUTINE SURFCE (X,Y,A,FK,NFK,NDP)
C     ----------------------------------------------------------------
C     THIS SUBROUTINE REQUIRES THE FOLLOWING SUBROUTINES, VELCTY,
C     AND CONDER
C     ----------------------------------------------------------------
      DIMENSION S(3,3), EM(4,3), E(3), YVW(3), KMAT(25,30), C(4), BUFFER
     $(1), AX(1800), AY(1800), CTOUR(5), U(50), V(50), B(50), IVFT(21)
      COMMON /DATA/ S(3,3)
      COMMON /DATA/ EM(4,3)
      COMMON E,YVW,KMAT,C,BUFFER,AX,AY,CTOUR,PROJCT,D,TT,CXY,MAX,GRID,
     $DCON,DEP,WL,AMM,ANN,DY,FAN,CIN,DT,RT
      I = X+1.
      J = Y+1.
      FI = I
      FJ = J
      XL = X+1.-FI
      YL = Y+1.-FJ
      IF (MAX-1) 3,3,1
    1 IF (ZI-FI) 3,2,3
    2 IF (ZJ-FJ) 3,6,3
    3 ZI = FI
      ZJ = FJ
      C(1) = KMAT(I,J)
      C(2) = KMAT(I+1,J)
      C(3) = KMAT(I+1,J+1)
      C(4) = KMAT(I,J+1)
      DO 4 II=1,3
         YVW(II) = 0.
         DO 4 L=1,4
    4 YVW(II) = YVW(II)+C(L)*EM(L,II)
      DO 5 II=1,3
         E(II) = 0.
         DO 5 JJ=1,3
    5 E(II) = E(II)+S(II,JJ)*YVW(JJ)
    6 DEP = (E(1)+E(2)*XL+E(3)*YL)*DCON
      IF (DEP) 7,7,8
    7 NDP = 2
      GO TO 14
    8 IF ((DEP/WL)-0.5) 9,9,10
    9 NFK = 2
      GO TO 11
   10 NFK = 1
   11 CALL VELCTY (CXY,TT,MAX,DEP,NFK)
      PCX = E(2)*DCON
      PCY = E(3)*DCON
      DN = -PCX*SINF(A)+PCY*COSF(A)
      CALL CONDER (DN,TT,CXY,MAX,NFK)
      GO TO (12,13), NFK
   12 FK = 0.0
      GO TO 14
   13 FK = -DN/CXY
   14 RETURN
      END
```

PROGRAM VARIABLES

```
00310 R  B       00503 I  I       00534 I  JJ      00000 R  U       00513 R  YL
00543 R  DN      00527 I  II      00532 I  L       03144 R  V       00520 R  ZI
00505 R  FI      00454 I  IVFT    00537 R  PCX     00511 R  XL      00523 R  ZJ
00507 R  FJ      00504 I  J       00541 R  PCY
```

```
     COMMON VARIABLES

 17477 R   AMM        01372 R   C          17471 R   DOCN       17505 R   FAN        17513 R   AT
 17501 R   ANN        17507 R   CIN        17473 R   DEP        17467 R   GRID       17462 R   TT
 01404 R   AX         17444 R   CTCUR      17511 R   DT         00014 I   KMAT       17475 R   NL
 10424 R   AY         17464 R   CXY        17503 R   DY         17466 I   MAX        00336 R   YVN
 01402 R   BUFFER     17460 R   D          00000 R   E          17456 R   PROJCT

     DATA VARIABLES

 00022 R   EM         00000 R   S

     STATEMENT NUMBERS

       1 00702           4 00744           7 01042           9 01053          11 01060          13 01130
       2 00707           5 01000           8 01045          10 01056          12 01122          14 01133
       3 00714           6 01025

               FORTRAN DIAGNOSTIC RESULTS  FOR    SURFCE

   COMPILED LENGTHS OF SURFCE   - P   01202   C   17515   D   00052
NO ERRORS
```

MS FORTRAN (4.2)/MSOS 12/07/72

```
      SUBROUTINE VELCTY (CXY,TT,MAX,DEP,NFK)
      IF (MA)-1) 1,1,2
    1 BAR = 6.2831854/TT
      CXXO = TT*32.2/6.2831854
      CCC = CXXO
      GO TO 3
    2 CCC = XCXY
    3 GO TO (4,5), NFK
    4 CXY = CXXO
      GO TO 7
    5 CO 6 M=1,90
         CXY = CXXC*TANHF(BAR*DEP/CCC)
         IF (ABSF(CXY-CCC)-.JJJ05) 7,6,6
    6 CCC = (CXY+CCC)/2.
    7 XCXY = CXY
      RETURN
      END
```

PROGRAM VARIABLES

```
00003 R   BAR        00011 R   CCC        00007 R   CXXO        00016 I   M        00013 R   XCXY
```

STATEMENT NUMBERS

```
1 00033        3 00047        4 00055        5 00060        6 00103        7 00115
2 00045
```

FORTRAN DIAGNOSTIC RESULTS FOR VELCTY

```
COMPILED LENGTHS OF VELCTY   - P  00161   C  00000   D  00000
NO ERRORS
```

```
                                   MS FORTRAN (4.2)/MSOS          12/07/72
          SUBRCUTINE CCNDER (CN,TT,CXY,MAX,NFK)
          REAL LCGF
          IF (MAX-1) 1,1,2
        1 C1 = TT/12.5663708
          C2 = 6.2831854/(32.2*TT)
        2 GC TC (4,3), NFK
        3 C3 = C2*CXY
          A1 = C2/(1.+C3)
          A2 = C3/(1.-C3)
          A3 = LCGF(1.+C3)
          A4 = LCGF(1.-C3)
          CN = (CN/C1)*(1./(A1+A2+A3-A4))
        4 RETURN
          END

      PRCGRAM VARIABLES

  00023 R    A1          00024 R    A3          00003 R    C1          00011 R    C2          00014 R    C3
  00022 R    A2          00026 R    A4

      STATEMENT NUMBERS

        1 00037          2 00050          3 00056          4 00125

                   FORTRAN DIAGNOSTIC RESULTS  FOR    CONDER

   CCMPILED LENGTHS OF CCNDER   - P   00166   C   00000   D   00000
NC ERRCRS
```

```
                         MS FORTRAN (4.2)/MSOS            12/07/72
      SUBROUTINE PCD (C,E,PCTDIF)
      DIMENSION C(4), E(3)
      REAL MAXIF
      IF (C(1)*C(2)*C(3)*C(4)) 2,1,2
    1 PCTDIF = 999.
      GO TO 3
    2 P1 = ABSF((C(1)-E(1))/C(1))
      P2 = ABSF((C(2)-E(1)-E(2))/C(2))
      P3 = ABSF((C(3)-E(1)-E(2)-E(3))/C(3))
      P4 = ABSF((C(4)-E(1)-E(3))/C(4))
      PCTDIF = 100.*MAXIF(P1,P2,P3,P4)
    3 RETURN
      END

    PROGRAM VARIABLES

  00002 R    P1          00004 R    P2          00006 R    P3          00010 R    P4

    STATEMENT NUMBERS

     1 00025          2 00030          3 00077

               FORTRAN DIAGNOSTIC RESULTS  FOR    PCD

   COMPILED LENGTHS OF PCD      - P   00173   C   00000   D   00000
 NO ERRORS
```

```
      SUBROUTINE STORE (X,Y,A,KMAX,TIME,KCIN,KREST,MMAX)
      DIMENSION S(3,3), EM(4,3), E(3), YVN(3), KMAT(25,30), C(4), BUFFER
     $(1), AX(1800), AY(1800), CTOUR(5), U(50), V(50), B(50), IVFT(21)
      COMMON /DATA/ S(3,3)
      COMMON /DATA/ EM(4,3)
      COMMON E,YVN,KMAT,C,BUFFER,AX,AY,CTOUR,PROJCT,D,TT,CXY,MAX,GRID,
     $DCON,DEP,WL,AMM,ANN,DY,FAN,CIN,DT,RT
      IF (CIN) 3,3,1
    1 IF (KMAX-1) 2,2,5
    2 AT = 0.0
    3 K = KMAX+KCIN
      IF (K.GT.MMAX.OR.K.LE.0) GO TO 8
      AX(K) = X
      AY(K) = Y
      IF (CIN) 9,9,4
    4 ZA = A
      ZCXY = CXY
      GO TO 9
    5 ET = TIME-AT
      IF (CIN-ET) 7,6,3
    6 K = KMAX+KCIN
      IF (K.GT.MMAX.OR.K.LE.0) GO TO 8
      AX(K) = -X
      AY(K) = Y
      KREST = KREST+1
      AT = AT+CIN
      GO TO 4
    7 DSC = (ET-CIN)*(CXY+ZCXY)*3600./(GRID*2.)
      AA = (A+ZA)/2.
      XM = DSC*COSF(AA)
      YM = DSC*SINF(AA)
      K = KMAX+KCIN
      IF (K.GT.MMAX.OR.K.LE.0) GO TO 8
      AX(K) = -X+XM
      AY(K) = Y-YM
      KREST = KREST+1
      KCIN = KCIN+1
      AT = AT+CIN
      GO TO 5
    8 CONTINUE
    9 RETURN
      END
```

```
   PROGRAM VARIABLES

00524 R   AA        00522 R   DSC       00506 I   K         00526 R   XM        00510 R   ZA
00504 R   AT        00514 R   ET        00000 R   U         00530 R   YM        00512 R   ZCXY
00310 R   B         00454 I   IVFT      00144 R   V

   COMMON VARIABLES

17477 R   AMM       01372 R   C         17471 R   DCON      17505 R   FAN       17513 R   RT
17501 R   ANN       17507 R   CIN       17473 R   DEP       17467 R   GRID      17462 R   TT
01404 R   AX        17444 R   CTOUR     17511 R   DT        00014 I   KMAT      17475 R   WL
13424 R   AY        17464 R   CXY       17503 R   DY        17466 I   MAX       00006 R   YVN
01402 R   BUFFER    17460 R   D         00000 R   E         17456 R   PROJCT

   DATA VARIABLES

00022 R   EM        00000 R   S
```

```
STATEMENT NUMBERS

 1 00552            3 00561            5 00614            7 00655            8 00745            9 00746
 2 00557            4 00607            6 00624

               FORTRAN DIAGNOSTIC RESULTS  FOR    STORE

  COMPILED LENGTHS OF STORE    - P   01034   C   17515   D   00052
NO ERRORS
```

```
      SUBROUTINE DRAW (N,KMAX,KCIN,KREST)
C     ------------------------------------------------------------------
C     THIS SUBROUTINE REQUIRES THE FOLLOWING SUBROUTINES,PLOT AND
C     NUMBER.
C     ------------------------------------------------------------------
      DIMENSION S(3,3), EM(4,3), E(3), YVW(3), KMAT(25,30), C(4), BUFFER
     $(1), AX(1800), AY(1800), CTOUR(5), U(50), V(50), 8(50), IVPT(21)
      COMMON /DATA/ S(3,3)
      COMMON /CATA/ EM(4,3)
      COMMON E,YVW,KMAT,C,BUFFER,AX,AY,CTOUR,PROJCT,D,TT,CXY,MAX,GRID,
     $CCON,DEP,WL,APM,ANN,DY,FAN,CIN,DT,RT
      XN = N
      KMAX = KMAX+KCIN
      IF (AX(KMAX)) 1,2,2
    1 AX(KMAX) = -AX(KMAX)
      KREST = KREST-1
    2 IF (XMODF(N,2)) 6,3,6
    3 KTWO = KMAX-1
      KADD = -1
      LAST = +1
      MC = KREST+1
      IF (FAN) 4,5,4
    4 CALL NUMBER (AX(KMAX)/DY,AY(KMAX)/DY,0.35/DY,XN,0.0,-1)
    5 CALL PLOT (AX(KMAX)/DY,AY(KMAX)/DY,3)
      IF (KMAX-1) 17,17,9
    6 KTWO = +2
      KADD = +1
      LAST = KMAX
      MC = 0
      IF (FAN) 8,7,8
    7 CALL NUMBER (AX(1)/DY,AY(1)/DY,0.35/DY,XN,0.0,-1)
    8 CALL PLOT (AX(1)/DY,AY(1)/DY,3)
      IF (KMAX-1) 17,17,9
    9 IF (CIN) 11,11,10
   10 IF (AX(KTWO)) 12,11,11
   11 CALL PLOT (AX(KTWO)/DY,AY(KTWO)/DY,2)
      GO TO 15
   12 AX(KTWO) = -AX(KTWO)
      WI = 0.05
      MC = MC+KADD
      IF (XMODF(MC,10)) 14,13,14
   13 WI = 0.10
   14 XPN = AX(KTWO)/DY
      YPN = AY(KTWO)/DY
      K = KTWO-KADD
      XPL = AX(K)/DY
      YPL = AY(K)/DY
      CSC = SQRTF((ABS(XPN-XPL))**2+ABS(YPN-YPL)**2)
      CALL PLOT (XPN,YPN,2)
      XB = +WI*(YPN-YPL)/CSC
      YB = -WI*(XPN-XPL)/CSC
      CALL PLOT (XPN+XB,YPN+YB,2)
      CALL PLOT (XPN-XB,YPN-YB,2)
      CALL PLOT (XPN,YPN,2)
   15 IF (KTWO-LAST) 16,17,16
   16 KTWO = KTWO+KADD
      GO TO 5
   17 IF (KADD) 18,20,20
   18 IF (FAN) 22,19,22
   19 CALL NUMBER (AX(1)/DY,AY(1)/DY,0.35/DY,XN,0.0,-1)
```

```
      GO TO 22                                                          0  61
   20 IF (FAN) 21,22,21                                                 0  62
   21 CALL NUMBER (AX(KMAX)/DY,AY(KMAX)/DY,0.35/DY,XN,0.0,-1)           0  63
   22 RETURN                                                            0  64
      END                                                               0  65-

    PROGRAM VARIABLES

00310 R    B          00507 I   KADD       00000 R   U        00501 R   XN       00543 R   YB
00537 R    DSC        00506 I   KTWO       00144 R   V        00533 R   XPL      00535 R   YPL
00454 I    IVFT       00510 I   LAST       00522 R   WI       00526 R   XPN      00530 R   YPN
00532 I    K          00511 I   MC         00541 R   XB

    COMMON VARIABLES

17477 R    AMM        01372 R   C          17471 R   DOCN     17505 R   FAN      17513 R   RT
17501 R    ANN        17507 R   CIN        17473 R   DEP      17467 R   GRIC     17462 R   TT
01404 R    AX         17444 R   CTOUR      17511 R   DT       00014 I   KMAT     17475 R   WL
10424 R    AY         17464 R   CXY        17503 R   DY       17466 I   MAX      00006 R   YVN
01432 R    BUFFER     17460 R   D          00000 R   E        17456 R   PROJCT

    DATA VARIABLES

00022 R    EM         00000 R   S

    STATEMENT NUMBERS

   1 00621       5 00730       9 01001      13 01045      17 01203      20 01237
   2 00627       6 00721      10 01005      14 01047      18 01207      21 01243
   3 00635       7 00736      11 01012      15 01171      19 01213      22 01267
   4 00654       8 00761      12 01027      16 01176

              FORTRAN DIAGNOSTIC RESULTS  FOR    DRAW

   COMPILED LENGTHS OF DRAW     - P   01342   C   17515   D   00052
NO ERRORS
```

```
      FUNCTICN TANHF (X)
      A = EXP(X)
      B = EXP(-X)
      TANHF = (A-B)/(A+B)
      END

   PRCGRAM VARIABLES

 00002 R    A          00004 R    B

             FCRTRAN DIAGNOSTIC RESULTS  FOR    TANHF

  CCMPILED LENGTHS OF TANHF    - P  00061  C  00000  D  00000
NC ERRORS
```

```
                                   MS FORTRAN (4.2)/MSOS          12/07/72
          FUNCTION XMODF (I,J)                                                  0   1
          XMODF = MOD(I,J)                                                      0   2
          END                                                                   0   3-

                FORTRAN DIAGNOSTIC RESULTS  FOR    XMODF

   COMPILED LENGTHS OF XMODF    = P   00036   C   00000   D   00000
NO ERRORS
```

MS FORTRAN (4.2)/MSOS 12/07/72

```
      FUNCTION MODF (X,Y)                                          R  1
      I = X+0.5                                                    R  2
      J = Y+0.5                                                    R  3
      MODF = MOD(I,J)                                              R  4
      END                                                          R  5-
```

PROGRAM VARIABLES

00003 I   I   00004 I   J

FORTRAN DIAGNOSTIC RESULTS FOR MODF

COMPILED LENGTHS OF MODF - P 00050 C 00000 D 00003
NO ERRORS

```
      SUBROUTINE PLOTS (IBUF,NLCO,LDEV)
      IF (ISW-1) 2,1,2
    1 CALL ENDPLOT (20)
    2 CALL APICHY (20,40.0,20.0,0.0,40.0,20.0,-2.,-2.,-1.0,-2.0)
      ISW = 1
      RETURN
      END
```

PROGRAM VARIABLES

```
00001 I    ISW
```

STATEMENT NUMBERS

```
1 00022            2 00025
```

FORTRAN DIAGNOSTIC RESULTS FOR PLOTS

```
COMPILED LENGTHS OF PLOTS   - P   00104   C   00000   D   00000
NO ERRORS
```

```
                              MS FORTRAN (4.2)/MSOS          12/07/72
      SUBROUTINE PLOT (X,Y,IPEN)
      IF (ISW) 5,1,5
    1 CONTINUE
      GO TO (3,2), SSWTCHF(6)
    2 CALL LEADER
      GO TO 4
    3 CONTINUE
    4 CONTINUE
      CALL AXISXY (20,40.0,20.0,0.0,40.0,20.0,-2.,-2.,-2.0,-2.0)
      ISW = 1
    5 CONTINUE
      IF (IPEN) 6,6,7
    6 ISW = 0
      CALL PLOTXY (-2.0,-2.0,0,0)
      CALL ENDPLOT (20)
      RETURN
    7 CONTINUE
      IP = IABS(3-IPEN)
      CALL PLOTXY (X,Y,IP,0)
      RETURN
      ENTRY WHERE
      RETURN
      END

    PROGRAM VARIABLES

 00017 I    IP           00001 I    ISW

    STATEMENT NUMBERS

     1 00026         3 00041         4 00042         5 00071         6 00076         7 00116
     2 00036

              FORTRAN DIAGNOSTIC RESULTS  FOR    PLOT

   COMPILED LENGTHS OF PLOT     - P  00176   C   00000   D   00000
NO ERRORS
TIME    002.38 MIN
EQUIP,51=MTCOEGU01
LOAD,56
RUN
```

SUBP

36373	SIGNF	36410	UNIT	36515	BUFFER	37225	TAPCHAND	37444	PAUSE	37531	WHATKIND
37570	CHNRTNS	40044	MTLOCPRR	40126	TYPEOUT.	40324	WHATISIT	40623	NRD	41015	NRC
41122	T.NOTRDY	41145	NWR	41212	RAAR	41271	MTWPRR	41513	MTWINS	42013	MTWPRR
42311	MTDER	42327	CRDER	42371	CPDER	42501	PRCPR	42517	SCAR	43072	SYMBOL
44036	NUMBER	44436	MOD	44477	XL	44515	CHARTF	44554	Q1CSPLOT	44575	C1OSCPLT
45453	MTCRPT	45475	DRIV3691	46500	ROWR5	46541	WRITET	47124	XYMOVE	50232	PLATZ
51052	C8CERROR	51321	EXTREMA1	51426	SENSWTCH	51472	ABSF	51503	FIXF	51543	FLCATF
51597	.SINCOS	52064	LOGF	52264	SQRTF	52365	PCWRF	52477	XTOI	52722	EXPF
53045	C1CADRI	53232	CIO.MSIO	53654	CONTROL	54652	BCDINP	56005	FORMAT	56420	BCDOUT
60243	DATE	60314	DATEX	60324	PLOT	60522	FLOTS	60626	MODF	63676	XMODF
63734	TANHF	61315	DRAW	62357	STORE	63413	PCD	63606	CONCER	63774	VELCTY
64155	SURFCE	65357	MOVE	66460	RAYN	70233	FRONT	70710	PCHIF	70770	GRAF
71455	SHORE	72711	NUMCON	74261	TITLE	75457	SWAVE				

ENTR

36373	XSIGNF	36373	SIGN	36373	SIGNF	36410	UNITST	37057	LENGTHF	36515	Q8QBUFIN
37337	C8CREWND	37464	Q8QPAUSE	40422	MTEXIT2	41133	TN.EXIT	41125	TN.E1	41126	TN.CIO
41143	TN.OUT	41134	TN.REJ1	41137	TN.REJ2	41122	T.NOTRDY	41145	NWR	41015	NRC
40712	BCR..	42011	IC.GATE	42012	FC..	41753	CUMMY..	43542	AETHCW	43593	PRGNAME
40126	TYPEOUT.	41570	STATUS..	41604	WRITE..	41622	ERASE..	41636	WRITED..	41627	READB..
41614	READCALL	41617	READMODE	41610	WRTMCDE	41654	NOISE..	41630	RCBCALL	41641	MODE..
40625	NRC	41737	SNR	40324	WHATISIT	40410	MTEXIT	40049	MTLOCPRR	42013	MTWPRR
41333	MTRPRR	41333	NPCHECK	37777	CIOREJ	37735	REJECT	37612	CICCALL	37570	CHNRTN
37627	INIST	37635	STNMIHS	40023	STATBUF	37652	BEGRTN	40015	STCREUFF	37621	CALLSTAT
37722	CHFRCPE	37643	STOPTPRT	40016	RTNEXT	37646	INDX3	37720	INDX33	42501	PRCPR
42371	CPDER	42327	CRDER	42319	MTDER	42311	MTDERNM	40431	SUMCHECK	43462	TAB.SRCH
43592	CKSMFLAG	41511	FLAG..	41763	MTSTB	41613	READ..	41510	SETUP..	40771	CHKNCISE
40623	NSR..	41563	BKSP..	40543	USTWD2	40577	SRF	43070	SCARUST1	42924	SCARNM
44554	CICSPLCT	36373	ISIGN	44515	TFCHAR	46211	RPT4.4	46130	HCGKRD5	46471	CCCEIND
45503	DRIVER07	45475	DRIVER06	46471	FLG1CH	46533	READ5	37444	Q8CSTOP	37227	Q8QBACKS
37331	C8CENFIL	36523	Q8QBUFOT	46517	WRITES	36413	UNITSTP	45453	MTCRPT	46711	WRITET
44643	CICSUPLT	47650	XYMOVE	47151	PERRNUMB	47414	LABLE	47124	INITFL	47320	ISC
47569	TICK	51034	LABELY	51033	LABELX	51036	IY	51035	IX	51045	Q1CRLSW
51332	MIN1	51327	MAX1	51324	AMIN1	51321	AMAX1	51332	XMIN1F	51327	XMAX1F
51324	MIN1F	51426	SSWTCH	51503	XFIXF	51503	IFIX	51543	FLOAT	51597	COS
51565	SIN	52064	ALOG10	52064	LOG10F	52067	ALOG	52264	SQRT	52365	POWRF
51543	FLCATF	52477	XTOI	52722	EXPF	51503	FIXF	53127	Q1QDVRX	53152	Q1QDVXR
53233	C1CSTRX	53155	Q1QSTXR	53147	Q1QMLXR	53144	C1CSEXR	53133	Q1QACXR	53152	Q1QDVIR
53144	C1CSBIR	53133	Q1QADIR	53123	Q1QMURX	53117	Q1CSERX	53077	Q1CACRX	53073	C1CDVRI
53063	C1CSBRI	53045	Q1QADRI	53457	Q8QECFRC	53634	Q8QFCTAB	42517	SCAR	54472	RAARREJ
54161	C8CMSIG	54516	Q8QINFMS	54533	Q8QRJMES	54447	C8QCCNVT	53743	Q8CARRAY	53723	Q8QIOTAB
53657	C8CEXITS	53684	Q8QENTRY	53654	UTESLMIT	51052	C8CERRCR	54526	PWRIELD	54457	Q8CBCCWT
55631	NCBCIABT	55625	DCIABTON	55637	NOBCILJS	55634	BCILJSCN	54753	Q8QLGINC	51163	Q9QERROR
53703	C8CIOSET	53665	Q8QSENSE	54250	Q8QECITS	53232	CIO.MSIO	56335	Q8CIFRMT	56343	Q8CFORMT
54473	PRCGNAME	53655	Q8QOUTTB	37531	WHATKIND	54103	C8QICSVB	53774	Q8CICERR	54530	PWRTBL
41212	RAAR	57161	LEDZER.F	56663	LEDZER.I	56522	C8QLGOTC	60314	DATEX	60460	WHERE
51472	IABS	44477	LEADER	51431	SSWTCHF	44437	MOD	52722	EXP	52477	Q1CEXRI
51472	ABS	52264	SQRTF	51321	MAX1F	52367	LOGF	63742	TANHF	63636	CONCER
64020	VELCTY	51472	ABSF	61620	DRAW	63123	STORE	63427	PCD	66123	MOVE
65020	SURFCE	53166	Q1QSTRI	60633	MODF	51565	SINF	51557	COSF	51472	XABSF
70712	PCNTF	53067	Q1QMURI	53147	Q1QMUIR	60700	XMODF	71063	GRAF	44375	NUMBER
43375	.SYMBOL	53155	Q1QSTIR	52374	Q1QEXRR	56535	C8QLGOTR	56530	Q8QLGOTI	57260	Q8GENGOT
56420	C8CINGOT	55447	Q8QENGIN	54764	Q8QLGINR	54760	C8QLGINI	54652	Q8GINGIN	60344	PLOT
50232	AXISXY	47327	ENDPLOT	50743	PLOTXY	70511	FRONT	67453	RAYN	72280	SHORE
73600	NUMCON	75077	TITLE	63246	DATE	63535	FLOTS	76633	SWAVE	10600	FGPBCXS
12206	LST	00240	UC	13225	START2	10323	SETCLOCK	01366	SEL	04661	RSTCREQ
04646	RSTCRE	02164	RPT	12654	RIO	12315	RHT	12515	RCCKF1	11566	PERRACD
10577	NCEXIT	03352	MSIO.SP	04725	MSIOFLG	03202	MSIO	11564	MIFORADD	11537	MIBUF
11567	MIBKADD	12477	MEMCRY	12375	LOCS	13473	LOADMSIO	14002	LCACER	12733	LENGRCT
00644	ICCCN	10567	ICP	12265	EST.	10214	EINT.	10200	DINT.	12251	CST
12376	CIT.RTP	12430	CIT	10357	CIP	07246	CIC3.01	07400	CIC2.2	00367	CIC6.7

```
 00043  CIO         12335  BRHT        12645  BNJ.        13572  BLCK.CH1    12464  BKALAFLG    10576  BKEXIT
 35213  BK.SP       11565  BERRADD     11364  BCDBUF      12430  ALGOPT      12143  AET         00025  ACCCLNTS
 10600  ABNORMAL

LDTA
    NONE

CCPM
 13470   33204

DATA
 73405

EXTA
    NONE

(MEMORY) =   33205     (MEMCRYE) =   36372
```

6.1 Memory Requirements

This program as listed above requires 33,205 octal memory spaces (MEMØRY) for all arrays and program compilation. In all there are only 33,640 octal memory spaces available (MEMØRYE). The difference is 434; this is equivalent to 192 unused floating point word locations in the computer core. Since the computer compiling routine is always being updated (with subsequent changes in the available memory space), these memory requirements should not be extended at the present time.

If more space than this is required, i.e. to load a bigger depth matrix, space may be obtained by sacrificing some of the power of the program and by removing some of the subroutines. The subroutines which may be removed without altering the basic operations of the program are: SHØRE, NUMCØN and FRØNT. The calling statements for the removed subroutines, of course, must be deleted.

7.0 OPERATING INSTRUCTIONS

This section of the report will be written with only the user in mind. In this section, therefore, no reference will be made to the previous sections. Unfortunately, some repetition will follow. This repetition, however, is thought to be of help especially when making use of this program.

The most important variables that must be read by the computer in order to achieve useful and workable results are as follows (in order of importance):

a. Physical size of area of interest (this must be rectangular) - the maximum size of a plot is 22 x 28 inches. Generally, it is advisable to make the physical size of the output plot exactly the same size as that area of interest on the hydrographic chart which is used for establishing the depth grid. The reason for this will be stated later. The physical size is determined by the variable denoted as HT which is actually the maximum length of the Y axis in inches. The Y axis is *always* chosen to be parallel to the coast and the maximum length of the X axis is calculated on the basis of HT and the relative dimensions of the depth grid.

b. Depth grid is a two-dimensional array of *integer* depths *equally* spaced over the area described by the variable HT. The maximum dimensions of this variable (which is denoted by KMAT) are 25 x 30. In other words, there cannot be more than 25 equally spaced depths in the X direction and 30 equally spaced depths in the Y direction. This matrix does not have to span the whole area denoted by HT but must be wholly within this area. It is advisable, however, to have this matrix span the entire area. To do this, there must be some manipulation of the value of HT and the dimensions of KMAT.

c. Grid Spacing. This variable which is denoted as GRID will be determined after establishing the value of HT and the dimensions of KMAT. GRID is then set equal to the number of *feet* (actual) between grid depths.

A description of the data required by this program is now given. Variables along with their formats are listed in the order in which they are required with suggested values for fast operation.

Card 1	MXPLØT	- Number of plots required by one run of the program. Generally there is a new plot for every set of ray cards (these will be discussed later). Format is I3.
	PRØJCT	- Project number. Format is A6.
Card 2	TT	- Period of waves to be used. Format is F5.1.
	NØR	- Number of wave rays or number of ray cards to be read in. Format is I4.
	MM	- X dimension of depth grid. Format is I4.
	NN	- Y dimension of depth grid. Format is I4.
	GRID	- Defined in Section 2.3. Format is F7.0.
	DCØN	- Factor which must be multiplied by the depths given in the depth matrix to yield depths in feet, i.e. if depths are in fathoms DCØN = 6. Format is F7.2.
	NSH = 0	- Variable that specifies whether a shoreline is to be drawn. If a shoreline is to be drawn NSH = 1, (special alterations to the depth grid must be made for this) otherwise NSH = 0. This is generally what is used because it is the easiest, and computer operating time is kept to a minimum. Format is I4.
	NCØ = 0	- Variable that specifies whether a selected depth is contoured or not. Up to five depths may be contoured. If NCØ = 0, no contours are denoted. Otherwise, NCØ must be set equal to the number of depths which are to be contoured. Generally this is set to 0 for reasons of time. Format is I4.

NXCMAT - Variable which specifies whether a new depth grid is to be read in for this set of rays. NXCMAT = 0 if a depth grid is to be read, otherwise it is set > 0. Generally NXCMAT = 0 for first plot and > 0 for the rest provided all plots use the same depth grid.
Format is I4.

NPT = 1 first run
= 0 for others - Variable which specifies the format of the printed output (line printer).

- If NPT = 1, the location of every point (X,Y) calculated along a ray path is printed along with the depth (DEP), angle of ray (A), time of travel to that point (TIME), the number of that point along the ray (MAX), the maximum percent difference between the depth at this point and one of the surrounding points (PCTDIF) and the spacing from the last point represented as a factor of the value of GRID(D). If NPT = 0 only X,Y,A and TIME are typed out only for the first and last point along each ray. This is the usual value for NPT since it saves printing time and paper.
Format is I4.

NAX = non-zero - Variable which specifies whether the borders of the plot are to be calibrated or not. If NAX = 0, they are uncalibrated; if NAX ≠ 0, the borders will be calibrated with integral values of grid units. If procedure in section (a) is followed NAX = 0.
Format is I4.

CIN = 0 - Variable which specifies whether or not crest marks are to be placed along the wave rays along with the time of travel to that point. If CIN > 0 crest marks are made; if CIN = 0 no crest marks are made. NOTE: If CIN > 0 and the number of points along a ray > 1000 the program will terminate. For this reason and for reasons of time CIN = 0 for most jobs. CIN/TT corresponds to the number of waves between crest marks.
Format is F7.0.

HT - Length of Y axis in inches.
Format is F9.3.

	NØFRNT	- Variable which specifies whether or not a straight line wave front is used; if NØFRNT ≠ 0 the program proceeds to calculate the equally spaced starting points along a straight line which is determined from two points which are read from cards. This variable should be zero if NEWRAY = 0. Format is I3.
	NEWRAY	- Variable which specifies whether or not the starting points along the new line wave front must be recalculated or read in from cards: if NEWRAY ≠ 0 these points are either recalculated by reading in another data card containing the two end points on the new line and the angular orientation of the front, or read in from cards. Format is I5.
Card 3	IVFT	- This variable specifies the format under which the depth grid values are to be read in. Format is 20A4.
Cards 4 → N (say)	KMAT	- Depths in grid. These values are read in as follows: for Y = 0 all the X's are read in, in increasing order. Then for Y = 1, 2, etc.

NOTE: Cards 3 → N are not required if NXCMAT > 0.

Card N + 1	CTØUR	- Matrix of depths to be contoured. Format is 5F8.2.

NOTE: This card is not required if NCØ = 0.

Cards N + 2 → M (say)

a. If NØFRNT = 0

A	- Angle in degrees along which the ray heads initially. Format is F7.2.
X,Y	- Coordinates of starting point of ray. Format is 2F6.2.
FAN	- 0 for all our applications. (There are NØR of these cards.)

b. If NØFRNT ≠ 0

A	- as above. Format is F7.2.
XST,YST	- Coordinates of one end point of straight line wave front. Format is 2F6.2.
XEND,YEND	- Coordinates of the opposite end. Format is 2F6.2.

NOTE: This card (there is only one card used if (b) option is taken) may be omitted after the first calculation of all the starting points if the same wave front is used for successive plots.

If there is only one plot these are all the cards that are required. If there is more than one plot the computer will ask for more of cards 2 through to M for as many plots as required. A paper tape or magnetic tape is output depending on whether the logical unit number 51 is equipped to the tape punch or magnetic tape. This output tape must be plotted on the PDP-8 computer by computer operators.

7.1 Additional Notes

(1) When this program is submitted to be run it must be specified on the job description card that the background is *not* to be used.

(2) For test purposes the program may be run with Sense Switch 6 on. This allows the program to run faster because no tape is output. An idea of how the plot looks may be gained by requesting a picture of the scope output display. This provides a fast means of checking all the data and the resultant plot. NOTE: Card A105 must be removed and MXPLØT set equal to one before employing this option.

(3) If the depth grid is of the same size as the borders of the area the resultant plot from the PDP-8 can then be laid on top of the hydrographic chart and the shoreline drawn in by hand in order to see how the wave rays come in on the shore.

(4) The plot program to be used by the PDP-8 is called PLØTLS and all plots should be of B quality with ballpoint pen markings.

8.0 EXAMPLE RUNS

To exhibit the use of this program two example runs are included. The first run makes use of all options except the fan option and indicates the data required for multiple plots. The next run indicates the fan and shoreline option. The depth grid used in both instances is the depth and referred to as the small grid by Wilson (1966) in his report. This grid represents the shoreline area near the mouth of the Chesapeake Bay.

8.1 Run # 1

As mentioned above, all options, except the fan option, were employed in this run. Two plots were prepared by this example (Figures 5 and 6). Figure 5 depicts the direction of travel (with equal time marks) of a 4.0 second wave over a contoured bottom from the SSE direction and travelling to a shoreline. The borders of the plot are calibrated in grid units and the scale of the output plot is equal to the scale of the original hydrographic chart. The option of reading the starting points of the rays was employed. A printout of most of the data input may be found in Figure 7. Figure 8 depicts the output for one ray when NPT = 1.

The second plot (Figure 6) depicts the direction of travel of an 8.0 second wave from the SSE direction. The borders of the plot are calibrated and the scale of the output plot is one-half the scale of the hydrographic chart. The starting points of the rays were determined by employing the FRØNT subroutine. A printout of the data input may be found in Figure 9. Figure 10 depicts the output for all the rays when NPT = 0.

8.2 Run # 2

One plot was prepared for this example (Figure 11). This plot depicts the directions from which 8.0 second waves finally terminate at the indicated position near the shoreline. The borders of the plot are calibrated in grid units and the scale of the output is one-half the scale of the hydrographic chart. Equal time marks are indicated on the rays. The starting point and the various ray angles were read from cards. A printout of the data input (up to first ray card) is given in Figure 12 and the output (NPT = 0) is given in Figure 13.

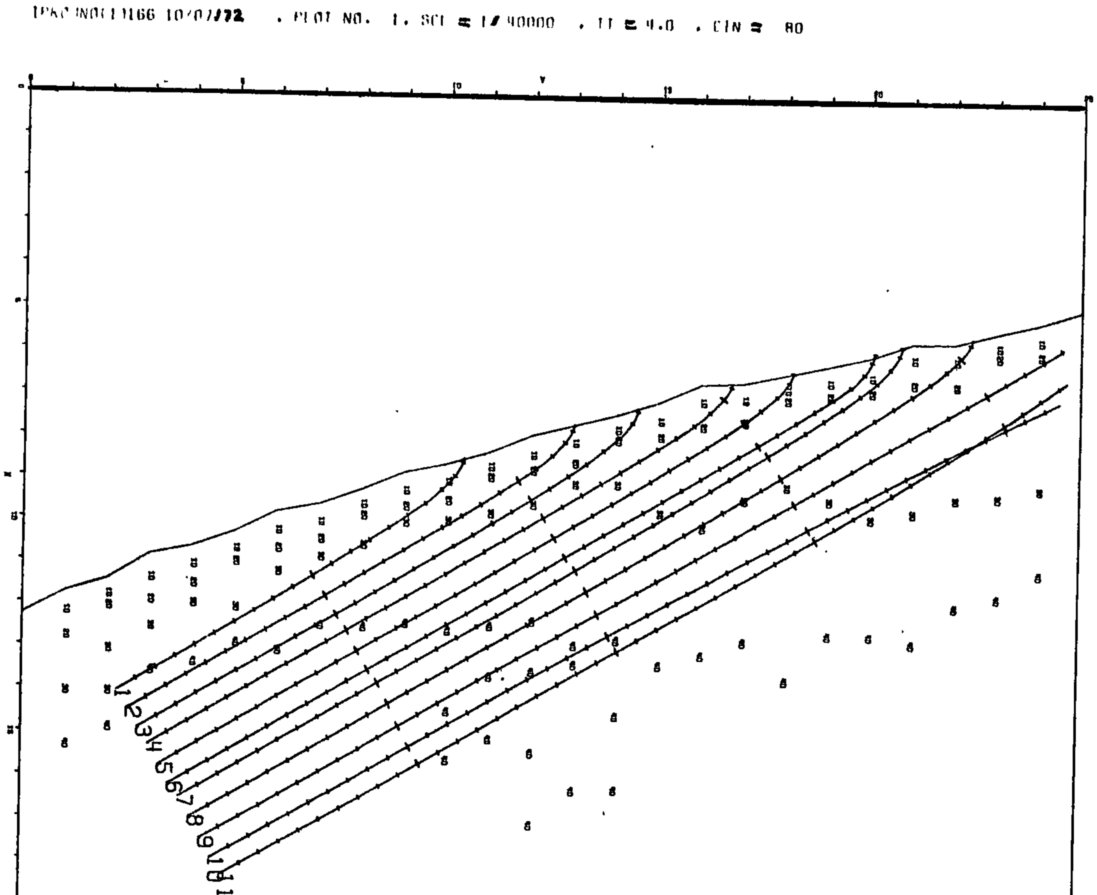

FIGURE 5: Run # 1, Plot # 1, Straight Line Wave Front with All Options except FRØNT T = 4 sec

IPROJNO(1)166 10/07/72 , PLOT NO. 2, SCL = 1/ 80004 , TT = 8.0 , CIN = 0

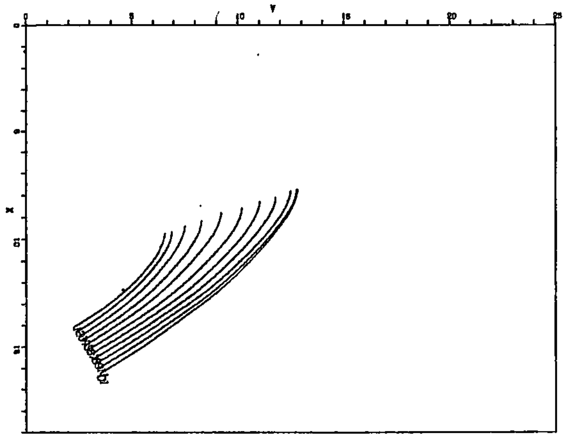

FIGURE 6: Run # 1, Plot # 2, Straight Line Wave Front employing only the FRØNT Option T = 8 sec

```
PXFLCT  PRCJCT
    2    166

  TT  NOR  PP  NN   GRID   OCCN NSH NCO NXCMAT NPT NAX  CIN      HT   NOFRNT NENRAY
  4.0  11  20  26   3038   1.00   1   4      0   1   1   80  22.785      0      1

VARIABLE FCRMAT FOR KMAT
(10(I2,1X),40X)

DEPTH GRID VALUES (KMAT)
  0   0   0   0   0   0   0   0   0 -41
-32 -24  -9  27  30  40  43  45  51  55
  0   0   0   0   0   0   0   0   0 -43
-32 -22   8  25  30  39  43  45  51  56
  0   0   0   0   0   0   0   0 -48 -43
-36 -15  20  30  30  42  45  45  55  57
  0   0   0   0   0   0   0 -47 -41 -36
-24   4  23  38  42  46  47  50  56  57
  0   0   0   0   0   0   0 -42 -38 -33
-18  10  32  37  47  46  47  50  54  53
  0   0   0   0   0   0   0 -45 -38 -30
 -5  22  30  42  45  46  49  51  54  55
  0   0   0   0   0   0 -44 -28 -33 -25
  6  29  36  40  42  42  45  52  51  52
  0   0   0   0   0   0 -37 -37 -33 -18
 11  35  36  46  42  45  48  45  43  57
  0   0   0   0   0   0 -37 -35 -32  -9
 27  33  37  44  44  45  46  43  43  40
  0   0   0   0   0 -37 -33 -32 -26   5
 31  35  37  46  45  45  49  46  47  50
  0   0   0   0   0 -36 -33 -32 -19  11
 32  35  36  44  43  35  45  46  46  50
  0   0   0   0   0 -34 -33 -26 -12  25
 32  25  37  45  36  40  45  50  44  50
  0   0   0   0 -36 -33 -32 -25   2  28
 32  24  39  43  36  37  47  40  48  50
  0   0   0   0 -33 -32 -30 -20  10  30
 34  23  36  41  37  37  39  45  46  50
  0   0   0   0 -37 -27 -23 -15  22  30
 32  34  38  41  43  36  39  46  45  47
  0   0   0 -35 -30 -25 -22  -2  24  26
 32  34  36  39  43  47  41  42  45  47
  0   0   0 -32 -28 -24 -20  10  27  28
 30  34  36  40  45  49  45  43  48  47
  0   0   0 -31 -28 -25 -20  12  29  29
 32  36  38  41  45  49  49  50  50  53
  0   0   0 -29 -28 -25 -15  22  26  30
 34  36  37  36  43  45  52  50  50  51
  0   0   0 -20 -22 -25  -6  25  26  29
 32  33  35  41  47  45  55  50  51  50
  0   0 -31 -27 -26 -23   0  27  27  27
 31  32  36  44  44  45  50  50  49  52
  0   0 -27 -27 -25 -22  12  27  27  27
 32  24  26  42  46  49  51  52  53  56
  0   0 -28 -25 -23 -19  11  27  27  29
 33  36  41  43  46  43  52  53  52  55
  0   0 -26 -25 -25 -15  25  28  26  29
 34  36  43  44  46  51  53  51  53  55
  0   0 -20 -25 -24  -4  25  26  27  30
 34  40  44  48  49  50  54  53  53  54
  0 -20 -20 -24 -23   4  25  25  26  30
 30  41  45  50  50  51  54  51  53  54

SCUNDING VALUES TO BE CCNTCURED
  10   20   30   40

ANGLE     X      Y  FAN
120.00 14.07  2.25  0
```

FIGURE 7: Input Data up to First Ray Card for Run # 1, Plot # 1

PROJECT NO. 166, 10/07/72, PLOT NO. 1, PERIOD = 4.0 SEC., RAY NO. 1.

MAX	X	Y	ANGLE	TIME	PCTDIF	DEPTH	D
1	14.07	2.25	120.00	0	6.7	34.56	.421
2	13.86	2.61	120.14	.017	3.3	36.87	.421
3	13.63	3.00	120.20	.036	4.1	40.94	.450
4	13.38	3.43	120.31	.057	4.1	40.04	.499
5	13.13	3.86	120.42	.077	4.1	39.15	.488
6	12.89	4.27	120.56	.097	5.8	38.23	.478
7	12.65	4.67	120.74	.116	5.8	36.82	.466
8	12.42	5.05	120.95	.135	6.7	35.50	.449
9	12.20	5.43	121.17	.153	6.7	34.46	.433
10	11.98	5.78	121.39	.170	1.1	34.72	.420
11	11.76	6.15	121.56	.188	5.2	33.98	.423
12	11.54	6.50	121.68	.205	5.2	34.17	.414
13	11.33	6.85	121.80	.222	5.2	34.36	.417
14	11.10	7.21	121.90	.240	2.3	34.41	.419
15	10.88	7.56	122.21	.257	40.9	32.67	.420
16	10.67	7.90	122.78	.274	40.9	31.81	.398
17	10.46	8.23	123.18	.290	1.9	30.46	.388
18	10.25	8.54	123.41	.306	1.9	30.37	.371
19	10.05	8.84	123.63	.321	1.9	30.27	.370
20	9.84	9.15	124.61	.337	25.0	26.93	.369
21	9.65	9.41	126.54	.350	25.0	23.03	.324
22	9.48	9.64	129.04	.363	25.0	19.76	.281
23	9.32	9.82	132.09	.374	25.0	16.72	.241
24	9.18	9.97	135.60	.383	25.0	13.91	.204
25	9.06	10.08	138.01	.391	31.8	15.89	.170
26	8.91	10.21	141.97	.401	15.9	11.91	.154
27	8.79	10.29	147.48	.409	15.9	8.82	.145
28	8.70	10.34	152.93	.415	15.9	6.25	.108
29	8.63	10.38	157.98	.420	15.9	4.26	.076
30	8.58	10.39	162.40	.425	15.9	2.81	.052
31	8.55	10.40	166.13	.428	15.9	1.80	.034
32	8.53	10.41	169.17	.431	15.9	1.13	.022
33	8.51	10.41	171.59	.433	15.9	.70	.014
34	8.50	10.41	173.51	.435	15.9	.43	.009
35	8.50	10.41	175.09	.436	15.9	.25	.005
36	8.49	10.41	177.56	.438	15.9	.07	.005

RAY REACHED SHORE.

ANGLE	X	Y	FAN
120.00	14.50	2.50	0

FIGURE 8: Sample Output Data for Run # 1, Plot # 1, NPT = 1

TT	NOR	MM	NN	GRID	CCCA	ASH	NCC	NXCHAT	NPT	NAX	CIN	HT	NOFRNT	NEWRAY
8.0	11	20	26	3038	1.00	0	0	1	0	1	0	11.392	1	1

ANGLE	XST	YST	XEND	YEND
120.00	14.07	2.25	16.22	3.50

FIGURE 9: Input Data for Run # 1, Plot # 2

(continued from Figure 7 except for remaining ray cards for Plot # 1)

PROJECT NO. 166, 10/07/72, PLOT NO. 2, PERIOD = 8.0 SEC.

RAY NO.	MAX	X	Y	ANGLE	TIME	
1	1	14.07	2.25	120.00	0	
1	88	9.71	6.57	182.05	.206	RAY REACHED SHORE.
2	1	14.28	2.38	120.00	0	
2	89	9.64	6.93	182.98	.214	RAY REACHED SHORE.
3	1	14.53	2.53	120.00	0	
3	92	9.41	7.51	183.07	.230	RAY REACHED SHORE.
4	1	14.71	2.63	120.00	0	
4	97	9.14	8.30	181.23	.249	CURVATURE APPROXIMATIONS NOT CONVERGING.
5	1	14.93	2.75	120.00	0	
5	105	8.80	9.22	183.13	.276	RAY REACHED SHORE.
6	1	15.14	2.88	120.00	0	
6	112	8.57	10.19	181.54	.300	RAY REACHED SHORE.
7	1	15.36	3.00	120.00	0	
7	120	8.29	11.02	182.91	.325	RAY REACHED SHORE.
8	1	15.57	3.13	120.00	0	
8	125	8.09	11.77	183.01	.344	RAY REACHED SHORE.
9	1	15.79	3.25	120.00	0	
9	136	7.81	12.48	181.19	.368	CURVATURE APPROXIMATIONS NOT CONVERGING.
10	1	16.00	3.38	120.00	0	
10	139	7.74	12.77	182.95	.378	RAY REACHED SHORE.
11	1	16.22	3.50	120.00	0	
11	139	7.73	12.80	182.94	.379	RAY REACHED SHORE.

FIGURE 10: Output Data for Run # 1, Plot # 2, NPT = 0

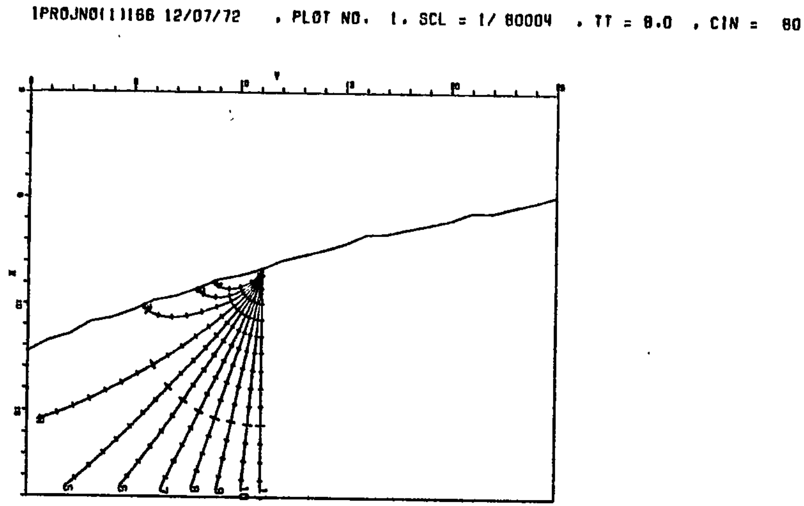

FIGURE 11: Run # 2, Plot # 1, Point Source employing the FAN and Shoreline Option T = 8 sec

```
NXFLCT  PRCJCT
    1    166

  TT   NOR   FM   NN    GRID    DCCN NSH NCD NXCMAT NPT NAX  CIN        HT   NCFRNT NEWRAY
 8.0   11   20   26    3038    1.00   1   0      0   0   1      80   11.392       0      1

VARIAELE FORMAT FOR KMAT
(10(I2,1X),40X)

DEFTH GRID VALUES (KMAT)
  0   0   0   0   0   0   0   0   0 -41
-32 -24  -9  27  30  40  43  45  51  55
  0   0   0   0   0   0   0   0   0 -43
-32 -22   8  25  30  39  43  45  51  56
  0   0   0   0   0   0   0   0 -48 -43
-36 -15  20  20  30  42  45  49  55  57
  0   0   0   0   0   0   0 -47 -41 -36
-24   4  23  38  42  46  47  50  56  57
  0   0   0   0   0   0   0 -42 -38 -33
-18  10  32  37  47  46  47  50  54  53
  0   0   0   0   0   0   0 -45 -38 -30
 -9  22  30  42  45  46  49  51  54  55
  0   0   0   0   0   0 -44 -38 -33 -25
  6  29  36  40  42  42  49  52  51  52
  0   0   0   0   0   0 -37 -37 -33 -18
 11  35  36  46  42  45  48  49  43  57
  0   0   0   0   0   0 -37 -35 -32  -9
 27  33  37  44  44  45  46  43  43  40
  0   0   0   0   0 -37 -33 -32 -26   5
 31  35  37  46  45  45  49  46  47  50
  0   0   0   0   0 -36 -33 -32 -19  11
 32  35  36  44  43  35  45  46  46  50
  0   0   0   0   0 -34 -33 -26 -12  25
 32  35  37  45  36  40  45  50  44  50
  0   0   0   0 -36 -33 -32 -25   2  28
 32  34  39  43  36  37  47  40  48  50
  0   0   0   0 -33 -32 -30 -20  10  30
 34  33  36  41  37  37  39  49  46  50
  0   0   0   0 -37 -27 -23 -15  22  30
 32  34  38  41  43  36  39  46  45  47
  0   0   0 -35 -30 -25 -22  -2  24  26
 32  34  36  39  43  47  41  42  45  47
  0   0   0 -32 -28 -24 -20  10  27  28
 30  24  36  40  45  49  49  43  48  47
  0   0   0 -31 -28 -25 -20  12  29  29
 32  36  38  41  45  49  49  50  50  53
  0   0   0 -29 -28 -25 -15  22  26  30
 34  26  37  36  43  45  52  50  50  51
  0   0   0 -20 -22 -25  -6  25  26  29
 32  33  39  41  47  45  55  50  51  50
  0   0 -31 -27 -26 -23   0  27  27  27
 31  32  36  44  44  45  50  50  49  52
  0   0 -27 -27 -25 -22  12  27  27  27
 32  34  36  42  46  49  51  52  53  56
  0   0 -28 -25 -23 -19  11  27  27  29
 33  36  41  43  46  43  52  53  52  55
  0   0 -26 -25 -25 -15  25  26  26  29
 34  36  43  44  46  51  53  51  53  55
  0   0 -20 -25 -24  -4  25  26  27  30
 34  40  44  48  49  50  54  53  53  54
  0 -20 -20 -24 -23   4  25  25  26  30
 30  41  45  50  50  51  54  51  53  54

ANGLE       X      Y  FAN
350.00   8.30  11.10   1
```

FIGURE 12: Input Data up to First Ray Card
for Run # 2, Plot # 1

```
FRCJECT NC.   166, 12/07/72, FLCT NO.  1, FERICD =  8.0 SEC.

RAY NC.     RAY        X          Y        ANGLE       TIME

    1         1      8.30      11.10     350.00          0
    1        51      8.95       8.85     190.71       .137                                 RAY REACHED SHCRE.

 ANGLE     X      Y   FAN
351.C0  8.30 11.10  1
    2         1      8.30      11.10     351.00          0
    2        55      5.22       8.33     192.84       .165                                 RAY REACHED SHCRE.

 ANGLE     X      Y   FAN
352.C0  8.30 11.10  1
    3         1      8.30      11.10     352.00          0
    3       129     10.06       5.50     187.74       .251                                 RAY REACHED SHCRE.

 ANGLE     X      Y   FAN
353.C0  8.30 11.10  1
    4         1      8.30      11.10     353.00          0
    4       142     15.44        .47     287.91       .382                                 RAY REACHED GRIC BCLNDARY.

 ANGLE     X      Y   FAN
354.C0  8.30 11.10  1
    5         1      8.30      11.10     354.00          0
    5       138     18.55       1.83     310.34       .393                                 RAY REACHED GRIC BCLNDARY.

 ANGLE     X      Y   FAN
355.C0  8.30 11.10  1
    6         1      8.30      11.10     355.00          0
    6       124     18.56       4.44     322.65       .348                                 RAY REACHED GRIC BCLNDARY.

 ANGLE     X      Y   FAN
356.C0  8.30 11.10  1
    7         1      8.30      11.10     356.00          0
    7       118     18.62       6.37     333.06       .326                                 RAY REACHED GRIC BCLNDARY.

 ANGLE     X      Y   FAN
357.C0  8.30 11.10  1
    8         1      8.30      11.10     357.00          0
    8       114     18.53       7.84     340.94       .310                                 RAY REACHED GRIC BCLNDARY.

 ANGLE     X      Y   FAN
358.00  8.30 11.10  1
    9         1      8.30      11.10     358.00          0
    9       112     18.60       9.02     347.48       .304                                 RAY REACHED GRIC BOLNDARY.

 ANGLE     X      Y   FAN
359.C0  8.30 11.10  1
   10         1      8.30      11.10     359.00          0
   10       110     18.51      10.19     354.42       .297                                 RAY REACHED GRIC BCLNDARY.

 ANGLE     X      Y   FAN
      0  8.30 11.10  1
   11         1      8.30      11.10          0          0
   11       110     18.57      11.10      -0.00       .298                                 RAY REACHED GRIC BCLNDARY.
```

FIGURE 13: Output Data for Run # 2, Plot # 1, NPT = 0

9.0 REFERENCES

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