Hydraulics Research
Wallingford

A COMBINED REFRACTION AND DIFFRACTION MODEL

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ABSTRACT

In many coastal situations, refraction and diffraction are of equal importance in determining inshore wave conditions. Models exist which are able to describe each process separately, but an attempt to combine both has not been made.

This report describes a modified version (OUTRAY II) of the wave refraction model currently in use at Hydraulics Research Ltd. Modifications, including diffraction calculations, are based on the Sommerfeld solution, which reduces a groyne or breakwater to a simple, semi-infinite straight line.

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1 INTRODUCTION

This report is intended for use with the OUTRAY user manual (Ref 1), which contains a detailed account of the refraction techniques used by OUTRAY II. These techniques have been developed over a number of years at Hydraulics Research Ltd and form the basis of an efficient, low-cost model. Though appropriate for many situations, OUTRAY is limited to cases in which refraction is the dominant process and as such is unable to account for diffraction effects. When coastal features such as breakwaters have a strong effect on inshore wave conditions through diffraction, it then becomes necessary to include them in a refraction study.

This can be illustrated with reference to a previous study made at Penmaenmawr in North Wales (Fig 1). In this example, waves arriving from the North-East and the North-West are diffracted by Puffin Island and the Great Ormes Head respectively. Under such circumstances, therefore, a study would ideally consider the combined effects of refraction and diffraction when calculating inshore wave conditions. OUTRAY II is designed for use in situations such as this.

2 BACKGROUND

2.1 Modelling of refraction

The following description represents a brief account of the refraction techniques used by OUTRAY and OUTRAY II. A comprehensive analysis is available in the OUTRAY handbook (Ref 1).

OUTRAY II employs a backtracking method based on the principle of reversible ray paths. The model traces a fan of rays at regular angular intervals from a refraction point. The rays undergo refraction and, if they reach the specified offshore boundary, finally contribute to the transfer functions. These transfer functions can then be used in further calculations to determine both inshore wave spectra and significant wave heights.

2.2 Modelling of diffraction

OUTRAY II employs two subroutines to calculate the necessary diffraction coefficients, both of which are contained in the program block DNEXSUBS (see Fig 2). The coefficients are determined by the Sommerfeld solution (Ref 3), which considers waves incident on a semi-infinite, straight line segment. The line segment is used to represent coastal features such as breakwaters and headlands.

The rays are sent out in a fan, in either a clockwise or anticlockwise direction, chosen so that rays strike the breakwater before striking the offshore boundary. In Figure 3 the rays have been traced in an anticlockwise direction such that rays 1,2 and 3 are consecutive. Point E represents the refraction point, and BD the semi-infinite breakwater.

Ray 2 is termed the 'shadow ray' and it is to the angular box containing this ray that the contribution of diffracted rays in region D (Fig 4) is added. This contribution is calculated for each individual wave period. The three quantities WDSH (the path length of ray 1), ADSH and BDSH are required by WDIFF to calculate the diffraction coefficient of every ray that is influenced by the breakwater. This calculation takes two possible forms:

1. Each ray which crosses the extended line of the breakwater (AB in Fig 3), while missing the breakwater itself, is modified by a diffraction

coefficient which results in a re-distribution of the transfer function values.

2. The contribution of rays in region D to the angular box containing ray 2 (Figs 3 and 4) is calculated once for each wave period. For each angular box contained in D, an average diffraction coefficient WHT is calculated and squared. If refraction is considered important in this region then the coefficients are multiplied by their corresponding transfer function values (calculated at point B, the breakwater end point). This array is consequently used to transfer the offshore energy spectrum from the offshore boundary to point B. A maximum of 15 spectra can be transferred in this manner. The new spectra can be used in the normal way, with the transfer functions, to calculate inshore wave conditions.

3 OUTRAY II

3.1 Information required to run OUTRAY II

3.1.1 MULTSPEC

An offshore spectrum is required, and must have the following format.

IMAX JMAX
TSTART TSTEP
WDIR U10 DUR H3OFF TZOFF WVDIR
(SPT(I,J), I = 1,IMAX), J = 1,JMAX)

where the parameters represent

IMAX	Number of wave periods
JMAX	Number of offshore boxes

WDIR	Wind direction in degrees true north
U10	Wind speed in ms^{-1} at a height of 10m above the sea surface
DUR	The storm duration (seconds)
H3OFF	The significant offshore wave height (metres)
TZOFF	Mean offshore wave period (seconds)
WVDIR	Wave direction inshore in degrees true north
SPT(I,J)	The spectral component $S(f_i,\theta_j)df_i d\theta_j$ for the Ith angular box and Jth wave period

3.1.2 DREFDATA

The parameters shown below which are lower case are identical to those used by OUTRAY, while the upper case parameters represent the additional break-water information required by OUTRAY II.

```
title
mxplot   nray   LINED
scale papsiz
NFRQ    NROTA    NTOB    NOSP
GRAD    CONST    DIFF    RTNBKW
XL1    XL2    YL2    YL2
nc
xg(1)    yg(1)    im(1)    jm(1)    xo(1)    yo(1)
   .                                           .
xg(nc)  yg(nc)  im(nc)  jm(nc)  xo(nc)  yo(nc)
ig    xs    ys    wlevel    dmin
stang    eang
t
-1.0    -1.0
ang(1)        ...     ang (10)
  .           ...       .
ang(jmax-9) ...    ang(jmax)
```

The additional parameters are defined as follows:

LINED	Describes the orientation of the breakwater relative to the global x and y axes. If the breakwater is parallel to the x- or y-axis then LINED = 3 or 1 respectively. LINED = 2 when the breakwater has a finite, non-zero gradient. If diffraction is to be ignored, then LINED $\leqslant$ 1 and the variables described below (on lines 3-5) can be set to dummy values
NFRQ	The number of wave frequencies considered for each run
NROTA	If NROTA $\leqslant$ 0 the rays are traced in a clockwise direction, otherwise they are traced in an anticlockwise sense
NTOB	If depth variations in region D (see Fig 4) are significant, refraction becomes important, and NTOB is set to a positive number (ie NTOB $\geqslant$ 0). In such circumstances the program reads in a set of transfer functions, obtained at the breakwater tip, and multiplies each component by its corresponding frequency spectrum component SPT(I,J)
GRAD	The breakwater lies on the line y = GRAD*X + CONST, where GRAD represent the gradient relative to the positive global x-axis. If the breakwater is parallel to either the x-or y-axis (ie LINED $\neq$ 2) then GRAD can be set to any dummy value

CONST	If LINED = 2, then CONST equals the y-coordinate of the extended breakwater as it intersects the global y-axis (in metres)
DIFF	DIFF represents the perpendicular distance from the breakwater at which the individual ray is considered to have been stopped (ie the breakwater is assumed to be 2*DIFF metres wide)
RTNBKW	The angle in degrees true north of the breakwater measured at its tip ($0 \leqslant$ RTNBKW $\leqslant 360$). See Figure 4
XL1,XL2,YL1,YL2	The horizontal limits XL1, XL2 (XL2 $\geqslant$ XLI) and vertical limits YL1, YL2 (YL2 $\geqslant$ YL1) define the rectangle containing the breakwater. If the breakwater is parallel to the x-axis then YL1 = YL2, and similarly if parallel to the y-axis, XL1 = XL2. The limits are relative to the global axes and in metres.

3.1.3 TFUNCGENWB

If NTOB $\geqslant 0$ (see previous section) then a set of transfer functions TFUNCGEWB must be obtained for the point at the tip of the breakwater. The file requires the following format:

```
TN(1,1)          ...     TN(IMAX,1)
   .                         .
TN(1,JMAX)       ...     TN(IMAX,JMAX)
UN(1,1)          ...     UN(IMAX,1)
   .                         .
```

UN(1,JMAX)	...	UN(IMAX,JMAX)
VN(1,1)	...	VN(IMAX,1)
.		.
VN(1,JMAX)	...	VN(IMAX,JMAX)

where IMAX is the number of wave periods and JMAX the number of offshore boxes.

3.2 Operation of OUTRAY II

3.2.1 The code generating program - DGENPROG

DGENPROG, the code generating program, and its corresponding control file DGENDATA are used to generate the main program segment DOUTRAY2. In order to run DGENPROG, the input/output channels must be assigned as follows.

Channel number	Input/output file	
1	I	The control file DGENDATA
2	O	The output file DOUTRAY2

3.2.2 The wave refraction/diffraction program - DOUTRAY2

The program segment DOUTRAY2 contains the master segment and the transfer function subroutines. to run this segment, the two subroutine blocks DNEXSUBS and DREFSUBS must be made available, and the input/output channels assigned as follows:

Channel number	Input/output file	
1	I	The control file DREFDATA (see 3.1.2)

2	O	The ray file DRAYGEN (see 3.3.2)
4	O	The cell adjacency file DNEXLOUT (see 3.3.2)
11	I	The depth grid file (see Ref 1)
15	I	The offshore spectrum file MULTSPEC (see 3.1.1)
16	I	The transfer function file TFUNCGENWB - if NTOB ⩾ 0 (see 3.1.3)
17	O	The modified offshore spectrum file MULTSPEC2 (see 3.3.3)
23	O	The transfer function file for display DTFNPGEN (see 3.3.4)
24	O	The condensed transfer function file DTFUNCGEN (see 3.3.4)

3.3 Output from OUTRAY II

3.3.1 DNEXLOUT

As well as containing information about the grid system, this file also contains details of rays which cross the extended line of the breakwater. The format of this information is as follows.

T ADSH BDSH WDSH NORAY W

T	Wave period (seconds)
ADSH	Angle between ray and true north as it crosses imaginary line
BDSH	Angle between true north and last ray to hit breakwater
WDSH	Path length of last ray to strike breakwater
NORAY	Ray number
W	The square of the diffraction coefficient

3.3.2 DRAYGEN

This file is written to only if NRAY is set to a positive number. When written to it contains information on each ray that either strikes the breakwater, or reaches the offshore boundary. Each line gives details of a single ray.

T AIN AON ANU NORAY XE YE WT CFIN

T	Wave period
AIN	The bearing in degrees true north of the wave ray at the refraction point
AON	The bearing in degrees true north of the wave ray at either the offshore boundary or the breakwater
ANU	The value of the refraction coefficient (μ) for this ray
NORAY	The NORAYth ray to be traced for period T
XE,YE	The co-ordinates, relative to the global axes, of the ray path end point

WT	The path length of the completed ray in number of wave lengths
CFIN	The wave celerity at the ray end-point in ms^{-1}

3.3.3 MULTSPEC2

The offshore spectrum is read by OUTRAY II from the file MULTSPEC (see 3.1.1), modified, and written to a new file MULTSPEC2 which has an identical format to the original file.

3.3.4 The transfer function files

The modified transfer functions are written to two files, as in OUTRAY, which are called DTFUNCGEN and DTFNLPGEN.

3.4 Description of diffraction subroutines

3.4.1 DIFFR (W, MDSH)

DIFFR is one of two diffraction subroutines attached to NEXSUBS. DIFFR calculates and sets all the parameters which are required by WDIFF to calculate the diffraction coefficients. The variables transferred by the subroutine call statement, are defined as follows.

Name	Description	Input/Output
W	The ray path length	I
MDSH	Variable indicating whether the rays have passed the breakwater	I

3.4.2 WDIFF (THETAØ, THETA, R, W)

WDIFF is called by DIFFR to calculate the diffraction coefficient for a particular combination of THETAØ, THETA and R which are defined by

Name	Description	Input/Output
THETAØ	Incident angle	I
THETA	Diffracted angle	I
R	Path length	I
W	The square of the diffraction coefficient	O

For descriptions of the variables transferred by the common block statements see the appendix to this report.

4 SAMPLE RUNS OF OUTRAY II

4.1 Introduction

In this section a comparison of two separate runs is made - the first a refraction-only run, and the second a combined refraction-diffraction run. A previous refraction study at Sines Harbour, Portugal (Ref 4), was used as a basis for these runs (see Fig 5). The grid system constitutes two rectangular grids of roughly equivalent proportions (Fig 6). The breakwater is represented in the model by a vertical straight line segment.

As in OUTRAY, the main program segment is created by use of DGENPROG and DGENDATA.

4.2 The runs

4.2.1 The CONTROL FILE

Table 1 shows the form of the control file DREFDATA to be used in both runs. The refraction point is

~ 300m offshore, in a region that is well protected by the breakwater. The local grid coordinates of this point are, in metres, (1187.5, 1131.25) and the offshore boundary is chosen to be the positive global x- and y-axes. Rays are sent out at one degree intervals, from 90°N to 270°N, for each of the 7 wave periods (4 seconds to 16 seconds in 2 second increments).

4.2.2 Run ONE

For the first run LINED is set to 0 in the control file DREFDATA which will result in a refraction-only run equivalent to the OUTRAY model. Table 2 shows the resulting transfer function file, DTFNLPGEN.

4.2.3 Run TWO

In run two LINED is set the alternative value of 1 which enables the model to access the two diffraction subroutines DIFFR and WDIFF. Setting LINED to a positive number means that the breakwater parameters on lines 3 to 5 of DREFDATA must be set.

Here DIFF equals 50m, NROTA is set to 1 (so that rays are traced in an anticlockwise sense) and NTOB to 0 because the breakwater is sufficiently close to the offshore boundary to make refraction in area D (see Fig 4) relatively unimportant. In addition to the control file, an offshore spectrum file MULTSPEC is required (Table 3). This file contains one spectrum (so NOSP is set to 1), and is based on the Pierson-Moskowitz distribution, obtained for a wind/wave direction of 270°N, offshore wave height 3.7m and offshore wave period 8.4 seconds.

In addition to the transfer function files, a modified offshore spectrum file MULTSPEC2 is created

(Table 4). A comparison of this file with MULTSPEC reveals systematic differences between the two spectra. Components bounded by 0°N and 220°N are unchanged, while those bounded by 230°N and 360°N are zero. Each component in the angular box 220°N-230°N has an added diffraction component which represents the accumulated wave energy contained in the angular region 230°N-360°N. The transfer function file (Table 5) exhibits similar variations when compared to the original file (Table 1). Components in the angular region 230°N-360°N are likewise zero, while the remaining components display a 'redistribution' of the original refraction-only values.

If NRAY is set to a positive number then information concerning diffraction processes is written to DNEXLOUT (Table 6). ADSH, BDSH and the path length are the three principal variables used by WDIFF to calculate the square of the diffraction coefficient W for every ray that crosses the extended line of the breakwater. Each value of W is consequently used to modify the transfer functions, and this accounts for the aforementioned redistribution.

4.2.4 Inshore wave conditions

Tables 7 and 8 show the resulting inshore wave conditions for each of the two runs. There is a significant difference between the two inshore wave heights, demonstrating in this more extreme case the effect of including diffraction in the refraction calculations.

5 CONCLUSION

In conclusion, OUTRAY II offers a quick, effective and relatively cheap model with which to describe simple diffraction processes, and as such represents a useful companion to the refraction model currently available.

6 ACKNOWLEDGEMENTS

The report was compiled by Chris Russell of the Coastal Engineering Section of the Maritime Department at Hydraulics Research Limited. The help of Mr H N Southgate, Dr A Brampton and Dr P J Hawkes is gratefully acknowledged.

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2. Brampton, A H and Steel, A J. North Wales Coast Road A55, at Penmaenmawr - a wave refraction study. Report EX 885, June 1979.

3. Sommerfeld, A. Mathematische Theorie der Diffraktion, Math Annalen, 47, 1896.

4. Southgate, H N. Wave disturbance studies for a proposal coal berth at Sines Harbour, Portugal. Report EX 1175, December 1983.

Tables

TABLE 1 - Control file DREFDATA

```
INSHORE POINT IN SINES HARBOUR, PORTUGAL
   0        1        1
   7        1        0        1
   0.0      0.0     50.0      0.0
 100.0    100.0   2880.0   5000.0
2
125.0      125.0      29   19      0.0000      2500.0
250.0      250.0      15   11      0.0000      0.0000
1 1187.5   1531.25  2.00 1.0
    90.0    270.0
     4.0      1.0
     6.0      1.0
     8.0      1.0
    10.0      1.0
    12.0      1.0
    14.0      1.0
    16.0      1.0
    -1.0     -1.0
000-010 010-020 020-030 030-040 040-050 050-060 060-070 070-080 080-090 090-100
100-110 110-120 120-130 130-140 140-150 150-160 160-170 170-180 180-190 190-200
200-210 210-220 220-230 230-240 240-250 250-260 260-270 270-280 280-290 290-300
300-310 310-320 320-330 330-340 340-350 350-360
```

TABLE 2 - Listing of DTFNLPGEN with LINED = 0 (i.e. no diffraction)

TRANSFER FUNCTION TN

FREQUENCY (HZ)	0.250	0.167	0.125	0.100	0.083	0.071	0.062
ANGLE (DEG NORTH)							
000-010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
010-020	0.000	0.000	0.000	0.000	0.000	0.000	0.000
020-030	0.000	0.000	0.000	0.000	0.000	0.000	0.000
030-040	0.000	0.000	0.000	0.000	0.000	0.000	0.000
040-050	0.000	0.000	0.000	0.000	0.000	0.000	0.000
050-060	0.000	0.000	0.000	0.000	0.000	0.000	0.000
060-070	0.000	0.000	0.000	0.000	0.000	0.000	0.000
070-080	0.000	0.000	0.000	0.000	0.000	0.000	0.000
080-090	0.000	0.000	0.000	0.000	0.000	0.000	0.000
090-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100-110	0.000	0.000	0.000	0.000	0.000	0.000	0.000
110-120	0.000	0.000	0.000	0.000	0.000	0.000	0.000
120-130	0.000	0.000	0.000	0.000	0.000	0.000	0.000
130-140	0.000	0.000	0.000	0.314	0.111	0.114	0.232
140-150	0.000	0.000	0.394	0.210	0.112	0.117	0.256
150-160	1.000	0.984	0.394	0.631	1.392	1.490	1.704
160-170	1.000	0.880	0.965	1.263	0.828	1.040	0.987
170-180	1.000	0.978	0.951	0.522	0.723	0.949	1.031
180-190	1.000	0.978	0.850	0.832	0.845	0.824	0.756
190-200	1.000	0.978	0.752	0.618	0.605	0.553	0.604
200-210	1.000	0.978	0.850	0.833	0.722	0.809	0.731
210-220	1.000	0.978	0.848	0.726	0.846	0.820	0.896
220-230	1.000	0.978	0.852	0.836	0.841	0.805	0.868
230-240	1.000	0.978	0.857	0.945	0.955	1.055	0.989
240-250	1.000	0.880	0.862	0.843	0.946	1.031	1.231
250-260	1.000	0.978	0.769	0.844	0.939	1.014	0.935
260-270	0.900	0.293	0.483	0.317	0.350	0.376	0.525
270-280	0.100	0.296	0.097	0.422	0.462	0.370	0.257
280-290	0.000	0.496	0.000	0.000	0.114	0.242	0.375
290-300	0.000	0.000	0.000	0.105	0.112	0.117	0.000
300-310	0.000	0.000	0.000	0.000	0.000	0.106	0.115
310-320	0.000	0.000	0.094	0.000	0.000	0.000	0.000
320-330	0.000	0.000	0.000	0.000	0.000	0.000	0.000
330-340	0.000	0.000	0.000	0.000	0.000	0.000	0.000
340-350	0.000	0.000	0.000	0.000	0.000	0.000	0.000
350-360	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TABLE 3 - Listing of offshore spectrum , MULTSPEC

```
**********************************************************
*                                                        *
*      7      36                                         *
*      4.0     2.0                                       *
*    270.0    10.0   86400.0   3.67    8.37 270.0        *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.001  0.001  0.002  0.001  0.000  0.000   *
*      0.001  0.002  0.005  0.006  0.004  0.001  0.000   *
*      0.002  0.006  0.011  0.014  0.010  0.004  0.001   *
*      0.003  0.010  0.021  0.025  0.018  0.006  0.001   *
*      0.004  0.015  0.030  0.037  0.026  0.009  0.002   *
*      0.005  0.018  0.036  0.045  0.032  0.011  0.002   *
*      0.005  0.018  0.036  0.045  0.032  0.011  0.002   *
*      0.004  0.015  0.030  0.037  0.026  0.009  0.002   *
*      0.003  0.010  0.021  0.025  0.018  0.006  0.001   *
*      0.002  0.006  0.011  0.014  0.010  0.004  0.001   *
*      0.001  0.002  0.005  0.006  0.004  0.001  0.000   *
*      0.000  0.001  0.001  0.002  0.001  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*      0.000  0.000  0.000  0.000  0.000  0.000  0.000   *
*                                                        *
**********************************************************
```

TABLE 4 - Listing of modified offshore spectrum , MULTSPEC2

```
************************************************************
*                                                          *
*      7       36                                          *
*      4.0      2.0                                        *
*   270.0    10.00   86400.0 3.67    8.37 270.0            *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0010 0.0010 0.0020 0.0010 0.0000 0.0000    *
*      0.0012 0.0028 0.0076 0.0101 0.0077 0.0023 0.0003    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
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*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*      0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000    *
*                                                          *
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TABLE 5 - Listing of DTFNLPGEN with LINED = 1 (i.e. diffraction)

TRANSFER FUNCTION TN

FREQUENCY (HZ)	0.250	0.167	0.125	0.100	0.083	0.071	0.062
ANGLE (DEG NORTH)							
000-010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
010-020	0.000	0.000	0.000	0.000	0.000	0.000	0.000
020-030	0.000	0.000	0.000	0.000	0.000	0.000	0.000
030-040	0.000	0.000	0.000	0.000	0.000	0.000	0.000
040-050	0.000	0.000	0.000	0.000	0.000	0.000	0.000
050-060	0.000	0.000	0.000	0.000	0.000	0.000	0.000
060-070	0.000	0.000	0.000	0.000	0.000	0.000	0.000
070-080	0.000	0.000	0.000	0.000	0.000	0.000	0.000
080-090	0.000	0.000	0.000	0.000	0.000	0.000	0.000
090-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100-110	0.000	0.000	0.000	0.000	0.000	0.000	0.000
110-120	0.000	0.000	0.000	0.000	0.000	0.000	0.000
120-130	0.000	0.000	0.000	0.000	0.000	0.000	0.000
130-140	0.000	0.000	0.000	0.314	0.111	0.114	0.232
140-150	0.000	0.000	0.394	0.210	0.112	0.117	0.256
150-160	1.000	0.984	0.394	0.631	1.392	1.490	1.704
160-170	1.000	0.880	0.965	1.263	0.828	1.040	0.987
170-180	1.000	0.978	0.951	0.522	0.723	0.949	1.031
180-190	1.000	0.978	0.850	0.832	0.852	0.826	0.743
190-200	1.002	0.989	0.758	0.622	0.580	0.541	0.647
200-210	0.990	0.946	0.864	0.926	0.852	0.941	0.824
210-220	1.079	1.010	0.809	0.606	0.695	0.534	0.570
220-230	0.167	0.076	0.071	0.079	0.091	0.047	0.051
230-240	0.000	0.000	0.000	0.000	0.000	0.000	0.000
240-250	0.000	0.000	0.000	0.000	0.000	0.000	0.000
250-260	0.000	0.000	0.000	0.000	0.000	0.000	0.000
260-270	0.000	0.000	0.000	0.000	0.000	0.000	0.000
270-280	0.000	0.000	0.000	0.000	0.000	0.000	0.000
280-290	0.000	0.000	0.000	0.000	0.000	0.000	0.000
290-300	0.000	0.000	0.000	0.000	0.000	0.000	0.000
300-310	0.000	0.000	0.000	0.000	0.000	0.000	0.000
310-320	0.000	0.000	0.000	0.000	0.000	0.000	0.000
320-330	0.000	0.000	0.000	0.000	0.000	0.000	0.000
330-340	0.000	0.000	0.000	0.000	0.000	0.000	0.000
340-350	0.000	0.000	0.000	0.000	0.000	0.000	0.000
350-360	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TABLE 6 - Extract from DNEXLOUT showing additional information

PERIOD	ADSH	BDSH	PATH LENGTH	RAY NUMBER	W
4.00	222.50	223.50	61.789	48	0.38
4.00	221.50	223.50	61.789	49	0.54
4.00	220.50	223.50	61.789	50	0.75
4.00	219.50	223.50	61.789	51	0.99
4.00	218.50	223.50	61.789	52	1.20
4.00	217.50	223.50	61.789	53	1.33
4.00	216.50	223.50	61.789	54	1.29
4.00	215.50	223.50	61.789	55	1.08
4.00	214.50	223.50	61.789	56	0.86
4.00	213.50	223.50	61.789	57	0.82
4.00	212.50	223.50	61.789	58	1.01
4.00	211.50	223.50	61.789	59	1.16
4.00	210.50	223.50	61.789	60	1.05
4.00	209.50	223.50	61.789	61	0.88
4.00	208.50	223.50	61.789	62	0.98
4.00	207.50	223.50	61.789	63	1.11
4.00	206.50	223.50	61.789	64	0.96
4.00	205.50	223.50	61.789	65	0.94
4.00	204.50	223.50	61.789	66	1.09
4.00	203.50	223.50	61.789	67	0.96
4.00	202.50	223.50	61.789	68	0.99
4.00	201.50	223.50	61.789	69	1.05
4.00	200.50	223.50	61.789	70	0.94
4.00	199.50	223.50	61.789	71	1.06
4.00	198.50	223.50	61.789	72	0.95
4.00	197.50	223.50	61.789	73	1.04
4.00	196.50	223.50	61.789	74	0.97
4.00	195.50	223.50	61.789	75	1.03
4.00	194.50	223.50	61.789	76	0.97

ABLE 7 - Inshore wave results for run with LINED = 0
(i.e. no diffraction)

OFFSHORE SPECTRUM (ALL ANGLES OF APPROACH)

FREQUENCY F	0.250	0.167	0.125	0.100	0.083	0.071	0.063
SPECTRUM S(F)DF	0.0300	0.1040	0.2080	0.2580	0.1820	0.0620	0.0120

INSHORE VALUES, FOR WDIR = 270.0 DEGREES NORTH

FREQUENCY F	0.250	0.167	0.125	0.100	0.083	0.071	0.063
SPECTRUM S(F)DF	0.015	0.050	0.077	0.108	0.086	0.032	0.007
THBAR(F)	-108.3	-106.0	-114.0	-115.5	-116.6	-117.2	-117.4
VAR. SIGSQ(F)	24.4	24.4	18.5	18.5	17.7	17.2	16.9

INSHORE SIGNIFICANT WAVE HEIGHT = 2.449 METRES
INSHORE SIGNIFICANT WAVE PERIOD = 8.335 SECS

SIGNIFICANT WAVE HEIGHT RATIO = 0.667
SIGNIFICANT WAVE PERIOD RATIO = 0.996

APPROX. WAVE ANGLE INSHORE = 245.660
APPROX. VARIANCE INSHORE = 19.188

ABLE 8 - Inshore wave results of run with LINED = 1
(i.e. DIFFRACTION)

OFFSHORE SPECTRUM (ALL ANGLES OF APPROACH)

FREQUENCY F	0.250	0.167	0.125	0.100	0.083	0.071	0.063
SPECTRUM S(F)DF	0.0012	0.0038	0.0086	0.0121	0.0087	0.0023	0.0003

INSHORE VALUES, FOR WDIR = 270.0 DEGREES NORTH

FREQUENCY F	0.250	0.167	0.125	0.100	0.083	0.071	0.063
SPECTRUM S(F)DF	0.000	0.001	0.001	0.002	0.001	0.000	0.000
THBAR(F)	-138.7	-144.4	-143.8	-144.1	-143.4	-141.1	-141.3
VAR. SIGSQ(F)	8.3	7.8	14.8	14.6	1000.0	18.3	1000.0

INSHORE SIGNIFICANT WAVE HEIGHT = 0.318 METRES
INSHORE SIGNIFICANT WAVE PERIOD = 8.431 SECS

SIGNIFICANT WAVE HEIGHT RATIO = 0.087
SIGNIFICANT WAVE PERIOD RATIO = 1.007

APPROX. WAVE ANGLE INSHORE = 216.283
APPROX. VARIANCE INSHORE = 12.769

Figures

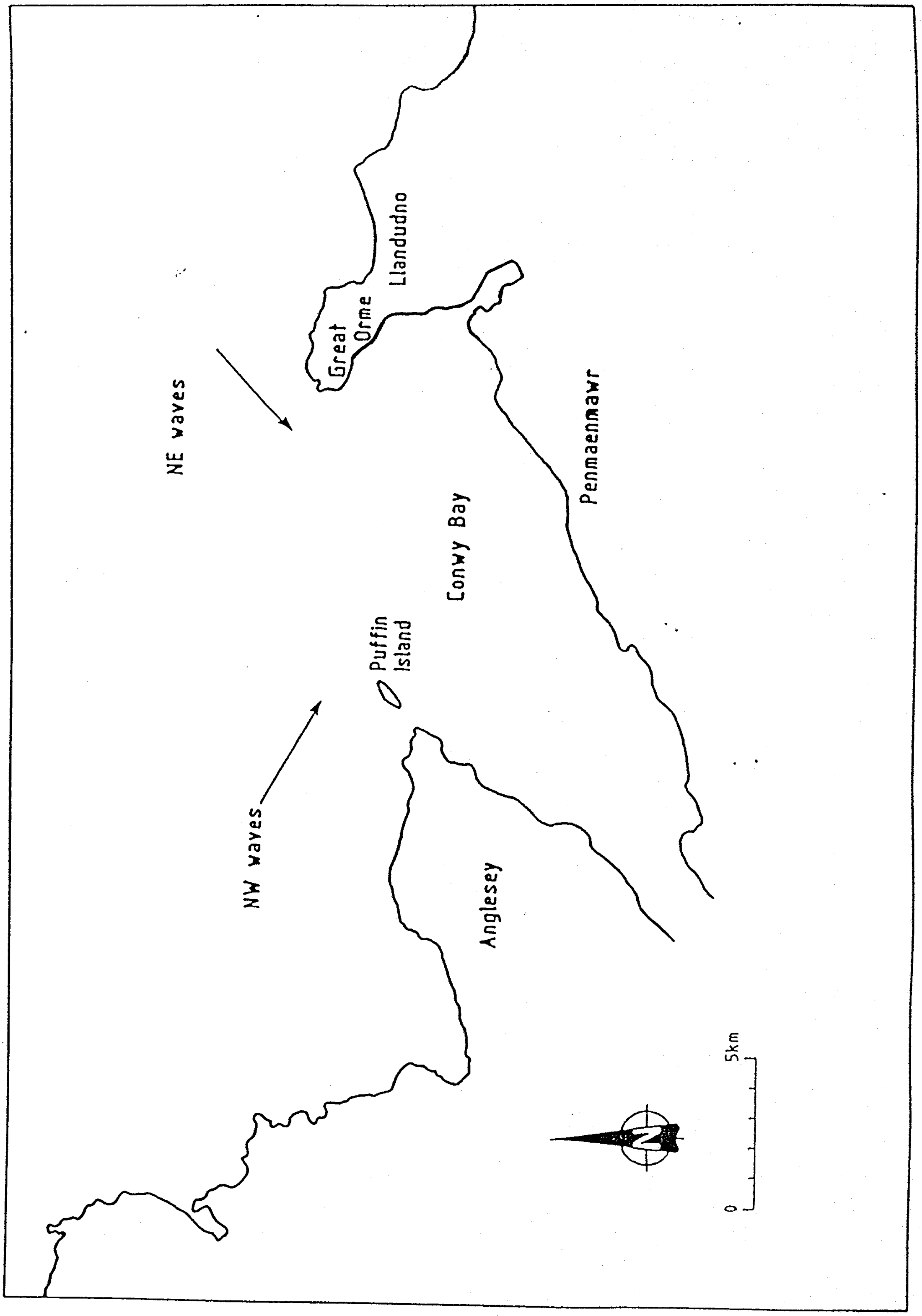

Fig 1 Site of Penmaenmawr showing possible inshore wave directions

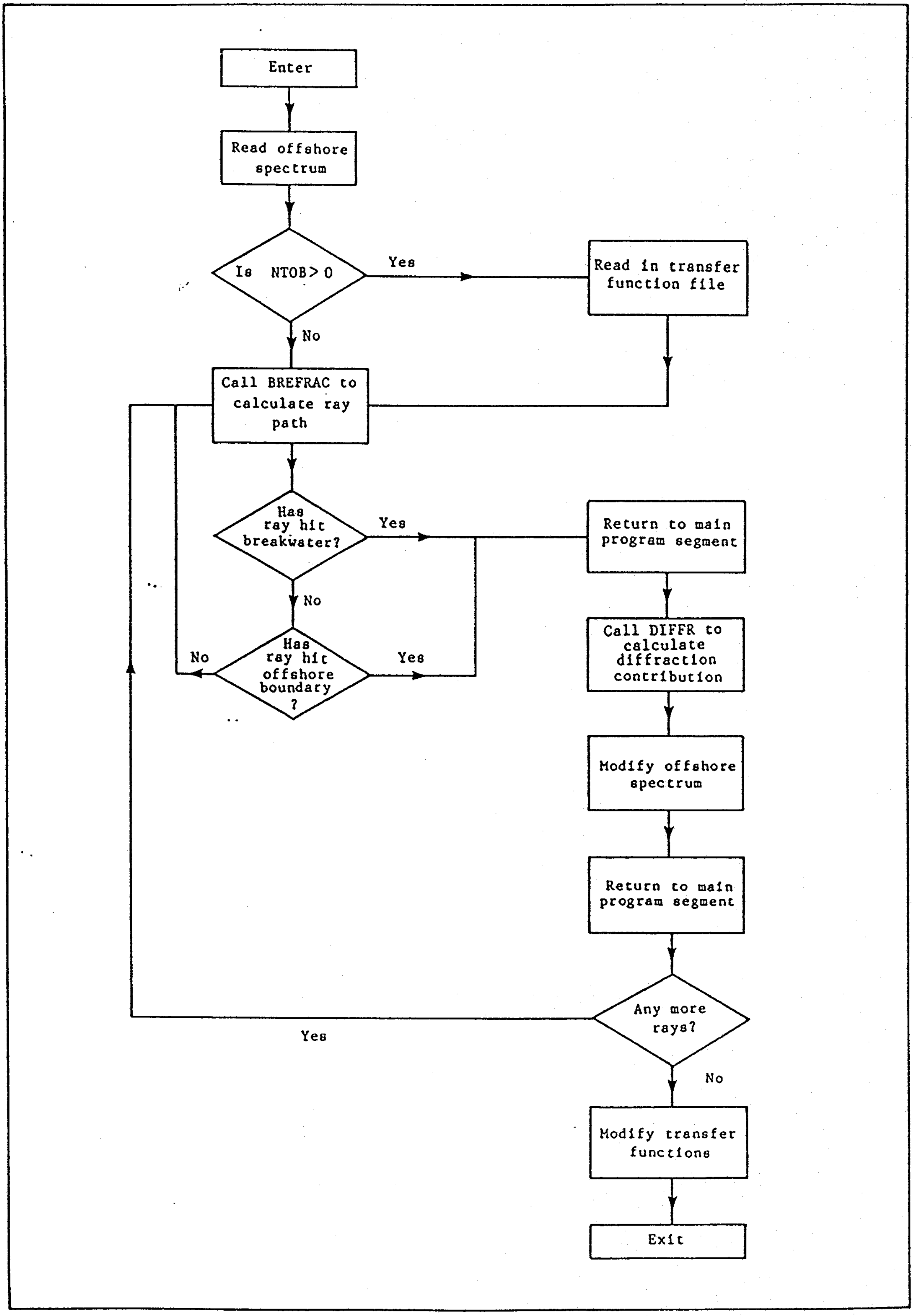

Fig 2 Simple Flow Chart representing diffraction calculations in OUTRAY II

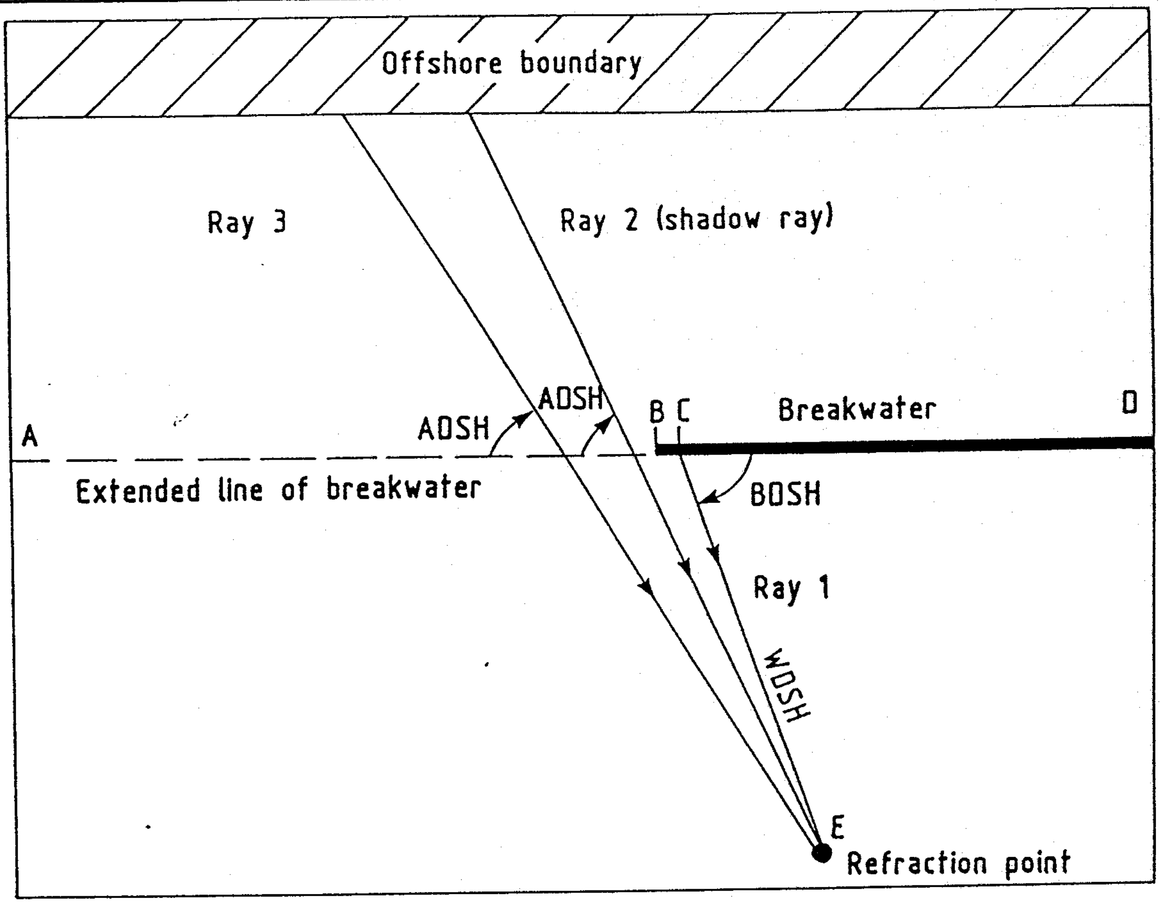

Fig 3 Simplified diagram of breakwater set up

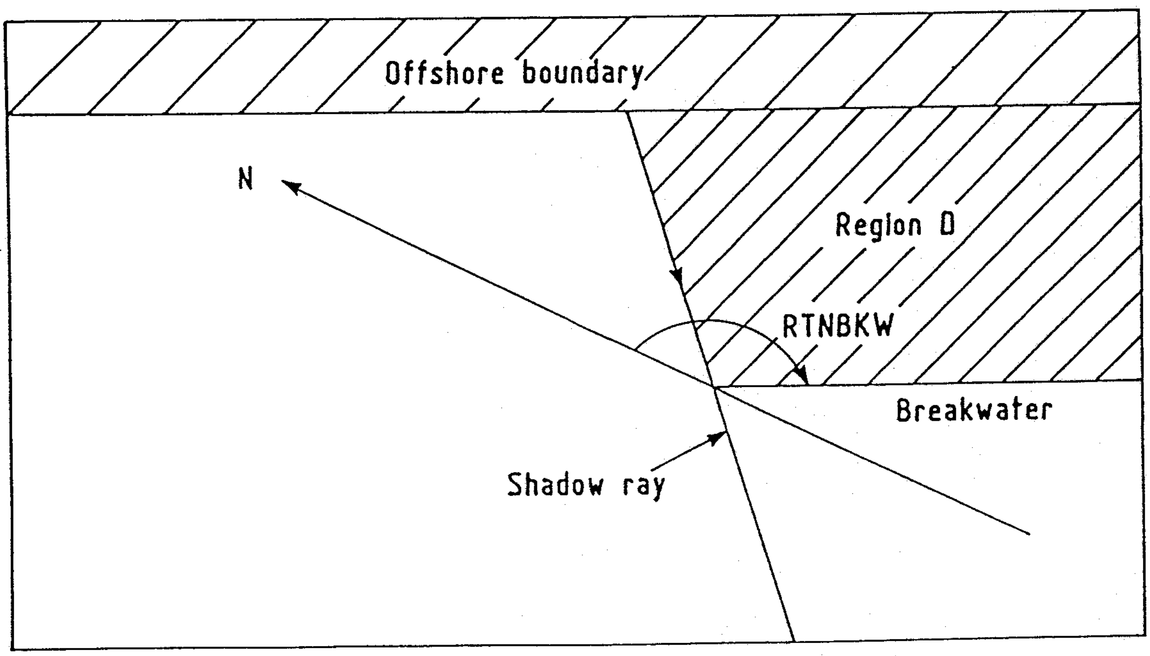

Fig 4 Location of region D

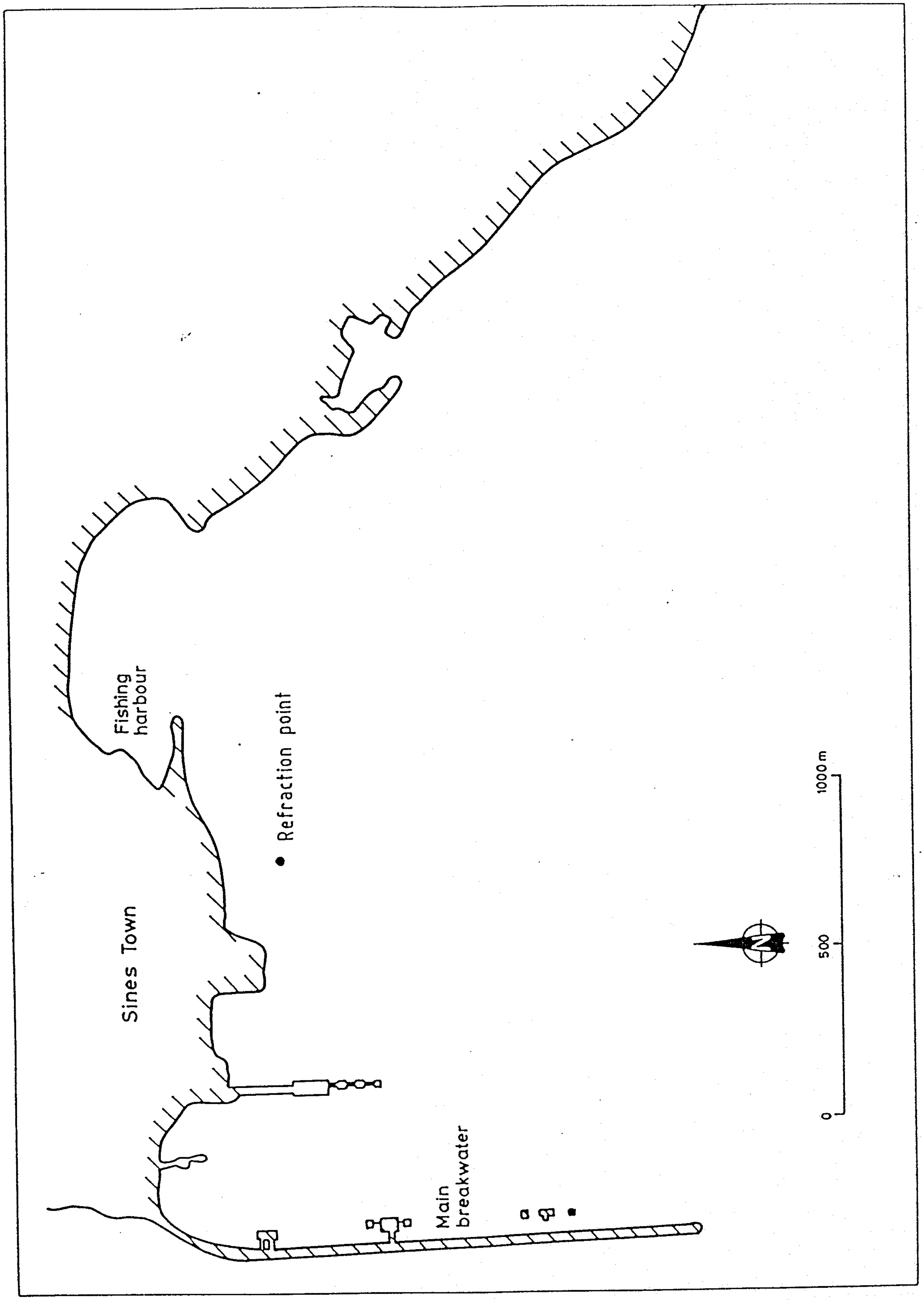

Fig 5 Site of Sines Harbour, Portugal

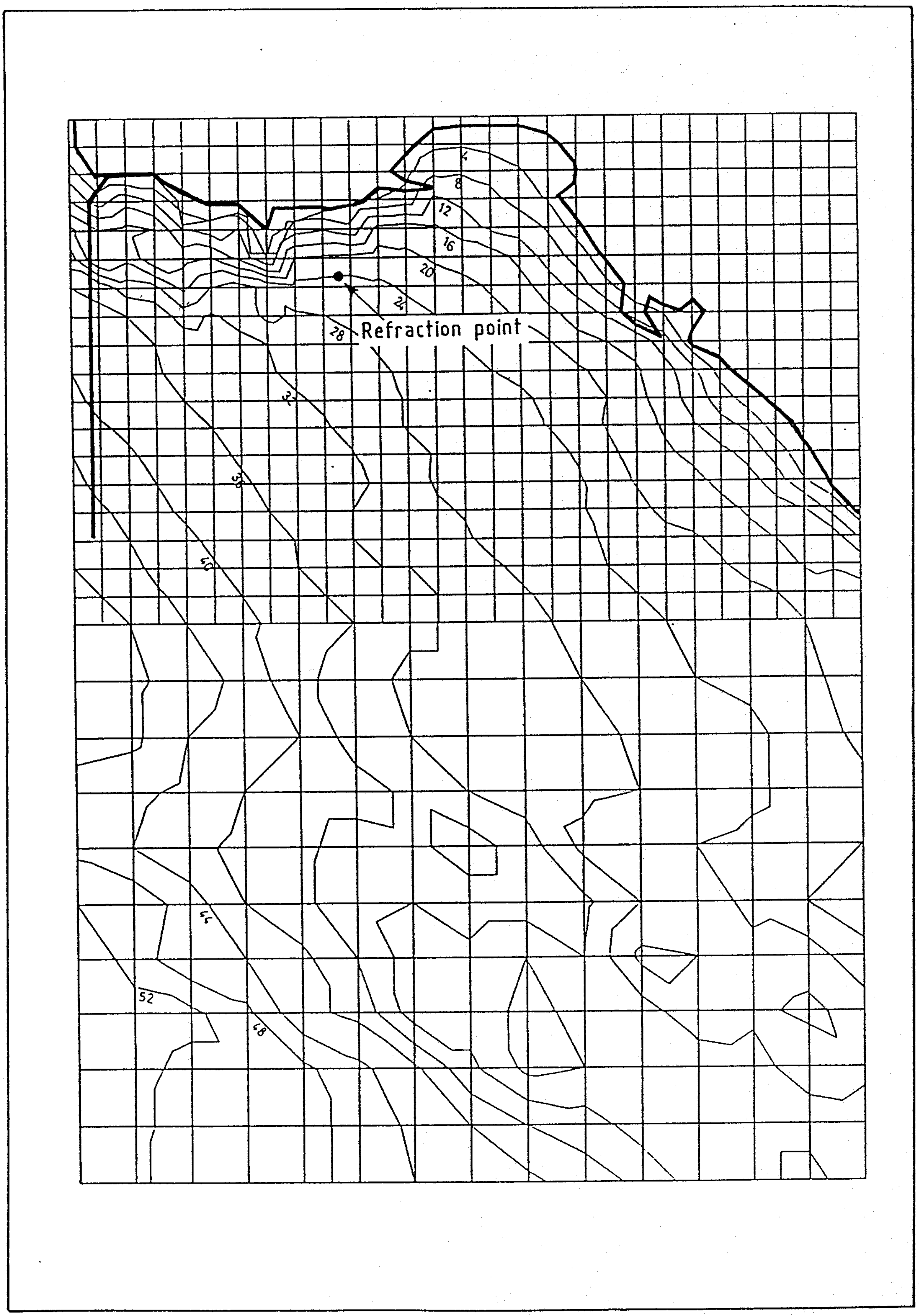

Fig 6 Model grids and depth contours at Sines Harbour with break-water construction

APPENDIX

Details of Common Blocks
Unique to OUTRAY II

APPENDIX

Details of Common Blocks unique to OUTRAY II

Name	Variable	Description	Value set
/OFSPEC/	SPT(15,15,72)	Offshore spectrum array	DOUTRAY2
	MBOX	Number of angular boxes	DOUTRAY2
	NOSP	Number of spectra in MULTSPEC	DOUTRAY2
/DIFRAC/	ADSH		DBREFRAC
	BDSH	See 3.2.1	DOUTRAY2
	WDSH		DOUTRAY2
	RTNBKW		DOUTRAY2
	LINED		DOUTRAY2
/BWATER/	GRAD	See 3.1.2	DOUTRAY2
	CONST		DOUTRAY2
	DIFF		DOUTRAY2
/NGRID/	NGRID	Number of grids	DOUTRAY2
	IG	Number of grids containing current ray position	DOUTRAY2
	NRAY	See 3.2.2	DOUTRAY2
/DBRY/	XL1,XL2	See 3.1.2	DOUTRAY2
	YL1,YL2		
/PERIOD/	T	Period	DOUTRAY2
	IP	Calculations using IPth frequency	DOUTRAY2