DIFFRAC Version 5.0

Diffraction model

English DIFFRAC manual MS-DOS PC-program

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Note: These appendices are NOT available in ASCII due to the use of formulae. They can be found in the documentation.

1 Applicability

The DIFFRAC program can be used to describe wave behaviour in and around structures in water of nearly uniform depth. The phenomena accounted for are diffraction and reflection. Partial reflection is modelled at reflecting edges of the schematised basins according to user defined coefficients. DIFFRAC models the behaviour of short or long crested regular waves (i.e. with or without directional spreading). In practice, the results for regular waves give a good guide to the behaviour of random waves but the user should take care in the interpretation of cross patterns and standing wave patterns in basins where reflection plays a large role.

DIFFRAC is in principle a good model to compute the short wave penetration of harbours of uniform or nearly uniform water depth. However, in situations where there is a long approach channel (typically where the bottom slope is shallow in the neighbourhood of the harbour), refraction of the waves at the sides of the channel can play a very important role in determining the penetration of the harbour. It is not possible to model such refraction well using DIFFRAC and the use of a combined refraction-diffraction model is recommended for such situations. This comment is also applicable for situations where there are large depth variations within the harbour. DIFFRAC can only account for refraction along the boundaries which connect basins of different depth. Along these boundaries the direction of the refracted wave is correctly modelled but the change in wave height over the boundary is only approximately correct. This approximation deteriorates for waves arriving more obliquely to the boundary and for boundaries between basins with large depth differences.

The seiching response (long wave resonance) of harbours or waterways of uniform depth can be studied using DIFFRAC. However, it is emphasised that even quite small variations in depth can have a significant effect on resonant behaviour and it is therefore generally recommended to use a combined refraction-diffraction model to study seiching response.

This manual describes the computational aspects of running DIFFRAC. We strongly advise the user to read Appendix A on schematisation before applying the software.

2 Installation instructions and file description

2.1 Configurations

The configurations supported are IBM-XT, -AT, 80486 or compatible PCs with:

- 640 KByte internal memory [1],
- MS-DOS operating system version 3.1 or higher,
- Graphics card CGA, EGA, EGC or HERCULES (or 100% compatible),
- IBM-Graphics compatible printer for a screen dump of the graphic screens,
- A hard disk with about 5 MByte free space (DIFFRAC uses the hard disk as virtual memory during the computation of large problems).

It is advised to use a configuration fitted with:

- an 8087, 80287 or 80387 floating point (numerical) co-processor.

Some users load programs into their PCs which remain in the background while other programs are running (e.g. The Norton Commander, some software to adapt the screen driver). These use up part of the 640 KByte of internal memory and can cause some problems when running the DIFFRAC package. We suggest that these programs be removed or not loaded if problems are experienced.

2.2 Software Structure

The DIFFRAC packet consists of 3 programs:

- A pre-processor (PREDIF)
- A processor (DIFFRAC)
- A post-processor (POSDIF)
- A post-processor for batch use (POSBAT)

[1] To run DIFFRAC it is usually required to remove all resident software in the background memory

PREDIF is used to make input suitable for the main computational program, DIFFRAC. This is done using a user friendly, menu controlled, whole screen data entry system with on-line help. The program DIFFRAC computes the solution to the wave penetration problem without any user interaction. POSDIF arranges print and graphical output in the form required by the user. This is also controled using a menu driven, whole screen data entry system.
The graphical output can also be generated without any user interaction with the program POSBAT. In Figure 1 a structure diagram of DIFFRAC is given.

The supplied software is suitable for application on machines both with and without a co-processor (8087, 80287 or 80387 chip).

2.3 Files

The supplied disks contain the following files:

diskette 1/3:	
DIFFRAC.EXE	program executable DIFFRAC
DEMO*.INP	input file for DIFFRAC/ PREDIF
READ.ME	remarks about this release
DIFF_EN.DOC	abridged manual in ASCII code (this file)
diskette 2/3:	
PREDIF.EXE	pre-processor executable
PREDIF.MTR	file containing data entry screens
PREDIF.HLP	file containing on line help
PREDIF.MSG	message file
PREDIF.CFG	configuration file for pre-processor
DEMO*.INP	input file for DIFFRAC/ PREDIF
diskette 3/3:	
POSDIF.EXE	post-processor executable (interactive)
POSBAT.EXR	post-processor executable (batch)
POSDIF.MTR	file containing data entry screens
POSDIF.HLP	file containing on line help
POSDIF.MSG	message file
POSDIF.CFG	configuration file for post-processor
DEMO*.RES	DIFFRAC results file
DEMO*.POS	file containing output instructions for post-processor

2.4 Installation

Create a directory on the hard disk and copy all files (DOS-commands: MD <name>, CD <name>, COPY <a: *.*>). <name> is the name of a directory, sub-directory or path.

Allocate at least the following numbers of files and buffers in the CONFIG.SYS file: 'files=20' and 'buffers=15'. If a path is set to the directory which contains the obligatory program files, you may start the program from any directory. This path may be set in the AUTOEXEC.BAT file.

For graphic output to the screen, the graphics driver must be defined, which is done in the first line of the .CFG files (PREDIF.CFG and POSDIF.CFG).
The following drivers are available:

"IBM" (corresponding to CGA resolution van 640*200),
"EGA" (corresponding to EGA resolution van 640*350),
"OLIVETTI" (corresponding to EGC resolution van 640*400),
"HERCULES" (corresponding to HERCULES resolutie van 720*348).

If the HERCULES driver is used the command 'HGC full print' should be given before running DIFFRAC if you wish to make screen dumps of graphical screens to the printer (it is recommended to include this instruction in the AUTOEXEC.BAT file). Similarly the 'GRAPHICS' command should be given when the Olivetti driver is used. If possible the printer should be set up in IBM emulation mode, see the manual for your printer.

If it is intended to make hard copies of plots using a plotter then the correct type of plotter should be specified in line 2 of the configuration file. The plotters supported are:

"CAPCOMP 84"	for a CALCOMP plotter in A4 format
"HP7475A A4"	for HP7475 plotter in A4 format (HPGL code is produced)

Note that the DOS 'MODE' command should be given for the port to which the plotter is connected (e.g.: 'MODE COM1: 9600, e, 7, 1, P' for the HP 7475A plotter. This is to specify the protocol to be used for the PC to communicate serially with the plotter. Most plotters have 'dip' switches which can also be used to specify the communication model, so care should be taken with this procedure.

However, if the plotter has already been used for other applications it is likely that these actions have already been carried out and the 'MODE' command placed in the 'autoexec.bat' file. In this case, no action is required. If an HP compatible laser-jet printer is available, it may be possible to make plots on it using the HPGL files produced by DIFFRAC. If this is required, the user should consult the manual for the printer.

3 Running the DIFFRAC package

As described in section 2 the DIFFRAC package consists of a pre-processor (PREDIF), the computational program itself (DIFFRAC), a post-processor (POSDIF) and a special version of the post-processor to run in batch mode (POSDAT). This chapter describes the purpose of each of the programs in the package.

PREDIF

The user can start the pre-processor with the instruction PREDIF(.EXE). The first time that the package is used, we would advise the user to keep the user interface scheme (see section 4) to hand while entering the data.

Note that before running PREDIF for the first time, the PREDIF.CFG file must be edited to give the correct screen and hard plotter drivers for the users configuration (see Section 2).

PREDIF creates the input required to run DIFFRAC and stores it in the 'model' file (extension: .INP). The schematisation data to be stored in such a model file must be complete, consistent and a valid input file for DIFFRAC. However, it is also possible to store incomplete schematisation data in a workfile (extension: .WRK), which can be read in during a later PREDIF session and finished off to create a valid .INP file. The trunk of the file names can be chosen freely by the user, although PREDIF usually suggests part of the name based on a user ID code (see below).

The coordinates of points to be used in the schematisation can either be entered by hand or from a file (e.g. produced using a digitiser). This file must have the extension .POL. The first line of this file must be an integer giving the number of point coordinates in the file and the subsequent lines must contain those coordinates (x followed by y on each line in free format).

PREDIF can make screen and hard copy plots of the schematisation, enabling the user to check the data entered and to produce plots of the schematisation for reports. Hard copy plots are written to files which can later be copied to the plotter (see section 2 on the MODE setting). In each PREDIF session the user should give a code of up to five characters to identify the schematisation or run. This code will later be used as the basis for the trunk of the output file names. The user is free to change these trunk names or to add upto 3 additional letters to give further identification.

The user interface for PREDIF is described in the following chapter.

DIFFRAC

The actual computational program is started by the instruction:

'DIFFRAC <name>.INP <ENTER>'

Where <name> is the trunk name of the input file created by PREDIF. DIFFRAC creates 2 output files with the extensions ".OT2" and ".RES". The trunks of these files are identical to the trunks of the model (.INP) file. The .OT2 file contains information on the schematisation and the numerical solution of the problem. The .RES file contains the information required to inspect the results of the computation using the post-processing program and can not directly be examined by the user as it is in binary format.

In medium and large computations, DIFFRAC uses the hard disk as virtual memory. The required space which must be available depends on how large the problem is and on how the schematisation has been divided into basins. An estimate of the maximum and minimum hard disk space which may be required is given on the plot of a complete schematisation produced by PREDIF. The user should check the space available on the hard disk before running DIFFRAC. In principal the hard disk is always used as virtual memory regardless of the size of the problem. The number of equations depends on the schematization which is applied, particularly the location of connecting edges between the bassins. If there are problems with the required free disk space one might consider defining more basins in the schematisation of the problem.

DIFFRAC works using a boundary element method. This means that potential sources ('boundary elements') are distributed along the defined edges of the harbour. The maximum number of boundary elements which can be defined is 300. On the plot of the schematisation produced by PREDIF an estimate of the number of border points and the total number of boundary elements is given.

The user may wish to make a series of DIFFRAC computations in batch mode. This can be an advantage for large schematisations with a long computation time. In such a situation a number of input files can be prepared in advance, either using the pre-processor or by editing existing input files, and the results for each input file computed overnight. The batch file (with the extension .BAT) should have the contents:

'DIFFRAC <name-1>.INP
'DIFFRAC <name-2>.INP
.. .. ..

'DIFFRAC <name-i>.INP

.. .. ..

'DIFFRAC <name-n>.INP

where 'name-i', is the chosen name of the input-file for run i. Note that the names of the output and result files will have the same trunk as the input file. The runs can then all be executed by entering the name of the batch file. The results can then be examined or plotted later as described below using the post-processor.

POSDIF

The post-processing program is started by the instruction:

'POSDIF <ENTER>'

As for the pre-processor, an overview of the menu screens for the post-processor is given in section 4.

There are two main options in POSDIF, the definition of an output task and the execution of an output task. Note that once an output task has been defined, the instructions are written to a file called <name>.POS, where <name> is defined by the user. These instructions may then be executed interactively under POSDIF or in batch mode using POSBAT (see below). The batch mode is mainly useful for large output grids (used for iso-line plots) when the computational time can be a number of hours.

Plot output made in batch mode can only be made to plot files which can later be copied to a plotter (note that the suitable plotter must be given in the configuration file POSDIF.CFG - see section 2). The files created will be numbered sequentially as: <name>.P01, <name>.P02, ... <name>.Pnn, where <name> is the trunk of the .POS file name. This means that no more than 99 plots can be generated at once using the same .POS file unless the plot files are renamed in the batch file.
Each plotfile can be copied to the plotter by the command:

COPY <name>.Pnn COMn

where COMn is the serial communication port to which the plotter is connected (see section 2).

During interactive use of the program, plot output can also be made to the screen from where a hard copy plot on a printer can also be made.

Data can also be generated in a form suitable for use in the TEKAL and TEKUNI packages (these are graphics package available from DELFT HYDRAULICS). This data is written to the files <name>.Tnn and <name>.Unn, where <name> is the trunk of the .POS file name, and nn is the sequential number of the TEKAL or TEKUNI file created using <name>.POS.

The program POSBAT can be used to generate results in batch mode. This program can be started with the command:

POSBAT <name>.POS

Where <name>.POS is a file already created using POSDIF. Any error messages will be written to a file <name>.ERR. A number of such runs can also be carried out in batch mode by placing a series of run commands in a batch file with the extension .BAT.

4 Description of user interfaces

4.1 General

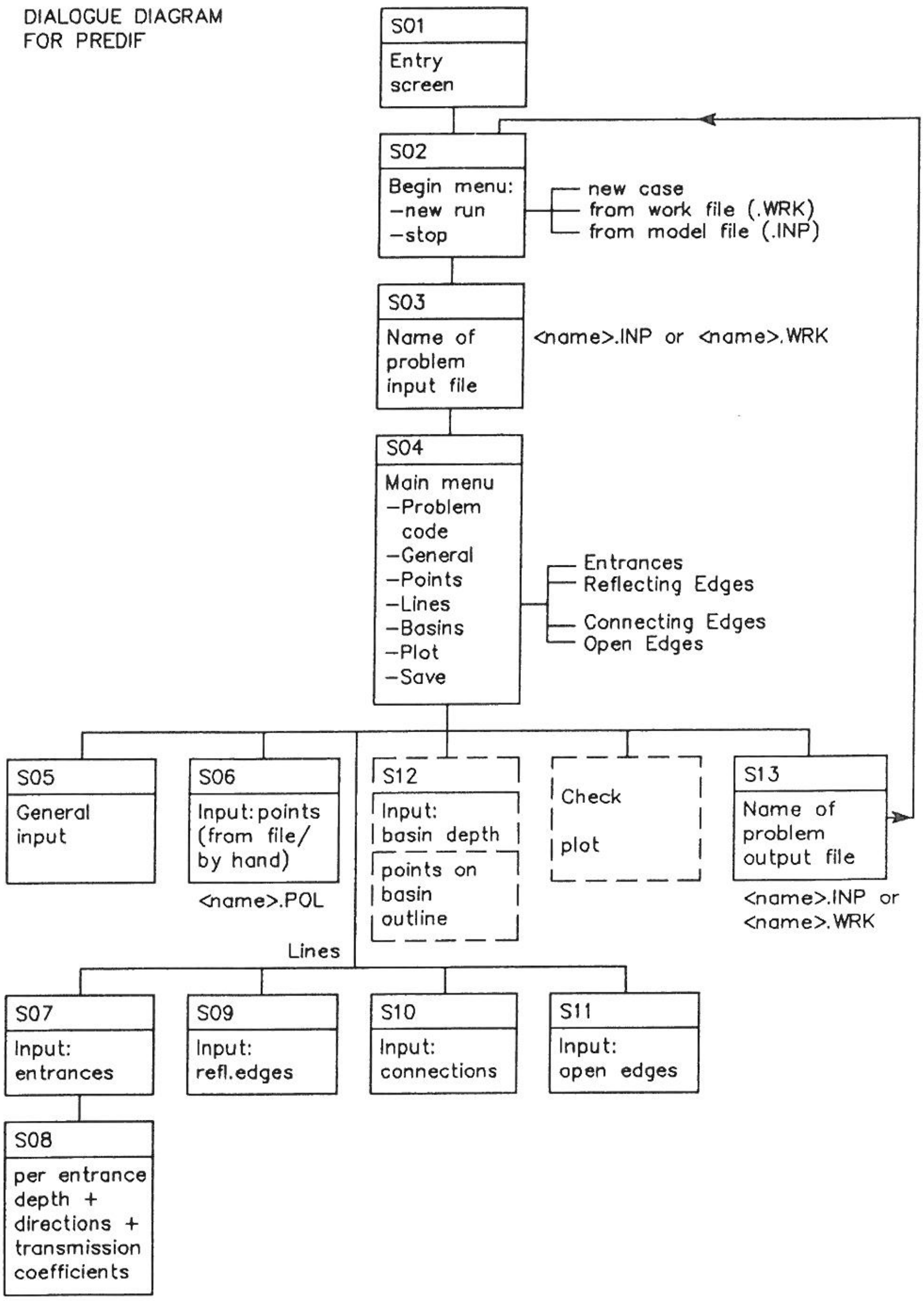
This chapter gives an overview of the user interfaces used in the programs PREDIF and POSDIF. As described in the previous chapter, the programs DIFFRAC and POSBAT are started directly from DOS and do not have a user interface.

The interface presents the input data and help information to the user in a standard, user friendly format which is also used in other DELFT HYDRAULICS software. Further, navigation between the screens and the handling the input fields is also standardized. If the user requires help on the the handling of a screen or the data to be input, <F1> gives ONLINE HELP. In principle this HELP information has been designed to give sufficient background to generate the input. Therefore, in what follows only a schematic representation of the user interface is given, followed by a general description of the screen and field handling.

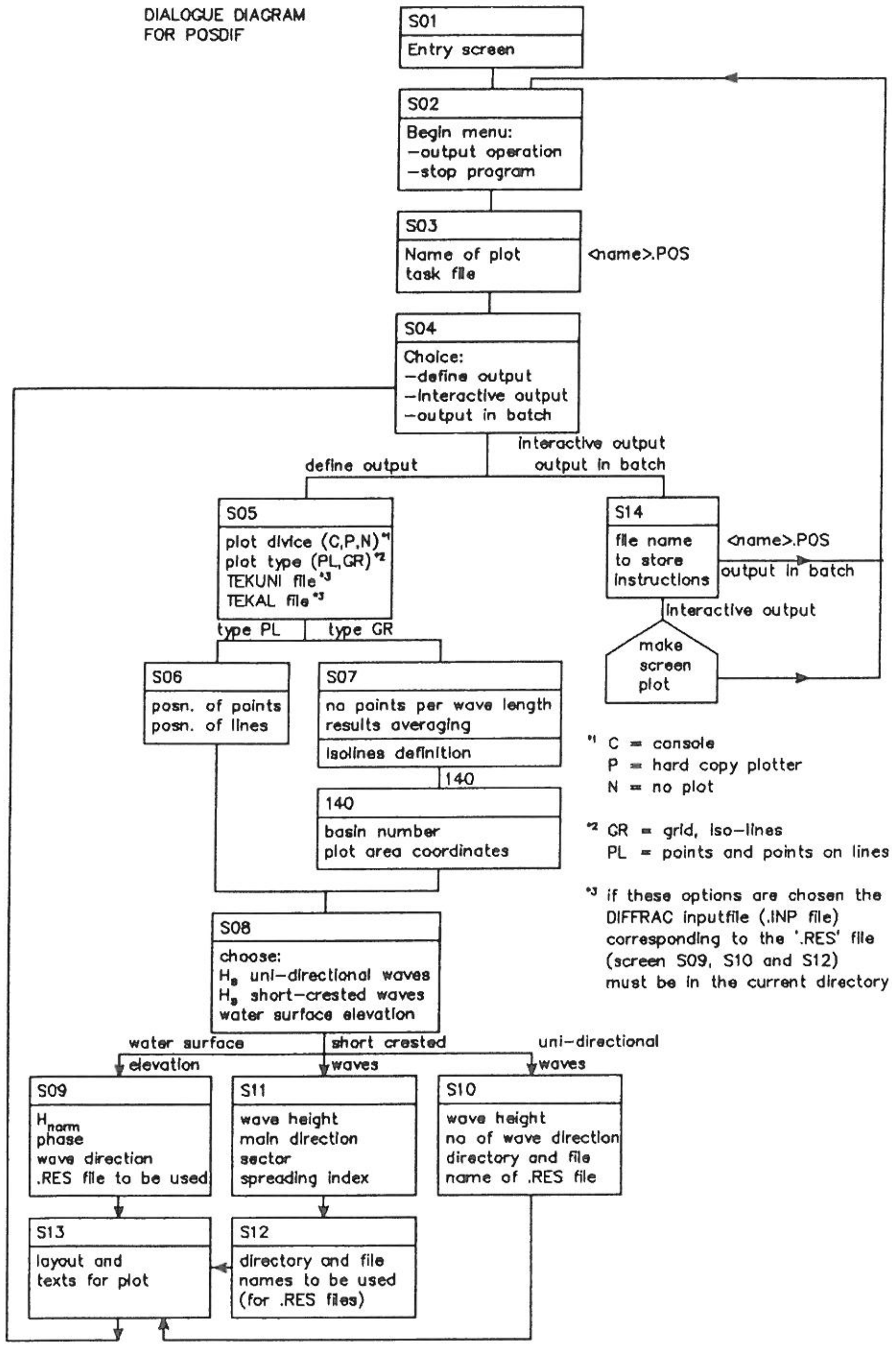
Generally, attempts to enter unlikely data or to perform impossible actions are signalled by a message at the bottom of the screen. In some cases, numeric input is protected against the input of values outside the physically realistic range. If a value is outside this range the user is warned, and progress is not possible until a realistic value is given. Further, if an unlikely (but possible) value is entered, the user is asked to confirm this.

4.2 Overview of Pre/Post-processor Screens

The general procedure in the pre-processor (PREDIF) can be represented as:


DIALOGUE DIAGRAM
FOR PREDIF
S01
Entry
screen
S02
Begin menu:
-new run
-stop
new case
from work file (.WRK)
from model file (.INP)
S03
Name of
problem
input file
<name>.INP or <name>.WRK
S04
Main menu
-Problem
code
-General
-Points
-Lines
-Basins
-Plot
-Save
Entrances
Reflecting Edges
Connecting Edges
Open Edges
S05
General
input
S06
Input: points
(from file/
by hand)
<name>.POL
S12
Input:
basin depth
points on
basin
outline
Check
plot
S13
Name of
problem
output file
<name>.INP or
<name>.WRK
Lines
S07
Input:
entrances
S09
Input:
refl.edges
S10
Input:
connections
S11
Input:
open edges
S08
per entrance
depth +
directions +
transmission
coefficients

The general procedure in the post-processor (POSDIF) can be represented as:



4.3 Navigation in the screens and entering data

The effect of the navigation and data entry key-strokes depends on the function of the field or screen where they are used. FOUR types of function (identified as I to IV) are defined as follows:

- I to read data (reals/integers/strings),
- II to read a data array (integers/reals),
- III to select an option in a MENU,
- IV to present and inspect generated data.

LEAVING THE SCREEN - (see also instructions on the screen's baseline):

Return	-	confirm menu choice (I - IV)
PgUp	-	leave screen, save data and step back (I - IV)
PgDn	-	leave screen, save data and step forward (I - IV)
Esc	-	leave screen to step back one or more levels (I - IV) without saving changes

MOVING BETWEEN FIELDS:

Cursor Up/Down	-	move up/down one field	(I and II)
CTRL/Cursor right	-	move one field to the right	(I and II)
CTRL/Cursor left	-	move one field to the left	(I and II)
Return	-	move to the next field	(I and II)

Home	-	move to the first row of the array	(II, III and IV)
End	-	move to the last row of the array	(II, III and IV)
Ctrl/PgUp	-	scroll up in array	(II, III and IV)
Ctrl/PgDn	-	scroll down in array	(II, III and IV)

Cursor Up/Down	-	move up/down in menu	(III)
Return	-	confirm choice and leave screen	(III)

MOVING WITHIN A FIELD:

Home	-	move to the first character in the field (I)	
Cursor right	-	move one character to the right	(I and II)
Cursor left	-	move one character to the left	(I and II)
Backspace	-	delete last character	(I and II)
Insert	-	toggle to insert mode	(I and II)
Delete	-	delete actual character	(I and II)
Ctrl/End	-	clear field to end	(I and II)

SPECIAL KEYS:

F1	-	help information for current field
<CTRL> F1	-	additional help information
any key	-	continue after HELP or MESSAGE at baseline
F9	-	temporary exit to DOS
P or p	-	dump graphic screen to printer
any key	-	return to menu from graphic screen

The user can also use the following keys while entering array data:

<CTRL> F2	-	Insert row below current line
<CTRL> F3	-	Delete current row
<CTRL> F4	-	Import data from file (when activated)
<Esc>	-	Leave screen abandoning any changes made

5 Output

5.1 General

The output of the actual DIFFRAC computation is restricted to a description of the schematisation and an optional indication of the numerical accuracy of the solution. This information is contained in the '.OT2' file.

The numerical accuracy of the results is given as the number of reliable significant figures in the end results. A number between 0 and 7 will be given. If the accuracy is given as 0 or 1 significant figures, the problem is ill-conditioned and the results are unreliable. This is generally caused by a poor schematisation (see Appendix A). If the schematisation appears to be good then an improvement of the accuracy of the numerical solution may be obtained by changing the number of points per wavelength or by very slightly changing the wave period.

The actual computed wave conditions can be examined using the post-processing program, POSDIF. Both graphical and printed output can be generated using this program. The program presents the user with a series of menu-driven, user-friendly data entry screens with on-line help information.

In this section, a general description of the possibilities is given and advice is given on the interpretation of the results.

Three types of parameters can be plotted:

- the wave height (uni-directional waves),
- the wave height (short-crested waves) - only available if results have been computed for three or more wave directions, and
- the file surface elevation (uni-directional waves only).

For each of these parameters, two types of plot can be made using the post-processor:

- an isoline plot,
- a 'points' plot.

In both sorts of plot, the post-processor first computes the wave height at relevant output points based on the results of the main computation with DIFFRAC. This computation may take some time for large problems.

In both types of plot, the edges defined by the user are plotted as a background which enable the user to locate the output.

Two sorts of isoline plot are available:

- an overall plot,
- a detail plot.

In an overall plot, a grid is automatically generated to cover each basin with a user defined mesh size in wavelengths. Note that this grid bears no relation to anything used in the solution method.

A detail plot is a plot of the wave height in a rectangular area. The rectangle has two sides parallel to the x-axis and the user defines the rectangle by giving the coordinates of the upper right and lower left corner points. The mesh size is also defined by the user in number of output points per wavelength. Note that such a detail plot can only be produced using a single basin.

In an isolines plot, isolines of the plot parameter are drawn at user defined levels (given in m). The program uses the following plot procedure:

- Compute the value of the plot parameter at each point in the mesh from the source strengths computed in the solution (see Appendix A). If required the wave height is computed including the effects of directional spreading.

- Generate a quadrilateral grid which covers the schematisation of each basin. One diagonal is constructed in each mesh of the grid to form a grid of triangles bisected by each wave height isoline using linear interpolation. It can be shown theoretically that either zero or two sides of each triangle are bisected by a given isoline. The position of the bisection points are then found using linear interpolation and are joined to form the isolines.

- Points outside a region derived from the outline of the basin are excluded. The region lies at a fixed distance inside the basin outline to ensure that the plotted isolines are not influenced by grid points outside the basin.

In many of the situations modelled by DIFFRAC, reflection at the boundaries of an enclosed basin plays an important role. These reflections lead to standing or cross wave patterns in the wave height with a node to anti-node length scale of about half a wave length. If this is the case, at least 5 or 6 nodal points per wave length are required in the output grids (see below) to make sensible isoline plots, particularly in areas close to (within several wave lengths) of the reflecting edges.

The computed value of the wave height depends on whether the output grid points lie on a node or an anti-node. If insufficient points are used to distinguish the pattern of nodes and anti-nodes, the plot obtained depends on the position of the output grid points relative to this pattern. The results can thus be considered to be of no value.

The result of an isoline plot of the wave height made correctly in such a situation often consists of a series of circular isolines around each node and anti-node. This sometimes gives a plot which is extremely difficult to interpret because there are so many iso-lines. Further, in reality the incident wave field is irregular (frequency spreading) and it is unlikely that such a wave height pattern is realistic except close to the quays. At some distance away from the quays, the nodes and anti-nodes of each spectral component will have a different spatial distribution, leading to a much smoother pattern of wave height variation. A smoothing option has therefore been built into DIFFRAC, to enable better interpretation of the results.
In this case, a fine grid is generated by the program which covers each basin with the mesh size defined by the user, dx. A rough mesh is then defined by grouping the output points in the fine mesh into rectangles of m by n points (m and n are user defined. m*dx and n*dx should both be of the order of magnitude of a half wavelength unless they are both defined as 1 when there is no smoothing. It is recommended that m and n are chosen to be equal in most situations.) The smoothed wave height is then computed in each rough mesh according to:

$$\overline{H} = \sqrt{\left(\frac{1}{m.n} \sum_{i=1}^{m} \sum_{j=1}^{n} H_{ij}^2\right)}$$

Where m.n is the number of points in the rough rectangle lying in the basin and H_{ij} are the wave heights computed at the output points lying both in the rough rectangle and in the basin. Note that the smoothing is based on an energy principle. Note that it is general not sensible to apply smoothing to plots of the water surface elevation as the average water surface elevation is zero.

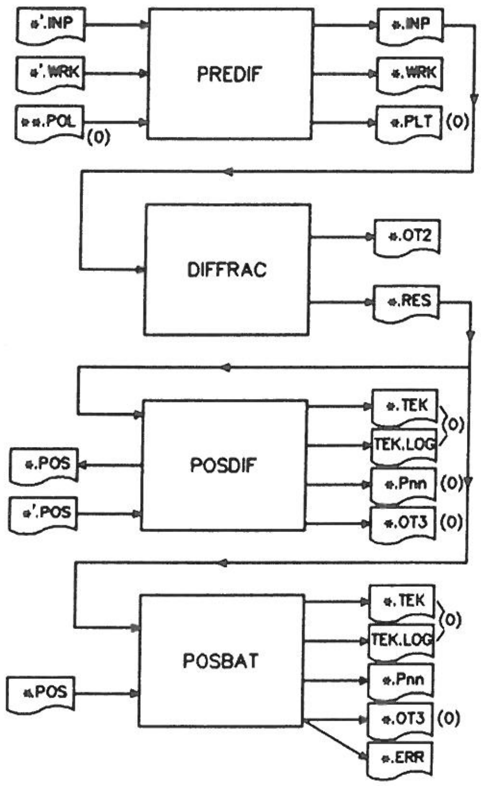
In a 'points' plot, a cross is plotted at each output point defined by the user (using the post-processor). Next to the cross, the wave height in cm is written. This allows the user to gain insight into the pattern of wave penetration and reflection. Note that if reflections are expected, at least 5 points per wavelength should have been requested, to be able to distinguish this pattern. A points plot may be made either in an overall plot or in a detail plot but note that no smoothing can be applied. If a points plot is made, the results at each point are also written to the file <name>.OT3.

References

Shore Protection Manual 1984. Coastal Engineering Research Centre, Vicksburg, Mississippi, US Army Corps of Engineers. Chapter 2, section V, Wave reflection, p.p. (2-109)-(2-129).

Berkhoff, J.C.W., Mathematical models for simple harmonic linear water waves diffraction and refraction. DELFT HYDRAULICS, Publ. No. 163, 1976.

Kostense, J.K., Meijer, K.L., Dingemans, M.W., Mynett, A.E. and Van den Bosch, P. Wave energy dissipation in arbitrarily shaped harbours of variable depths. Proc. 20th Int. Conf. Coastal Eng., 1986, pp. 2002-2016.



(0) = optional

*, **, *' = trunk identifications of files

.INP file	: model file with schematisation data to run DIFFRAC
.WRK file	: work file to store incomplete schematisation data
.POL file	: file with coordinates of points to be used in the schematisation
.PLT file	: file with plot of schematisation
.OT2 file	: result file of DIFFRAC containing information on the schematisation and the numerical solution of problem
.RES file	: result file of DIFFRAC containing information required to inspect results
.POS file	: task file for post-processing task
.TEK file	: result file of POSDIF and POSBAT for use in TEKAL package
TEK.LOG file	: corresponding file with overview of data written to .TEK file
.Pnn file	: files with plot output prepared by POSDIF/POSBAT
.OT3 file	: result file POSDIF/POSBAT with "point plot" information
.ERR file	: file with error messages during POSBAT run

Figure 1 Structure diagram of DIFFRAC

Appendix A

Advice on schematisation

A.1 General

DIFFRAC computes the wave penetration into one or more coupled harbour basins accounting for the effects of diffraction and (partial) reflection. Each basin is assumed to have a constant water depth and reflecting boundaries are assumed to be vertical. Refraction is only accounted for along the edge connecting two basins of different depth. This refraction is highly schematised and the use of seperate basins can not generally be relied upon to represent refraction effects.

The user must provide information about the situation to be modelled, including the position of edges, their type (entrance, connecting, reflecting or open) and associated information (e.g. wave height, period, and direction for entrances and reflection coefficient for reflecting edges.) The user must also define the water depth in each basin. This information can be input using the pre-processor which has detailed on-line help (See section 3).

This Appendix explains the terminology used and gives advice on schematisation, using harbour basins as examples. A simplified description of the theory underlying DIFFRAC is given since a knowledge of this is essential to make a good schematisation.

The axis system is a right handed rectangular axis system. Directions are measured anti-clockwise w.r.t. the x-axis. The user may use a system in any orientation but must give all coordinates in a single system. Note that the y-axis runs at 90° to the x-axis. Thus if the x-axis points east, the y-axis points north.

Very occasionally, a schematisation may give a system of equations which is ill-conditioned (difficult to solve numerically). At this stage we can only give limited advice on how to avoid this problem (see below). However, in each DIFFRAC computation a condition number may be computed which gives an idea of the accuracy of the numerical solution.

A.2 Terminology

Potential source

A solution to the wave equation for uniform water depth which has a singularity at its centre. In DIFFRAC sources are used which represent waves radiating outwards from their centres. The wave height associated with the source is independant of direction and varies with distance from the centre.

Boundary element

A section of an edge on which a potential source is placed. The user must define how many boundary elements should be distributed per wavelength along the edges.

Basin

Part of the schematisation of a harbour. The schematisation may consist of a single basin or a number of basins connected to each other. The outline of a basin is represented by a number of points, which are connected with each other to form a continuous line running in an anti-clockwise sense around the basin. An edge must be defined between each pair of adjacent points in a basin.

Edge

A straight line forming a part of the outline of a basin. An edge may be one of the four types:

- an incident wave entrance,
- an open edge,
- a reflecting edge,
- a connecting edge.

An edge is defined by the coordinates of its end points. Its direction is from the first point to the second point given in the basin definition.

Direction

Directions are given in degrees anti-clockwise with respect to the x-axis unless otherwise stated. The wave direction is the direction to which the wave is travelling. Bearings (nautical definition) are not used.

Normal

The normal to an edge is defined to be 90° anti-clockwise to the direction of the edge. The normal to an edge must point into the basin in which it is defined (see Figure A1).

Inside

The inside of an edge is the side which borders on the basin. The normal points into the basin.

Outside

This is the side of an edge which is not the inside.

Wave entrance edge

This is an edge along which waves are incident.

Reflecting edge

An edge which (partially) reflects waves. Reflection coefficients are defined by the user for each edge.

Connecting edge

This is an edge which connects two basins, that is an edge between two basins through which waves can pass.

Open edge

This is a section of the boundary of a basin which does not reflect any waves back into the basin. No potential sources are distributed along such an edge.

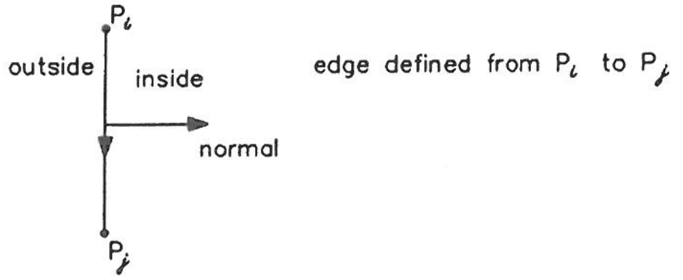


Figure A1 Definition of the direction normal to a boundary

A.3 Simple description of theory

In this section an overview of the solution method is given. For more details see Appendix C.

DIFFRAC works using a boundary element method. This means that there is no computational grid inside the schematised area but that 'potential sources' are distributed along all defined edges except open edges. A 'potential source' is a valid solution to the wave equation for uniform water depth which has a singularity at its centre. In DIFFRAC sources are used which represent a wave radiating outwards from the centre where the wave height is independant of direction. The wave potential in a basin is then obtained by summing the contributions from the sources distributed along all edges of the basin. The amplitude and phase of each source is unknown and a system of equations is constructed to find these unknowns such that the total potential:

- satisfies the reflection boundary condition at each reflecting edge,
- gives the required incoming wave height and direction at wave entrances,

A total potential is thus obtained which represents a valid solution to the wave equation throughout the schematised area and which satisfies all of the boundary conditions. The density of distribution of sources (boundary elements) along the boundary is left up to user choice with a minimum source density of 5 per wavelength, in order to obtain sufficient resolution in the application of the boundary conditions. The recommended source density is 8 per wavelength.

Note that the boundary conditions are only satisfied on the inside of the boundary elements and not on the outside. This has consequences for the schematisation of problems as described in A.4.

A.4 Schematisation

In this section advice on schematisation is given using the example of harbour basins, as this is the most common application for DIFFRAC.

Figure A2 shows an idealization of a simple harbour design where the harbour consists of a number of quays, a wave absorbing beach and two rubble mound breakwaters along the entrance.

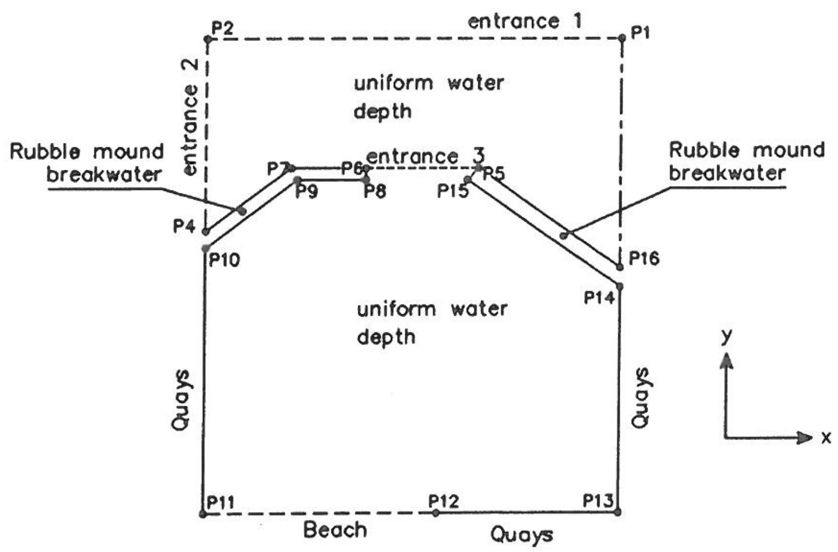


Figure A2 Layout of schematised harbour with various possibilities for the location of the wave entrance

The user must first give the coordinates of the points, P1 to P16, which will be used to define the harbour outline (see input screens in pre-processor). In DIFFRAC a right handed rectangular axis system is used.
Directions are measured anti-clockwise w.r.t. the x-axis. The user may use a system in any orientation but must give all coordinates in a single system. Note that the y-axis runs at 90° to the x-axis. Thus if the x-axis points east, the y-axis points north.

Subsequently the user must specify the outlines of the problem to be schematised by a number of edges which connect the above mentioned border points forming a continuous line according to the required type of boundary. Note that the outline of a harbour must always form a continuous line (closed) running in an anti-clockwise direction.

The way various types of boundary which may be used in DIFFRAC are now described.

Reflecting edges

For each reflecting edge the user should define a reflection coefficient and estimate the incident wave angle to the normal to the edge. A rough guide to reflection coefficients is as follows:

• Quays and vertical walls	90%
• Non-porous slopes with non-steep incident waves	50%-80%
• Breakwaters with non-steep incident waves	40%-50%
• Non-porous slopes with steep incident waves	30%-50%
• Breakwaters with steep incident waves	25%-40%
• Steep beaches (1:15)	10%-20%
• Gently sloping beaches	0%- 5%
• All situations with very long waves (period > 60 s)	100%

These reflection coefficients are for very rough guidance. The reflection coefficient is influenced by the following factors:

- slope of the reflecting structure/feature,
- porosity of the reflecting structure,
- roughness of the reflecting structure,
- steepness of the approaching waves.

The user is referred to the literature for further details (e.g. SPM [1984], Allsop [1990], Postma [1989], Seelig [1983], Van der Meer [1988]).

The angle of wave approach to the edge normal (see Figure A3a) must be given because the mathematical formulation for the reflection boundary condition is a function of this variable. In the mathematical formulation applied in the program the parameter R1 is used which depends of the incident wave angle α and the physical reflection coefficient R as follows:

$$R1 = \frac{(R/100 - 1)\cos\alpha + R/100 + 1}{(1 - R/100)\cos\alpha + R/100 + 1}$$

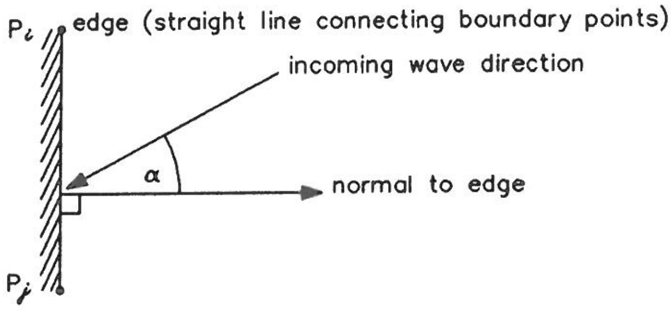


Figure A3a Definition of the angle α between the incoming wave and the normal to the edge P_i to P_j

For high reflection coefficients (R > 70%) and nearly normal wave approach ($\alpha < 30°$) this function is weak and α may be given as 0°. Otherwise α should be estimated on the basis of the incident wave direction, the direction to the tip of a protective breakwater or the direction to a reflecting wall (see Figures A3(b), (c) and (d), respectively).

Figure A3b shows a situation where incident waves can directly reach the edge from P_i to P_j. The angle α is in this case simply the angle between the incident wave and the normal to the edge.

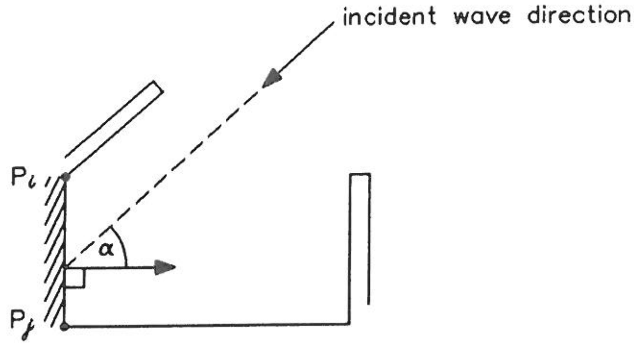


Figure A3b Estimation of the angle α for the situation where the edge is directly exposed to incident waves

Figure A3c shows a situation where the reflecting edge is in the lee of a breakwater. The direction of the incoming wave at the breakwater is determined as the direction between the centre of the edge and the tip of the breakwater.

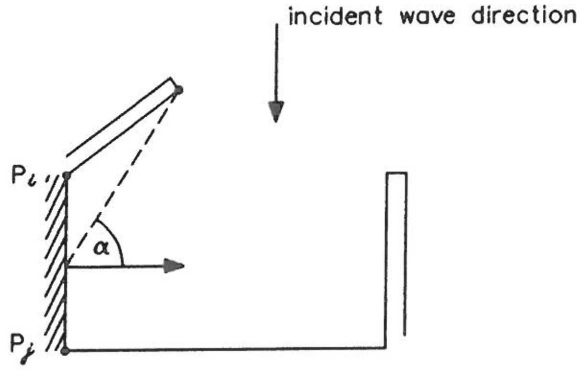


Figure A3c Estimation of the angle α for an edge protected from the incident wave by a breakwater

Figure A3d shows a situation where reflection is the main mechanism whereby waves reach the reflecting edge. The angle of approach of the incident waves is found by tracing the path of the incident wave from the entrance to the reflecting edge as illustrated in the figure.

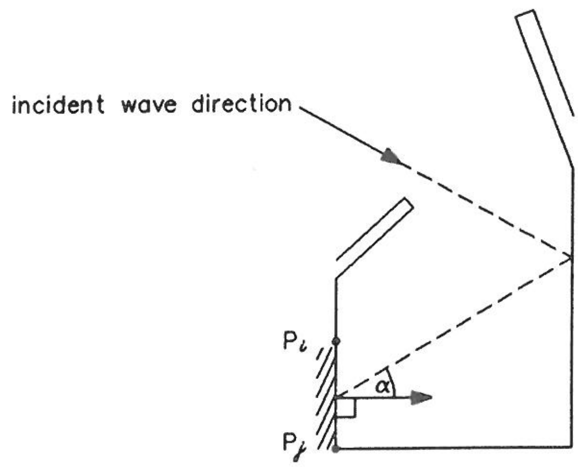


Figure A3d Estimation of the angle α for the situation where waves reach the reflecting edge by reflection

A higher estimation of α gives more wave reflection. Further, the effect of is symmetric, so that a value of -20° would give exactly the same result as +20°. The value of α should thus always be given as a real between 0° and 90°.

In Appendix B.2 an example is given of the estimation of α for a case where the wave may be coming from more than one direction.

Under certain conditions (see 'open edges'), it is advantageous to define parts of the boundary with zero or low reflection as open edges.

Open Edges

The user may define an open edge wherever an edge is absorbing or where waves pass out of the basin into an area of water from which no waves will return. For example, the beach running between P11 and P12 in Figure A2 may be defined as an open edge. This has two benefits:

- it is not necessary to apply a boundary condition which introduces approximations for low reflection coefficients,
- no sources are distributed along open edges, therefore it decreases the number of computational points thus saving computation time.

However it is not permissible to define an edge as open if the outside of a wall in the same basin can radiate waves directly INTO the basin through the edge (see also section A.3). The user bears responsibility that the schematisation which is applied satisfies this condition. A rule of thumb is that waves can radiate directly into the basin through the open edge if at any place on the open edge the outside of a reflecting edge is visible anywhere within the outer area of 180°. Figure A4 illustrates acceptable and unacceptable schematisations.

The schematisation illustrated in A4a is unacceptable because the outside of the edge P9 to P10 (in the same basin) radiates waves which pass into the harbour through P12 and P13. This means that extra waves are modelled as entering the basin which in reality would not exist and the results of the computation will be unreliable.

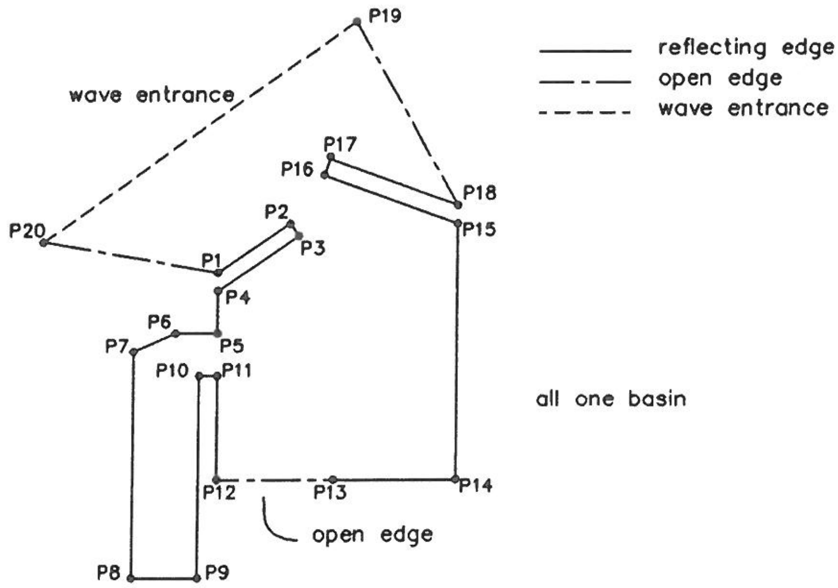


Figure A4a Example of unacceptable use of an open boundary

The schematisation illustrated in Figure A4(b) is acceptable because the reflecting edge with zero reflection between P12 and P13 ensures that all necessary boundary conditions are satisfied (but see the disadvantages stated in the paragraph on reflecting edges).

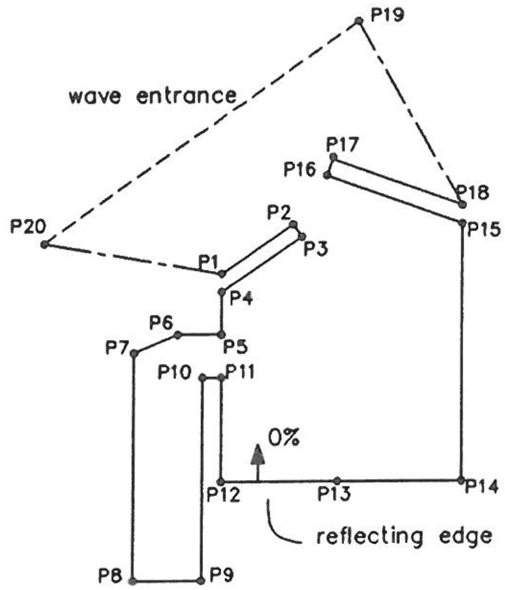


Figure A4b Acceptable schematisation using a reflecting edge with 0% reflection

The schematisation shown in Figure A4c is acceptable because the open edge from P12 to P13, is 'protected' from P9 to P10 by the inside edge running between P12 and P21. A further requirement, which is satisfied, is that any waves arriving at the edge P12 to P21 are not reflected back into the basin.

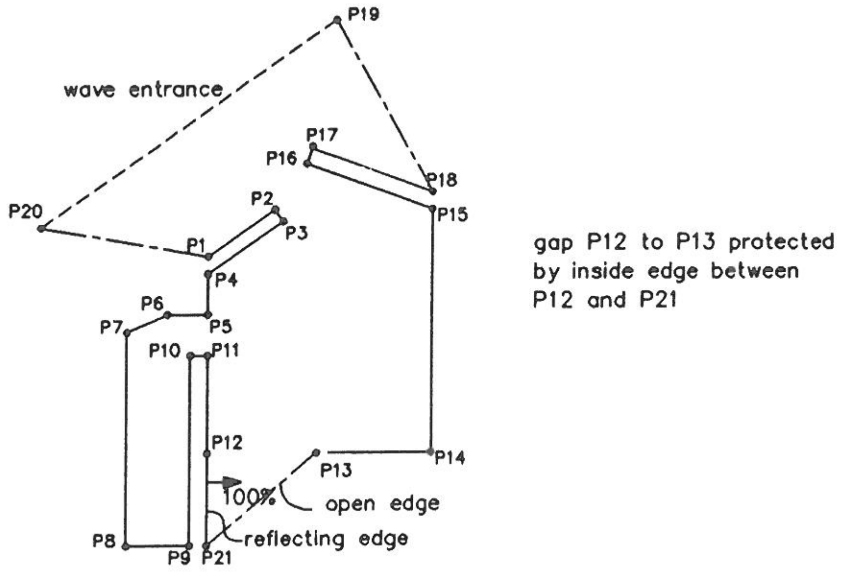


Figure A4c Acceptable schematisation using a reflecting edge to protect open edge from inwardly radiating waves

The preferred solution is illustrated in Figure A4d, where the side harbour is schematised as a seperate basin. The reflecting edges in each basin then only have influence on the potential in the other basin via the connecting edge (P5 to P11). The outside of the edge P9 to P10 can therefore not radiate waves into the basin through the open edge because they are in separate basins. This schematisation has the further advantage that splitting the problem into two smaller basins gives a more efficient numerical solution.

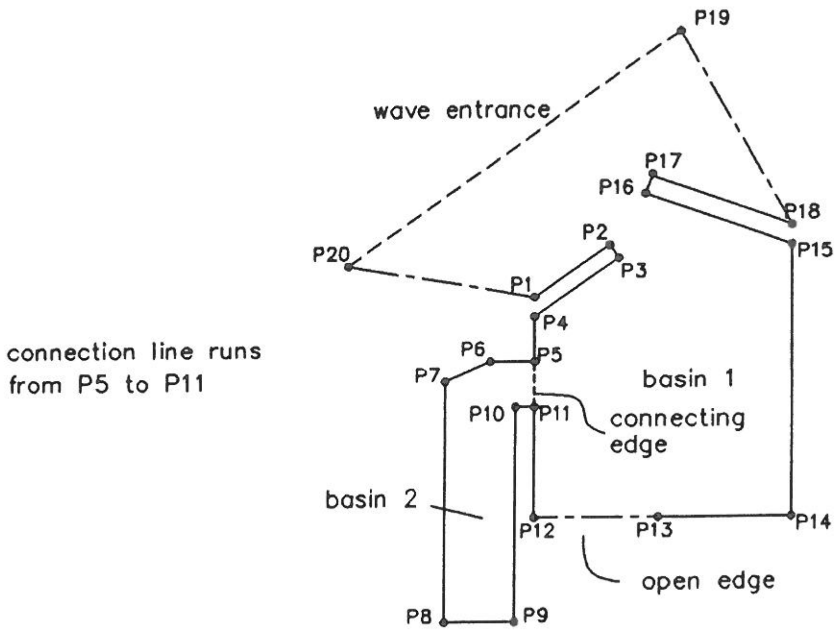


Figure A4d Acceptable schematisation using two basins

Wave entrance edges

Figure A2 illustrates the position of several possible wave entrances for the schematisation. The orientation of the wave entrance should be neither parallel nor nearly parallel to the wave direction. Further, the waves reflected from breakwaters close to the harbour entrance can influence the wave conditions in the harbour by diffraction. It is therefore preferable to place the wave entrance some distance outside the harbour entrance. If the wave entrance is placed across the harbour entrance (e.g. to save the number of computational points) as in entrance 3 in Figure A2, DIFFRAC can not account for the reflection effect. However, this does not usually have a substantial effect on the solution.

If the wave entrance is placed away from the harbour entrance, as for wave entrances 1 and 2, the user should ensure that the wave entrance is sufficiently long to avoid end effects at the harbour entrance. As a rough guide, end effects penetrate an area behind the wave entrance at an angle of 20° to the wave direction (see Figure A5).

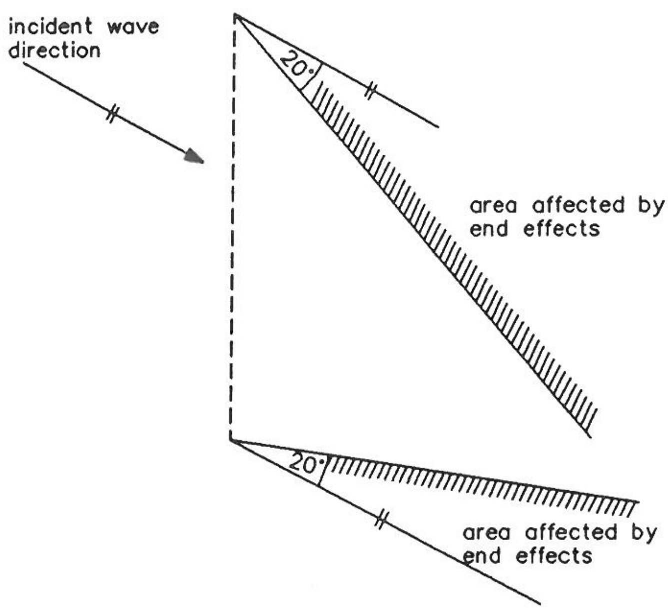


Figure A5 Area influenced by end effects

Thus:

- entrance 1 in Figure A2 is suitable for wave directions between -60° and 115°,
- entrance 2 is suitable for wave directions between +20° and -20° (directions anti-clockwise with respect to x),
- entrance 3 in Figure A2 is suitable for incident wave directions between -30° and -150°, restricted by the need for the incident wave direction not to be parallel or nearly parallel to the entrance.

When directional spreading is being applied, the above conditions must be satisfied for every individual direction being computed. Note that for the application of directional spreading, exactly the same schematisation geometry must be used for each individual direction to be included in the computation.

In summary the wave entrance should be:

- not parallel or within 30° of each incident wave direction,
- preferably a few wave lengths away from outer breakwaters,
- sufficiently long to avoid end effects at the area of interest or at the harbour entrance,
- all wave entrances in a single basin should lie on a straight line.

Wave directions to be computed

When the wave height is to be computed including the effects of directional spreading, computations should be carried out for a sufficient number of individual wave directions over a sufficient range. For most realistic incident wave conditions, most of the energy is within ± 35° of the main wave direction. We would suggest computations between -40° and +40° of the main wave direction at intervals of a maximum of 10°.

Schematisation of breakwaters

If a breakwater is internal to a basin then both sides of the breakwater must be schematised so that the 'outside' of an edge can never directly be 'seen' from a point of interest inside the basin containing it (Figure A4a).
Further, internal breakwaters should be schematised so that they are at least three times as wide as the distance between potential sources along an edge. Half a wavelength should be sufficient. This is to prevent numerical ill-conditioning of the system of equations which can occur when potential sources become too close to each other. Breakwaters ending in a point should therefore also be avoided. Note that, within reason, breakwaters can be schematised as wider than they

really are without significantly affecting the solution. If the wave entrance does not lie in the harbour entrance both sides of the breakwaters adjacent to the entrance should be schematised (see e.g. Figure A2). This allows outwards reflection of the incident waves and some diffraction of these reflected waves into the harbour.
The schematisation as shown in Figure A6 is possible because the sides of the breakwater are situated in different basins. In this case the width of the breakwater is no longer important.

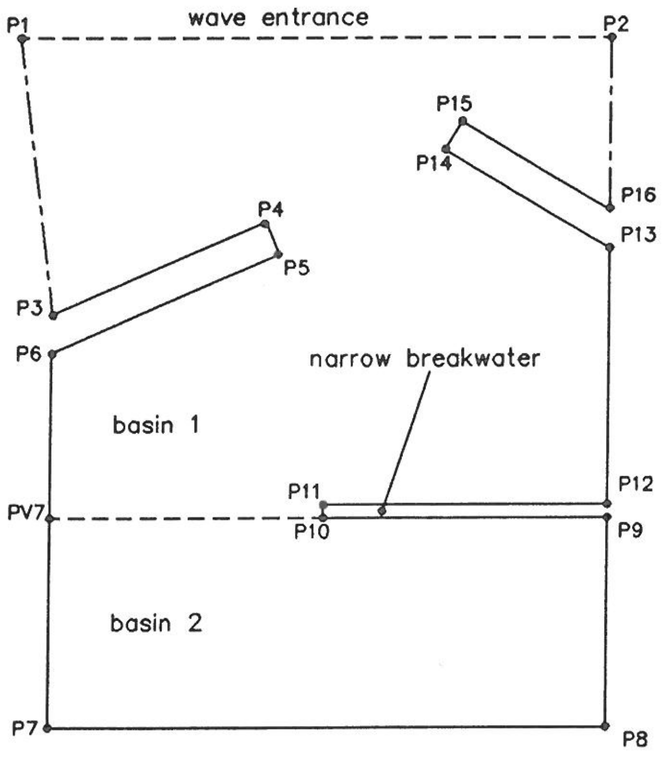


Figure A6 Schematisation of a thin breakwater using separate basins

Detached breakwaters or ISLANDS which lie completely within a single basin should be connected to the outer boundary by two open boundaries as shown in Figure A7. These open boundaries must run in opposite directions. Note that the locations of the points P7 and P7' should be chosen to be very slightly different. The same applies to P6 and P6'.

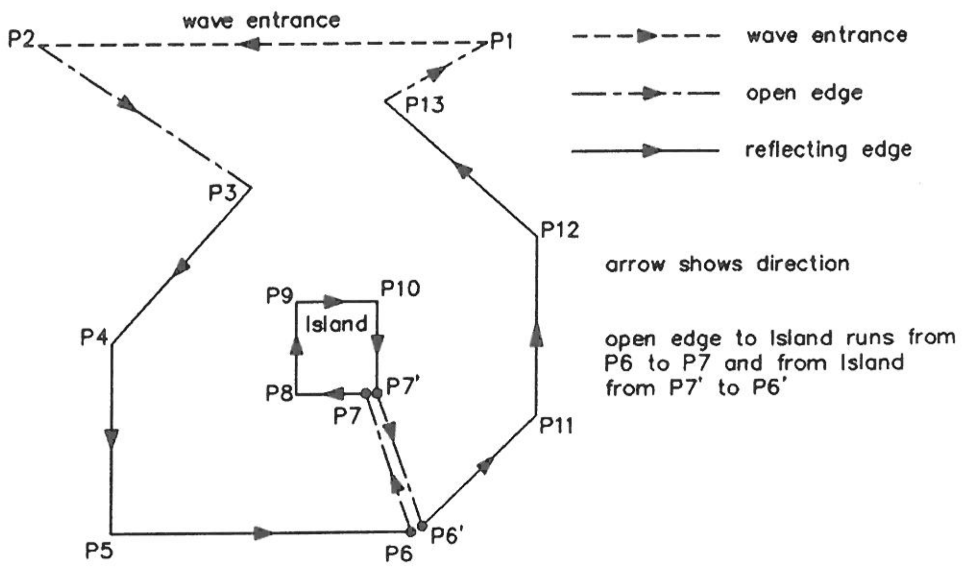


Figure A7 Use of open boundaries in the schematisation of an 'offshore' breakwater or island

Using separate basins

In general, numerical solution for a schematisation consisting of a number of basins is considerably faster than numerical solution for a schematisation consisting of a single basin with about the same number of boundary elements. It is therefore recommended to split problems up into different basins whenever this can be done without introducing too many extra boundary elements. However, the user should be aware that some approximations are used in the modelling of connecting edges. These do not generally have serious consequences but can lead to inaccuracy when long connecting edges are used within a basin, particularly for seiching problems. It would therefore not be advised to split the schematisation in Figure A2 into seperate basins. This would also have the disadvantage of introducing many extra boundary elements. However the division into two basins shown in Figure A4d is advantageous as the connection-line between the two basins is relatively short.

Seperate basins can also be used to:

- Represent variations in the water depth within the harbour system. Each basin can be assigned its own water depth. DIFFRAC will account for refraction along the boundaries which connect basins of different depth. However it is emphasised that this refraction is highly schematised. It should not be thought that combined refraction and diffraction can be modelled by using seperate basins. The choice of the number of basins must be based primarily on the geometry of the harbour which is considered and not on the basis of bathymetry.
- Allow the use of open edges (see paragraph on open edges).
- Model narrow breakwaters without causing numerical ill-conditioning (see section on schematisation of breakwaters). The schematisation shown in Figure A7 is acceptable because the two sides of the narrow breakwater are in seperate basins.

References to Appendix A

Allsop, N.W.H. (1990). Reflection Performance of Rock Armoured slopes in random waves. Proc. 22th Int. Conf. Coastal Eng., Vol. II, pp. 1460-1472, ASCE, Delft.

Postma, G.M. (1989). Wave reflection from rock slopes under random wave attack. Msc. Thesis, Delft University of Technology.

Seelig, W.N. (1983). Wave reflection from coastal structures. Proc. Conf. Coastal Structures '83, pp. 961-973, ASCE.

Van der Meer, J.W. (1988). Rock slopes and gravel beaches under wave attack. Doctoral thesis, Delft University of Technology. Also: Delft Hydraulics Communication No. 396.

Appendix B
Examples of applications

B.1 Schematisation of 'Semi-Infinite' Breakwater

B.1.1 Introduction

The results of an analytical solution for the wave diffraction behind a semi-infinite breakwater is presented in the Shore Protection Manual (1984). This situation is represented in Figure B1.

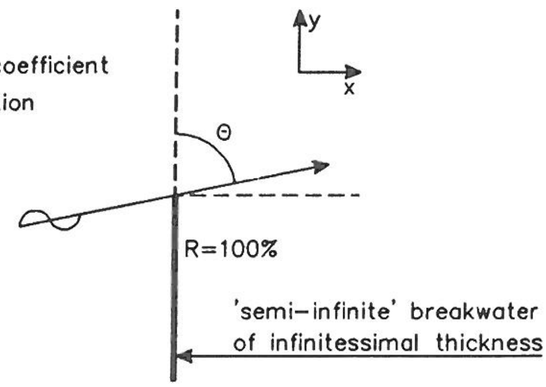


Figure B1 Situation represented by analytical solution of semi-infinite breakwater

This semi-infinite breakwater is 100% reflecting and is infinitely thin. The results of the analytical solution are widely used in engineering practice for the estimation of the wave behaviour behind coastal structures.

Figure B2 shows the results of the analytical solution for an angle of wave approach of 90°. As expected the wave height in the area to the left of the Figure, which is not sheltered by the breakwater is relatively undisturbed. However note that at a distance of about 9 wave lengths at an angle of 105° behind the breakwater, the wave height is actually increased by diffraction effects.

The purpose of the DIFFRAC computation described in the following section is to see to what extent the DIFFRAC results agree with the analytical solution and highlight some aspects of the schematisation. The schematisation used is given in the file DEMO1.INP.

B.1.2 Schematisation for DIFFRAC

The selected schematisation for DIFFRAC is shown in Figure B3. The following paragraphs describe the motivation for this schematisation. The wave period was chosen to be 5.064 s and the water depth in the basin 100 m, giving a wave length of 40 m.

The area of interest for output is a semi-circle of radius 10 wave lengths on the lee side of the breakwater (see Figure B3).

The breakwater

The edges of the breakwater are those connecting points 3, 4, 5 and 6 in the schematisation. The position of point 3 is determined by the length of the wave entrance and the supporting reflecting edge between points 2 and 3, discussed below. Similarly the location of point 6 is determined by the area which we wish to include in the schematisation. The direction of wave propagation will be such that all points above point 6 behind the breakwater will not be influenced by the shortening of the breakwater there. The wave height at locations below point 6 should be below 0.1 m and is of less interest.

The breakwater has been chosen to be half a wave length (20 m) thick to avoid problems associated with the breakwater being too thin (see Appendix A).

The position of the breakwater head has been chosen to coincide with the position of the breakwater head in the analytical solution as far as possible. However, points 4 and 5 cannot both be at the breakwater tip because of the restrictions on it thickness and some compromise is therefore necessary. In practice this will not have too much effect.

Wave entrance and supporting reflecting edge

The wave entrance runs from point 1 to point 2 and the supporting reflecting edge from point 2 to 3.

The position of the wave entrance along the x-axis was chosen to be 2½ wave lengths (100 m) from the breakwater (in Appendix A it is advised to have at least 2 wave lengths separation). The orientation of the wave entrance was chosen to be normal to the angle of wave incidence.

The position of point 1 on the y-direction was chosen to be sufficiently high (12 wave lengths, 480 m) that end effects did not influence the area where we were interested in the output (see Figure B3). The position of point 2 in the y-direction was chosen on the basis of similar criteria. However, end effects associated with point 2 are eliminated by including a totally reflecting wall between points 2 and 3. This mirrors the schematisation above point 3 and effectively increases the modelled length of both the wave entrance and the up-wave side of the breakwater. Although the problem is not symetrical, we can use this technique here because the local situation is nearly symmetrical. In fact, the supporting edge is not really necessary since end effects would not reach the area of interest.

Open boundaries

The position of the open boundaries was chosen to delimit the area of interest along edges where other sort of boundaries are not required because waves are not expected to radiate inwards along them.

B.1.3 Post-processing (POSDIF)

We wish to make a contour plot with POSDIF on the same scale as that shown in Figure 2 (10 mm = 1 wave length = 40 m). That is 1:4000. N.B. In this manual this is not the scale due to photo reduction!!

In the area of interest, we do not expect standing wave patterns but we never the less compute output on a grid with 5 points per wave length. This enables us to average the results over a 2 point by 2 point square before they are plotted and still maintain reasonable resolution. This averaging tends to give a smoother picture of the wave height variations which is easier to interpret (note that smoothing should not be used in situations where the user is interested in the cross/standing wave patterns).
The window chosen was with x from -100 m to 400 m to include the wave entrance and 10 wave lengths behind the breakwater. The window in the y-direction ran from -320 m to 400 m to include 10 wave lengths above the breakwater and 8 below. This window fits into the plot area on a scale of 1:4000.

The results of the plot are shown in Figure B4. Note the following:

- The area in front of the breakwater, where 100% reflection is taking place should be disregarded because of the averaging used.
- The area in the top part of the plot is clearly influenced by end effects (due to the finite length of incoming wave boundary). Some small disturbance (wave height between .95 m and 1.05 m) is still seen outside the area where the end effects were expected.
- The diffraction pattern behind the breakwater is very similar to that expected on the basis of the analytical solution.

B.2 Semi-Infinite Breakwater with Directional Spreading

B.2.1 Introduction

The schematisation and solutions presented in this demo are similar to those presented in B1 except that the application here is modelled with short crested incident waves (directional spreading) with a main direction of 0^0 (along the x-axis). Seven wave directions are modelled at 15^o intervals between -45^o and 45^o to allow simulation of the effects of directional spreading.

The discussion of the basic schematisation is not repeated here. Only the aspects of schematisation particularly related to directional spreading are discussed here.

B.2.2 Schematisation

The selected schematisation is shown in Figure B5. The following paragraphs describe the motivation for this schematisation. The wave period was chosen to be 5.064 s and the water depth in the basin 100 m, giving a wavelength of 40 m.

The breakwater

The breakwater is schematised as thin in this schematisation. This is because the two sides of the breakwater are in different basins in this schematisation (see below) and it is no longer necessary to schematise the breakwater as broader than it in reality is.

The reflecting edges of the breakwater are those connecting points 3, 4, 5 and 6. Points 4 and 5 are very close together at the head of the breakwater (0,0). The position of points 3 and 4 is determined by the need to model a sufficient length of the breakwater for the wave directions which have to be considered. The head of the breakwater is 100 m from the edge of the shadow zone for the most extreme wave direction modelled, 45^o (see below). The shadow zone for this direction is at 65^o from the lower end of the incident wave boundary. Note that more length has been allowed than for the schematisation for unidirectional waves since:

- it is not possible to apply a reflecting edge between the incident wave boundary and the breakwater;
- a wider range of directions has to be applied.

The incident wave boundary

The incident wave boundary is placed at 2.5 wavelengths (100 m) from the reflecting edges. The length of the incident wave boundary is such that waves from all the modelled directions are not influenced by boundary effects in the area behind the breakwater.

The extent of the incident wave boundary below the head of the breakwater is determined by the need to keep the head of the breakwater away from the shadow zone for the most extreme wave direction (45^{0}, see section for the breakwater above). The extent of the incident wave boundary above the breakwater is determined by the need to restrict the shadow zone of the most extreme wave direction (-45^{0}) behind the breakwater. The schematisation was made to allow three wavelengths behind the head of the breakwater. In practice, it is likely that the area with correct results will be somewhat larger since the weighting applied to this direction is small (about 7%). The areas effected by end effects for the most extreme wave directions are also shown in Figure B5.

Open boundaries

The position of the open boundaries was chosen to delimit the area of interest. Considering the area that results are influenced by end effects for some directions, the open boundaries could have been given to delimit a smaller area. However, in the post-processing, results for individual wave directions can also be obtained. Delimiting a smaller area would prevent use of the results from some directions where the results are valid.

B.2.3 Post-processing (POSDIF)

We wish to make a contour plot using POSDIF on the same scale as that shown in Figures B2 and B4. That is 1:4000 (in this manual, this is NOT the scale. This is due to reduction of the plots from A4 to A5 !).

The wave height is computed on a square grid with 5 points per wavelength.

The window chosen was with x from -100 m to 200 m and with y from -300 m to 100 m. This was chosen smaller than the window for the computation for uni-directional waves in order to:

- restrict the area of results plotted possibly influenced by edge effects (the top right hand corner of the plot area may still be slightly influenced);

- restrict the amount of computer time required. (The wave height has to be computed at each grid point for each of the 7 wave directions).

The amount of spreading chosen was that corresponding to a spreading index of 4 (standard deviation of wave direction weighted according to wave energy is about 25°).

The resulting plot is shown in Figure B6. The following observations are made:

- The results agree well with hand computations made using the weighting factors given in the output file (demo4s.o01) and the figures given in the SPM (1984);
- The pattern of wave height variation behind the breakwater is rather smooth;
- The wave height in the top part of the plot is always around 1.0. This suggests that edge effects are not playing a very significant role;
- The standing wave pattern in front of the breakwater can be seen more clearly in this case because no spatial averaging has been used and it can be reasonably resolved with 5 output grid points per wavelength (nodes and anti-nodes are at about 1/2 wavelength intervals normal to the breakwater).

B.3 Wave penetration of Salvetta harbour

B.3.1 Introduction

Salvetta is a fictional fishing town on the mediterranean coast where the harbour is regularly used by fishing vessels and pleasure yachts. Container vessels also call at the port occasionally and are accomodated in the outer part of the harbour, where new quays are proposed as part of a local economic expansion plan. The layout of the harbour is shown in Figure B7.

B.3.2 Schematisation

DIFFRAC can be applied to determine the wave penetration of the harbour. During the initial design phase, the penetration of waves with a 10 year return period is studied. The way DIFFRAC can be applied to study the wave penetration of the harbour is described in the following paragraphs. Figure B8 shows key details of the schematisation. The schematisation used is given in the file DEMO2.INP.

Schematisation of the wave entrance

The main wave directions which may penetrate the harbour come from directions between 60° N and 100° N at the 10 m line. The harbour is well protected from waves coming from more Northerly directions. Waves can not come from more southerly directions because of the effects of refraction unless they are of short period, in which case they will be of low height and will not exite response from the container vessels. It has also been chosen to make computations for waves of period 10 s (wave length of order 100 m as this period corresponds to waves with a 10 year return period.

The wave entrance in the schematisation is oriented so that its normal is in the 80° N direction to accomodate most relevant incident wave directions. The position of the incident wave boundary is chosen so that it is 2 wave lengths away from all reflecting structures (200 m). Its length is chosen so that the wave field will be undisturbed by boundary effects at the harbour entrance for the wave directions to be computed. As a general rule, these boundary effects penetrate the computational area at an angle of 20° to the wave direction from the tip of the wave entrance (see Figure B8).

Schematisation of sea side of the breakwaters

The wave which is reflected outwards from the outer side of the breakwaters near the harbour entrance can diffract into the harbour and it is therefore necessary to model these correctly (see thick lines in Figure B8). Furthermore it is planned to model the container berths and the outer harbour area as one basin. Therefore, the outer area must be protected from the reverse side of the sources distributed along the inner edge as shown by the broken lines in Figure B8 (these need not follow the outside of the breakwater if the waves reflected by them will not enter, relevant parts of the computational area but in this case this case convenient). Note, however, that all breakwaters should be schematised to be more than one third of a wave length thick to prevent numerical instability and cross talk through the breakwater. For these breakwaters the choice of the wave direction to the breakwater normal can simply be estimated from the direction of the normal and the wave direction. In this case, a reflection coefficient of 30% was chosen for the outside of the breakwaters, as recommended in Appendix A of the manual. Note that the position of these edges should be chosen AFTER the positions of the edges to represent the inside of the harbour have been chosen. This allows the criteria for the width of the breakwater to be satisfied by displacing the outer edges. The wave behaviour in the harbour is less sensitive to the position of these edges than to the position of the inner edges.

Schematisation of inner side of the rubble mound breakwaters

The position of the schematised reflecting edges should correspond to the place where these breakwaters break the water surface. This side of the breakwaters should therefore be schematised before the outside, the position of which is less critical.

The reflection coefficient for these breakwaters was chosen to be 40% because we expect that the wave steepness is lower for the waves inside than outside the harbour.

The last aspect of the schematisation of these breakwaters is the estimation of the angle between the wave direction and the breakwater normal. This is illustrated in Figure B8 for a wave direction of 90°N. Below the way in which these reflection coefficients were chosen is discussed.

(i) Wave direction 90° N. Along section A of the breakwater waves can arrive by three mechanisms:

- *Diffraction past the tip of the breakwater.*
  These waves will be low in height and travel at nearly 90° to the breakwater normal.
- *Reflection from the outer breakwater opposite.*
  These waves arrive at the breakwater at an angle of 45° to the normal.
- *Waves radiating out of the harbour.*
  These waves will be very low in height and after reflection will have little effect on the conditions in the harbour. These waves are therefore ignored.

The choice of angle is thus a compromise between the first two of these conditions and an angle of 50° was chosen. Note that the choice of a larger angle generally leads to more reflection and is therefore conservative.

The main mechanisms for waves to arrive along section B of the breakwater is directly through the gap between the two outer breakwaters. The waves arrive at the breakwater at an angle of 65° to the normal.

The waves arriving at section D of the breakwaters have generally diffracted around the tip of section C and arrive nearly normally to section D. A wave diffraction of 0° to the normal is therefore applied.

Schematisation of the quays

The quays around the container ship berths and the berths in the fishing harbour are vertical walls. These are modelled at their real position with a reflection coefficient of 90%. The dependance of the results on the given wave direction to the normal is very small for this reflection coefficient and the default 0°, is therefore chosen for these edges.

Schematisation of the small yacht harbour

We considered that for short waves, the wave conditions in the small yacht harbour would be lower than those just outside the entrance. Thus, to restrict the number of boundary elements in the problem, the yacht harbour was left out of the schematisation and the entrance was treated as an open boundary. Note that a part of the entrance has been included in the schematistation to ensure that the reverse side of edges cannot radiate into the harbour.

Schematisation of the beach

The beach has a reflection coefficient of between 5% and 10%. However, it is treated as an open boundary. This reduces the number of boundary elements in the problem and avoids the problems associated with the sensitivity of the solution to the given approach angle for edges with a low reflection coefficient. The error in the predicted wave height in the harbour resulting from the schematisation is minimal. Note that there may be problems resulting from the outside of edges in the same basin which are radiating waves into the harbour through this open boundary. However, the error is only very small because of the small wave penetration in this area.

B.3.3 Results

The results of the DIFFRAC computation for this problem are also given in the form of a iso-line plot of the wave height. POSDIF was applied to make this plot with an output grid with 4 points per wave length. The results are then averaged over a square of 2 by 2 points. No window was defined and the whole area was thus plotted.

The iso-line plot is shown in Figure B9. Note that the boundary of the areas with a wave height reduction of less than 50% run approximately parallel with the incident wave direction. The wave height in the inner harbour is very low.

B.4 Wave Penetration of Salvetta harbour with Spreading

B.4.1 Introduction

The schematisation and solutions presented in this demo are similar to those presented in B3 except that the application here is modelled with short crested incident waves (directional spreading) with a main direction of 0^0 (along the x-axis). Eight wave directions are modelled at 10^0 intervals between 150^0 and 220^0 to allow simulation of the effects of directional spreading.

The discussion of the basic schematisation (see section B.3) is not repeated here. Only the aspects of schematisation particularly related to directional spreading are discussed here.

B.4.2 Schematisation

The selected schematisation is shown in Figure B10. The following paragraphs describe the motivation for this schematisation. The wave period was chosen to be 10 s and the water depth in the basin 10 m, giving a wavelength of 92 m.

The wave penetration with directional spreading is based on two runs, the run DEMO2S1 for the wave directions 150^0, 160^0, 170^0 and 180^0, (between 120^0N and 90^0N) and the run DEMO2S2 for the wave directions 190^0, 200^0, 210^0 and 220^0, (between 80^0N and 50^0N). This allows the approach angle of the waves to the outer breakwaters to be schematized more realistically and demonstrates the combination of the results of two separate runs using the POSDIF program.

Wave entrance

The wave directions applied to simulate directional spreading are to 150^0 to 220^0 w.r.t. the x-axis (50^0N to 120^0N). Note that this is slightly broader than the range of main wave directions which can reach the harbour (see section B.3.2). The wave entrance has been rotated slightly with respect to the uni-directional wave schematisation so that it is normal to waves from 85^0N. This allows the area influenced by end effects (see Figure B10) to be restricted without unduly increasing the number of points in the schematisation. This results in the fact that a short length of the entrance is close to the sea side of the breakwaters. However, this is well separated from the harbour entrance and will not have a significant influence.

Sea side of the breakwaters

The sea side of the breakwaters was schematised in exactly the same way as for the uni-directional waves. However, for the purposes of calculating the approach angle to the breakwaters, the wave direction was considered to be 165° for the run DEMO2S1, and to be 205° for the run DEMO2S2. Thus estimations of the approach angles will be within 15° of the actual approach angle in each of the runs.

Inner side of the rubble mound breakwaters

The choice of reflection coefficients is as for the unidirectional wave case. Further, since the direction of waves along sections A, B and D of the breakwater are largely determined by diffraction, it should not be expected that the wave approach angle will be substantially affected by the original wave direction. Therefore, the approach angles for the uni-directional wave case are maintained.

The quays, small yacht harbour and beach

The schematisation of the quays, the small yacht harbour and the beach was exactly the same as for the uni-directional wave case.

B.2.3 Post-processing (POSDIF)

The window chosen for the contour plots includes the entire computational area (this is done by choosing the coordinates of the window all to be 0.). This means that some areas are included where end effects may play a role.
The amount of spreading chosen was that corresponding to a spreading index of 4 (standard deviation of wave direction weighted according to wave energy is about 25°). This is normal for a medium developed sea state.

As for the uni-directional case an output grid with 4 points per wavelength was applied with an averaging over a square of 2 by 2 points.

The resulting plot is shown in Figure B11. The following observations are made:

- The results show areas influenced by end effects between the northern end of the wave entrance and the outer breakwaters of the harbour. In this area the wave height falls below 0.9 m. However, it does not extend to the vicinity of the harbour entrance and will therefore not have a significant influence on the results in the area of interest.

- The wave height pattern both outside and inside the harbour is rather irregular due to the influence of standing waves following reflection from the breakwaters both inside and outside the harbour. In prototype, these patterns would probably be less pronounced due to the effects of frequency spreading in the incident wave field.
- The wave penetration of the harbour is larger than for the case with uni-directional waves (see section B3). This should be expected, since a number of directional components in this case can penetrate the harbour much more effectively.

B.5 Harbour resonance computation

DIFFRAC computations for waves with a long period were carried out for a rectangular harbour basin. The schematisation used is given in the file DEMO3.INP. A total number of 75 boundary elements per wave length were applied. The DIFFRAC results are compared with the analytical solution for this problem given by Berkhof (1976) in Figure B12. These show a good qualitative agreement. However, it appeared that when a coupling boundary was used in the DIFFRAC schematisation, the amplitude of the resonance at the resonant period ($\lambda / L = 4.7$) is reduced by about 20%. For this reason, we do not advise the use of coupling boundaries in harbour resonance problems.

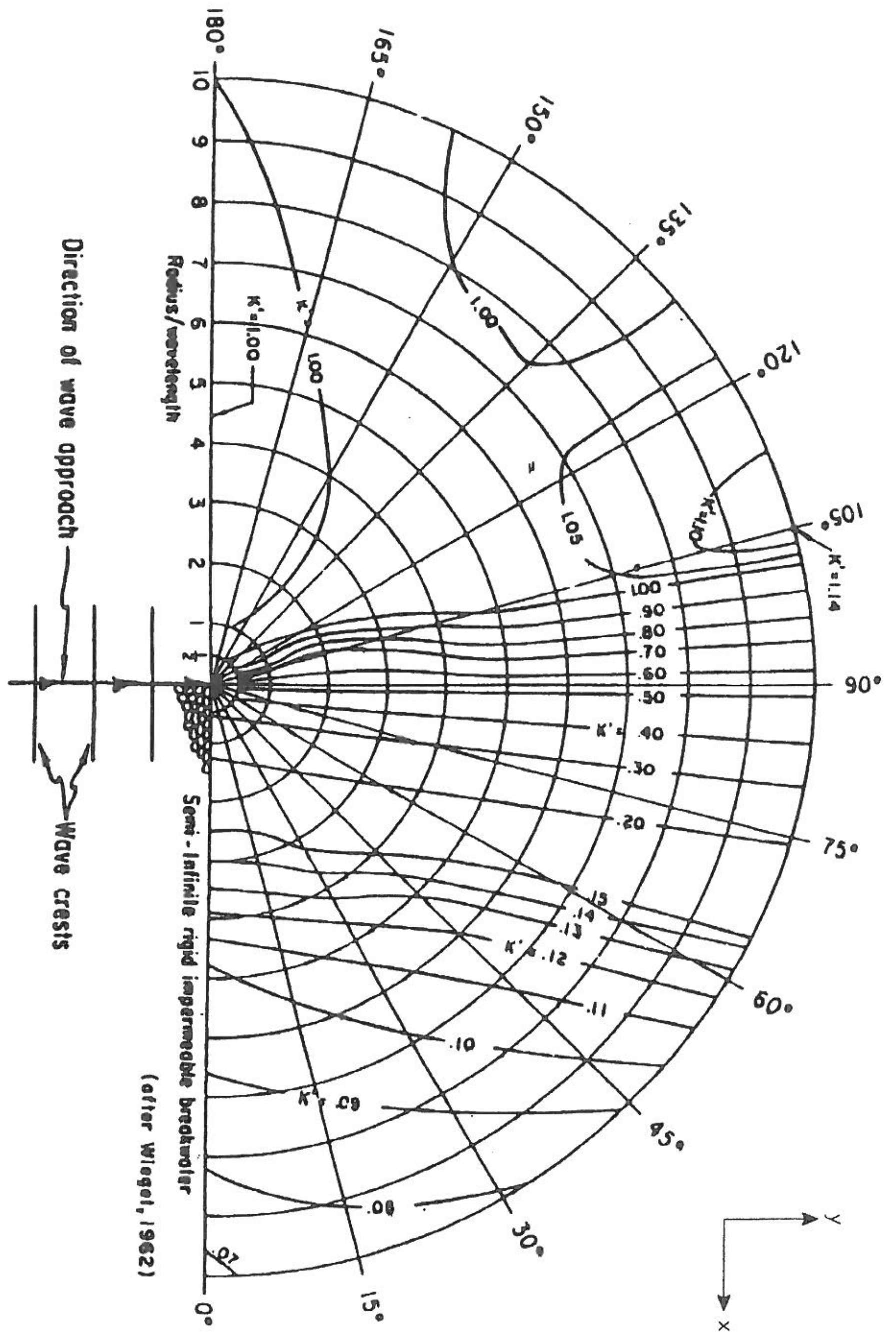
When DIFFRAC computations were made with a smaller number of boundary elements per wave length, very bad results were obtained. Therefore it is advised to use about 75 element per wave length for resonance problems.

In general, the user should be cautious in the application of DIFFRAC for harbour resonance problems (seiches computations), particularly when there are any significant variations in the water depth. In reality, even small variations in water depth can have very large effects on the amplitudes of oscillations (see e.g. Kostense et al., 1986). Further, the application of coupling boundaries to account for such variations in depth is also not recommended. This is because of the effect of coupling boundaries on the predicted harbour resonance described above.

Similar problems have not been found in short wave harbour problems using a coupling boundary. The advice not to use coupling boundaries thus only applies to resonance problems.

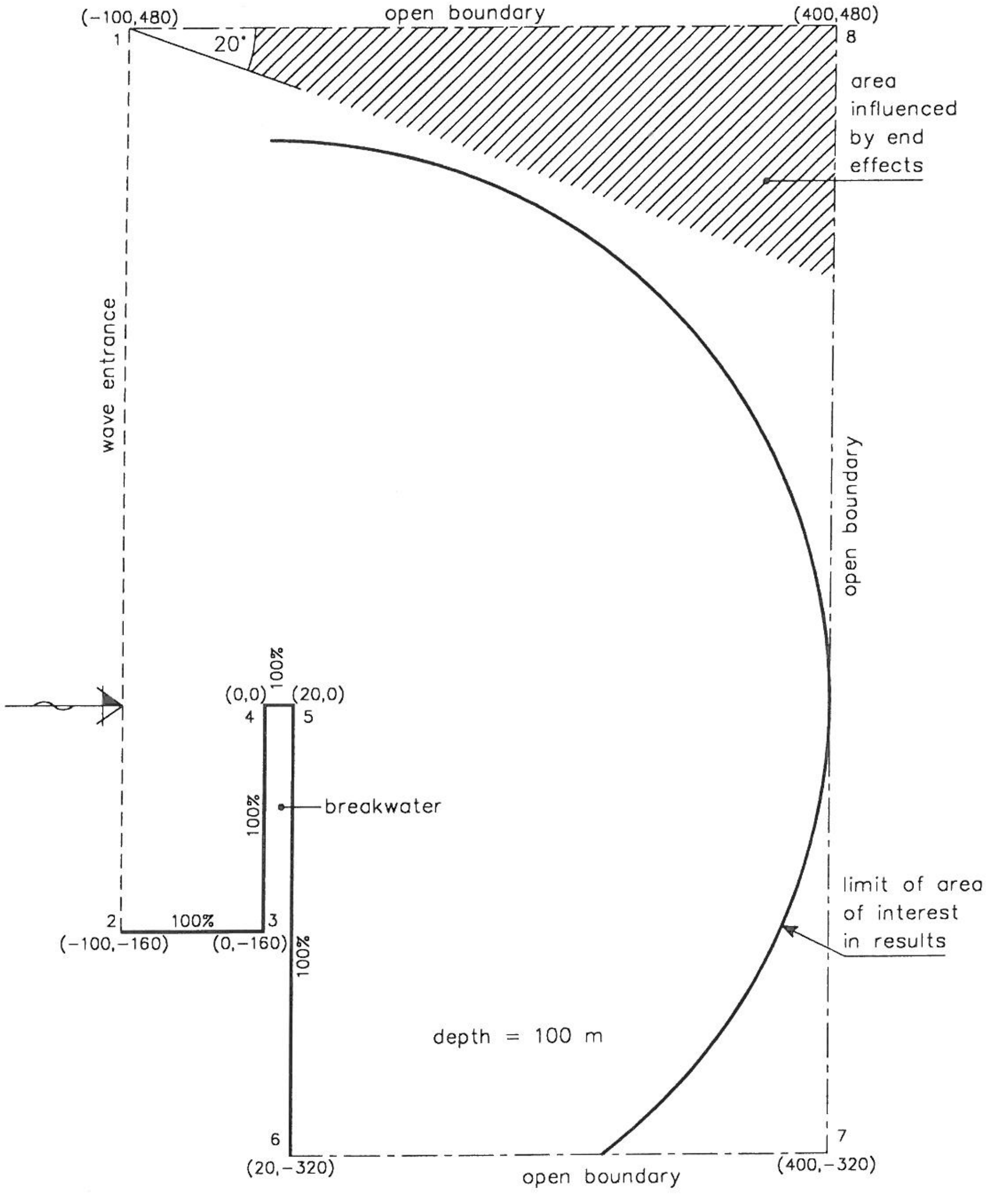
References to Appendix B

Kostense, J.K., Meijer, K.L., Dingemans, M.W., Mynett, A.E. and Van den Bosch, P. Wave energy dissipation in arbitrarily shaped harbours of variable depths. Proc. 20th Int. Conf. Coastal Eng., 1986, pp. 2002-2016.



DIFFRACTION BEHIND A BREAKWATER WITH A WAVE DIRECTION OF 90° (SPM 1984)

DELFT HYDRAULICS	H 71	FIG. B2

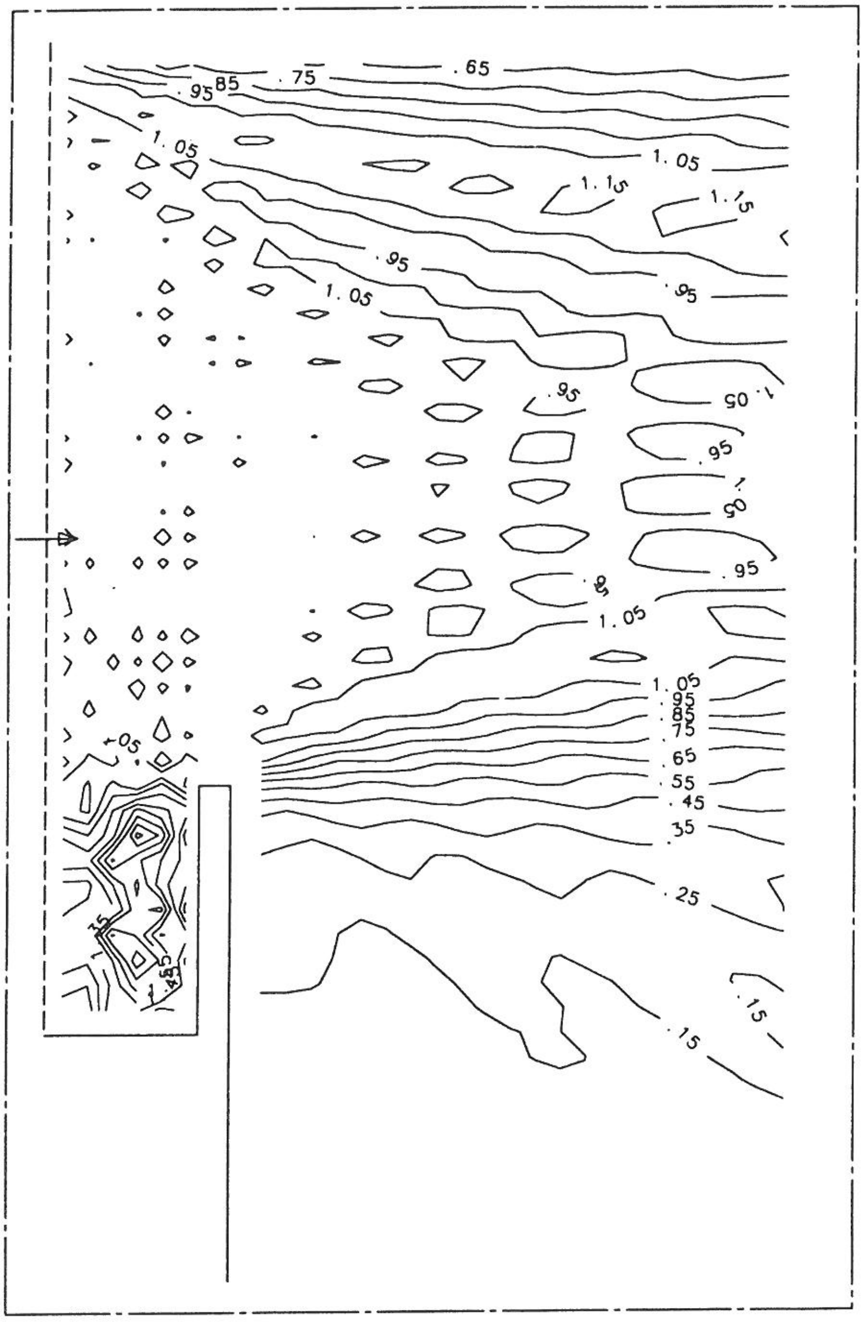


DIFFRAC SCHEMATISATION OF
SEMI-INFINITE BREAKWATER

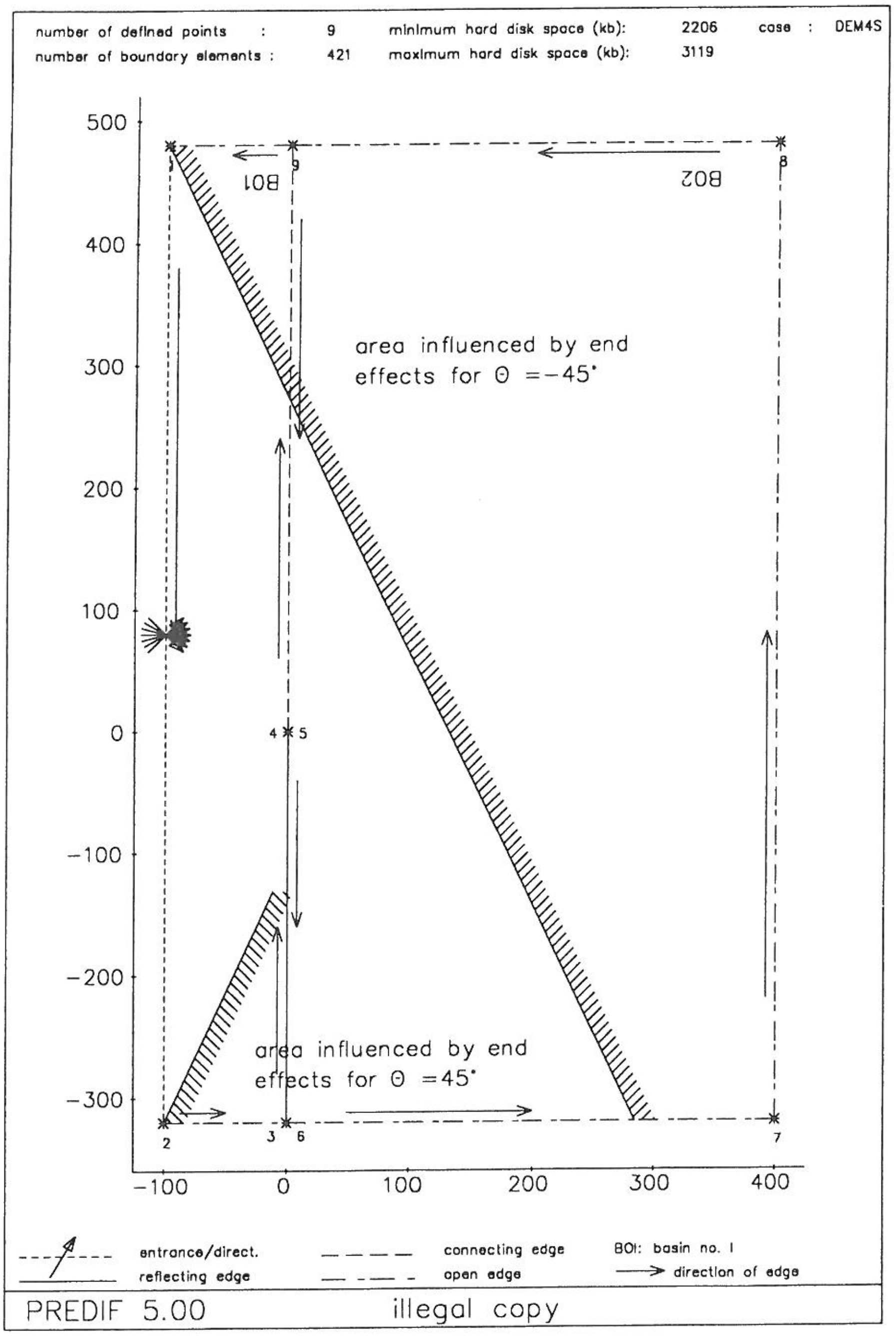
DELFT HYDRAULICS

H 71

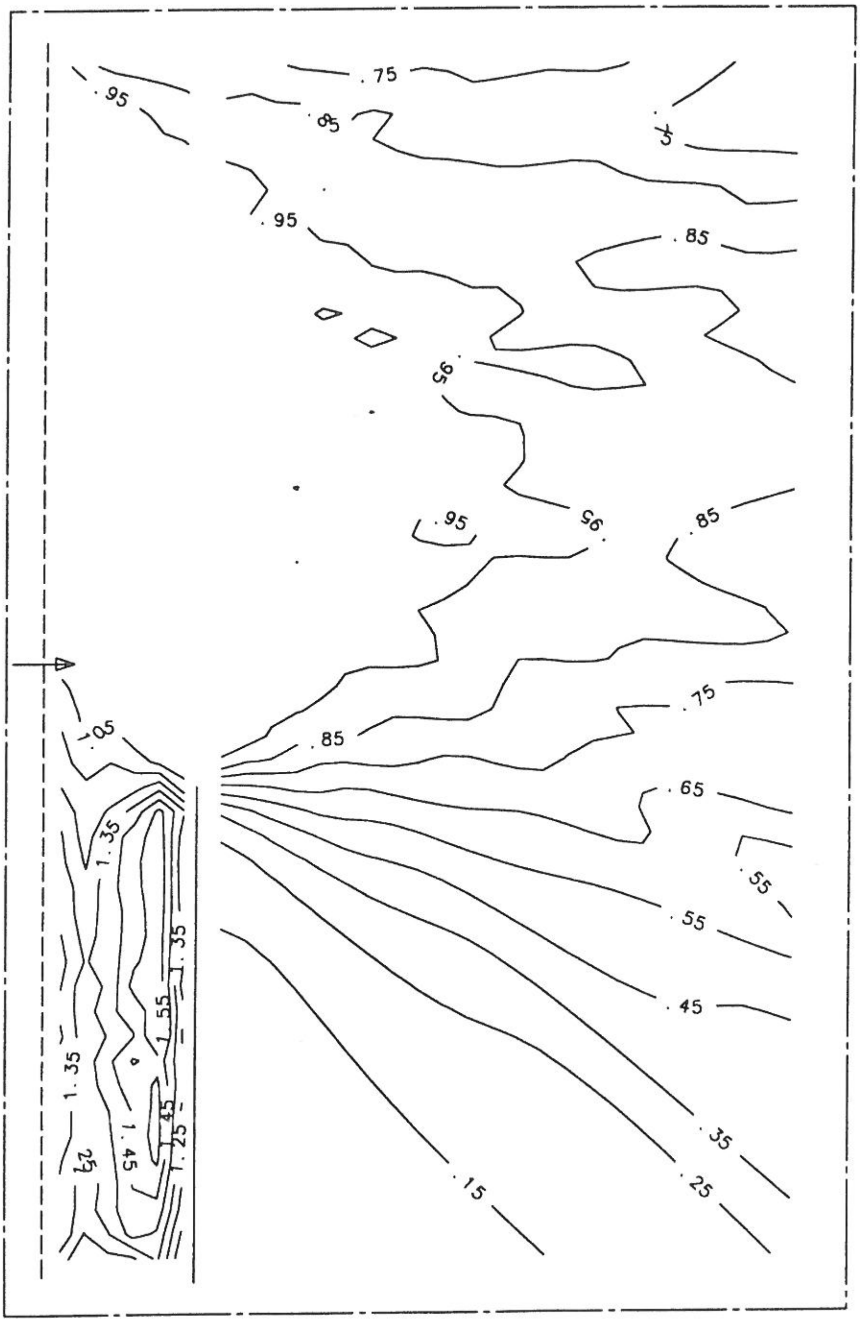
FIG. B3



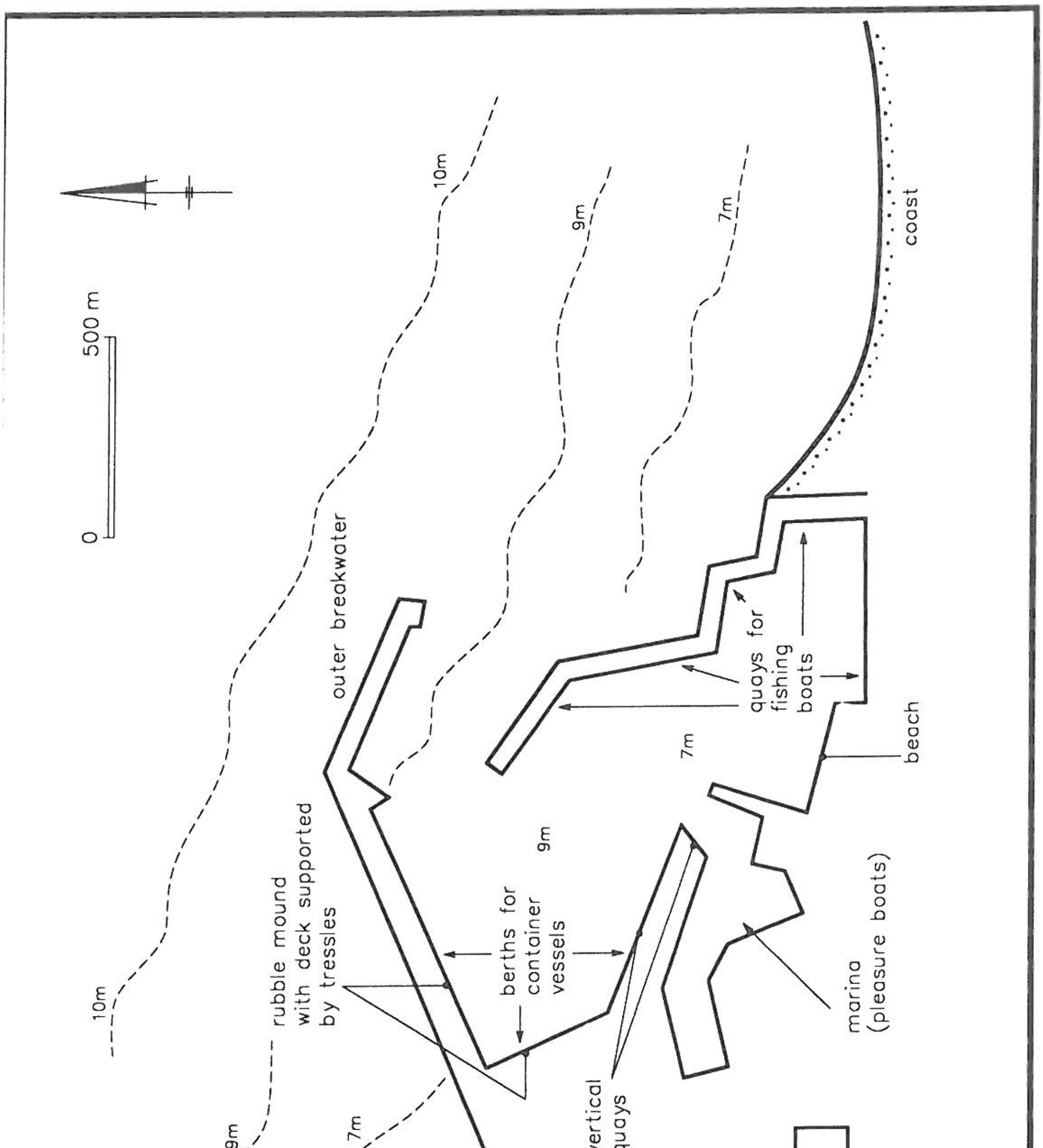
DIFFRACTION BEHIND SEMI-INFINITE BREAKWATER UNIDIRECTIONAL WAVES	DEMO1	T=5.064s
	SCALE 1: 4000	
DELFT HYDRAULICS	H 71	FIG. B4



SCHEMATISATION AND AREAS AFFECTED BY END EFFECTS FOR SEMI-INFINITE BREAKWATER WITH DIRECTIONAL SPREADING	SCALE 1:5000
DELFT HYDRAULICS	H 71 / FIG. B5



DIFFRACTION BEHIND SEMI-INFINITE BREAKWATER SHORT-CRESTED WAVES	DEMS1	T=5.064s
	SCALE 1: 4000	
DELFT HYDRAULICS	H 71	FIG. B6

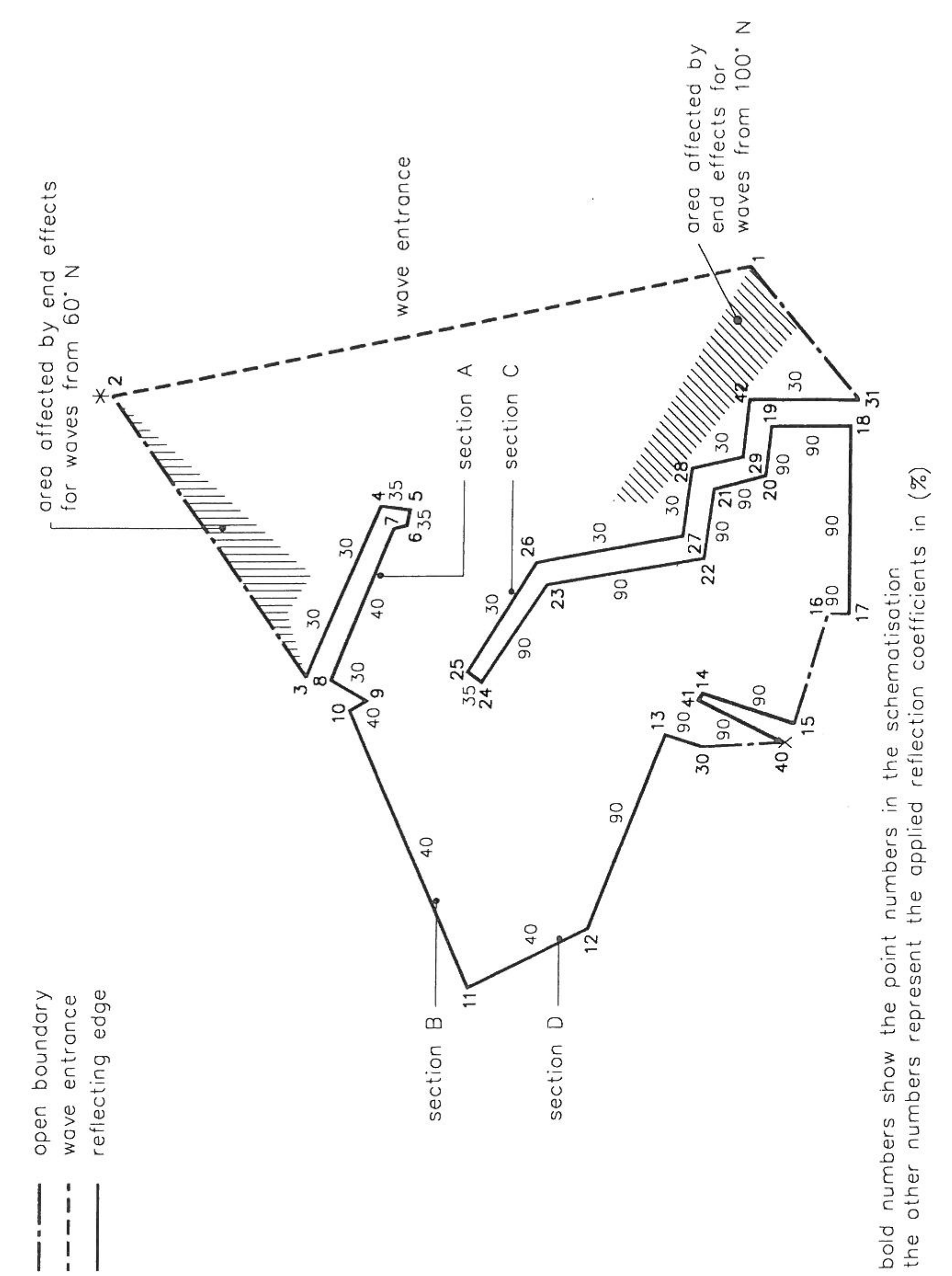


LAYOUT OF SALVETTA FISHING HARBOUR

DELFT HYDRAULICS

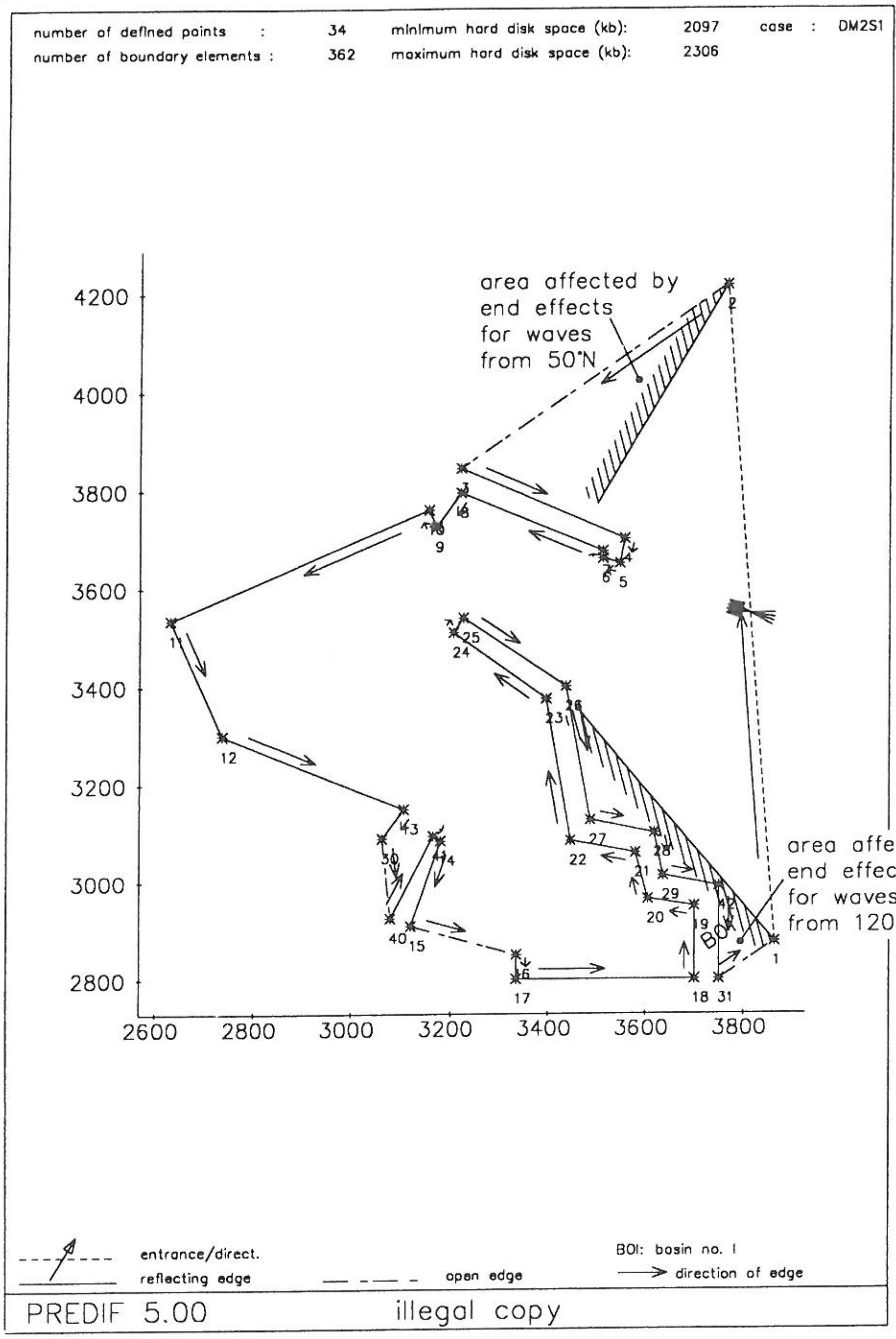
H 71

FIG. B7



SCHEMATISATION REFLECTION COEFFICIENTS FOR THE FISHING HARBOUR		
DELFT HYDRAULICS	H 71	FIG. B8

ISO-LINES SHOWING WAVE PENETRATION OF THE HARBOUR UNDIRECTIONAL WAVES	DEMO2	T=14s
	SCALE 1:9000	
DELFT HYDRAULICS	H 71	FIG. B9



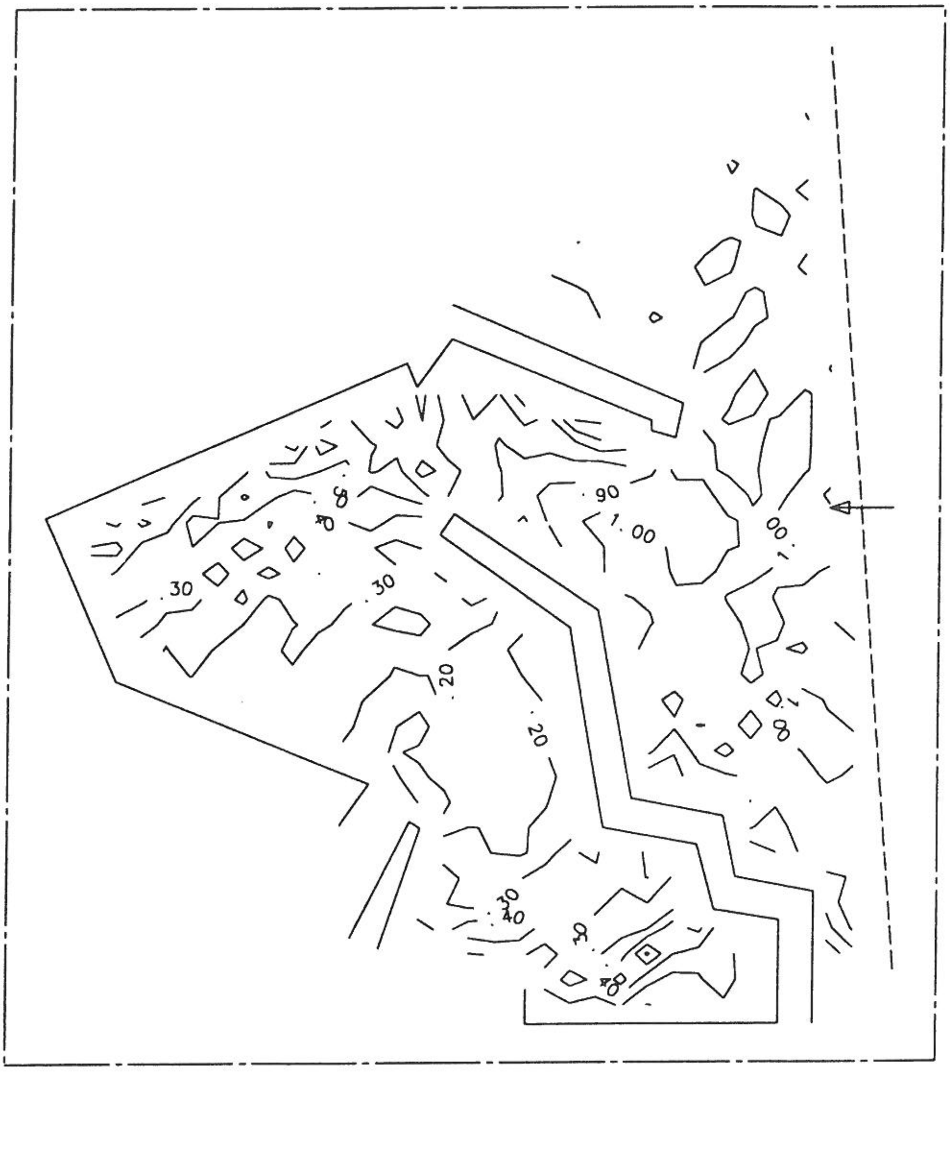
SCHEMATISATION, REFLECTION COEFFICIENTS AND AREAS AFFECTED BY END EFFECTS

SCALE 1:12500

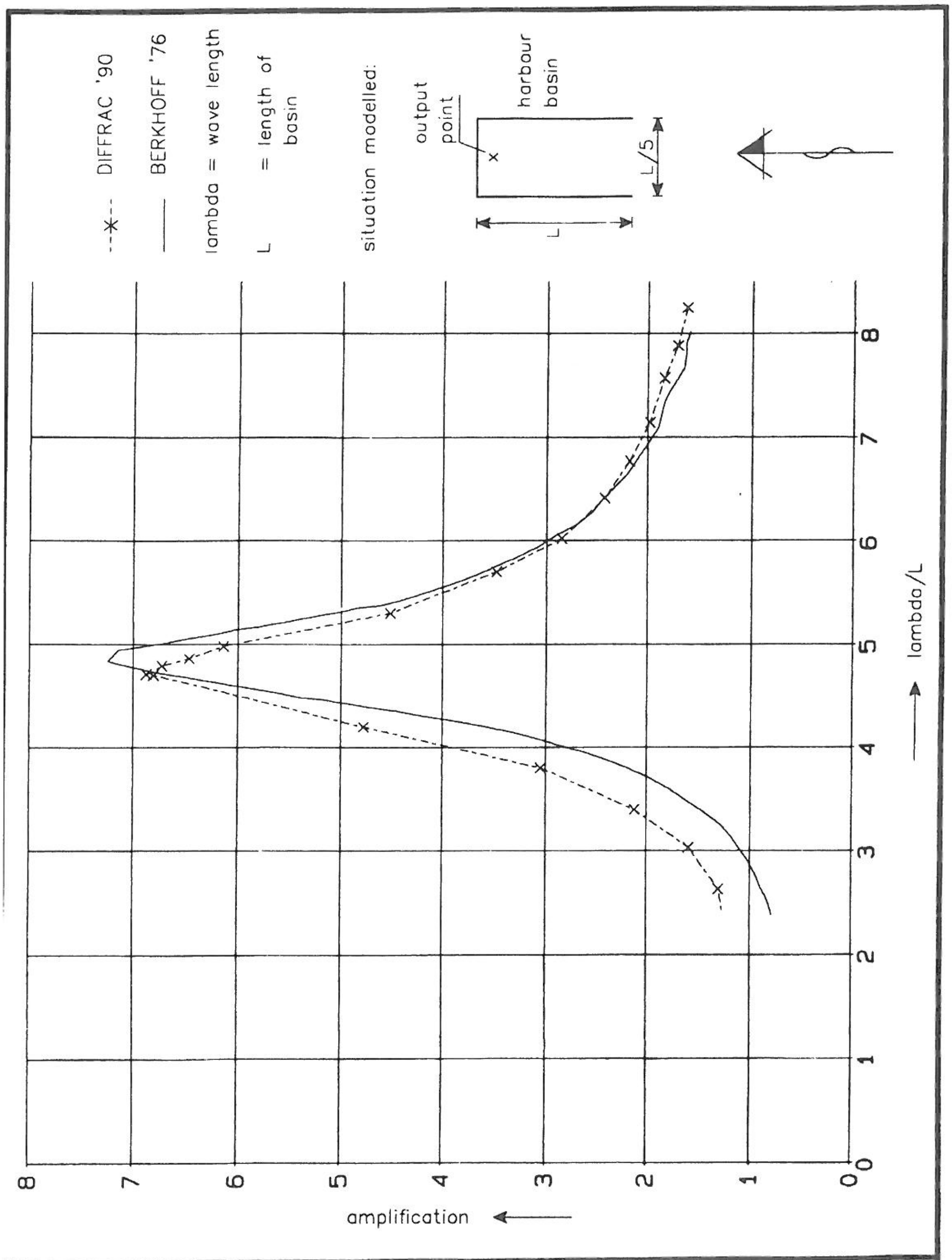
DELFT HYDRAULICS

H 71

FIG. B10



ISO-LINES SHOWING WAVE PENETRATION OF THE HARBOUR SHORT CRESTED WAVES	DEM2S12	T=14s
	SCALE 1:9000	
DELFT HYDRAULICS	H 71	FIG. B11



LONG WAVE RESONANCE IN A RECTANGULAR HARBOUR BASIN

DELFT HYDRAULICS | H 71 | FIG. B12

Appendix C
Mathematical-physical formulation

C.1 Methodology

The wave penetration computations are based on the phenomenon of diffraction, which is the three-dimensional effect resulting from the interruption of a wave train by an obstruction. The wave crests behind the obstruction will be strongly curved and along the crest a large variation of the wave height will occur, which results in a transfer of energy along the wave crest.

The mathematical model for the computation of wave penetration in areas with an arbitrary shape is based on the linear theory for harmonic water waves. The simplifications made in the mathematical formulation are:

1. The fluid is ideal, no viscosity or turbulence effects are taken into account.
2. The fluid motion is irrotational, so a potential formulation can be used.
3. There is no energy dissipation in the area of propagation, no wave breaking and no bottom friction.
4. The formulation is linearized so only small amplitude water wave (small wave steepness) can be considered.
5. The wave motion is simple harmonic in time (regular waves).
6. Over the area of propagation the water depth must be constant. Boundaries of the domain must be schematized as vertical, but they may have partial reflection properties.

With these assumptions, the problem can be formulated mathematically as the determination of the wave potential function $\phi(x,y,z)$, which must satisfy the Laplace equation:

$$\frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial y^2} + \frac{\partial^2 \Phi}{\partial z^2} = 0 \qquad \text{(C.1)}$$

in which:

Φ = three-dimensional potential (complex)
x,y = horizontal coordinates
z = vertical coordinates

In vertical direction the solution domain has the boundaries $z = 0$, which is the mean water level, and $z = -h$, which is the constant bottom plane. At these boundaries the following conditions are given:

$$\frac{\partial\Phi}{\partial z} - \frac{\tilde{\phi}^2}{g}\Phi = 0 \qquad \text{at } z = 0 \tag{C.2}$$

$$\frac{\partial\Phi}{\partial z} = 0 \qquad \text{at } z = -h \tag{C.3}$$

with:

$\tilde{\phi}$ = angular frequency of the wave motion
g = acceleration due to gravity
h = water depth

Due to the constant waterdepth a separation of variables is possible, resulting in the formulation:

$$\Phi = -\frac{g}{\tilde{\phi}} i \frac{\cosh k(z + h)}{\cosh(kh)} \phi \qquad \text{with } i = \sqrt{-1} \tag{C.4}$$

in which k must satisfy the dispersion relation:

$$\tilde{\phi}^2 = gk \tanh(kh) \tag{C.5}$$

Substitution of equation (C.4) in the Laplace equation results in the Helmholtz equation:

$$\frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + k^2\phi = 0 \tag{C.6}$$

with:

ϕ = two-dimensional potential (complex)
k = wave number = $2\pi/L$
L = wavelength

The boundary conditions in the horizontal plane are given by:

$$\frac{\partial\phi}{\partial n} + ka\phi = o \tag{C.7}$$

at fixed partial reflection boundaries by which $\partial/\partial n$ means the normal derivative. The non-dimensional constant "a" indicates the rate of reflection power in terms of amplitude reduction and phase shift. For complete reflection the value for a is 0, and so (C.7) changes into:

$$\frac{\partial\phi}{\partial n} = 0 \tag{C.8}$$

At open parts of the boundaries, such as the entrance to the sea, the radiation condition has to be fulfilled. At sea an incident wave field ← must be given. In general the incident wave is given by the expression:

$$\tilde{\phi} = \tfrac{1}{2}\tilde{H} \exp\left[ik(x \cos\alpha + y \sin\alpha)\right] \tag{C.9}$$

with:

$\tilde{H}$ = wave height of the incident plane wave
α = angle of incidence

The solution of the Helmholtz equation (C.6) for the boundary conditions as described above is as follows. The problem is linear in $\tilde{\phi}$ and hence the resulting wave pattern can be constructed from a part generated by the incident wave and a part following from partial reflected waves, which can be seen as waves which are generated by the harbour contour.

The boundary conditions (C.7) and the radiation condition at the harbour entrance result in an integral equation for the source intensity in each point of the contour. Once the potential ϕ has been computed, the wave height pattern H(x,y) in the solution domain (harbour) can be found by:

$$H(x,y) = \tilde{H}\sqrt{\phi_1^2 + \phi_2^2} \tag{C.10}$$

in which:

ϕ_1 = real part of ϕ
ϕ_2 = imaginary part of ϕ

C.2 Integral equations

In this paragraph the integral equations are given which define the problem.

For a point P laying at a wall of the harbour schematisation yields the next equation:

$$\mu(P) + \int_C \mu(M) \frac{\partial G(P;M)}{\partial \eta} ds + ka(P) \int_C \mu(M)\, G(P;M)\, ds = 0 \tag{C.11}$$

and a point P laying at the entrance of the harbour,

$$\int_C \mu(M)\, G(P;M)\, ds = \int_{C_0} \mu_0(M')\, G(P;M')\, ds + \phi(P) \tag{C.12}$$

and

$$\frac{U_e}{k}\left[\mu(P) + \int_C \mu(M)\,\frac{\partial G(P;M)}{\partial n}\,ds\right] + \frac{U_e(o)}{k_o}\left[\mu_o(P) + \frac{\partial \phi}{\partial n_o}(P)\right] = 0 \qquad (C.13)$$

in which:

μ	=	source intensity
$G(P;M)$	=	potential in point P due to a point source in M
s	=	distance along a harbour contour
k	=	wave number
a	=	complex reflection coefficient ($a = x + iy$)
U_e	=	energy velocity
ϕ	=	complex potential
$\partial\phi/\partial n$	=	normal derivative of potential
C	=	contour of harbour

The subscript o indicates the "sea area"

With these integral equations the source intensity functions μ and μ_o are uniquely defined and can be solved numerically. Once the intensity functions have been found the potential at each point can be computed. For complicated harbours with many basins it is possible to split up the harbour into more areas corresponding to the basins and to express the solution in each area as a source integral over the boundaries of the area. Requirements of continuity for the normal velocity and wave height at the boundary between two areas create a set of integral equations for the unknown intensity functions μ of all basins.

C.3 System linear equations

A basin consisting of n computational points in the total harbour schematisation (including connecting boundaries) delivers a complex system of linear equations of order n. This system is solved by the method of Gauss-elimination.
The number of right hand sides of this system of linear equations is equal to the number of incident wave directions.

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DIFFRAC

PC-software

January 1995

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