MIKE
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MIKE 21 EMS

Elliptic Mild-Slope Wave Module

User Guide

The expert in **WATER ENVIRONMENTS**

MIKE 2017

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PRINTING HISTORY

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1 About This Guide

1.1 Purpose

The main purpose of this User Guide is to enable you to use the Elliptic Mild-Slope module of MIKE 21, for determination and assessment of wave dynamics in ports, harbours and smaller coastal areas, where the forcing wave conditions can be represented by monochromatic and unidirectional waves. The User Guide is complemented by the On-line Help.

The following section, Section 2 INTRODUCTION, gives you a short description of the module MIKE 21 EMS and the type of applications it can be used for.

Section 3, GETTING STARTED, contains a step-by-step procedure which can be followed when working on an application or when writing a proposal. It is the intention that by following this procedure, and by using the Reference Manual (Section 5), you should be able to get good and reliable results from MIKE 21 EMS although a formal procedure is no substitute for common sense.

Section 4, EXAMPLES includes a number of MIKE 21 EMS applications in order to get you started.

Section 5, REFERENCE MANUAL describes the parameters in the MIKE 21 EMS dialogues. It provides more details on specific aspects of the operation of MIKE 21 EMS and is what you will normally refer to for assistance if you are an experienced user. The contents of this section is the same as found in the On-line Help.

In Section 6, SCIENTIFIC BACKGROUND, you can find information on the scientific background for MIKE 21 EMS and a reference list.

An INDEX is found at the end of this MIKE 21 EMS User Guide.

1.2 Assumed User Background

Although MIKE 21 EMS has been designed carefully with emphasis on a logical and user-friendly interface, and although the User Guide contains modelling procedures and a large amount of reference material, common sense is always needed in any practical application.

In this case, “common sense” means a background in wave mechanics which is sufficient for you to be able to check whether the results from MIKE 21 EMS are reasonable or not. This User Guide is not intended as a substitute for - and it cannot replace - a basic knowledge of the area in which you are working: mathematical modelling of wave problems.

It is assumed that you are familiar with the basic elements of MIKE 21: file types and file editors, the Plot Composer, the MIKE Zero Toolbox, the MIKE 21 Toolbox and the Bathymetry Editor. An introduction to these can be found in the MIKE 21 Short Introduction and Tutorial.

2 Introduction

2.1 General Description

The Elliptic Mild-Slope Module MIKE 21 EMS is based on an efficient numerical solution of the so-called “mild-slope” wave equation, which governs the motion of time harmonic water waves of infinitesimal height (linear waves) on a gently sloping bathymetry with arbitrary water depth.

It is a linear refraction-diffraction model including wave breaking, friction and back-scattering. Partial reflection and transmission through piers and breakwaters are included. Sponge layers are applied when full absorption of wave energy is required. The model includes a general formulation of radiation stresses to be applied in crossing wave trains and areas of strong diffraction.

MIKE 21 EMS is based on a unique solution method. The time-harmonic variation is subtracted and the elliptic equations are reformulated as mass and momentum type equations, which are solved by a finite difference scheme utilising the ADI algorithm.

For a given wave period, the model will determine the wave heights, the particle velocity components, the surface elevation and, in case of wave breaking, the wave radiation stresses in the model area.

Figure 2.1 MIKE 21 EMS is often applied to study long period oscillations (harbour resonance and seiching) in ports and harbours

2.1.1 Application Areas

MIKE 21 EMS is used for determination of harbour resonance and seiching due to long period waves and for calculation of wave fields in smaller coastal areas, where diffraction and wave breaking are important and where the forcing wave conditions can be represented by a monochromatic and unidirectional wave. The model is applicable to any water depth and the only restriction is that non-linear effects such as e.g. amplitude-dispersion and wave-wave interaction are not included. The model can also be applied to the study of short period wave disturbance in harbours, but since the model operates with monochromatic and linear waves it is generally recommended to apply MIKE 21 BW for this purpose.

3 Getting Started

3.1 General

The purpose of this chapter is to give you a general check list which you can use for computation of wave dynamics in ports, harbours and smaller coastal areas using the MIKE 21 Elliptic Mild-Slope module.

The work will normally consist of the six tasks listed below:

- defining and limiting the wave problem
- collecting data
- setting up the model
- calibrating and verifying the model
- running the production simulations
- presenting the results

Each of these six tasks are described for a "general wave study" in the following sections. For your particular study only some of the tasks might be relevant.

Please note that whenever a word is written in *italics* it is included as an entry in the *On-line Help* and in the *Reference Manual.*

3.2 Defining and Limiting the Wave Problem

3.2.1 Identify the wave problem

When preparing to do a study you have to assess the following before you start to set up the model:

- what are the "wave conditions" under consideration in the "area of interest"?

- what are the "important wave phenomena"? The following phenomena should be taken into consideration:
  - Shoaling
  - Refraction
  - Diffraction
  - Reflection
  - Bottom dissipation
  - Wave breaking
  - Wind-wave generation
  - Frequency spreading
  - Directional spreading
  - Wave-wave interaction
  - Wave-current interaction

The MIKE 21 EMS module can handle these phenomena with the exception of wind-wave generation, frequency/directional spreading, wave-wave and wind-current interaction.

- what is the “area of influence” of the wave phenomena?

3.2.2 Check MIKE 21 EMS capabilities

Next, check if the MIKE 21 EMS module is able to solve your problem. This you can do by turning to Chapter 2, which gives a short description of MIKE 21 EMS and an overview of the type of applications for which MIKE 21 EMS can be used, and by consulting the Scientific Documentation.

3.2.3 Selecting model area and grid spacings

Draw up your model area on a sea chart showing the area of interest and the area of influence. This is normally an iterative process as on one hand you should keep the model area as small as possible, while on the other hand you have to include the total area of influence. The choice of the grid spacing in the x,y-space depends on the wave conditions and the bathymetry for which the simulations are to be performed:

- the grid spacing in the x,y-plane must be selected to provide adequate resolution of the bathymetry, and the wave field under consideration.

- the grid spacing in the x,y-space must be selected to satisfy the stability criterion for the numerical scheme which is applied in the MIKE 21 EMS module.

In practice, the choice of the grid spacing is often a compromise between low computer costs, storage requirements and high accuracy. *Selection of the Model Area* are given under *Bathymetry* in the *On-line Help*.

3.2.4 Check computer resources

Finally, before you start to set up the model, you should check that you are not requesting unrealistic computer resources:

- the *CPU time* required should be estimated.
- the *Disk Space* required should be estimated.

3.3 Collecting Data

This task may take a long time if, for example, you have to initiate a monitoring program. Alternatively it may be carried out very quickly if you are able to use existing data which are immediately available. In all cases the following data should be collected:

- bathymetric data such as sea charts from local surveys or, for example, from the Hydrographic Office, UK, or MIKE C-MAP.
- boundary data, which might be measurements (existing or planned specifically for your model), observations etc.
- information on the bottom friction.
- information on reflection characteristics of structures.
- calibration and validation data; these might be measured wave parameters at selected locations, e.g. root mean square wave height and peak wave.

3.4 Setting up the Model

3.4.1 What does it mean

“Setting up the model” is actually another way of saying transforming real world events and data into a format which can be understood by the numerical model MIKE 21 EMS. Thus generally speaking, all the data collected have to be resolved on the spatial grid selected.

3.4.2 Bathymetry

You have to specify the bathymetry as a type 2 data file containing the water depth covering the model area. Describing the water depth in your model is one of the most important tasks in the modelling process. A few hours less spent in setting up the model bathymetry may later on mean extra days spent in the calibration process.

3.4.3 Boundary conditions

The boundary conditions are specified as two wave generation lines inside the model area. The wave considered is determined by specification of the wave period and the wave height (see *Internal Generation*).

3.4.4 Bed friction

The bed friction is specified as a constant Nikuradse roughness parameter (see *Bed Friction*).

3.4.5 Breaking

The wave breaking is determined by specification of two breaking parameters (see *Breaking*).

3.4.6 Reflection

Partial reflection from breakwaters are specified as a type 2 data file containing the equivalent linear friction factor in all grid points (see *Reflection*).

3.4.7 Absorption

The absorption of waves is specified as a type 2 data file containing damping values of sponge layers in all grid points (see *Sponge Layers*).

3.5 Calibrating and Verifying the Model

3.5.1 Purpose

Having completed all tasks listed above you are ready to do the first wave simulation and to start on the calibration and verification of the model.

The purpose of the calibration is to tune the model in order to reproduce known/measured conditions for a particular situation.

The calibrated/tuned model is then verified by running one or more simulations for which measurements are available without changing any tuning parameters. This should ensure that simulations can be made for any situation similar to the calibration and verification situations with satisfactory results. However, you should never use simulation results, whether verified or not, without checking if they are reasonable or not.

3.5.2 Calibration and verification situations

The situations which you select for calibration and verification of the model should cover the range of situations you wish to investigate in the production runs. However, as you must have some measurements/observations against which to calibrate and, as the measurements are often only available for short periods, you may only have a few events from which to choose.

3.5.3 Calibration factors

When you run your calibration run the first time and compare the simulation results to your measurements you will in many cases see differences between the two. The purpose of the calibration is then to tune the model so that these differences become negligible. The most important calibration parameters are the partial reflection, bottom friction and wave breaking coefficients.

3.6 Running the Production Simulations

As you have calibrated and verified the model you can get on to the “real” work, that is doing your actual investigation. This will, in some cases, only include a few runs.

3.7 Presenting the Results

Throughout a modelling study you are working with large amounts of data and the best way of checking them is therefore to look at them graphically. Only in a few cases, such as when you check your bathymetry along a boundary or you want to compare simulation results to measurements in selected locations, should you look at the individual numbers. Much emphasis has therefore been placed on the capabilities for graphical presentation in MIKE 21 and it is an area which will be expanded and focused on even further in future versions.

Essentially, one plot gives more information than scores of tables and if you can present it in colours, your message will be even more easily understood.

A good way of presenting the model results is using contour plots of the calculated wave parameters, e.g. the significant wave heights and the mean wave periods, and in form of vector plots showing the mean wave directions.

Plotting in MIKE Zero is done by using the Plot Composer tool.

4 Examples

4.1 General

One of the best ways of learning how to use a modelling system like MIKE 21 is through practice. Therefore we have included some applications which you can go through yourself and which you can modify, if you like, in order to see what happens if some of the parameters are changed.

The specification data files for the examples are included with the installation of MIKE 21. For each example a directory is provided. The directory names are as follows:

- Diffraction test:
  .\Examples\MIKE_21\EMS\Diffraction
- Detached breakwater:
  .\Examples\MIKE_21\EMS\Detached-Breakwater
- Demo diffraction:
  .\Examples\MIKE_21\EMS\Demo-Diffraction

Please note the layout of figures and illustrations presented in this release of the User Guide are optimised for the integrated On-line Help in MIKE Zero. Thus, the examples may also be found through the Online Help for the Elliptic Mild Slope Wave Editor.

4.2 Diffraction Test

4.2.1 Purpose of the example

This example is included to illustrate the phenomenon of diffraction. Diffraction is an important process in regions which are sheltered by barriers such as breakwaters, jetties or inlets.

The example describes what happens when a single fully reflecting breakwater interrupts a regular wave train.

4.2.2 Model set-up

The model set-up is illustrated in Figure 4.1. The model size is 1200 m by 700 m with a uniform depth of 40 m. Wave absorbing sponge layers are applied at the eastern and northern model boundary, while the western boundary is fully reflective. The area of interest is the shadow zone behind the breakwater. Due to radiation of energy from the point of diffraction the western boundary has to be placed quite far from this area to avoid reflections.

The wave period is 8 s resulting in a wave length of 98.7 m. As the grid spacing is 10 m the resolution is about 10 points per wave length which is sufficiently in this case as no strong reflection occurs (minimum 10-15 points per wave length is generally recommended).

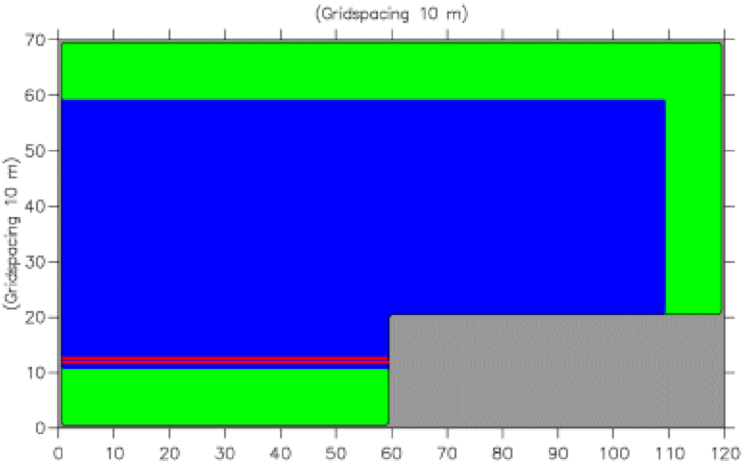


Figure 4.1 Model layout. The 10 point wide areas indicate sponge layers and the two lines internal generation lines

4.2.3 Model results

Model results are presented in Figure 4.2 showing a 3D picture of the instantaneous surface elevation. Figure 4.3 shows isolines of the wave disturbance coefficient in the entire domain.

The model results are in good agreement with semi-analytical solutions to the Helmholtz equation (which the mild-slope wave equation reduces to in the present case), see e.g. Shore Protection Manual (1984). A reference list is included in the Reference Manual section.

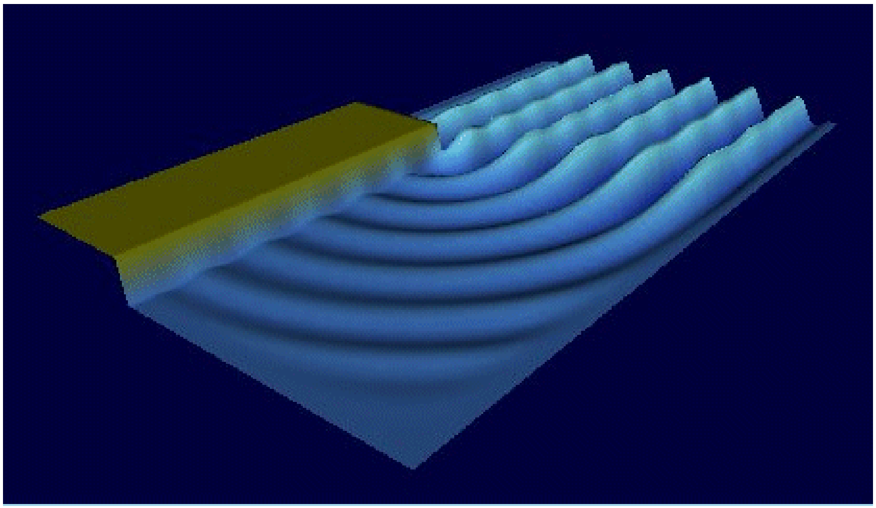


Figure 4.2 Model results. The figure shows the instantaneous surface elevation behind a fully reflective breakwater. The incoming waves have a period of 8 s and the water depth is 40 m

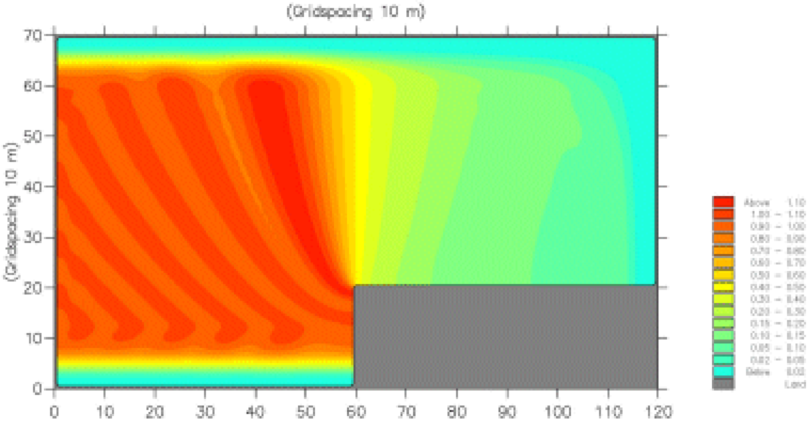


Figure 4.3 Model results. The figure shows the wave disturbance coefficient behind a fully reflective breakwater

4.2.4 List of data and parameter files

All data required for this examples are included in the installation:

Binary data files

Name:	Layout.dt2 (and Layout.ct2)
Description:	Bathymetry and sponge layer coefficients

Parameter files

Name:	Diffraction.ems
Description:	Diffraction test

4.3 More Examples

4.3.1 Detached Breakwater

Purpose of the example

This example is included to illustrate the combined phenomenon of diffraction and wave breaking in connection with detached breakwaters. It is assumed that the wave forcing can be represented as a regular and unidirectional wave.

Model set-up

The model is 500 m by 1500 m with a depth decreasing linearly from about 11 m to 2 m, see Figure 4.4. Absorbing sponge layers are applied at the eastern and western model boundaries, while the northern and southern boundaries are fully reflective. The area of interest is the shadow zone behind the detached breakwater. Due to the radiation of energy from the point of diffraction the northern and southern boundaries have to be placed quite far from this area to avoid reflections.

Figure 4.4 Example of detached breakwaters in the coastal zone

Waves are generated with a period of 8 s along the western boundary in grid lines j= 14 and j= 15. The grid spacing is chosen 5 m since the maximum wave length is approximately 75 m. This corresponds to about 15 grid points per wave length. The initial time step (automatic selection of time step is applied) is chosen to be 0.5 s.

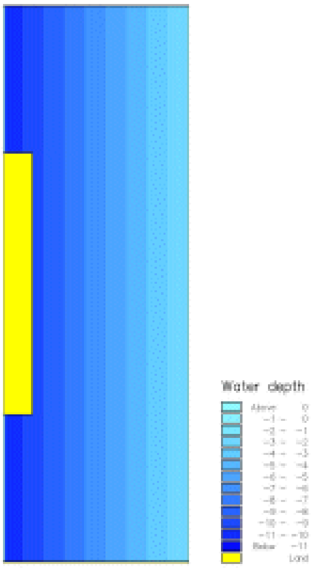


Figure 4.5 Model bathymetry

Default parameters are used for the description of wave breaking.

The calculated radiation stresses are used as the driving forces in the subsequent hydrodynamic modelling using the MIKE 21 Flow Model.

Model results

Model results are presented in Figure 4.6 showing a contour plot of the instantaneous surface elevation and a map of the H_{rms} wave height. Also the calculated radiation stress field (S_{xy}) is shown in the figure together with the calculated steady state wave induced currents and wave set-up.

The maximum set-up is in the order of 0.20 m and the maximum current speed is in the order of 1 m/s.

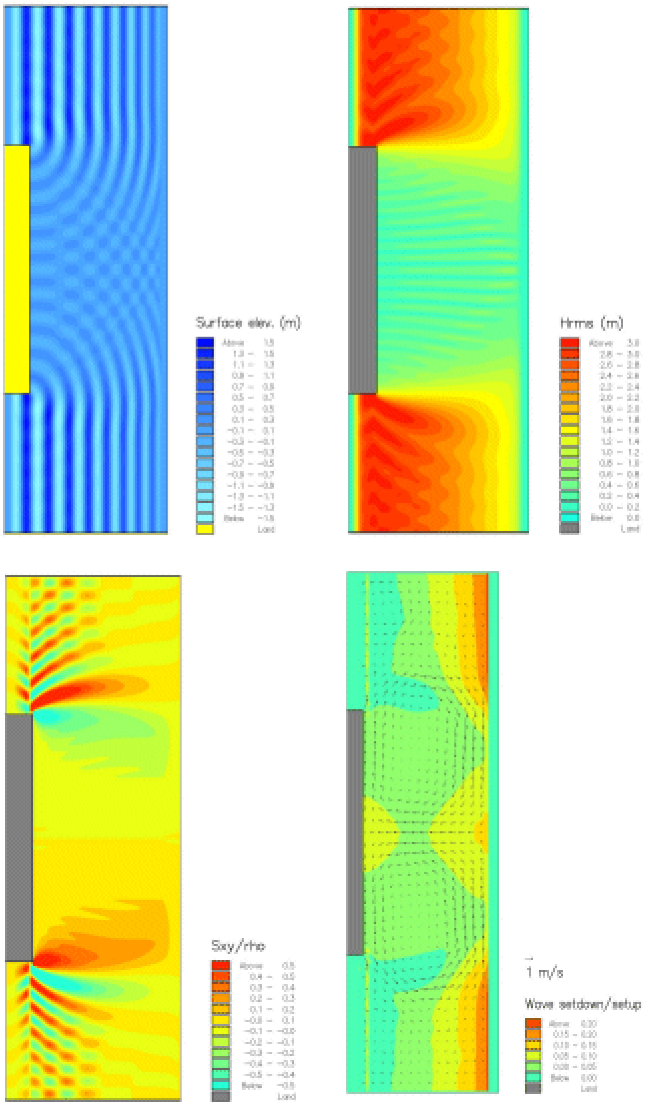


Figure 4.6 Model results.
The upper panel shows the instantaneous surface elevation (left) and the wave height H_{rms} (right).
The lower panel shows the calculated stress S_{xy} (left) and the simulated wave induced currents (by the MIKE 21 Flow Model) behind the breakwater

List of data and parameter files

All data required for these examples are included in the installation:

Binary data files for MIKE 21 EMS

Name: Layout.dt2 (and Layout.ct2)
Description: Bathymetry and sponge layer coefficients

Binary data files for MIKE 21 Flow Model

Name: HD-bathy.dt2 (and Layout.ct2)
Description: Bathymetry for Flow Model

Parameter files for MIKE 21 EMS

Name: Detached_Breakwater.ems
Description: Detached_Breakwater

Parameter files for MIKE 21 Flow Model

Name: Wave_Induced_Current_Simulation.m21
Description: Detached_Breakwater - Flow Model

4.3.2 Demo Diffraction

This simple example simulating wave diffraction is designed for use when running MIKE 21 EMS in demo mode.

The following data file and specification file (within the folder of Demo-Diffraction) are supplied with MIKE 21:

Name: Demo-Layout.dfs2
Description: Bathymetry and sponge layer

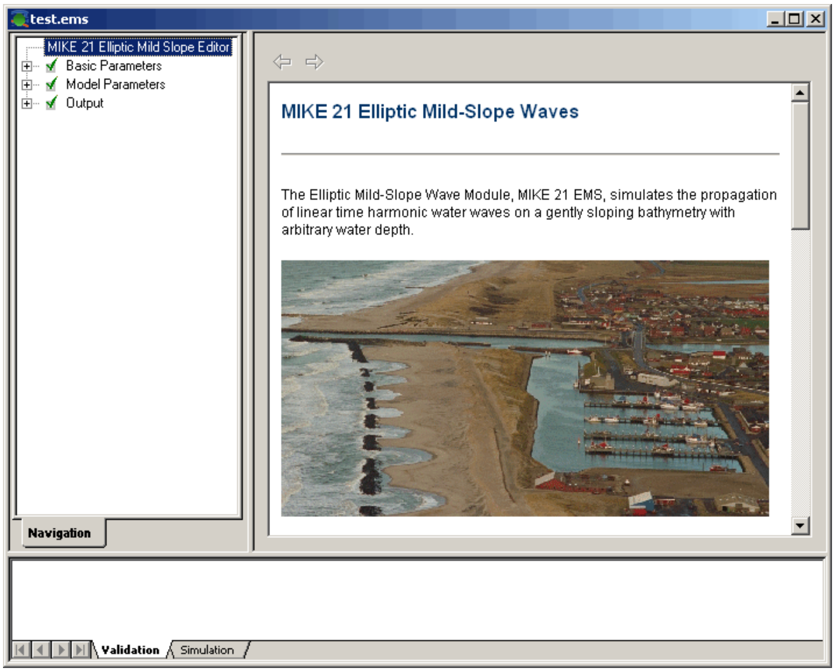
Name: Diffraction.ems
Task: Model: MIKE 21 EMS Elliptic Mild Slope Waves
Description: Demo simulation, wave diffraction

Please note that in order not to overwrite the specification files you should copy them to your own working folder or rename them.

5 Reference Manual

5.1 Introduction

It is intended that you use this manual when you are doing model applications with MIKE 21 EMS and need to know how various input, output, etc. are specified or defined. The sections are organised in the order in which they appear in the MIKE 21 EMS editor (Figure 5.1). Thereafter, all other entries are arranged alphabetically in section 5.5.



MIKE 21 Elliptic Mild-Slope Waves

The Elliptic Mild-Slope Wave Module, MIKE 21 EMS, simulates the propagation of linear time harmonic water waves on a gently sloping bathymetry with arbitrary water depth.

Figure 5.1 MIKE 21 EMS editor

The Reference Manual entries are also available in the online help for MIKE 21 EMS.

It is assumed that you are familiar with the operation of MIKE 21 under the MIKE Zero platform.

5.2 Basic Parameters

The basic parameters group consists of the following sections:

- Bathymetry
- Iteration description

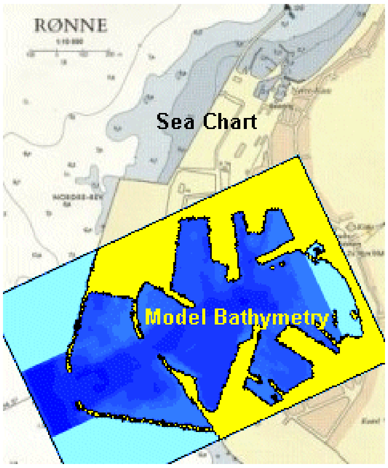


Figure 5.2 Setup of model bathymetry

5.2.1 Bathymetry

Providing MIKE21 EMS with a suitable model bathymetry is essential for obtaining reliable results from your model. Setting up the bathymetry requires more than just specifying a 2D array of accurate water depths covering the area of interest. It also includes the appropriate selection of the area to be modelled, the grid spacing, location and type of boundaries etc.

The bathymetry is specified as a 2D map in dfs2 format.

When setting up the bathymetry it should be kept in mind that shallow water results in small wave lengths which imply small grid spacing which again results in increased CPU time.

Selecting the model area

In deciding the area to be included in your model, you must consider the area of interest, and the positions and types of the model boundaries to be used.

In many wave applications, such as enclosed harbour basins, the area of interest is relatively well defined. Here, the selection of the area to be modelled reduces to deciding on the position and type of the boundaries.

A typical situation is illustrated in Figure 5.3.

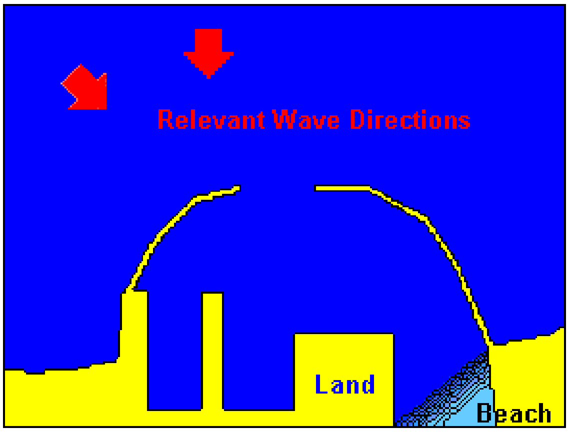


Figure 5.3 Enclosed harbour

In many cases involving breakwaters, what happens in part of the area between the outer face of a breakwater and an adjacent model boundary may have no influence on the main area of interest. These areas can be turned into **(artificial) land** without affecting the accuracy of the results, as shown in Figure 5.4. This can result in significant savings in computation time.

It is stressed that the selection of model area and **Artificial land** areas is closely connected to the wave conditions to be modelled. In this context the wave direction and directional spreading is important. (see Set-up of Internal Generation Lines).

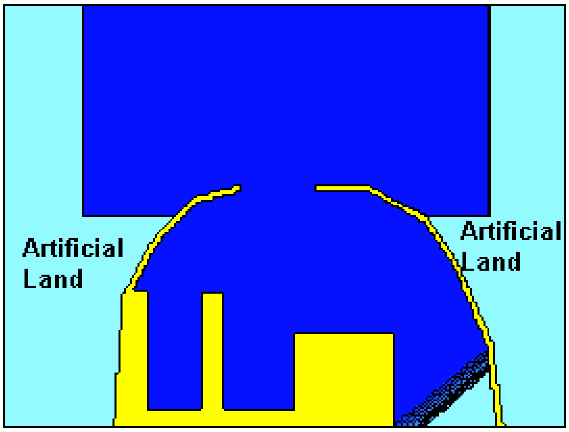


Figure 5.4 Enclosed harbour with reduced computational area

In the example, the shallow area inside the harbour is also converted to land values, for two reasons:.

- It is assumed that the shallow area/beach will absorb the wave energy. Therefore sponge layers will be placed in front of the land values.
- The minimum water depth in the model area defines the grid spacing, as the minimum wave length is defined by the minimum water depth in combination with the minimum wave period (see Grid spacing). Therefore very shallow areas should be avoided, where possible, to reduce the CPU demand.

The areas, unimportant for the propagation into the harbour, may differ for different incoming wave directions. This is described in Set-up of Internal Generation Lines *(p. 46)*.

In other applications, such as semi-enclosed harbours, along exposed coastlines, or around offshore structures, the area to be modelled is not as well defined. Then, it is important that the model should extend far enough from the area of interest to ensure that model results will not be influenced by close proximity to the model boundaries.

As a rule of thumb, the distance between the end of a structure and an adjacent closed boundary should preferably be five or six wavelengths.

Boundaries

All boundaries in MIKE 21 EMS have to be closed boundaries. They are set up by specifying the grid points along the boundary as land.

A closed boundary does not allow any flow across the boundary. A closed boundary is fully reflective when not combined with sponge or friction layers. For a closed boundary, boundary conditions (such as surface elevations) can not be specified.

Grid spacing

It is important that the grid size is selected so as to provide adequate resolution of the main characteristics of the bathymetry and waves under consideration.

Regarding the waves, the grid spacing should be chosen to allow for at least 10 grid points per wave length.

However, for harbour resonance studies where complicated standing wave patterns can be expected it is recommended to allow for 15 points per wave length (especially if the automatic selection of time step is applied).

Based on the minimum water depth and wave period you can calculate the corresponding wave length using DHI's linear wave calculator included in the On-line Help.

The number of iterations necessary to achieve a steady state solution will decrease for increasing values of $L/\Delta X$.

Further it is required that the grid spacing in combination with the time step is selected to fulfil the CFL criterion, i.e. the Courant number should be less than one.

Sign convention

Bed levels (water points) are specified as negative values when they are below the bathymetry datum, and positive values when they are above it.

Note that simulations are carried out using the still water level (SWL) as reference. SWL = bathymetry value + shift of reference level, see Figure 5.5.

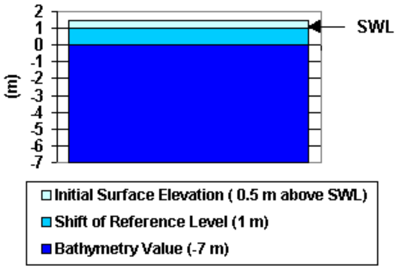


Figure 5.5 Definition of levels

Bathymetry value representing land

All bathymetry values (including increment of bathymetry) above 0.0 are assumed as land. In the model calculation grid points with values higher than this value are always considered as land.

Artificial land

Artificial land is a term used for areas which in the “prototype” are water, but in the model are described as land. Artificial land should only be applied to water areas, which have no influence on the wave conditions in areas of interest.

The idea of applying artificial land is to save computational time.

In the example below, artificial land has been applied on both sides of the harbour entrance and for an area inside the harbour representing a shallow area, where the wave energy is absorbed. In the example the modelled waves approaching the harbour are unidirectional. If the wave field had been directional (short crested) a wider spacing between the two artificial land areas would have to be chosen to allow for the directionality.

To be able to separate 'real' and 'artificial' land in the subsequent plotting it is a good idea to assign the two types of land different values in the bathymetry file e.g. 10 for real land, and 5 for artificial land.

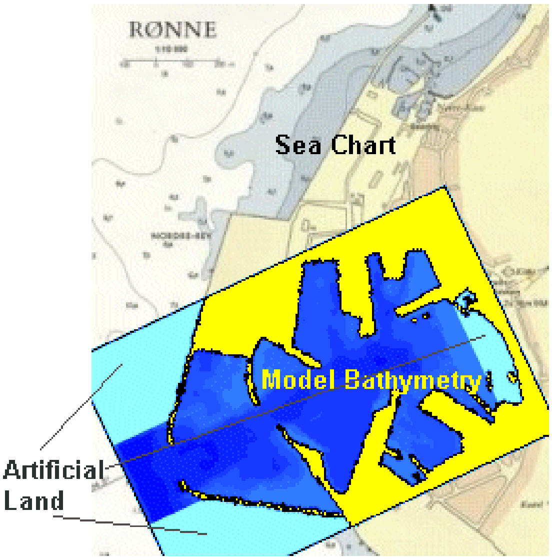


Figure 5.6 Example of bathymetry including artificial land

Increment bathymetry/shift of reference level

The still water level (SWL) is used as the main reference level for short wave simulations, see Figure 5.7.

You can, however, use any convenient datum for setting up the bathymetry of your model. This may for example be Chart Datum, lowest astronomical tide (LAT), or mean sea level (MSL). The actual datum you use is not important. What is important, is that for each simulation you must provide the model with the correct height of the still water level, i.e. the model reference level, relative to the datum used in setting up your bathymetry, see the figure below.

This is done by specifying the Shift of Reference Level. Then, the model will automatically make any internal adjustments necessary for that particular model simulation. In this way it is possible to carry out model simulations using a range of different water levels, without having to alter the bathymetry.

Additionally, it is essential that the boundary conditions and initial surface elevations are specified relative to the SWL.

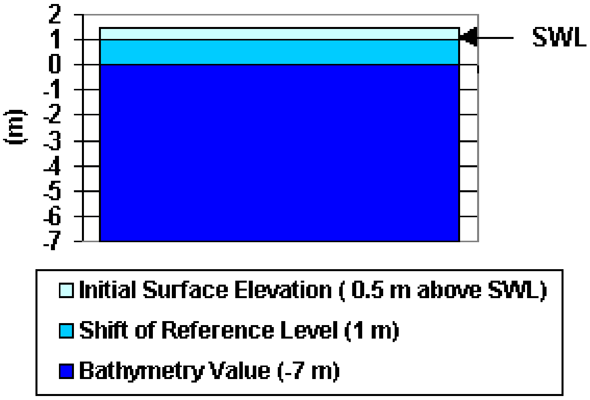


Figure 5.7 Sign convention of bed levels

5.2.2 Iteration description

The iteration procedure can be performed in two ways:

- Using a constant time step, Δt.
- Using a computerised strategy for automatic change of the time step during the iteration.

In both cases the initial time step is limited by a Courant number less than or equal to one, i.e.:

$$\Delta t \cong \frac{\Delta x}{c} \tag{5.1}$$

where *c* is the phase Celerity of the wave.

The method used in the automatic selection of the time step is described in detail in Madsen and Larsen (1987) available in the Scientific Documentation.

Maximum number of iterations

The default value is 500 for the maximum numbers of iterations.

If there are indications or doubts whether a steady state is obtained or not, it is recommended to run a simulation using constant time step and save the results during the iteration. Afterwards you can compare the results with the steady state solution obtained by use of the automatic time step strategy.

Time step

The iteration procedure can be performed in two ways:

- Including automatic selection of time step
  i.e. using a computerised strategy for automatic change of the time step Δt during the iteration.
- Excluding automatic selection of time step
  i.e. using a constant time step, Δt, during the computation.

In both cases the initial time step is limited by a Courant number less than or equal to one, i.e.

$$\Delta t \le \frac{\Delta x}{c} \tag{5.2}$$

where c is the phase Celerity of the wave.

Courant number

The Courant Number is an expression which describes the number of grid points that wave information will travel in one time step. It is defined as follows:

$$C_r = c\frac{\Delta t}{\Delta x} \tag{5.3}$$

where c is the wave propagation speed (or Celerity), Δt is the time step, and Δx is the grid spacing.

Note: The Courant number should always be equal to, or less than, 1.

Celerity

For small amplitude waves, non-linear effects can be neglected and analytical methods can be used to derive the linear dispersion relation.

The phase celerity using Stokes first order theory is given by

$$c = \sqrt{\frac{g\tanh(kh)}{k}} \tag{5.4}$$

where c is the celerity (= L/T), k the wave number (= 2π/L), h the water depth, and g is the gravitational acceleration (= 9.81 m/s^2). L and T are the wave length and wave period, respectively.

For the calculation of various wave parameters you can use DHI's linear wave calculator.

Stop Criterion

You should usually apply a stop criterion for convergence of β=0.005.

In some applications (e.g. a very small harbour connected to a large outer area) it may appear that the iteration for the steady state solution (using automatic time step strategy) is stopped (i.e. CP < β) before a steady state is reached in the area of main interest (the small harbour). The steady state solution is obtained much faster in the outer area. In such cases you may use a smaller value of b, e.g. 5 x 10^{-4}.

If there are indications or doubts whether a steady state is obtained or not, it is recommended to run a simulation using constant time step and save the results during the iteration. Afterwards you can compare the results with the steady state solution obtained by use of the automatic time step strategy.

Convergence - Background

Every time step comprises two standard double sweeps with the present value of Δt plus one extra book-keeping double sweep with the double value of Δt.

After each time step the test parameter TP is determined:

$$TP = max\begin{cases} \dfrac{NORM(S^n - S_*^n)}{NORM(S^n - S_*^n)} \\ \dfrac{NORM(P^n - P_*^n)}{NORM(P^n - P_*^n)} \\ \dfrac{NORM(Q^n - Q_*^n)}{NORM(Q^n - Q_*^n)} \end{cases} \tag{5.5}$$

Furthermore the local convergence parameter CP is determined,

$$CP = \frac{NORM(S^n - S^{n-1})}{NORM(S^n)}\sqrt{\alpha} \tag{5.6}$$

S^{n-1} is the value of the surface elevations obtained from the previous time step, S^n is the value obtained from the new first two double sweeps (using Δt), S_*^n is the value obtained from the book-keeping double sweep (using 2 x Δt) and analogous for the pseudo fluxes, P and Q. Finally *a* is defined as the ratio between the initial time step and the local time step. The actual computation of the norm is done in the following way:

$$NORM(S^n - S^{n-1}) = \sqrt{\sum_i \sum_i ABS(S_{ij}^n - {}_{ij}^{n-1})^2} \tag{5.7}$$

Now the strategy adopted for the automatic change of Δt is the following:

When TP falls in the intervals

]0,0.05],]0.05,0.10],]0.10,0.15],]0.15,0.30],]0.30,0.40],]0.40,0.60]

one accepts the present computation and changes Δt by a factor

4, 2, 1.5, 1, ½ or 1/4 respectively for the next time step.

However, when TP falls in the interval]0.6, ∞ [one rejects the present computation and starts the step again with Δt changed by a factor 1/16.

The maximum time step chosen by the automatic selection of time step can be expected to be in the interval of 1/4 to 1/8 of the wave period considered.

The iteration for the steady state is stopped when

$CP < \beta$ or $N > N_{max}$

where β is the stop criterion for convergence and N_{max} the maximum number of time steps/iteration. Both β and N_{max} have to be specified by the user.

The values of norm (S^n), TP, CP and α during the iteration are listed in the log file.

5.3 Model Parameters

Besides the definition of the bathymetry you may use one or more of the following facilities:

- Absorbing boundaries and/or areas

- Partial reflecting structures/beaches
- Structures with wave transmission
- Wave breaking parameters
- Bed friction parameters

Finally, you have to specify the wave input.

5.3.1 Facilities

It is possible to use the following facilities for the simulation of the waves;

- Absorbing boundaries and/or areas - Absorbing boundary or Sponge layers

- Possible partial reflecting structures/beaches - Wave reflection

- Possible structures with wave transmission - Transmission through structures

- Wave Breaking parameters - Wave breaking

- Bed friction parameters - Bed friction

The last two facilities are often regarded as calibration parameters to tune the model against prototype and/or model test data, if available.

Absorbing boundary

An absorbing boundary allows wave energy to pass out of the model area without reflections propagating back into the model area.

In the model an absorbing boundary consists of a number of sponge layers backed up by a closed boundary (land values).

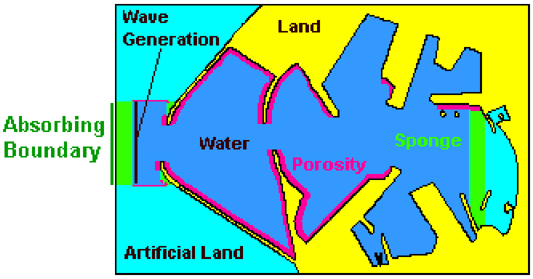


Figure 5.8 Example of absorbing boundary

Sponge layers

Sponge (or absorbing) layers can be used as numerical wave absorbers in the wave simulations. These may e.g. be set up along model boundaries to provide radiation boundary conditions, which absorb wave energy propagating out of the model area.

Figure 5.9 shows an example of sponge layers used to model a fully absorbing beach and to absorb waves radiating out of the model area.

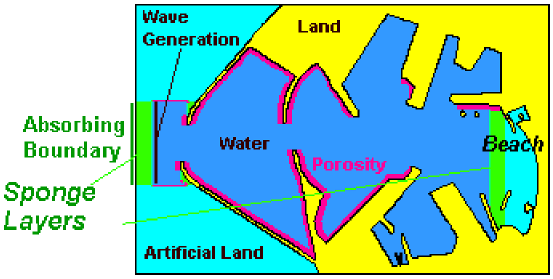


Figure 5.9 Example of sponge layer application

Specifying Sponge Layers

You can choose not to include sponge layers, or to specify the sponge layers by providing your model with a map of sponge layer coefficients, in much the same way as you specify friction values. The 2D map is read from a data file.

General guidelines for the preparation of this 2D map are as follows:

- very good absorbing characteristics are obtained for a sponge layer width of one to two times the wave length corresponding to the most energetic waves
- for typical short-wave studies (grid spacings of 3-6 m) the sponge layers should be at least 20 lines wide
- for 2D studies involving longer waves (e.g. harbour resonance studies) sponge layers may need to be 50 or even more grid lines wide
- the sponge layer coefficients at open water grid points should always be set to unity (i.e. sponge coefficient = 1.0)
- to minimise reflections, the values of the sponge layer coefficients should be close to unity along the first grid line, and should increase smoothly towards the boundary/land

Given the guidelines above, you are free to select your own values for the sponge layer (damping) coefficients.

Recommended Sponge Values

When selecting the sponge layer coefficients, the following formula has been found to work well:

$$C_{sponge} = a^{(r^{(i-1)})} \qquad ,i = 1,N_{sponge} \tag{5.8}$$

where a and r are assigned constant values, and N_{sponge} is the number of sponge lines (counting from the closed boundary towards the first grid line).

The implemented method is based on the sponge layer technique introduced by Larsen and Dancy (1983).

For twenty grid lines, it is recommended to use a= 7, and r=0.7. The sponge layer coefficients are then obtained by setting the value at the line closest to the closed boundary equal to a (the base value) and successively taking the square root for the subsequent points. The resulting values are shown in Table 5.1.

Table 5.1 Resulting values for 20 layers, using a=7 and r=0.7

Grid point	Sponge value
Land point	Land point
1	7
2	3.9045
3	2.5947
4	1.9492
5	1.5955
6	1.3868
7	1.2572
8	1.1738
9	1.1187
10	1.0816
11	1.0565
12	1.0392
13	1.0273
14	1.0190
15	1.0132
16	1.0092
17	1.0064
18	1.0045
19	1.0031

Table 5.1 Resulting values for 20 layers, using a=7 and r=0.7

Grid point	Sponge value
20	1.0022
Open water	1

Please note that the MIKE21 Toolbox include a tool for automatic generation of sponge layers.

Wave reflection

Wave reflection from e.g. structures, or a beach, can be modelled by applying friction values (less than 1) at the grid points representing the structures. If no friction values are specified, the reflection will be 100% from land points.

As the friction results in dissipation of energy, the reflection may be controlled by the friction values and the number of friction layers.

If the friction values are not backed up by land values, the friction layers will result in both reflection and transmission through the layers representing e.g. a permeable breakwater.

If no reflection is wanted, sponge layers should be applied - absorbing all wave energy entering the layers.

Transmission through structures

Transmission through porous structures are modelled by applying friction values at grid points representing the structures.

To determine the friction values and the number of friction layers to represent a given transmission coefficient the **MIKE21 Toolbox** tool **Calculation of Reflection Coefficients** should be used.

Friction layers

Friction values are used to model either partial reflection and/or transmission through structures. If friction values are backed up by land, partial reflection will take place. Conversely, (partial) transmission will also take place if the friction values are not backed up by land points.

You specify the friction values by a 2D map read from a data file.
General guidelines for the preparation of this 2D map are as follows:

- The friction values at open water grid points should be set to zero.

- The friction should only be set to a value different from zero along structures where you want to include the dissipation effect of porous flow.
- The friction layer should normally be 3-5 or more grid points wide.
- The water depth in the friction layer should be almost uniform, and should be set to the water depth at the front of the structure.
- For impermeable structures, the friction layer should be backed by an impermeable land grid point.

Figure 5.10 shows an example where friction layers are applied to model partial reflection.

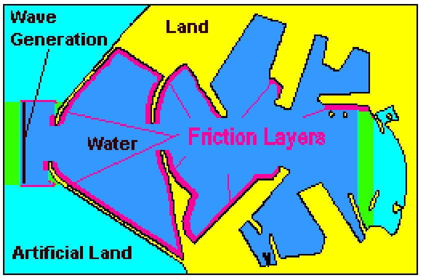


Figure 5.10 Example of applied friction layers

When determining the parameters to be used in your simulation, the values of the porous flow parameters are not that important. Unless you have a specific reason for using other values, these parameters can usually be left at their default values, which are:

- Kinematic viscosity: $1.4 \cdot 10^{-6}$ m^2/s
- Stone diameter: 0.2 m
- Laminar resistance parameter: 1000
- Turbulent resistance parameter: 2.8

For a given set of porous flow parameters (see above), the friction values required to obtain a desired reflection coefficient, can be determined by the use of the **MIKE21 Toolbox** program **Calculation of Reflection Coefficients**.

Wave breaking

Wave breaking is the process by which waves loose (dissipate) energy when the waves have grown too steep (i.e. reach a limiting steepness) and therefore become unstable, or when the waves are too high to be supported by the water depth (i.e. reaches a limiting H/d).

The formulation in MIKE 21 EMS of wave breaking due to large wave steepness and limiting water depth is based on the formulation of energy dissipation by Battjes and Janssen (1978):

$$\frac{dE}{dt} = \frac{\alpha}{8\pi} Q_b \omega H_{max}^2 \tag{5.9}$$

where H_{max} is the maximum allowable waveheight

$$H_{max} = \frac{\gamma_1}{k} \tanh\left(\frac{\gamma_2}{\gamma_1} kh\right) \tag{5.10}$$

and Q_b is the fraction of breaking waves determined by

$$\frac{1 - Q_b}{\ln(Q_b)} = -\left(\frac{H_{rms}}{H_{max}}\right)^2 \tag{5.11}$$

γ_1 and γ_2 are the two wave breaking parameters. γ_1 controls the steepness condition and γ_2 controls the limiting water depth condition.

In the equations T is the wave period, k is the wave number, d is the water depth and H_{rms} is the rms value of the wave height.

α is fixed to one in MIKE 21 EMS.

Bed friction

Bed friction is the process by which the wave looses (dissipates) some of its energy. The amount of energy dissipated increases with distance, wave height, wave period and decreasing water depth.

The formulation in MIKE 21 EMS of dissipation of energy due to bed friction is based on the quadratic friction law.

Monochromatic waves

For monochromatic waves the energy dissipation is:

$$\frac{dE}{dt} = \frac{1}{6\pi} \frac{f_e/2}{g} \left(\frac{\omega H}{\sinh(kh)}\right)^3 \tag{5.12}$$

in which f_e is a wave energy loss factor, ω is the angular frequency, k is the wave number, h is the water depth and H is the wave height.

Rayleigh distributed wave heights

In the situation of Rayleigh distributed wave heights the energy dissipation is (Dingemans, 1983):

$$\frac{dE}{dt} = -\frac{1}{8\sqrt{\pi}}\frac{f_e/2}{g}\left(\frac{\omega H_{rms}}{\sinh(kh)}\right)^3 \tag{5.13}$$

in which H_{rms} is the rms-value of the wave height.

The wave energy loss factor, f_e, can be specified as a function of the Nikuradse roughness parameter, k_N, by the empirical expression (Swart, 1974):

$$\begin{aligned} f_e &= 0.25 \qquad a_b/k_n < 2 \\ f_e &= \exp\left(-5.977 + 5.213\left(\frac{a_b}{k_n}\right)^{-0.194}\right) \qquad a_b/k_n \geq 2 \end{aligned} \tag{5.14}$$

Here a_b is the amplitude of the particle motion at the bed. You can use DHI's linear wave calculator to find typical wave characteristics.

Specifying the friction coefficient

The wave friction coefficient is specified as a constant for the entire model area.

Recommended values

Battjes and Janssen used the following values for the wave breaking parameters:

$$\gamma_1 = 0.88 \text{ and } \gamma_2 = 0.80 \tag{5.15}$$

The dissipation of energy due to wave breaking of steep waves is controlled by the parameter γ_1. By increasing the value of γ_1 this dissipation can be reduced. In MIKE 21 EMS the default value for γ_1 is 1.0 while for γ_2 the default value is as specified by Battjes and Janssen. The value for γ_1 was suggested by Holthuijsen et al. (1989).

Battjes and Stive (1985) found an expression for 2 by calibrating the dissipation model against measurements. They obtained:

$$\gamma_2 = 0.5 + 0.4\tanh(33 S_0) \tag{5.16}$$

where S_0 is the deep water wave steepness calculated as $H_{rms,0}/L_{0p}$ using

$$L_{0p} = \frac{gT_p^2}{2\pi} \tag{5.17}$$

IMPORTANT NOTE: The use of the Battjes and Janssen formulation implies the assumption of an irregular wave train, with a truncated Rayleigh distribution for wave heights. In such a distribution, the different waves break at different locations resulting in a "smoothed" rate of energy dissipation. This is in contrast with the behaviour of pure regular (monochromatic) waves in which there is a clear breaking point where the waves break. Hence, MIKE 21 EMS should not be used for investigating wave decay in pure regular waves.

When you include the wave breaking facility in your MIKE 21 EMS simulation it is for simulating the case of irregular waves where the wave climate is parameterised as H_{rms}, T_p. In this case, the specified wave height, H, and period, T, for the regular waves must correspond to H_{rms} and T_p, respectively.

5.3.2 Wave input

The boundary wave conditions to MIKE 21 EMS consist of specifying the waves entering the model area of interest. The time harmonic waves are generated internally inside the model boundaries (all boundary points must be land points) using a source term in the mass equation.

Wave height

Generally the wave heights appearing in MIKE 21 EMS (input and output) are relative wave heights (scaling factors) due to the linearity of the wave model (regular waves).

In simulations where either wave breaking and/or bed friction is included, the wave height is absolute and specified as H_{rms} (in meters as default).

Wave period

Generally the wave period correspond to the period of a regular wave.

In simulations where either wave breaking and/or bed friction is included, the wave period corresponds to the period of most energetic waves, e.g. the spectral peak period T_p.

Generation lines

The boundary wave conditions are specified using internal wave generation. The position of the generated waves is determined by specification of two parallel lines (starting and ending points).

Internal wave generation

Internal generation of waves is performed by adding the discharge of the incident wave field along the specified generation line. One of the advantages of using internal generation is that sponge layers can be placed behind the generation line, to absorb waves leaving the model area.

Note that the added amount of water will propagate in two opposite directions, hence only half of the specified wave energy will enter the area of interest. Therefore, two parallel generation lines should be specified in order to obtain an incoming wave as specified.

Set-up of Internal Generation Lines

The positions of the internal generation line and combined sponge layers are dependent upon the incoming wave conditions - especially the wave direction.

The position of the generated waves is determined by specification of two parallel lines (starting and ending points).

Note that the added amount of water will propagate in two opposite directions, hence only half of the specified wave energy will enter the area of interest. Therefore, two parallel generation lines should be specified in order to obtain an incoming wave as specified.

The generation lines can either be parallel to one of the axes of the computational grid or orientated with an angle to the grid.

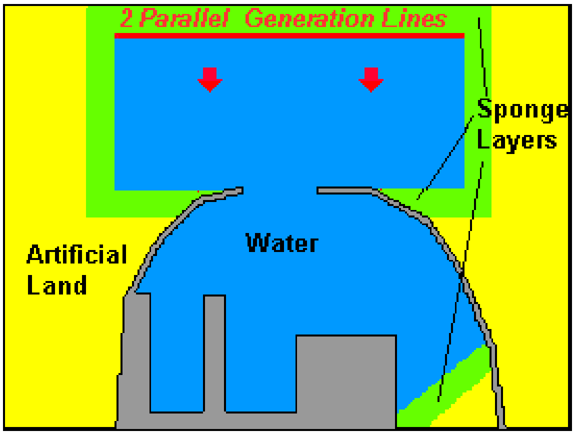


Figure 5.11 Example of model setup

The correct generation of the incident wave conditions can only be obtained on the assumption that the water depth is constant along the open boundary or the internal generation line. Therefore, the internal generation lines should be placed in areas where there is no or only a small variation in the water depth.

5.4 Output Parameters

The basic result from MIKE 21 EMS consist of a two-dimensional map containing the steady state wave height (relative or absolute) in all grid points. Following parameters are saved as steady state output:

- Wave heights
- Depth-averaged particle velocities
- Surface elevation

The temporary solution (wave height) during iteration can be saved in different output areas within the full area of your model. These areas can overlap, include a part of the model or include the whole model area.

As an option, the MIKE 21 EMS can provide maps of radiation stresses on the steady state wave field. Since the radiation stresses are caused by wave breaking, this option is only possible if wave breaking is specified.

5.4.1 Result

The basic results from MIKE 21 EMS consist of two-dimensional arrays containing the wave height (relative or absolute) in all grid points.

The temporary solution during iteration can be saved in different output areas within the full area of your model. These areas can overlap, include a part of the model or include the whole model area.

5.4.2 Steady state

Besides the temporary solutions, the steady state wave heights (relative or absolute), depth-averaged particle velocity and surface elevation can be saved as a separate output area.

Particle velocity

General description

From the pseudo fluxes P and Q introduced in the mild-slope equation, it is possible to determine the depth-averaged particle velocity components of the wave motion, u and v, as:

$$u = U_R \cdot \cos\omega t - U_I \cdot \sin\omega t$$
$$v = V_R \cdot \cos\omega t - V_I \cdot \sin\omega t$$

where

U_R = Real (P)/d · c/cg
V_R = Real (Q)/d · c/cg
U_I = Imag (P)/d · c/cg
V_I = Imag (Q)/d · c/cg

Here d is the water depth, c is the wave celerity and c_g is the group celerity.

Output from the model

2D maps of U_R, V_R, U_I and V_I are stored in the steady state output data file together with the calculated wave heights and elevations (only if automatic selection of Time step is applied).

The four scalars can be plotted as vectors [(U_R, V_R) or (U_I, V_I)] to illustrate particle velocities at two different instants during the wave period ($\omega t = 0$ or $\omega t = 3n/2$).

Generally the unit of the particle velocity is (1/s) due to the linearity of the wave model. In simulations where Wave breaking and/or Bed friction is applied, the particle velocity is absolute (in m/s).

Vector plots of the instantaneous depth-averaged particle velocities are very suitable for visual detection of nodes and anti-nodes in studies of harbour resonance.

Surface elevation

General Description

From the complex form of the surface elevation introduced in the mild-slope equation it is possible to determine the surface elevation, s, as:

$$s = S_R \cdot \cos\omega t - S_I \cdot \sin\omega t \tag{5.18}$$

where *SR* = Real (S) and *SI* = Imag (S)

Output from the Model

2D maps of *SR* and *SI* are stored in the steady state output data file together with the calculated wave heights and particle velocities (only if automatic selection of Time step is applied).

The two scalars can be plotted as contour lines to illustrate surface elevations at two different instants during the wave period ($\omega t = 0$ or $\omega t = 3\pi/2$).

5.4.3 Radiation stresses

General description

When short waves approach the coast, refraction tends to align the wave fronts with the underlying contours. However, the waves will normally break at an angle with the coast, and the momentum of the breaking wave in connection with the mass transport of the waves will then generate a current parallel to the shoreline. This is called a *longshore current* (or a littoral current) and it is responsible for the development of many sandy coasts, since it transports the sediment along the coast, which is brought into suspension by the particle motion near the bed in the surf zone.

The generation of the longshore current can be described by a net stress, the so-called radiation stress, in the momentum equation. In the simple case of monochromatic progressive waves the radiation stress can be expressed as a function of the wave height, the wave number and the water depth:

$$S = \frac{1}{16}\rho g H^2 (1 + 2G) \tag{5.19}$$

where:

$$G = \frac{2kd}{\sinh(kd)} \tag{5.20}$$

Here *k* is the wave number and *d* is water depth.

In MIKE 21 EMS the calculation of the radiation stress is much more complicated due to the possible reflections from breakwaters. The method used is based on Copeland (1985) where the calculation of the radiation stresses from a linear progressive wave plus an arbitrarily reflected or back-scattered wave is based on the surface elevation and the two pseudo fluxes, which are the dependent variables in the MIKE 21 EMS equations.

Output from the model

In MIKE 21 EMS simulations where wave breaking is applied, it is possible to specify the calculated steady state radiation stresses (the three components S_{xx}, S_{xy} and S_{yy}) as output in a separate type 2 data file. This file can later on be used as input to the hydrodynamic module, MIKE 21 Flow Model, for the simulation of longshore currents.

5.5 Execution

When simulating MIKE 21 EMS you typically launch the setup from the user interface. It is however also possible to launch a setup in Batch mode.

In both cases a Log file is generated.

5.5.1 Batch mode

If you have a number of runs to be executed in a row you might run the model setups in batch mode. The procedure is as follows:

- prepare your specification files (PFS-files) for your runs, ie. files with extension .ems.
- prepare a runEMS.bat file (the filename needs to have the extension .bat) in a text editor. The bat-file should include the following line for each specification file (for Release 2016, 64 bit installation):
  start /wait c:\”Program Files (x86)”\DHI\2016\bin\x64\MzLaunch.exe *filename***.ems**.
- Execute runEMS.bat in a command-prompt or simple click on the text file in your windows file manager.

Following this procedure your runs will be executed in a row as described in the runEMS.bat file.

Batch execution can also be initiated using the Launch Simulation Engine that can be accessed from the Start menu.

5.5.2 Log file

The log output (ASCII) file has the same name as the input file, but the suffix is “.log”. This file contains a list of all the specifications used for the execution, plus information about the input data and the output data.

6 Scientific Documentation

Scientific documentation for MIKE 21 EMS can be accessed online via the Documentation index.

The references listed below provide you with more basic information applicable to the MIKE 21 EMS wave module.

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