MIKE 21 PMS

Parabolic Mild-Slope Wave Module

User Guide

The expert in **WATER ENVIRONMENTS**

MIKE 2017

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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 parabolic, linear refraction/diffraction wave module of MIKE 21, MIKE 21 PMS, for applications involving the propagation and transformation of short-period and short-crested waves in nearshore areas. 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 PMS 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 PMS although a formal procedure is no substitute for common sense.

Section 4, EXAMPLES, describes a simple MIKE 21 PMS application in order to get you started. The “what key to press” procedure for this example is described in detail.

In addition to this simple example, more complicated examples are given. These are chosen to cover typical application areas of MIKE 21 PMS. The emphasis in these examples is on how the parameters are selected and how the results are presented.

Section 5, REFERENCE MANUAL, describes the parameters in the MIKE 21 PMS dialogues. It provides more details on specific aspects of the operation of MIKE 21 PMS 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 REFERENCES, you can find information on the scientific background for MIKE 21 PMS and a reference list.

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

1.2 Assumed User Background

Although MIKE 21 PMS has been designed carefully with emphasis on a logical and user-friendly interface, and although the 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 problems which is sufficient for you to be able to check whether the results from MIKE 21 PMS 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

MIKE 21 PMS is a linear refraction-diffraction model based on a parabolic approximation to the elliptic mild slope equation. The model takes into account the effects of refraction and shoaling due to varying depth, diffraction along the perpendicular to the predominant wave direction and energy dissipation due to bottom friction and wave breaking. The model also takes into account the effect of frequency and directional spreading using linear superposition.

MIKE 21 PMS is based on a parabolic approximation to the elliptic mild slope equation. Several parabolic approximations are implemented in MIKE 21 PMS ranging from the Simple approximation valid for small angles to the more sophisticated approximations valid for large wave angles (up to, say, +/-60°). The parabolic equation is solved using the Crank-Nicholson finite difference scheme.

The basic output data from the model are integral wave parameters such as the root mean square wave height, the peak wave period and the mean wave direction. Other output data that can be obtained from the model are radiation stresses and instantaneous surface elevations.

2.1.1 Application Areas

MIKE 21 PMS can be applied to the study of wave disturbance in open coastal areas and for computing wave fields in coastal areas with structures (e.g. groynes, detached breakwaters) when back-scatter (reflection into the incoming waves) can be neglected and diffraction is predominantly perpendicular to the main wave direction.

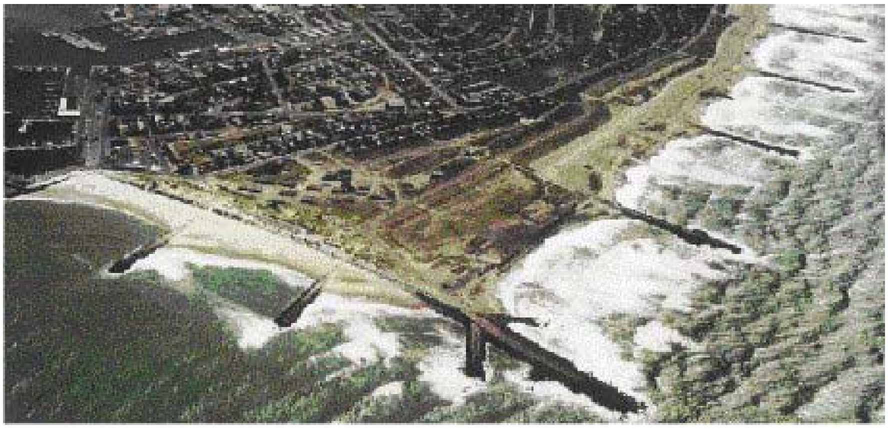


Figure 2.1 MIKE 21 PMS is often used for calculation of wave fields in coastal areas where structures like groynes and detached breakwaters are present

The assessment of wave conditions (i.e. wave heights, wave periods and wave directions) and wave-induced currents are essential for the calculation of sediment transport and erosion/deposition patterns in the coastal zone.

Wave conditions and radiation stresses (the driving forces for wave-induced currents) can be calculated using MIKE 21 PMS.

It should be noted that MIKE 21 PMS is a parabolic approximation to the elliptic mild slope equation governing the refraction and diffraction of linear waves over mildly sloping bathymetry. As in all parabolic approximations, MIKE 21 PMS does not include diffraction and reflection accurately (diffraction along the x-direction is neglected, back-scatter is neglected). Thus, it should NOT be used in harbour wave disturbance studies, where these effects can be very important. In general, it should not be used in studies where diffraction is the most important phenomenon of interest.

3 Getting Started

3.1 General

The purpose of this section is to give you a general check list which you can use when modelling applications involving the propagation and transformation of short-period waves in nearshore areas using the MIKE 21 Parabolic 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 blocking
  - Wave breaking
  - Wind generation
  - Frequency spreading
  - Directional spreading

  - Wave-wave interaction
  - Wave-current interaction

The MIKE 21 PMS module can handle these phenomena with the exception of diffraction along the predominant wave direction (diffraction along the perpendicular to the predominant wave direction is included), reflection into the incoming wave field, ie. back scatter (forward scatter is included), wave blocking, wind generation, non-linear wave-wave interaction and wave-current interaction.

Furthermore, it should be noted that frequency and directional spreading are included in MIKE 21 PMS using the principle of linear superposition.

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

3.2.2 Check MIKE 21 PMS capabilities

Next, check if the MIKE 21 Parabolic Mild Slope module is able to solve your problem. This you can do by turning to Section 2 which gives a short description of MIKE 21 PMS and an overview of the type of applications for which MIKE 21 PMS 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.

When deciding on your model area you have to consider the alignment of the grid to the dominant direction of wave propagation in the model area. You also have to consider the *Boundary Conditions*. Guidelines for *Selecting the Model Area* are given under *Bathymetry*.

The choice of the grid spacing in the x-y plane depends on the wave conditions for which simulations are to be performed, and on the bathymetry in the area of interest:

- the grid spacings, Δx, Δy must be selected to provide adequate resolution of the bathymetry
- the grid spacings must also be selected to provide adequate resolution of the wave field under consideration. A minimum of 5-7 grid points per wave length is recommended

In practice, the choice of the grid spacing is often a compromise between low computer costs and storage requirements and high accuracy.

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 for the output should be estimated

This can be done by running a test simulation. Please also refer to section 5.5.2 and 5.5.3.

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.

- boundary data, which can be measurements (existing or planned specifically for your model), observations etc.

- information on the bottom friction.

- calibration and validation data; these can be measured wave parameters at selected locations, eg root mean square wave height, peak wave period and mean wave direction.

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 PMS. 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 dfs2 data file containing the water depths for the model area. Describing the water depths 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

Depending on which combination of boundary input you are going to use (see *Boundary Conditions*) you have to prepare one of the following types of data for the the offshore boundary ("model west"):

- wave parameters describing the wave conditions (stationary simulation)
- a dfs0 data file containing wave conditions as it varies with time. It should be noted that MIKE 21 PMS uses the wave conditions for each time step to compute the steady state nearshore wave distribution for that time step
- a dfs2 data file containing the distribution of wave energy with frequency and direction at the boundary. It may have one or several time steps. This file should be created using the MIKE 21 Tool: Generate Wave Energy Spectrum

For the lateral boundaries ("model north" and "south"), you will have to choose one of the following types of boundary conditions:

- Reflecting. This condition ensures that any incident wave at the boundary is perfectly reflected. Note that only forward scattering is included in the model.
- Absorbing. This condition ensures that the incident waves at the boundary are fully absorbed. At the outflow lateral boundary, incident waves propagate out of the model without any reflection, while at the inflow lateral boundary no waves can propagate into the model area
- Symmetrical. This condition ensures that the gradient of the wave conditions across the lateral boundary is zero. Basically, this is synonymous with assuming that the contours are locally straight and parallel near the boundary. Recommended for most applications.

3.4.4 Bottom friction coefficients

The bottom friction can be specified either as a friction factor or as a Nikuradse roughness parameter (see *Bottom Dissipation*). In both cases the values can be given either as a constant for the entire model area or as a dfs2 data file (two-dimensional map).

3.4.5 Wave breaking

Wave breaking is modelled using the Battjes & Janssen formulation (see *Wave Breaking* and the reference list in Section 6). You specify the parameters α, γ_1 and γ_2.

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.

3.5.2 Calibration and verification situations

The situations that 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 situations from which to choose.

3.5.3 Calibration factors

When you run your calibration simulation 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 factor in the calibration is the accuracy of the data. Hence, in order to reduce the differences, you may have to change the basic model specifications listed in section 3.4. The bottom friction coefficient is the basic calibration parameter.

An increase of the bottom friction coefficient in shallow water depths usually leads to increased energy dissipation and thus decreased wave heights. The converse is also the case. In deeper waters, the effect of bottom friction will be negligible since the wave will not feel the bottom.

You may also use the parameters for wave breaking as calibration parameters, however you should be careful in tuning these parameters. The parameter α controls the rate of energy dissipation after breaking, γ_1 controls the amount of steepness related breaking, while γ_2 controls the amount of depth related breaking. An increase in α increases the rate of energy dissipation. In contrast, an increase in γ_1 reduces the amount of steepness related breaking. Likewise, increasing γ_2 reduces the amount of depth-related wave breaking.

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.

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 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, eg significant wave heights and mean wave periods and in form of vector plots showing mean wave directions.

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 this or that parameter is changed.

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

Refraction and Shoaling test:
.\Examples\MIKE_21\PMS\plane-NB

Detached Breakwater:
.\Examples\MIKE_21\PMS\dbw

Lawit Shore Approach:
.\Examples\MIKE_21\PMS\lawit

Port Entrance Channel:
.\Examples\MIKE_21\PMS\gulfch

Port Extension:
.\Examples\MIKE_21\PMS\port

Demo:
.\Examples\MIKE_21\PMS\demo

4.2 A Simple Example: Refraction and Shoaling Test

4.2.1 Purpose

The purpose of the present section is to guide you through the first example of a very simple MIKE 21 PMS application.

Please note that, in this section, words shown in **boldface** correspond to input you have to type at your keyboard or to an item on a dialogue.

4.2.2 Defining the problem

This first example has been chosen as a fairly simple one, so that it is possible to check the results analytically.

The problem is:

- the refraction and shoaling of regular wave trains propagating onto a plane beach
- The test conditions are:
- the model area is 400 m perpendicular to the beach and 2000 m along the beach. The beach has a constant slope of 1:20
- at the upwave boundary the significant wave height is 1 m and the mean wave period is 7 s. The direction of wave approach is 260° N (coming from). The model orientation is 0° N. Thus, the angle between the mean wave direction and the x-axis is 10°

Additional information required by MIKE 21 PMS are:

- the grid spacing is selected to be 4 m

4.2.3 Setting up the model

You start MIKE 21 PMS by selecting **File** -> **New** in the MIKE Zero environment. A dialogue box appears (Figure 4.1). You then select **MIKE 21** and a list of MIKE 21 modules appears as shown in the figure. MIKE 21 PMS is the **Parabolic Mild-slope Waves** module. It can be selected by either double-clicking the name or pressing OK after high-lighting it.

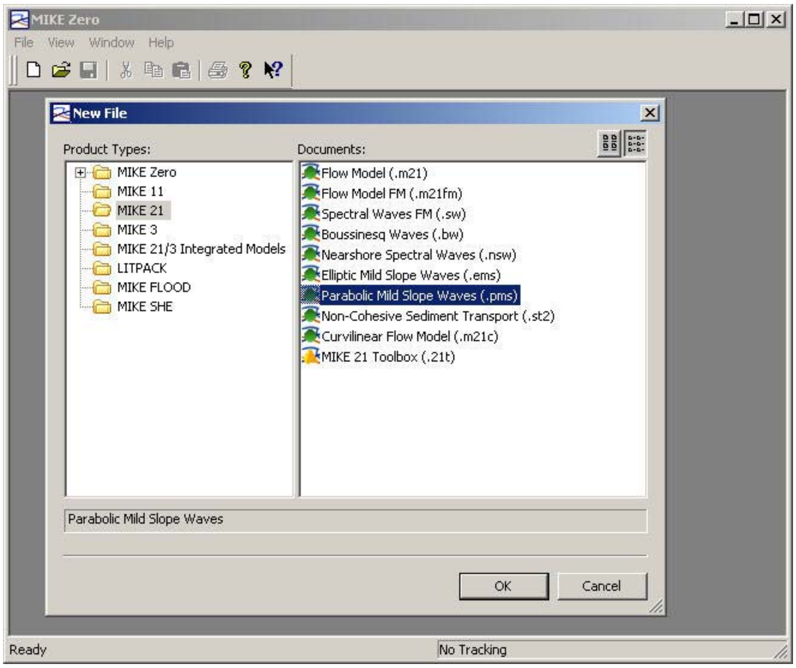
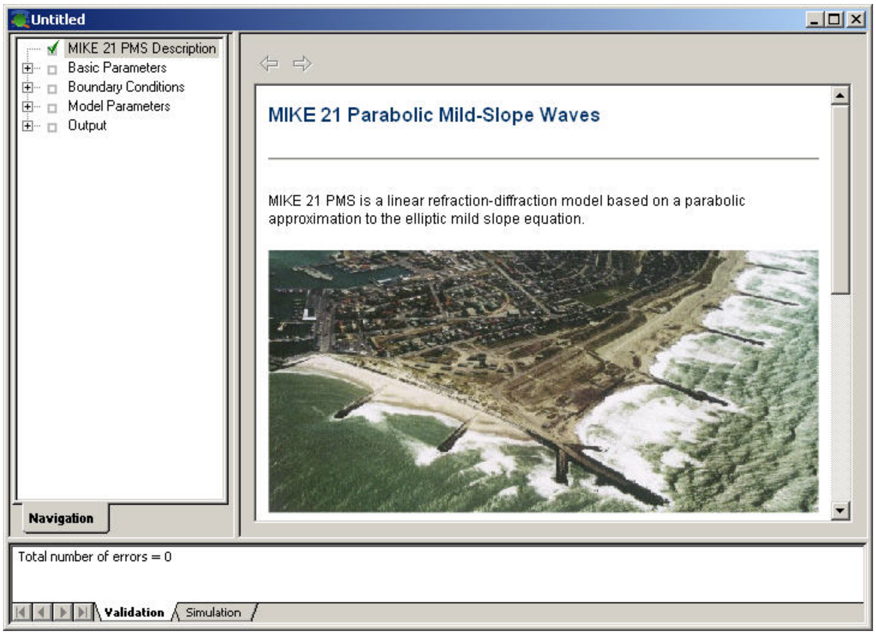


Figure 4.1 Starting the MIKE 21 PMS editor from the MIKE Zero environment

You are then presented with the following start-up page for the MIKE 21 PMS editor (Figure 4.2).



MIKE 21 Parabolic Mild-Slope Waves

MIKE 21 PMS is a linear refraction-diffraction model based on a parabolic approximation to the elliptic mild slope equation.

Total number of errors = 0

Figure 4.2 MIKE 21 PMS editor

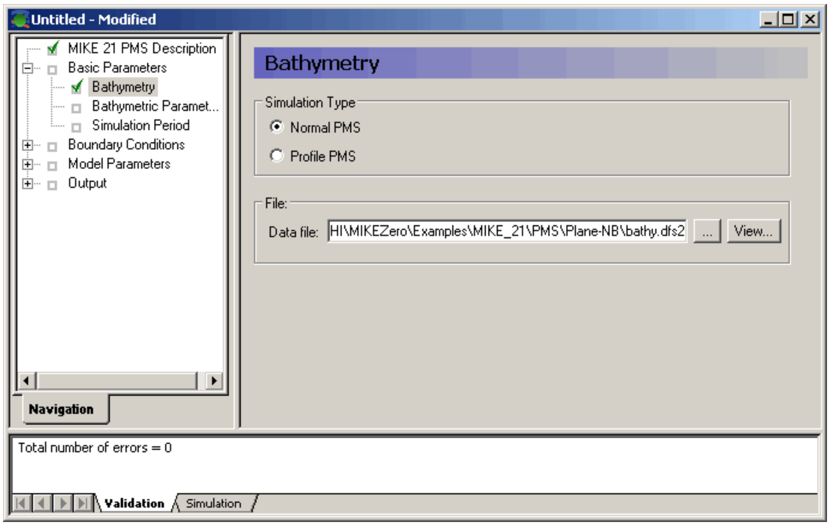
To get help for the items on the dialogue pages you are working with, you can press **F1** at any time.

The MIKE 21 PMS parameters are grouped under four main headings:

- Basic Parameters
- Boundary Conditions
- Model Parameters
- Output

For each one, a description of the contents is given to the right while the actual parameters are entered on sub-dialogues.

First, you must select the type of MIKE 21 PMS simulation and the bathymetry to work with. This is done on the **Bathymetry** dialogue page, see 4.3. For this example you select **Normal PMS**. Then the path to the bathymetry file (a dfs2 file for a normal PMS simulation) must be specified. For the present example, the bathymetry **bathy.dfs2** is included with the installation in the subfolder **plane-NB** as explained in Section 4.1.



Simulation Type

● Normal PMS

○ Profile PMS

File:

Data file: HI\MIKEZero\Examples\MIKE_21\PMS\Plane-NB\bathy.dfs2

Total number of errors = 0

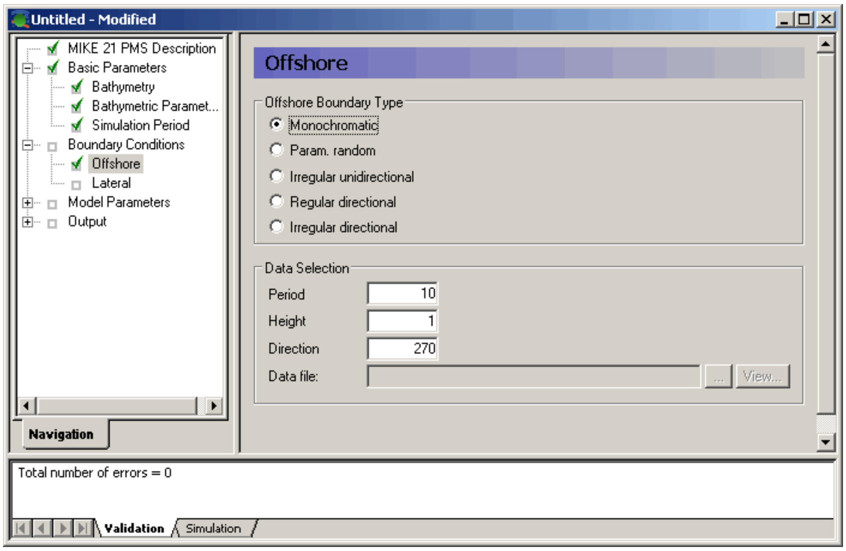
Figure 4.3 Selecting the bathymetry to work with and the type of simulation

The next dialogue **Bathymetric Parameters** shows the origin of the bathymetry (latitude, longitude), the orientation of the bathymetry and the value representing land. These parameters are taken from the specifications given in the bathymetry file and can not be changed.

The final dialogue page under the **Basic Parameters** heading is the **Simulation Period** page. When specifying the **Time Description**, you can either specify **Stationary** or **Quasi-stationary** simulation. **Stationary** is used if you are simulating only one wave event corresponding to one offshore wave boundary condition, while **Quasi-stationary** should be used if you are simulating several sets of wave events corresponding to a time series of offshore wave boundary conditions.

For a stationary simulation you specify the **Simulation start time**, which is the calendar time for the situation you are going to simulate given as day/month/year and time. For a **Quasi-stationary** simulation you also specify the **Time step interval** (in seconds) and the **Number of time steps**. For this example, you can use the defaults for all specifications on this dialogue.

You then proceed to **Boundary Conditions**. In order to specify the boundary wave conditions at the offshore, upwave boundary (i.e. along x = 0) you select **Offshore**. Here you can specify the type of wave climate (regular or irregular, unidirectional or directional), and the wave conditions. For this example, you select **Monochromatic** waves and specify the wave **period** to be 7 s, the wave **height** to be 1 m and the wave **direction** to be 260° (Figure 4.4).



Offshore Boundary Type
● Monochromatic
○ Param. random
○ Irregular unidirectional
○ Regular directional
○ Irregular directional

Data Selection
Period 10
Height 1
Direction 270

Total number of errors = 0

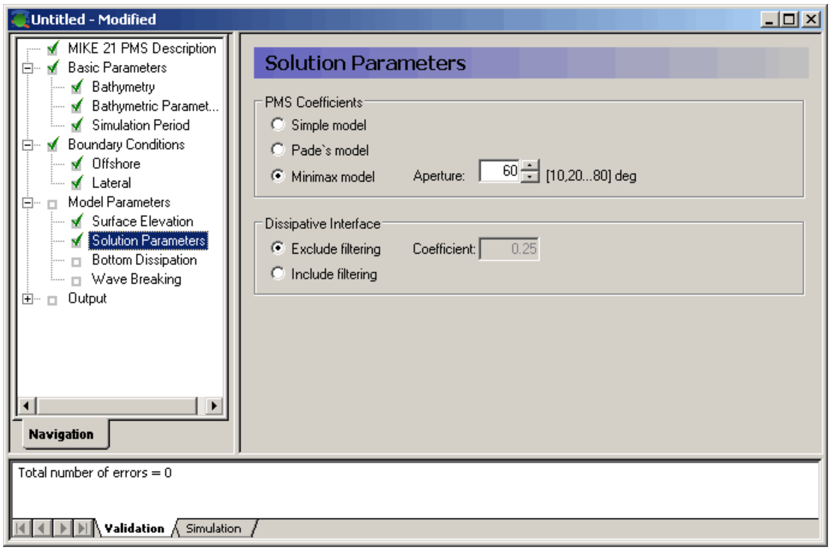
Figure 4.4 Specifying offshore boundary conditions

The next boundary condition dialogue is called **Lateral**. Here you specify boundary conditions at the lateral boundaries (model north and model south). For each lateral boundary, the boundary condition can be specified as **Symmetrical**, **Absorbing** or **Reflecting**. The physical meaning of these boundary conditions is explained under the entry *Lateral Boundary Conditions* in the On-line Help and in the Reference Manual (5.3.2 Lateral wave conditions *(p. 45)*). For this example you specify **Symmetrical** boundary conditions at both boundaries.

Now proceed to **Model Parameters**. This is where you select the physical specifications for your model. Here you can **Include** or exclude (by not including): **Bottom Dissipation** (wave energy dissipation due to bottom friction) and **Wave Breaking** (wave energy dissipation due to wave breaking). For this example you exclude wave breaking and bottom dissipation (the default) since this is only a refraction and shoaling test.

You can also specify the **Surface Elevation** and the **Solution Parameters** for the parabolic approximation under **Model Parameters**. On the **Surface Elevation** dialogue, you specify the surface water level relative to the reference level used in the bathymetry. Usually you will need to use this facility when carrying out simulations in e.g. tidal areas, in which case you specify the tidal water levels relative to the reference datum. This is not necessary for this example, so you accept the default.

On the **Solution Parameter** dialogue (Figure 4.5), you can select the type of parabolic approximation you want to use, and the dissipative interface. An explanation of the various types of parabolic approximations can be found in the Reference Manual (5.4.2 Solution parameters *(p. 46)*) and in the On-line Help. For this example, you should choose the defaults.



PMS Coefficients

○ Simple model

○ Pade`s model

● Minimax model   Aperture: 60 [10,20...80] deg

Dissipative Interface

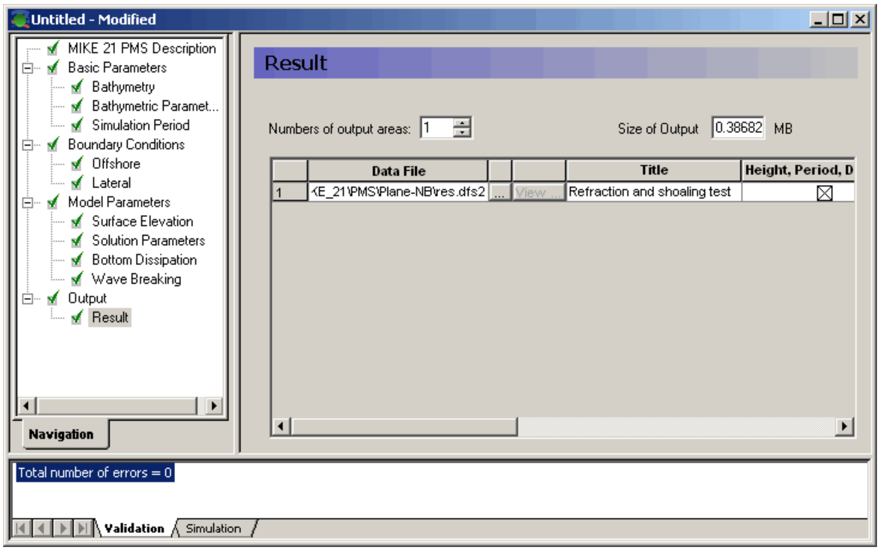
● Exclude filtering   Coefficient: 0.25

○ Include filtering

Total number of errors = 0

Figure 4.5 Specifying the Solution Parameters

Finally, you select the **Output** specifications. For this example, you specify the **Number of Output Areas** as 1 (Figure 4.6) and click the mouse just below the row of headings starting with **Data File**. You can now specify the name and path of the output **Data File** (specify the name as e.g. **res**), a descriptive title for the file (e.g. **Refraction and Shoaling Test**) and which parameters to output (to see them all, use the horizontal scroll bar). For these parameters, use the defaults.



Numbers of output areas: 1   Size of Output 0.38682 MB

	Data File			Title	Height, Period, D
1	<E_21\PMS\Plane-NB\res.dfs2	...	View ...	Refraction and shoaling test	☒

Total number of errors = 0

Figure 4.6 Specifying the output file name and the type of output

After finishing the model input, you select **File -> Save As**... and specify **plane-nb** as the file name.

4.2.4 Running the simulation

Finally, you can run the simulation by selecting **Run -> Start simulation**... from the MIKE Zero environment. When the simulation has finished (the time required will depend on your computer; a status window box is shown where the simulation can be followed) you should check the **plane-nb.log** file which is saved in the same folder as your **plane-nb.pms** specification file.

4.2.5 Presenting the results

In order to see the refraction and shoaling of the waves on the plane beach, you can extract and plot the values of the wave direction and the wave height, respectively, at a line perpendicular to the beach (for details on how to do this please refer to your MIKE 21 Short Introduction and Tutorial).

In Figure 4.7 the two line plots are shown. The model results are in very good agreement with the analytical solution.

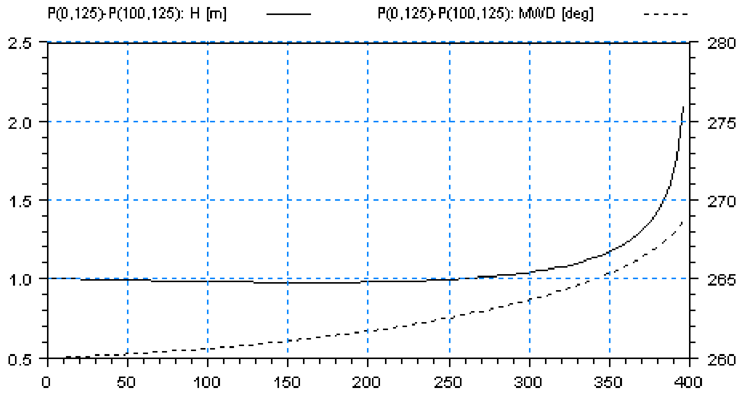


Figure 4.7 Wave parameters along a line perpendicular to the plane beach, wave height and wave direction

4.3 More Examples

4.3.1 Detached breakwater

Purpose of the study

The purpose of the study was to simulate the morphological evolution behind a single detached breakwater exposed to the action of waves. This study was part of a research project on Coastal Morphodynamics carried out at DHI. It involved the simulation of waves, wave-induced currents, sediment transport and bed level evolution.

For the study, several combinations of breakwater layouts, wave conditions and beach slopes were investigated. In this manual, one of the simulations for the wave field is included.

Defining and limiting the wave problem

The vertical breakwater is 300 m long and 40 m wide, with the wall facing the coast located at a distance of 280 m from the shoreline. The beach has a constant slope of 1:50. The model area extends 2100 m in the longshore direction and 700 m cross-shore direction.

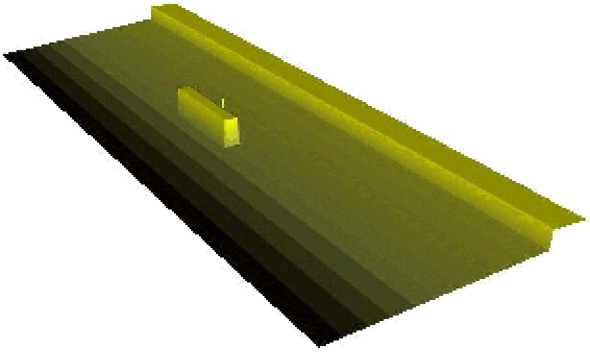


Figure 4.8 Bathymetry used in the MIKE 21 PMS detached breakwater example

The wave conditions at the offshore boundary (depth = 12 m) is specified as root mean square wave height H_{rms} = 1.98 m, peak wave period T_p = 8s, with the wave crests approaching parallel to the breakwater.

For this problem the effect of shoaling, refraction, diffraction, bottom dissipation and wave breaking are important. The effect of reflection from the breakwater is taken to be negligible, and since we are not interested in the waves immediately behind the breakwater where the parabolic approximation is inaccurate, the wave simulation was carried out using the parabolic mild slope module, MIKE 21 PMS.

Setting up the model

A grid spacing of 5 m is chosen in the x- and y-directions. This gives a resolution of 5 grid points per wave length at a water depth of 1 m.

At the two boundaries perpendicular to the shoreline (model north/south) the wave conditions are unknown beforehand. Therefore, symmetrical conditions (depth contours parallel to the y-axis) are applied there.

The bottom friction is specified using a constant Nikuradse roughness parameter of 1.5 mm, while the parameters in the Battjes & Janssen (1978) wave breaking formulation are specified as:

α = 1.0, γ_1 = 1.0, γ_2 = 0.8 (the default wave breaking option and values).

Presenting the results

The model results are presented as contours of root mean square wave heights, H_{rms} and wave direction vectors scaled by the wave height. The influence of wave breaking close to the shore is clearly evident, as well as the reduction of the heights behind the breakwater due to wave diffraction.

A good visual impression of refraction and diffraction can usually be obtained by plotting contours of instantaneous surface elevations, see 4.9.

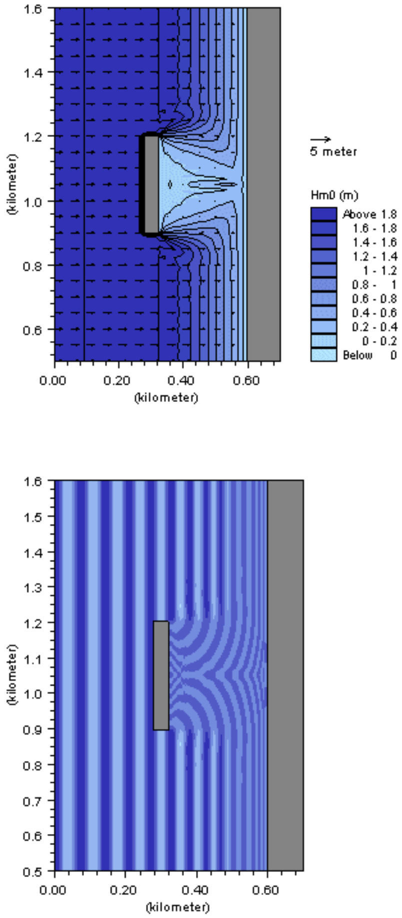


Figure 4.9 Examples of output from the detached breakwater example. Wave heights and directions (upper), instantaneous surface elevations (lower)

List of data and specification files

The following data file is supplied with MIKE 21 PMS:

Name:	Bathy.dfs2
Description:	Detached Breakwater Example, bathymetry

The following specification file was used for running the simulation:

File:	dbw.pms
Task	Model: MIKE 21 Parabolic Mild Slope
Description:	Detached breakwater simulation

Please note that in order not to overwrite the specification file, you should copy it over to your own working folder or rename it.

4.3.2 Lawit shore approach

Purpose of the study

The purpose of the study was to assess the changes in sediment transport due to the construction of new coastal structures (a detached breakwater and groyne field) in the Lawit area.

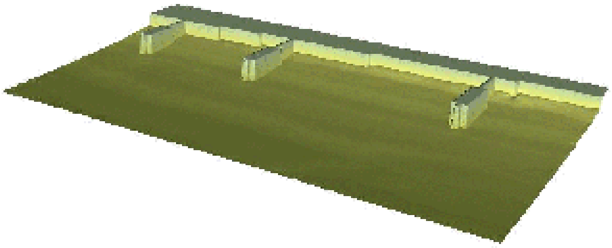


Figure 4.10 Bathymetry used in MIKE 21 PMS Lawit shore approach

The study area is located between the rocky headlands of Tg. Pelar and Tg. Batu Laut along the east coast of Peninsula Malaysia.

The study involved the simulation of waves, currents and sediment transport for a number of situations. In the study of the wave climate, a coarse grid MIKE 21 NSW model extending to “deep” water (depths greater than 60 m) was also used. Boundary wave conditions were extracted from these MIKE 21 NSW simulations for the detailed wave simulations using the MIKE 21 PMS module in the immediate study area. Here, a wave simulation for the area around the groyne field is presented.

The data used in this example has been deliberately changed from those used in the study.

Defining and limiting the wave problem

The wave conditions at the offshore boundary (model west boundary) is specified as: root mean square wave height H_{rms} = 2.0 m, peak wave period T_p = 9 s and a wave direction of 50°N (wave coming from).

Setting up the model

A grid spacing of 5 m is chosen in the x- and y-direction. This gives an adequate resolution of the wave length at the deepest location, down to a water depth of 0.6 m. Shoreward of this depth the resolution requirement can be relaxed since this is in an area of low wave heights due to dissipation.

At the offshore boundary, the offshore wave conditions are applied. At the lateral boundaries the wave conditions are unknown beforehand. Therefore symmetrical boundary conditions are applied there.

The bottom friction is specified using a constant Nikuradse roughness of 0.65 mm, while the default parameters for the Battjes & Janssen wave breaking formulation is used.

Presenting the results

The model results can be presented as contours of root mean square wave heights, H_{rms} and wave direction vectors scaled by the wave height.

A visual impression of refraction and, to a small extent, diffraction can be obtained by plotting contours of the instantaneous water levels.

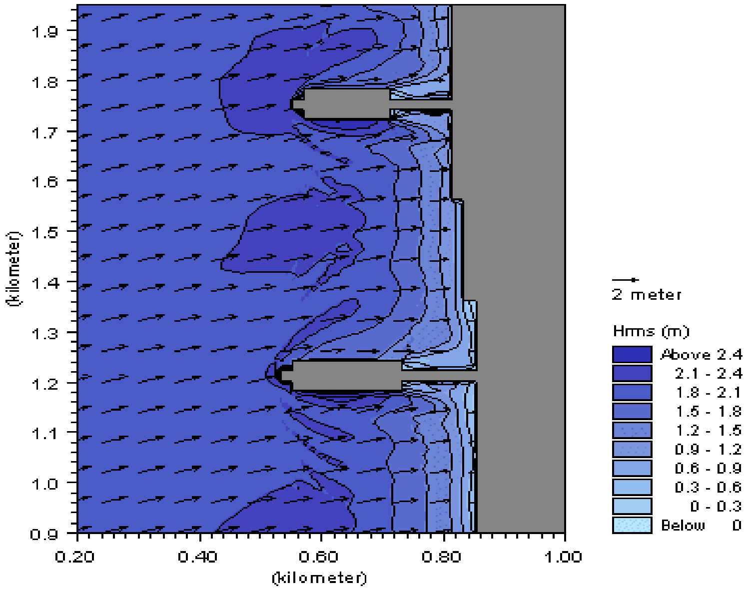


Figure 4.11 Model results, Lawit shore approach. The chart shows the computed wave field illustrated by mean wave direction and root-mean square wave height for a sub-area of the model domain

List of data and specification files

The following data file is supplied with MIKE 21 PMS:

Name:	Bathy.dfs2
Description:	Lawit shore Approach Example, bathymetry

The following specification file was used for running the simulation:

File:	Lawit.pms
Task:	Model: MIKE 21 Parabolic Mild Slope
Description:	Lawit shore approach simulation

Please note that in order not to overwrite the specification file, you should copy it over to your own working folder or rename it.

4.3.3 Port entrance channel in the Arabian Gulf

Purpose of the example

The purpose of this example is to illustrate the effect of an entrance channel on the incident wave climate at a harbour entrance.

The study area is the entrance channel to a major port in the Arabian Gulf.

Defining and limiting the wave problem

The wave conditions at the offshore boundary is specified as: significant wave height H_{m0} = 2.32 m, peak wave period T_p = 8.6 s and wave direction 110°N (coming from). It is required to assess the influence of frequency and directional spreading on the wave conditions at the harbour entrance. Thus, three wave simulations are investigated corresponding to three different wave conditions at the offshore boundary. These are:

1. Regular, unidirectional waves
2. Irregular (Pierson-Moskowitz (PM) spectrum), unidirectional waves
3. Irregular (PM spectrum), directional ($\cos^5$ directional spreading) waves.

Setting up the model

A grid spacing of 6 m is chosen in the x- and y-directions. This gives a resolution of 12 points per wave length (using the peak wave period) at the minimum water depth. This resolution is adequate.

At the offshore boundary the offshore wave conditions are applied. Note that the specification of the offshore wave conditions when using irregular waves and/or directional waves requires that the MIKE 21 Tool Generate Wave Energy Spectrum should be applied first to prepare the distribution of wave energy with frequency and direction.

A number of 10 discrete frequencies were used to represent the PM spectrum, with unequal frequency interval but equal energy content in each discrete frequency. The minimum frequency is 0.05 Hz, while the maximum frequency is 0.5 Hz. Similarly 10 discrete directions were used to represent the $\cos^5$ spreading function with constant interval between the discrete directions. The maximum deviation from the mean wave direction is specified as 20°.

At the lateral boundaries, the wave conditions are unknown beforehand. Therefore, symmetrical boundary conditions are applied there.

Note that breaking and bottom friction are not included in this example.

Presenting the results

The model results can be presented as contours of wave disturbance coefficients. The wave disturbance coefficients can be obtained using the Grid Editor to divide the calculated wave heights in the entire area by the incident wave heights. Alternatively, since only linear processes are considered (breaking and bottom dissipation not included), the wave disturbance coefficients can be calculated directly by specifying an incident wave height of unity (1). The model results can also be presented as map of surface elevations as shown in Figure 4.12.

The results compare favourably with computations using the Boussinesq wave model, MIKE 21 BW.

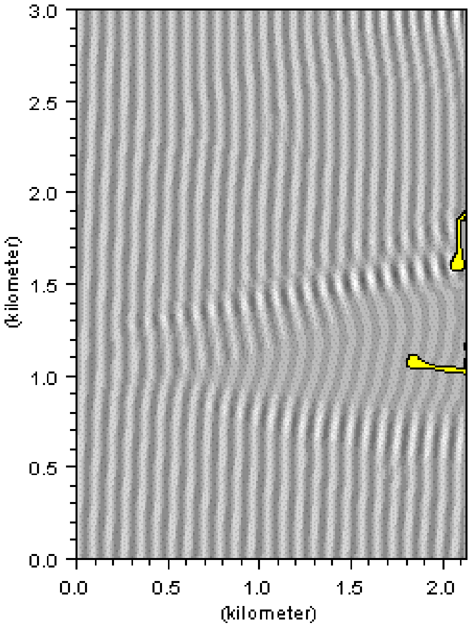


Figure 4.12 Model results, Port Entrance example. The chart shows contours of instantaneous surface elevations in case of regular, uni-directional waves

A strong concentration of wave energy can be noticed on the southern bank of the channel. This is due to the refraction effect of the entrance channel. This focussing phenomenon leads to reduced wave disturbance at the harbour entrance. The effect of including frequency spreading and directional spreading is to decrease the amount of wave disturbance at the channel banks, and increase the wave agitation at the entrance.

List of data and specification files

The following data file is supplied with MIKE 21 PMS:

Name: Bathy.dfs2
Description: Entrance channel in the Arabian Gulf

The following specification files were used for running the simulations:

1. Regular (monochromatic), unidirectional waves at the offshore boundary

   File: mnuni.pms
   Task: Model: MIKE 21 Parabolic Mild Slope

2. Irregular (PM spectrum), unidirectional waves at the offshore boundary

   File: gulfch.21t
   Task: MIKE 21 Tool Generate Wave Energy Spectrum
   Description: Specs. for calculating energy distribution

   File: pmuni.pms
   Task: Model: MIKE 21 Parabolic Mild Slope
   Description: Specs. for MIKE 21 PMS simulation

3. Irregular (PM spectrum), directional ($\cos^5$ spreading) waves at the offshore boundary

   File: gulfch.21t
   Task: MIKE21 Tool Generate Wave Energy Spectrum
   Description: Specs. for calculating energy distribution

   File: pmcos.pms
   Task: Model: MIKE 21 Parabolic Mild Slope
   Description: Specs. for MIKE21 PMS simulation

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

4.3.4 Port extension

Purpose of the study

The purpose of the study was to investigate the changes in sediment transport due to an extension of An-P'ing Port, Taiwan. Of special interest was the potential sedimentation outside the port entrance area and the long-term influence of the extended port on the shoreline stability. It should be noted that the example has been changed somewhat compared to the study. The

Institute for Harbours and Marine Technology (IHMT), Taiwan, has kindly made the wave study available for inclusion in this manual.

The study involved the simulation of waves, currents and sediment transport for a number of situations. The tide is modest, so the wave-induced currents were the main focus. Waves, currents and water levels were measured at a location not far from the existing port. Here, a wave simulation for the existing port layout is presented.

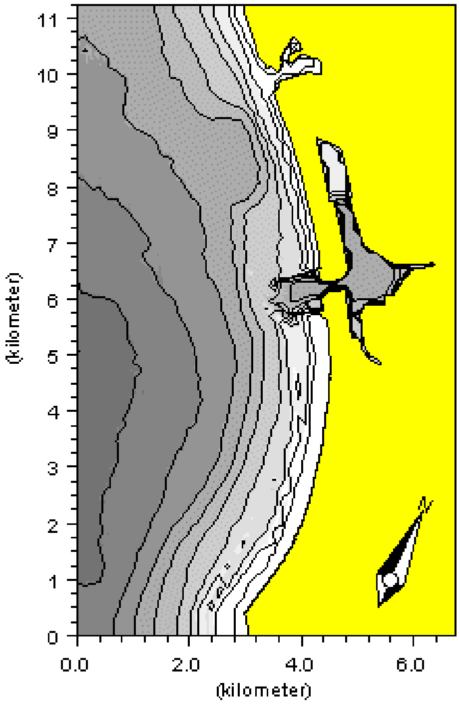


Figure 4.13 2D view of the model bathymetry for the existing port layout, An-P'ing Port, Taiwan

The application of the profile version of MIKE 21 PMS for calculating the radiation stresses at the lateral boundaries is also included . The output from the profile simulation is used in the next step of the study to help generating boundary conditions for the flow model (MIKE 21 NHD) that was used to calculate the wave-induced currents. In many cases the output created directly by the normal MIKE 21 PMS simulation contains small reflections at the two lateral boundaries that the MIKE 21 Tool Wave Generated Current and Setup does not handle well. See the Reference Manual (Remarks and hints *(p. 47)*) for more details on this problem

Defining and limiting the wave problem

At the offshore boundary, the significant wave height is 1.25 m, the peak wave period is 6.84 s and the mean wave direction is 280°. The simulation is carried out for a tidal cycle lasting approximately 24 hours. A shorter run time can be obtained by selecting fewer time steps in the simulation period.

The influence of frequency and directional spreading is included using a JONSWAP frequency spectrum and assuming a $\cos^6$ directional spreading.

Setting up the model

A grid spacing of 5 m in both directions is chosen. This gives an adequate resolution of the wave field and the bathymetry.

At the offshore boundary of the model the offshore wave conditions are applied. The MIKE 21 tool Generate Wave Energy Spectrum is applied first to prepare the distribution of wave energy with frequency and direction. A number of 10 discrete frequencies were used, with equal energy interval. The minimum and maximum frequencies are 0.05 Hz and 0.5 Hz, respectively. Similarly, 10 discrete directions are used to represent the $\cos^6$ spreading function with constant interval between directions.

At the lateral boundaries, the wave conditions are unknown beforehand so symmetrical boundary conditions are applied there. Note that the depth contours in the bathymetry are straightened out locally near these two boundaries to keep unwanted reflections at a minimum. This is generally recommended when using the radiation stress output to drive wave-induced currents in a flow model.

Default values are used for wave breaking and bottom friction. A dfs0 file with water level variations throughout the tidal cycle is specified under **Surface Elevation**. Output are specified at every two hours.

Presenting the results

The model results can be presented as contours of significant wave heights, H_{m0}, and wave direction vectors scaled by wave height. The results of the profile simulation can be shown as a line plot showing the variation of the significant wave height and the radiation stress component S_{xy} over the profile. In a case with straight and coast-parallel depth contours, it is the gradient of S_{xy} with respect to x that is the driving force behind the wave-induced currents.

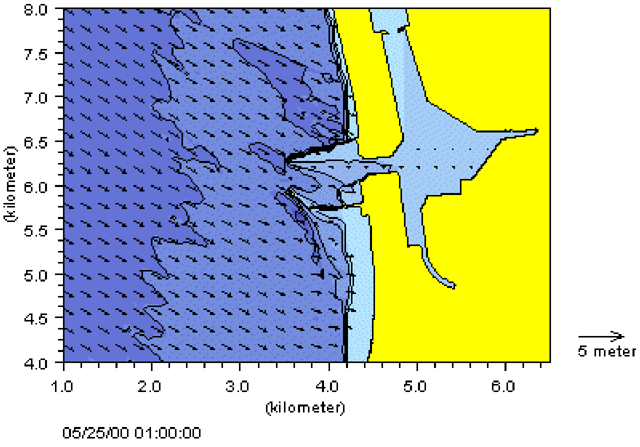


Figure 4.14 Model results for a subarea, 2D simulation. Significant wave height (contours) and mean wave directions (arrows)

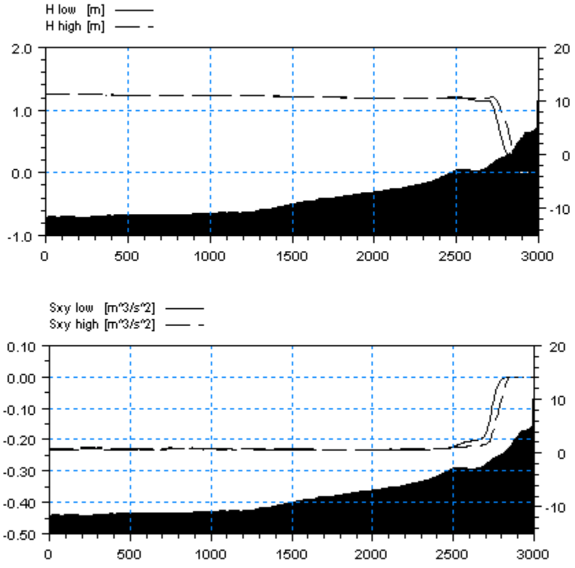


Figure 4.15 Model results, 1D simulation. Significant wave height (upper) and radiation stress component S_{xy} (lower) at low and high water level

List of data and specification files

The following data files (all within the folder of **port**) are supplied with MIKE 21:

Name: bathy.dfs2
Description: Bathymetry

Name: bathy-profN.dfs1
Description: Bathymetry, profile from model north boundary

Name: Tide_measured.dfs0
Description: Tidal water levels

The following specification files were used for running the simulations:

File: energyspectrum.21t
Task: MIKE 21 Tool Generate Wave Energy Spectrum
Description: specs. for calculating energy distribution

File: port-2D.pms
Task: Model: MIKE 21 PMS Parabolic Mild Slope Waves
Description: Port extension simulation, normal

File: profileextraction.tst
Task: MIKE Zero Toolbox, extraction, profile series from 2D series
Description: Extraction of boundary profile from 2D bathymetry

File: port-1D.pms
Task: Model: MIKE 21 PMS Parabolic Mild Slope Waves
Description: Port extension simulation, profile

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

4.3.5 Demo

This simple example simulating wave transformation across a uniform beach profile is designed for use when running MIKE 21 PMS in demo mode.

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

Name:	bathy.dfs2
Description:	Bathymetry

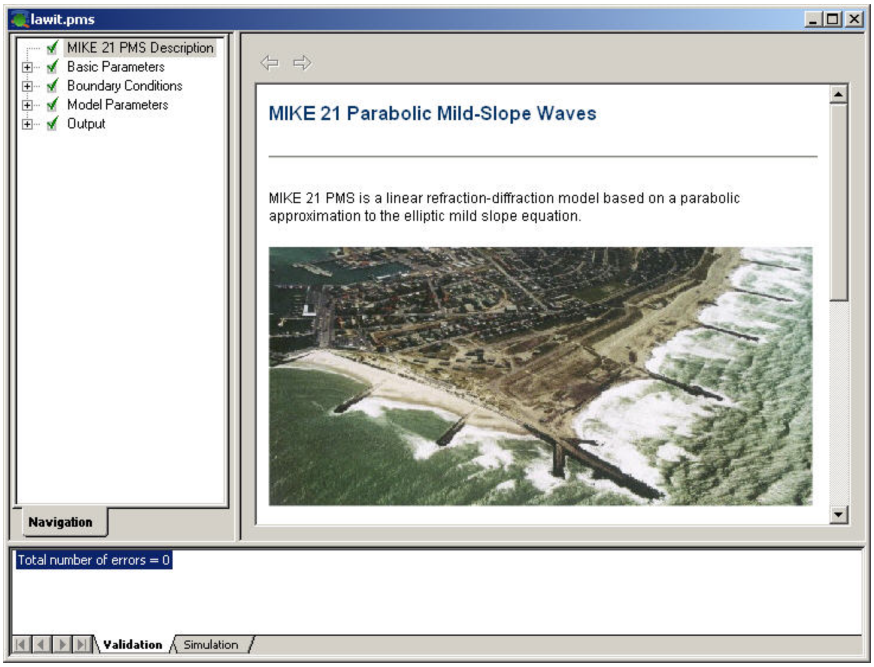
Name:	demo.pms
Task:	Model: MIKE 21 PMS Parabolic Mild Slope Waves
Description:	Demo simulation, wave transformation

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 the intention that you use this manual when you are doing model applications with MIKE 21 PMS 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 PMS editor (Figure 5.1).



MIKE 21 Parabolic Mild-Slope Waves

MIKE 21 PMS is a linear refraction-diffraction model based on a parabolic approximation to the elliptic mild slope equation.

Total number of errors = 0

Figure 5.1 MIKE 21 PMS editor

The Reference Manual entries are also available in the integrated On-line Help for MIKE 21 PMS.

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

5.2 Basic Parameters

In the Basic Parameters group you specify the type of MIKE 21 PMS simulation, the bathymetry and the simulation period for your simulation.

The MIKE 21 PMS model can be run in two modes, a normal mode (2DH) and a profile mode(1DH). The choice of simulation type decides the format of the bathymetry file.

5.2.1 Simulation type

The MIKE 21 PMS model can be run in two modes, a *normal* mode and a *profile* mode.

Normal

The normal mode corresponds to the normal, two-dimensional MIKE 21 PMS that you use to calculate wave and radiation stress fields in your model area.

Profile

The profile mode corresponds to a one-dimensional MIKE 21 PMS that has been developed to help the user generate lateral boundary conditions to the flow model (MIKE 21 NHD) for wave-driven current problems. You can of course also use it for other purposes, but it is *not* a substitute for a proper, two-dimensional wave simulation.

The output from the one-dimensional MIKE 21 PMS in terms of radiation stresses can be used directly as input to the MIKE 21 Tool for Wave Generated Current and Setup (WAVCUR) that is used to calculate boundary conditions to MIKE 21 NHD for wave-generated currents.

The profile version of MIKE 21 PMS is identical to the two-dimensional version of MIKE 21 PMS, but assuming completely uniform conditions in the model y-direction. It is very important that you use the same parameters for the profile set-up as for the corresponding two-dimensional set-up in order to ensure consistency between the two-dimensional radiation stress field and the lateral boundary conditions for the subsequent MIKE 21 NHD simulation.

5.2.2 Bathymetry

Providing MIKE 21 PMS with a suitable model bathymetry is essential for obtaining reliable results from your model. Setting up the bathymetry requires more than just specifying an array of accurate water depths covering the area of interest. It also includes the appropriate selection of the area to be modelled and the grid spacings.

You can use any convenient datum for setting up the bathymetry of your model. This can be Chart Datum, Lowest Astronomical Tide (LAT) or Mean Sea Level (MSL). The actual datum is unimportant. What is important is that for each simulation, you must provide the model with the correct height of the water level relative to the datum used in the setting up of your bathymetry. This is done on the Surface Elevation dialog page. The water level is positive when above your bathymetry datum. In this way it is possible to carry out simulations using a range of different water levels without having to alter the bathymetry.

The bathymetry is specified as a dfs2 file when running a normal simulation, or a dfs1 file when only running a profile simulation. The profile is usually extracted from the two-dimensional model bathymetry at the position of the lateral boundaries using the same grid spacing as for the two-dimensional bathymetry.

Selection of the model area

MIKE 21 PMS is a linear refraction-diffraction model based on a parabolic approximation to the elliptic mild slope equation. In making the parabolic approximation, a number of assumptions were made that limits the allowable angle between the x-axis and the direction of wave propagation to small wave angles (typically less than 10°).

Further improvements to the parabolic approximation method makes it possible to extend the angle between the x-axis and the direction of wave propagation to, say, ± 60°. This is the so-called wide-angle parabolic approximation. MIKE 21 PMS includes these wide-angle formulations, see section 5.4.2 Solution parameters *(p. 46)*.

Note: When using MIKE 21 PMS it is essential that the x-axis of the grid is aligned within a limited angle with the dominant direction of wave propagation in the model area (for definitions of wave direction, coordinate system, etc., see Figure 5.2). When more than one incident wave direction is being considered, it may be necessary to set up a separate bathymetry for each wave direction to be investigated.

In MIKE 21 PMS, boundary conditions in form of wave parameters must be specified for the incoming waves at the offshore wave boundary ($x = 0$). Typically, no information is available regarding the wave conditions at the lateral boundaries ($y = y_{max}$ and $y = 0$). In this case, a symmetry boundary condition is usually applied indicating that the depth contours are assumed to be straight and parallel at these boundaries. Alternatively, absorbing boundary conditions can be applied. For more details, see section 5.3 Boundary Conditions *(p. 45)*.

The wave field near these model north and south boundaries will only be correct in very simple cases. Therefore, it is important in a real application that the area of interest lies well inside the model area.

Note: The wave field propagating into the area of interest should enter the model through the offshore wave boundary (i.e. orient your model so the waves enter through the offshore boundary). In general, the offshore wave boundary (model west) should be placed in areas where the wave field is reasonably uniform, while the lateral boundaries (model north and south boundaries) should be placed in areas where the contours are generally straight and parallel to the y-axis.

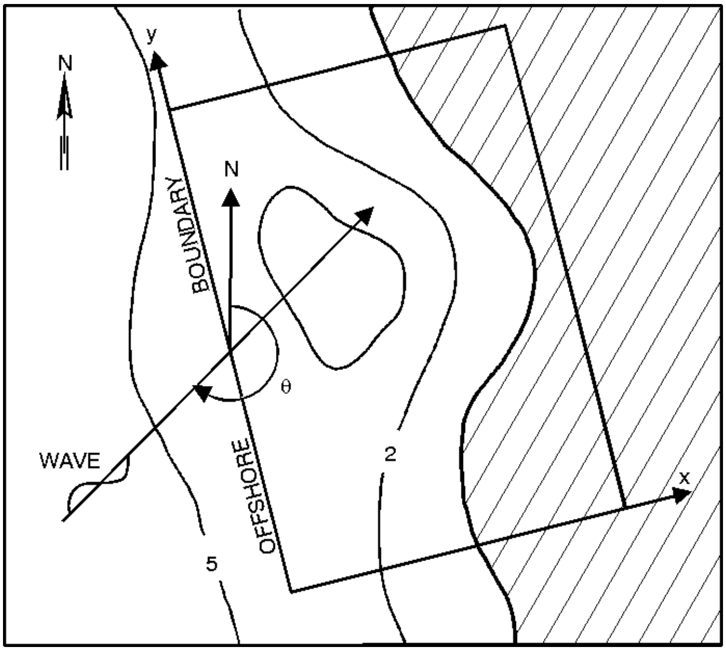


Figure 5.2 Computational grid

Grid spacings

In MIKE 21 PMS constant grid spacing in the x- and y-directions are used. The grid spacings must be chosen to provide adequate resolution of the bathymetry and the wave field in the x-y plane.

Regarding the waves, the grid spacing must be chosen to allow a **minimum** of 5-7 grid points per wave length.

Furthermore, if the results of the wave simulation is to be used in the simulation of wave-induced currents, it is important that you use a sufficient number of grid points in the surf zone (zone between the breaker line and the shoreline). This is necessary since the wave-induced currents are related to gradients in radiation stresses which again depend on the rate of wave dissipation. Thus, it is important to resolve the wave energy decay process if the results are to be used to calculate wave-induced currents. A good rule-of-thumb is to use a minimum of 8-10 grid points in the surf zone.

The grid spacing in the x-y plane is determined from the specification of the bathymetry.

Note: You can usually relax the requirement of 5-7 grid points per wave in very shallow waver ($d/L_o < 0.01$), where the wave height is small. However, this should be checked by running the model with different grid spacings (sensitivity analysis).

Remarks and hints

Please note that:

- Bed levels are specified as negative values when they are below the bathymetry datum, and positive values when they are above it.
- Calculations are only performed in grid points for which the water depth is larger than 0.05 m.
- The depth given to a grid point represents not only the depth right at that point, but the area surrounding the grid point.

Please also note that MIKE 21 PMS is a mild slope model. This means that the equations are derived assuming that depth variations are slow (compared to the wave). The model is normally robust, but sometimes rapid depth variations from one grid point to the next may cause instabilities.

If instabilities occur, please check your bathymetry to see if:

- There are very rapid depth variations around the onset of the instabilities (or a little distance before). If so, the solution is to smoothen them out.
- The lateral boundaries are close to protruding structures or land (same thing in the model). Reflections may then occur between boundary and land since the lateral boundary conditions are not perfect and land is reflecting. If so, you should try to enlargen the model domain, or orient the model slightly differently. Sometimes choosing another parabolic approximation may solve the problem if it is not too severe.

An example of rapid depth variations causing instabilities is shown in Figure 5.3. In this case, the bed slope near the breakwater (shown in light colour) is around 1:2. This proved too steep a slope for the wave field investigated, resulting in severe instabilities originating at the structure. The grid spacing in this case was 2 m and the waves were coming in obliquely at the structure.

To the left in Figure 5.3 the original bathymetry is shown, to the right it is shown how the problem was solved by removing the rapid depth variations. The main results will not be affected by this.

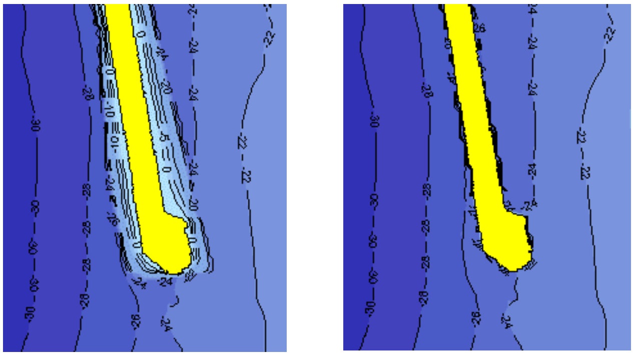


Figure 5.3 Example of too rapid depth variations (left) and how to solve the problem (right)

5.2.3 Bathymetric parameters

For the bathymetry, the following area information is presented:

- The orientation of your model. This is defined as the angle between true North and the y-axis of the model measured clockwise. A mnemonic way of remembering this definition is by thinking of NYC, which normally means New York City, but which for our purpose means “from North to the Y-axis Clockwise”. This parameter is used internally in MIKE 21 PMS for calculating directions with respect to the +x-axis so it is important that it is correct.
- The origin of your model area (latitude, longitude).
- The value assigned to true land points in your bathymetry.

For profile simulations, the origin of the model area is not used.

5.2.4 Simulation period

MIKE 21 PMS can be run in two modes: *stationary* and *quasi-stationary*. Stationary is used if you are simulating only one wave event corresponding to one offshore wave boundary condition, while quasi-stationary is used if you are simulating several sets of wave events corresponding to a time series of offshore wave boundary conditions. It is very important to note, however, that each of these wave event are mutually independent.

For the quasi-stationary case, the simulation period is specified using the simulation start date and time, the number of time steps and the time interval (in seconds) between each time step.

Note: When running MIKE 21 PMS in quasi-stationary mode, the input data files must include, but are not limited to, the entire simulation period.

5.3 Boundary Conditions

MIKE 21 PMS solves a partial differential equation and, like all other differential equations, it requires boundary conditions at all the open boundaries. The boundary conditions are divided into Offshore Wave Conditions, and Lateral Boundary Conditions.

For profile simulations, the specification of lateral boundary conditions is not necessary due to the assumption of uniformity in the y-direction (d/dy = 0).

5.3.1 Offshore wave conditions

At the offshore boundary (model west boundary), the incoming wave conditions are specified. These can be specified in one of the following ways(1):

- Constant wave parameters (when the simulation period covers only one time-step) specified using:

  1) root mean square wave height, H_{rms} (m)

  2) peak wave period, T_p (s)

  3) mean wave direction, θ_m (deg N)

- A dfs0 data file (when the simulation period covers several time-steps) containing wave parameters (H_{rms}, T_p and θ_m) as they vary with time. It should be noted that MIKE 21 PMS uses the wave conditions for each time step to compute the steady state nearshore wave distribution for that time step.

- A dfs2 data file containing the distribution of wave energy with frequency and direction at the boundary. This file is required for simulations of irregular waves and/or waves with directional spreading. The dfs2 data file should be prepared using the MIKE 21 Tool Generate Wave Energy Spectrum, and it may contain several time steps.

5.3.2 Lateral wave conditions

For the lateral boundaries (model north and model south), you will have to choose one of the following types of boundary conditions:

- Reflecting. This condition ensures that any incident wave at the boundary is perfectly reflected. Note that only forward scattering is included in the model.

---

1 Note: monochromatic, uni-directional waves are specified using wave height H, wave period T and wave direction θ

- Absorbing. This condition ensures that the incident waves at the boundary are fully absorbed. At the outflow lateral boundary, incident waves propagate out of the model without any reflection, while at the inflow lateral boundary, no waves can propagate into the model area.
- Symmetrical. This condition ensures that the gradient of the wave conditions across the boundary (d/dy) is zero. Basically, this is synonymous with assuming that the contours are locally straight and parallel near the boundary. Recommended in most applications.

5.4 Model Parameters

The model parameters in MIKE 21 PMS include physical input data (surface elevation) as well as parameters controlling the type of parabolic approximation (solution parameters) and parameters controlling the dissipation processes (wave breaking and bottom friction).

5.4.1 Surface elevation

For wave simulations in tidal areas, it is important that the correct water depths are used in the wave simulation. This will ensure that the changes in wave conditions due to varying water depths resulting from the tides are properly modelled. You can specify the correct surface elevation/water level in your study area on the Surface Elevation dialog page.

The surface elevation can be specified as a constant for the entire model area, as a two-dimensional map read from a data file (a dfs2 file) or as a time-series (only for the quasi-stationary mode). For profile simulations, the two-dimensional map of surface elevations reduces to a dfs1 file that you must create before running the simulation.

Note: You must specify the surface elevation relative to the same datum used for preparing the bathymetry. You specify a positive surface elevation if it lies above the datum, and a negative surface elevation if it is below the datum. The total water depth is then calculated as (- bathymetry bed level + surface elevation).

Example:

Bathymetry bed level:	- 15.3 m
Surface water level:	+ 2 m
Total water depth:	- (-15.3 m) + 2 m = 17.3 m

5.4.2 Solution parameters

The solution parameters cover the type of parabolic approximation used in MIKE 21 PMS and a dissipative interface.

Parabolic approximation

Different types of parabolic approximations are implemented in MIKE 21 PMS. These are:

- Simple model
- Padé's model
- Minimax model with varying aperture

The Simple model corresponds to the simplest type of parabolic approximation to the elliptic mild slope model. This model requires that the angle between the positive x-direction and the wave propagation direction is very small (<10°), otherwise significant errors will be present in the solution.

The Padé's model is an improvement on the Simple model, in that it allows wider angles, up to ± 45°, (see Kirby, 1986) between the +x-direction and the wave propagation direction.

The Minimax model is based on a minimisation of the maximum error in the parabolic approximation for a given aperture width (Kirby, 1986). Thus, there are different Minimax models for 10°, 20°, 30°, etc. Note that using the Minimax model for 60° (for example) implies that you are using a parabolic approximation that minimises the error for waves propagating within 60° to the x-axis. However, there can exist slight errors for waves propagating at smaller angles.

Dissipative interface

The dissipative interface is used to filter out the high wave number noise that is produced in certain applications with parabolic approximation models. This is especially the case in applications involving sharp variations in wave height due to wave breaking. The local energy density, E is filtered using:

$$E^*_j = \tau \cdot E_{j-1} + (1 - 2\tau)E_j + \tau \cdot E_{j+1} \tag{5.1}$$

where τ is a filtering coefficient, usually set at 0.25 (default in MIKE 21 PMS).

The dissipative interface is not used for profile simulations.

Remarks and hints

The Pade's model usually gives reasonable results in most applications if the wave angle is less than 45°. Generally, you should not use the Minimax model for very wide aperture angles (> 70°) in coastal computations, since the cumulative effect of the errors at the smaller angles may become important near the coast.

As discussed in Johnson & Poulin (1998), results from MIKE 21 PMS may generate spurious currents (currents travelling in the wrong direction) when using the radiation stresses to drive wave-generated currents in a flow model. These currents are due to inherent errors in the parabolic approximation method. Usually, the problem can be solved or minimised by selecting the type of parabolic approximation carefully and using the profile version of MIKE 21 PMS to generate output for the calculation of boundary conditions to the flow model (see Profile *(p. 40)* and Example 4.3.4 Port extension *(p. 33)*).

However, it may not always be sufficient in cases with directional waves with a very large angle sector. Here, one of the following solutions can be tried:

- reduce the maximum deviation from MWD used in setting up the directional energy spectrum
- smoothen the boundary data generated by the MIKE 21 Tool Wave Generated Current and Setup using constant eddy viscosity instead of the Smagorinsky formulation
- for extreme cases with MWD nearly at 60° to the +x-axis, copy the radiation stress components in the output from the 2D MIKE 21 PMS output from j=1 to j=0 (or, from j=jmax-1 to j=jmax)

✓ Secondly, when using any parabolic equation wave model, one should also be conscious of the possibility of “apparent” wave dissipation in deep water, which may look physical as it drives a current in the correct direction. This effect is larger for the higher order MINIMAX approximations (Johnson & Poulin, 1998). The best way of minimising this problem is to select the parabolic approximation that best suits the wave direction sector in the model.

5.4.3 Bottom dissipation

The wave friction coefficient - the friction factor c_{fw} or the Nikuradse roughness parameter k_N - can be specified either as a constant for the entire model area or as a two-dimensional map read from a data file (a dfs2 file). For profile simulations, the two-dimensional map reduces to a dfs1 file that you must create before running the simulation.

General description

Bottom friction is the process by which the wave loses (dissipates) some of its energy due to the effect of friction at the sea bed. This effect is cumulative and the amount of energy dissipated increases with distance, wave height, wave period and decreasing water depth.

The formulation in MIKE 21 PMS of dissipation of energy due to bottom friction is based on the quadratic friction law to represent bottom stress. For monochromatic waves, the corresponding energy dissipation is given as:

$$\frac{dE}{dt} = \frac{-1}{6\pi}\cdot\frac{c_{fw}}{g}\cdot\left(\frac{\omega H}{\sinh(kd)}\right)^3 \tag{5.2}$$

where $E = H^2_{rms}/8$, ω is the circular frequency, H is the wave height, k is the wave number, d is the water depth and c_{fw} is the wave friction factor.

The friction factor $c_{fw} = f_w/2$ can be specified directly or calculated using the empirical expression see Jonsson (1966); Swart (1974)

$$\begin{aligned} f_w &= 0.24 && a_b/k_N < 2 \\ f_w &= \exp\left(-5.977 + 5.213\left(\frac{a_b}{k_N}\right)^{-0.194}\right) && a_b/k_N \geq 2 \end{aligned} \tag{5.3}$$

where k_N is the Nikuradse roughness parameter and a_b is the amplitude of the particle motion at the bottom.

For random waves with Rayleigh distributed wave heights, and a single frequency, ω, the rate of energy dissipation was given by Dingemanns (1983) as:

$$\frac{dE}{dt} = -\frac{1}{8\sqrt{\pi}}\cdot\frac{c_{fw}}{g}\left(\frac{\omega H_{rms}}{\sinh(kd)}\right)^3 \tag{5.4}$$

where $E = H^2_{rms}/8$, ω is the frequency and H_{rms} is the root mean square wave height.

Note: For simulations with an irregular wave spectrum, the equation above is used with the characteristic frequency taken as the energy-averaged mean frequency. For simulations with parametric random waves, the same expression is used with the characteristic frequency taken as the specified peak frequency.

Remarks and hints

The bottom friction in areas dominated by sand depends on the grain size of the sediment and the presence of bed forms. For more details see for example Nielsen (1979) and Roudkivi (1988). For the case where there is no bed form, the Nikuradse roughness parameter k_N can be estimated by Nielsen (1979)

$$k_N = 2.5 \cdot d_{50} \tag{5.5}$$

where d_{50} is the median grain size. In the presence of ripples k_N can be much larger than this value and should be estimated including the ripple characteristics. The bed roughness can be further increased due to the presence of vegetation.

In general, it is quite difficult to assess this parameter, thus it is used as a calibration factor.

5.4.4 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 hence become unstable, or when the waves are too high to be supported by the water depth (i.e. reach a limiting H/d).

General description

The formulation in MIKE 21 PMS of wave breaking due to large wave steepness and limiting water depth is based on the formulation of Battjes & Janssen, 1978. They introduced the following expression for the rate at which the energy is dissipated due to wave breaking:

$$\frac{dE}{dt} = -\frac{\alpha}{8\pi} \cdot Q \cdot \omega H_{max}^2 \tag{5.6}$$

where E is the total energy, ω is the frequency, H_{rms} is the rms-value of the wave height, H_m is a maximum allowable wave height, Q_b is the fraction of breaking waves and α is an adjustable constant. The rate of dissipation is controlled by α, and the maximum wave height is calculated using:

$$H_{max} = \gamma_1 \cdot k^{-1} \cdot \tanh(\gamma_2 kd / \gamma_1) \tag{5.7}$$

where k is the wave number, d is the water depth and γ_1 and γ_2 are two wave breaking parameters. γ_1 controls the steepness condition and γ_2 controls the limiting water depth condition.

The expression above for dissipation in breaking waves is used for both monochromatic and random waves in MIKE 21 PMS. The main difference between these two wave types is in the calculation of the fraction of breaking waves, Q_b.

For monochromatic waves, the fraction of breaking waves is calculated as 0 or 1 depending on whether the waves are breaking ($H \geq H_m$) or non-breaking ($H < H_m$).

For random waves (or parametric random waves), the fraction of breaking waves is calculated using the assumption of a truncated Rayleigh distribution for the wave heights (as done by Battjes & Janssen). This gives the following expression for Q_b:

$$\frac{1 - Q_b}{\ln(Q_b)} = -\left(\frac{H_{rms}}{H_{max}}\right)^2 \tag{5.8}$$

Wave breaking parameters

Four different ways of specifying the wave breaking parameters are included:

- The parameters α, γ_1 and γ_2 are specified directly as constant values for the entire area. This is the default option and applies in most cases.
- Battjes and Stive (1985). Here γ_2 is specified as a function of deep water wave parameters. α and γ_1 are specified directly as constant values.
- Nelson (1987). Here γ_2 is a function of the local bed slope. Steepness related breaking is excluded (γ_1 is not used). α is specified directly as a constant value.
- The parameters α, γ_1 and γ_2 are specified in each grid point (a dfs2 file for a Normal PMS simulation or a dfs1 file for a Profile PMS simulation). The file must have only one time-step and exactly three items.

Remarks and hints

Battjes & Janssen (1978) used the following values for the three wave breaking constants

$$\alpha = 1.0, \quad \gamma_1 = 0.88 \quad \text{and} \quad \gamma_2 = 0.8 \tag{5.9}$$

Note: In MIKE 21 PMS the default value for γ_1 is 1.0 while for α and γ_2 the default values are those used by Battjes & Janssen. The value for γ_1 was suggested by Holthuijsen et al. (1989).

In a subsequent paper, Battjes & Stive (1985) found an expression for γ_2 by calibrating the dissipation model against measurements. They obtained:

$$\gamma_2 = 0.5 + 0.4\tanh(33 \cdot S_0) \tag{5.10}$$

where S_0 is the deep water wave steepness calculated as $H_{rms,0}/L_{0p}$. $H_{rms,0}$ (= $H_{m0}/\sqrt{2}$) is the deep water root mean square wave height and L_{0p} is the deep water wave length based on peak frequency. In Battjes & Stive (1985), $\alpha = 1.0$ and $\gamma_1 = 0.88$.

Nelson (1987) suggested a dependence of depth-related wave breaking on the local bed slope according to

$$\gamma_2 = 0.55 + 0.88 \cdot \exp\left(-0.012 \cdot \frac{1}{\tan\theta}\right) \tag{5.11}$$

where $\tan\theta$ is the bed slope. The expression is valid for $\tan\theta >= 0$, i.e. decreasing water depth in the direction of wave propagation.

Note: In MIKE 21 PMS when $\tan\theta < 0$ in this expression, $\tan\theta = 0$ is used. The local mean wave direction is used when calculating the bed slope relative to the wave propagation direction. Please note that steepness-related breaking is disabled for this option.

A map of breaking coefficients can be useful in certain cases, e.g.:

- When you wish to tune the model to reproduce desired losses over submerged structures.
- If you have an inshore wave recorder and need to build your wave climate on this, you can back-refract and back-shoal the wave record to the offshore boundary and when actually running the simulation, breaking can be switched off between the boundary and the wave recorder location while keeping wave breaking between the recorder and the shore. Of course, this assumes that it is the surf zone that is of interest in the simulation.

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.

5.5 Output

MIKE 21 PMS allows you to save results from up to four output areas within the full area of your model. These areas can overlap, include a part of the model area or include the whole model area. For each output area selected, MIKE 21 PMS gives you the option of specifying the frequency in space and time at which the results are to be saved.

MIKE 21 PMS also allows you to select the items to be stored for each output area. The results from the different output areas are stored in separate disk files.

5.5.1 Results

The basic results from MIKE 21 PMS consist of two-dimensional arrays (dfs2 files) containing the following integral wave parameters:

- The root mean square wave height, H_{rms} or the significant wave height, H_{m0}.
  Note that the root mean square wave height, H_{rms} is output for simulations with regular waves, while the significant wave height, H_{m0} is output for simulations with irregular waves (i.e. using a frequency spectrum).
- The peak wave period T_p
- The mean wave direction θ_m

as well as the and the radiation stresses S_{xx}, S_{xy} and S_{yy}.

Note: For profile simulations, the output is still a dfs2 file, since the MIKE 21 Tool Wave Generated Current and Set-up expects such a file. The results over the profile is copied to an extra line in the file so the number of grid points in the y-direction becomes 2.

Output area

This is defined in both the x- and y- direction by the first and last grid point to be stored and the frequency by which the results is stored. For profile simulations, the number of grid points in the y-direction is fixed to 2 and the frequency is fixed to 1.

Items

It is possible to select the three integral wave parameters, the instantaneous surface elevation, the x- and y-components of the vector showing the mean wave direction, the three radiation stress components, or a combination of these four types of output.

Definition of wave parameters

The root mean square wave height H_{rms} and the significant wave height, H_{m0} are defined by

$$\begin{aligned} H_{rms} &= 2\sqrt{2E_1} \\ H_{m0} &= 4\sqrt{E_1} \end{aligned} \tag{5.12}$$

where the total wave energy E_1 is

$$E_1 = \int_{\theta_{min}}^{\theta_{max}} \int_{f_{min}}^{f_{max}} E(f, \theta) \cdot \mathrm{d}f\mathrm{d}\theta \tag{5.13}$$

where θ_{min}, θ_{max} are the wave direction limits, while f_{min}, f_{max} are the lower and upper bounds for the wave frequency used in preparing the energy spectrum.

The peak wave period T_p is defined as the wave period containing maximum energy.

The mean wave direction θ_m is defined by

$$\theta_m = \arctan(b/a) \tag{5.14}$$

where

$$a = \frac{1}{E_1} \int_0^{2\pi} \cos\theta \cdot E(\theta) d\theta \tag{5.15}$$

$$b = \frac{1}{E_1} \int_0^{2\pi} \sin\theta \cdot E(\theta) d\theta \tag{5.16}$$

Note: In these formulas, the mean wave direction is defined relative to the model x-axis measured positive anti-clockwise; in the output file, the mean wave direction is defined with respect to true North.

Results from MIKE 21 PMS can also be obtained in form of two-dimensional arrays containing the x- and y-components of a vector **U** = (u,v) defined by

$$u = H_{m0} \cdot \cos\theta_m \tag{5.17}$$

$$v = H_{m0} \cdot \sin\theta_m \tag{5.18}$$

A vector plot of **U** can be used to show the mean wave direction in the model area.

Finally, MIKE 21 PMS can provide resulting maps of radiation stresses S_{xx}, S_{xy} and S_{yy} which are defined by

$$S_{xx} = \rho\frac{g}{2}\cdot(F_u + F_p) \tag{5.19}$$

$$S_{xy} = \rho\cdot\frac{g}{2}\cdot F_{uv} \tag{5.20}$$

$$S_{yy} = \rho\frac{g}{2}(F_v + F_p) \tag{5.21}$$

Here F_u, F_{uv}, F_v and F_p are defined by

$$F_u = \int_0^{2\pi}\cos^2\theta\cdot(1+G)E(\theta)d\theta \tag{5.22}$$

$$F_{uv} = \int_0^{2\pi}\sin\theta\cdot\cos\theta\cdot(1+G)E(\theta)d\theta \tag{5.23}$$

$$F_v = \int_0^{2\pi}\sin^2\theta\cdot(1+G)E(\theta)\cdot d\theta \tag{5.24}$$

$$F_p = \int_0^{2\pi}G\cdot E(\theta)d\theta \tag{5.25}$$

where G is given by

$$G = \frac{2kd}{\sinh(2kd)} \tag{5.26}$$

Remarks and hints

In some cases for large wave angles (e.g. $\theta \geq 60°$), the calculated mean wave direction at the offshore boundary deviates from the input wave direction by, say, 3°. This is due to the way that direction is calculated:

$$\sin\theta = \frac{\sin(k \cdot \Delta y \cdot \sin\theta_{inp})}{k \cdot \Delta y} \tag{5.27}$$

where θ_{inp} is the specified input wave direction.

For a typical grid spacing of 5 m, the θ–deviation is very small for MWD < 50° (relative to the +x-axis). The deviation also reduces as the number of grid points per wave length increases.

5.5.2 Disk space

The disk space used by your simulation will depend mainly upon the amount of output data you request to be stored on the disk for further processing.

Small files

Two smaller output files are created during a wave simulation. These are a *.pms* input file containing your input specifications and a *log* print file containing a description of the model set-up and run statistics.

Large files

MIKE 21 PMS allows you to save results from up to four different output areas. These are stored in separate disk files.

The disk space is calculated automatically on the Output page of the MIKE 21 PMS editor.

Remarks and hints

Please note that MIKE 21 PMS does not check if there is sufficient disk space available for the output files.

5.5.3 CPU time

At the end of the simulation the CPU time for your wave simulation is printed in the log file.

The non-linear source terms (wave breaking and bottom dissipation) are introduced implicitly. Hence, a non-linear iteration is performed at each grid point. Therefore the CPU time depends on the number of iterations needed to satisfy the stopping condition for this iteration.

6 Scientific References

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

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

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