CHAPTER 207

IDENTIFICATION OF SOME RELEVANT PROCESSES IN COASTAL MORPHOLOGICAL MODELLING

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ABSTRACT: This paper presents a coastal morphology modelling system based on an explicit forward time integration scheme for the morphological evolution involving the following stages: a) Initialisation, b) Sediment transport computation using a deterministic sediment transport model, c) Wave computation using an arbitrary wave model, d) Hydrodynamic computation assuming a mobile bed evolving at $\partial z/\partial t$, with optional use of a module to determine the apparent roughness in combined wave-current motion and e) Bed level update scheme using an improved second order Lax Wendroff scheme. A series of numerical tests is performed with the aim of evaluating the effect of space-varying hydraulic roughness in combined waves and current, choice of wave modelling approach and of directionality of the waves on the morphological evolution. A detached breakwater is used as test case.

INTRODUCTION

The numerical modelling of morphological evolution in coastal areas has experienced an important development in recent years and is becoming a feasible alternative to physical modelling. The morphological modelling system considered here

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consists of a wave module, a depth-integrated hydrodynamic module (in which the two horizontal dimensions are taken into account), a quasi-3D sediment transport module (Deigaard et al., 1986) and a modified second order Lax-Wendroff scheme for updating the bed level. A module for accounting for the effect of wave-related bed roughness on the current (Fredsøe, 1984) is also included in the modelling system. In the morphological model, the way in which the different modules are coupled is user-specified; for example, the influence of currents on wave refraction (influence of current module on wave module) may be accounted for or not; the same applies to the influence of waves on the apparent bed resistance for currents (influence of wave module on current module).

While the flow of information among the different modules and the inherent stability of such a modelling system have been discussed in detail (de Vriend, 1987 and de Vriend et al., 1993), an assessment of the influence of relevant parameters related to practical aspects of morphological modelling is still lacking. A series of numerical tests has therefore been devised in order to identify relevant parameters from the point of view of coastal area morphological modelling. The following aspects have been considered:

- The type of wave model used to simulate the propagation and transformation of the nearshore wave field
- The influence of directional spreading of the waves
- The influence of accounting for the apparent (wave-related) bed roughness on the current field, and consequently on the sediment transport field and the rates of bed level change.

The use of the model complex in practical engineering situations is further illustrated by investigating the morphological evolution behind a detached breakwater using different layouts and wave parameters.

DESCRIPTION OF THE MODELLING COMPLEX

The modelling of the morphological response in the coastal zone, both on a natural coast and a coast influenced by structures, requires in principle simultaneous simulation of waves, currents and sediment transport, as the bathymetry develops.

Considering the various time scales which are involved, an explicit approach has been developed with sequential calculations of waves, currents, sediment transport and rates of bed level changes. The first version of the present model was described in Andersen, et al. (1988).

A block flow chart, showing the morphological modelling scheme, is illustrated in Figure 1. This figure is explained as follows: Given the initial bathymetry and

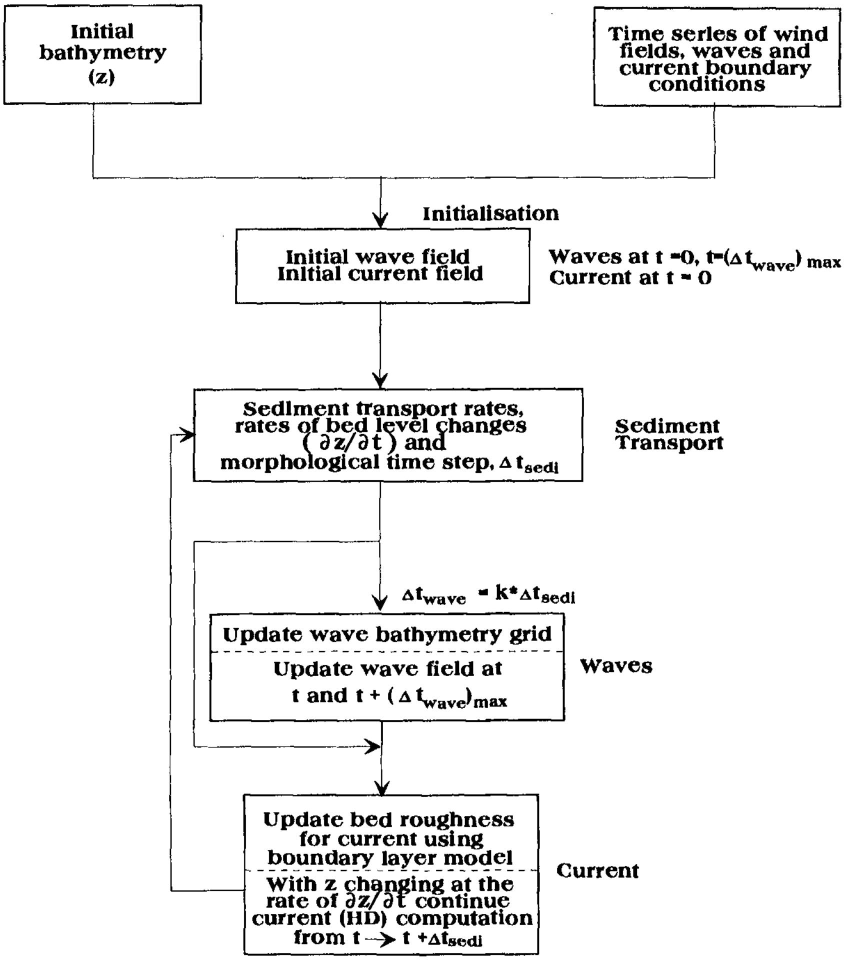


Figure 1. Block flow chart for morphological model.

time series of boundary wave and current conditions, the initial wave and current fields are first computed before entering the morphological loop. Then the loop is entered and the sediment transport, the rates of bed level changes $\partial z/\partial t$ and the allowable maximum morphological time step, DTsedi (based on the stability condition for the bed update scheme) are computed. Next the wave field is updated if necessary (since this is done every k-th update of the sediment transport field, where k is an integer ≥ 1). Next the bed resistance map is updated taking into account the apparent roughness in combined wave-current motion using a boundary layer model, and lastly the hydrodynamic calculation is continued from present time, T, to T+DTsedi, where the sediment transport field is updated. Using the calculated $\partial z/\partial t$, the bed level is gradually updated during the hydrodynamic computation. The whole process is then repeated in a cyclical loop until the prescribed length of simulation is completed.

In the sections below, the modules in the modelling complex are described.

Wave Models

The wave models presently built into the morphological complex are: an elliptic mild slope model, MIKE 21 EMS, a parabolic mild slope model, MIKE 21 PMS and a spectral nearshore wind wave model, MIKE 21 NSW.

MIKE 21 EMS is a linear refraction-diffraction wave model including back-scattering and wave breaking. The model solves the mild slope equation (Berkhoff, 1972), and includes a general formulation of radiation stresses which applies in crossing wave trains and in areas of strong diffraction. Of the three models, this is the most accurate for monochromatic linear waves under the test conditions chosen and is selected as our reference model. However, it is the one with the largest computational requirements.

MIKE 21 PMS is based on a simplification of the mild slope equation assuming wave propagation in one predominant direction (x-dir), neglecting diffraction in this direction and back-scattering in the opposite direction. Using the approach of Kirby (1986), this model is made to allow large-angle (up to 60 deg.) propagation to the x-dir. Furthermore, MIKE 21 PMS includes the effect of a frequency spectrum and directional spreading. The model is extremely cost-efficient and requires a very low computational effort, being approximately 50 times faster than the elliptic mild slope model for the same setup.

MIKE 21 NSW is a stationary directionally decoupled parametric model based on the wave action conservation equations as formulated by Holthuijsen et al. (1989). It describes the propagation, growth and decay of short-period waves in nearshore areas. The model takes into account the effects of refraction and shoaling due to varying depth as well as wind generation, energy dissipation due to bottom friction and wave-breaking plus the effect of current on these phenomena. Although this model does not include diffraction (an important effect behind the breakwater), it is nevertheless included in the analysis to illustrate the relative importance of this limitation.

In the three wave models, wave-breaking is formulated using the theory of Battjes and Janssen (1978).

Flow Model

The hydrodynamic module in the morphological modelling complex is MIKE 21 HD, which solves the vertically integrated equations of conservation of mass and momentum in two horizontal dimensions. The rate of bed level changes $\partial z/\partial t$ has been included in the equation for conservation of water mass. The methods of solution are described in Abbott et al. (1973, 1981, 1988).

The hydrodynamic model is capable of operating with a space- and time-varying hydraulic roughness. The theory of Fredsøe (1984) for the apparent roughness in combined waves and currents has been implemented. The apparent roughness is updated every morphological time step.

The hydrodynamic model uses fluxes or levels as boundary conditions. In cases where the boundaries cut through the surf zone, the conditions are found from the radiation stress gradients assuming quasi-stationary flow.

Sediment Transport Model

A deterministic intra-wave period model for non-cohesive sediment is applied. A detailed description is given in Deigaard et al. (1986) It is noted that the model covers the range from pure current to combined current and waves (breaking or non-breaking). It is a basic assumption in the present model complex that the transport capacity is a function of the local conditions only, ie. no time and space lag effects are included.

The Bed Level Changes $\partial z/\partial t$

The rates of bed level change are described by the equation of continuity:

$$\frac{\partial z}{\partial t} + \frac{1}{1-n}\frac{\partial q_x}{\partial x} + \frac{1}{1-n}\frac{\partial q_y}{\partial y} = 0$$

where x, y and z are horizontal and vertical space coordinates, respectively; t is time, n is porosity and q_x, q_y are sediment transport rates in x- and y-directions. A second-order accurate explicit finite-difference method is applied. The truncation errors are eliminated by applying a modified Lax Wendroff scheme, see Abbott (1978). The solution is kept stable by adjusting the morphological timestep so that the maximum Courant number, reflecting migration rates of bed forms, is ≤ 1.

THE CHOICE OF WAVE MODEL

The most appropriate wave model must be chosen depending on the dominating phenomena in the area to be studied using the morphological model. Morphological modelling requires many repetitive calculations of the wave field. Consequently, there is a need for finding the optimal balance between accuracy and computational effort.

The problem has been investigated by calculation of the initial wave, current and sediment transport fields behind an offshore breakwater for normally incoming waves with the three wave models available in the morphological complex: the elliptic mild slope model, EMS, the parabolic mild slope model, PMS, and the spectral wind wave model, NSW.

The phenomena shoaling, depth refraction and breaking are all well described by the three models. Diffraction is best described by the elliptic model, approximately by the parabolic model and not at all in the spectral wind wave model. To compensate for the lack of wave energy penetration behind the breakwater in the case of the spectral wave model, this model was run with directional spreading of the incoming waves.

The studied configuration is a 300 m long shore-parallel breakwater located 280 m from the shoreline on a plane sandy beach with a slope of 1:50. The wave height (H_{RMS}) and period are 2m and 8s, respectively, at 10 m water depth. The sediment is sand with a median grain size of 0.25 mm and a gradation σ_g corresponding to $(d_{84}/d_{16})^{½} = 1.1$.

A grid spacing of 5m was used in the EMS and PMS models. Furthermore, the front face of the breakwater is assumed to have zero reflection in the EMS model. This is achieved by placing a 5-line sponge layer inside the breakwater. The incident wave field is assumed to be monochromatic and unidirectional in the EMS and PMS models. For the NSW model, the grid spacing was chosen as DX=2m, DY=10m and a $\cos^2$ directional spreading function was used. The bed roughness in the wave models was chosen as 1.5mm.

The radiation stresses from the wave models are interpolated to a square grid with DX=DY=10m used for the hydrodynamic simulations. The hydrodynamic time step is 6 s and a bed roughness corresponding to a Manning number (in the Strickler sense) of 32 is used.

Figure 2 shows the contours of wave heights, wave-induced currents and sediment transport vectors from the three models.

Although the NSW model does not include diffraction, some wave energy can be observed behind the breakwater due to the use of a broad-banded ($\cos^2$) directional spectrum. However, the computed NSW wave heights in the diffraction zone are much smaller than corresponding EMS waves, while the PMS wave heights are generally closer to the EMS waves.

All three models drive two eddies between the breakwater and the shoreline. The maximum current speed in the EMS model is slightly greater than 1m/s, which is nearly the same as obtained with the PMS model. However, the current speeds are generally lower for the NSW model, the maximum in this case being about 0.8m/s. The difference in wave-induced currents between NSW and the others is partly due to directional spreading in NSW: the directional spreading results in a smoothing of the radiation stress field, and hence in a reduction of the radiation stress gradients.

The combined wave and current fields are used for calculating the sediment transport rates. As can be expected from a comparison of the waves and current fields, the sediment transport rates computed using the NSW model are about a factor 3 smaller than those calculated using the EMS model. In contrast, the PMS model results are generally much closer to the EMS values, except for the alternating high and low transport rates computed close to the shoreline behind the breakwater which arise from alternating bands of high and low wave heights (constructive/destructive interference) which are well described by the EMS model, but only partially modelled in the PMS model.

It is concluded that the PMS model is an optimal choice for computing the sediment transport field and hence the morphology response behind the offshore breakwater, since it gives comparable results to the EMS model at a much lower cost.

The NSW model is found to be unsuitable for computing sediment transport rates for the test setup selected in which diffraction is an important phenomenon.

EFFECTS OF DIRECTIONAL SPREADING

The effects of directional spreading of the waves on the flow field and on the sediment transport field have been investigated with a similar setup as used for the discussion of types of wave model. The parabolic mild slope model has been applied and the direction of the waves at 10m depth is 10°. Furthermore, the distance from the shoreline to the breakwater is now 200m. Simulations have been made with unidirectional waves and with directional spreading. Five (5) directional components have been used to resolve the directional energy spectrum which at 10m water depth is described as $\cos^5(\theta-\theta_{mean})$.

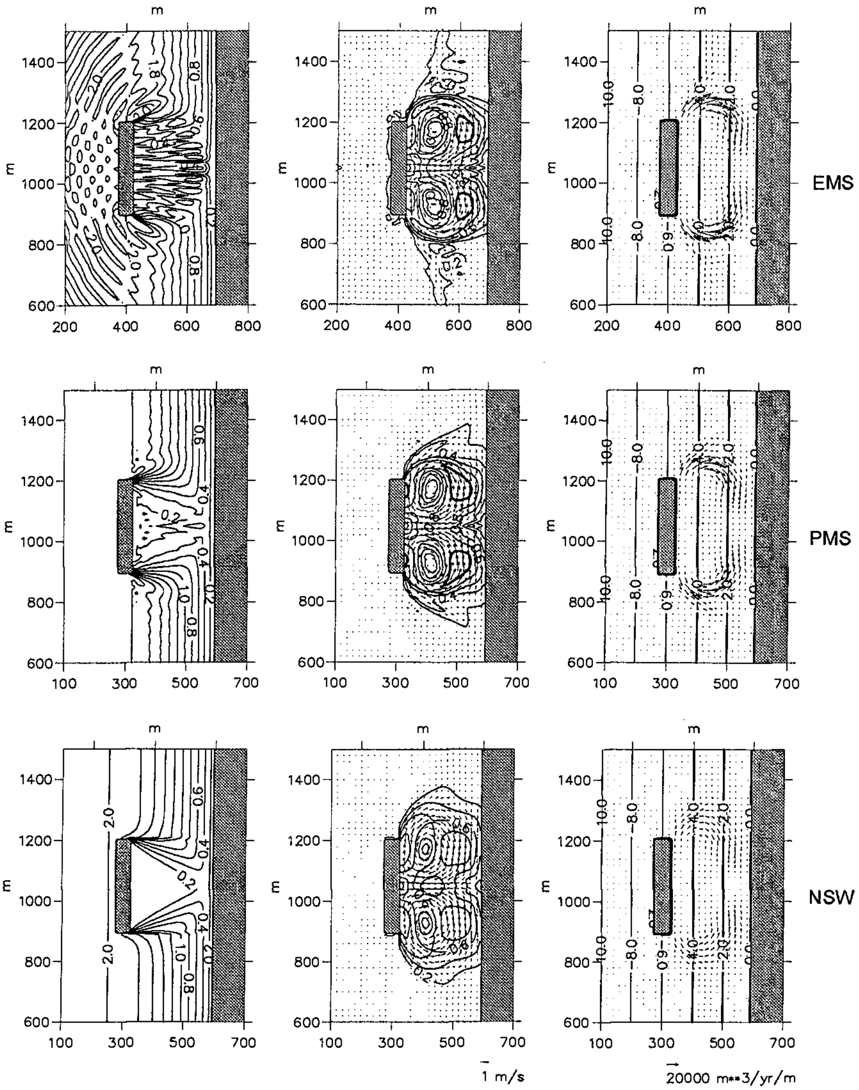


Figure 2. Contours of wave heights (a), current speeds (b) and sediment transport field (c).

The calculated initial wave, current and sediment transport fields are shown in Figure 3.

The comparison of the two wave heights fields shows an increase of H_{RMS} behind the breakwater in the case of directional waves compared to unidirectional waves. The longshore currents and the littoral drift are both decreased along the open coast due to the directional spreading. However, the sediment transport into the area behind the breakwater has increased with the directional spreading, both from 'updrift' and from 'downdrift'.. This is also seen from the comparison of longshore sediment transport shoreward of the breakwater.

The different changes in the transport along the open coast and behind the breakwater indicate that the directional spreading also influences the morphological response.

EFFECT OF APPARENT ROUGHNESS

The effect of the apparent hydrodynamic roughness due to the presence of a turbulent wave boundary layer on the morphological evolution is evaluated by comparison of initial current and transport fields calculated using a constant hydraulic roughness, k_N = 0.625 mm (grain roughness) and an apparent roughness, k_w, respectively. k_w is calculated according to Fredsøe (1984). The data for these tests is as follows: length of the breakwater is 100 m, distance from shoreline is 200m, beach slope is 1:50 out to 10m depth, grain size (d_{50}) is 0.25, gradation (σ_g) is 1.1, wave height H_{RMS}, direction, period (at 10 m depth) are respectively 2.0 m, 10° and 8s. The waves are unidirectional and the model used is MIKE 21 PMS.

The two sets of results are compared in Figure 4. The presence of the wave boundary layer increased the hydraulic roughness by a factor of 5 to 10 in the area most relevant with respect to sediment transport. This leads to reduction of current speeds with a factor of about 0.6 and reduction of the sediment transport with a factor of 0.3 - 05.

From the comparison of littoral drift shoreward of the breakwater shown in Figure 4, it appears that apart from an obvious difference in time scale of the morphological response the non-linearities will lead to a different erosion/deposition pattern when the space-varying roughness is included.

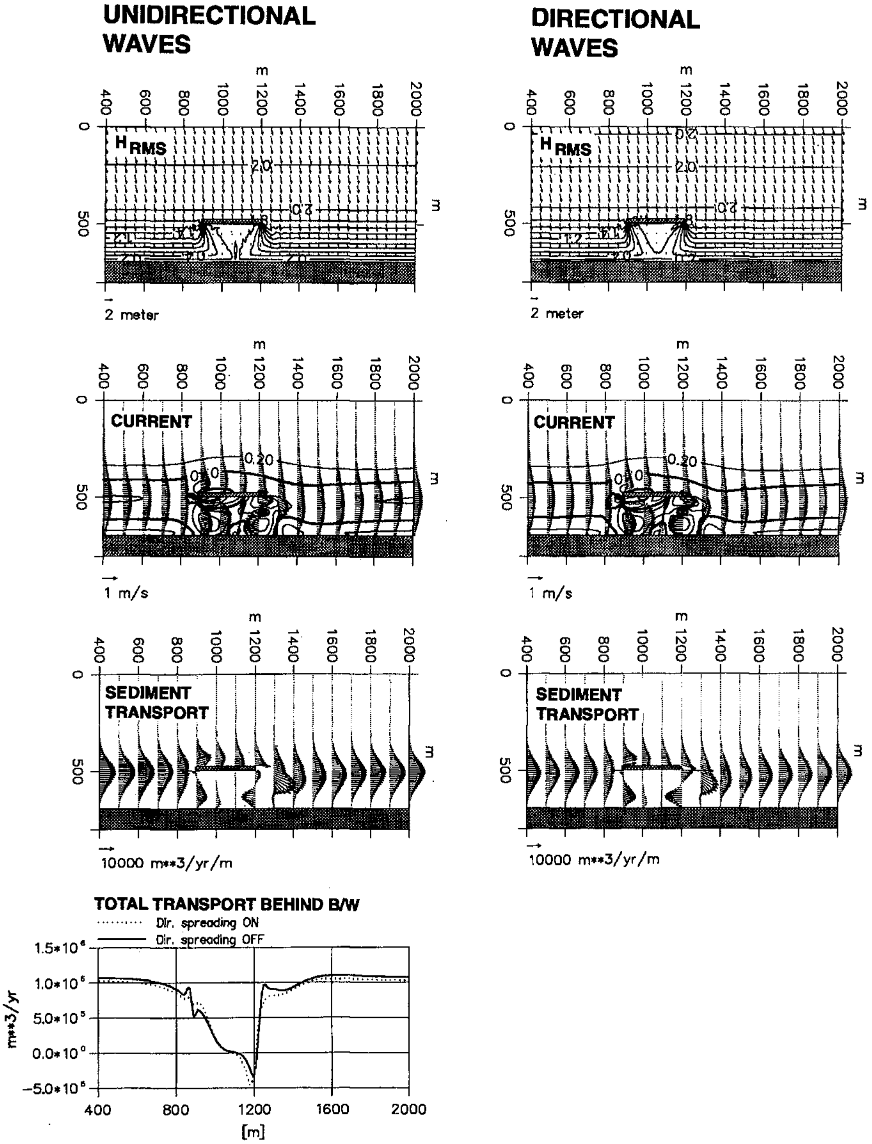
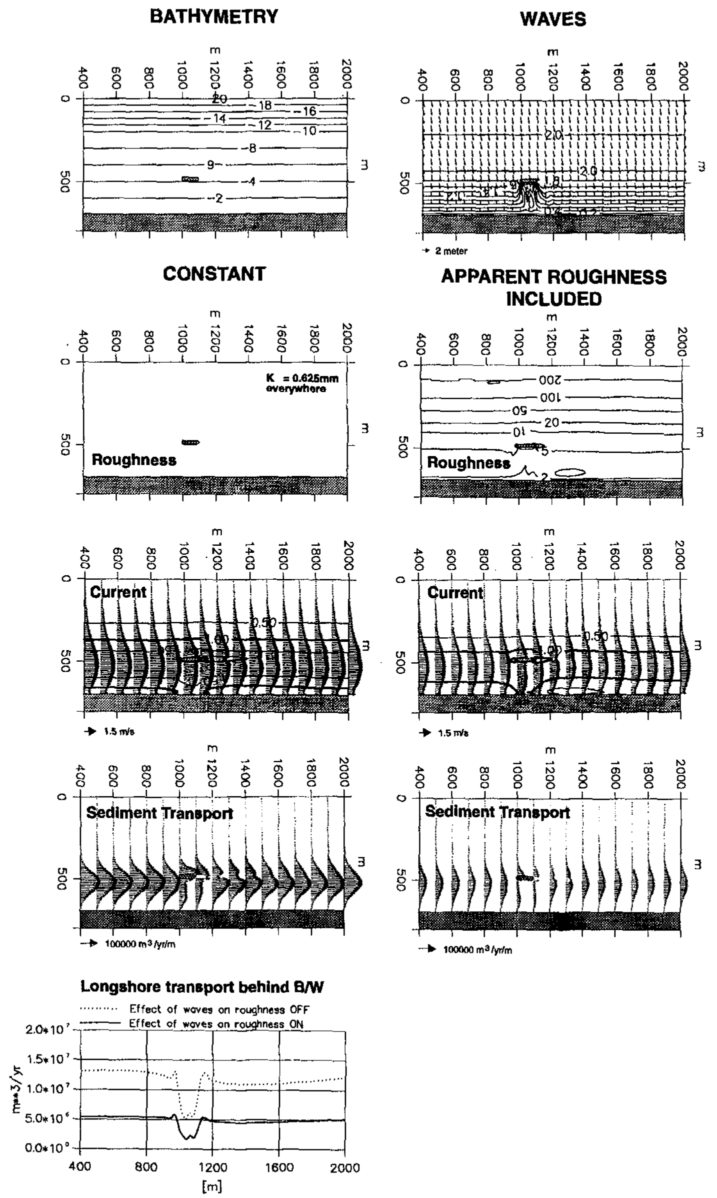


Figure 3. Wave, current and sediment transport fields for unidirectional and directional waves. Comparison of longshore sediment transport.


BATHYMETRY

WAVES

CONSTANT

APPARENT ROUGHNESS INCLUDED

Longshore transport behind B/W

Figure 4. Roughness distribution and current- and sediment transport fields for constant and wave-enhanced roughness. Comparison of longshore sediment transport.

ON THE EFFECTS OF SHORE-PARALLEL BREAKWATERS

The overall purposc of discussing morphological models is to produce tools to guide and support the design of coastal structures.

Although the present modelling complex does not include all relevant processes, a first attempt at a systematic study of the effects of shore-parallel breakwaters on sandy beaches has been initiated.

The initial conditions for all the presented simulations are a plane beach with a slope of 1:50 extending out to a depth of 10 m. The coastline is a fixed boundary which cannot be eroded. The incoming waves have been kept constant in time along the offshore boundary. The morphological evolution has been simulated for different dimensions of the breakwater and different incoming waves. The applied model setup is as previously described. The wave module applied is MIKE 21 PMS and the waves have been taken as unidirectional.

In Figure 5, the bed contours after a certain period of time are shown for varying angle of the incoming waves, varying wave height, varying distance from the shore to the breakwater and varying length of the breakwater. For the four different comparisons all other parameters are kept constant. (Note that in Figure 5, areas between the 0.5m contour and the shoreline are black. This is only to make the illustration clear).

The simulations indicate that localised scour occurs around the heads of the breakwater and a double or single-peaked salient forms behind the breakwater.

With increasing angle of the incoming waves the pattern changes from being localised redistribution of sediment to a trap for the littoral drift followed by downdrift erosion.

The salient peak 'updrift' decreases, while the 'downdrift' peak increases and is shifted further downdrift with increasing angle.

Sand ridges oriented at an obtuse angle to the shoreline are also seen for the simulations with large angle of incidence. The reason for the occurrence of this ridges is still under investigation.

As the distance of the breakwater to the shoreline decreases, there is a reduction of the scour around the breakwater heads and a greater tendency of tombolo formation.

With decreasing wave height, the surf zone becomes narrower, accompanied with a decreasing total littoral drift and a slower overall morphological response. However, it is noted that the deposition close to the shoreline is slightly increased for the smaller waves due to the fact that the trapped littoral transport in this case is trapped in the very narrow surf zone close to the shore, as opposed to being distributed over a wide surf zone as for the high waves.

The length of the breakwater and the distance from shore both influence the development of the salient, and determine whether it is single or double-peaked.

These first results are only indicative and future long simulations and detailed quantitative analysis are expected to contribute considerably to the established knowledge of design of breakwaters.

CLOSING REMARKS

The effeets of a number of relevant processes in coastal morphological modelling have been investigated in this paper. The processes considered are: (1) the choice of wave model, (2) effect of directional spreading, and (3) the influence of wave boundary layer on the hydraulic roughness used in flow modelling. It is concluded that the above processes influence the results of the morphological modelling.

Using the presented model complex, the morphological response of a single detached breakwater subject to different wave conditions was investigated. A qualitative description of the effects of various layouts and wave conditions is also presented. The occurrence of sand ridges downdrift of the breakwater for large angle of wave incidence is noted, however this subject is still under investigation.

Overall, these first results are indicative and future work is expected to contribute considerably to the established knowledge on morphological modelling and the design of offshore breakwaters.

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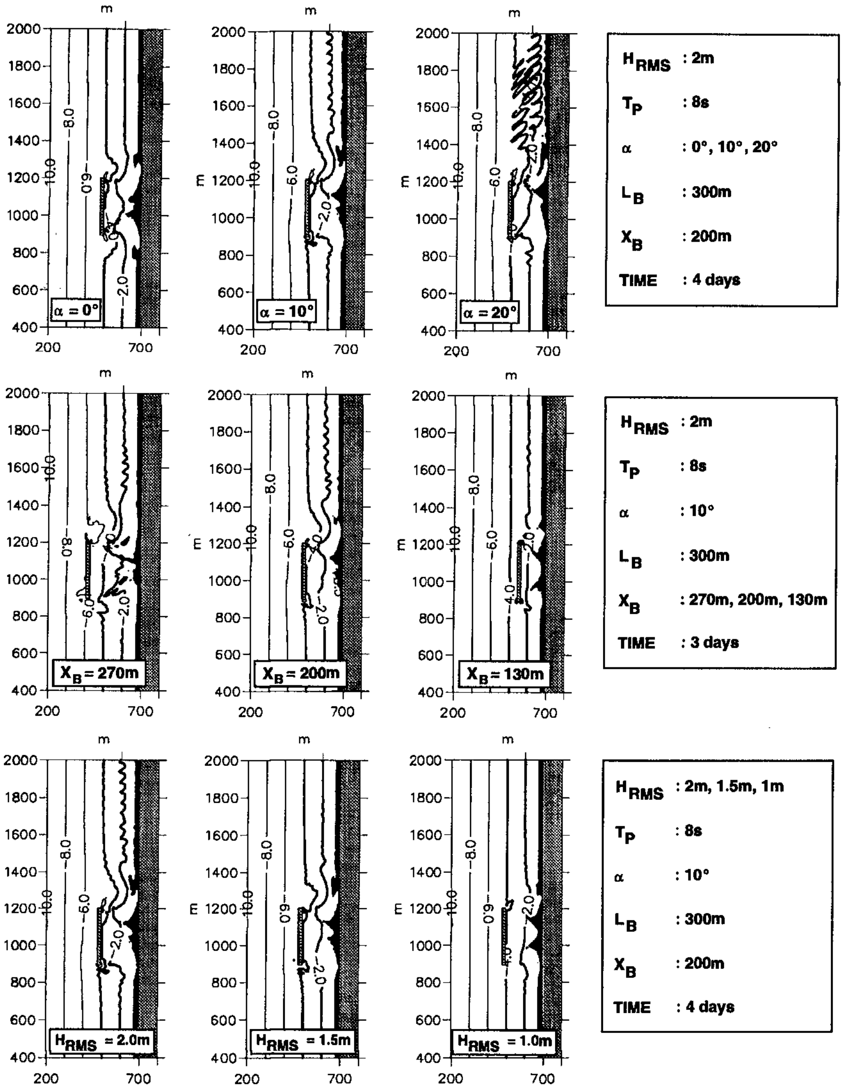
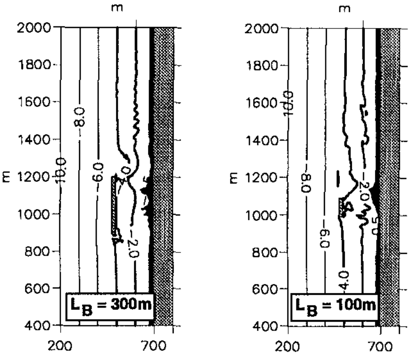


Figure 5. Simulated bathymetries for different combination of breakwater design and wave parameters. Common parameters: initial bed slope 1:50, medium grain size 0.25 mm, $\sigma_g = 1.1$.



H_{RMS}	: 2m
T_P	: 8s
α	: 10°
L_B	: 300m, 100m
X_B	: 200m
TIME	: 2 days

Figure 5 cont'd.

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