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MORPHOLOGICAL MODELLING OF THE WET-DRY INTERFACE AT VARIOUS TIMESCALES

Dano Roelvink[1], Giles Lesser[2] and Mick van der Wegen[3]

ABSTRACT

Many coastal areas, estuaries or rivers have boundaries of a varying degree of softness, which gradually or episodically erode or accrete. Typical related processes are waves hitting the dune, soil mechanical failures like avalanching, abrasion and scour of clay banks. The current article discusses four practical options to model these areas with a numerical approach, depending on the physical situation, the model resolution and the time-scales of interest. The cases under consideration are the uniform profile approach, algorithms used in avalanching and dune erosion, dry-wet cell bank erosion and cut-cell bank erosion.

The current research shows that realistic bank erosion behavior can be obtained with relatively simple and promising methods. Nevertheless, contrary to the current formulations the processes of bank erosion and bed erosion preferably should be decoupled allowing their own formulations. This would allow for different and independent timescales. An important parameter would be the slope allowed between dry and wet cells and of cells that were wet and are occasionally dry due to tidal processes or wave action. Furthermore, verification of most of the suggested methods is an ongoing effort.

1. INTRODUCTION

Morphological developments of areas that are under water have been extensively studied and modeled with numerical approaches. Usually hydrodynamic parameters such as the velocity and the water depth are coupled to sediment transport formulations. Based on the divergence of the sediment transport field bed level changes can be calculated and the bathymetry can be updated every time step. A range of physical processes that is typically not included in numerical hydrodynamic/morphodynamic models governs the exchange of sediment between areas that are wet at least part of the time, and dry areas, which can be dry beaches, dunes, banks or high marshes. However, numerical modeling of the dry-wet interface is becoming more and more robust and applicable to engineering problems at relevant spatial scales and time-scales. Reasonable

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approximate models exist and can be applied, despite unresolved complexities in describing the physical behavior of bottom sediments and hydrodynamics.

In the real world many coastal areas, estuaries or rivers have boundaries of a varying degree of softness, which gradually or episodically erode or accrete. Typical related processes are waves hitting the dune, soil mechanical failures like avalanching, abrasion and scour of clay banks. In the current article we will discuss four practical options to model these areas, depending on the physical situation, the model resolution and the time-scales of interest. The cases under consideration are the uniform profile approach, avalanching and dune erosion, dry-wet cell bank erosion and cut cell bank erosion.

2. UNIFORM PROFILE APPROACH

An example of a typical engineering case is the study of the morphological impact of the construction of an island in the near shore area. This study was carried out in the framework of the possible development of a new airport on an island in front of the Dutch coast. For that purpose a 2D model was set up for the coastal domain, using Delft3D-RAM (see Roelvink et al., 2001) including tidal hydrodynamics, waves and morphology. In the RAM approach, the morphological updating is decoupled from the hydrodynamic (waves and currents) and sediment transport models, using a simplified transport model that mimics the reaction of sediment transport to bottom changes. This simplified model is not capable of capturing complex cross-shore processes, even if the resolution would allow it. Still, it was of interest to model the effect of the moving coastline on (mainly longshore) sediment transport rates. In this case a method was needed that would allow the coastal profile to move back and forth in a uniform way, much as is assumed in coastline models. This allowed the use of a single 2DH approach where both the large-scale scour around the proposed island and the effects on the maintenance of the coastline could be assessed.

The method concerned consists of three steps. First, it calculates the amount of sediment eroding and settling above a certain level, for example above the level of relevant wave impact. Secondly, it adjusts the profile above the relevant level by redistributing the same amount of sediment according to a uniform profile. Thirdly, the next time step of the complete model uses the adjusted, uniform profile.

By applying this method it was possible to run the model for relatively long time spans (decades) with representative wave conditions, while avoiding instabilities due to small-scale processes near the boundaries and at the same time allowing for adjustment of the position of the coastline.

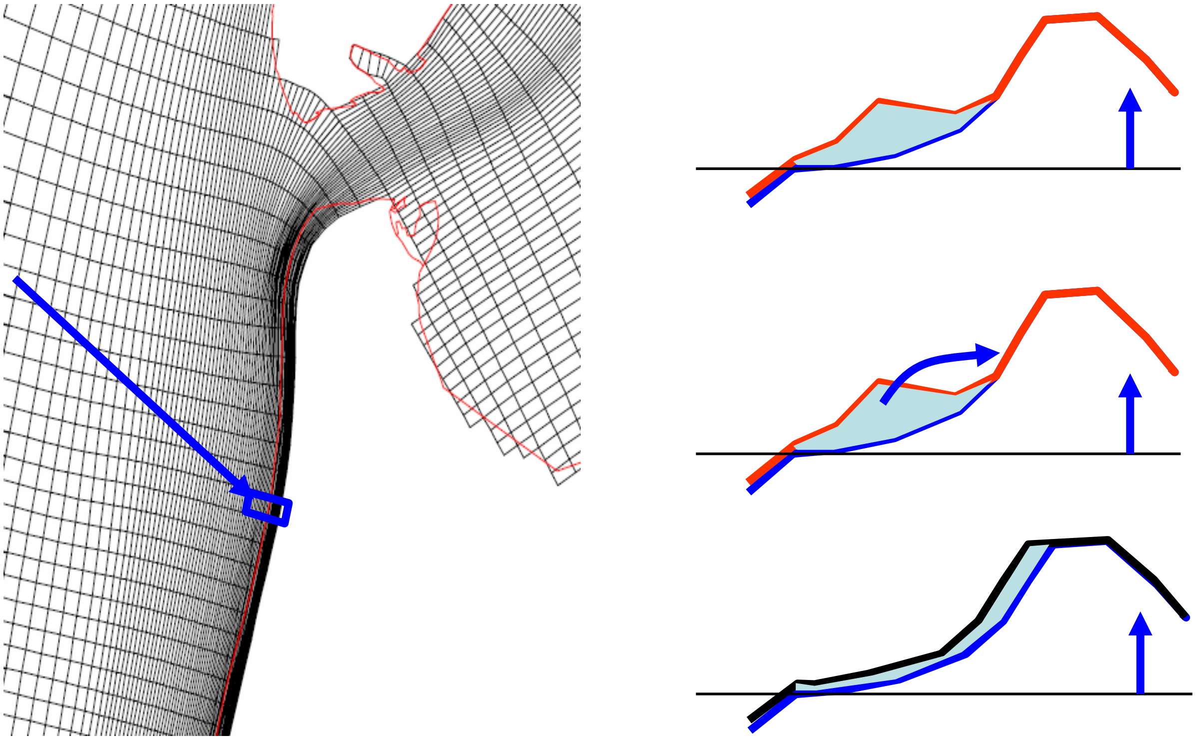

Figure 1 2D Model domain and cross sectional profile at indicated location after 1 timestep and at the start of the next timestep after profile adjustment

3. AVALANCHING AND DUNE EROSION

The process of dune erosion has been studied extensively. Basically, dune erosion can be modeled as function of offshore transport due to return flow, especially taking place during stormy conditions. There are various methods to extrapolate offshore transport taking place at a wet area (and calculated using a process based approach) to the dry dune top, where details of the swash zone processes and geotechnical processes are usually neglected or modeled in a very crude way. The current method follows a similar approach.

The method allows that, at wet cells, hydrodynamic wave conditions are described by a process based approach, including for example wave induced return flow and low frequency surf beat induced by released energy of deep water wave groups. Sediment transport in the wet cells is calculated based on the calculated wave induced velocities, and profile changes can be computed within the wet cells. In the case of strong offshore directed transports this leads to scour just in front of the dunes, but without further measures the dune will not participate in the process and an unrealistically steep profile can be created between the last wet cell and the next dry cell. The process of scouring leads to an ever deeper hole in front of the dry beach/dune, which reduces the amount of wave breaking and undertow; as the scouring process continues, the process slows down, just as it does in the case of erosion in front of a sea wall.

A relatively simple algorithm to avoid this is to introduce avalanching: when the slope between any two points exceeds a given critical slope, the two adjacent depths are adjusted towards that critical slope. However, in reality the slopes above water are generally much steeper than those below water. In the example below we have assumed a slope 1:1 for the dry dune and 3 in 10 for the underwater part. In combination with resolving the low-frequency swash motions, which makes the wet part of the model occasionally reach the dune foot, this simple mechanism made a very big difference in predicting the erosion of the dune and the evolution of the nearshore profile; whereas without the avalanching mechanism the beach profile just lowers and dune erosion is negligible, with the avalanching mechanism the profile evolution very closely matches that observed during a large-scale dune erosion experiment (Arcilla et al. 1994, test 2E).

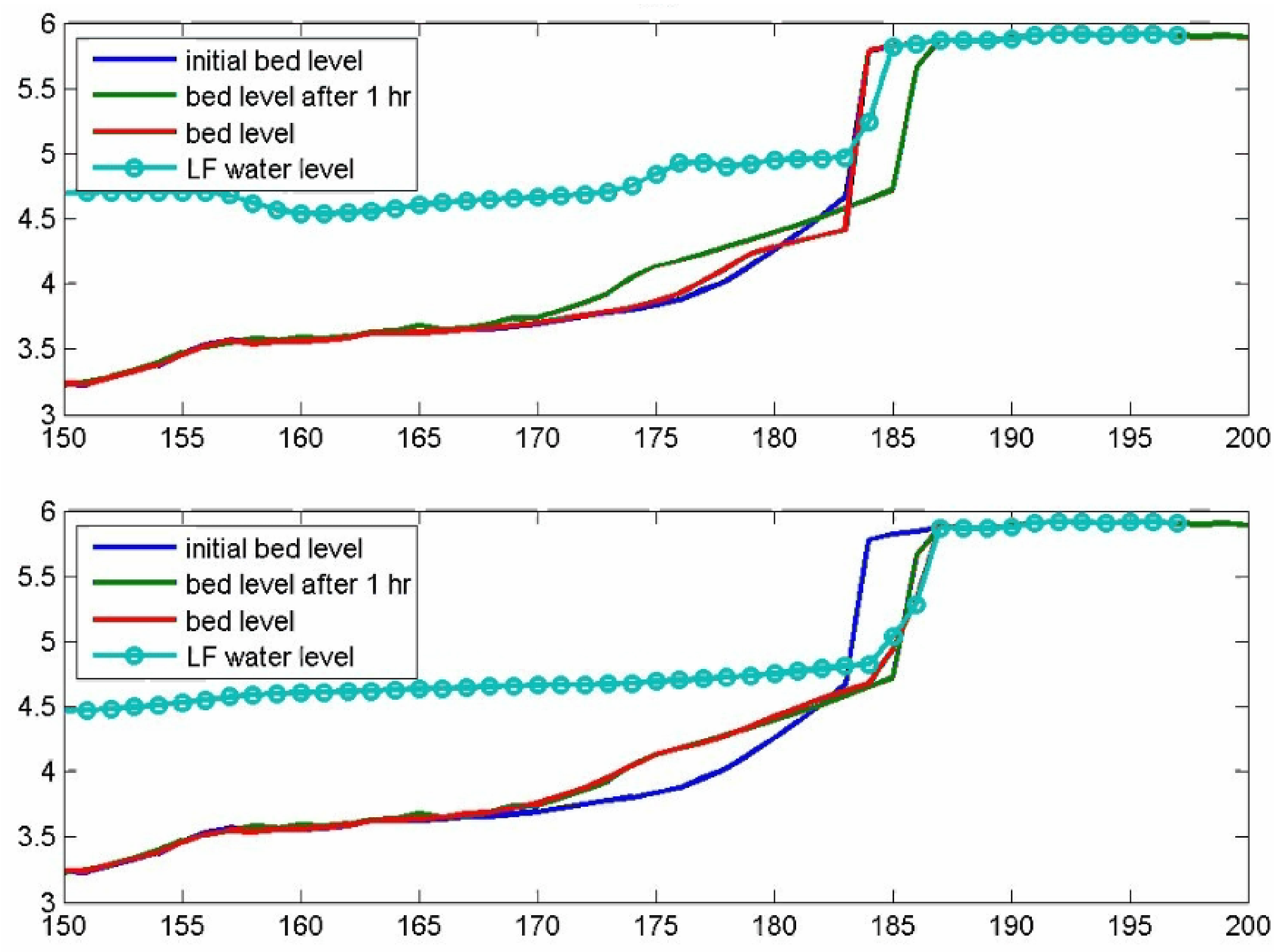

Figure 2 Evolution of upper beach and dune front without (top) and with (bottom) avalanching mechanism. LIP11D Test 2E, first hour.

4. DRY-WET CELL BANK EROSION

As long as the speed of lateral erosion is dominated by events happening under water, simple approaches where the erosion of wet cells is ‘transferred’ to adjacent wet cells, for instance in modeling the lateral growth of breach width in a sand body (e.g. Roelvink et al, 2003) or the long-term evolution of estuarine channels (see Van der Wegen et al., 2006). The basic assumption made in this approach is that it is the speed at which eroded material can be removed, rather than the details of the processes that erode the dry bank or beach, which determines the lateral erosion speed. Every time step the erosion of a wet cell is then partly or fully assigned to the adjacent dry cell, implicitly transporting sediment from the dry cell to the wet cell.

We will clarify the effect of this method with a simple example. Let us take a uniform channel, with width of 200 m and a length of 2000 m, uniform initial depth of 5 m and a current velocity of 1 m/s. At 200 m from the upstream boundary a rectangular patch of dry bank is placed, with bank height 2 m above still water level, length 120 m and width 60 m. The Delft3D system (see Lesser et al., 2004) was applied, in 2DH mode and standard Van Rijn transport formulations, with a Chezy value of 65 and a D50 of 0.2 mm. The bed evolution shown in figure 3 makes it clear that allowing the bank to erode can have a major impact on the evolution. Without the 'dry cell erosion' algorithm, the bank extending into the channel acts as a permanent obstacle, where a scour hole develops at the upstream edge and sand accumulates in the lee. With the algorithm turned on, the initial behavior is similar, but then the hump erodes and can be moved out of the model area.

One can imagine that once a 'dry' cell becomes 'wet', the erosion process in the new wet cell is slow due to the small water depth, the relatively high friction and related small velocities. New wet cells even cannot erode further as erosion is directly passed on to next dry cell. An extra feature of the method would be to make the erosion factor depend on the depth of the new wet cell, allowing maximum erosion only in case of relatively large depths.

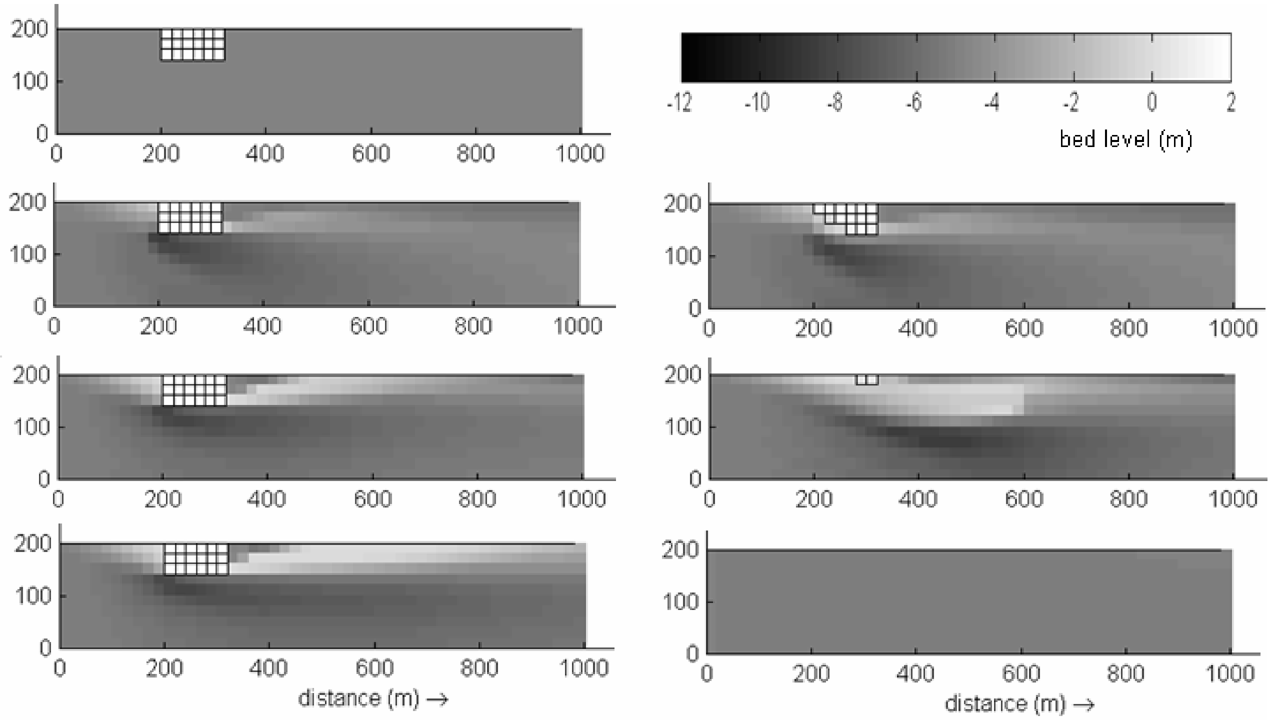

Figure 3. Bed level development without (left) and with (right) allowing for dry-wet cell bank erosion.

5. CUT-CELL BANK EROSION

The cut cell approach assumes a fixed finite difference grid. Normally, all cells are allowed for adjustment of the bed level during model runs. Adjustment of the banks can be allowed by the use of polygons representing the banks of the domain and cutting grids so that the hydrodynamic equations are only applied to the wet part of the cell. Adjustment of the banks per time step is then allowed in a similar way as the bed is updated, i.e. as a function of local shear stresses, sediment or soil properties and/or local slopes.

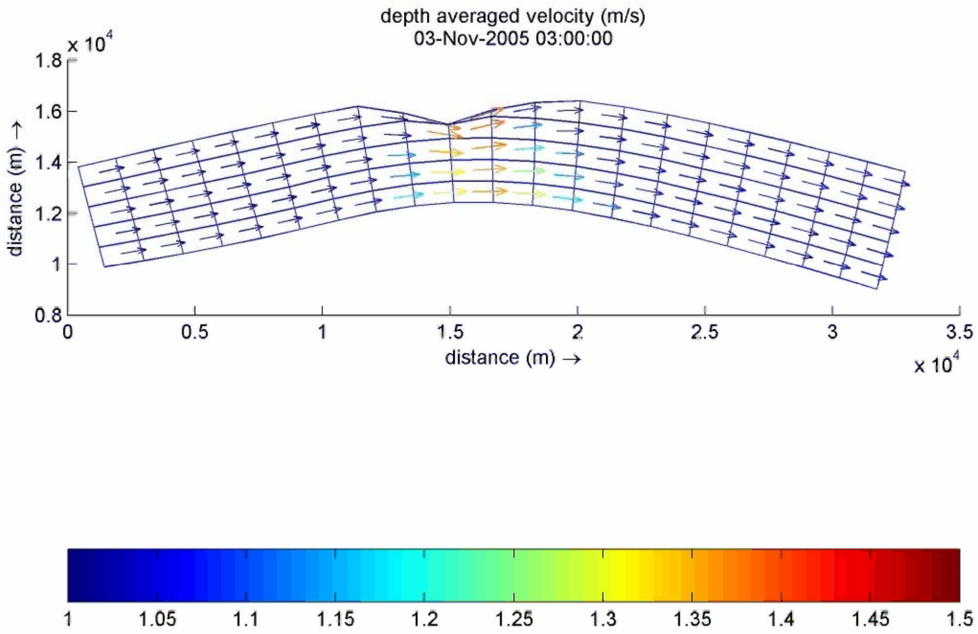

Figure 4. Cut cell approach indicating initial state of the model. The higher velocities at the contraction will result in bank erosion under the assumption of a fixed bed level.

4. DISCUSSION

In the foregoing, four methods have been suggested to include bank erosion in numerical modeling. However, verification of the model results was only partly possible in case of the dune erosion process. All other methods still need verification with measurements in nature or under laboratory conditions. For example, the suggested methods for bank erosion are closely related to ‘normal’ bed related sediment transport processes. Method 3 even explicitly relates the (bank) erosion of dry cells to the bed erosion of the adjacent wet cells. Preferably the processes of bank erosion and bed erosion should be decoupled allowing their own formulations. This would allow for different and independent timescales. An important parameter would be the slope allowed between dry and wet cells and of cells that were wet and are occasionally dry due to tidal processes or wave action.

Further, long term dune erosion processes are also subject to aeolian transport, which is not included in the current model formulations. A next step to obtain reasonable behavior on a time-scale of years is to use empirical relations between the beach width and the rate of retreat or accretion of the dune foot, and to use this to link the beach and dune movement to the behavior of the wet beach.

5. CONCLUSIONS

The current research shows that realistic bank erosion behavior can be obtained with relatively simple methods, as long as the details of the erosion process are not of interest and the speed of erosion is determined by the speed at which eroded material can be removed.

The results gave stable and ‘logical’ results, although verification of the suggested methods is an ongoing effort.

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