BEACH AND NEARSHORE MORPHOLOGY, HYDRODYNAMICS AND SEDIMENT TRANSPORT MEASUREMENTS

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1. INTRODUCTION

The field experiments during April-May 1998 (Egmond-Pilot campaign) and October-November 1998 (Egmond-Main campaign) focused on the morphology, hydrodynamics, sediment transport, and morphodynamics on the intertidal beach and in the barred nearshore. The (non-) uniformity in the alongshore direction of the hydrodynamics and morphology and associated morphodynamics attained a lot of attention, since this was of special interest to the COAST3D project.

The two- and three-dimensional morphodynamics of the beach system is discussed in the next session, together with some remarks about the coupling between the beach and nearshore system. Thereafter, the two- and three-dimensional morphodynamics of the nearshore is presented, followed by some detailed measurements of sediment transports along a cross-shore profile across the inner subtidal bar. Finally, some concluding remarks are made with respect to the improvements of the understanding of the physics of coastal sand transport and morphodynamics, and to the validation of some numerical models regarding hydrodynamics and sand transport

2. BEACH MORPHOLOGY AND HYDRODYNAMICS

De Boer and Kroon (in prep.) studied the morphological changes of the intertidal bars for both Egmond campaigns. The cross-shore profiles of the intertidal beach were almost daily recorded along an alongshore stretch of 1 km and a spacing of 50m. The general frequently observed cross-shore behaviour of the intertidal bars with a generation phase near the low-water line and an onshore migration over the whole intertidal beach up to the high-water line was observed. However, there was a lot of longshore variability in this cross-shore behaviour, with different phases of bar behaviour along the coast. This hindered a direct coupling between the parameterised hydrodynamic conditions and the morphological response.

The presence and longshore spacing of intertidal rip channels at Egmond beach was studied over a year (1998-1999) with the use of the ARGUS images (Meesen, 2000). The smallest longshore spacing (about 200m) was observed under high-energy wave conditions (e.g., Egmond-Main campaign). These rips changed rapidly over time and were not persistent. During low-energy wave conditions, the rip spacing increased (about 400m) and the rips were persistent in time. This persistence was mainly caused by the lack of energy on the beach to transform the feature.

The presence of a horizontal flow circulation on an intertidal beach with a cell topography was studied for a flood period with small waves (H_s = 0.46 m) and a flood period with shore normal incoming waves (H_s = 1.3 m) by Kroon and De Boer (2001). A horizontal flow circulation developed in case of small water depths over the intertidal bar with local relative wave heights over 0.35. In this case, the flow circulation was driven by the onshore mass fluxes of water (Stokes drift and roller flux). The measured mean current velocities in the feeder channel were compared with computed mean velocities, based on the mass flux balance at the intertidal beach and were in the same order of magnitude.

The time-series of beach and inner nearshore morphologies were used to study the relation between the beach volume, the longshore locations of intertidal rip channels (drainage locations) and the depth of the crest of the inner nearshore bar (De Boer, 2000; De Boer and Kroon, submitted). In case of moderate wave energy conditions (H_s range of 0.5-2m) during the Egmond-Pilot campaign, the longshore location of the drainage locations were in line with the locations of low beach volumes in the cross-shore profiles, and with the location of a hardly developed or no inner nearshore bar. In case of high-energy wave conditions (H_s range of 1-5m) during the Egmond-Main campaign, the beach morphology responded with a time lag of O(10^2 hour) to the rapidly changing morphology of the inner nearshore bar. This implied a strong coupling between the morphologies of the nearshore and the beach. Furthermore, the longshore patterns and variations in the inner nearshore bar may be imprinted on the intensity of the rip currents on the beach and/or on the longshore accelerations and decelerations of wave driven longshore currents.

3. NEARSHORE MORPHOLOGY AND HYDRODYNAMICS

The morphological changes of the subtidal bars were studied by Ruessink et al. (2000). They divided the behaviour in two-dimensional and three-dimensional behaviour, with the former corresponding to the overall onshore/offshore bar migration and the latter corresponding to the horizontal amplitude growth, migration or length scale change of quasi-regular morphology, such as crescentic shapes or rip channels. The two- and three-dimensional variability of bar crest positions of the inner and outer bar during the Egmond-Main campaign were determined with the use of the bathymetric surveys of the WESP and with the use of ARGUS video-images of breaking-induced foam. The inner-bar crestlines were analysed with complex empirical orthogonal function analysis. The results of this analysis showed that 85% of the variance was in the first complex mode and corresponded to an amplitude growth and alongshore migration of a non-uniformity (‘crescentic shape’) with an alongshore length of about 600 m. The alongshore migration rate varied between 0 and 150 m/day and was well related to the alongshore component of the offshore wave energy flux. The second complex mode (10% of the variance) described the alongshore-averaged cross-shore bar migration. The main result of the morphological changes of the inner nearshore bar-lines is that the short-term variability in bar-crest position (days to weeks) is supposed to be mainly caused by the alongshore changes in the quasi-regular topography (alongshore non-uniformity). The long-term variability in inner bar-crest position (years to decades) is supposed to be caused by the alongshore-uniform onshore/offshore bar behaviour. Thus, the answer to the question whether the 2.5D Egmond system is to be regarded as a 2D system or a 3D system depends on the time scale of interest.

In Ruessink et al. (2000), morphological data from direct in-situ surveys and from indirect remote-sensing sources were fused. This was made possible by a detailed study on the relationship between high, breaking-induced intensities in the video images and the underlying barred morphology, see for detailed results Van Enckevort and Ruessink (submitted), Kingston et al. (2000) and Ruessink et al. (in prep.). The intensity-based bar crest positions of the video images differed from the bathymetric data by a time-varying distance of about O(10m). The exact difference in position is a function of the offshore wave height, the water level and the bathymetry itself. In case of a non-saturated wave field, the video-based intensity position and the bathymetric derived or modelled (roller maximum) positions moved offshore with a decrease in water level or an increase in wave height. In case of a saturated wave field, the time-varying distance between video-based intensity positions and the measured (bathymetry) and modelled positions were only a function of the waterlevels. Model computations further showed that an increase of the depth of the outer bar crest (final stage of the inter-annual nearshore bar cycle) reduced the outer bar differences and increased the inner bar differences between video-based intensity positions and predicted roller maxima. The findings mentioned here for the video technique apply also to bar crests positions estimated from time-averaged X-band radar images (Ruessink et al., in prep.)

The detailed hydrodynamics of especially the alongshore-current distributions over the troughs and bars is studied by Ruessink et al. (submitted). The measurements of the mean alongshore currents over the inner nearshore bar were compared with the results of a one-dimensional (along a cross-shore profile) time-averaged and depth averaged alongshore momentum balance between forcing, bottom stresses and lateral mixing. The forcing components included breaking waves, winds and alongshore surface slopes over 10 to 100 km length. The input data were collected during the Egmond-Main campaign and include a wide range of conditions with maximum mean currents of 1.4 m/s. The inclusion of the roller effect in the wave forcing improved the predictions of the mean currents compared to a model without rollers.

Ruessink et al. (submitted) further studied to what degree the performance of their alongshore current model depended on the degree of alongshore non-uniformity in the bathymetry. To that end, they quantified this non-uniformity as a nondimensional metric, χ^2, defined as the spatially averaged and normalized squared difference between the depth d(x,y) and the alongshore (y) averaged cross-shore depth profile d(x)

$$\chi^2 = \frac{1}{LxLy} \int_0^{Lx} \int_0^{Ly} \left(\frac{d(x,y) - \bar{d}(x)}{\bar{d}(x)} \right)^2 dy\, dx$$

where Lx and Ly are the cross-shore and alongshore length of the survey region, respectively. It was found that the one-dimensional model performance was independent of χ^2 for $\chi^2 < 0.02$. In other words, even though the bathymetry showed some alongshore non-uniformities, their effect on the alongshore current distribution was negligible. However, for $\chi^2 > 0.02$, mainly observed in the second part of the campaign, the model skill deteriorated in the trough (but not seaward of the bar crest). This implies that alongshore currents induced by alongshore non-uniformities in bathymetry were most pronounced in the trough, consistent with earlier model and laboratory studies. Further work is needed to determine if χ^2 is a robust indicator of effects of alongshore non-uniform bathymetry on nearshore hydrodynamics. If it is a robust indicator, then χ^2 may be used to decide whether or not one wants to rely on a profile or an area model.

4. SEDIMENT TRANSPORT MEASUREMENTS

Suspended sand transport measurements carried out on a meso-tidal beach at Egmond were used to examine the sand suspension mechanism and transport rates under waves. Two tests measured under similar wave conditions showed very different suspension patterns, due to different scales of suspension related to the bed form dimensions.

The effects of the hydrodynamic conditions and bed form dimensions on the time-averaged suspended sediment concentrations and depth-integrated suspended sediment transport were studied in detail. The measurements of wave height, velocity, and sediment concentration at four or five locations in a cross-shore array over the inner nearshore bar were performed using the Coastal Research Instrumented Sledge (CRIS). Sand transport measurements were performed at eight elevations above the bed from 0.02 to 1.0 m. The depth-integrated suspended transport rates ($q_{suspension}$) were determined using the measured time series of velocity and concentration. Two records of surface elevation, currents and suspended sand concentrations showed that the bed form dimensions were a major control in the sediment suspension mechanism. The bed form roughness was used as a key parameter in the modelling of the sand concentrations.

The relation between suspended sand concentrations, the near bed orbital velocities and the bed forms is shown in Figure 1. The solid line in this figure indicates the concentrations at 0.02 m above the bed, the dashed line at 0.04 m and the dotted line at 0.10 m above the bed. Each data point in this graph is the average of 10 or more tests with the same onshore orbital velocity. The error bars show the standard error between those 10 tests. The near bed concentrations remained more or less constant for orbital velocities between 0.32 and 0.89 m/s and increased for larger values. The bed forms generally changed from rippled bed for calm conditions to flat bed or mega ripples for mild storm conditions.

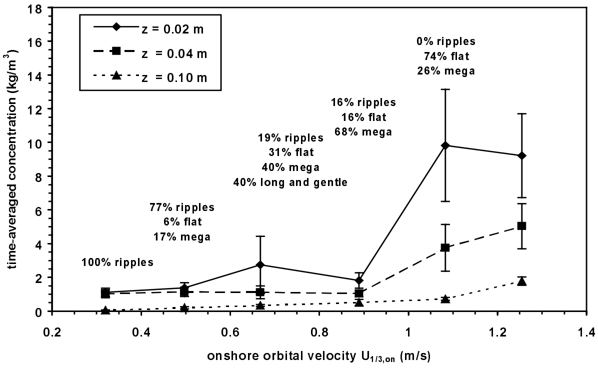

Figure 1 Class- and time-averaged near bed concentrations and bed form type as a function of peak onshore orbital velocity.

The difference in suspension pattern between a flat bed and a rippled bed under the same offshore conditions was studied for two records. In case of a flat bed, the suspension process was intermittent and the suspension events were related to groups of high amplitude waves in which the maximum concentration at 0.02 m above the bed was about 2 kg/m^3. The concentrations over a rippled bed were larger with showing peak values of nearly 5 kg/m^3 and the suspension events were more related to individual waves. The sand transport rate was also modelled (TRANSPOR2000; Van Rijn, 2000) and ran with measured wave height, depth-averaged cross-shore and longshore velocities, orbital velocities, and sediment parameters. The model underestimated the vertical mixing for calm conditions and thus underestimated the measured values. A bed roughness height of 0.02 m or 0.03 m gave best results under calm conditions and a value of about 0.02 m was best for mild-storm conditions. The model also underestimated the near bed concentrations for mild storm conditions. However, the model represented the general trend in the measured transport rates fairly well using a fixed bed roughness height of 0.02 m, which was in line with the bed form height.

Despite a wide range of bed form dimensions found in the field, the general trend of the data could be reasonably well predicted using a numerical model. Driven by the locally measured hydrodynamics and using a fixed bed roughness height the model predicted the current-related suspended transport rates near Egmond showed reasonably good agreement with measured values (based on tuning of bed roughness to a height of 0.02 m for both calm and minor storm conditions). The vertical sorting of sediment was important under calm conditions and should be taken into account in the model computations (multi-fraction mode). Encouraging agreement was found between the measured and computed current-related transport rates (within a factor 2) after tuning of the bed roughness.

5. CONCLUDING REMARKS

The COAST3D field experiments at Egmond gave us the opportunity to improve our understanding of the physics of coastal sand transport and morphodynamics, and to the validate some of our models regarding hydrodynamics and sand transport.

The main findings of the Egmond field experiments are related to the relative importance of two- and three-dimensional aspects in the morphodynamics. These findings are:

- A three-dimensional cell morphology with an intertidal bar, a feeder channel and a rip is often observed on the Egmond beach. The associated horizontal cell circulation pattern (onshore mass flow over the bar, alongshore mass flow through the feeder channel and offshore flow through the rip) is only observed during moderate wave energy conditions. The cell morphology is more or less inherited during low energy wave conditions. During high energy wave conditions, the increase of water levels on the beach due to the wave set-up and storm surge levels causes an extra undertow that transport the sediment off the beach. After the initial formation of small rips through the intertidal bar, the profile flattens. Morphodynamic modelling efforts are still in its infancies due to the small water depths and hardly understood sediment fluxes due to non-linear waves (bores and swash).
- The location of the rips and the net volume of the beach is often related to the inner nearshore morphology. The alongshore variability on the beach is strongly related to the depth of the crest of the inner nearshore bar and seems to follow its behaviour in time.
- The inner nearshore morphology showed a short-term variability in bar-crest position (days to weeks) caused by the alongshore changes in the quasi-regular topography (alongshore non-uniformity). The long-term variability in the inner bar-crest position (years to

decades) is supposed to be caused by the alongshore-uniform onshore/offshore bar behaviour. This means that morphodynamic modelling efforts of the inner nearshore have, in some way, to incorporate the alongshore variability in morphology in order to get reliable short-term predictions. Possible ways forward are use of a profile model with a cross-shore profile, averaged in the alongshore direction, or of an area model.

- Modelling of the alongshore current across the inner bar showed that the performance of a model that neglects alongshore bathymetric variation still results in accurate predictions of the alongshore current structure in the case of weak bathymetric variations. Apparently, the effects of the non-uniformities on the hydrodynamics are small in this case. However, with increasing non-uniformities in morphology, the model skill deteriorated, particularly in the inner bar trough. The skill of this profile model was found to depend on χ^2, computed as the spatially averaged and normalised squared difference between the depth profiles and the alongshore averaged cross-shore depth profile. It is unknown whether χ^2 also applies to other aspects of the hydrodynamics, such as the undertow. If it does, then the parameter χ^2 could be used to decide whether or not it is justified to simplify a 2.5D system to a 2D system from a hydrodynamical point of view.
- The detailed measurements of the local hydrodynamics and suspended sediment concentrations over the inner nearshore bar offered a first validation set to improve the vertical distribution of the suspended sediment fluxes and to test the influence of natural bed forms on these distributions.

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