

EFFECT OF SURFACE ROLLERS ON THE FORMATION OF CRESCENTIC BARS: LARGE ANGLES OF INCIDENCE.

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The formation of crescentic bars is examined using a morphodynamic model based in linear stability analysis. The effect of surface rollers for off-normal wave conditions is examined. The effect of the rollers is to increase the e-folding times with increasing the angle of incidence. For angles large enough the formation of crescentic bars is even inhibit. The main effect of the rollers it be through hydrodynamics. The longitudinal changes in current produced by the rollers cause the maximum of sediment concentration to be shifted towards the coast with the final effect of prevent the formation of crecscentic bars.

Keywords: crescentic bars, rip chanel, surface rollers, morphodynamics, surfzone.

INTRODUCTION

The effect of surface rollers on the formation of crescentic bars/rip channel systems (for a description of these features see van Enckevort et al., 2004) is examined with a morphodynamic model. During wave breaking energy is transferred to surface rollers and subsequently, this energy is dissipated into the water masses generating currents and surface setup. To accurately predict mean alongshore currents it is essential to consider the roller contributions (Ruessink et al., 2001). Moreover, turbulent bores, generated by surface rollers, increase sediment resuspension in the surf zone (Voulgaris and Collins, 2000).

Coastal morphodynamic models have generally neglected the effect of rollers. The study of Ribas et al. (2011) however show that accounting for the stirring of sediment by surface rollers, trough turbulent bores, is essential to simulate and interpret the formation of inner-surfzone transverse sand bars. Reniers et al. (2004) modelled rip channel formation taking into account the rollers. Unfortunately, Reniers et al. (2004) do not investigate specifically the impact of consider the surface rollers, and their contribution to sediment transport, on the overall results. Calvete et al. (2011) in investigation the effect of the rollers of surface rollers on crescentic bars for different angles and they conclude that surface rollers inhibit their formation for large angles of incidence.

The objective of this work is to study the mechanism that inhibits the formation of crescentic bars for large angles of incidence. Results with a model including rollers will be compared with those of Calvete et al. (2005) that did not consider the effect of the rollers. The paper is organized as follows. In the next section the numerical is presented, then follows the numerical results and ends with discussion and conclusions.

THE MODEL

The model used in the present study is based in the model of Ribas et al. (2012). This model describes feedbacks between depth-averaged currents, waves and rollers and the bed, allowing for the development of bedfoms that are the results of self-organized processes.

In this model the energy dissipated by breaking feeds the surface rollers. The wave- and depth-averaged roller energy balance is an extension of the one proposed by Reniers et al. (2004),

$$\frac{\partial(2E_r)}{\partial t} + \frac{\partial}{\partial x_j} (2(v_j + c_j)E_r) + S_{jk}^r \frac{\partial v_k}{\partial x_j} = -\mathcal{D}_r + \mathcal{D}_w \quad j, k = 1, 2 \quad (1)$$

where E_r is the energy of the roller and S_{jk}^r are the radiation stresses due to roller propagation computed following Svendsen (1984), and c_j the phase speed. Finally, the roller energy dissipation rate, $\mathcal{D}_r$, is modeled following Ruessink et al. (2001). The fluid motions are governed by the wave- and depth-averaged mass and momentum balance equations, where the radiation stresses due to both wave and roller propagation are included.

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The volumetric sediment transport is modeled as depth-integrated volumetric sediment concentration (C_{di}) advected by the depth-averaged current, as proposed by Soulsby (1997):

$$q_i = C_{di} \left(v_i - \Gamma \frac{\partial h'}{\partial x_i} \right) \quad i = 1, 2 \quad (2)$$

The depth integrated concentration, C_{di} , includes an extra term due to the stirring of sediment created by the bore induced turbulence, following Reniers et al. (2004). It reads

$$C_{di} = A_s \left(\left(|\vec{v}|^2 + \frac{0.018}{c_D} u_{rms}^2 + n_{rol} u_{rol}^2 \right)^{0.5} - u_{crit} \right)^{2.4} \quad u_{rol} = \left(\frac{\mathcal{D}_r}{\rho} \right)^{1/3} \left(e^{(D/H)} - 1 \right)^{-1/2} \quad (3)$$

where the parameter A_s accounts for the sediment properties, u_{rol} is a representative turbulence velocity of the vortices created after roller energy is dissipated, n_{rol} is a constant parameter and u_{crit} is the threshold flow intensity to transport sediment. For further details about this model we refer to Ribas et al. (2012).

This system of equations is first solved to find a morphodynamic equilibrium (steady bottom), i.e. a basic state, for an alongshore uniform bottom topography and a particular forcing wave conditions (wave period, wave height and wave direction) on the offshore boundary. The stability of this state is subsequently analyzed by performing a linear stability analysis. The output of the linear stability analysis is the spatial pattern, alongshore periodicity, growth rate (or e -folding growth time) and migration velocity of the fastest growing mode (FGM).

In order to analyze the effects of surface rollers numerical experiment for this model and a reduced version of this model that excludes the effect of the rollers has been also used. On this model radiation stresses due to rollers, S_{jk}^r , and the representative turbulence velocities of the vortices created by rollers, u_{rol} , are has been cancelled.

RESULTS

All numerical experiments have been done for an alongshore uniform topography with an alongshore bar located at 80m from the shore and at 1.5m depth. This profile is the same as the one used by Yu & Slinn (2003). Figure 1 shows the basic states for the two model in the case of an intermediate angles of incidence. This figure shows that the effect of the surface rollers on the longshore current is to increase it on the trough area and to shift the maximum of the current to the shore. The depth-averaged sediment concentration is increased on the bar and the maximum is also shifted to the coast. The large increase of the depth-averaged sediment concentration close to the shore is in control of the formation of surfzone transverse finger bars, see Ribas et al. (2012).

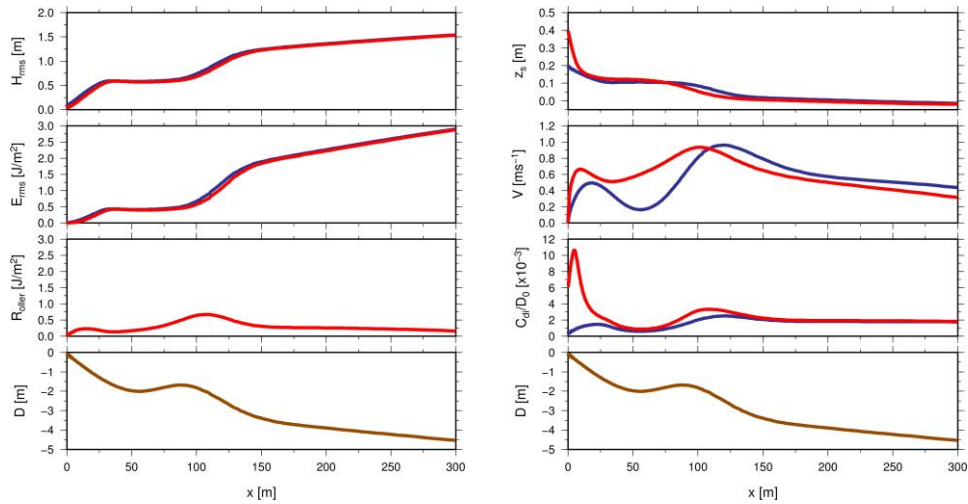


Figure 1. Basic state solution obtained for the default case study for wave period $T_w=8.0s$, wave height $H_{rms}=1.5m$ and offshore angle of incidence $\theta_\infty=25.0^\circ$. Left panels, from top to bottom: wave height, wave energy, roller energy and bed level. Right panels, from top to bottom: free surface elevation, longshore current, depth-averaged sediment concentration and bed level. Red lines for the full model results, blue lines for computations excluding the effect of the rollers.

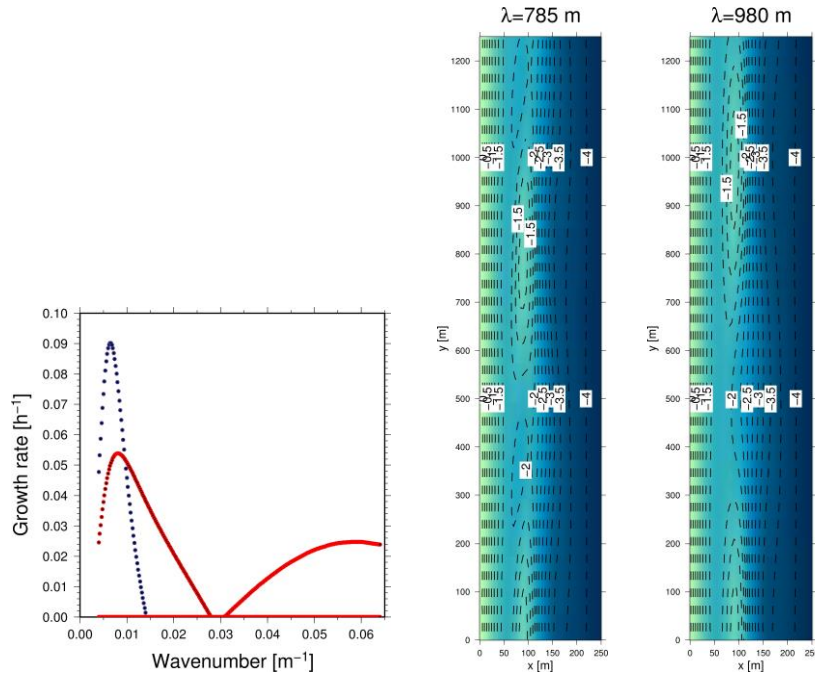


Figure 2. Left: Growth rate curves for offshore wave conditions of $T_w=8.0s$, $H_{rms}=1.5m$ and $\theta_\infty=25.0^\circ$. Red dots for the full model, blue dots for computations excluding the effect of the rollers. Right panels: bedform patterns of the FGM for the full model (left) and the model excluding the rollers (right).

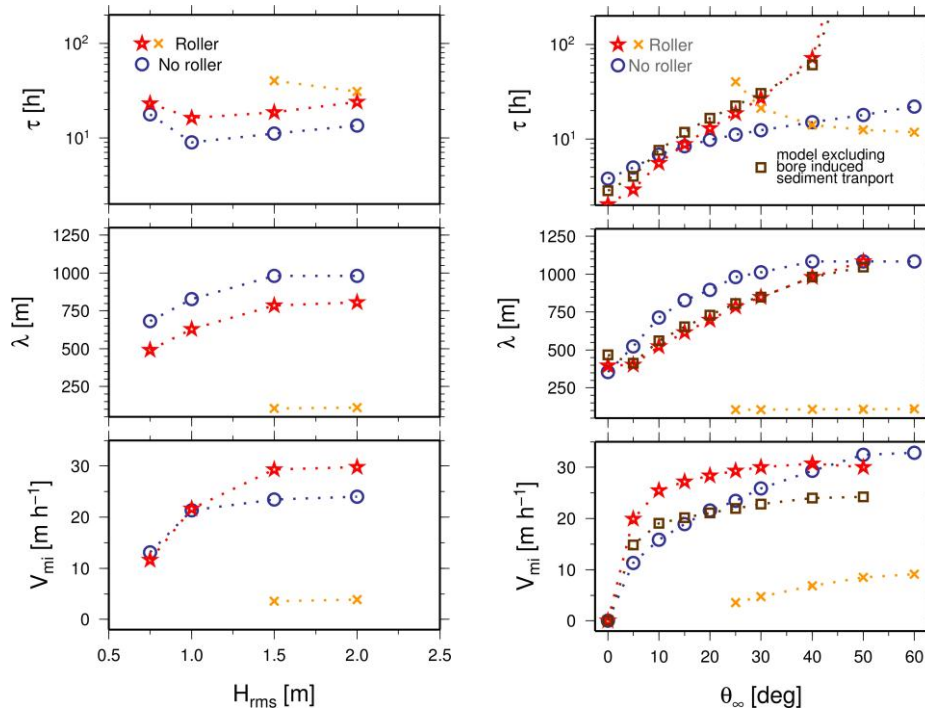


Figure 3. Comparison of results with (red stars) and without rollers (blue circles). From top to bottom, e-folding growing time, spacing and migration speed for crescentic bars with different offshore condition. Left: Wave height exploration for $T_w=8.0s$ and $\theta_\infty=25.0^\circ$. Right: Wave angles exploration for $T_w=8.0s$ and $H_{rms}=1.5m$, wave incidence angles. Black squares correspond to a modified model the includes the effect of the rollers only in the hydrodynamics.

Figure 2 shows the positive eigenvalues corresponding to the basic state show in Figure 1. For this particular condition the FGM for the model with rollers have a wavelength $\lambda=785\text{m}$, an e-folding time $\tau=19\text{h}$ and a migration celerity $V_m=29\text{m/h}$, whilst for the model without rollers the FGM has $\lambda=980\text{m}$, $\tau=10\text{h}$ and $V_m=24\text{m/h}$. In both cases the FGM correspond to crescentic bars, see figure 2.

Systematic explorations varying offshore wave conditions have been: wave periods T_w of 6.0s, 9.0s and 10.0s; wave heights H_{rms} of 0.75m, 1.0m, 1.5m and 2.0m; and offshore angles of incidence θ_∞ between 0° and 60.0° . Results of both models show similar behavior with respect changes in wave period and wave height see figure 3. For low energy and short period waves the instability disappears. In the experiments for medium or large wave energy conditions, see figure 3., the model without rollers finds growing patterns for all wave angles, whereas the model with rollers growing patterns with long wavelengths are found for very oblique waves. For angles large enough the formation of crescentic bars is even inhibit. This is in good accordance with observations, see Wright & Short (1984). The effect of the rollers on the spacing and migration of the crescentic bars is minor.

In order to get more insight into the effect of the rollers simulations with a third model, that includes the rollers in the hydrodynamic model but ignores the contribution of turbulent bores in the sediment transport parameterization by doing $n_{roll} = 0$ in equation (3), were carried out. Results from this model are also plotted in Figure 3 with black squares. Since the behavior of the third model is similar to the one obtained with the model including rollers on both the hydrodynamic and the sediment transport, the main effect of the rollers for crescent bars is in the hydrodynamics. The effect of the turbulent bores on sediment transport is negligible. Note that, in constrast to this results, the transport caused by turbulent bores is essential to generate oblique finger bars (Ribas et al., 2012).

To understand the different behavior of the model with and without rollers it is convenient to compare the results for large angles of incidence. Figure 4 shows differences between the two models for large angles of incidence ($\theta_\infty=40.0^\circ$). On the top three panels the longshore current, depth-averaged sediment concentration and bed level of the basic state are plotted. An important difference between the two models is that the maximum of the depth-averaged sediment concentration has been shifted towards the coast in the model with rollers with respect the model without rollers. This shift, that is small for near normal wave condition and increases for large angles of incidence, is consequence of the changes in the longshore current due the rollers.

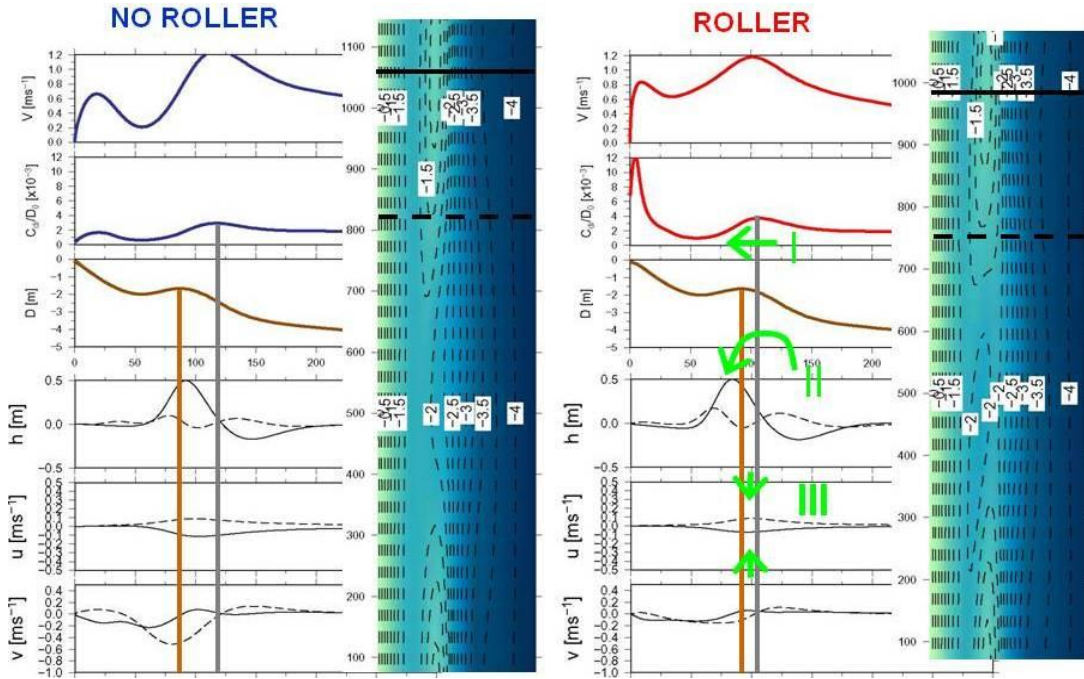


Figure 4. Comparison of results for large angles of incidence ($T_w=8.0\text{s}$, $H_{rms}=1.5\text{m}$ and $\theta_\infty=40.0^\circ$) of the model with (right) and without rollers (left).

The lower three panels of figure 4 shows, from top to bottom, the perturbation of the bottom and cross-shore and longshore velocities. On these panels the continuous lines correspond to a cross-shore profile at the crest of the bar for the corresponding magnitude. Dash lines are profiles located between the crest of the bar and the channels. The perturbation of the bottom is also shifted toward the shore in the results of the model with rollers. The shift is due to the corresponding shift in the depth-averaged sediment concentration. A third important difference between the two models is that the perturbation of the cross-shore velocity diminishes for large angles at the model that include the rollers.

CONCLUSIONS

The formation of crescentic bars is examined using a morphodynamic model based in linear stability analysis. The effect of surface rollers for off-normal wave conditions is examined by comparing the results with a model without rollers. The main conclusion are the following:

- The main effect of the rollers is to inhibit the growth of crescentic bars for large angles of incidence.
- Rollers focus of sediment towards the crest of the bar inhibiting the development of crescentic bars.
- The effect of the rollers on the spacing and migration of the crescentic bars is minor.
- For crescentic bars, the effect of the turbulent bores on sediment transport is negligible.

The validity of these conclusion would have to be supported by field measurement of the concentration of sediment on a longshore bar and, on the model context, by nonlinear models.

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