A New Shoreline Instability Mechanism Related to High-Angle Waves

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1. Introduction

The alongshore wave driven sediment transport can render a rectilinear coastline unstable in case of very oblique wave incidence. This can be seen by looking at the total alongshore transport rate Q (m^3/s), which can be parameterized, for instance, by the CERC formula:

$$Q = K H_b^{5/2} \sin 2(\theta_b - \phi) \qquad (1)$$

where K is an empirical constant, H_b is the wave height at breaking, θ_b is the angle between wave fronts at breaking and mean shoreline orientation and ϕ is the angle of the local shoreline. For ϕ=0, keeping H_b constant and varying θ_b, Q has a maximum for $\theta_b = 45^o$, and this has been recognized as the source of the instability for $\theta_b > 45^o$ (Zenkovitz, 1959). But because of wave refraction wave angle at breaking is hardly larger than 45^o and shoreline instability would rarely occur in nature. If one assumes that a change of the shoreline is linked to the same change on the bathymetric contours up to deep water and that these contours are approximately rectilinear, Q can be cast as a function of the wave angle in deep water, θ_0, in such a way that it has a maximum for $\theta_0=42^o$. As a result, the shoreline is unstable if $\theta_0>42^o$, which is not uncommon (Ashton et al., 2001). The hypotheses of the latter study are very strong but Falqués and Calvete (2005) (and others later on) showed that realistic bathymetric changes linked to shoreline changes could also lead to the instability provided that they reach deep enough into the shoaling zone. The aim of this contribution is: i) showing that wave angle at breaking can be larger than 45^o in some cases, ii) showing that the instability can occur in this case without involving bathymetric changes in the shoaling zone (which are essential for the traditional high-angle wave instability, where $\theta_b < 45^o$) and iii) exploring the features emerging from the instability and their typical length and time scales.

2. Preliminary results using a one-line type model

We have used a linear stability model (1D-morfo) based on the one-line shoreline approximation that is capable of describing shoreline instabilities associated to high-angle waves (Falqués and Calvete, 2005). High angles at breaking, θ_b, are more easily found in case of locally generated wind waves in shallow enclosed water bodies. Therefore, we focus in small short period waves with high angles in relatively shallow water. We assume waves of H_s=0.35 m, T_p=1.4 s with an angle $\theta=70^o$ at a water depth, D=1 m. By assuming $\gamma_b = (H_{rms})_b/D_b=0.5$, these waves break approximately at D_b=0.34 m with an angle $\theta_b = 45.1^o$. By assuming that the shoreline perturbation does not reach beyond the surf zone, i.e., $D_c=D_b$, we have computed the growthrate, σ, as a function of the alongshore wavelength, L. It is seen that shoreline undulations of any wavelength can emerge and σ grows without bound when $L \rightarrow 0$. Thus, in contrast with the traditional high-angle wave instability ($\theta_b < 45^o$, $D_c>D_b$) there is no preferred wavelength.

3. Discussion

Shoreline instability is driven by the alongshore gradients in Q in case of an undulating shoreline. These gradients come from the gradients in ϕ, H_b and θ_b in equation (1). If $D_c=D_b$, the waves do not feel any bathymetric perturbation before breaking, with the result that the undulations in the shoreline do not cause gradients in H_b and θ_b. In this case, the governing equation for the shoreline displacement (one-line approximation) is a diffusion equation with positive (negative) diffusivity if $\theta_b < 45^o$ ($\theta_b > 45^o$) (Falqués, 2003). The free wave-like solutions of a diffusion equation with negative diffusivity, $\varepsilon < 0$, have a positive real growthrate $\sigma = -\varepsilon/L^2$, which is well reproduced by the 1D-morfo model. But it is obvious that this behaviour is unrealistic as the one-line approximation is only valid at length scales larger than the surf zone width. Thus, the 1Dmorfo instability curve is only valid for $L > \sim 50$ m and for smaller wavelengths surf zone processes might interact with the basic instability driven by the littoral drift described by 1D-morfo. As a result, the $\sigma(L)$ curve would have a maximum for some L_m, hence determining a characteristic wavelength. This requires, however, the use of a fully 2DH morphodynamic model and work is in progress in this line. The present research has been motivated by the fact that complex morphologies are very frequent at the shores of shallow enclosed water bodies as lakes, basins and bays.

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