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Periodic Wave Shoaling Over Barred-Beaches in a Fully Nonlinear Numerical Wave Tank

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ABSTRACT

A numerical wave tank based on fully nonlinear potential flow theory is used to calculate changes in local properties of periodic waves shoaling over barred-beaches. Results show that highly nonlinear wave decomposition phenomena occur over the bars. These are analyzed in detail and discussed in the paper.

KEYWORDS : Numerical wave tank, shallow water wave transformations, coastal engineering.

INTRODUCTION

Bars on beaches are important topographic features for many coastal engineering problems. For sufficiently high incident waves, shallow berms, and steep side slopes, bars induce large wave modulations, mostly on their onshore side, and, as a result, significant variations with depth of wave parameters such as celerity c, height H, and front to back asymmetry s_2/s_1 (Fig. 1). As we will see, these modulations result from highly nonlinear wave decomposition phenomena occurring when waves propagate into the deeper water region beyond the bar.

Such decomposition phenomena have been well observed, over submerged obstacles, shelves, or bars, in the field (e.g., Byrne, 1969; Young, 1989) and in the laboratory (e.g., Beji and Battjes, 1993). They were analyzed and modeled using weakly nonlinear and weakly dispersive Boussinesq equations (BE) (e.g., Freilich and Guza, 1984; Seabra-Santos et al., 1987) or low-order Stokes-type expansions (e.g., Massel, 1983; Rey, 1992; Rey et al., 1992). Driscoll et al. (1992) and Ohyama and Nadaoka (1994) used models based on Fully Nonlinear Potential Flow (FNPF) theory to calculate periodic wave propagation over submerged rectangular obstacles. They showed that, for large wave height to depth ratios over the obstacles, to correctly describe wave decomposition, the strong nonlinearity in the wave field requires using a fully nonlinear method in which both wave shape and celerity are correctly calculated. This was also observed by Grilli et al. (1994) who studied the propagation of large solitary waves (breaking and non-breaking) over submerged trapezoidal breakwaters, using both a FNPF model and laboratory experiments. For waves propagating over steep obstacles on a flat bottom, Driscoll et al. (1992) and Ohyama and Nadaoka (1994) showed that higher harmonics are generated as bound waves in the shallower water region over the obstacle, and then released as free waves beyond the obstacle, where wave nonlinearity is weaker due to the deeper water depth. The initial harmonic generation depends on the dimensions of the obstacle (i.e., berm depth and width) and on incident wave period (i.e., wavelength) and height (i.e., incident steepness).

Grilli and Horrillo (1996,1997b) used a FNPF *Numerical Wave Tank* (NWT) to calculate nonlinear properties of periodic waves, of height H_o and period T in deep water, shoaling over "cylindrical beaches", i.e., beaches with *monotonously decreasing and mildly sloping* depth variation $h(x)$. Their two-dimensional (2D) NWT combined (Grilli et al., 1989; Grilli and Subramanya, 1996; Grilli and Horrillo, 1997a) : (i) a higher-order Boundary Element (BEM) solution of Fully Nonlinear Potential Flow (FNPF) equations; (ii) an exact generation of finite amplitude periodic waves (*Streamfunction Waves*) at the deeper water extremity (Γ_{r1}); and (iii) an *Absorbing Beach* (AB) at the far end of the tank (featuring both free surface absorption on Γ_f and lateral active absorption on Γ_{r2}; Fig. 1). A feedback procedure was developed to adaptively calibrate the beach absorption coefficient so as to absorb the period-averaged energy of waves entering the AB at $x = x_l$. After absorption of initial transient waves, computations in the NWT reached a *quasi-steady* state for which reflection from the AB was shown to be very small. Nonlinear properties of shoaling waves were calculated and validation tests were performed to assess their sensitivity to the AB location and to the resolution of the spatial discretization. Numerical results were also compared to laboratory experiments for periodic wave shoaling and propagation over a bar (Beji and Battjes, 1993). All the tests were found satisfactory.

Using this validated NWT, Grilli and Horrillo (1997b) (GH) calculated the shoaling of waves of various heights and periods over 1:35, 1:50, and 1:70 slopes, both plane and natural (i.e., with a bathymetry following Dean's (1991) equilibrium beach profile), up to very close to the breaking point. Both local (H, c, L,...) and integral properties of shoaling waves were calculated and, due to the low reflection from the slope and the AB, found to be very repeatable for successive waves. For various mild slopes, nonlinear properties of waves of different height and period but same deep water steepness k_oH_o were found to be almost identical when compared at the same relative depth kh. In the shallower water region, linear, weakly nonlinear, and higher-order steady wave (Sobey