NUMERICAL MODELING OF EROSION AND OVERWASH OF VEGETATED DUNES

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Paper topic: Beach morphodynamics and sediment transport

1. Introduction

Coastal dunes and sandy beaches protect coastal areas against the destructing effect of storm surge and waves. Nowadays, increasing storm surge and waves as a result of global warming and sea level rise have made coastal dunes as an essential part of beach nourishment projects. In order to increase the protective ability of the dunes and reduce the dune erosion and overwash vegetation has been used as an effective natural defense. The field data by Hayashi et al. (2010) indicated that woody plants on a natural dune appeared to have prevented overwash during a severe storm. However, the effect of vegetation on dune erosion and overwash during storms has never been included in the process-based numerical models.

In this study, the cross-shore process-based numerical model CSHORE is expanded to include the vegetation effects on the hydrodynamics and sediment transport. The expanded CSHORE is compared with the exploratory experimental data by Gralher et al. (2012) who conducted five tests to examine the effects of woody plants on erosion and overwash of high and low dunes. Table 1 summarizes the five tests conducted in sequence. The comparisons of the profile evolution, wave overtopping rate, q_o and sediment overwash rate, q_{bs} data are conducted for all 63 runs in the five tests HW, HN, HB, LW and LB. Furthermore, the measured cross-shore variations of the mean surface elevation, $\overline{\eta}$, free surface standard deviation, σ_η, mean of the cross-shore velocity, $\overline{U}$, standard deviation of the cross-shore velocity, σ_U, and wet probability, P_w are compared to the computed results.

2. Numerical Model CSHORE

The background of the cross-shore process-based numerical model CSHORE is given by Kobayashi et al. (2009). In this study, CSHORE is expanded to include the vegetation effects. The hydrodynamic model in CSHORE is based on the depth-integrated, time-averaged continuity, momentum, and energy equations. The instantaneous horizontal force τ_b acting on flowing water per unit horizontal area is given by

$$\tau_b = \frac{1}{2}\rho f_{bc} |U| U \qquad ; \qquad f_{bc} = f_b + C_D b h_* N \tag{1}$$

where τ_b=equivalent bottom shear stress; f_{bc}=equivalent bottom friction factor; U=depth-averaged instantaneous cross-shore velocity; f_b=bottom friction factor which is of the order of 0.01 for sand beaches; C_D=drag coefficient of the order of unity; b=width of each vegetation stand normal to U; h_*=submerged height of a vegetation stand; and N=number of vegetation stands per unit horizontal area with $N=1/S^2$ and S=spacing between vegetation stands. Time and probabilistic averaging of Eq. (1) is performed analytically to obtain the time-averaged $\overline{\tau}_b$ in the time-averaged cross-shore momentum equation where the overbar indicates time averaging. The time-averaged rate of wave energy dissipation due to τ_b in the energy equation is given by $\overline{U\tau_b}$ which is expressed analytically in terms of the mean and standard deviation of U and h. The effect of the exposed part of the vegetation on the bed load and suspended sediment transport rates is accounted for by the use of the equivalent bottom friction factor f_{bc} in Eq. (1).

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3. Comparison with Experiment

The experiment was conducted by Gralher et. al. (2012) in the wave tank of the University of Delaware. A 400-s burst of irregular waves corresponding to a TMA spectrum were generated in this experiment. The spectral significant wave height and peak period were approximately 19 cm and 2.6 s, respectively. Alongshore transects at 2 cm cross-shore intervals with an accuracy of ± 1 mm were recorded after each wave burst by using a laser line scanner. Water and sand transported over the impermeable vertical wall during each 400-s run were collected in a basin.

The comparisons of the measured and predicted dune profiles after selected runs of HB, HN, and HW tests are shown in Figure 1. In general, CSHORE is shown to predict the dune profiles after each run fairly well. The discrepancies between the predicted and measured dune profiles are found to be largest for the LW test. CSHORE underpredicts dune erosion especially after major overwash started. CSHORE reproduces the cross-shore variations of the mean and standard deviation of the free surface elevation η and the horizontal velocity U, within about 20% errors. The comparison of the measured and computed wave overtopping rate q_o shows that CSHORE cannot predict the transition from minor to major overwash well. CSHORE overestimates q_o during the minor overwash and underestimates q_o during the major overwash for all tests except LW. The comparison of the sediment overwash rate, q_{bs} is similar to the overtopping rate.

References

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Table 1. Summary of five dune tests.

Test	Dune	Vegetation	Number of Runs	Total Duration (s)
HB	High	Bare	6	2 400
HN	High	Narrow	6	2 400
HW	High	Wide	28	11 200
LB	Low	Bare	3	1 200
LW	Low	Wide	20	8 000

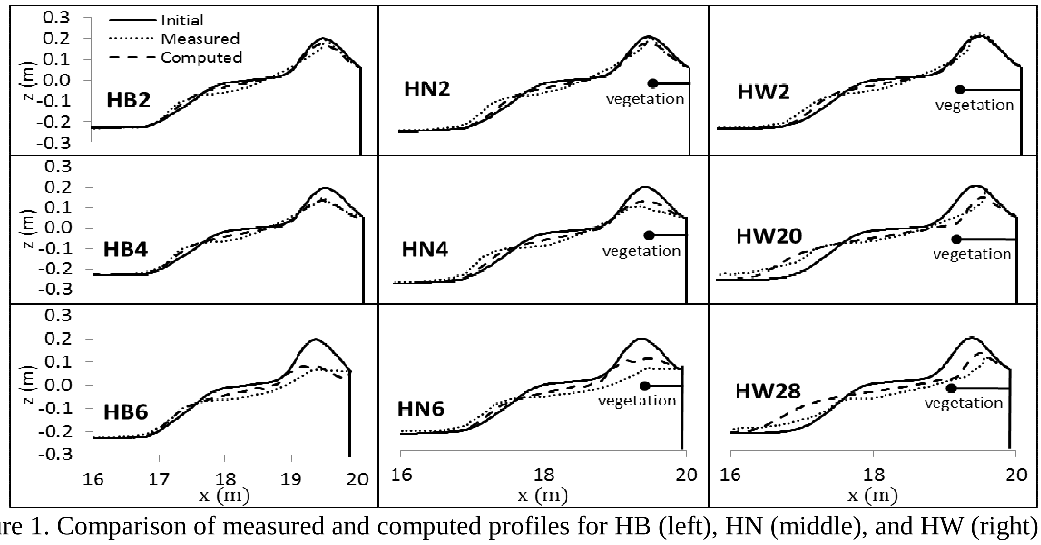

Figure 1. Comparison of measured and computed profiles for HB (left), HN (middle), and HW (right) tests where the run number affixed to the test name indicates the profile evolution in each test.