MODELLING THE INFLUENCE OF COASTAL VEGETATION ON BEACH PROFILES

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INTRODUCTION

Natural beaches are highly dynamic environments and in particular during storms as the cross-shore sediment transport is dominant due to more extreme waves where foreshore sediments are eroded and deposited offshore in the form of a bar. Observing these processes during natural stormy conditions is difficult; while scaled laboratory experiments help to provide crucial understanding of these processes in the swash zone and inner surf zone, they are limited by scaling effects and free wave impacts. A sophisticated tool to address these gaps is needed to significantly advance the knowledge in cross-shore sediment transport processes. Established models like XBeach aim to address this gap, but it is known that such depth integrated models use reduced physics leading to several free calibration parameters. 3D and LES type models would include more physics but suffer from extreme computational costs. With little compromise in governing physics and decent computational time, IH2VOF-SED is a RANS based, 2DV, one-phase model developed to provide accurate morphodynamic predictions for a given storm event. Most sandy beaches are often confined in the lower part by submerged vegetations like Posidonia oceanica. These vegetations do play a role in wave transformation, sediment dynamics and support marine life. This work extends the scope of application of the model, including the modelling of vegetation and its effects on cross-shore sediment transport processes. Sediment transport experiment using flexible cylindrical mimics of Posidonia oceanica carried out in the medium-scale flume of the Hydraulic Laboratory of Southeast China University by (Gong et al., 2024) is used to validate the model's capabilities.

NUMERICAL MODEL

IH2VOF-SED is a depth resolving model developed to accurately predict the breaking and inner surf zone processes (García-Maribona et al., 2021). The hydrodynamic part of the model is governed by the RANS equations, while the sediment transport components, bed load and suspended load transport are resolved separately through an empirical formula and by solving advective-diffusive equation. The vegetation model is based on the work by (Maza et al., 2013). The effect of vegetation is accounted for as an additional drag force in the governing momentum equation as follows:

$$\frac{\partial \overline{u_i}}{\partial t} + \overline{u_j}\frac{\partial \overline{u_i}}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} + g_i + \frac{1}{\rho}\frac{\partial \overline{\tau_{ij}}}{\partial x_j} - \frac{\partial \overline{\left(u_i' u_j'\right)}}{\partial x_j} - \overline{F_{D,i}} \quad (1)$$

where, $\overline{u_i}$ is the mean velocity, $\overline{p}$ is the mean pressure, $\overline{u_i' u_j'}$ is the Reynolds stress $\overline{\tau_{ij}}$ is the mean viscous tensor. $\overline{F_{D,i}}$ is a momentum loss as a drag force given below:

$$\overline{F_{D,i}} = \frac{1}{2} C_D a N \overline{u_{rel,i}} \left|\overline{u_{rel,i}}\right| \quad (2)$$

where, C_D is the drag coefficient, N is the number of plants per unit area, $\overline{u_{rel}}$ is the relative velocity which is the difference between the plant and the flow velocities. Further the vegetation induced turbulence is accounted in the k-Ɛ turbulence closure model including additional terms that depend on the drag force and empirical coefficients. The plant motion is also dynamically resolved and the velocities within the vegetation meadow are accordingly modified.

MODEL VALIDATION

(Gong, et al., 2024) experiments, conducted using flexible cylinders mimicking Posidonia oceanica, are used to validate the model under various regular wave scenarios. Four scenarios are presented in Table 1, where B and V represent the Bare beach and Vegetated beach tests.

Table 1 - Tested scenarios

CaseID	Water depth (m)	Wave height (m)	Wave Period (s)	Scenarios
H45	0.4	0.12	1.2	B & V
H40	0.45	0.12	1.2	B & V

The numerical domain begins at the wave gauge located most offshore in the laboratory near the wave maker, using the waves recorded at that location as the input wave condition. Grid sizes of Δx = 0.031 m in the horizontal and Δy = 0.010 m in the vertical are used. The vegetation meadow is 2m long and is located in the shoaling zone oriented to the slope of the beach following the experimental set-up. The active height of the vegetation meadow at the beginning of the experiment is 15 cm, the width of each mimic is 4 mm, and the shoot density is 980 plants/m^2. The grain size is defined as D50 =0.0003m, fall velocity(w_s) = 0.0767 m/s and the porosity is 0.4. The average computation time of one simulation with 600s of morphological time is about seven hours.

RESULTS

In this section morphological results are presented and discussed. Starting from an initial flat beach slope of 1:10, the final bed morphology seen in the laboratory, as well in the numerical results, shows the formation of double bars after the breaking point. Figure 1 shows the final beach profiles of case H45. In the bare beach scenario, a deeper trough immediately after the location of the vegetation meadow is observed together with a larger primary bar. In the vegetated beach scenarios, the bar is reduced in size and formed near-shore, attributed by the resultant wave energy attenuation and weaker undertow.

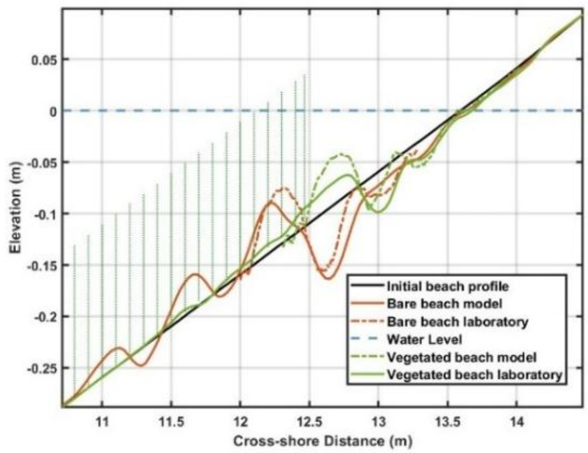

Figure 1 – Case H45, the light green vertical parallel lines denote the vegetation meadow. The black line is the initial beach state. Solid orange and green lines are the final bare and vegetated beach profiles from the model. Dashed orange and green lines are final bare and vegetated beach profiles from the laboratory.

For case H40 as seen in Figure 2 there is reduced bar formation, but the location is relatively unchanged. The velocity profiles indicate the bare beach has stronger undertow in the location of vegetation and immediately after the meadow it is higher for the vegetated case. Hindrance of this undertow resulted in less sediment transport within the meadow. Attenuation to the waves also can observed for the vegetated case.

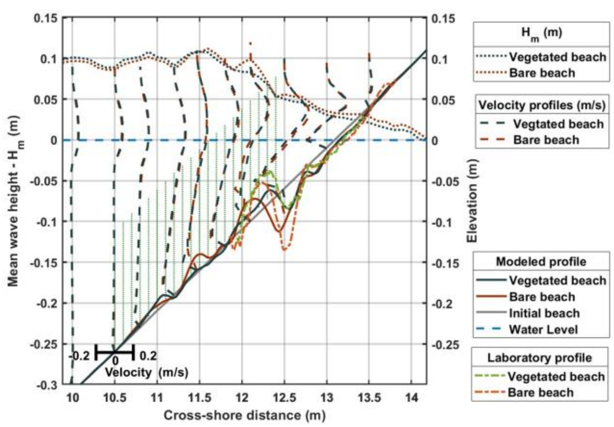

Figure 2 – Case H40, light green parallel vertical lines denote the vegetation meadow. The grey line is the initial beach state. Dark green and orange solid lines are final modelled vegetated and bare beach profiles. Light green and orange dashed lines are the final laboratory vegetated and bare beach profiles. The dark green and orange dashed lines are the horizontal velocity profiles along the flume. The dotted dark green and orange lines show the wave height evolution over the vegetation and the bare beach.

The key difference between cases H45 and H40 is that with the increased water depth the bar has formed further near-shore in the vegetated case. This is particularly due to the more gradual attenuation of wave height before breaking as available free board is larger for H45, while for H40, the breaking occurs early within the vegetation field. Figure 3 shows the velocity distribution at the morphological time of 550 s for Case H40. Stark reduction in the undertow can be observed between the bare and vegetated beach cases.

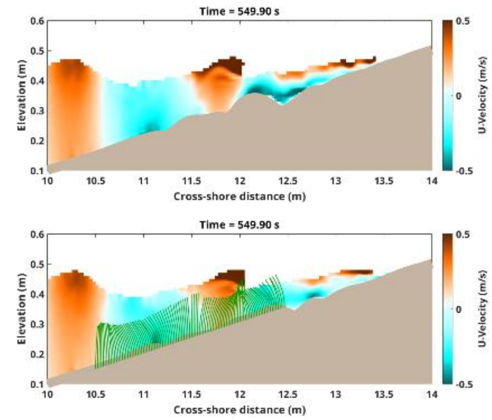

Figure 3 – Case H40, horizontal velocity distribution at the morphological time of 550 s with bare beach, top panel, and vegetated beach, bottom panel.

The Brier Skill Score (BSS) obtained for these scenarios are, for Case H40, 0.71 and 0.62 for bare beach and vegetated beach respectively, and for Case H45, 0.65 and 0.52 for the bare beach and vegetated beach respectively. The measurement error is not accounted for the BSS and thus in the classification for standard BSS these predictions are classified as excellent.

CONCLUSION

The model performs well in predicting the typical cross-shore morphological changes during an erosive condition for a bare and a vegetated beach profile. The effect of submerged flexible vegetation by means of wave and velocity attenuation is well represented by the model. Notable aspects are the associated computational cost and that no morphodynamic calibration is needed.

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