SedInterFoam: a multi-phase numerical model for sediment transport and its application to swash zones

Narayan Kumar, University of Delaware, narayank@udel.edu
Antoine Mathieu, EDF France, amathieu@udel.edu
Benjamin Tsai, University of Delaware, btsai@udel.edu
Tian-Jian Hsu, University of Delaware, thsu@udel.edu
Jack A. Puleo, University of Delaware, jpuleo@udel.edu
Julien Chauchat, LEGI, Université Grenoble Alpes, julien.Chauchat@univ-grenoble-alpes.fr

BACKGROUND AND INTRODUCTION

Rising sea levels and extreme storm events due to climate change have emerged as a significant concern for coastal communities. High-fidelity modeling of the physical processes occurring in the swash zone can help in understanding the exchange of sediment between emerged and submerged portions of the beach undergoing rapid morphological evolution.

Wave propagation and breaking over sloping beaches in the surf zone causes complex evolution of flows and turbulence. To model the resulting sediment transport, the air-water interfaces (free-surface) need to be solved simultaneously with the sediment phase through a three-phase modeling methodology to simulate bathymetry changes as a holistic system. A widely used open-source model for sediment transport, SedFoam (Chauchat et al., 2017) is formulated for miscible liquid and particle phases and lacking the capability in modeling air-water-sediment interfaces for more complete coastal processes.

Recently, a consistent three-phase model including the miscible liquid-sediment phase and the immiscible air phase is developed and the new model is named SedInterFoam (Mathieu et al. 2023, in preparation). The main objective of this study is to apply SedInterFoam to investigate the hydrodynamics and morphodynamics induced by a solitary wave breaking over a sloping beach reported in a comprehensive laboratory experiment by Sumer et al. (2011).

METHODS

We use SedInterFoam to simulate an experimental study conducted in a 28-m long wave flume involving solitary wave breaking over an erodible sediment bed of a planar beach (Sumer et.al., 2011). SedInterFoam is an extended version of SedFoam (Cheng et al., 2017; Chauchat et al., 2017) created using OpenFOAM (Rusche, 2003) with the capability to resolve air-water interfaces following Klostemann et al. (2013) for Reynolds-averaged Navier-Stokes (RANS) and 3D large-eddy simulation (LES). In this study, we incorporate the open-source waves2Foam (Jacobsen et al., 2012) into SedInterFoam for its surface wave generation and absorption capability. We adopt two-dimensional-vertical (2DV) RANS model with the $\kappa - \varepsilon$ turbulence closure to validate the hydrodynamics and morphodynamics observed in the laboratory experiment. Numerical gauges of free-surface, velocities, and sediment concentration are installed in the model domain to gain insights into the complex physical processes that cause the resulting beach profile change.

RESULTS AND DISCUSSION

The model's capability of simulating wave propagation, shoaling, breaking, run-up, and rundown processes are evaluated by comparing the free-surface elevation time-series at different cross-shore locations along the sloping portion of the wave flume. The physical experiment shows the existence of a hydraulic jump when the backwash flow impinges into the inner-surf zone. Numerical simulations capture this feature, but the intensity of the hydraulic jump depends on the modeled beach permeability.

Modeled erosion and accretion of bed profile is compared with measured data after the impact of 4 solitary waves (Figure 1). The accretion and erosion pattern seaward and landward of the wave break point is predicted well by the numerical model. In the full paper, we will present a more complete investigation on the mechanisms causing the observed accretion/erosion. In particular, we will evaluate the effects of permeability and closure of particle stress on the predicted pore-pressure and their vertical gradient, which is important for triggering liquefaction in more energetic events with strong wave-swash interactions.

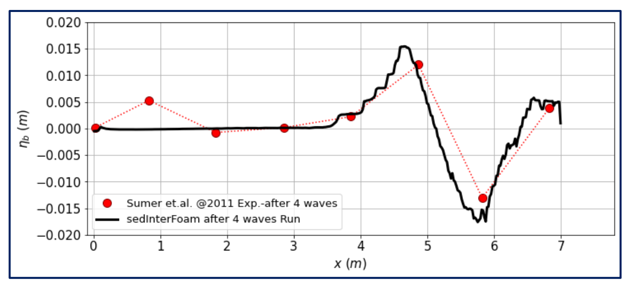

Figure 1 - A comparison of measured (symbol) and modeled (line) beach profiles.

CONCLUSION

The development of the open source three-phase flow model SedInterFoam provides a new tool to investigate coastal sediment transport in the surf and swash zones. By simulating a laboratory experiment of solitary wave breaking over a sloping beach of fixed or erodible bed, results demonstrate the capability of SedInterFoam in predicting waves, flows, sediment transport and beach profile evolution. Further numerical investigations are still needed to increase the model capability to simulate pore pressure and the resulting sediment transport in a wide range of flow conditions and grain sizes driven by more complex wave-swash interactions.

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