

MODELLING WAVE HYDRODYNAMICS AROUND POROUS ARTIFICIAL REEF WITH COUPLED MESH-BASED AND MESHLESS NUMERICAL METHODS

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INTRODUCTION

Nature-based coastal protection solutions, such as artificial reefs, often consist of porous modules with complex geometries. While the porous designs are due to the requirements of promoting benthic habitat and attenuating incident waves, it is unclear how porosity and novel shapes affect the hydrodynamics near the modules. Meshless computational fluid dynamics (CFD) models are ideal for simulating the detailed hydrodynamic interactions between the waves and novel-shaped porous coastal structures. However, such CFD methods are computationally demanding, constraining the model domains to the immediate vicinity of structures. In comparison, mesh-based wave models can simulate larger scales due to the smaller computational demands but lack the required details to understand the impact of structural porosity. The aim of this work is to present a 3D coupled numerical model of mesh-based and meshless methods for simulating the wave-driven hydrodynamics near porous artificial reef modules to reproduce the physical experiments in a large-scale wave flume.

NUMERICAL MODELLING

This work applied one-way offline coupling of non-hydrostatic wave-flow model Simulating WAVes till Shore (SWASH) and smoothed particle hydrodynamics (SPH) solver DualSPHysics. SWASH is a mesh-based non-hydrostatic wave model that solves Reynolds-Averaged Navier-Stokes equations to simulate wave transformation on grid points, whereas DualSPHysics is a meshless solver of Navier-Stokes equations by discretizing the domain into particles. The numerical setup extended the coupling method in Lowe et al. (2022) to full 3D simulations of wave flume tests of porous artificial reef modules (Figure 1). In addition, the strategy of imposing open boundary conditions between SWASH and DualSPHysics in Capasso et al. (2023) was utilized to focus the DualSPHysics simulation to near the module and in turn to increase the SPH resolution.



Figure 1: Porous artificial reef module - Bombora (MMA Offshore, Perth, Australia)

In the numerical wave flume (Figure 2), SWASH first simulated coarse-resolution (≥ 5 cm) velocity field as upstream and downstream (flume-wise direction) boundary conditions for a fine-resolution (≤ 1 cm) SPH domain near the module. The hydrodynamics near the module was further resolved by DualSPHysics in detail. The coupled model aimed to reduce the overall computational demand by utilizing the efficiency of SWASH in generating boundary conditions while maintaining the effectiveness of DualSPHysics in resolving free surface deformation and hydrodynamic flows near the module in a full 3D setup.

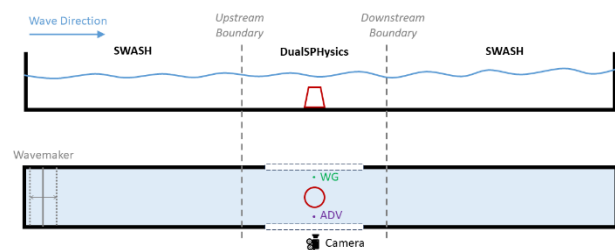


Figure 2: Lateral view (top) of the setup of coupled numerical flume and plan view (bottom) of physical flume (more details below) with locations of wave gauge (WG) and acoustic doppler velocimeter (ADV). Dimensions are not-to-scale and indicative only.

MODEL VALIDATION

The simulated bulk wave properties, velocity field near the module and the hydrodynamic forces on the module were compared with experimental data from wave flume tests for validation. The wave flume is 54 m long, 1.5 m wide and 1.6m deep. The experimental setup is similar to that of the numerical model (Figure 2). Previously-conducted experiments tested regular waves with periods of 1.5 - 5.5

s, wave heights of 0.05 - 0.15 m, and water depths of 0.3 - 0.9 m. Wave gauge (WG) and acoustic doppler velocimeter (ADV) were placed to each side of the module at mid-depth, and load cell was attached to the bottom of the module to measure the hydrodynamic forces. A camera was directed at the module through a viewing window to capture the evolution of free surface.

RESULTS

The coupled method significantly reduced the domain size in DualSPHysics and hence enabled longer simulation times (~100 s) in 3D. Compared with the video frames from the camera, the particle output (0.1 s temporal resolution) from DualSPHysics captured the deformation of free surface in cases with breaking waves over the module. The time series of wave height and total in-line hydrodynamic force generally agreed with experimental measurements. The vertical profiles of horizontal velocities around the module captured the flow acceleration through the pores (Figure 3).

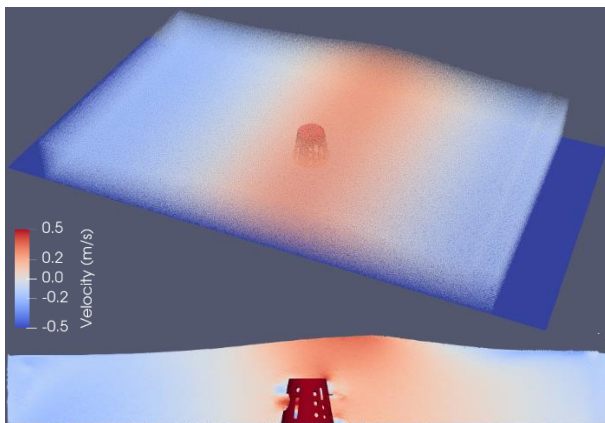


Figure 3: Oblique 3D view (top) of a wave crest passing the module simulated by DualSPHysics and lateral view (bottom) of detailed flow acceleration through the pores of the modules. Positive velocities (red) are rightward.

REFERENCES

- Capasso, S. et al., (2023). Regular wave seakeeping analysis of a planing hull by smoothed particle hydrodynamics: A comprehensive validation. *Journal of Marine Science and Engineering*, 11(4): 700.
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