A COMPREHENSIVE HYDRODYNAMIC ANALYSIS OF WATER WAVES INTERACTION WITH SUBMERGED BREAKWATERS: NUMERICAL AND EXPERIMENTAL STUDY.

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The present work describes the numerical investigation with experimental comparisons of water waves interaction with porous structures.
The main objective of this work is to assess the ability of the Volume-Averaged Reynolds Averaged Navier-Stokes-based module within the OpenFOAM numerical toolbox to accurately model and simulate the most relevant hydrodynamic processes involved in the interaction between waves and low-crested breakwaters. The numerical approach is further validated against measurements obtained from the small-scale laboratory tests conducted for a wide range of wave conditions at LOMC's wave channel (University of Le Havre, France).

NUMERICAL APPROACH

The C++ based open-source code OpenFOAM, which uses the finite volume method (FVM) to solve the Navier-Stokes equations, is used in combination with the Waves2Foam libraries, developed by *Jacobsen et al. (2012),* to carry out the aimed 2D computations.

In the porous media approach, the Navier-Stokes equations are averaged over a superficial volume then integrated to derive the Volume-Averaged Reynolds-Averaged Navier Stokes (VARANS) equations.
The VARANS equations governing a two-phase flow under the incompressible, immiscible and unsteady-state assumptions are written as a mass conservation equation (*eq.1*), a momentum balance equation (*eq.2*), listed as follows:

$$\frac{\partial}{\partial x_i}\frac{u_i}{n} \qquad (1)$$

$$\frac{\partial u_i}{\partial t} + u_j\frac{\partial}{\partial x_j}\frac{u_i}{n} = -\frac{n}{\rho}\frac{\partial p}{\partial x_i} + \frac{n}{\rho}\left(\mu S_{ij}\right) + n f_i + \left[a u_i - b u_i|u_i| - c\frac{\partial u_i}{\partial t}\right] \qquad (2)$$

where, (*i*,j) represent the x-, y- and z- directions in the cartesian coordinates, μ ,ρ and n denote the density, dynamic viscosity and porosity, respectively. u_i is the velocity fields, p is the fluid pressure field, f_i denotes the gravitational acceleration vector and S_{ij} stand for the diffusion term.
The last term in the left -hand side of eq.2 accounts for the effects of the porous media and it is modelled by the Extended Darcy-Forchheimer equation where a is the Darcy linear term and b is the Forchheimer quadratic term.

The free surface can be determined by solving the advection equation for both the viscosity and density functions of fluid, and thus the following phase volume fraction conservation equation(*eq.3*) is used:

$$\frac{\partial \varphi}{\partial t} + \frac{u_i}{n}\frac{\partial \varphi}{\partial x_i} = 0 \qquad (3)$$

where φ denotes the volume fraction indicator which takes a value of 1 when the cell is full of water, 0 when it is empty and lies between 0 and 1 for the interface.

Finally, the waves are modelled and generated thanks to the relaxation zone method within the wave2Foam libraries. Then, the set of the aforementioned equations is solved applying a combination of the MULES and the PIMPLE algorithms at each time step in the considered *porousInterFoam* solver.

EXPERIMENTAL SET-UP

Two trapezoidal low-crested breakwaters made of homogeneous materials are considered. The first one is made of calibrated quartzite rocks of an averaged nominal diameter ranging from 28 to 36 mm and a porosity of 0.475. The second one is made of polyurethane foam with a porosity of 0.954.
The experiments are performed in the 35 meters long, 1.2 meter high and 0.9 meter wide wave flume of LOMC-University of Le Havre. The wave flume is equipped with a piston-type wavemaker which is supplied with an active wave absorption system.

The free surface evolution is recorded using resistive wave probes that are positioned at different locations to separate incident and reflected waves. Additionally, pressure probes are installed on the bottom, inside the submerged structure to measure the wave transmission inside the porous media.

The choice of the investigated configuration and waves conditions is based on the work of *Garcia et al. (2004).*
More details and results will be provided during the oral presentation.

REFERENCES

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