PhD call 2024

Modified ISPH method for modeling the waves interaction with coastal structures

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Context and problem statement

Coastalization, evident since the 1970s, entails the increasing appeal and human-induced alteration of coastlines, posing risks like erosion and submersion. Defense structures have been constructed at high costs to safeguard coastlines, and with global change (rising sea levels), political decisions are necessary to either preserve or question these defenses.

The Nouvelle Aquitaine region faces these risks, as highlighted by the November 2023 storms, Ciaran and Domingos (see Fig. 1). Reflecting on territorial planning, the region has initiated the CORALI program, aimed at providing scientific insights for predicting coastal changes and anticipating adaptations to erosion and submersion. CORALI involves universities and research organizations forming the R3 (Regional Research Network) RIVAGES consortium.

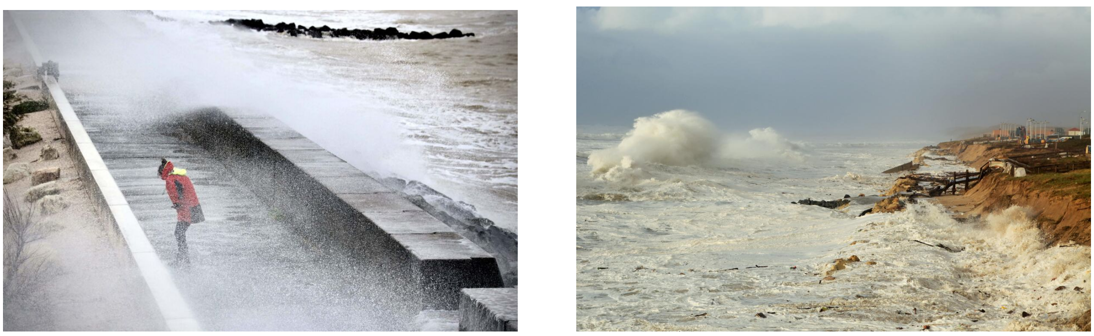

Figure 1: (Left) Thunderstorms Ciarán, 02/11/23, at quai du Lazaret, La Rochelle. (Right) Erosion and submersion at Lacanau (South-West of France).

As part of the CORALI programm, the P' Institute and laboratory M2N contribute expertise in computational fluid mechanics and propose here a PhD thesis

on numerical modeling of wave-defense structure interaction. The thesis aims to **enhance Smooth Particle Hydrodynamics (SPH) methods, particularly effective in simulating free-surface flows**. Numerical simulations will refine empirical laws governing defense structure performance, such as reflection coefficient, crest height, overflow discharge, and structure stability, by incorporating structure characteristics.

Subject

Challenges and scientific issues about SPH methods

Numerical modeling allows the simulation of complex interactions between waves and defense structures, yielding data unattainable through experiments (Khayyer et al., 2018). These models typically employ Eulerian (mesh-based) or Lagrangian (mesh-free) approaches. Lagrangian methods such as ISPH and WCSPH are particularly suitable for studying wave-defense structure interactions (Pahar and Dhar, 2017). While WCSPH requires small time-steps to mitigate numerical errors, ISPH involves solving the computationally expensive Poisson equation. Modifications proposed by Ramos Ortega et al. (2020, 2022) have reduced CPU time by solving the Poisson equation on a grid and introducing a new kernel based on Taylor expansion. Coupling ISPH with the penalization method (Bruneau et al., 2008) has been suggested to simulate water flow in porous defense structures.

These adjustments enabled Ramos Ortega et al. to replicate experimental findings (Clavero et al., 2020) regarding wave-defense structure interaction. However, ISPH may face limitations in evaluating reflection, transmission, and dissipation coefficients due to errors in estimating the free surface position (see Fig. 2), which depends on particle spatial distribution. Thus, controlling particle distribution near the free surface is crucial for simulating wave-defense structure interaction, a focal point of the present PhD project.

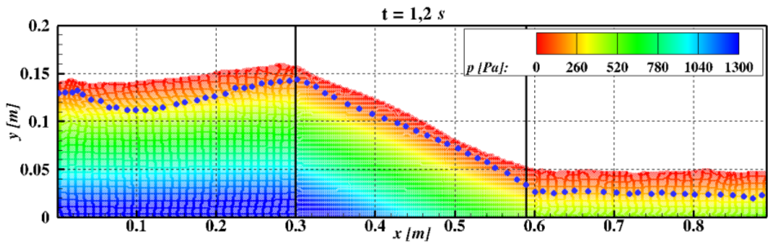

Figure 2: Comparison between numerical (ISPH) and experimental results (blue dots) of the free surface during the impact of a wave on a defense structure (Ramos Ortega et al., 2022).

Modifications and enhancements to the ISPH method

Building upon Ramos Ortega et al.'s research (2020, 2022), the first two years of the PhD will concentrate on enhancing ISPH for improved numerical simulation of free surface dynamics during wave-defense structure interactions. This involves optimizing particle distribution, especially near the free surface, using remeshing techniques, based on a remeshing kernel, that redistribute particles on a grid. The accuracy of remeshing depends on kernel-function selection, considering factors like support size, regularity, and moments conservation. The equation (1) defines the kernel function $\Lambda_{2,1}$, also known in the literature as M'_4 and used in Ramos Ortega et al.'s research. This kernel function, written here with the notation $\Lambda_{p,r}$, saves $p = 2$ moments, has regularity $\mathcal{C}^r = \mathcal{C}^1$ and support size $[-2; 2]$ (see Fig. 3) :

$$(1) \qquad \Lambda_{2,1}(x) = \begin{cases} 1 - \frac{5}{2}|x|^2 + \frac{3}{2}|x|^3 = p_0(|x|), & |x| \leq 1, \\ \frac{1}{2}(1 - |x|)(2 - |x|)^2 = p_1(|x|) & 1 \leq |x| \leq 2 \\ 0 & |x| \geq 2. \end{cases}$$

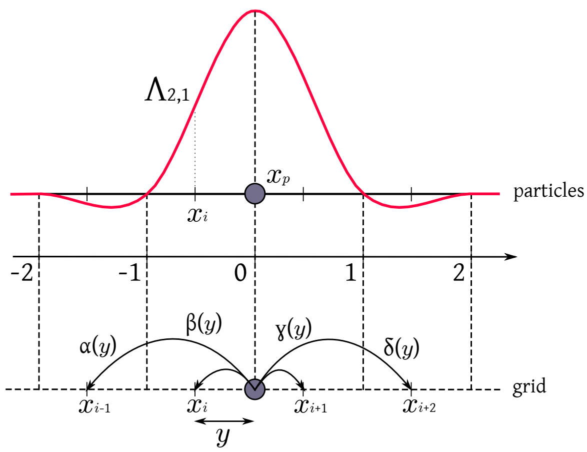

Figure 3: Kernel function $\Lambda_{2,1}$. The quantity carried by the particle is redistributed on 4 grid points according to 4 weights $\alpha(y), \beta(y), \gamma(y), \delta(y)$, depending on the distance y between the particle and the grid point considered.

A preliminary comparison of various kernels will be conducted to determine the most suitable for these interactions. Following this, Cottet et al.'s (2014) methodology for kernel construction will be applied to develop a new kernel tailored for free surface treatment.

Validation through comparisons with laboratory experimental data

The adapted ISPH will undergo testing through two benchmarks. The first benchmark assesses its capability to simulate water sheet impact on a wall, a scenario with significant free surface deformations, based on Lobovsky et al.'s (2014) classical experiment. Experimental data for this benchmark will be provided by Laboratory SIAME (University of Pau), focusing on defense structures and also involved in the CORALI project. The second benchmark, based on Milesi's (2019) doctoral work at Ecole Centrale Marseille, involves a sloshing test in a tank with water and a porous material-covered bottom on a hexapod, studying sloshing damping. Comparing experimental and numerical results will validate the modified ISPH.

Application to marine submersion in Nouvelle Aquitaine region

The final year of the PhD will focus on an applied study of submersion in the Nouvelle Aquitaine region, characterized by two types: atmospheric surge-induced submersion in the North and wave-induced submersion in the South. In the North, submersion, exacerbated by swell, poses ecological challenges, whereas in the South, breaking waves threaten protection structures and may cause socio-economic impacts and population displacement. Selection of precise workshop sites will be driven by consultations with the physical and sociological research groups involved in the CORALI project.

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Summary of the objectives during the thesis

- Implementing the modifications to the ISPH method:
  - comparison of different remeshing kernels in terms of free surface position and of reflection, transmission, and dissipation coefficients.
  - updating of the coupling between the ISPH method and the Brinkman penalization technique for the simulation of wave impact on porous defense structures.
- Validating these modifications with respect to experimental setups and data:
  - Benchmark n°1: dam break (from the SIAME's experimental data).
  - Benchmark n°2: damping of sloshing in a tank with a porous bottom (from Milesi).
- Applying the modified and validated ISPH method to submersion in Nouvelle Aquitaine.

The results will be subjected to publications in international journals (i.e. J. Comp. Phys., Int. J. Num. Meth. Fluids, ...), presented at international conferences and reported back to the CORALI consortium.

Required skills

Candidates must hold a research master's degree or an engineering degree in **scientific computing** and/or **numerical fluid mechanics**. Candidates are expected to have skills in **computer programming** (experience in high-performance computing would be highly appreciated) as well as in numerical analysis, particularly a good understanding of numerical methods and schemes for fluid mechanics.

How to apply ?

Application by email at anthony.beaudoin@univ-poitiers.fr and chloe.mimeau@cnam.fr, only with PDF format, with the following documents:

- CV
- motivation letter
- marks from previous semesters (S1 and S2 of Master 1, and if available, S1 of Master 2)
- contact of persons of reference (former supervisors, professors, . . .)