Simulation of the HarshLab floating platform for offshore experimentation using FEniCS-HPC

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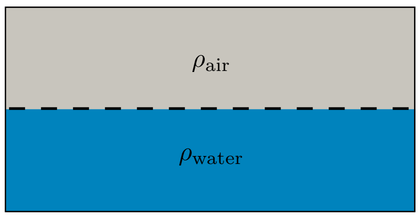
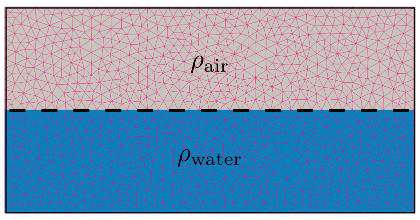
SIMULATION METHODOLOGY

Two phase-flow



The domain is partitioned



1. Variable density incompressible Navier-Stokes equations

$$\begin{cases} \rho\,\partial_t \mathbf{u} + \rho\,(\mathbf{u}\cdot\nabla)\mathbf{u} - \frac{1}{Re}\,\nabla\cdot(\mu\,\nabla\mathbf{u}) + \nabla p - \frac{1}{Fr^2}\,\rho\,\mathbf{e}_y = 0 & \text{Momentum eq.} \\ \partial_t\rho + (\mathbf{u}\cdot\nabla)\rho = 0 & \text{Mass eq.} \\ \nabla\cdot\mathbf{u} = 0 & \text{Continuity eq.} \end{cases}$$

The unknowns, $\mathbf{U} = (\mathbf{u},\ \rho,\ p)^{\mathrm{T}}$, are the velocity, the density, and the pressure.

μ dynamic viscosity

$Re = \frac{\rho_0 L_0 U_0}{\mu_0}$, $Fr = \frac{U_0}{\sqrt{g L_0}}$ Reynolds and Freud numbers, and ρ_0, L_0, U_0, μ_0 reference values. $\mathbf{R}$ and $\mathcal{L}$ are the strong residual and the space differential operator.

The test functions are first order Lagrange polynomials associated to the partition of the domain

The continuous equations are projected onto the space of the test functions $\mathbf{V} = (\mathbf{v},\ \eta,\ q)^{\mathrm{T}}$

2. Direct finite element discretization

$$(\rho\,\partial_t\mathbf{u},\,\mathbf{v}) + (\rho\,(\mathbf{u}\cdot\nabla)\mathbf{u},\,\mathbf{v}) + \frac{1}{Re}\,(\mu\,\nabla\mathbf{u},\,\nabla\mathbf{v}) + (\nabla p,\,\mathbf{v}) - \frac{1}{Fr^2}\,(\rho\,\mathbf{e}_y,\,\mathbf{v})$$

$$+\quad (\partial_t\rho,\,\eta) + ((\mathbf{u}\cdot\nabla)\rho,\,\eta) \;-\; c_{\mathrm{CT}}\left(\frac{|R_{\mathrm{d}}|}{\|\nabla\rho\|}\,\frac{(\rho-\rho_1)(\rho_2-\rho)}{(\rho_2-\rho_1)\|\nabla\rho\|}\,\nabla\rho,\nabla\eta\right)$$

Compression to prevent the mixing of the air and the water

$$+\quad (\nabla\cdot\mathbf{u},\,q)$$

$$-\quad (\tau\,\mathbf{R}(\mathbf{U}),\,\mathcal{L}(\mathbf{V})) \;+\; c_{\mathrm{m}}\left(h\,\frac{\|\mathbf{R}_{\mathrm{m}}\|}{\|\nabla\mathbf{u}\|}\,\nabla\mathbf{u},\nabla\mathbf{v}\right) \;+\; c_{\mathrm{d}}\left(h\,\frac{|R_{\mathrm{d}}|}{\|\nabla\rho\|}\,\nabla\rho,\nabla\eta\right) \;=\; 0$$

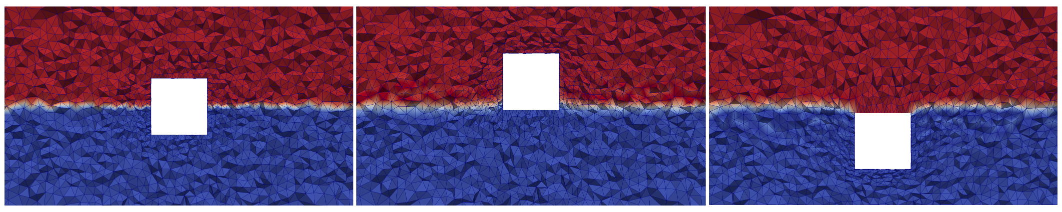
GLS Stabilisation to prevent numerical instabilities caused by the advection

Discontinuity Capturing to prevent oscillations where big gradients exist (e.g. in the interphase)

Floating body

An ALE moving mesh strategy is applied

The mesh velocity is subtracted to the convective velocity



The mesh is deformed following the movement of the floating body. The nodes on the boundary of the body move with the body velocity. The movement of the rest of the nodes is governed by the linear elasticity equations.

The vertical velocity of the body is computed as follows by a simplified rigid body motion scheme using Newton's second law:

$$m_{body}\,\partial_t\mathbf{u}_{body} = \underbrace{-m_{body}\,g}_{\text{Gravitational force}} + \underbrace{\int_{\Gamma_{body}} -p\;n_2\;ds}_{\text{Vertical force applied by the fluid on the body}}$$

In this work we only take into account vertical translations. Rotation and translation in the other directions is not considered here.

3. ALE direct finite element discretization

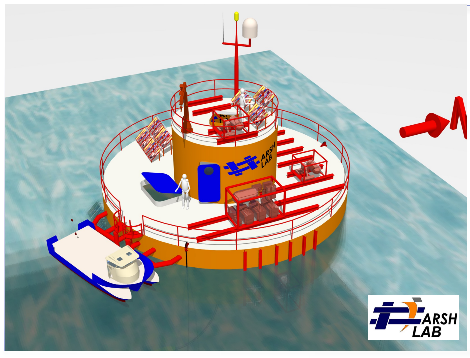
$$(\rho\,\partial_t\mathbf{u},\,\mathbf{v}) + (\rho\,((\mathbf{u}-\mathbf{u}_{\mathrm{mesh}})\cdot\nabla)\mathbf{u},\,\mathbf{v}) + \frac{1}{Re}\,(\mu\,\nabla\mathbf{u},\,\nabla\mathbf{v}) + (\nabla p,\,\mathbf{v}) - \frac{1}{Fr^2}\,(\rho\,\mathbf{e}_y,\,\mathbf{v})$$

$$+\quad (\partial_t\rho,\,\eta) + (((\mathbf{u}-\mathbf{u}_{\mathrm{mesh}})\cdot\nabla)\rho,\,\eta) \;-\; c_{\mathrm{CT}}\left(\frac{|R_{\mathrm{d}}|}{\|\nabla\rho\|}\,\frac{(\rho-\rho_1)(\rho_2-\rho)}{(\rho_2-\rho_1)\|\nabla\rho\|}\,\nabla\rho,\nabla\eta\right)$$

$$+\quad (\nabla\cdot\mathbf{u},\,q)$$

$$-\quad (\tau\,\mathbf{R}(\mathbf{U}),\,\mathcal{L}(\mathbf{V})) \;+\; c_{\mathrm{m}}\left(h\,\frac{\|\mathbf{R}_{\mathrm{m}}\|}{\|\nabla\mathbf{u}\|}\,\nabla\mathbf{u},\nabla\mathbf{v}\right) \;+\; c_{\mathrm{d}}\left(h\,\frac{|R_{\mathrm{d}}|}{\|\nabla\rho\|}\,\nabla\rho,\nabla\eta\right) \;=\; 0$$

HARSHLAB



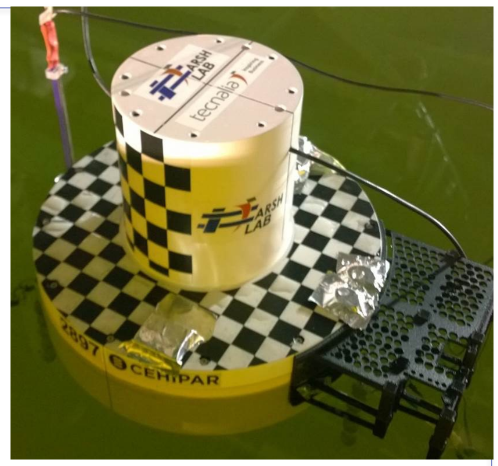
HarshLab is a floating platform that serves as an offshore laboratory in real marine environment. It will be installed at BiMEP facilities in the Basque coast. Its functionality consists of:

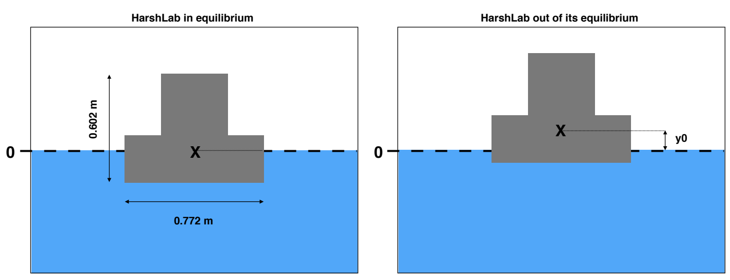
- Assessment of materials, components and systems in a real offshore environment.
- Evaluation and monitoring of corrosion and fouling.
- Behaviour analysis of umbilical cables, risers and mooring components.
- Training of personnel in offshore operations.

In the framework of computational fluid dynamics the goal of this work is to study and predict the dynamics of this kind of off-shore devices.

DECAY TEST VALIDATION

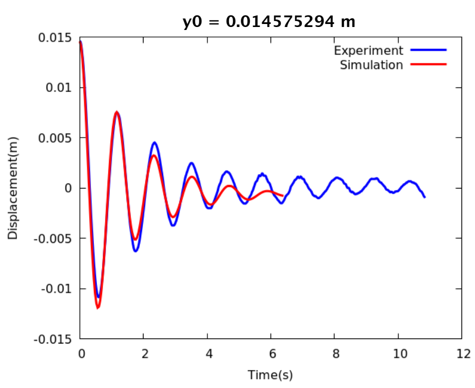
The **experimental test campaign** was carried out at the CEHIPAR wave tank in Madrid. Two scaled down prototypes of the HarshLab were used for operational (1:13.6 scale) and extreme conditions (1:35 scale). The campaign included decay test with and without mooring, forced oscillation, regular and irregular waves, and towing tests. Displacement, velocities, and accelerations at the six degrees of freedom, fluid pressures, and mooring system tension were measured.

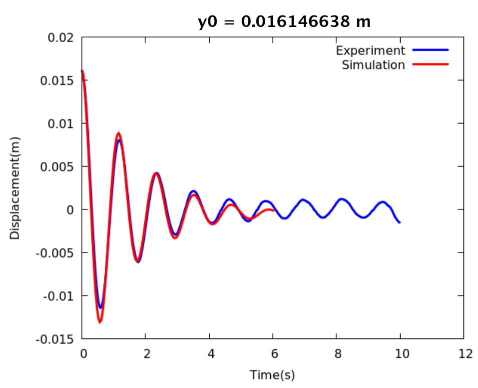


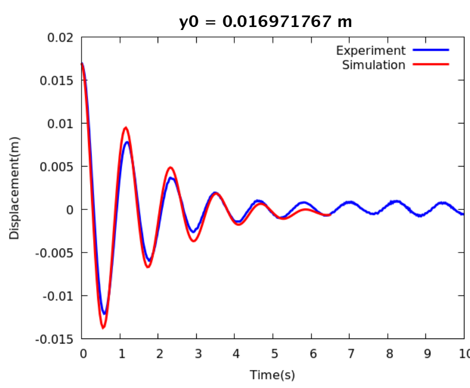


In this work we concentrate on the **decay test without mooring**. In this test the HarshLab is taken out of its equilibrium and released. Then it starts to oscillate until it reaches the equilibrium again. We use the 1:13.6 scaled prototype as described in the picture the left. The computational domain is a cube of 8 x 6 x 8 m. The Reynolds number is around 1.5e6. No-slip boundary conditions are applied on the HarshLab surface. The final time is approximately 6.5s.

Experiment versus simulation results. Vertical displacement of the platform for three different initial positions.







Mesh: 600,000 nodes; 3,473,239 tetra

24h of computing time

480 cores on Beskow supercomputer

FEniCS-HPC, an in house high-performance scientific computing code for the solution of partial differential equations with the finite element method.