WAVE AND CURRENT INTERACTION WITH MOORED FLOATING BODIES USING OVERSET METHOD

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Keywords: *Overset mesh, Wave-current interaction, mooring systems*

Introduction

Nowadays floating structures like breakwaters, floating wave energy converters, offshore platforms and floating wind turbine substructures are widely applied in coastal and offshore engineering because they offer many advantages over traditional solutions. For example, floating breakwaters can be installed in deep waters, limiting the environmental impact and offering a cheaper solution compared with traditional breakwaters (Chun-Yan Ji et al., 2016). Characterization of waves and current interaction with the floating structure is a complex issue due to the relevance of the non-linear physical processes involved that hinder the resolution of the problem in an analytical way. Therefore, the main methodology has been physical modeling. During the last decades, the improvements in hardware architecture have encouraged the development of numerical models, with the main goal of reducing the number of carried out physical model tests, as they are more expensive than the numerical ones.

Numerical modelling of floating bodies is still being a very challenging issue, especially for large body displacements. Despite of the good performance of potential flow models in predicting floating body dynamics, there are still physical processes which are not well reproduced with that approximation. Their strong assumptions yield into a lack of accuracy when high non-linear effects become predominant. In addition, the presence of restrictions to motion induced by mooring elements also introduces additional non-linear features which are sometimes out of the framework of the use of potential flow models. The use of Computational fluid dynamics (CFD) approach overcomes potential model limitations especially for non-linear effects. When CFD models are applied to solve waves and current interaction with floating bodies, several issues arise such as the numerical treatment of the floating element, mooring implementation and also the computational cost.

The main challenge regarding wave-floating structure interaction is how to handle the mesh motion to perfectly reproduce the complexity of body motion and the flux around it. Although several approaches are available in literature regarding the numerical implementation of the mesh motion as described in Jasak and Tukovic 2010, (also implemented in OpenFOAM enviroment), or in Liu et al. 2017, the implementation of the overset mesh grid (also called "Chimera grid") (Meakin Robert L., 1999, Petersson N. Anders, 1999, Suhs and Rogers, 2002) appears as the most accurate one for large body displacements. In a Chimera grid scheme, a complex geometry is decomposed into a system of geometrically simple overlapping grids (first step: grid generation). Boundary information is passed between these grids via interpolation of the flow variables, and many points may not be used (second step: interpolation, hole cutting and determination of interpolation weights).

In this work, we will present a numerical analysis of wave and current interaction with floating bodies. The objective of the work is to present a set of numerical implementations performed in OpenFOAM environment with the use of the overset mesh method to study moored floating body dynamics due to the combined action of waves and current. The implementations, included in IHFOAM (Higuera et al., 2013) (www.ihfoam.ihcantabria.com) are a new set of boundary conditions to generate waves and current without the use of relaxation zones. The main consequence is that the computational cost can be reduced due to the use of smaller domains. In addition, the implementation of mooring will be also presented in order to extend the use of the model to realistic conditions. Numerical model predictions compared with laboratory data of wave interaction with moored floating bodies have been performed showing a high degree of agreement. The combined effect of waves and current, traveling in the same direction than waves, and their interaction with floating bodiesand mooring will be also studied. Results will show the applicability of the new implementations to be included in real problems.

Wave – floating body interaction: validation cases

A numerical wave tank was developed in order to validate wave interaction with a floating breakwater as in Rhaman et al. (2006). The dimensions of wave tank were 2.8m long, 1.9 wide and 1.2 of high. It is shown in the figure 1. The floating body is 30.4 cm long, 68 cm wide and 13.7 cm deep. The body is anchored to the bottom with linear spring devices. A simplified model of linear spring with damping was considered in the numerical models developed. This kind of device applies a dumping when the spring is at rest, avoiding the small numerical errors that could arise at the beginning of the simulation. This mechanism was implemented in OpenFOAM, modifying the existing linear spring model. More deatails about the implelentation will done during the presentation.

The mesh consisted of 2 grids, being the external one the global domain mesh. The internal mesh was used floating body. The overset mesh was performed between the two grids. The dimensions of the external grid were: $\Delta x = 3$cm, $\Delta y = 4$cm, $\Delta z = 4$cm and $\Delta x = 2.5$ cm, $\Delta y = 4.5$ cm, $\Delta z = 1.5$ cm for the internal grid. Discretization around the floating body was refined up to: $\Delta x = 0.625$ cm, $\Delta y = 1.125$ cm, $\Delta z = 0.375$ cm. This discretization allowed to accurately generate all wave conditions and to validate the model.

Because of the tension of mooring lines was omitted in Rhaman et al. (2006), realistic values of the devices used to calibrate and validate the model developed were estimated based on literature. The equivalent stiffness and damping of the linear spring have been calibrated numerically yielding: k=323.47 N/m and c = 200 Kg/s, for the spring and damping coefficients. Additionally, k-epsilon model has been used for turbulence modeling. Wave generation and active absorption was defined as boundary condition on the left of domain while only active absorption was used at outlet on the other side of domain. A classical non-slip boundary condition was assigned to the bottom. The top was defined as atmosphere and the lateral walls have been defined as slip.

Two cases were considered:

- **Case A**:
  - Wave Height: 3.1cm, water depth: 65 cm, wave period: 1s
  - Mooring system: 4 inclined mooring chains (ϑ= 60)
- **Case B**:
  - Wave Height: 7.3 cm, water depth: 65 cm, wave period: 1.3s
  - Mooring system: 4 vertical mooring chains (ϑ= 90)
  - The results of the two cases and the comparison with laboratory data of Rhaman et al. (2006) are shown in the figures 3,4 and 5.

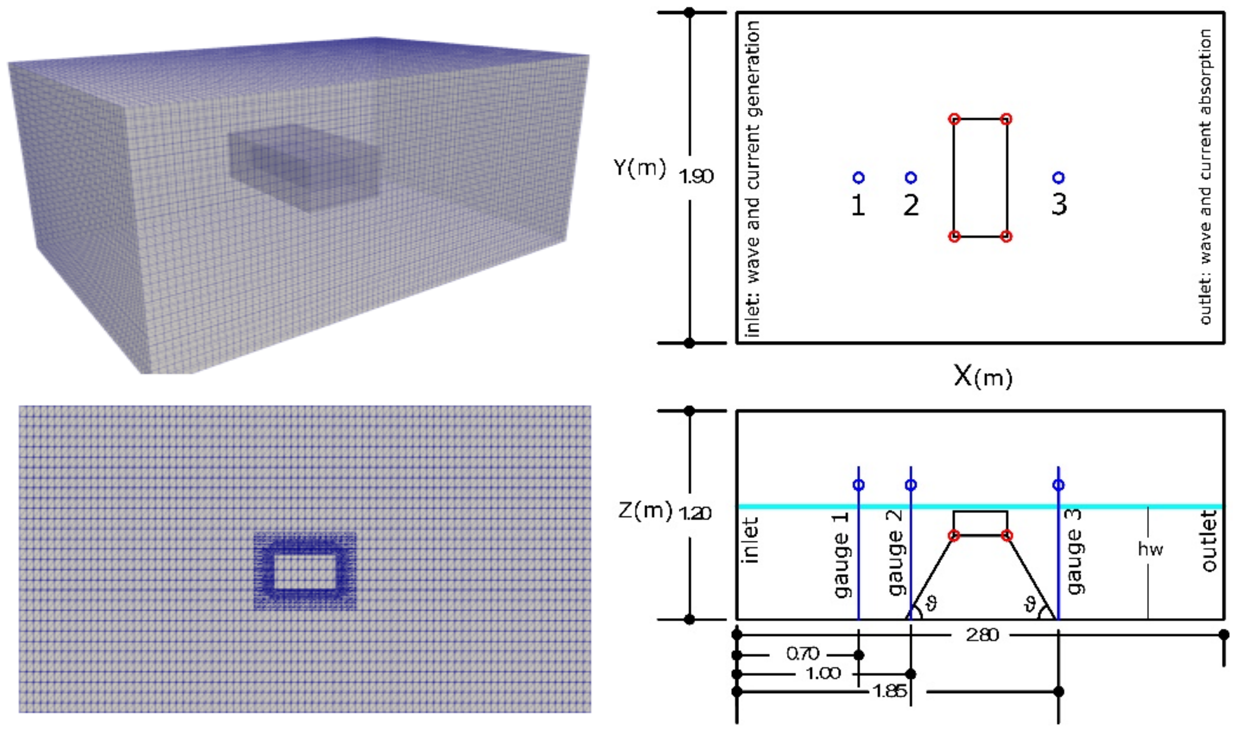

Figure 1: On the left: the global 3D mesh. On the bottom: a section of the mesh showing the two system of grids used to perform the overset mesh. On the right: Numerical wave tank developed.

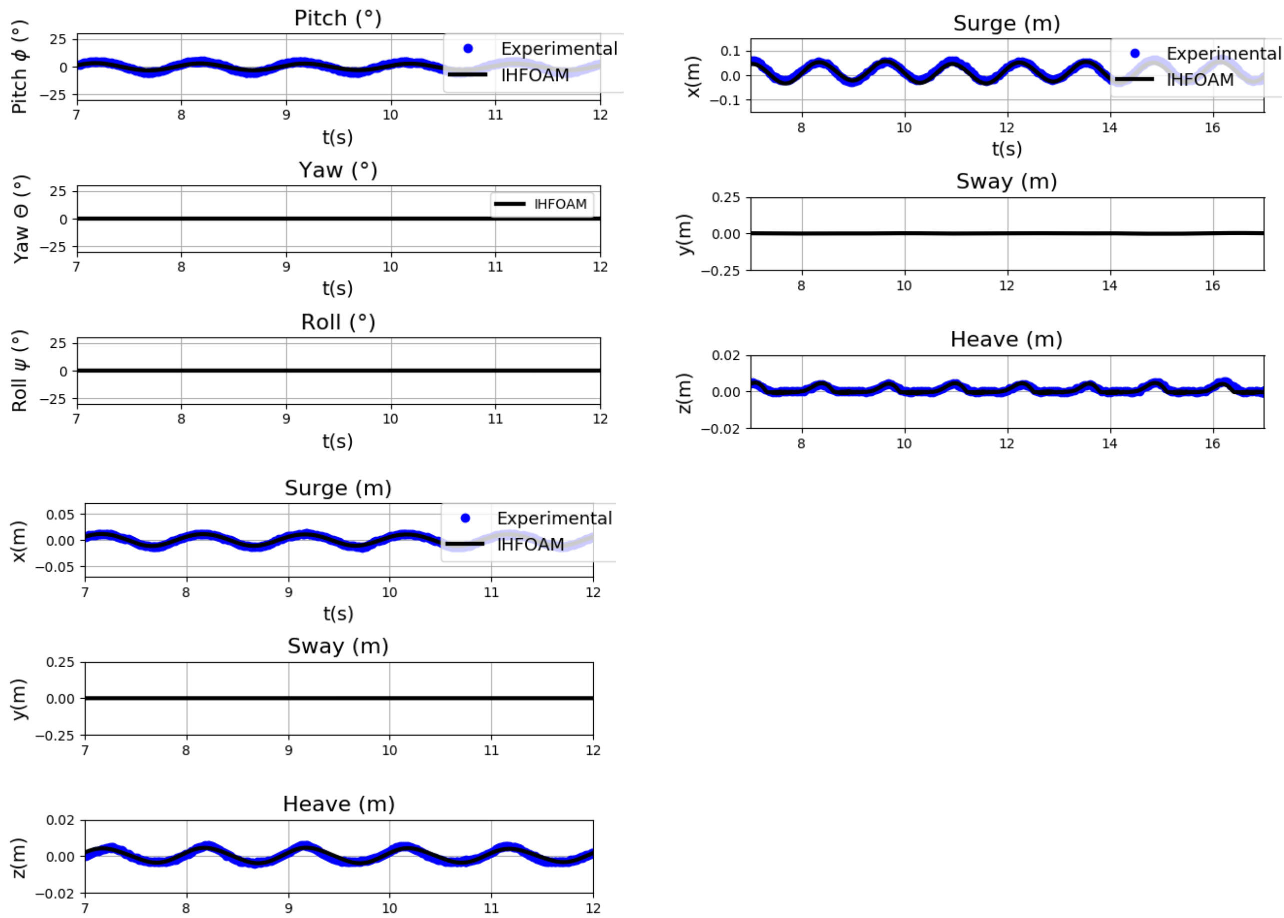

Figure 2: On the top: Case B: H = 3.1cm, T = 1s, h = 65cm. Pitch, Yaw and Roll (degrees) and Surge, Sway and Heave (m). On the bottom: Case A: H = 7.3cm, T = 1.3s, h = 65 cm . Surge, Sway and Heave (m).

Wave and current interaction

Once the model was calibrated and validated, the combined effects wave and current were analyzed. The new set of boundary conditions implemented in IHFOAM allow generating waves with a depth-uniform current. Uniform current was imposed at the patch inlet for current generation. In the present work we analyzed the effect of the interaction of current with regular second order Stokes waves. Firstly three simulations with three different values of current in horizontal direction were carried out for each of the cases above.

The case A (H = 7.3cm, T = 1.3s, h = 65cm) was selected to develop the numerical simulations of only current action and wave-current interaction. The following values of positive and negative current were considered:

- Ux current = + 0.25 m/s
- Ux current = + 0.5 m/s
- Ux current = + 0.75 m/s

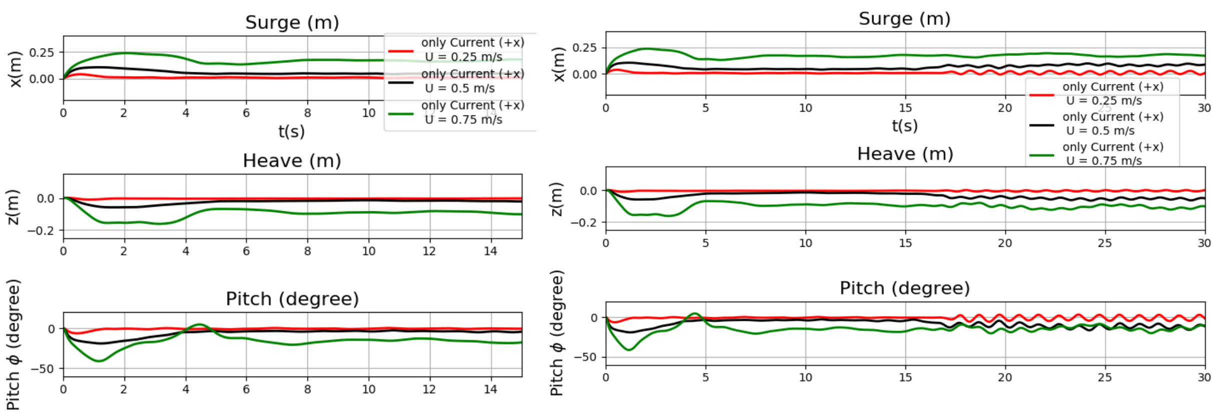

Figure 3: On the left: Only current interaction – Comparison of Surge, Heave and Pitch under the action of positive current. Positive current: U = 0.25 m/s, U = 0.5 m/s, U = 0.75 m/s, in red, black and green, respectively. On the right: Wave-current interaction – Comparison of Surge, Heave and Pitch under the action of wave and positive current of magnitudes 0.25, 0.5 and 0.75 m/s. The wave case considered is: Case A: H = 7.3cm, T = 1.3s, h = 65cm.

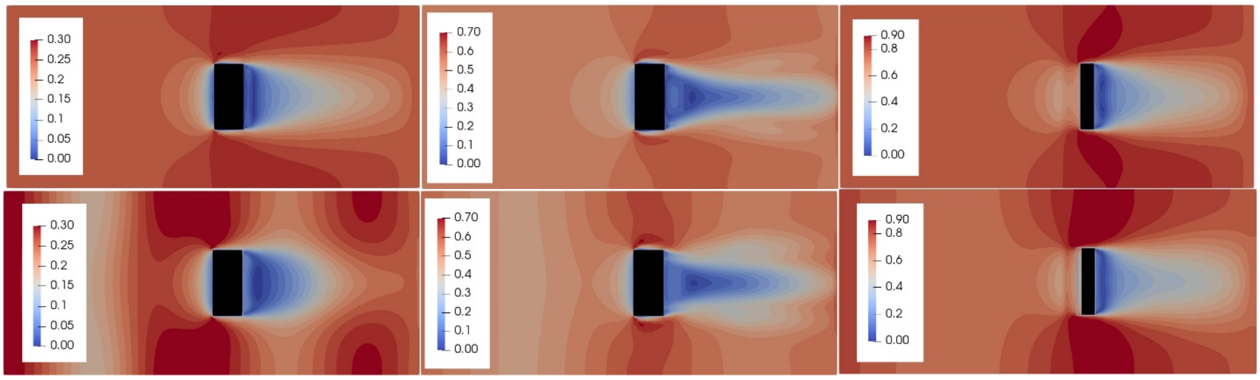

Figure 4: On the top, from the left to the right: velocity field magnitude U(m/s) induced by only current of 0.25 –0.5 –0.75 m/s, respectively. On the bottom, from the left to the right: wave-current interaction with current intensities of 0.25 –0.5 – 0.75 m/s, respectively. The wave case considered is: Case A: H = 7.3cm, T = 1.3s, h = 65cm.

Conclusions

A numerical model for wave-current interaction was carried out. The new implementations in IHFOAM, including a modified linear spring model and wave and current join generation, were used to demonstrate that this model could be used for all offshore and coastal engineering application of wave-current floating structure interaction. Numerical implementations were validated with existing experimental data in literature showing a good agreement in the reproduction of the six degrees of freedom of the floating body subjected to the action of waves. The new implementations were stressed to analyse the combined effects of waves and currents. When performing the overset mesh, high dynamic mesh motion stability was achieved for all the cases. Finally, the main goals were accomplished with a not so expensive computational grid. The computational time for wave and current case (the most expensive simulation) was 20 hours with 16 cores.

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