Modelling Wave Energy Converter (WEC) pointer absorbers using AMR techniques with both subcycling and non-subcycling

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Abstract

Wave energy has received significant attention in both academic and industrial areas during the past few decades. Among all of Wave Energy Devices (WEC) devices, many researchers focus on modeling the point absorber since it can provide a large amount of power in a small simple device when compared with other technologies. In this present work, we developed an efficient Structured Adaptive Mesh Refinement (SAMR) framework to model the interactions between the wave and pointer absorber by directly solving the Naiver-Stokes equation in a conservative manner. In particular, the level set function is used to capture the air-water interface, and re-initialization across different levels is applied. The Discrete Immersed Boundary Method (DIBM) is applied to describe geometry of the pointer absorber and include its effects on the incoming wave, which is generated in the inlet and absorbed by using a sponger layer closed to the outlet. To save computational cost, meshes are only refined near the air-water interface and surface of point absorber. Specially, both non-subcycling, where a uniform time step is employed for all variables on composite levels, and subcycling, in which variables on different levels advance via different time steps, are embedded in the SAMR framework. Cases about wave generation and fluid-structure interaction are obtained to validate the above proposed algorithm. Results show that subcycling takes significantly less CPU hours than non-subcycling to model the wave and pointer absorber interaction. Heave motions under different wave inputs are compared with previous experiments as well as results from potential flow theory, which shows viscous effects are important in this process. Future work including coupling AMR with Turbulent Models (e.g. RANS or LES) are also listed as an extension.

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Introduction & Motivation

Wave energy has received significant attention in both academic and industrial areas during the past few decades [1]. Among all of Wave Energy Devices (WEC) devices, many researchers focus on modelling the point absorber since it can provide a large amount of power in a small simple device when compared with other technologies (Fig 1).

In this present work, we developed an efficient Structured Adaptive Mesh Refinement (SAMR) code (Fig 2) based on the *AMReX* framework [2] to model the interactions between the wave and pointer absorber by directly solving the Naiver-Stokes equation in a conservative manner. Specially, both subcycling and non-subcycling methods are embedded in the SAMR framework.

Besides validating the proposed algorithm, we find that using AMR can significantly reduce the computational cost. It is also noticed that the potential theory over-predicts the heave amplitude of the WEC when compared with our fully resolved simulation.

Figure 1: *A prototype of OPT's PowerBuoy wave energy generation system* NREL PIX 17114 [1]

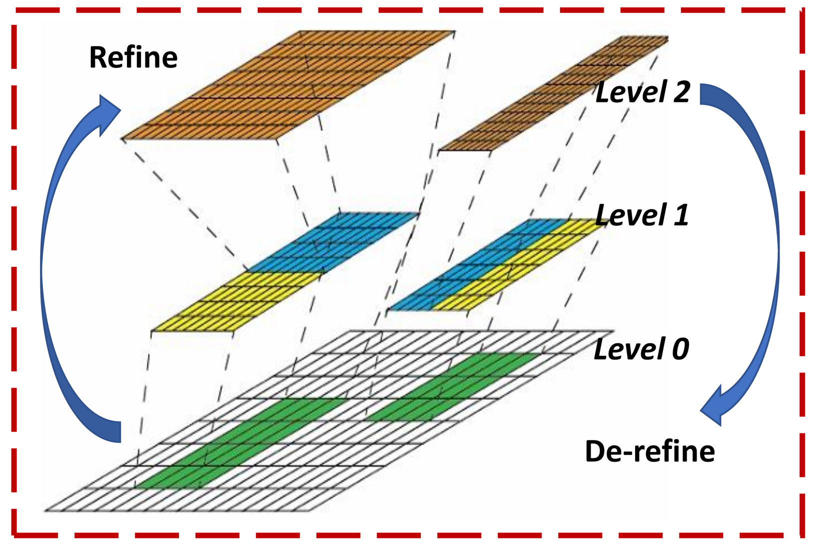


Figure 2: *Sketch of SAMR*

Numerical Methods

Governing equations

For the single level, we solve the Naiver Stokes equations by using the projection method. The air-water interface is captured by the level set function ϕ. The re-initialization algorithm is applied after every time step to make ϕ satisfy the signed distance function and guarantee the mass conservation.

- NS equations

$$\frac{\partial \boldsymbol{u}}{\partial t} + \nabla\cdot(\boldsymbol{u}\boldsymbol{u}) = \frac{1}{\rho(\phi)}\left(-\nabla p + \frac{1}{Re}\nabla\cdot 2\mu(\phi)D + \rho(\phi)\frac{z}{Fr} - \frac{1}{We}\kappa(\phi)\delta(x)\boldsymbol{n}\right) + \boldsymbol{f}_{ib}$$

$$\nabla\cdot\boldsymbol{u} = 0$$

- Level set advection equation

$$\rho(\phi) = \frac{\rho}{\rho_w}, \mu(\phi) = \frac{\mu}{\mu_w}$$

$$\frac{\partial \phi}{\partial t} + \nabla\cdot(\boldsymbol{u}\phi) = 0$$

$$Re = \frac{\rho_w U L}{\mu_w}, Fr = \frac{U^2}{gL}, We = \frac{\rho U^2 L}{\sigma}$$

Discrete Immersed Boundary (IB) method

The IB method is used to accurately capture the surface of the WEC. A forcing term $\boldsymbol{f}_{ib}$ is applied to the external forcing points located near the immersed boundary (red triangles in Fig 3). The velocity at these external forcing points is interpolated from surrounding fluid points (purple circles in Fig 3) and the solid points (blue squares in Fig 3).

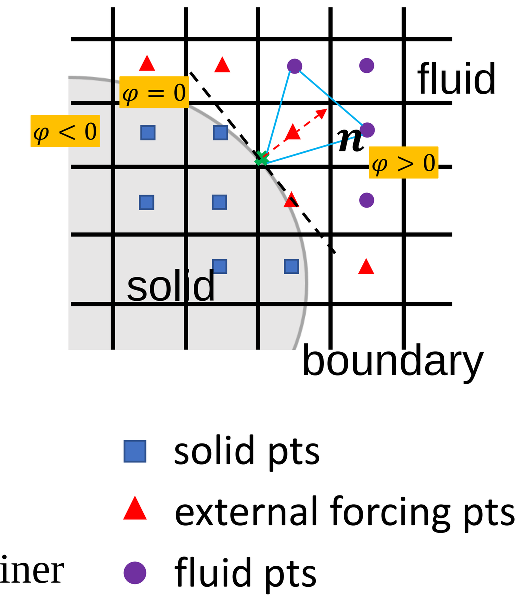


Figure 3: *Sketch of IB method*

Synchronization

For multi levels, we use the subcycling or non-subcycling methods for time evolution (see the next part). When data on a finer level catches up with data on a coarser level, synchronization operations are used to maintain the momentum conservation.

Numerical Methods (cont.)

Subcycling v.s. Non-subcycling

Sub-cycling refers that data at different levels are advanced with different timesteps. Since coarser levels have a larger grid space than finer levels, timestep on coarser levels can be larger than that on finer levels if the CFL number is kept as a constant on different levels. Non-subcycling means that variables on different levels advance with the same timestep, restricted by that on the maximum level [3]. Compared with the subcycling, non-subcycling has a smaller timestep for each step and advances relatively slowly.

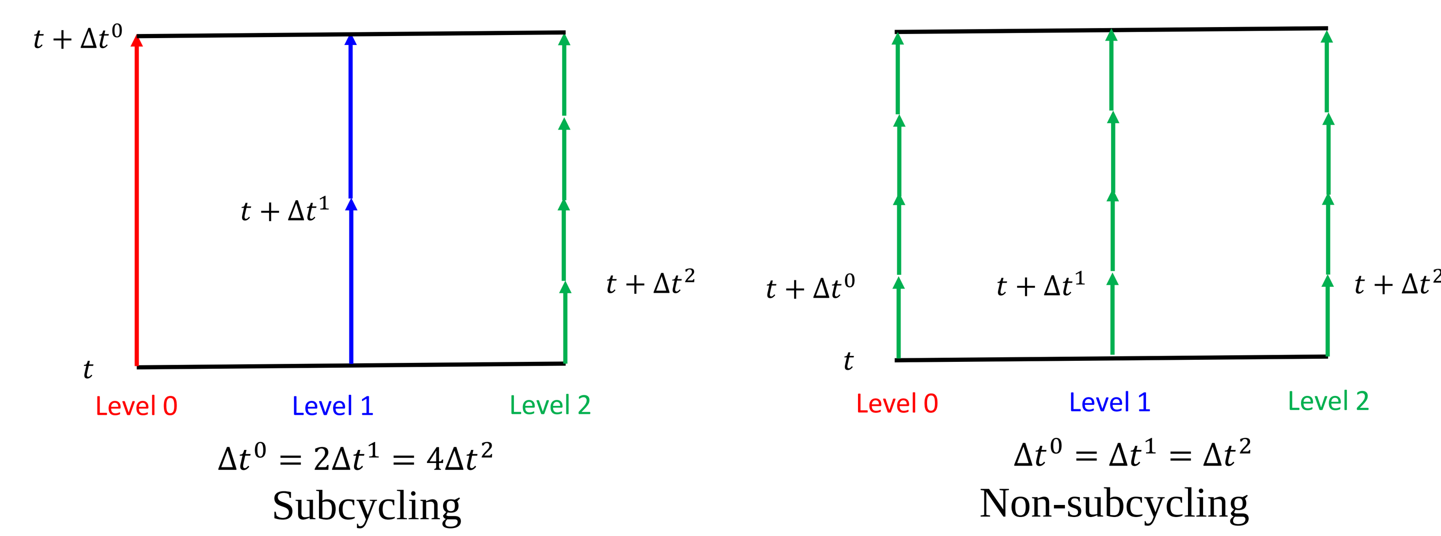
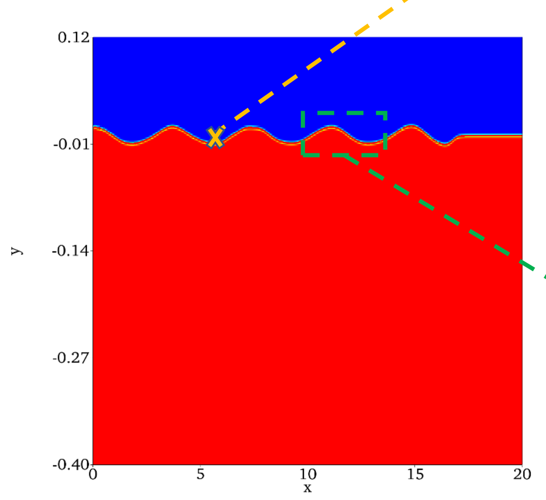


Figure 4: *Sketch of different cycling methods*

Validation

Velocities are prescribed at the inlet boundary based on the linear wave theory and smoothed by using the level set function. A damping zone is placed at the right side of the computational domain for absorbing the incoming wave. To validate the wave generation and the wave damping algorithms, we consider the single level cases as well as the multi level cases.

For the single level situation, we tested the grid convergence, which shows the medium grids (nine grid cells per wave height) are good enough to capture the correct wave profile.



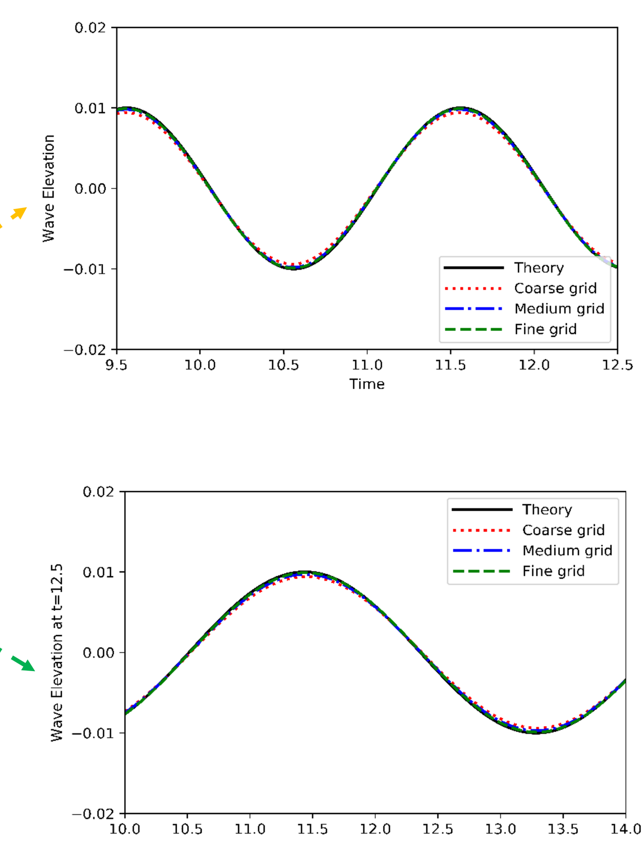
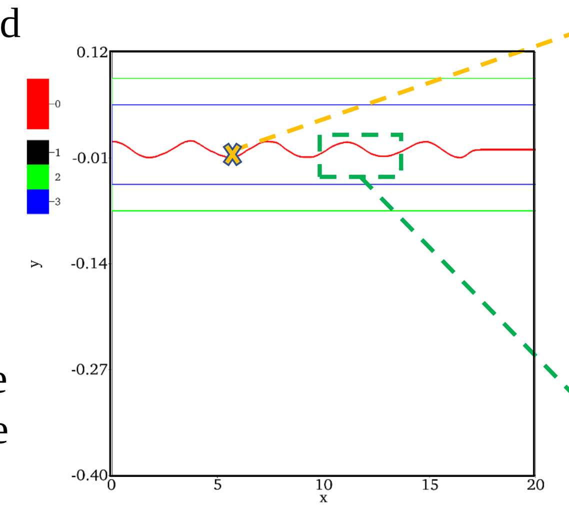


Figure 5: *Density field of the single level case*

For the multi level cases, we tested both the subcycling and non-cycling methods. When compared with the medium grid on a single level, results show that both wave generation and wave damping algorithms work well within the AMR framework.



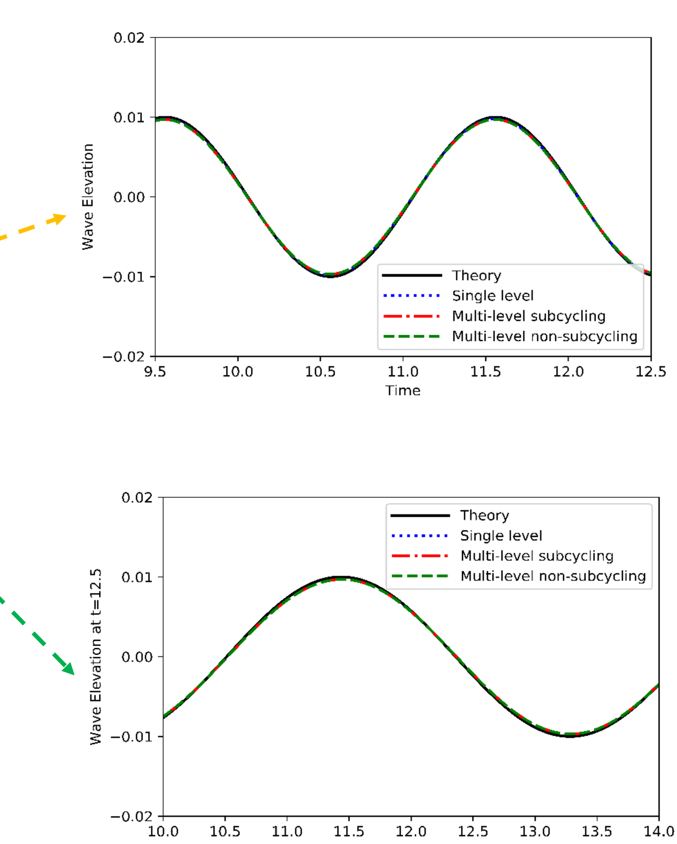


Figure 6: *Grids hierarchy of the multi level case*

WEC Cases and Results

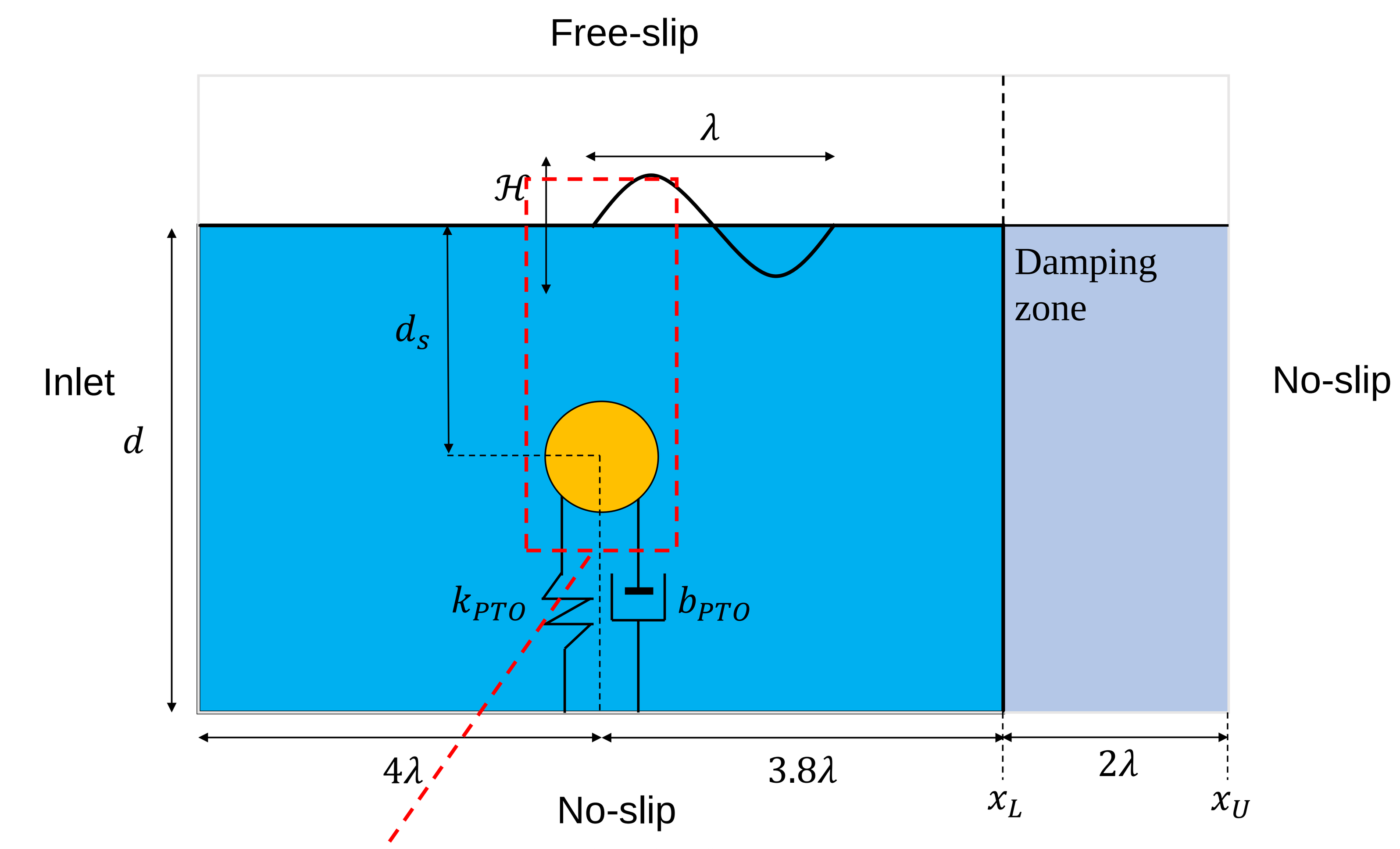


Figure 7: *Sketch of WEC set up* [4]

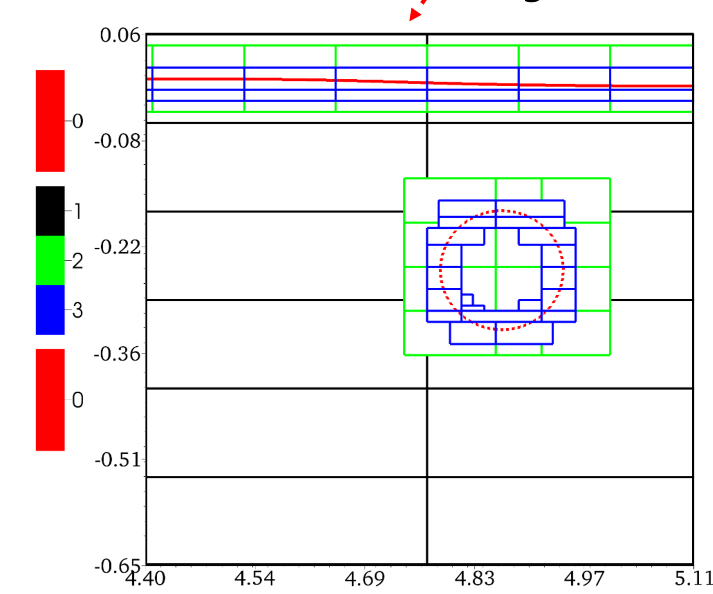


Figure 8: *Grid hierarchy with refinement*

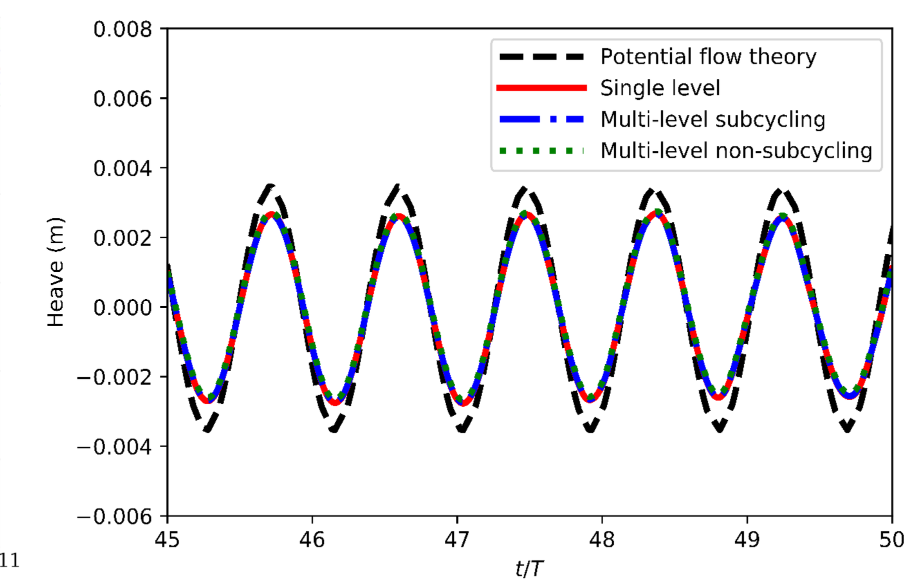


Figure 9: *Heave motion for different cases*

- To compare the computational efficiency among different WEC cases with fixed amount of work, 128 CPU cores on the *Cray XE6m* HPC *machine* are used. The wall time (Fig 10) is normalized by the total wall time of the multi-level subcycling case.

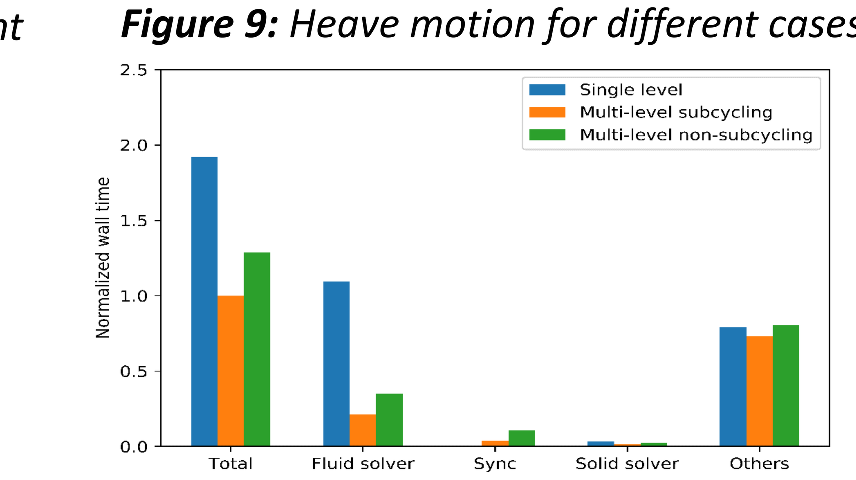


Figure 10: *Profiling results*

Conclusions

- Wave generation and wave damping algorithms are validated.
- Potential flow theory over-predicts the heave amplitude of the WEC because it overestimates the wave excitation loads on the submerged buoy.
- Subcycling reduces more computational cost compared with the non-subcycling and the single level case. The synchronization step and solid solver do not take too much time.

References

[1] Y.-H. Yu, Y. Li, *CAF 2013*
[2] W. Zhang, et al. *JOSS 2019*
[3] A.S. Almgren, et al. *JCP 1998*
[4] P. Dafnakis, et al. *Fluid Dynamics, 2019*