Programma STM 2016

Fruitore: Andrea Bardazzi
Istituto di afferenza: Istituto Nazionale per Studi ed Esperienze di Architettura Navale (INSEAN)
Qualifica Assegnista di ricerca

Final Report

The objective of my stay at the Centre of Autonomous Marine Operations and System (NTNU AMOS). Dept. of Marine Technology, NTNU, in Trondheim concerns the development of numerical tools, based on the Harmonic Polynomial Cell (HPC) methodology, for the study of the hydroelastic interaction as consequence of the impact of a breaking water wave or incipient breaking waves against deformable structure [LMBF10],[LBF10], [LBFG14]. The HPC method, proposed by Shao and Faltinsen [SF12],[SF14], is an higher-order (4th) field method for the solution of Laplace equation, which discretize the computational domain by overlapping cells. The high order of accuracy as well as the computational efficiency, make the HPC method a suitable tool for the solution of potential flow. Because the final aim of this research is the study of hydroelastic interaction between structure and fluid flow characterized by a strong non-linear behaviour and free-surface with large curvature, a proper modelling of the free-surface is required in order to simulate such kind of fluid flows. During the stay, in collaboration with the PhD student Finn-Christian Hanssen and under the supervision of Prof. Marilena Graco, Prof. Odd. M. Faltinsen and Ing. Claudio Lugni, we developed and compared two different strategies for the treatment of the free-surface for potential flow problem.

The first strategy proposed is an immersed boundary (IM) method, where the free surface is considered submerged in a fixed background grid and markers (Lagrangian or semi-Lagrangian) are used to track its temporal evolution.

In figure (1) is shown the free-surface configuration for the IM method. The dynamic boundary condition for the free surface is satisfy by the use of ghost node placed out of the physical domain and by the cells, shaded in gray, just below the free-surface. The imposition of the boundary condition twice for the same markers do not lead to a singular global coefficient matrix.

The second approach consists in a multi-grid (MG) method, where several structured grid exchange information about the velocity potential in certain connection nodes. In our work we considered only two grid: a background grid fixed in time and a free-surface fitted grid that follows the free-surface deformation during its temporal evolution in accordance with the kinematic and dynamic free-surface boundary conditions. In figure (2) is shown a simplified configuration for the MG method. The free-surface grid is built, at each time step, starting from the free-surface markers and going below following the local normal direction.

Several test cases, as the long-time propagation of waves with increasing steepness in a periodic wave tank, the propagation of a solitary wave over a long distance, a plunging wave packet, periodic waves generated by a piston wavemaker in shallow water and periodic waves generated by a flap wavemaker in deep water, have been reproduced with the two approaches for their validation and comparison of their performances. The two methods shown a good agreement with each other, and also with the reference results for each of the studied problems. In cases of very steep waves the MG methods seems to be more robust than the IB which shows the insurgence of saw-tooth instability and a filtering is then required for the stability of the method. The

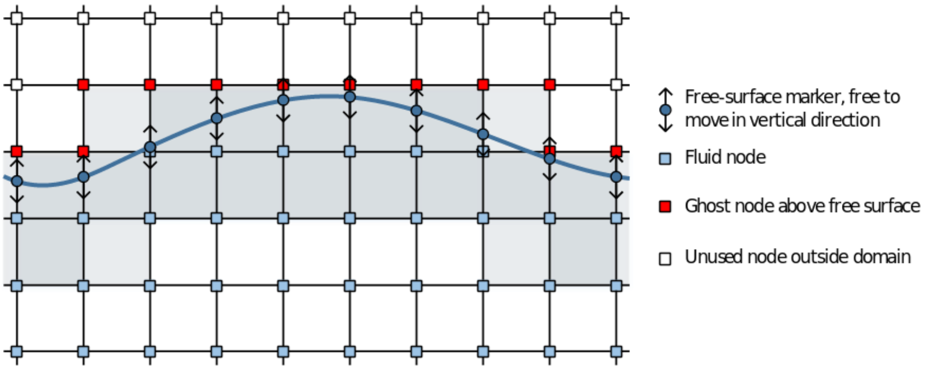

Figure 1: IB free-surface method: The free surface is an immersed boudary in a structured Cartesian grid and it is tracked by markers moving only in vertical direction. The cell shaded in gray are used to impose the free-surface conditions.

implementation of the IM scheme has turned out to be easier due to the structured squared grid and it can be made efficient in term of cpu time because the geometry remains fixed in time. Only a partial re-building of the global matrix coefficient is required at every time step because the computational domain may change with time depending on the position of the free-surface. Differently from the IM, the numerical implementation of the MG method is more complex and particular attention is required for the treatment of the connection nodes as well as for the nodes of the free-surface fitted grid close to the boundary of the physical domain. Also the cpu time can be higher respect the IM method due to the re-meshing of the free-surface fitted grid at each time step. To improve the efficiency of MG method a stretching of the computational grids is required. It has been proved that an optimized configuration (920 computational nodes respect to the 2280 of a "base" configuration) performs approximately 2.36 time faster and requires 59% less of memory.

In order to study phenomena as flip-through or overturning wave where a fully-Lagrangian formulation is required, the activities performed indicates that the MG method is more suited because it can be more adaptable in case of local grid refinement when the free-surface is characterized by large curvature.

A manuscript entitled "Free-Surface Tracking with the Harmonic Polynomial Cell Method" has been submitted to the International Journal for Numerical Methods in Engineering.

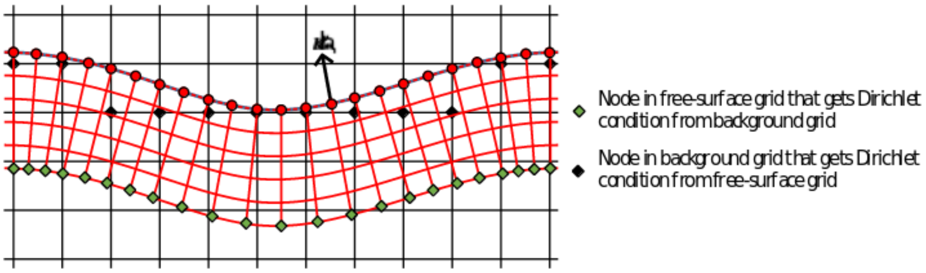

Figure 2: MG free-surface method: the markers (red dots) track the free-surface deformation, deforming the grid fitted with the free-surface (red lines). The fitted grid is overlapping with a Cartesian background grid (black lines) and the communication between the two grid occurs at the highlighted nodes in each grid (diamond markers).

References

[LBF10] C Lugni, M Brocchini, and OM Faltinsen. Evolution of the air cavity during a depressurized wave impact. ii. the dynamic field. *Physics of Fluids (1994-present)*, 22(5):056102, 2010.

[LBFG14] Claudio Lugni, A Bardazzi, OM Faltinsen, and G Graziani. Hydroelastic slamming response in the evolution of a flip-through event during shallow-liquid sloshing. *Physics of Fluids (1994-present)*, 26(3):032108, 2014.

[LMBF10] C Lugni, M Miozzi, M Brocchini, and OM Faltinsen. Evolution of the air cavity during a depressurized wave impact. i. the kinematic flow field. *Physics of Fluids (1994-present)*, 22(5):056101, 2010.

[SF12] Yan-Lin Shao and Odd M Faltinsen. Towards efficient fully-nonlinear potential-flow solvers in marine hydrodynamics. In *ASME 2012 31st International Conference on Ocean, Offshore and Arctic Engineering*, pages 369–380. American Society of Mechanical Engineers, 2012.

[SF14] Yan-Lin Shao and Odd M Faltinsen. A harmonic polynomial cell (hpc) method for 3d laplace equation with application in marine hydrodynamics. *Journal of Computational Physics*, 274:312–332, 2014.