Modeling and high-order simulations of wave-body interactions

This project aims at developing an efficient parallel numerical model for wave body interactions based on a depth-averaged description. The final aim is to simulate the interaction of nonlinear and possibly (weakly) dispersive waves with fixed structures (bridges, pontoons, etc), as well as with bodies in forced (wave generation), or free (wave energy devices, ships) motion.

For engineering analysis, linear wave models are widely used. For example, numerous wave-energy models, as e.g. WEC-Sim from NREL [wec] or Aqwa by Ansys [ans], the hydrodynamic coefficients are often computed by panel codes as WAMIT [wam] or Nemoh [bar]. These coefficients are then used in the dynamic equations with convolution integrals to account for memory effects. Additional effects are included by means of ad-hoc corrections, which may involve some non-linearity, but the underlying wave propagation remains linear. For floating structures, recent studies [yu, pal, esk, bos] indicate that linear models may provide significantly wrong oscillation amplitudes for the floater. As a result these models may provide unrealistic constraints on a structure, or excessive over-prediction of the power extracted from the waves.

On the other end of the spectrum 3D VOF-RANS codes allow in principle a resolved simulation of the wave field and of the flow under/over the structures/bodies [yu, pal, deb]. These models are fully nonlinear, fully dispersive, and account for all effects, including generation and propagation of vorticity, as well as viscous dissipation. However, besides many issues still open related e.g. to turbulence modeling, or to the management of the water-air interface, the cost of obtaining resolved simulations is prohibitive. In [es1] for example simulations of a realistic wave energy device with irregular sea-states are discussed reporting approximately 150 000 CPU hours for a single run.

Simplified models can be obtained in several ways. For large scale simulations one may neglect, in a first approximation, viscous and rotational effects. In this case, efficient fully nonlinear potential models can be devised [fnpf]. These models account for the full range of nonlinear and dispersive effects at the cost of keeping a three-dimensional description. For long waves, however, dispersive effects are often weak, and depth averaged approximations can be used. These Boussinesq-type equations (BTE) allow to describe wave hydrodynamics in horizontal dimensions only. This makes them computationally less demanding, while still accounting for fully nonlinear effects. The lower-dimensional description opens the door to the study of waves interacting with many structures, as well as to parametric analyses with e.g. many realizations of irregular sea states. This approach has been and is still used extensively for free
surface modeling in coastal applications (see e.g. [bro,kir], and extended to wave-body interactions initially in [jia] and recently in [es2, lan1,bos].

Following these initial contributions, this project focuses on the study and implementation of more flexible and robust numerical treatments of the wave-body coupling. To be more precise, the models under consideration involve the coupling of two systems: 1) a BTE type differential system, with an evolutionary hyperbolic character with additional dispersive terms; 2) a system under the body involving an evolution equation for the flow speed, and an elliptic equation for the body surface pressure. The key to a correct resolution of the forcing on the body is the approximation of the latter, requiring an appropriate formulation and implementation of the discrete boundary/coupling conditions with the free surface domain. The presence of the dispersive correction in the BTE systems arises additional difficulties in this coupling (dispersive boundary layers). The main contributions of this PhD will be related to
1) careful modeling of the coupling of the two types of equations and analysis of the transmission conditions at the interface;
2) fully nonlinear coupling conditions based on a characteristic analysis of the free surface and under-body models, properly recast in a first-order (pseudo-)hyperbolic form in a relative- frame of reference accounting for horizontal drift of the body. Upwind as well as generalized/dissipative/stable numerical coupling fluxes will be devised;
3) a high order embedded stabilized finite element discretization based on extrapolation techniques guaranteeing genuine second (or higher) order for both variables and gradients [son, nou] for hyperbolic and elliptic PDEs;
4) an efficient parallel implementation in Inria’s C++ finite element library Aerosol [Aero];
5) validation and exploitation of the model on realistic applications relevant to ship hydrodynamics, and wave energy.

This work follows the activities of the European Ocean ERANET project MIDWEST, and will benefit of the interactions with the members of this project, in particular DTU Compute (Denmark) and RISE (Sweden). The formulation of the embedded coupling with benefit of the collaborations within Inria Associated Team HAMSTER with the Civil Engineering department of Duke University. The PhD candidate will work in the Inria team CARDAMOM in close collaboration with other developers of the Aerosol Library, as well as of the UHAINA wave model based on the same library. This work will also be part of the research program “Wave-structure interactions and marine renewable energies” funded by the Del Duca Fundation.
Bibliography

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