Fluid-Structure Coupling for Sloshing in Flexible Tanks

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Sloshing flows, i.e. resonant fluid motion in confined domains, play a significant role in many practical circumstances. Early work relevant to this topic is reported e.g. in [1]. In the field of naval hydrodynamics, ship response to incoming waves can excite violent motions of transported liquids (crude oil, gas, etc.). Most of the tanks are smooth inside and the resulting small fluid dynamic damping of the system is very small, thus increasing the sloshing amplitudes. On this ground, large oscillatory structural loads are expected, as well as local impulsive loads (slamming) on lateral walls (in case of small filling level) or on the tank roof (for higher filling heights).

Accurate prediction of sloshing loads is of main concern during the design stage of ship tanks. In most of the applications, the dynamic interaction between the structural vibrations and the flow field is neglected, i.e. fluid loads are determined by studying liquid sloshing in rigid tanks. However, the accuracy of this simplified analysis is questionable when dealing with lighter structures or high-strength structural steels. This latter case is of growingly importance in current design practice, and the modeling of fluid-structure interaction is needed to understand the various hydroelastic phenomena and to assess the safety of the system.

The scope of the presentation is to review our ongoing effort in developing a simulation tool to describe the coupled structural-fluid dynamic system. The adopted fluid-structure model consist of three components: a fluid dynamics solver, a structural dynamic solver, and an interaction model along the fluid-structure interface, see e.g. [6, 3]. More precisely, by virtue of the high Reynolds number typically encountered in practical applications, the flow field is described through an inviscid model. Nonlinear free surface motions are allowed, though a linearized version of the problem will be used as a test case against available analytical solution. Linear elasticity theory is used to describe the dynamic behavior of the flexible tank.

To handle unsteady free-surface motions typically encountered in sloshing flows we employ an high order boundary element method based on B-Spline representation [5]. This method is well suited to handle standing waves and impulsive free-surface motions. A semi-discrete finite element formulation for the structural dynamic equation of motion is used for the flexible walls of the tank.

Starting from a variational formulation of the coupled problem [8], we investigate some possible algorithms to solve the full unsteady interaction phenomenon.

Many different schemes from fully implicit to fully explicit can be used for the time discretization of the problem [4, 2, 7]. Relevant merits and disadvantages of the various possible approach for the problem at hand will be presented and discussed. Issues related to the stability and the accuracy of the numerically coupled simulations will also be examined with the objective of identifying a stable, accurate and efficient algorithm to solve the coupled sloshing problem.

Finally, some initial results on a fully explicit interaction two-dimensional model problem will be presented.

References

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