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Prediction of Dam Break Hydrodynamic Wall Pressure

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ABSTRACT

In this paper, hydrodynamic wall pressure resulting from a dam break simulation is analyzed in detail. The simulation has been done real-time in three dimensions using an innovative particle-cluster approach that is able to simulate complex liquid dynamics in much shorter time than classical continuum mechanics approaches. The results for impact pressure, water height and wave speed are in very good qualitative and quantitative agreement with results from experiments and CFD solutions carried out at Groningen University. Special focus has been set on the unsteady wall pressure distribution during initial and reflection wave impact.

KEY WORDS: Green Water loading; dam break; wall pressure; particle-cluster approach; wave propagation; Lennard-Jones potential; Lagrange method.

INTRODUCTION

Dam break and Green Water loading are complex physical processes in riverside and offshore applications. It covers phenomena like sloshing, wave propagation and liquid-structure interaction, see (Bozkus and Kasap, 1998). Applying continuum fluid mechanics for a simulation approach, Euler and Navier-Stokes solvers provide a time accurate simulation only if an appropriate free surface determination and propagation is implemented. In consequence, computation time and required memory resources increase with increasing code complexity and accuracy requirements.

In this paper, an innovative approach is highlighted that is able to predict the hydrodynamic wall pressure resulting from water impact on a test container after dam break.
This approach does not follow the classical continuum mechanics methods, but is Lagrangian in nature. A large number of microscopic liquid particles (molecules, ions) are supposed to be concentrated in particle-clusters of macroscopic dimensions. These clusters are connected to each other by a Lennard-Jones potential originally in use in molecular dynamics. The potential parameters have been transformed into macroscopic domain using fundamental mechanical and chemical relations. Thermodynamic laws are fulfilled by introducing Fourier's law of heat transfer and an energy dissipation scheme that obeys the conservation of momentum. Numerically, the cluster trajectories are computed using a Velocity-Verlet integration scheme. An innovative neighborhood list has been designed that permits a linear dependence of the computation time from the number of particle-clusters. A variable time-step scheme allows a drastic reduction of computation time, see section "Computation Time".
The results obtained from the particle-cluster simulations are in very good qualitative and quantitative agreement with experimental data and CFD solutions from Groningen University. Snapshots in time and some results for the wall pressure for different cluster sizes are discussed.
An outlook providing additional simulation results for extended dam break problems like wave impact will be presented and discussed in this paper.

THE PARTICLE-CLUSTER APPROACH

Particle methods discretize the liquid volume with particles instead of structured or unstructured meshes. One big advantage of particle methods stands out from the lack of topology; deformation, contact and complex geometries can be handled more easily, see (Mueller and Charypar and Gross, 2005). Various applications are known for this method, from dam break simulation in (Liang, 2004), phase transition and interactive applications in (Mueller and Charypar and Gross, 2005) and (Vignjevic and De Vuyst and Campbell and Bourne, 2005). Smooth Particle Hydrodynamics (SPH), the most advanced particle-based simulation method, is Lagrangian in nature, i.e. the motion of a number of discrete particles is followed in time. Variables such as velocity, density, deformation gradient and stress are obtained from particle motion using interpolation functions known as kernels. The pioneer work on SPH appeared in 1977 (Lucy) in the Astronomical Journal. Since then, numerous publications report the progress in the methodology as well as its application for various hydrodynamic problems. Monaghan explains in (Monaghan and Thompson and Hourigan, 1994) the re-construction of the liquid free surface in detail. A special variant of Lagrange methods is described in (Huyer and Grant, 2000) for naval applications. There, a Lagrange vorticity method is applied to unsteady hydro-dynamical offshore problems.

The basic idea of the particle cluster approach is to concentrate a specific number of microscopic particles (molecules, ions) in clusters