DYNAMIC WAVE IMPACT SIMULATION USING AN INNOVATIVE PARTICLE-CLUSTER SCHEME

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Summary In this paper, the wave impact on a solid submitted to forced oscillations is highlighted. This kind of wave impact is typical for offshore applications like ship foredeck loading where the ship undergoes low-frequency, but high amplitude oscillations. The simulation has been done using an innovative three-dimensional particle-cluster scheme that is able to simulate complex liquid dynamics. A large number of microscopic liquid particles (molecules, ions) are supposed to be concentrated in particle-clusters of macroscopic dimensions. These clusters interact via a Lennard-Jones potential. The potential parameters have been transformed into macroscopic domain using fundamental mechanical, thermodynamical and chemical relations. The wave impact has been simulated time-accurately in six degrees-of-freedom. The simulation results have been successfully validated against experiments and CFD simulations carried out at Groningen University, The Netherlands.

INTRODUCTION

The understanding of wave impact on a solid is a contimuous challenge in scientific research and in the design of technical applications that have to withstand highly dynamic wave impact. In [6], the author gives an example for wave impact on the foredeck of a container ship. Estimation of the forces and physical wave characteristics (Water height, impact frequency, wall pressure) has been difficult as experiments are expensive and often limited to specific test cases, see [2]. Today, those experiments are more and more replaced by numerical simulations. With rising computer power, complex simulation codes like Euler and Navier-Stokes are able to simulate even complex flow phenomena like dam break and wave impact, [6]. These codes mostly require multi-processor computers and considerable ressources in memory and computation time. Especially in highly dynamic processes with solids moving in six degrees-of-freedom in a liquid, it is strongly desireable to have a simulation model that is flexible in handling moving geometries, running on a local computer and providing accurate solutions within a drastically reduced computation time. The innovative particle-cluster approach presented in this paper fulfills all these requirements.

THE PARTICLE-CLUSTER APPROACH

The particle-cluster approach presented here combines the advantages of molecular dynamics with those of continuum mechanics; the inter-particle forces within the liquid and fundamental thermodynamics are in congruency with molecular dynamics theory, see [9]. It has been validated in applied hydrodynamics as well as in aerospace technique, especially for the prediction of sloshing effects and highly dynamic liquid impact, see [2]. The basic idea is to concentrate a specific number of microscopic particles (molecules, ions) in clusters of macroscopic scale. These clusters have the shape of a sphere and interact with each other via a non-linear Lennard-Jones potential.

$$\left.\begin{aligned} U_{ij} &= \alpha \cdot \epsilon \cdot \left(\left(\frac{\sigma}{r_{ij}}\right)^m - \left(\frac{\sigma}{r_{ij}}\right)^n \right) \quad , \quad \alpha = \frac{1}{m-n}\left(\frac{m^m}{n^n}\right)^{\frac{1}{m-n}} \\ r_{ij} &= \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2} \quad , \quad r_0 = \sqrt[m-n]{\frac{m}{n}} \cdot \sigma \end{aligned}\right\} \tag{1}$$

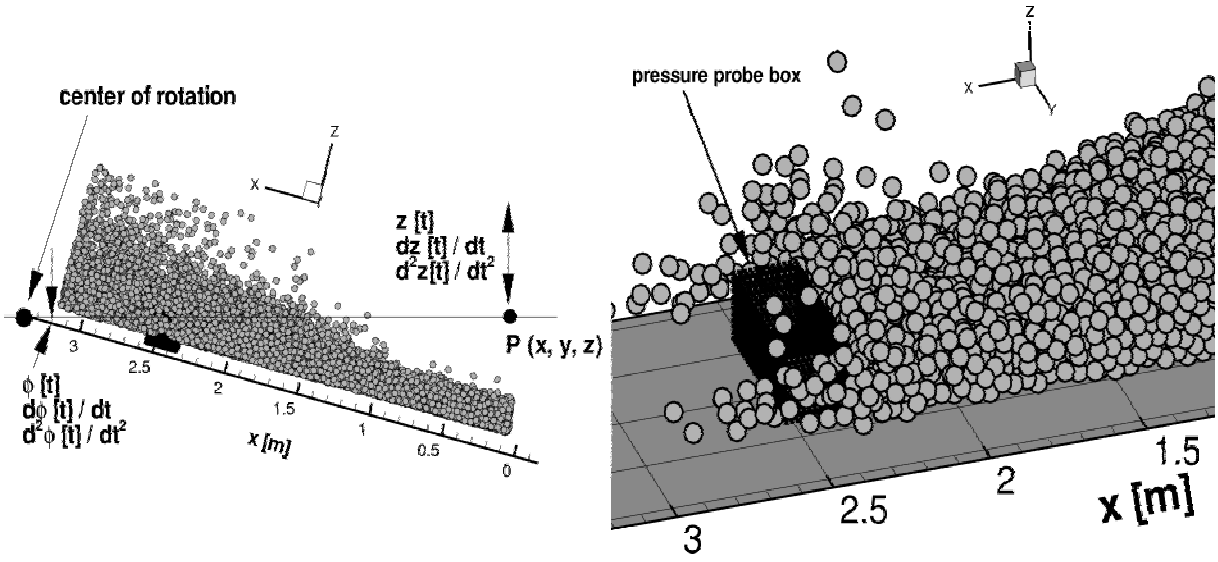
The quantity U_{ij} denotes the potential energy between two particle-clusters i and j. The quantity ϵ is the bond energy, σ the cluster diameter, r_0 the rest distance, m and n are exponents for the repulsing and attracting parts of the potential and r_{ij} the distance vector between the clusters.

The equation of motion for each particle-cluster i is obtained by applying Lagrange's formula in Cartesian coordinates x,y and z. Inserting the Lennard-Jones potential, equ.(1) gives, after some algebraic transformation:

$$m \cdot \ddot{q}_i - \sum_{\substack{j=1 \\ j \neq i}}^{N} \left(\alpha \cdot \epsilon \cdot r_{ij}^{(-2)} \cdot \left(m \cdot \left(\frac{\sigma}{r_{ij}}^m\right) - n \cdot \left(\frac{\sigma}{r_{ij}}^n\right) \right) \cdot (q_i - q_j) \right) \tag{2}$$

The particle-cluster trajectories are computed according to the fundamental laws of classical mechanics, see [4], including Newton's action-reaction principle and the conservation of momentum, locally and globally. With the equation of motion being conservative, an innovative energy dissipation scheme based on the individual particle-cluster velocities has been designed to capture dissipative effects. The physical characteristics of a liquid, in particular viscosity and incompressibility, see [8] and [5], are well represented. The liquid dynamics have been implemented according to Newton's fundamental laws of dynamics with respect to an accelerated reference system.

$$a_{liquid,i} = \frac{d' v_i}{dt} = \sum_{\substack{j=1 \\ j \neq i}}^{N} \left(\frac{F_{ij}}{m_{liquid,i}} \right) + \frac{F_{reservoir,i}}{m_{liquid,i}} + g - a_{reservoir}$$



(a) dynmaic wave impact simulation

(b) wave impact on pressure probe box

Figure 1. dynamic wave impact particle-cluster simulation

$$-\left[\frac{d\Omega_{reservoir}}{dt} \times r_i + \Omega_{reservoir} \times (\Omega_{reservoir} \times r_i)\right] - 2 \cdot \Omega_{reservoir} \times v_i \tag{3}$$

Special focus has been set on the design of a smart neighbourhood list (discretization in space, see [3]) and a local time stepping algorithm (discretization in time, see [7] and [1]), resulting in a linear dependency of the computation time from the number of particle-clusters.

EXPERIMENT AND SIMULATION

The geometrical set up of the wave impact simulation consists of a rectangular box separated into two compartments by a removeable wall. At $t = 0s$, the box contains a specific volume of liquid in one compartent and a pressure probe box in the empty compartment, see Fig. 1, b). At $t > 0s$, the separating wall is removed and the liquid splashes into the compartment of the pressure probe box, simulating a wave approaching the foredeck of the ship. Before and during the wave impact, the simulation box undergoes forced accelerated rotations according to Fig. 1, a), simulating low-frequency ship oscillations with respect to the y-axis. Additionally, a vertical oscillatory translation is commanded to catch the up and down motion of the ship on the waves. Theoretically, any ship motion can be commanded in six degrees-of-freedom. For demonstration purposes, rotation with respect to the y-axis and vertical translation have been chosen here to represent the most important contributions of the ship motion. The pressure is measured at different positions on the pressure probe box. The particle-cluster approach has been successfully validated against experimental results and CFD simulations at Groningen University, see [6].

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