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Smoothed Particle Hydrodynamics Simulations of Dam-Break Flows Around Movable Structures

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In this paper, 3D weakly compressible smoothed particle hydrodynamics (WCSPH) and incompressible smoothed particle hydrodynamics (ISPH) models are used to study dam-break flows impacting either a fixed or a movable structure. First, the two models' performances are compared in terms of CPU time efficiency and numerical accuracy, as well as water surface shapes and pressure fields. Then, they are applied to investigate dam-break flow interactions with structures placed in the path of the flood. This study found that the ISPH modeling approach is slightly superior to the WCSPH approach because more stable particle motion and pressure distribution can be achieved with a reasonable CPU load.

INTRODUCTION

Monaghan (1994) first extended the smoothed particle hydrodynamics (SPH) modeling concept to incompressible flows with free surface by using a weakly compressible assumption. An equation of state was used to link the density with the pressure field, which is the commonly used WCSPH approach. Since then, the SPH method has been found to have great potential for problems involving the large deformation of free surfaces, moving interfaces, and deformable boundaries. For example, Gómez-Gesteira and Dalrymple (2004) reproduced the impact of a dam-break flow on a tall structure using a 3D weakly compressible SPH (WCSPH) model. In addition, although the SPH modeling technique has been widely used in the research community, very few engineering applications have been reported because of the relatively high computational cost of the technique. Recent work in the parallelization of the SPH code could enable some realistic simulations (Ferrari et al., 2009).

Despite being very effective in water-surface tracking, the conventional WCSPH method has been found to suffer from unphysical fluctuations in pressure prediction. This is caused by small density errors in calculation, which can be amplified through the equation of state. Some effective treatments have been made to correct the density errors and kernel gradient errors, which significantly improved the WCSPH simulation capacity. On the other hand, quite a few incompressible models with better stability properties have been established. For example, Cummins and Rudman (1999) were the pioneers who put forward the projection SPH (PSPH) method, which imposed a zero-divergence requirement in the derivation of the pressure Poisson equation (PPE). Follow-on development of the PSPH method leads to the divergence-free ISPH models. Besides, following the principles of the moving particle semi-implicit (MPS) method (Koshizuka et al., 1998; Gotoh and Sakai, 1999), in which the constant-density condition was used to derive the PPE to enforce the incompressibility requirement, Shao and Lo (2003) proposed the density-invariant ISPH method. Further improvement was made by Hu and Adams (2009), who combined the velocity divergence-free and density-invariant algorithms.

The performances of various WCSPH and ISPH approaches have been compared over the years. Cummins and Rudman (1999) simulated a vortex spin down and Rayleigh–Taylor instability and found that the PSPH method produced more accurate results with better computational efficiency for the low and medium particle resolutions. More detailed comparisons and evaluations of different SPH modeling techniques, as well as their potential improvements, were reported by Khayyer and Gotoh (2010b) for the dam-break flow over a wet bed.

This paper's purpose is twofold. First, we would like to make an objective comparison between the two standard SPH modeling approaches, i.e., WCSPH and ISPH. Although Chen et al. (2013) found that the improved WCSPH approach is more attractive than the standard SPH approach, we need to take precautions to ensure that the two methods are compared on an equal footing. For example, some relevant numerical treatments, such as density normalizations and kernel/kernel gradient corrections, should be disabled in the WCSPH approach. Another objective is to use an improved ISPH pressure algorithm to investigate the 3D dam-break flow interactions with fixed and movable structures. Although quite a few 2D ISPH applications have been reported with similar problems, very little work has been undertaken using the 3D approach. One reason for this could be the long CPU time, because the computational cost increases rapidly with the size of the PPE matrix, and an extra dimension drastically increases the number of coupled equations. Another reason could be the stability of the ISPH

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