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Some modifications of MPS method for incompressible free surface flows

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As a Lagrangian mesh-free method, the Moving Particle Semi-implicit (MPS)[1] method is very suitable for simulating violent flows, such as breaking waves on free surface. However, despite its wide range of applicability, the original MPS algorithm suffers from some inherent difficulties in obtaining an accurate fluid pressure. The severe pressure fluctuation in both spatial and time domain restricts its wide applications to engineering problems, especially for nonlinear fluid structure interactions. Different modifications to improve the method have been proposed [2-5] in the literature. This paper proposes the following modifications to improve the accuracy of pressure calculations and the stability of the method. i) A mixed source term, consisting of the divergence of intermediate velocity and the particle density variation, is introduced into the pressure Poisson equation with no artificial term in the formulation, so that it is case-independent. ii) Neumann pressure boundary condition in the form $\boldsymbol{n} \cdot \nabla p = \rho(\boldsymbol{n} \cdot \boldsymbol{g} - \boldsymbol{n} \cdot \dot{\boldsymbol{U}})$, physically representing force equilibrium on the interface, is applied to solid boundary particles to generate the coefficient matrix of pressure Poisson equation [6], and to adjust the matrix coefficients relating to the particles close to solid boundary in association with adding virtual particles, considering the pressure gradient effect within a particle's support domain. iii) Position shifting; based on the distances of each particle to the neighbour particles, its position is slightly shifted after each time step to maintain the regularity of particle distribution. This modification shows an obvious improvement of the accuracy of gradient calculation and Laplacian approximation. iv) A new version of "cell-link" neighbour particle searching strategy. The size of the cell is chosen to be the initial particle distance which is smaller than the one in traditional "cell-link" algorithm. Moreover, in order to avoid repetitive checking of particles' distances, the neighbouring list is updated simultaneously for both of one-pair particles in which one of them is currently as the centre particle. This centre particle is then excluded in the following neighbouring list generating process for the rest of all the particles. This new strategy reduces about 7/9 (~78%) of the searching area compared with traditional "cell-link" algorithm. And the overall neighbour list generating time would be reduced by about 30%~40%.

To verify the suitability of the proposed modifications, two benchmark free surface flow problems are presented, that is, two-dimensional dam break and liquid sloshing in a rectangular tank. The numerical results obtained are found to be in good agreement with the available experimental results. With the proposed modifications, the MPS method is shown to improve the stability and the accuracy of the pressure solution with quite smooth spatial and pressure distribution in spatial and time domains.

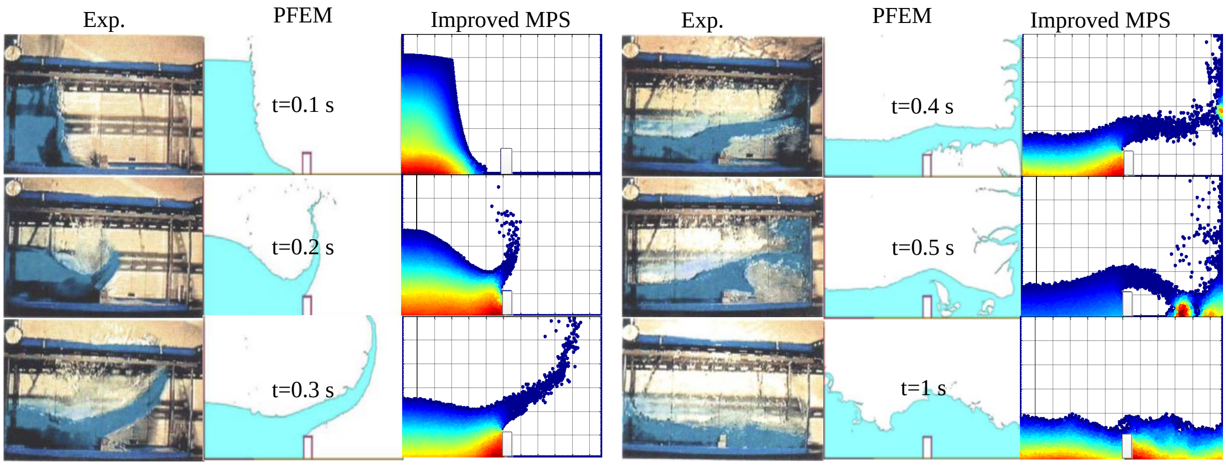

Fig. 1. Pressure contour of dam-break with obstacle

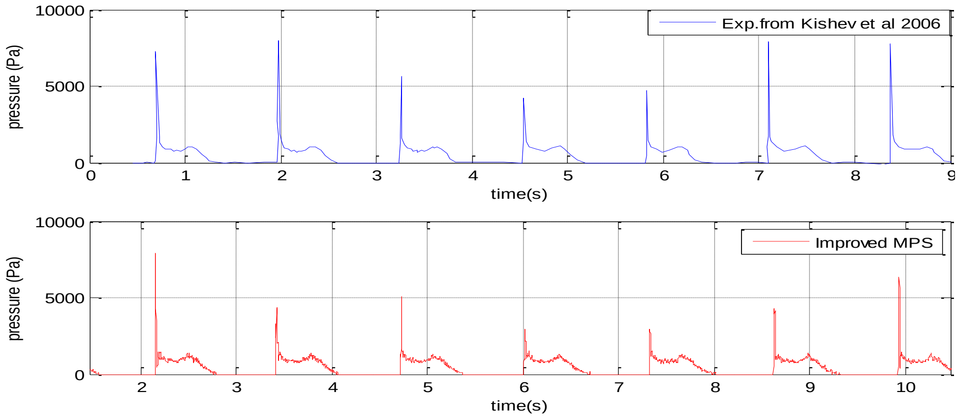

Fig.2 Pressure history of sloshing

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