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Numerical Implementation of Solid Boundary Conditions in Meshless Methods

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ABSTRACT

This paper presents a numerical investigation on the implementation of the solid boundary condition for the meshless methods modelling nonlinear waves. Three different types of implementation methods are tested. Two different nonlinear waves, i.e. monochromic waves and solitary waves, are generated by a piston–type wavemaker in the numerical tests. The free surface profiles and the pressure time history are analyzed. These investigations indicate that the implementation method of the solid boundary condition should be carefully selected; otherwise, spurious wiggles in the time histories of pressure are evident or much more number of particles than necessary must be used.

KEY WORDS: Meshless method; Solid boundary condition; Nonlinear waves

INTRODUCTION

Nonlinear waves, such as breaking waves and/or freak waves, may result in severe hazards for offshore and coastal structures. The numerical simulation of those waves attracts more and more attentions. Many numerical methods are developed for this purpose. They are grouped as mesh-based methods and meshless methods. The mesh-based methods for nonlinear water waves mainly include the finite element method (Ma and Yan, 2006; Ma, 2007), the boundary element method (Grilli, Guyenne and Dias, 2001) and the finite volume method (Devrard, Marcer, Grilli, Fraunie, and Rey, 2005). A limitation of those methods is that a computational mesh/grid is required. The mesh/grid may need to be updated repeatedly to follow the motion of the free surface and need to be maintained to have good quality. This is often a difficult task, particularly in the cases with breaking waves. In the meshless methods, the fluid domain is discretised as particles. They do not need computational mesh and, hence, have high potential to be used for modelling breaking waves.

By far, many meshless methods have been reported in the literatures, such as Meshless Local Petro-Galerkin (MLPG) (see, for example, Atluri and Zhu, 1998; Atluri, and Shen, 2002; Lin and Atluri, 2001), Moving Particle Semi-implicit method (MPS) (see, for instance, Koshizuka and Oka, 1996; Gotoh and Sakai, 2006), the Smooth Particle Hydrodynamic (SPH) (e.g. Monaghan, 1994), the finite point method (Onate, Idelsohn, Zienkiewicz, Taylor and Sacco, 1996), the element free Galerkin method (Belytschko, Lu and Gu, 1994), the diffusion element method (Nayroles, Touzot and Vilon, 1992). The SPH, MPS and MLPG have been used to simulate nonlinear water waves by many authors. Some references are cited here. Ma (2005a, b; 2007) simulated nonlinear water waves, sloshing waves and freak waves by using the MLPG. The MPS method has been applied to simulate the collapse of a water column (Koshizuka and Oka, 1996), the shallow water sloshing effect (Naito and Sueyoshi, 2002), the breaking waves (Gotoh and Sakai, 1999) and the wave-body interaction (Gotoh and Sakai, 2006). The SPH method has been successfully used to simulate waves propagating towards beaches (Monaghan 1994, Lo and Shao, 2002) and many other cases.

A key problem of meshless methods is how to implement the solid boundary condition which strongly affects the accuracy convergence of the simulation of the nonlinear waves, particularly their interaction with solid boundaries (e.g. the wavemaker and the floating body). To do so, Koshizuka and Oka (1996) developed a method, which is widely used in the application of MPS. This implementation method is referred as BC1 for brevity. In BC1, the solid boundary is discretised as several layers of particles (referred as wall particles in this paper) but only the particles in the first layer, which is the closest to the fluid, are involved in solving the boundary value problem (BVP) for the pressure. The same formulation for the pressure at the wall particles of the first layer as that for the fluid particles is used. However, the influence domain for these particles lies in one side of wall particles. This may reduce the overall accuracy. To overcome the problem, Hibi & Yabushita (2004) and Zhang, Morita, Fukuda & Shirakawa (2006) suggested another implementation method (referred as BC2). In the BC2, all the wall particles are considered in solving the BVP for the pressure. In this implementation, the neighbour particles of the wall particles in the first layer are distributed on both sides of the layer and therefore enhance the accuracy to some extent. However, in both BC1 and BC2, the physical solid boundary condition is only approximately satisfied and sometimes wiggles in the time history of pressure are observed (Hibi & Yabushita 2004 and Sueyoshi & Naito, 2004). Ma (2005a) employed another method to implement the boundary condition, in which the pressure gradient for the wall particles in the first layer is forced to satisfy the physical solid boundary condition. This is referred as BC3. Apart from these, Monaghan (1994) applied artificial force acting on