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A Semi-Infinite Numerical Wave Flume Using Smoothed Particle Hydrodynamics

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This paper presents the new boundary condition implemented in the LNEC (Laboratório Nacional de Engenharia Civil) SPH (Smoothed Particle Hydrodynamics) numerical model based on the SPHysics model and on a standard SPH formulation: This piston-type wave-maker now includes dynamic wave absorption and allows the simulation of a semi-infinite flume. Verification of the active wave-maker absorption is carried out through the simulation of the interaction between a regular incident wave and an impermeable vertical breakwater. Results show that the active wave-maker allows outgoing waves to be absorbed and reflection at the wave-maker to be avoided.

INTRODUCTION

Numerical modeling of the interaction among waves and coastal structures is a challenge due to the many nonlinear phenomena involved, such as wave propagation, wave transformation with water depth, interaction among incident and reflected waves, run-up/run-down and wave overtopping.

Numerical models, more or less complex depending on the approach and on the physical assumptions, allow the simulation of the propagation of waves and the near-shore transformation. The models based on the nonlinear Boussinesq equations, such as COULWAVE (Lynett and Liu, 2004), give good predictions when compared with field data and laboratory physical modeling. However, this does not model the breaking and highly nonlinear processes that occur when waves impinge on the coastal structures, such as overtopping. Numerical models based on Euler or Navier-Stokes equations—such as CANAL (Clément, 1996), based on the Boundary Element Method, or FLUINCO (Teixeira, 2001), based on a mixed Euler-Lagrange formulation of the free surface—allow the modeling of wave-structure interaction and calculating velocity and pressure field; however, they do not simulate wave breaking.

Only few numerical models allow the simulation of the very complex phenomena of wave breaking and overtopping. These are generally based on fluid dynamic equations, i.e. the Navier-stokes equations, and developed using an Eulerian approach. Numerical simulation of free-surface flows is treated using the Volume of Fluid (VOF) approach (Hirt and Nichols, 1981), such as the Reynolds Average Navier-Stokes (RANS) model COBRAS-UC (Lara et al., 2006). However, the accuracy of wave breaking and overtopping simulations strongly depends on the mesh, and a fine grid is necessary to ensure the modeling of those phenomena.

Recently, models based on Lagrangian methods, such as the Smoothed Particle Hydrodynamics (SPH) approach, have emerged. This method is based on the Navier-Stokes equations and a completely mesh-free technique. Monaghan (1994) shows the first application of the Lagrangian method for modeling free-surface flows. The advances in SPH models since 1994 show that the Lagrangian method is a very promising alternative approach to the simulation of wave breaking and overtopping due to its completely mesh-free technique. Several numerical models are constructed using the SPH method; one is the SPHysics model (Crespo, 2008; Crespo et al., 2008a, b), inspired by Monaghan's 1992 formulation.

The SPH numerical model used and developed at the LNEC (National Laboratory of Civil Engineering) is based on the original SPHysics model and specially developed for studies of wave interacting with impermeable and porous structures. This model aims to be a useful tool for real case studies of coastal engineering. Promising agreement with experimental data has been obtained for both free-surface elevation and overtopping discharge for impermeable coastal structures (Didier and Neves, 2009a, b, 2010a, b; Didier et al., 2011). The present numerical model includes 2 specific developments:

- a partial renormalization (i.e. partial filtering density), where renormalization is applied only for particles near the structure; this is an original method allowing for simultaneously propagating waves, without diffusion, and accurately modeling the pressure field near the structure (Didier et al., 2011); and,
- an active wave-maker absorption allowing for the simulation of a semi-infinite numerical wave flume.

This paper presents the implementation of the active wave-maker absorption in the SPH numerical model and an application to wave interaction with an impermeable vertical breakwater allowing the verification of the dynamic absorption technique.

SET OF EQUATIONS

The bi-dimensional momentum conservation equation in a continuum field and the conservation law, in Lagrangian form, for a viscous fluid are written as:

$$\frac{dv}{dt} = -\frac{1}{\rho}\nabla P + \Pi + g \qquad (1)$$

$$\frac{1}{\rho}\frac{d\rho}{dt} = -\text{div}\ (v) \qquad (2)$$

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KEY WORDS: Smoothed Particle Hydrodynamics (SPH), wave dynamic absorption, coastal engineering.