Proceedings of the Eighteenth (2008) International Offshore and Polar Engineering Conference
Vancouver, BC, Canada, July 6-11, 2008

ISBN 978-1-880653-70-8 (Set); ISBN 1-880653-68-0 (Set)

An Eulerian Scheme with Lagrangian particles for Solving Impact Pressure Caused by Wave Breaking

Hidemi Mutsuda, Yoshiaki Shinkura and Yasuaki Doi
Department of Social and Environmental Engineering, Hiroshima University
Higashi-Hiroshima, Hiroshima, Japan

ABSTRACT

In this study, a new approach to solve fluid structure interaction problems is described. A methodology was developed, the CIP-SPH method, based on coupling the smoothed particle hydrodynamics (SPH) method for solid phase with the cubic interpolated pseudo-particle (CIP) method for both air and water phases, and results are presented using this new advanced modeling technique. In the proposed method, the solid interface is automatically captured by particles overlapping on fixed grids. Therefore, deformations and motions of coastal structures caused by wave breaking can be calculated with smoothness, efficiency and accuracy. Moreover, both Wagner type and Bagnold type impact pressures with entrained air are numerically and directly estimated using the proposed method. The proposed method simplifies direct numerical simulation of the impact pressure and interaction between wave breaking and coastal/offshore structures.

KEY WORDS: CIP method, SPH method, Wave Breaking, Impact pressure, Wagner type, Bagnold type, Fluid-Solid Interaction

INTRODUCTION

Violent waves, such as tsunami and storm surges, green water and freak waves, have sufficient energy to propagate in offshore and nearshore regions. The impact pressure acting on coastal and offshore structures is related to violent weather/sea conditions. Forces due to the wave impact on structures are often critical in structural design. Therefore, the impact pressure caused by violent waves can be a criterion when coastal and ocean engineers determine design parameters. Important features of the wave impact include the rapidly varying hydrodynamic load and the consequent dynamics response of structures. These phenomena are localized in both space and time. In previous experimental studies, the impact pressure occurs when the wave front impinges on structures, and in this process, air is trapped and impulsive pressures are generated within the trapped air region. It is therefore extremely important to determine an instantaneous pressure distribution on the face of structures.

Despite being an important phenomenon, both the evaluation and prediction of the impact pressure are based on empirical formulae fitted to laboratory measurements. The entrained air has not been able to be directly measured in experiments nor calculated in previous numerical works. An oscillatory pressure caused by the entrapped air during impact can have significant influence on the dynamics and stability of coastal and ocean structures. The presence of entrained air and splash during the impact process affects the kinematics of local water particles and pressure, and consequently influences the magnitude of the impact force. A complete analytical and numerical solution of the impact acting on structures would therefore be difficult. Currently, it is difficult to propose a reliable theoretical and numerical model to predict and evaluate the extreme impact force and behaviors of entrapped air.

If a fluid force acting on a structure is exactly evaluated by a computational fluid dynamics approach, motion and deformation of coastal/offshore structures could be predicted. Therefore, it is very important to develop a new numerical scheme with robustness, high accuracy and efficiency, and calculate the fluid force in both air and water in coastal and ocean engineering. Numerical techniques accounting for air dynamics should be included in such a scheme and have the flexibility and robustness to apply to a wide variety of entrapped air dynamics.

In multi-physics analysis, the smoothed particle hydrodynamics (SPH) method (Gingold and Monaghan, 1977) is a Lagrangian technique in which both discrete and smoothed particles are used to compute approximate values of physical quantities and their spatial derivatives. Another particle-based simulation, called the moving particle semi-implicit (MPS) method (Koshizuka et al., 1996), is another gridless approach that represents fluids by a finite number of moving particles representing a gradient, Laplacian, and free surface. In the coastal and ocean engineering field, both SPH and MPS methods have been applied to wave breaking, tsunami, overtopping, flooding, slamming, sloshing, the motion of a floating body, and the spray motion near a ship hull. Many researchers have given impressive results using the particle-based method.

Conversely, in the grid-based approach, the volume fluid method, level set method, cubic interpolated pseudo-particle (CIP) method (Yabe et al., 2004) and other Eulerian schemes are used as direct numerical simulation methods for capturing interfaces using a fixed Cartesian grid. These grid-based methods have been quite popular in the application of a free surface interface. Recently, to overcome several difficult problems demanding sophisticated methods for evolving surfaces, the particle level set method (Enright et al., 2002), coupled level set and volume-of-fluid (CLSVOF) method (Sussman et al., 1998) and piecewise linear interface construction and volume-of-