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 Unstructured 3D LES Solver for Free Surface Flow and Breaking Waves

Xin Lv, Qingping Zou, Dominic Reeve and Zhengyi Wang

Centre for Coastal Dynamics and Engineering
School of Engineering, University of Plymouth

ABSTRACT

The objective of this study is to determine wave overtopping, breaking, turbulence and streaming in the surf zone and thus analyze the performance of sea defenses and predict coastal flood risk in extreme conditions. Two dimensional hydrodynamic models, based on structured grids, have gained prominence and been used for widespread applications in surf zone studies. Reasons for this include their relative simplicity to implement and low CPU time demand. However, the accuracy of predictions made by a 2D model may suffer from the neglect of the additional space direction. In addition, due to the difficulties posed by structured mesh schemes, surf zone geometries must be simplified before being transformed into the modeling domain, and many irregularly shaped structures have to be removed. Nowadays, the availability of greater computing power has driven the development of hydrodynamic models using 3D unstructured meshes. Compared with its structured counterpart, the unstructured model has several attractive advantages such as: flexible modeling of complex geometries, convenient adaptive meshing capabilities and homogeneous data structures well suited for massively parallel computer architectures. A novel, coupled Volume Of Fluid (VOF) / Level Set (LS) interface capturing scheme for the prediction of violent free-surface flows is presented in this study. This method will be integrated into a well validated 3D unstructured finite volume (FV) based solver to investigate breaking waves in the surf zone. Furthermore, large-eddy simulation (LES) will be employed to predict the turbulence.

KEY WORDS: surf zone; wave overtopping; free surface flow; VOF; Level Set; NS equations.

INTRODUCTION

The determination of wave overtopping is crucial to analyze the performance of sea defences and predict coastal flood risk in extreme conditions. Due to the violent nature of wave overtopping, the mechanism of this phenomenon is far from recognized yet.

Previous investigations on the wave overtopping mainly focused on the empirical formula derived from the laboratory experiments or field observations (Saville, 1995; Owen, 1980; Owen and Steele, 1993; C, Franco and L, Franco, 1999). Besides, lots of analytical work has also been done in this regard. However, there are strong limitations in putting these results into practice, since they rely heavily on a particular site and configuration. Therefore, there is a great interest in developing techniques which can predict the wave overtopping accurately and remain applicable over a whole range of structure geometry, water level and wave condition. Numerical models that solve the equations of fluid flow appear to provide just such an approach.

For decades, two dimensional hydrodynamic models, based on structured grids, have gained prominence and been used for widespread applications in surf zone studies (Kobayashi and Wurjanto, 1989; Titov and Synolakis, 1995; Nicholas, 1998; Li, et. al. 2004). Reasons for this include their relative simplicity to implement and low CPU time demand. However, the physical phenomena involved in wave overtopping, like the interaction between wave and structure, strong turbulence and eddy vortices, are three dimensional in their nature. That is why the accuracy of predictions made by a 2D model may suffer from the neglect of the additional space direction. In addition, due to the difficulties posed by structured mesh schemes, surf zone geometries must be simplified before being transformed into the modeling domain, and many irregularly shaped structures have to be removed. This impedes the further application of numerical methods into more complicated practical engineering problems.

In this study, a novel Coupled LS/VOF method based on Navier-Stokes (NS) equations for interfacial flow simulations on three dimensional unstructured tetrahedral grids is proposed. At each time step, we evolve both the level set function and the volume fraction. The level set function is evolved by solving the level set advection equation using a high resolution characteristic based finite volume method. The volume fraction advection is performed using a bounded compressive Normalised Variable Diagram (NVD) based scheme. The interface is reconstructed based on both the level set and the volume fraction information. In particular, the interface normal vector is calculated from the level set function while the intercepts are determined by enforcing mass conservation based on the volume fraction. The novelty of the method lies in that we use an analytic method for finding the