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Numerical Simulation of Long Wave Runup for Breaking and Nonbreaking Waves

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Tsunamis produce a wealth of quantitative data that can be used to improve tsunami hazard awareness and to increase the preparedness of the population at risk. These data also allow for a performance evaluation of the coastal infrastructure and observations of sediment transport, erosion, and deposition. The interaction of the tsunami with coastal infrastructures and with the movable sediment bed is a three-dimensional process. Therefore, for runup and inundation prediction, three-dimensional numerical models must be employed. In this study, we have employed Smoothed Particle Hydrodynamics (SPH) to simulate tsunami runup on idealized geometries for the validation and exploration of three-dimensional flow structures in tsunamis. We make use of the canonical experiments for long-wave runup for breaking and nonbreaking waves. The results of our study prove that SPH is able to reproduce the runup of long waves for different initial and geometric conditions. We have also investigated the applicability and the effectiveness of different viscous terms that are available in the SPH literature. Additionally, a new breaking criterion based on numerical experiments is introduced, and its similarities and differences with existing criteria are discussed.

INTRODUCTION

Large traveling water waves over the ocean, usually caused by earthquakes, submarine landslides, or volcanic eruptions, are known as tsunamis. Tsunamis have caused considerable widespread damage and loss of human lives. Since tsunamis are characterized as water waves with long periods and wavelengths, it is practical to consider them as solitary waves for the research application. These waves near the coastal area are usually investigated analytically by using either the Boussinesq or the shallow water wave equation. The Boussinesq approximation is valid for weakly nonlinear and long water waves. The set of equations for the latter approach can be directly derived from the former one by neglecting the dispersion effects and the vertical accelerations. Both sets of equations are characterized by the high wavelength-to-water depth ratio. Shallow water waves have been studied in laboratory experiments for decades (Synolakis, 1987; Pedersen and Gjevik, 1983). Also, elegant analytical solutions of the shallow water equations were developed by Synolakis (1987) and Pedersen and Gjevik (1983).

As in the case of any other wave, the solitary waves can break. Although breaking and nonbreaking waves have been extensively studied in the laboratory (Synolakis, 1986, 1987; Pedersen and Gjevik, 1983), the theoretical understanding of breaking solitary waves is incomplete because of the limiting boundary and initial conditions that are necessary to find a meaningful analytical solution. Even though the shallow-water type of equations can be incorporated with higher-order derivatives to simulate dispersion and other nonlinearities, their results are mainly limited by some critical assumptions such as two-dimensionality. In the last two decades, the SPH method has become an important tool in outreach efforts, in testing future engineering designs, and in tsunami research. Extensive SPH simulations have been conducted in order to study the dynamic behavior of such waves (Landrini et al., 2007; Khayyer et al., 2008). Nevertheless, most of the available SPH simulations in the literature are two-dimensional, and the effects of viscosity and/or turbulent viscosity are neglected. The simulation of nonbreaking and breaking solitary waves with three-dimensional numerical models offers an alternative approach to explore the linear and nonlinear physical processes occurring during near-shore propagation, runup, and the withdrawal of solitary waves. Recent developments in computer technology and a better understanding of numerical methods have provided the opportunity to carry out massively parallel simulations of fluid mechanics on a very small scale. Hence, it is possible to solve the fully three-dimensional Navier-Stokes equations. We have employed a three-dimensional Lagrangian approach to simulate the dynamics of breaking and nonbreaking solitary waves, thereby introducing some new insights into the behavior of these waves.

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