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Modelling of Solitary Wave Run-up on an Onshore Coastal Cliff by Smoothed Particle Hydrodynamics Method

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Abstract

The solitary wave run-up in the presence of an onshore coastal cliff is investigated using the Smoothed Particle Hydrodynamics (SPH) method. A composite topography made of a steep slope, a gentle beach and a steep coastal cliff was used in the experimental and numerical studies to represent real life scenarios. Comparison with laboratory measurements shows that the SPH model is able to capture the evolution and run-up of solitary waves for both non-breaking and slight breaking cases with reasonable accuracy.

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1. Introduction

It has been widely understood that tsunamis can cause catastrophic damages when it propagates inland. The tsunami waves are capable of destructing offshore and near-shore structures which would then behave as debris flowing inland, claiming lives and obstructing evacuation passages. Understanding the site specific wave characteristics and their interaction with man-made structures are essential for designs of coastal structures. Over the last decades, there have been a number of studies conducted by researchers using experimental and numerical

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means to understand tsunami wave run-up and its interaction with coastal structures. Thus far, most of these studies have been limited to a gentle sloping plane beach. Complex near-shore interaction between the onshore flows and near-shore topography can play an important role in shaping the site-specific inundation and subsequent interaction with man-made structures. Hill et al. (2012) compared the damage done to the island of Pulau Sibigau with its neighbouring islands by the 2010 earthquake and tsunami event which occurred in the Mentawai Islands off Sumatra, Indonesia. The undulating profile of Pulau Sibigau was significantly influenced by the presence of a very steep inland cliff on site. It is quite common to find this type of steep inland cliffs located closely to shorelines. Such topographical features could result in highly turbulent flows and amplification of flow depth at the vicinity of the cliff. Large scale water sprays and splashing can be generated due to the wave breaking at the cliff.

Solitary waves are often used as initial conditions to approximate tsunami waves because of the hydrodynamic similarity between the two. Numerically predicting solitary wave run-up presents a challenge since it involves nonlinear building of wave front, severe wave breaking and strong turbulent flow. A number of numerical methods have been developed to predict the wave run-up. Most of them are governed by the shallow water equations (SWEs), which works well when the geometry satisfies the long-wave approximation. As the bathymetry and topography profiles become more complex, the numerical results can differ significantly from the measured data. The study on the island Pulau Sibigao by Hill et al. (2012) proved this point after comparing the recorded data with their simulation results. Three-dimensional modelling carried out by Huang et al. (2013) showed that the wave forms under complex near-shore topography can be captured but at the expense of large computational effort. Recent emergence of meshless methods has provided a desirable alternative. Smoothed Particle Hydrodynamics (SPH) method, originally developed for astrophysics (Lucy, 1977; Gingold and Monaghan, 1977), has been under intense development over the last two decades since it was first introduced to model free surface flows (Monaghan, 1992; 1994). Readers are referred to Liu and Liu (2010) for a detailed overview on the SPH methodology. The SPH method was later extended to model solitary wave propagation and impact problems (Monaghan and Kos, 1999). Since then, there have been a large number of published papers reporting on the SPH modelling of wave impact problems. Shao and Lo (2002) and later Shao (2005) studied the solitary wave mechanics, wave interaction with breakwaters and breaking waves. Dalrymple and Rogers (2006) examined the propagation of highly nonlinear and breaking and later reported their modelling of tsunami waves (Rogers and Dalrymple, 2008). Gómez-Gesteira *et al.* (2010) provides an overview on the state-of-art of the SPH and its application in the wave propagation and interaction with coastal structures in both two- and three-dimensional cases.

The objective of this study is to investigate the solitary run-up in the presence of an onshore coastal cliff through laboratory and numerical studies. The so-called DualSPHysics (Crespo et al., 2011; Gomez-Gesteira et al., 2012a, 2012b) numerical model has been used for the scope. The model was developed to run on both CPUs and GPUs which enables large-scale applications to be simulated using the SPH method. Documentations on the validation and implementation of DualSPHysics can be found in Crespo et al. (2011) and Domínguez et al. (2011, 2013a, 2013b). In this paper, the flow depths at various onshore locations under different incident wave levels were simulated using the DualSPHysics model and compared with experimental measurements.

2. Smoothed Particle Hydrodynamics Methodology

2.1. SPH algorithm

The SPH formulations are based on the concept of integral interpolations. By using a kernel function to describe the connectivity between particles, the differential operators in the Navier-Stokes equations can be approximated by summations over discretized particles. For a function F that represents a physical variable over a domain of interest, the concept of integral representation can be written as a convolution product of the function itself and a smooth function called kernel function, $W(r - r', h)$.

$$F(r) = \int F(r')W(r-r',h)dr' \tag{1}$$