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A Study on Runup of Nonbreaking Double Solitary Waves on Plane Slope

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Abstract

The propagation and runup of the double solitary waves propagating in water of constant depth and climbing along a plane slope are studied experimentally and numerically. Well-designed run-up experiment and numerical simulation of double solitary waves are carried out. Time series of the surface elevation and waterline movement, are obtained. With regard to double solitary waves with same height, the runup amplification coefficient of the latter wave is less than that of the leading one when the relative wave crest distance is reduced to a certain threshold value. The detailed velocity field and energy budget are obtained using the numerical model and discussed in terms of characteristics of velocity field at the runup process of the double solitary waves.

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Keywords: Double solitary wave; runup; nonbreaking; plane beach; numerical simulation; wave flume experiment.

1. Introduction

It has been a traditional subject to understand the propagation of a solitary wave over a constant depth region and its runup against a sloping beach because of importance of evaluating potential inundation and impacts of tsunami on coastal structures.

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Synolakis (1987) developed an analytical solution for nonbreaking waves on a plane beach based on the nonlinear shallow water equation. Li & Raichlen (2001) proposed a nonlinear solution to the classical shallow water equation by using a hodograph transformation and reported an experimental study on runup process of nonbreaking and breaking solitary wave. Fuhrman and Madsen (2008) proposed the reduced surf similarity parameter for solitary waves, the beach slope divided by the offshore wave height to depth ratio, which provides good coherency with experimental breaking and runup data and analytical nonbreaking runup expressions.

The full nonlinear and highly dispersive Boussinesq equations were used by Zhao *et al.*(2012) to investigate the evolution and run-up of solitary waves and N-waves on plane beaches. They discussed variations of the potential energy and the kinematic energy during the run-up and rundown on a plane beach. Further, Zhao *et al.*(2013) carried out numerical simulation of tsunami waves propagating on the continental shelf with an extremely gentle slope). It is interesting to note that, from the numerical results obtained by the Boussinesq model, the N-shape tsunami waves could evolve into long wave trains, undular bores or solitons near the coastal area for the cases of different initial wave heights. Recently, Chan and Liu (2012) extended the analytical approach of Madsen and Schäffer (2010) to study the runup formulae of a train of solitary waves and concluded that, for the runup of two solitary waves where a wave is followed by one with a larger amplitude, the maximum runup is slightly smaller than that of a single solitary wave. Xuan *et al.* (2013) reported an experimental study of runup double solitary wave on a plane beach. Even though much work has been done about the overtaking or head-on collision of two solitary waves theoretically, particularly at the multi-solitary wave solution of the KdV equation, there are few studies on detailed description of the variation of velocity field and energy of a wave train of multiple soliton–like waves in the process of runup on a plane beach.

This paper presents an investigation on runup of the double solitary waves on a plane beach experimentally and numerically. The runup of the double solitary waves with different wave height on plane beaches are computed and compared with the measured data. Second, the details of the velocity field are obtained through numerical simulation at first. Then, the changes of the potential energy and the kinetic energy of the double solitary waves in the runup process are discussed.

2. Experimental Setup and Numerical Model

2.1. Experimental setup

We carried out experiments on the runup characteristics of two solitary waves in the wave flume of the MOE Key Laboratory of Hydrodynamics at Shanghai Jiao Tong University. The facility consists of a wave flume (65m long×1.8m deep×0.8m wide), a piston-type wave generation system and a wave elevation measurement system. A piston-type wave generator is installed at the left end of the wave flume and the paddle is moved horizontally in a prescribed trajectory by means of a hydraulic servo-system. At the right end of the wave flume, a slope beach is installed to eliminate the wave reflection. There are total 12 wave gauges along the wave flume, includes 11 gauges in the constant depth region and the remaining one at the slope to record the moving shoreline. The maximum wave runup is recorded by two high-speed cameras with 100Hz record frequency and 1024×1024 resolution.

Goring (1978) developed a solitary wave generation methodology in a wave flume which was modified by Malek-Mohammadi and Testik (2010) considering the non-steady-state characteristics of the piston-type wave generator during the wave generation process into account, is used to implement wave generation in a wave flume. Based on the permanent waveform hypothesis, the velocity of water particle in front of the wave paddle is equal to that of the wave paddle, so the velocity of wave paddle can be expressed as,

$$\overline{u}(\xi,t)=\frac{d\xi}{dt}=\sqrt{g\frac{\eta}{d}\left(d+\frac{\eta}{2}\right)\left(\frac{\eta}{d+\eta}\right)} \tag{1}$$

where t is the elapsed time since the start of the motion, $\overline{u}(\xi,t)$ is the depth-averaged horizontal velocity, d is still