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A numerical investigation on nonlinear transformation of obliquely incident random waves on plane sloping bottoms

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ABSTRACT

The statistical properties of obliquely incident irregular waves over a planar sloping bottom were investigated numerically by the well-known numerical wave model FUNWAVE 2.0. Irregular waves based on the averaged JONSWAP spectra with various wave heights and peak periods were simulated to propagate over planar bottoms. A wide range of incident angles from 0° though 75° were considered to study the influence of incident angles. It was found that incident angles have a significant influence on the wave nonlinearity. The wavelet-based bicoherence revealed that the degree of triad wave interactions of primary waves and the higher harmonics was apparently weakened by increasing wave incident angles. Importantly, using the simulated data, the Klopman wave height distribution was improved by incorporating the influence of obliquely incident angles. It was found that the improved Klopman distribution shows better performance for describing wave height distributions in shallow water depth. Moreover, two empirical formulae are recommended to reflect the relationship between the skewness and the asymmetry of waves and the Ursell number for obliquely incident waves on plane sloping bottoms.

1. Introduction

An accurate description on wave heights and shapes in coastal regions has been pursued in recent decades. The knowledge of the distribution of individual wave heights is crucial to estimate large waves, which is key in predicting the wave loading on coastal structures. With linear superposition and narrow banded assumptions, the random wave heights basically follow the Rayleigh distribution (Longuet-Higgins, 1952) in deep water. In shallow water, however, the Rayleigh distribution tends to overestimate the wave heights due to the depth-limited wave breaking and triad nonlinear interactions. Such overestimation leads to oversized structures in design and thus excessive costs. Thereafter, many researchers had made efforts in exploring the wave height distribution in shallow water. Glukhovskiy (1966) adopted a semi-empirical approach to modify the Rayleigh distribution and obtained a distribution by taking the influence of depth-limited breaking into account. Klopman (1996) made a version on the Glukhovskiy distribution based on laboratory data. Later on, Tayfun (1981) presented a theoretical distribution of wave height by considering the effects of wave breaking. However, Battjes and Groenendijk (2000) pointed out that the distribution by Tayfun (1981) is not suitable for shallow water waves. After evaluating the existing models, Battjes and Groenendijk (2000) proposed a composite Weibull distribution (CWD). To reflect the transitional region between a linear trend for the lower heights and a downward curved relation for the higher waves, the CWD is composited by two Weibull distributions. The EurOtop manual (Pullen et al., 2007) recommends the CWD to describe the wave statistics in shallow water. However, Mai et al. (2010). found the parameter set in the CWD given by Battjes and Groenendijk (2000) should be checked before taking into application. Caires and van Gent (Caires and van Gent, 2010) pointed out that, comparing with the experimental measurements and field data, the prediction by the CWD underestimates the large waves on flat bottoms in shallow water. Mendez et al. (2004). proposed a wave height distribution which is controlled by a shape parameter dependent upon the local wave properties. Katsardi et al (Katasrdi et al., 2013). experimentally studied the height and the crest distributions of unidirectionally propagating random waves on two mild slopes and found that the distribution of Mendez et al. (2004). and the CWD are more applicable than others. Natural waves basically approach to shorelines and structures obliquely. However, investigations on the influence of incident angles on wave height distributions in shallow water are limited. To address this issue, the present study focused on the effect of the incident angle on the wave height distribution in

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Table 1
Wave parameters in the experiments of Visser (1991).

Case	β	H (cm)	d (cm)	T (s)	α	Breaking type
1	1/10	7.2	40	2	30°	plunging
2	1/10	9.5	40	1	30°	plunging
3	1/20	8.9	40	1	15°	plunging
4	1/20	7.8	35	1	15°	plunging
5	1/20	7.1	35	2	15°	plunging

shallow water.

Additionally, due to the shoaling and the nonlinear effects, the shapes of gravity waves undergo significant changes in shallow water, i.e. wave crests tend to sharpen while the troughs tend to flatten with decreasing water depth. The shape distortion of surface elevations from Stokes waves can be represented by two parameters, i.e., skewness and asymmetry. Skewness is a measure of the asymmetry of the surface elevation with respect to the horizontal axis, while the lack of the vertical symmetry is known as wave asymmetry (Elgar and Guza, 1985). The water motion induced by gravity waves is closely related to the shape of surface elevations. It is well known that the skewness and the asymmetry of near-bed velocities are directly related to sediment transport in coastal regions (Gonzalez-Rodriguez and Madsen, 2007; Hoefel and Elgar, 2003; Nielsen, 1992, 2006; Zhang et al., 2011; Zheng et al., 2013). Furthermore, the evolution of the skewness and the asymmetry of waves is crucial to understand the structure failure of a coastal defense due to the toe scour and the functionality of a coastal defense to protect the beach behind it from wave attacks and erosions (Zou and Peng, 2011). Practically, it is difficult to measure near-bed velocities. Fortunately, Zou et al. (2003). found that near-bed velocities can be obtained by the measured surface elevations through a linear transfer function.

The cross-shore evolution of the skewness and the asymmetry of waves has been extensively studied by field measurement data (Doering and Bowen, 1995; Elgar and Guza, 1985; Ruessink et al., 2012) and laboratory data (Dong et al., 2014; Ma et al., 2015; Peng et al., 2009; Rocha et al., 2017). Elgar and Guza (1985) found that the absolute values of the skewness and the asymmetry increase due to wave shoaling, and then decrease sharply as wave breaking occurs. Doering and Bowen (1995) first found that both the skewness and the asymmetry of

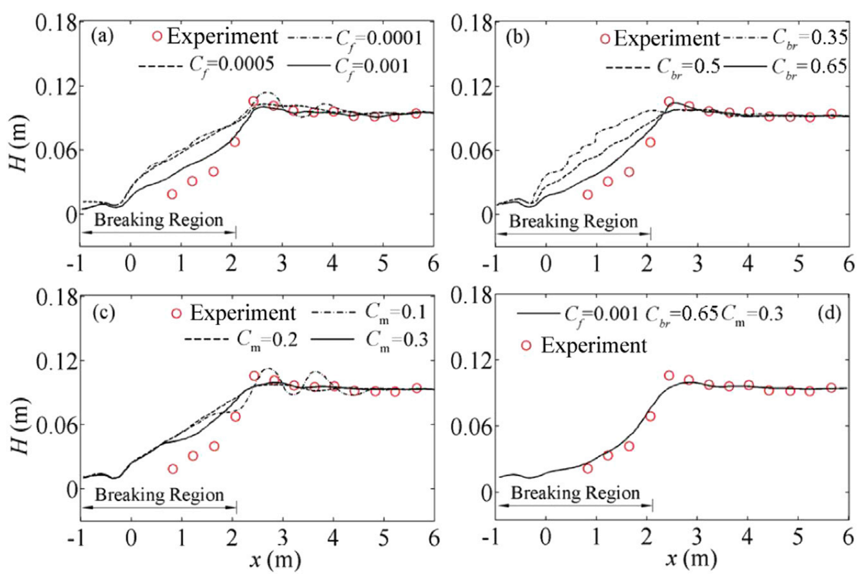

Fig. 1. Computed wave heights versus the data of a case (Case 2 in Table 1) of the experiment of Visser (Visser, 1991) using different set of the parameters in the numerical model.

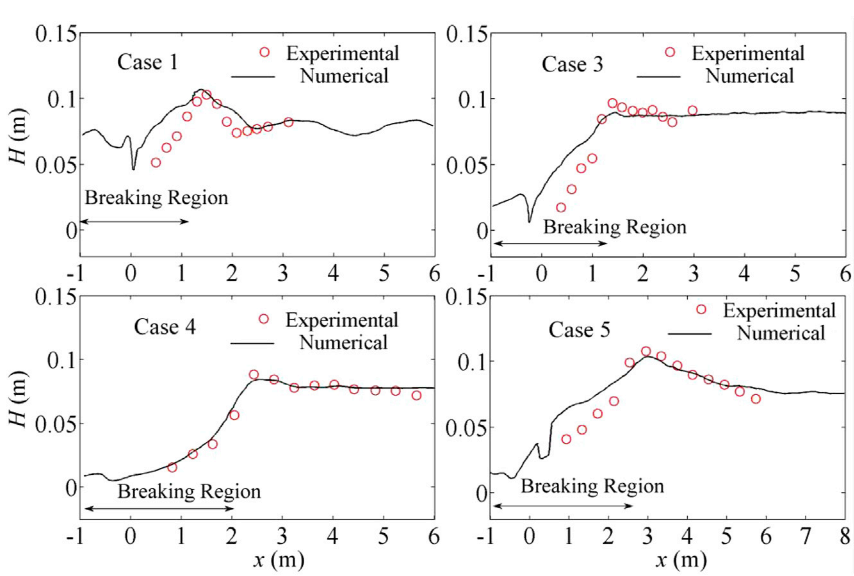

Fig. 2. Comparisons of wave height between computed results and experimental data of Visser (Visser, 1991) for the cases 1, 3, 4, 5 listed in Table.1.