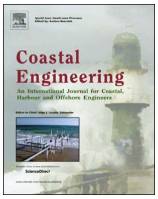
Coastal Engineering 121 (2017) 77–89

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng



Improving the parameterization of wave nonlinearities – The importance of wave steepness, spectral bandwidth and beach slope

M.V.L. Rocha[a,b], H. Michallet[a,*], P.A. Silva[b]

[a] Laboratoire des Ecoulements Géophysiques et Industriels, CNRS UMR 5519, UGA, CS40700, 38058 Grenoble, France
[b] CESAM & Department of Physics, University of Aveiro, 3810-193 Aveiro, Portugal

ARTICLE INFO

Keywords:
Velocity skewness
Velocity asymmetry
Wave non-linearity
Laboratory experiment
Boussinesq model

ABSTRACT

Wave-velocity nonlinearities are among the main drivers of sediment transport. For practical engineering purposes, they can be described by simple parameterizations that allow their easier inclusion in nearshore morphodynamic models. Most existing parameterizations propose the estimation of velocity nonlinearities only from local wave parameters (such as the Ursell number). Herein, it is demonstrated that this provides inaccurate estimations of the wave nonlinearities. Furthermore, the effect of offshore wave steepness, offshore spectral bandwidth and beach slope on the velocity nonlinearities is shown to be sufficiently important to merit its inclusion in the existing parameterizations. Ruessink et al. (2012) [28] parameterization is modified in order to include both offshore spectral bandwidth and a new parameter, NP_0, which takes into account the beach slope and the squared offshore wave steepness. The new parameterization results in a reduction of the wave-nonlinearities estimation error of more than 50%, particularly for the maximum values of nonlinearity (near breaking) that contribute the most for sediment transport.

1. Introduction

Understanding nearshore morphodynamics implies a profound knowledge of the hydrodynamics and its complex interaction with a mobile bed at different spatial and temporal scales. Along the beach cross-shore profile, as the surface gravity waves propagate from deeper water to the shore, their shape changes, primarily due to nonlinear wave interactions [14,9] and further on due to breaking. The nonlinear effects amplify the higher harmonics and cause the oscillatory flow to transform from sinusoidal in deep water, through velocity-skewed in the shoaling zone, to velocity asymmetric in the inner-surf and swash zones. These nonlinearities are of paramount importance for understanding sediment dynamics but, since they coexist in the field with other processes that can also influence sediment transport (e.g. wave breaking and bed forms), their particular role is not yet completely known.

Highly advanced phase-resolving wave models, such as those based on the Boussinesq or the RANS equations, are able to accurately describe the transformation of each individual wave as it approaches the shore. However, these models still have a computation cost too high for application in morphodynamics studies and thus, for practical engineering purposes, simple analytical theories (linear and nonlinear) are often employed. Skewness was early included in the analytical parameterizations of sediment transport and sand-bar migration numerical models [32]. Later on, it was found that to improve model performance, particularly regarding sand-bar onshore migration, asymmetry should be considered as well. New parameterizations were proposed (for e.g. [11,13,1,28]) and it became more clear how to include the effects of asymmetry. Cross-shore morphodynamic models that include these parameterizations have recently been developed [12,17], allowing a more accurate description of sand-bar onshore migration.

The currently used parameterizations for skewness and asymmetry rely mostly on an exclusive dependency of nonlinearity on local wave parameters (wave height and length) and water depth to describe the skewness and asymmetry along the beach profile, even though with the precaution of assuming the limits of validity to be constrained by the type of beach slope or range of offshore wave conditions. However, different researchers have already underlined the importance of considering characteristics such as the offshore wave steepness [8] and spectral bandwidth [23], as well as the beach slope [23,10,18], in order to correctly describe the wave nonlinearity at a given cross-shore position. Rocha et al. [25] compared the performance of existing parameterizations for different field-data sets and suggested that defining skewness and asymmetry from local wave parameters may not be enough, as the history of the wave propagation is also important.

---

* Corresponding author at: Laboratoire des Ecoulements Géophysiques et Industriels, CNRS UMR 5519, UGA, BP 53, 38041 Grenoble cedex 9, France.
E-mail addresses: marianavlmrocha@gmail.com (M.V.L. Rocha), herve.michallet@legi.cnrs.fr (H. Michallet), psilva@ua.pt (P.A. Silva).

http://dx.doi.org/10.1016/j.coastaleng.2016.11.012
Received 20 May 2016; Received in revised form 16 November 2016; Accepted 20 November 2016

Hence, there is still a lack of a comprehensive understanding on which factors, other than local wave parameters, may condition the evolution of the wave nonlinearities.

The present work is based on a high-resolution (both in space and time) data set of irregular wave conditions collected on a small-scale, fixed-bed, 1/80 laboratory beach and the results of numerical simulations obtained with SERR1D numerical model Cienfuegos et al. [4,5]. It demonstrates that velocity nonlinearities depend also on non-local wave parameters and proposes a modification of Ruessink et al. [28] parameterization to take into account this dependency and improve the prediction of velocity nonlinearities. Section 2 of this paper presents the analysis of GLOBEX data, with an emphasis on the cross-shore trends of wave and velocity nonlinearities. In Section 3, the numerical model that is used to simulate new wave conditions and its validation are briefly presented. Section 4 is dedicated to the investigation of the dependence of wave nonlinearities on non-local wave and beach parameters and the results are discussed and compared to previous work. Section 5 presents the new nonlinearity parameter and its inclusion in Ruessink et al. [28] parameterization of velocity nonlinearities. It also analyzes the improvement of current estimations of nonlinearities that is achieved with the new version of the parameterization. This work draws to an end with the conclusions, in Section 6.

2. The GLOBEX data set

2.1. The experiments

The laboratory data set analysed in this work was collected during the GLOBEX Hydralab IV project [27], held in the Scheldegoot in Delft, the Netherlands, in April 2012. The GLOBEX beach had an impermeable concrete bed and was 110-m long and 1-m wide, with an initial plain section of 16.57 m, followed by a slope of 1/80 until the end of the flume (see Fig. 1). The mean shoreline was located at 84.57 m from the wave-maker position at rest (x=0), corresponding to a still-water depth above the plain section of 0.85 m. The waves were generated by a piston-type wave-maker equipped with Active Reflection Compensation (ARC) to absorb waves coming from the beach and prevent their re-reflection from the wave-maker. All wave-paddle steering signals included second-order wave generation.

Table 1
GLOBEX irregular wave conditions.

Wave condition	H_{m0} (m)	T_p (s)	γ	Ur_0	Ib_0	H_0/L_0
A1	0.1	1.58	3.3	0.02	0.07	0.03
A2	0.2	2.25	3.3	0.10	0.06	0.04
A3	0.1	2.25	20	0.05	0.09	0.02

Herein, we focus on the three irregular-wave conditions complying to a JONSWAP spectrum (with peak enhancement factor γ) listed in Table 1. A1 corresponds to an intermediate-energy condition, A2 to a high-energy condition and A3 to a more narrow-banded case, similar to energetic swell conditions. The Ursell number, Ur, is a known measure of the wave nonlinearity and is here defined as in Ruessink et al. [28],

$$Ur = \frac{3}{8}\frac{H_{m0}k}{(kh)^3}, \tag{1}$$

where H_{m0} is the local significant wave height, k the local wave number computed with the linear theory using $T_p = m_0/m_1$, where m_n is the spectral moment of order n, and h is the local water depth. The Iribarren number, Ib, characterizes the type of breaker, taking into account the wave steepness, and is calculated according to Iribarren and Nogales [19],

$$Ib = \frac{\tan(\beta)}{\sqrt{\dfrac{H_{m0}}{L}}}, \tag{2}$$

where $L = 2\pi/k$ is the local wavelength and $\tan(\beta)$ is the beach slope. For calculating the Iribarren number offshore (or at the wave-maker), the offshore values of H_{m0} and L are considered. The offshore values Ur_0, Ib_0 and H_0/L_0 are also indicated in Table 1.

Each wave condition was ran for 75 min, followed by a rest period of approximately 15 min. A suite of instruments was deployed during all runs, including 22 wave gauges (10 of resistive-type and 12 of capacitive-type), sampling at 128 Hz, for measuring free-surface elevation and 5 Electromagnetic Current Meters (ECM), sampling at 128 Hz as well, and 2 side-looking Acoustic Doppler Velocimeters (ADV), sampling at 200 Hz, for recording flow velocities. After all wave conditions were completed, most instruments were repositioned and the same conditions were repeated with exactly the same wave-board motion. Overall, 10 batches were run, resulting in a total of 190 positions with free-surface elevation measurements and 47 with flow-velocity data (at 1–30 cm above the bed). One of the ADVs, positioned near the bottom (at about 6 mm above the bed) was used to extend the ECMs velocity measurements (which ended at x=79.48 m) further into the inner-surf/swash zone for depths shallower than 5 cm, adding 10 more cross-shore positions of velocity measurements (starting at x=78.73 m), of which at least three were, in average, located in the swash zone. The instrument spacing varied from 2.2 m offshore, to 0.55 m in the middle section and 0.37 m inshore. Fig. 1 illustrates the distribution of the instruments along the flume. A more detailed description of the experimental procedure and all the measurement instruments used can be found in Ruessink et al. [27]. A preliminary data analysis of GLOBEX measurements is also presented by Michallet et al. [22]. de Bakker et al. [3], Ruju et al. [29] and Tissier et al. [33] have also already analysed the GLOBEX irregular-wave cases in order to study nonlinear infragravity–wave interactions, wave run-up and short-wave celerity, respectively.

2.2. Cross-shore variation of free-surface elevation and velocity

The wave height and period are not the same for the three wave conditions and thus the waves do not shoal and break at the same cross-shore position. Hence, it is convenient to normalize the data to directly compare the wave evolution for the different conditions. Scaling the cross-shore position relatively to the breakpoint location is a way of normalizing the wave conditions in terms of energy and also allows the separation of the beach profile into different zones with distinct hydrodynamics. The breakpoint position is defined from the energy dissipation rate, as in Rocha [26].

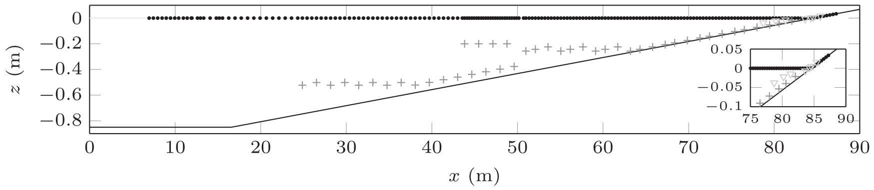


Fig. 1. Elevation z versus cross-shore distance x of the GLOBEX flume (x=0 is the position of the wave-maker at rest and z=0 is the still-water level). The dots represent the positions of the wave gauges, the pluses the ECM positions and the triangles the ADV positions considered in the scope of this paper. The figure in the corner represents a zoomed area near the shoreline.