Coastal Engineering 136 (2018) 41–55

Contents lists available at ScienceDirect

Coastal Engineering

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

Infragravity swash parameterization on beaches: The role of the profile shape and the morphodynamic beach state

Paula Gomes da Silva [*], Raúl Medina, Mauricio González, Roland Garnier

Environmental Hydraulics Institute "IH Cantabria", Universidad de Cantabria, C/Isabel Torres 15, 39011, Santander, Spain

ARTICLE INFO

Keywords:
Low frequency oscillation
Swash zone
Beach morphodynamic

ABSTRACT

A field campaign was undertaken at Somo beach in northern Spain, with the aim of understanding the processes involved in the generation of low frequency swash. Taking the parameterization presented in earlier studies as a starting point, a novel empirical model was defined based on a database which included datasets from Somo beach and from 9 other experiments. This new parameterization was obtained by relating the horizontal cross-shore component of the infragravity swash to the foreshore slope and the morphodynamic beach state through the non-dimensional fall velocity parameter. The role of previous sea states when determining the morphodynamic beach state was also assessed. A strong correlation between low frequency oscillations and the morphology of the beach was verified, resulting in a substantial improvement over existing infragravity swash predictions proposed in the literature.

1. Introduction

As waves approach the coast, part of the energy dissipates due to wave-breaking in the surf zone. The remaining energy reaches the beach and drives oscillations of the water edge over the foreshore. The vertical value of these oscillations is called runup (R) and it is composed of a (quasi) steady superelevation of the mean water level (setup - η), and by time-varying fluctuations around this superelevation (swash– S) (Miche, 1951; Guza and Thornton, 1982).

Swash oscillations are commonly analyzed in terms of incident (S_{inc} : 0.05 – 0.5 Hz) and infragravity (S_{ig} : 0.003 – 0.05 Hz) swash. Due to the complexity of nearshore wave-wave interactions and surf zone processes, most runup studies are based on empirical approaches which directly relate these oscillations to beach and offshore wave characteristics (e.g. Ruessink et al., 1998; Vousdoukas et al., 2009; Senechal et al., 2011). However, there is still considerable debate about just how runup is related to these environmental parameters, as well as about the range of application of empirical models because of site-specific conditions and nonlinear processes which may occur between the wave measurement point and the swash zone.

One of the earliest efforts to parametrize wave runup was presented by Hunt (1959). Based on laboratory experiments with monochromatic waves reaching structures, the author tested a number of composed parameters and demonstrated that the normalized runup value scales quite well with the surf similarity parameter (eq. (1)), also known as Iribarren number (ξ) (eq. (2) – Iribarren and Nogales, 1949; Battjes, 1974):

$$\frac{R}{H} = K\xi, \tag{1}$$

$$\xi = \frac{tan\beta}{\sqrt{H/L}}, \tag{2}$$

where R is the runup value of each wave, K is a constant, $tan\beta$, in this case, represents the slope of the structure, and H and L are the wave height and length, respectively.

Since then, much effort has been dedicated attempting to demonstrate that ξ could also be used to describe the runup distribution of random waves in natural beaches (Holman and Sallenger, 1985; Vousdoukas et al., 2009; Senechal et al., 2011). Correlations found in previous works using ξ_0 (Iribarren number calculated using the deep-water wave height) may indicate the effect of surf zone processes and beach characteristics on runup values (Holman and Sallenger, 1985; Poate et al., 2016), since it is a parameter commonly used to describe and parameterize wave-breaking, the amount of reflection, and the beach morphodynamic state, among others processes. Miche (1951) suggested that in situations of high ξ_0 the dissipation due to wave-breaking is low and waves reflect on the coast, resulting in high swash amplitudes. When ξ_0 is

* Corresponding author. Tel.: +34 675205249.
E-mail address: paula.gomes@alumnos.unican.es (P. Gomes da Silva).

https://doi.org/10.1016/j.coastaleng.2018.02.002
Received 14 August 2017; Received in revised form 28 December 2017; Accepted 7 February 2018

low, wave-breaking leads to the dissipation of the wave energy and saturation is expected on the shoreline. The saturation of the shoreline oscillations implies, then, that incident swash reaches a maximum while the infragravity swash keeps increasing according to the incident wave height (Guza and Thornton, 1982). Swash saturation is typically observed on beaches with dissipative characteristics, where wave breaking is an important dissipative process. Distinction on the swash behavior according to the morphodynamic characteristics was presented by Wright and Short (1984), who proposed a classification of the morphodynamic beach state based on the non-dimensional fall velocity parameter (eq. (3)) (Dean, 1973; Gourlay, 1968) and showed details about the amount of swash energy in each frequency band according to the beach state.

$$\Omega = H_s / w_s T_p, \tag{3}$$

H_s is the significant wave height, T_p is the peak period and w_s is the dimensional fall velocity parameter. As stated in that work, the swash zone of dissipative beaches ($\Omega \geq 6$, fine sediment, high wave energy and low-sloping foreshore) presents dominantly infragravity oscillations, while on reflective beaches ($\Omega \leq 1.5$, coarse sediment, low wave energy and steeper foreshore) high frequencies oscillations are dominant. Hughes et al. (2014) emphasized this difference in the amount of energy under different morphodynamic conditions through a conceptual model based on the evolutional characteristics of the swash's spectral signature. The model shows that the ratio of swash energy in the high and low frequency bands differs significantly from dissipative to reflective conditions and that the shape of the swash spectrum evolves from the first beach state to the later (and the opposite), through intermediate beach states.

The different response of infragravity and incident oscillations during diverse morphodynamic conditions led some studies to differentiate the parameterizations for distinct morphodynamic states. Nielsen and Hanslow (1991) measured runup distribution in six Australian beaches with different morphodynamic characteristics. The runup was then contrasted with the Hunt scaling of $tan\beta(H_0L_0)^{0.5}$ and different empirical parameterizations of runup distribution were proposed depending on the foreshore slope (eq. (4) to (6)).

$$R_2 = SWL + 1.98L_{zwm}, \tag{4}$$

where R_2 is the runup exceeded by 2% of the waves, SWL is the still water level and L_{zwm} is the vertical scale of the runup based on a Rayleigh distribution, given by:

$$L_{zwm} \approx 0.6(H_{0rms}L_0)^{0.5} tan\beta \quad for\ tan\beta \geq 0.1, \tag{5}$$

$$L_{zwm} \approx 0.05(H_{0rms}L_0)^{0.5} \quad for\ tan\beta < 0.1. \tag{6}$$

H_{0rms} is the root mean square wave height at 80 m depth and L_0 is the wave length at the same point. Note that, according to these formulas, low-sloping beaches ($tan\beta < 0.1$) show no dependence on the foreshore slope. It is also suggested in their work that a distinction between the formulas for low-slopping and steeper beaches can still be made in terms of the non-dimensional fall velocity parameter (eq. (3)). In this case, the steep behavior would be observed for $\Omega < 6$ and the flat behavior for $\Omega > 6$. The use of parameters like Ω had already been raised by Holman (1986) and Nielsen (1988) and it seems to provide a way to include the morphodynamic component in empirical runup equations.

Following the approach of previous works, Stockdon et al. (2006) combined information obtained during ten field experiments and constituted the most extensive analysis of wave runup until now (eq. (7) to (10)). The authors fitted the R_2, obtained from the runup video series, to the beach slope and wave parameters deshoaled to a depth of 80 m. A runup equation was then proposed in which the setup ($<\eta>$), infragravity (S_{ig}) and incident swash (S_{inc}) were all parametrized separately. The three values were related to the parameter $tan\beta(H_0L_0)^{0.5}$. As stated by Nielsen and Hanslow (1991), S_{ig} best fit showed no correlation with the foreshore slope (eq. (10)).

$$R_2 = 1.1\left(<\eta> + \frac{\sqrt{S_{inc}^2 + S_{ig}^2}}{2} \right), \tag{7}$$

$$<\eta> = 0.35tan\beta(H_0L_0)^{0.5}, \tag{8}$$

$$S_{inc} = 0.75tan\beta(H_0L_0)^{0.5}, \tag{9}$$

$$S_{ig} = 0.06(H_0L_0)^{0.5}, \tag{10}$$

where H_0 was defined as the significant wave height at a depth of 80 m.

Numerous works have subsequently proven the validity of Stockdon et al. (2006) equation (hereinafter S2006) in the most diverse coasts (e.g. Vousdoukas et al., 2009; Vousdoukas et al., 2012; Stockdon et al., 2014; Ruju et al., 2014; Park and Cox, 2016; Poate et al., 2016). However, despite its demonstrated skill in predicting runup on sandy beaches, S2006 can still present significant scatter (Guza and Feddersen, 2012) and improvements may be achieved by including, for example, the effect of very high-energy events or the influence of different grain sizes (Stockdon et al., 2014).

According to S2006, the vertical component of the infragravity swash is best parametrized by $(H_0L_0)^{0.5}$ and the authors defined it as being linearly independent of the beach slope (i.e. neither the foreshore nor the surf zone slope improved their fit). However, that relation means that beach profiles under the same wave conditions but with different morphologic characteristics will present the same infragravity swash (red circles in Fig. 1 indicate S_{ig} values calculated under a similar sea state on a dissipative and on a reflective beach). The application of eq. (10) would result, for example, in equal infragravity swash on beaches composed of gravel and on beaches with very fine sediment. Such equivalence between different beach types does not represent the reality of the swash process. For a given sea state, fine grain beaches tend to present higher dissipative conditions than gravel ones; the dissipation from wave-breaking is more significant and a larger amount of infragravity energy would be expected at the shoreline (Wright and Short, 1984).

The role of the beach slope in runup parameterizations was discussed by Ruggiero et al. (2001) (hereinafter R2001), who analyzed data from Oregon dissipative beaches, and verified a direct relation between R_2 and

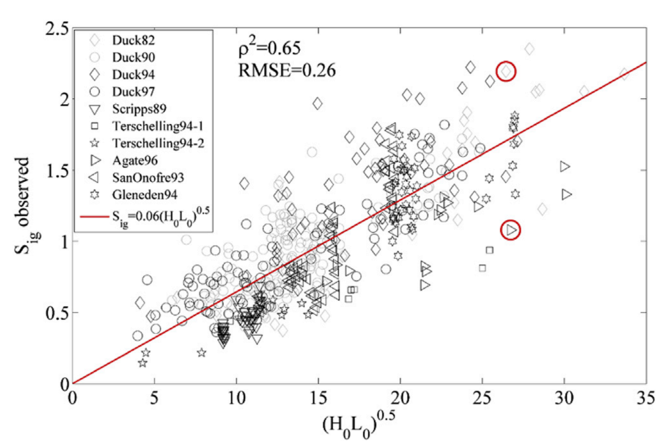

Fig. 1. Linear regression of S_{ig} with respect to S2006 parameter $(H_0L_0)^{0.5}$. Symbols represent each experiment analyzed by S2006. Red circles indicate an example of S_{ig} calculated under similar sea state in a dissipative (Agate) and a reflective (Duck) beach. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)