Coastal Engineering 115 (2016) 67–78

Contents lists available at ScienceDirect

Coastal Engineering

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

Empirical wave run-up formula for wave, storm surge and berm width

Hyoungsu Park *, Daniel T. Cox

School of Civil and Construction Engineering, Oregon State University, Corvallis, OR 97331-2302, USA

ARTICLE INFO

Article history:
Received 18 April 2015
Received in revised form 6 October 2015
Accepted 23 October 2015
Available online 30 December 2015

Keywords:
Wave run-up
Iribarren number
Boussinesq model
Hurricane
Dune
Berm

ABSTRACT

An empirical model to predict wave run-up on beaches considering storm wave and surge conditions and berm widths (dry beach) has been derived through a synthetic data set generated from a one-dimensional Boussinesq wave model. The new run-up equation is expressed as a function of a new Iribarren number composed of three regions: the foreshore, the berm or dry beach width, and the dune. The dissipative effect of the berm is included as a reduction factor expressed as a function of the berm width normalized by the offshore wavelength. The equation is relatively simple but is shown to be applicable for a fairly wide variety of berm widths and storm wave conditions associated with extreme events such as hurricanes, and it is shown to be an improvement over existing empirical run-up models that do not consider the berm width explicitly. In addition, the new parameterization of the Iribarren number considering the three regions and the berm width reduction factor are shown to improve other empirical models.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Many cases of inundation and coastal flooding occur during extreme events such as hurricanes when the maximum wave run-up exceeds the dune crest. Therefore, the severity of hurricanes can be grossly determined by the relation among the wave and surge conditions and the beach morphology (Sallenger, 2000). Although existing time-dependent numerical models provide accurate, deterministic estimates of wave run-up for given boundary conditions, it is nevertheless necessary to develop simplified expressions for wave run-up that can be used, for example, in probabilistic models for a range of surge and wave forcing and morphological conditions. The complex nature of wave run-up on realistic cross-shore profiles prohibits analytical solutions, so simplified run-up formulas rely on empirical approaches based on field observations (e.g., Holman, 1986) and laboratory experiments (e.g., Mase, 1989). Few field observations exist, however, of run-up during extreme storm events (e.g., Senechal et al., 2011), so it is necessary to consider the suitability of these empirical equations for extreme events.

Generally, wave run-up is characterized by the Iribarren number, which is also known as the surf-similarity parameter (Battjes, 1974), and is widely utilized for wave run-up on beaches and coastal structures and for tsunami inundation. The Iribarren number is

$$\xi = \frac{\tan\beta}{\sqrt{H/L}} \tag{1}$$

where β is the angle of the characteristic slope, H is the characteristic wave height, and L is the characteristic wavelength. For consistency, we use the nomenclature “Iribarren number” rather than “surf-similarity parameter” because the parameter is also used for coastal structures and tsunamis without surf zones, and we follow the conventional notation of ξ.

For beaches, β is often taken as the angle of the foreshore slope around the still water shoreline, although other values have been used such as the slope at the breakpoint or the mean slope over the active portion of the surf zone. For coastal structures, β is generally less ambiguous since rubble mound revetments and breakwater are typically built with a constant slope, usually much steeper than sand beaches. The characteristic wave height is typically the deep water wave height, H_0, the wave height at breaking H_b, or, in the case of coastal structures, the incident wave height at the toe of the structure, H_i. Similarly, the characteristic wavelength can be the deep water wavelength $L_0 = gT^2/2\pi$, the wavelength at breaking L_b estimated using linear wave theory and the local water depth at breaking, or the wavelength estimated at the toe of a coastal structure. There are a variety of wave conditions to consider such as regular waves from laboratory studies, irregular waves, and transient waves such as tsunamis. For regular wave studies, H and T are not ambiguous. For the case of irregular waves, H is generally characterized by the

* Corresponding author. Tel.: +1 541 602 8618; fax: +1 541 737 3052.
E-mail addresses: hyoungsu.park@gmail.com (H. Park), dan.cox@oregonstate.edu (D.T. Cox).

http://dx.doi.org/10.1016/j.coastaleng.2015.10.006
0378-3839/© 2015 Elsevier B.V. All rights reserved.

significant wave height H_s, and T is generally characterized by the peak period T_p, although other characterizations are possible such as $H_{1/10}$ or the mean wave period T_m. For transient wave studies such as for tsunamis modeled as solitary waves, H is generally the maximum positive displacement at a given depth, and T is defined as the duration over which the positive displacement exceeds a certain value, for example.

Since Hunt (1959), empirical run-up models have been expressed as a function of the Iribarren number,

$$\frac{R}{H} = K\xi \tag{2}$$

where R is the maximum run-up defined as the vertical projection above the still water level, and K is an empirical constant.

Holman (1986) used field observations of wave run-up at Duck, NC, to develop an empirical run-up model on natural beaches using a similar form as Eq. (2) and is given by

$$\frac{R_{2\%}}{H_0} = 0.83\xi_f + 0.2 \tag{3}$$

where the run-up is the value exceeded by 2% of the run-up events, $R_{2\%}$, normalized by the significant wave height in deep water. The Iribarren number is defined using the angle of the foreshore slope β_f, significant wave height in deep water, and the wavelength in deep water using the peak wave period:

$$\xi_f = \frac{\tan\beta_f}{\sqrt{H_0/L_0}} \tag{4}$$

Mase (1989) developed a similar run-up equation based on irregular waves generated in a laboratory on a plane slopes and is written as

$$\frac{R_{2\%}}{H_0} = 1.86\xi_f^{0.71} \tag{5}$$

where Eq. (4) was used to define the Iribarren number in a similar manner as Holman (1986), and the foreshore slope was the same as the slope for the incident waves prior to breaking and ranged from 1/30 to 1/5.

Using data sets from US East and West Coast beaches, Stockdon et al. (2006) developed an empirical wave run-up model (hereinafter referred to as the "Stockdon model" for brevity) using an Iribarren-like form given as

$$R_{2\%} = 1.1\left(0.35\tan\beta_f(H_0L_0)^{0.5} + 0.5\left[H_0L_0\left(0.563\tan\beta_f^{\,2} + 0.0004\right)\right]^{0.5}\right) \tag{6}$$

This model is composed of separate terms to consider different contributions of the wave setup and swash. The swash (the second term on the left hand side of Eq. (6)) is further separated into two parts considering incident wave and infra-gravity wave effects.

In parallel with the development of empirical equations for wave run-up on beaches, there has been significant development for wave run-up equations on coastal structures. Unlike studies on beaches, studies of run-up on coastal structures were developed primarily using laboratory experiments due, in part, to difficulties of direct measurements on coastal structures during storms. Van der Meer and Stam (1992) provided an empirical run-up equation as piecewise continuous function composed of linear and power curve using the Iribarren number

$$\frac{R_{2\%}}{H_s} = \begin{cases} 0.96\xi_m & \xi_m < 1.5 \\ 1.17\xi_m^{0.46} & \xi_m \geq 1.5 \end{cases} \tag{7}$$

where ξ_m is the Iribarren number defined using the structure slope, H_s is the significant wave height of the incident waves at the toe of the structure and, and the subscript m denotes that the wavelength is computed using the mean period. This work was later extended by De Waal and Van der Meer (1992) and VanderMeer (1998) to provide a general wave run-up model on dikes to account for the design of the berm, roughness effects of the dike, and wave direction through a combination of reduction factors and is given as

$$\frac{R_{2\%}}{H_s} = 1.6\,\gamma_1\gamma_2\gamma_3\xi_p \tag{8}$$

where the subscript p denotes that Iribarren number is defined using the peak period T_p. The reduction factor γ is a dimensionless number less than 1.0, determined experimentally to account for effects of the berm geometry, γ_1, surface roughness such as natural grass or rock, γ_2, and wave direction, γ_3. This run-up model has an empirical maximum limit of $R_{2\%}/H_s = 3.2\,\gamma_2\,\gamma_3$.

Eqs. (7) and (8) have been widely adopted for the design of coastal structures, and examples of their application are summarized in coastal engineering manuals (e.g., Pullen et al., 2007; USACE, 2003). Similar to run-up models for beaches, some empirical models use slightly different forms of the Iribarren number, particularly when defining the slope because some revetments and dikes may be composed of multiple slopes or may include relatively short, flat berms. The need to account for the profile shape was recognized by Saville (1958), and models generally employ an 'equivalent slope' as summarized by Mase et al. (2013).

Although tsunamis can occur on vastly different scales compared to wind waves on beaches and coastal structures, the Iribarren number has been found to be a suitable parameter for tsunami run-up studies. For example, Kobayashi and Karjadi (1994) combined numerical model results with laboratory experiments to develop an empirical formula to predict the run-up height normalized by the incident solitary wave amplitude (A_0) as a function of Iribarren number, given as

$$\frac{R}{A_0} = 2.955\,\xi^{0.395} \tag{9}$$

where the Iribarren number is defined using a characteristic period for the solitary wave defined as the duration over which the free surface exceeds $0.05A_0$. Kobayashi and Karjadi (1994) show that Eq. (9) is applicable for $0.125 < \xi < 1.757$ and that changing the definition of the characteristic period based on exceedance of either $0.01A_0$ or $0.1A_0$ changes the predicted run-up on the order of 10%.

The application of Iribarren number for tsunami run-up was analytically studied by Madsen and Fuhrman (2008), and it highlighted that run-up solutions for the canonical run-up depend on Iribarren number for the non-breaking regular wave. Furthermore, Madsen and Schaeffer (2010) provided analytic run-up solutions for the periodic and transient waves in terms of the Iribarren number, considering separate breaking and non-breaking regimes. The solutions are the minimum value between these two terms, given respectively as,

$$\frac{R}{A_0} = \begin{cases} C_1\,\xi_1^{2.0} \\ C_2\,(A_0/h_0)^{-0.25}\xi_1^{-0.5} \end{cases} \tag{10}$$

where A_0 is the maximum amplitude of the transient (tsunami) wave modeled using a Gaussian profile and h_0 is the water depth offshore and can be idealized as the water depth at the continental shelf. For laboratory studies and numerical simulations, h_0 is typically the water depth in the constant-depth section at the seaward boundary. C_1 and C_2 are analytical constant depending on input wave types (e.g., single wave, $C_1 = 0.1512$ and $C_2 = 4.0513$) as discussed in Madsen and Schaeffer (2010). The Iribarren number ξ_1 is defined by a uniform slope, the amplitude of the single wave A_0, and the deep water wavelength based on a representative period. For the case of a single wave which sustains the solitary wave shape but its frequency is independent

Download English Version:

https://daneshyari.com/en/article/1720552

Download Persian Version:

https://daneshyari.com/article/1720552

Daneshyari.com