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Wave runup prediction using M5′ model tree algorithm

S. Abolfathi [a,*], A. Yeganeh-Bakhtiary [b,c], S.M. Hamze-Ziabari [b], S. Borzooei [d]

[a] Flow Measurement & Fluid Mechanics Research Centre, Coventry University, CV1 5FB Coventry, UK
[b] School of Civil Engineering, Iran University of Science & Technology (IUST) , Tehran 16884, Iran
[c] Civil Engineering Program, Faculty of Engineering, Institut Teknologi Brunei (ITB), Brunei Darussalam
[d] Politecnico di Torino, DIATI, C.so Degli Abruzzi 24, 10129 Torino, Italy

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ABSTRACT

In recent years, soft computing schemes have received increasing attention for solving coastal engineering problems and knowledge extraction from the existing data. In this paper, capabilities of M5′ Decision Tree algorithm are implemented for predicting the wave runup using existing laboratory data. The decision models were established using the surf similarity parameter (ξ), slope angle ($\cot\alpha$), beach permeability factor (S_p), relative wave height (H/h), wave spectrum (S_s) and wave momentum flux (m). 451 laboratory data of the wave runup were utilized for developing wave runup prediction models. The performance of developed models is evaluated with statistical measures. The results demonstrate the strength of M5′ model tree algorithm in predicting the wave runup with high precision. Good agreement exists between the proposed runup formulae and existing empirical relations.

1. Introduction

Runup of waves on beaches and coastal structures has been studied extensively by coastal engineers, due to the importance of runup height in design of coastal structures (U.S. Army Corps of Engineers, 2002). Nearshore zone is the most dynamic part of the coastal area where wave activities result in complicated hydrodynamic behaviours with varying time and length-scale. One of the most important parameters in dealing with the nearshore hydrodynamics is the wave runup height. During the uprush of water on the beach/structure face or so-called wave runup, the remaining kinetic energy of incident broken waves dissipates and transforms into potential energy as it runs up. Wave runup height is a major concern for design of coastal infrastructure to minimize the occurrence of overtopping. Wave runup height depends on number of parameters such as the incident wave climate and specifically wave height (H), material and the slope. Fig. 1 is the definition sketch of wave runup.

The wave runup height is a complex time-varying function of intersection location between the ocean and the beach/structure which depends on nonlinear transformation of waves in breaking zone, refraction of waves, porosity and roughness of slope materials, topography of the nearshore zone, three-dimensional velocity field in the shallow water column and turbulent kinetic energy budget of the incident waves. Therefore, due to such complications in nearshore hydrodynamics and morphodynamics and also due to lack of precise field measurements, our understanding of underlying physical mechanisms of nearshore processes is limited and there is no rigorous theoretical approach to predict the runup height. Hence, the existing formulae for runup prediction are only based on empirical approaches of experimental data.

2. Previous studies

Previous studies of the wave runup can be generally categorized to monochromatic and irregular wave conditions based on laboratory measurements. This section aims to review the existing widely accepted approaches to determine the wave runup for regular and irregular wave conditions.

2.1. Regular wave

Hunt (1959) studied wave runup on smooth and rough bed conditions and proposed empirical relations for runup prediction based on the shape of breaking wave in surf zone (Eqs. (1) and (2)).

$$\frac{R_u}{H} \approx 3 \qquad (1)$$

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* Corresponding author.
E-mail address: soroush.abolfathi@coventry.ac.uk (S. Abolfathi).

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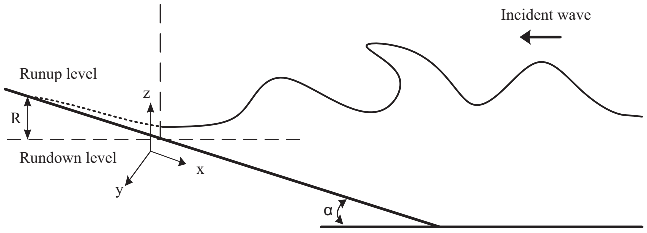

Fig. 1. Schematic sketch of wave runup.

$$\frac{R_u}{H}=\frac{\tan\,\alpha}{\sqrt{\left(\frac{H}{L_0}\right)}};\quad \frac{R}{H}=\xi \tag{2}$$

where R_u is the maximum vertical runup from still water level, L_0 is the deep water wave length $[L_0=\frac{g}{2\pi}T^2]$, α is the beach slope, H is the wave height and ξ is the surf similarity or Iribarren number. Eq. (1) predicts the runup height for surging or standing waves on steep slope and Eq. (2) is valid for spilling or plunging breaker type on mild slope. Both Eqs. (1) and (2) are valid for impermeable beach type.

2.2. Irregular waves

One of the first widely used formula to predict irregular wave runup is proposed by Wassing (1957) which relates the runup to the effective wave height of incident waves (H_s) and the bed slope ($\tan\alpha$) (Eq. (3)).

$$R_{u2\%}=8\,H_s\,\tan\,\alpha;\quad \tan\,\alpha<\frac{1}{3} \tag{3}$$

$R_{u2\%}$ represents the wave runup height exceeded by highest 2% of runup and H_s is the average of highest 1/3 waves in an irregular wave terrain. Eq. (3) is only valid for mild uniform slopes. Battjes (1974) modified Hunt (1959) formula for irregular wave conditions (Eq. (4)):

$$\frac{R_{u2\%}}{H_s}=C_m\xi_{om} \tag{4}$$

where $\xi_{om}=\tan\,\alpha/\sqrt{(H_{1/3}/L_{om})}$, L_{om} is wave length in deep water using mean irregular wave period (T_m). Constant C_m varies between 1.33–2.86.

Ahrens (1981) performed laboratory measurements for irregular wave runup on impermeable bed with the slope range of $\tan\alpha$ = ¼ *to* 1 and proposed Eq. (5) for runup height of irregular waves.

$$\frac{R_{2\%}}{H_{mo}}=C_1+C_2\left(\frac{H_{mo}}{gT_p^2}\right)+C_3\left(\frac{H_{mo}}{gT_p^2}\right)^2 \tag{5}$$

C_1, C_2 and C_3 are the coefficients derived from the best fitting method of the data, H_{mo} is zero-moment wave height and T_p is the wave period associated with spectrum peak frequency. For spilling and plunging breaker waves, on impermeable bed and slope range of 1/1–1/4, Ahrens (1981) derived Eq. (6) using deep water Iribarren number ξ_{op}, based on spectrum peak frequency wave period (T_p).

$$\frac{R_{2\%}}{H_{mo}}=\frac{2.26\xi_{op}}{(1+0.234\xi_{op})}\quad \text{for}\ \ \xi_{op}\le 2.5 \tag{6}$$

Coastal Engineering Manual (U.S. Army Corps of Engineers, 2002) employed Ahrens (1981) data and proposed two equations for irregular wave runup (Eqs. (7) and (8)).

$$\frac{R_{u2\%}}{H_{mo}}=1.6\xi_{\text{op}}\quad \text{for}\ \ \xi_{op}\le 2.5 \tag{7}$$

$$\frac{R_{u2\%}}{H_{mo}}=4.5-0.2\xi_{\text{op}}\quad \text{for}\ \ 2.5\le\xi_{op}\le 9.0 \tag{8}$$

Mase (1989) conducted series of laboratory tests for irregular wave runup measurements with the wave steepness range of 0.007–0.07 and slope range of 1:5–1:30. Eqs. (9)–(11) summarize the formulae proposed by Mase (1989) for the maximum runup (R_{max}), the 2% average runup ($R_{2\%}$) and the mean runup ($\overline{R}$).

$$\frac{R_{max}}{H_0}=2.32\xi^{0.77} \tag{9}$$

$$\frac{R_{2\%}}{H_0}=1.86\xi^{0.71} \tag{10}$$

$$\frac{\overline{R}}{H_0}=0.88\xi^{0.69} \tag{11}$$

Van der Meer and Stam (1992) employed regression method and proposed runup based on an extensive series of irregular wave runup measurements. They examined the effects of slope angle, permeability of slope, incident wave climate and spectral shape (S_S) on the wave runup. Van der Meer and Stam (1992) performed most of their measurements with a Pierson-Moskowitz spectrum, however, some data recorded with wide spectrum and narrow spectrum. Van der Meer and Stam (1992) stated that use of mean period (T_m) for evaluating the Iribarren number (ξ_{om}) gives similar maximum runup, unless the spectrum is very narrow. Van der Meer and Stam (1992) empirical model combined the effect of wave period, wave height and slope angle into Iribarren number and did not look at these parameters independently. Also, the effect of spectral shape was not considered on the runup prediction in their model. In the current study, the spectral shape was employed as a quantitative input parameter for wave runup prediction (Section 4).

Hughes (2004) used a new concept of wave momentum flux (M_f) to improve empirical correlations for waves and nearshore coastal processes. He employed Fourier approximation wave theory and proposed an empirical relation for the wave momentum flux (Eq. (12)).

$$\left(\frac{M_f}{\rho gh^2}\right)_{max}=A_0\left(\frac{h}{gT^2}\right)^{-A_1} \tag{12}$$

where ρ is the water density, h is the water depth, g is the gravitational acceleration, A_0 and A_1 are the empirical coefficients as a function of relative wave height parameter (H/h). The wave momentum flux parameter was obtained for the experimental data of Granthem (1953), Saville (1955), Ahrens (1981) and Mase (1989) and used as input parameter ($\frac{M_f}{\rho gh^2}=m$) in development of M5′ MTs (Section 4). Table 1 summarizes the empirical relations proposed for all the data used in this paper.

3. Soft computing approach

In the last decade, there has been a growing trend in the use of Decision Tree (DT) algorithms such as Classification And Regression Trees (CART) and Model Trees (MTs). Decision trees are a Machine Learning (ML) technique with the capability of discovering and extracting the knowledge from a data set and derive a set of rules amongst data set parameters (Solomatine and Dulal, 2003). Model trees (Quinlan, 1992) fall into ML category and are promising numerical prediction method. The efficiency and robustness of MT algorithms in prediction has been well proved (Solomatine and Dulal, 2003; Bhattacharya and Solomatine, 2005). A MT is an inverted tree with a root node located at the top of the tree and the leaves at the bottom. The data instants are first