Available online at www.sciencedirect.com
ScienceDirect
Coastal Engineering 54 (2007) 765–769
Coastal Engineering
An International Journal for Coastal, Harbour and Offshore Engineers
www.elsevier.com/locate/coastaleng

Improved representation of breaking wave energy dissipation in parametric wave transformation models

J.M. Alsina [1], T.E. Baldock *

Department of Civil Engineering, University of Queensland, Brisbane, Qld 4072, Australia

Received 13 December 2006; received in revised form 26 March 2007; accepted 21 May 2007
Available online 20 June 2007

Abstract

An improved formulation to describe breaking wave energy dissipation is presented and incorporated into a previous parametric cross-shore wave transformation model [Baldock, T.E., Holmes, P., Bunker, S., Van Weert, P., 1998. Cross-shore hydrodynamics within an unsaturated surf zone. Coastal Engineering 34, 173–196]. The new formulation accounts for a term in the bore dissipation equation neglected in some previous modelling, but which is shown to be important in the inner surf zone. The only free model parameter remains the choice of γ, the ratio of wave height to water depth at initial breaking, and a well-established standard parameter is used for all model runs. The proposed model is compared to three sets of experimental data and a previous version of the model which was extensively calibrated against field and laboratory data. The model is also compared to the widely used model presented by Thornton and Guza (1983) [Thornton, E.B., Guza, R.T., 1983. Transformation of wave height distribution. Journal of Geophysical Research 88 (No.C10), 5925–5938].

The new formulation leads to an important improvement in predicting wave height condition close to the shoreline in non-saturated surf zone conditions. The approach overcomes a problem in the original model, where amplification by shoaling could exceed energy dissipation by breaking in very shallow water, i.e. approaching the swash zone. In dissipative conditions an improvement is also noticeable. Of the four models considered, the new model gives the smallest error between predicted and measured wave heights for all three data sets presented.

Keywords: Wave transformation; Wave breaking; Unsaturated surf zone hydrodynamics; Swash zone boundary conditions; Energy dissipation; Parametric modelling

1. Introduction

Parametric wave propagation models are commonly used to predict wave properties in a broad range of coastal area problems. Their success is based on their simplicity and relatively high accuracy, which ranges between 10–20% after parameter fitting (Ruessink et al., 2003; van Rijn et al., 2003). This accuracy is sufficient for many coastal engineering applications. However, wave propagation models are also very often the first step to compute other hydro-morphodynamic variables, including wave set-up, wave-induced currents, swash zone boundary conditions (Guard and Baldock, 2007) and sediment transport, and errors in the wave transformation model may propagate in the computation scheme (de Vriend et al., 1993). Therefore, error reduction in computing wave propagation is an important issue.

Following the pioneering model of Battjes and Janssen (1978), hereafter BJ78, Thornton and Guza (1983) proposed a more advanced model by multiplying the energy dissipation for a breaking wave by the probability of that wave occurring and integrated over an empirical breaking wave probability density function derived from field data. Baldock et al. (1998) (hereafter B98) followed a similar approach and developed a model for wave transformation in non-saturated (i.e. not depth-limited) surf zone conditions, where a significant proportion of the incident wave energy remains at the shoreline in the form of short wave bores. They proposed a parametric model based on a full Rayleigh wave height distribution for breaking waves, which improved prediction of wave height close to the shoreline. For this purpose, Ruessink et al. (2003), hereafter R03, calibrated the B98 model against numerous laboratory and field data. R03 found that the model could be improved further, replacing the usual wave height to water depth ratio at the point

* Corresponding author. Tel.: +61 07 336 54170; fax: +61 07 336 54599.
E-mail addresses: josealsina@uq.edu.au (J.M. Alsina), t.baldock@uq.edu.au (T.E. Baldock).
[1] Tel.: +61 07 336 54170; fax: +61 07 336 54599.

0378-3839/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.coastaleng.2007.05.005

of initial breaking, γ, with an empirical free model parameter (here denoted by γ_{free}) obtained and optimised by inverse modelling. R03 found that the γ_{free} decreased in shallow water, which in the model represents greater energy dissipation for the same wave height and fraction of broken waves.

The aim of this study is to remove this additional empiricism from the model; firstly, to better describe the physics, and secondly, so that the model may be applied for conditions outside of those for which γ_{free} was determined by R03. The B98 model has been reformulated based on the theoretical developments first proposed by BJ78 using the turbulent bore dissipation model proposed by Le Méhauthé (1962). The suggested modification provides a better wave height prediction in the inner surf zone for a range of laboratory experiments data. Quantitative error analysis also indicates that the new model provides a better overall prediction of the data than the R03 calibration.

2. Parametric surf zone modelling

The wave transformation is modelled using the energy flux equation,

$$\frac{\partial E_{\mathrm{fx}}}{\partial x} = -D \tag{1}$$

where E_{fx} is the energy flux and is assumed to be equal to EC_{g}, E is the wave energy and C_{g} is the group velocity given by:

$$E = \frac{1}{8}\rho g H\mathrm{rms}^2 \tag{2}$$

$$C_{\mathrm{g}} = C\frac{1}{2}\left(1 + \frac{2kh}{\sinh 2kh}\right)\cos\theta \tag{3}$$

where C is the wave phase velocity, ρ is the water density and g is gravitational acceleration, k the wave number, h the water depth and θ is the incident wave angle. D represents a time averaged wave energy dissipation term which takes into account energy losses due to wave breaking and friction. Wave friction in the surf zone is reported as a relatively minor dissipation term compared to breaking dissipation and is consequently neglected here. Wave reflection is also neglected, since reflection analyses over sloping bathymetry (Baldock and Simmonds, 1999) indicates that the reflected short wave energy is likely to be less than about 5% of the incident short wave energy for typical Iribarren numbers.

For a single breaking wave the energy dissipation is estimated from the bore dissipation (Le Méhauthé, 1962; Battjes and Janssen, 1978) given by:

$$D = \frac{1}{4}\rho g f_{\mathrm{p}} B\frac{H^3}{h} \tag{4}$$

where f_{p} is the peak frequency and B is a fitting parameter taken equal to 1. In an irregular wave field, the overall dissipation term can be computed multiplying (Eq. (4)) by the number of waves breaking over the total number of waves in the wave field.

BJ78 used Eq. (4) assuming that the relationship H / h is close to 1 in the surf zone. Furthermore, they obtained an implicit equation for the fraction of waves breaking, Q_{b}, assuming a clipped Rayleigh probability distribution function (pdf) truncated at the maximum wave height H_{b}. Therefore in the surf zone when $H_{\mathrm{rms}} \rightarrow H_{\mathrm{b}}$; $Q_{\mathrm{b}} = 1$ (i.e. saturated surf conditions).

Thornton and Guza (1983), hereafter TG83, proposed an empirical pdf for the breaking waves with a weighted Rayleigh distribution based on field data from Torrey Pines beach. They obtained the total energy dissipation in the wave field by integrating (Eq. (4)) over the proposed pdf. B98 followed the TG83 approach, but replaced the truncated Rayleigh pdf in BJ78 and the empirical pdf in TG83 with a full Rayleigh distribution and abandoned the depth limiting constraint in the inner surf zone. This approach is supported by several laboratory and field observations (e.g. Thornton and Guza, 1983). The Rayleigh wave height pdf is:

$$p\left(\frac{H}{H_{\mathrm{rms}}}\right) = 2\frac{H}{H_{\mathrm{rms}}}\exp\left[-\left(\frac{H}{H_{\mathrm{rms}}}\right)^2\right]. \tag{5}$$

Therefore, given a breaking wave height H_{b}, the fraction of broken waves is found by integration of the Rayleigh distribution over all waves for which $H / H_{\mathrm{rms}} \geq H_{\mathrm{b}} / H_{\mathrm{rms}}$. Following BJ78, B98 used Eq. (4) assuming that the relationship H / h is close to 1 in the surf zone, which gives a simple explicit equation for the total energy dissipation in B98 and an analytical expression for the fraction of broken waves, Q_{b}, see B98 for details.

$$Q_{\mathrm{b}} = \exp\left[-\left(\frac{H_{\mathrm{b}}}{H_{\mathrm{rms}}}\right)^2\right]. \tag{6}$$

The maximum wave height prior to breaking is obtained by

$$H_{\mathrm{b}} = \frac{0.88}{k}\tanh\left(\gamma\frac{kh}{0.88}\right) \tag{7}$$

where γ is the only free parameter in the model. Several expressions exist to compute γ, with perhaps the most widely used that due to Battjes and Stive (1985):

$$\gamma = 0.5 + 0.4\tanh(33S_0) \tag{8}$$

where S_0 is the deep water wave steepness (H_0 / L_0).

Using the B98 model, R03 found that it was necessary to decrease γ_{free} in shallow water to obtain optimum fit to a large range of measured data, and this is equivalent to increasing the dissipation rate in the model. Recently, Apotsos et al. (2007) compared a number of wave models to an extensive surf zone wave height data set and found that B98 provided the most accurate predictions of the unfitted wave models (i.e. when model parameters were not optimised for each model run).

While good overall wave height predictions have been obtained using the original B98 model, some significant errors have been identified when simulating wave heights after wave breaking over a bar (Ruessink et al., 2001) and in areas close to