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PROBABILITY OF WAVE BREAKING ON A PLANE BEACH

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ABSTRACT

There are no fixed break points in random sea conditions except in a clear swell condition, whereas wave breaking normally occurs at a certain point for regular waves in the laboratory. Here, the probability of random breaking waves has been studied using field data and a numerical approach. In the numerical approach, four numerical models have been examined. As a result, the Goda model and Monte-Carlo method predict a similar probability, whereas the Thornton model and Battjes model show different results.

INTRODUCTION

As random waves propagate from deep water to the shore through the surf zone, they transform and deform by shoaling and breaking, as well as by diffraction and refraction. If regular waves propagate on a sloping beach with straight and parallel contours, the wave length and celerity decrease, whereas the wave height gradually increases. At a certain water depth, a regular wave breaks and decreases in height. This breaking point is easily recognized. In contrast to the clear breaking of regular waves, the random sea consists of a variety of wave heights, periods, and directions. So, as random waves approach the shore, the highest wave commences breaking far from the shore, many intermediate-size waves break on the seaward region of the longshore bar or on the bar crest, and the small-height waves start breaking near the shoreline. The wide area of wave breaking, where the waves dissipate most of their energy, is recognized as the surf zone. Therefore, it is not possible to define only one breaking point and one breaking height for a set of incident random waves, except in the situation of clear swell breaking on the seaward region of a longshore bar, or on a submerged breakwater. To derive an answer to describe this situation, a numerical analysis for a series of data on breaking waves has been conducted in this study.

For coastal engineers, an estimation of probability of breaking waves on beaches enters the solution for a number of coastal engineering subjects, for instance; the wave height distribution in shallow water, the longshore current distribution, and related sediment transport. In addition, if information on the number of breaking waves at a given point and wave height distribution across the shore is available, it will improve the estimation of wave forces and provide a better and more economical design procedure for coastal structures, rather than using a regular wave height distribution across the shore and one fixed breaking point for a given incident wave condition.

Due to the complexity of breaking wave mechanisms, the definition of "probability of wave breaking" is differs according to the researcher. The concepts of the probability of breaking waves according to Goda (1975,1983), Battjes and Janssen (1978), Thornton and Schaeffer (1978), Thornton and Guza (1989), and the Monte-Carlo method (M.C.method) by Kraus and Larson (1991), Larson and Kraus (1992) are studied here. The probability of breaking waves was not defined by Goda (1975,1983). However, the fraction of breaking waves is introduced here based on his wave breaking criterion. In addition, the manner of obtaining the probability of breaking waves by the M.C. method is introduced on the basis of a concept of "breaking or broken waves" for each individual wave composing the wave field. As a first step of the study, a method for describing the probability of breaking waves is introduced based on the DUCK85 data (Ebersole and Hughes (1987)), and an example of the spatial probability will be shown. Then we consider predictions of the four numerical models for breaking waves on plane beaches. Regarding breaking wave on a barred profile beach, Smith and Kraus (1991), Cai et al. (1992), and Smith and Kraus (1992 a, b) performed laboratory studies. So, it is expected that the present study can be a first possible step to explain breaking waves on a barred beach.

Before the development of the complete numerical model for the random sea composed of a frequency and directional spectrum, a plane beach with straight parallel contours and normal incident wave angle is assumed as well as a narrow-band spectrum. Thus, it is noted that wave diffraction and refraction as well as reflection are not taken into account in the present model development. Several methods exist in the literature for calculating the distribution of wave height of random waves in the surf zone. To our knowledge, these different methods have never been compared. In the present study, the validity and performance of the four models are examined.

DATA ANALYSIS FOR THE PROBABILITY OF BREAKING WAVES

It is necessary to obtain a record of direct measurement of the free surface elevation by capacitance type wave gages or photopoles to analyze the probability of breaking waves. Here, the data set of DUCK85 is used, Ebersole and Hughes (1987), Ebersole (1987). The free surface record was decomposed into individual waves by visual inspection with the zero-cross method to keep the number of random waves at each photopole the same; thus, each incident wave at the most offshore photopole is identified by the number and is traced as it moves shoreward. Comparison of this method to the normal zero-cross method without a filter and Ebersole's method (1987) is shown in Fig.1 for mean and significant wave height. Wave height gradually increases as water depth decreases until it reaches a maximum, and then again gradually decreases on the flat portion of the profile. This method gives results close to Ebersole's method rather than the normal zero-cross method without a filter: however, in contrast to Ebersole's method, which is fully computationalized, the present method requires much manual labor.

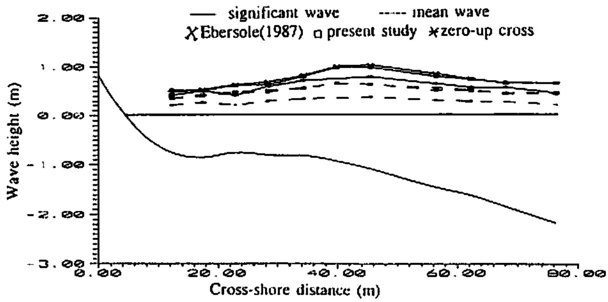


Fig. 1 Cross-shore distributions of characteristic wave heights

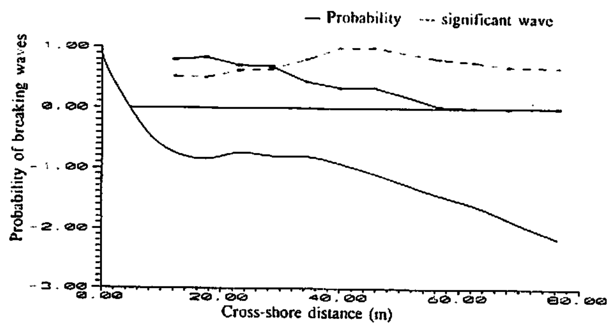


Fig. 2 Probability of breaking waves (59050955)

Finally, each individual wave was classified by visual inspection as non-breaking, breaking, or broken. The probability of breaking waves is shown with the cross-shore distribution of significant wave height in Fig. 2. The probability of breaking waves at the offshore photopoles is zero and gradually increases as the water depth decreases. The probability of breaking waves is nearly one third around the area where the significant wave height has a maximum.

BREAKING WAVE MODELS FOR RANDOM WAVES

Models for random wave transformation, deformation, and distribution have been proposed by several researchers over the last two decades. Here, the Goda model (G model), Thornton and Guza model (T-G model), Battjes and Janssen model (B-J model), and M.C. model proposed by Larson and Kraus are briefly reviewed. The concepts of each models are shown in Fig. 3.

(A) G model (1975, 1983)

The wave height distribution in deep water is assumed to follow the Rayleigh distribution, $P_0(\xi)$. Once breaking commences in shallow water, the probability of unbroken waves is

$$\begin{aligned} P_r(\xi) &= P_0(\xi) \quad ; \xi \le \xi_2 \\ &= P_0(\xi) - \frac{(\xi - \xi_2)}{(\xi_1 - \xi_2)} P_0(\xi) \quad ; \xi_2 < \xi \le \xi_1 \\ &= 0 \quad ; \xi_1 < \xi \end{aligned} \tag{1}$$

and the probability of breaking waves is

$$\begin{aligned} P_{br}(\xi) &= \frac{(\xi - \xi_2)}{(\xi_1 - \xi_2)} P_0(\xi) \; : \; \xi_2 < \xi < \xi_1 \\ &= P_0(\xi) \; ; \; \xi > \xi_1 \end{aligned} \tag{2}$$

where ξ_1 and ξ_2 are the upper and lower breaking limits. Thus, the probability of breaking waves is defined as (the area of breaking waves) / (the area of breaking and unbroken waves) in the wave height distribution.

(B) B-J model (1978)

Battjes and Janssen (1978) assumed that the variation of mean wave energy density as well as H^2_{rms} can be calculated based on the mean dissipation rate per area which is introduced by the bore approach for a given water depth as follows;

$$\frac{\partial(EC_g)}{\partial x} + D = 0 \tag{3}$$

where, EC_g is the energy flux in cross-shore direction, and D is the time-mean dissipation power per unit. To obtain the probability of breaking or broken waves, they assumed that the wave height of all waves which are breaking or broken at the given point is equal to maximum wave height at a given water depth. Based on the assumption of a Rayleigh wave height in deep water, the probability of breaking waves Q_b is obtained by solving the transcendental equation:

$$\frac{1 - Q_b}{\ln Q_b} = -\left(\frac{H_{rms}}{H_m}\right)^2 \tag{4}$$

(C) T-G model (1989)

Thornton and Guza (1989) developed an equation for the transformation of rms wave height from offshore to the beach based on the energy conservation equation as follows

$$\frac{\partial EC_g}{\partial x} = \langle \epsilon_b \rangle \tag{5}$$

where, $\langle \epsilon_b \rangle$ is the ensemble averaged dissipation due to wave breaking. To obtain the average energy dissipation, the distribution of breaking waves was assumed as a weighting of the Rayleigh pdf, $p_b(H)=W(H)\cdot p(H)$. So, the percent of breaking waves A_b, is

$$\begin{aligned} A_b &= \int_0^\infty p_b(H)dH = \int_0^\infty W(H)\cdot p(H)dH \\ &= W(H)\int_0^\infty p(H)d(H) = W(H) \end{aligned} \tag{6}$$

because the integral of the p.d.f is unity. They determined empirically hypothesized that the probability of a wave breaking depends only on H_{rms} and depth h so that:

$$W(H) = A_b = \left(\frac{H_{rms}}{\gamma h}\right)^4 \tag{7}$$

where, $\gamma \approx 0.4$ for rms wave in the T-G model.

(D) M. C. method

The M.C. method uses a series of individual waves randomly chosen to follow the Rayleigh distribution in deep water. Each individual wave transforms, breaks, and reforms at different points on the beach. The governing equation proposed by Dally (1980,1984) and Dally, Dean and Darlymple (1985), shown by eq. (8), is applied as the energy conservation equation.:

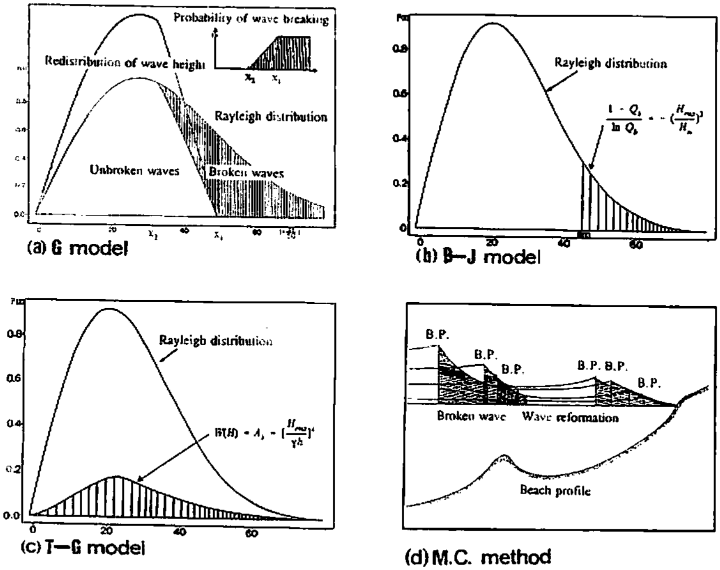


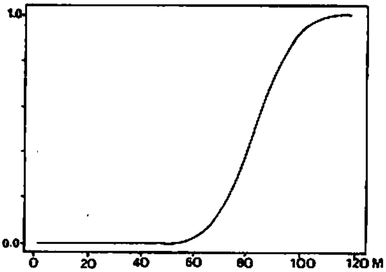
Fig. 3 Shematic diagrams of random breaking waves

$$\frac{\partial(EC_g)}{\partial x} = \frac{\kappa}{d}(EC_g - EC_{gs}) \qquad (8)$$

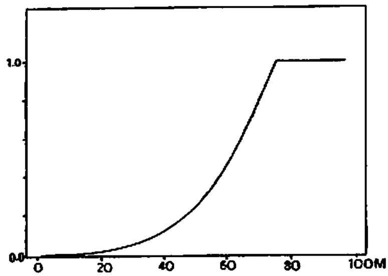
where, d is the total water depth, κ is a non-dimensional empirical coefficient, and C_{gs} is the energy flux of a stable wave. Dally (1992) also proposed a wave-by-wave algorithm for random breaking waves in which wave decay and reforming are the same with the M.C. method, and wave shoaling and incipient breaking are different. To obtain the probability of breaking waves, the concept "breaking and broken waves"is used here. If the local wave height is higher than the stable wave height or if the local energy flux is larger than the stable energy flux, the local wave is treated as a broken wave. The probability of breaking waves at a given point is directly given as a ratio (the number of the breaking waves and broken waves) / (the number of total waves). The M.C. method allows calculation of any characteristic wave height on the profile, such as H_{rms}, $H_{sig.}$ and H_{max}.

NUMERICAL RESULTS

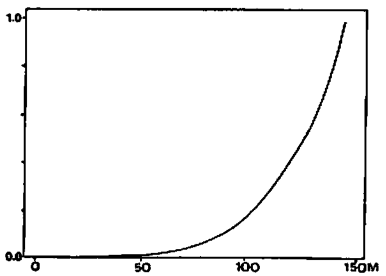
Numerical results for the probability of wave breaking on a 1/20 slope beach by the G model, B-J model, T-G model, and M.C. model are shown in Figs. 4 (a), (b), (c), and (d), respectively. It is clear that the probabilities of wave breaking by each model increase from 0 to one as the water depth becomes shallow. The probabilities of wave breaking by the G model and the M.C. method gradually increase as a convex curve, where as the probability of wave breaking by the B-J model and the T-G model gradually increase as a concave curve. It is noted that the probability of wave breaking by the B-J model becomes unity when H_{rms} is equal to H_m, and then stays at unity to the shoreline. So, there appears to be some inconsistency in this approach. In addition, it is not clear to the authors how the breaking criterion and breaking wave heights can be taken into the energy conservation equation proposed by T-G to derive the rms wave height where probably H_{rms} is equal to γh over a non-uniform beach profile.



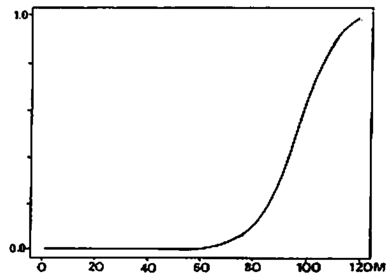
(a) Probability by Goda model



(b) Probability by Battjes and Janssen



(c) Probability by Thornton and Guza



(d) Probability by M.C. method

Fig. 4 Probability of breaking waves on a plane beach (numerical models)

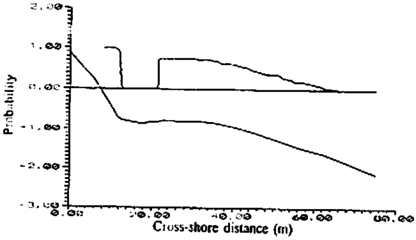


Fig. 5 Probability of breaking waves by the M.C. method (59050955)

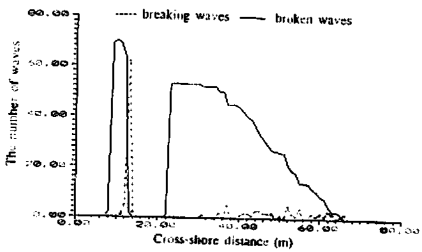


Fig. 6 The number of breaking waves and broken waves by the M.C. method (59050955)

Because it seems that the M. C. method has more potential to expand to the frequency spectrum, the M. C. method was applied to compute the probability of breaking waves over a barred profile of in the DUCK85 experiment. It is seen that the calculated probability increases as the water depth decreases, remains constant, and steeply decreases over a trough region as shown in Fig. 5. It seems that this behavior is somehow unusual. However, a possible explanation based on the individual wave approach governed by eq. (8) is shown in Fig. 6. The numbers of breaking waves (breaking points) and broken waves over the beach profile are shown by broken and solid lines, respectively. Many waves break on the offshore slope of the beach profile depending on their wave heights, periods, and the local water depth h. There are a few breaking waves on the flat portion of the profile, and most of the previously breaking waves had already broken before reaching the trough. Once the water depth increases behind the flat portion of the profile, most of the incident waves (except the unbroken small waves) start to reform in this region. As a result, most of the incident waves near the shoreline are definitely depth limited. Therefore, the incident waves near the shoreline behave like a series of regular waves. A series of regular waves break at the same position and the probability of breaking waves becomes unity. The above explanation might be correct to a certain extent, but the surface roller and catch up by successive random waves must also be considered in refinements of this model.

CONCLUDING REMARKS

The probability of random breaking waves has been studied numerically. Field data obtained at DUCK85 were analyzed by visual inspection to keep the number of waves the same at different photopoles. The representative wave height distribution by this method was almost equivalent to the Ebersole (1987) computational method. Based on the numerical analysis, it was shown that the probability of breaking waves by the Goda method and by the M.C. method are qualitatively similar. Those by the B-J model and the T-G model are similar to each other, but differ from results of the other two models. As a possible application of the M.C. method, computations have been carried out to a non-uniform beach profile. The result shows that the probability of random breaking waves is zero over the trough region, which is not believed to be correct by the authors. Because, the present approach is only based on the energy dissipation by breaking, it is necessary to consider the surface roller as a possible source of the white water in the surf zone in the next research. In addition, it is also necessary to calibrate the method by the original photopole pictures in future work.

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