CHAPTER 25

BREAKING CRITERION ON NON-UNIFORMLY SLOPING BEACH

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ABSTRACT

This paper deals with the breaker height on non-uniformly sloping beaches. A large number of experiments were carried out to obtain a breaking criterion on bar and step-type beaches. Based on the experimental data, a relationship among the breaker height, water depth, and wave period is investigated for various bottom configurations. As a result, the breaker height on non-uniformly sloping beaches is found to be well predicted by substituting an equivalent bottom slope in Goda's breaker index which has been obtained for uniformly sloping beaches. The equivalent bottom slope is defined as the mean slope in the distance of $5h_B$ offshoreward from a breaking point, where h_B denotes the water depth at the breaking point. The method for calculating the breaker height on natural beaches is also presented.

INTRODUCTION

The determination of the breaking point and breaker height is indispensable for planning and designing coastal structures. Theoretical investigations on the limiting wave condition of permanent waves on a horizontal bottom have been extensively done, for example, by Miche (1944), Hamada (1951), Yamada and Shiotani (1968), Schwartz (1974), and Cokelet (1977). However, there seems to be no theoretical treatment for the breaking height on sloping beaches.

Goda (1970) re-analyzed various laboratory data on the breaker height obtained by several researcheres, and proposed a breaker index. For bottom slopes less than 1/50, the index was determined to be coincident with the limiting wave condition presented by Yamada and Shiotani (1968). Since a large number of data were carefully re-analyzed, the breaker index is considered to be sufficiently reliable. However, in applying the index to the waves on non-uniformly sloping beaches such as natural beaches, it is not clear how to determine the representative value of the beach slope. This problem must be solved on the basis of empirical data because no theory adequately describes the breaking condition for such complicated bottom profiles.

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Therefore, we conducted a large number of experiments on the breaker height over non-uniformly sloping beaches. The aims of the experiments are

(1) To investigate the effect of change in bottom slope on breaker height.

(2) To propose a method to evaluate an equivalent bottom slope in order to apply Goda's breaker index to the waves breaking on non-uniformly sloping beaches.

First, the validity of Goda's breaker index is verified for uniformly sloping beaches. It is confirmed that in spite of some scatter in the data, the breaker index agrees well with experimental results. Next, from the measured values of breaker height, water depth and wave period, the apparent values of bottom slope which satisfy the equation of Goda's breaker index are evaluated. Then, the equivalent bottom slopes are approximated by a simple linear equation. The breaker height is estimated by using the equivalent bottom slope in Goda's breaker index, and compared with the experimental data.

EXPERIMENTAL SETUP AND PROCEDURE

The experiments were carried out by using a wave flume of 17m long, 0.6m wide, and 0.55m deep. Various bottom configurations were built in the wave flume by connecting steel segments, each of 1m long. The bottom profile can be changed by adjusting the lengths of columns of steel segments. For each bottom profile, regular waves with period of 0.7s to 1.6s were generated. The total number of cases amount to 670. Wave height was measured by two capacitance wave gages. The breaker point was determined as the point where the wave height was maximum.

EXPERIMENTAL RESULTS

Figure 1 compares Goda's breaker index with the experimental results for uniformly sloping beaches. In the figure, H_B denotes the breaker height, h_B the water depth at the breaking point, Lo ($=gT^2/2\pi$, g: gravitational acceleration, T: wave period) the wavelength of small amplitude waves in deep water, and S the bottom slope. The vertical axis is the breaker height to water depth ratio, H_B/h_B, and the horizontal axis is the relative water depth , h_B/Lo. The solid lines show Goda's breaker index for the bottom slopes of 1/10, 1/20, and 1/30. The open, semiclosed and closed circles denote the experimental data for the slopes of 1/10, 1/20, and 1/30, respectively. Although the experimental data for the slope of 1/10, having some scatter, show smaller values than those of Goda's breaker index, Fig. 1 shows, in general, a good agreement between the breaker index and the experimental data.

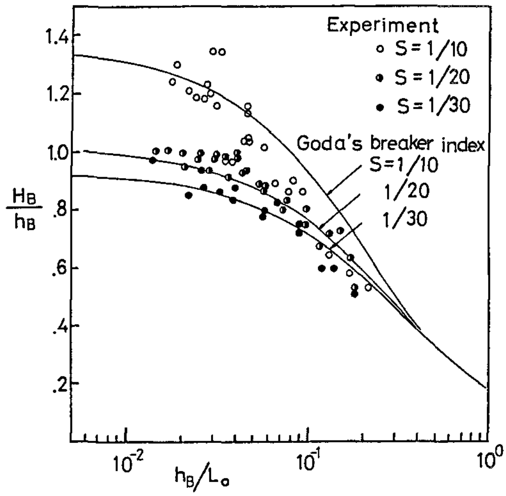


Fig. 1 Breaker index for uniformly sloping beaches.

In case of a step type beach as shown in Fig. 2, Goda's breaker index can not be applied without modification. If the incident wave height is large, the waves may break on the offshore slope S_1. As the incident wave height becomes smaller, the waves tend to break on the onshore slope S_2. In the latter case, the breaker height may be significantly influenced by the offshore slope S_1.

Figure 3 shows the relationship between the breaker height to water depth ratio and the relative water depth for bilinear bottom profiles (offshore slope S_1=1/20, onshore slope S_2=0 for Fig. 3-(a), and S_1=1/20, S_2=1/10 for Fig. 3-(b)). The curves represent Goda's breaker index for the bottom slopes, $S=S_1$ and S_2. The semiclosed circles and triangles in Fig. 3-(a) respectively denote the data for waves breaking on the slopes S_1=1/20 and S_2=0. The semiclosed squares and circles in Fig. 3-(b) respectively show the data for waves breaking on the slopes S1=1/10 and S2=1/20. In spite of some scatter in the data, most of the data lie between the two curves. This implies that the breaker height on the onshore slope is affected by the offshore slope.

In order to estimate the effect of the offshore slope on the breaker height, an equivalent bottom slope was defined and compared with the real slope. The equivalent slope, S^*, is defined as the slope which satisfies Goda's breaker index, which is approximately expressed as (Goda,1975)

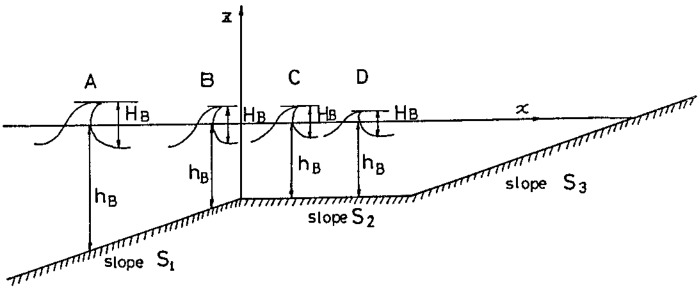


Fig. 2 Wave breaking on a step-type beach.

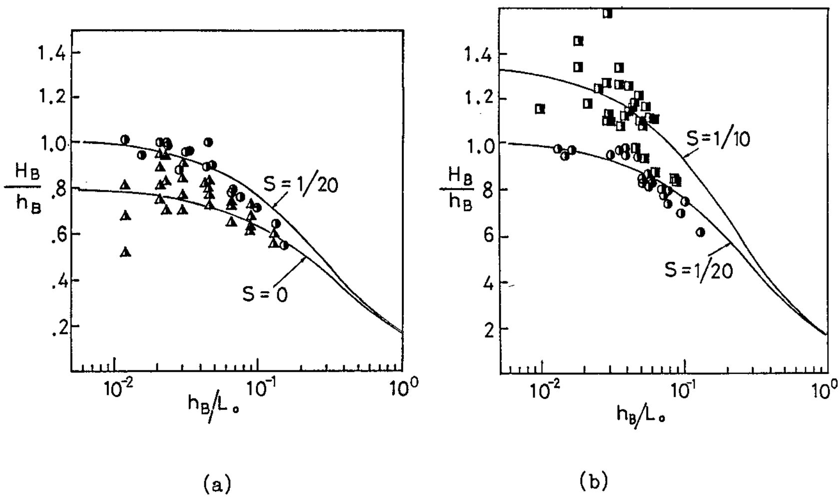


Fig. 3 Breaker index for step-type bottom profiles.

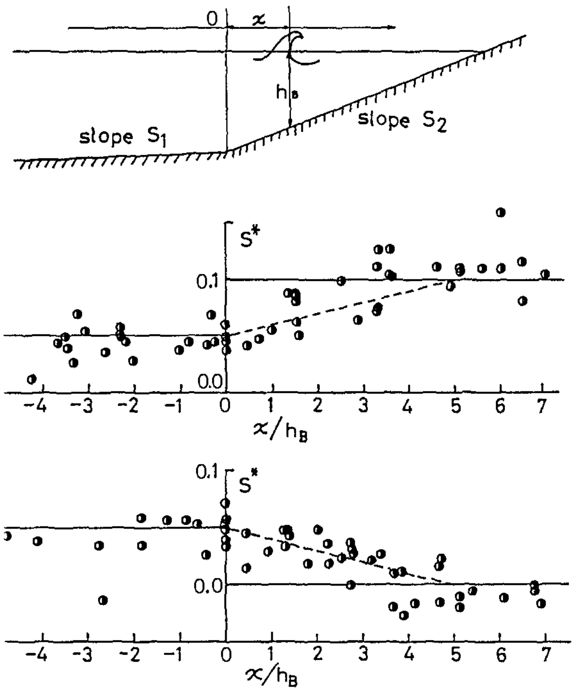


Fig. 4 On-offshore distributions of the equivalent bottom slope.

$$\frac{H_B}{h_B} = A\left\{1-\exp\left[-1.5\frac{\pi h_B}{L_0}(1+15S^{4/3})\right]\right\} \Big/ \left(\frac{h_B}{L_0}\right) \qquad (1)$$

where A takes the value of 0.17 for regular waves. From Eq. (1), the equivalent bottom slope, S^*, is expressed by

$$S^* = \left\{-\frac{1}{15}\left[\frac{\ln\left(1-\frac{1}{A}\frac{H_B}{h_B}\frac{h_B}{L_0}\right)}{1.5\pi(h_B/L_0)}+1\right]\right\}^{3/4} \qquad (2)$$

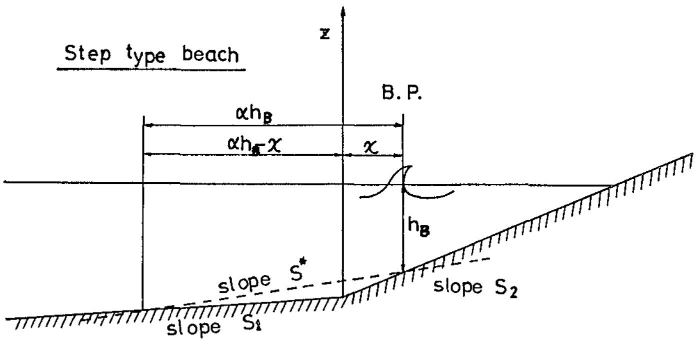
If we substitute the measured values of H_B, h_B and T into Eq. (2), we obtain a value of the equivalent bottom slope. Fig. 4 shows the on-offshore distribution of the equivalent bottom slope. The axis of the abscissa is normalized by the water depth h_B. A point x=0 is the point where the bottom slope changes. The middle figure is for the slopes of S_1=1/20 and S_2=1/10. The lower figure is for the slopes of S_1=1/20 and S_2=0. For waves breaking on the offshore slope, the values of the equivalent bottom slope are about 0.05 as an average relation, although there is a some scatter in the data. For waves breaking on the slope S_2 , the values of S^* changes almost linearly with the increase of non-dimensional distance. It is also found that the values of S^* tend to approach the values of actual slope S_2 in the vicinity of the point $x/h_B=5$. This means that for waves breaking onshoreward of the point of $x/h_B=5$, the breaker heights are no longer affected by the offshore slope S_1. In the transition zone, the value of the equivalent bottom slope can be approximated by the linear relationship:

$$S^*=S_1+(S_2-S_1)*x/5h_B \qquad (3)$$

The equivalent bottom slope expressed by Eq. (3) is illustrated by a broken line in Fig. 5. For a bar type beach, if waves break in the trough, the breaker height must be more influenced by the water depth at the top of the bar, h_{min}, than by the breaking water depth. Therefore, h_{min} was used to define the equivalent slope:

$$S^*=\left\{-\frac{1}{15}\left[\frac{\ln\left(1-\frac{1}{A}\frac{H_B}{h_{min}}\frac{h_{min}}{L_o}\right)}{1.5\pi(h_{min}/L_o)}+1\right]\right\}^{3/4} \qquad (4)$$

If the quantity in the curly brackets in Eq. (4) is negative, the value of S^* should take the opposite sign. It is found that Eq. (1) is nearly satisfied by substituting the equivalent bottom slope even for bar-type beaches. The equivalent bottom slope for a bar-type beach is illustrated by the broken line in Fig. 6.



$$S^*=\frac{(\alpha h_B-x)S_1+xS_2}{\alpha h_B}=\frac{(\alpha-X)S_1+XS_2}{\alpha}$$

$$X=x/h_B \qquad \alpha=5$$

Fig. 5 Definition sketch of the equivalent bottom slope for a step-type beach.

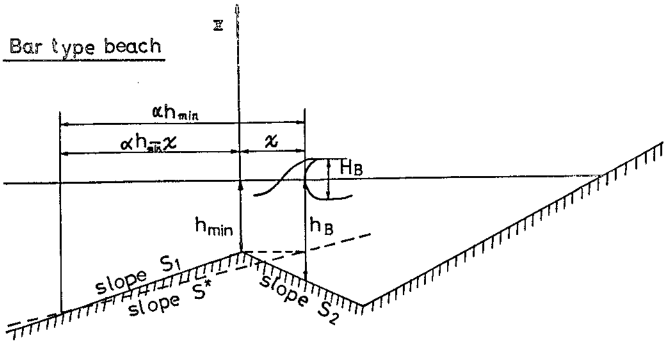


Fig. 6 Definition sketch of the equivalent bottom slope for a bar-type beach.

METHOD FOR CALCULATING BREAKER HEIGHT

On the basis of the above discussion, the method for calculating breaker height is summarized as follows:

(1) For a given site, calculate the mean slope in the range of $5h_B$ distant from that point.

(2) Calculate the breaker height, H_B, using Eq. (1) with use of the water depth, h_B, deepwater wavelength, Lo, and equivalent bottom slope S^*. For a bar-type beach, use the minimum water depth, h_{min} in stead of h_B.

Fig. 7 shows a comparison between the measured and calculated values of the breaker height for step-type beaches. The agreement between them is fairly good. For bar-type beaches, the comparison between them is shown in Fig. 8. The closed circles are for waves breaking on the offshore slope of a bar and the open circles are for waves breaking on the anti-slope of a bar. These figures show that the breaker height is well predicted by the present model.

For a natural beach, the procedure for calculating the breaker height is essentially the same as the procedure stated above. The schematic illustration is shown in Fig. 9.

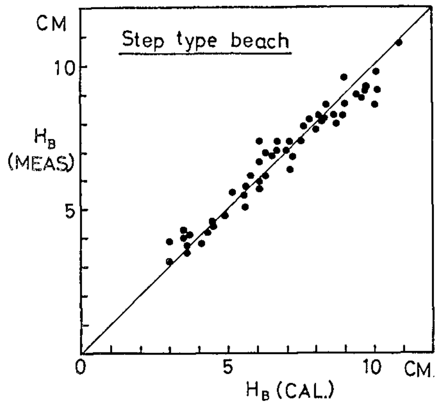


Fig. 7 Comparison between the measured and calculated values of breaker height for step-type beaches.

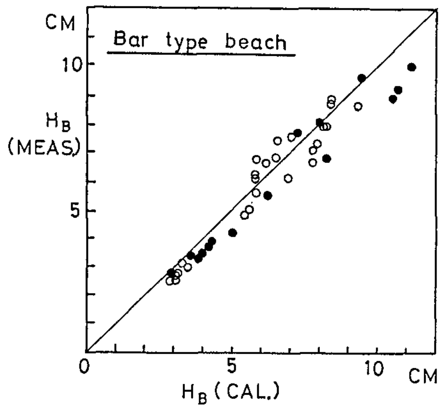


Fig. 8 Comparison between the measured and calculated values of breaker height for bar-type beaches.

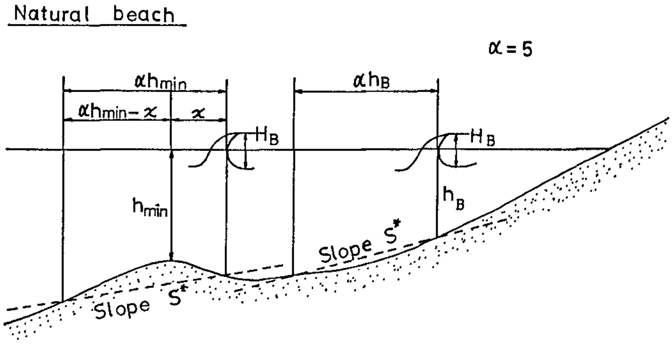


Fig. 9 Definition sketch of the equivalent bottom slope for a natural beach

CONCLUDING REMARKS

A large number of experiments were carried out in order to obtain a breaking criterion on non-uniformly sloping beaches. From the measured breaker height, water depth, and wave period, the equivalent bottom slope was evaluated by using Goda's breaker index. The spatial change of the equivalent bottom slope was examined; then it was found that the equivalent bottom slope can be determined as the mean slope in the distance of five times the water depth from a breaking point. Therefore, the breaker height on a non-uniformly sloping beach, can be predicted by substituting the equivalent bottom slope in Goda's breaker index. However, the applicability of the present model is limited because all of the data were obtained from laboratory experiments with monochromatic waves. Therefore, additional verification is necessary for irregular waves breaking on a natural beach.

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