# CHAPTER 77

## A NEW PARAMETER FOR WAVE BREAKING WITH OPPOSING CURRENT ON SLOPING SEA BED


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## INTRODUCTION

Opposing currents affect the wave breaking processes. The condition of wave breaking caused by opposing currents in deep water is described by the ratio of the wave celerity to the velocity of the opposing current(Yu(1952)). For the wave breaking caused by the opposing currents in shallow water on a flat bed, the equation given by Miche(1951) for the breaking criteria without current remains available (Iwagaki et al.(1980)). However, it is the breaking of shoaling wave in the presence of opposing current on a uniform slope, which is of concern in this paper.

Sakai et al.(1981) showed that the wave breaking affected by opposing currents on a sloping sea bed is characterized by a normalized unit width discharge $q^*$, as well as an incident wave steepness Ho/Lo and a slope of sea bed S, where $q^*$ is defined as $q^*= q/g^2T^3$; q: a unit width discharge, g: the gravitational acceleration, T: a wave period. They proposed diagrams for the breaker height and the breaking depth as a function of these three parameters. The breaker index curves in their diagrams show the relationships between the breaker height (or the breaking depth) and $q^*$ for waves with particular values of Ho/Lo and S, and it is much more convenient to give a general expression for the breaker indices for arbitrary conditions of $q^*$, Ho/Lo and S.

The purpose of this study is to formulate the effects of these parameters on wave breaking, based on the results of systematic experiments performed by the authors, and to derive an empirical and simplified expression for the breaker height and depth in the presence of opposing currents.


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The original idea is to choose the ratios of the breaker height (or depth) with opposing currents to the breaker height (or depth) without currents, and to search for an individual functional relationship between the ratios and each parameter ($q^*$, $H_0/L_0$ and S). Then, with the help of statistical approaches, these relationships are reorganized into a more simple relationship between the ratios and a new parameter.

## EXPERIMENTS

Experiments were conducted by using two wave channels, one of which is 26m long, 1m deep and 0.36m wide; the other is 24m long, 0.8m deep and 0.36m wide. These have the same systems of wave generation and of water circulation. The slopes of the bottom were 1/50, 1/30 and 1/15. Data acquisition of wave profiles was started when the first wave was generated, and the wave height was measured using five wave profiles from the sixth to the tenth, in order to avoid the reflecting waves. An incident wave height and length were calculated with the linear theory for wave with uniform current. The breakpoint was defined as a point which has the highest wave height. Experimental conditions of the unit width discharge, the wave period and the incident wave height are shown in table 1, and the ranges of the normalized unit width discharge and the incident wave steepness on each sea bed slope are given in Appendix A.

Table 1 Experimental conditions

| | |
|---|---|
| unit width discharge | $q$ : 0.0 ~ 790.0 ($cm^3/s/cm$) |
| wave period | $T$ : 0.83 ~ 2.40 (s) |
| incident wave height | $H_0$ : 1.1 ~ 24.0 (cm) |

## NEW PARAMETER

In the present study, the breaker height (or depth) in the presence of the opposing current is examined, as compare to the breaker height (or depth) in the absence of the current. In this approach, the breaker height (or depth) in the absence of the current is expected to be described as a function of the incident wave steepness and the sea bed slope. The results of the present experiments without currents give the relationships between the breaker height (or depth) and the incident wave steepness for each sea bed slope, as shown in Appendix B-1 and B-2. In stead of scattering of data, the average lines were obtained for each cases. In the following discussion these average lines will be used to estimate the breaker height (or depth) without current. In these figures, the breaker index curves proposed by Goda(1970) are also illustrated. The present results are consistent with Goda's curves.

The influence of opposing currents appears in the change of breaking depth more significantly than in that of breaker height, and the normalized unit width discharge $q^*$ explains the effects of opposing currents on wave transformation(Sakai and Saeki(1984)). The first step is to examine the relationship between Rh and $q^*$, where Rh is the ratio of breaking depth with and without opposing currents. Figure 1 shows the relationships between Rh and $q^*$ for given $H_0/L_0$ on the slope

1/30. Rh depends on q* linearly, and then the relationship is expressed by the regression line for each condition of Ho/Lo. Since the slopes of regression lines (SRL)h depend on Ho/Lo, the relationship between (SRL)h and Ho/Lo is examined. Figure 2 shows that (SRL)h is inversely proportional to Ho/Lo on a logarithmic scale in cases where Ho/Lo<0.05. (SRL)h also depends on the slope of sea bed. As shown in Figure 3, (SRL)h is proportional to the slope of sea bed S on a logarithmic scale. Then, the slope of regression line (SRL)h is described as follows:

$$(SRL)_h \propto (H_0/L_0)^{-a} \cdot S^{b} = ((H_0/L_0) \cdot S^{-c})^{-a} \quad (1)$$

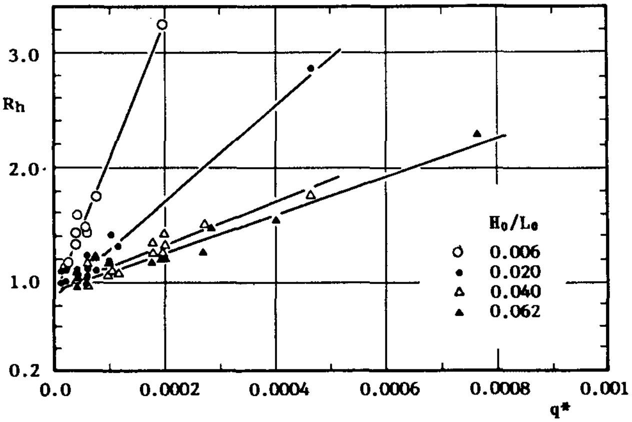



Figure 1 Relationship between Rh and q* (S=1/30)

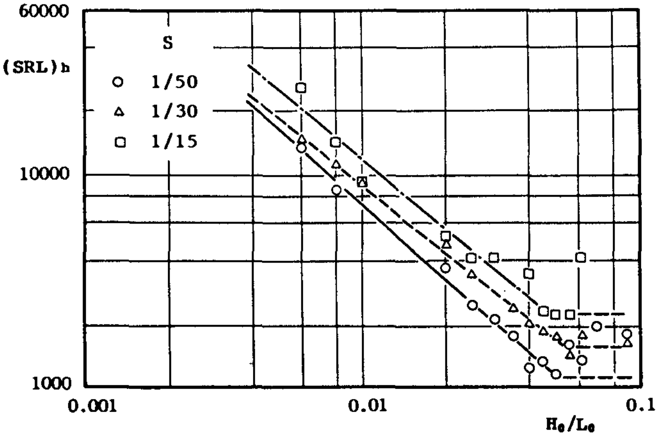



Figure 2 Effect of Ho/Lo on (SRL)h

To explain the combined effects of Ho/Lo and S on (SRL)h, the optimum value of c was found to be between 0.11 and 0.76. Figure 4 shows the relationship between (SRL)h and the combined parameter of Ho/Lo and S, with c=0.41, which gives the highest coefficient of correlation. Using the slope of regression line in this figure, (SRL)h can be formulated as a function of Ho/Lo and S.

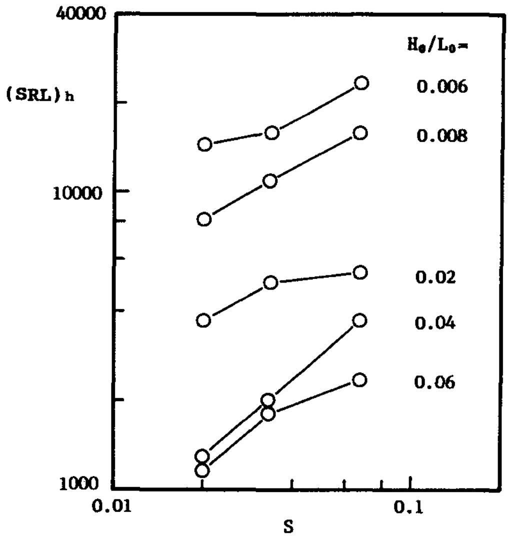



Figure 3 Effect of S on (SRL)h

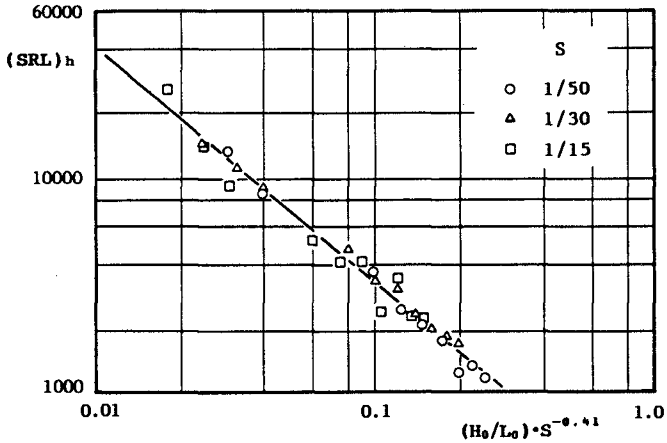



Figure 4 Combined effect of Ho/Lo and S on (SRL)h, with c=0.41

The relationships between RH and q* are illustrated in Figure 5, where RH means the ratio of breaker height with and without opposing currents. The slope of regression line (SRL)H was examined as to be related to Ho/Lo and S. A similar relationship was also obtained as follows:

$$(SRL)_H \propto (H_0/L_0)^{-a'} \cdot S^{b'} = ((H_0/L_0) \cdot S^{-c'})^{-a'} \qquad (2)$$

The optimum value of c' is between 0.14 and 0.65. Figure 6 gives (SRL)H expressed by the combined parameter of Ho/Lo and S, with c'=0.37.

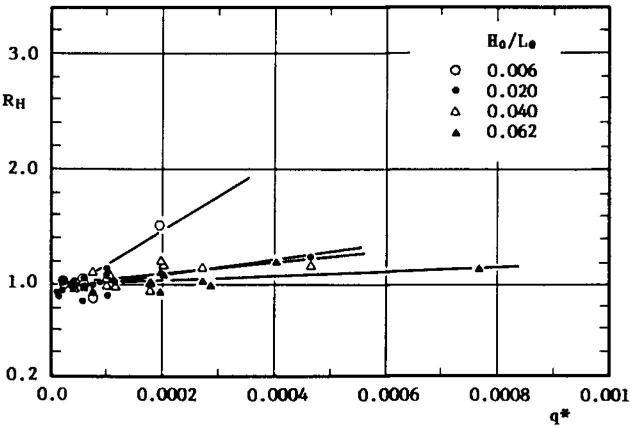



Figure 5 Relationship between RH and q* (S=1/30)

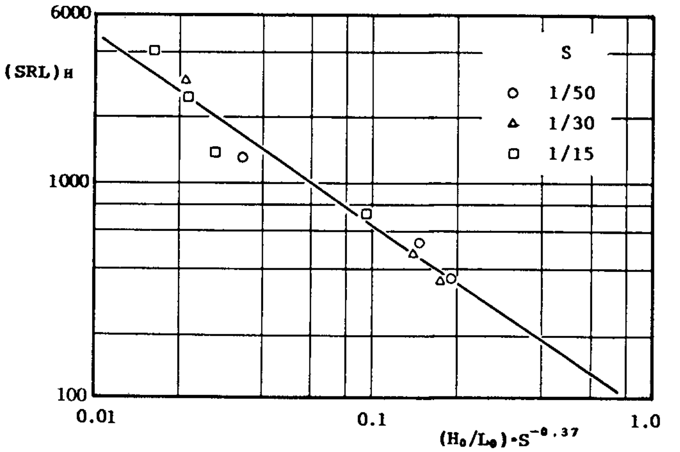



Figure 6 Combined effect of Ho/Lo and S on (SRL)H, with c'=0.37

For a given Ho/Lo and S, both Rh and RH are proportional to q* on a normal scale(see Figures 1 and 5). If the product of q* and (SRL)h (or (SRL)H) is chosen as a parameter, the relationship between Rh(or RH) and this parameter will be described by a single line. Since the range of optimum value of c overlaps with that of c', and it will be more convenient to define a single parameter, a new parameter was defined for both Rh and RH, as follows:

$$\varepsilon = \begin{cases} \dfrac{q^*}{H_0/L_0} \sqrt[4]{S} & H_0/L_0 \leqq 0.05 \\ \dfrac{q^*}{0.05} \sqrt[4]{S} & H_0/L_0 > 0.05 \end{cases} \tag{3}$$

For waves with Ho/Lo larger than 0.05, Ho/Lo is assumed to be 0.05, since Figure 2 shows that (SRL)h is not inversely proportional to Ho/Lo for such cases.

Using the proposed parameter, all data were rearranged into a relationship between the ratios and $\varepsilon$. Both ratios (Rh and RH) depend on $\varepsilon$ linearly as shown in Figure 7, and $\varepsilon$ explains the combined effects of q*, Ho/Lo and S on the wave breaking on a uniform slope, fairly well. Consequently, from the regression lines in this figure, Rh and RH are formulated as follows:

$$R_h = \begin{cases} 0.93 + 170\varepsilon & \varepsilon \geqq 0.0004 \\ 1.0 & \varepsilon < 0.0004 \end{cases} \tag{4}$$

$$R_H = \begin{cases} 0.96 + 30\varepsilon & \varepsilon \geqq 0.0013 \\ 1.0 & \varepsilon < 0.0013 \end{cases} \tag{5}$$

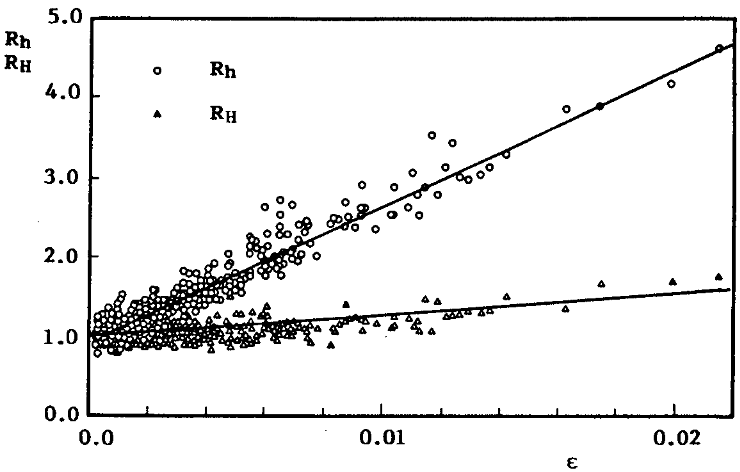



Figure 7 Expressions for Rh and RH by ε

## CONCLUSIONS

In the present study, the influences of opposing current on wave breaking were formulated as functions of a new parameter $\varepsilon$, which accounts for the combined effects of the unit width discharge, the incident wave steepness and the sea bed slope. These formulations give the ratios of the breaker height(or depth) with and without opposing currents. Several results have been reported for wave breaking without currents. For example, Goda(1970) proposed diagrams for the relationships between the ratio of the breaker height to the incident wave height and the incident wave steepness. For the breaking depth or the maximum breaker height in a given depth, Weggel(1972) described the ratio of water depth to wave height at breakpoint as a function of breaker height, incident wave length and sea bed slope. Goda(1975) also gave an another expression derived from his diagrams. These formulations and diagrams have been widely used to predict the breaker height and depth without currents. The present formulations gives the breaker height(or depth) with opposing currents, by using the breaker height(or depth) without current predicted by the previous studies.

## REFERENCES


Goda,Y.(1970), "A Synthesis of Breaker Indices", Transactions of the Japanese Society of Civil Engineers, JSCE, Vol.2, Pt.2.

Goda,Y.(1975), "Irregular wave deformation in the surf zone", Coastal Engineering in Japan, JSCE, Vol.18, 13-26

Iwagaki,Y. et al.(1980), "Fundamental Study on Breaking of Waves due to Currents"(in Japanese), Proc. of 27th Japanese Conference on Coastal Engineering, JSCE, 30-34

Miche,M.(1951), "Le Pouvoir Reflechissant des ouvrages Maritimes, Exposes a l'action de la Houle", Annales Ponts et Chaussees, 12 Annee, 285-319

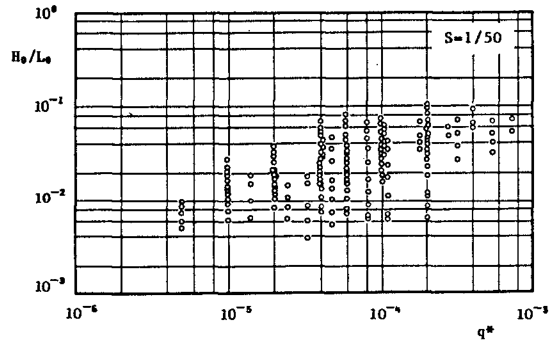
Sakai,S. et al.(1981), "Effects of Opposing Current on Wave Breaking on Slope"(in Japanese), Proc. 29th Japanese Conference on Coastal Engineering. JSCE, 138-143.

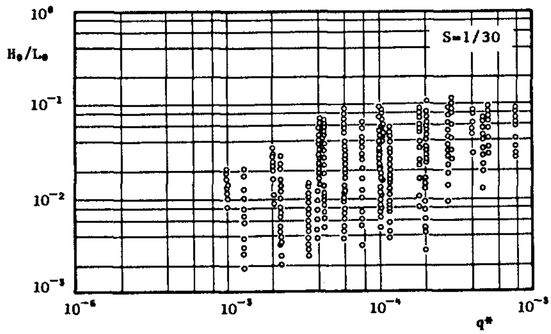
Sakai,S. and H. Saeki(1984), "Effects of Opposing Currents on Wave Transformation on Sloping Sea Bed", Proc. of 19th Coastal Engineering Conference, ASCE, 1132-1148

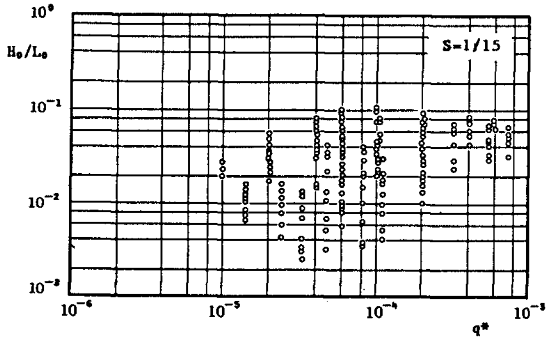
Weggel,J.R.(1972), "Maximum Breaker Height", Journal of the Waterways, Harbors and Coastal Engineering Division, ASCE, Vol.98, WW4, 529-548

Yu, Y.Y.(1952), "Breaking of Waves by Opposing Current", Transaction of AGU, AGU, Vol.33, No.1, 39-41

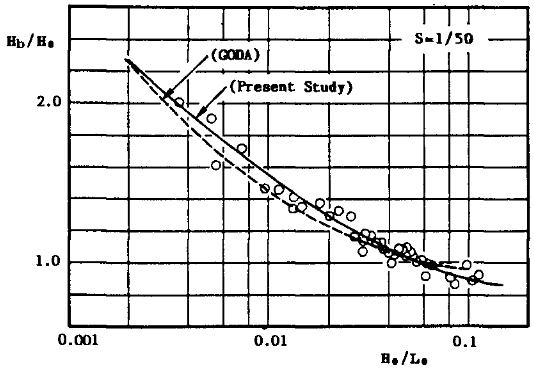
<u>Appendix A</u> Ranges of normalized unit width discharge and incident wave steepness

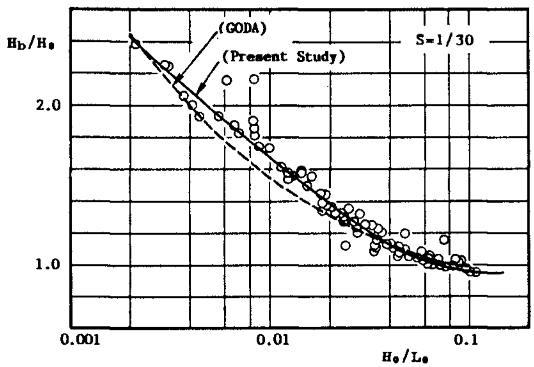


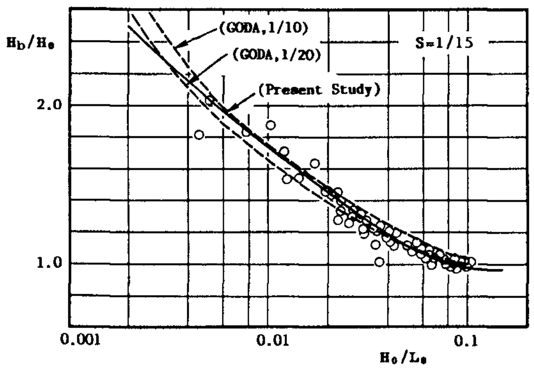



Appendix B-1 Breaker height without current



Appendix B-2 Breaking depth without current