

Comparison of breaker height formulas using large-scale wave tanks

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Abstract

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The breaker height is an essential requirement for design of coastal structures, as well as for the prediction of wave height transformation and beach deformation. Many formulas have been proposed to compute the breaker height. However, most of the existing breaker height formulas were developed based primarily on measured data from small-scale experiments. It is doubtful that those formulas are applicable in large-scale experimental conditions, which are more representatives of natural conditions. In this study, the predictive capability of 29 existing breaker height formulas is examined by comparison against measured data from the large-scale experiments of CRIEPI (1983) and SUPERTANK (1994). The comparison shows that the errors of the selected formulas vary from 8.7% to 69.4%. Overall, the formulas that give very good predictions are those by Ostendorf and Madsen (1979), Larson and Kraus (1989), Gourlay (1992), and Rattanapitikon and Shibayama (2000).

Key words : breaking index, breaking wave height, breaker height

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การเปรียบเทียบสูตรคำนวณความสูงที่คลื่นแตกโดยใช้ข้อมูลจากรางวัดคลื่นขนาดใหญ่

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ความสูงที่คลื่นแตกตัวเป็นข้อมูลที่สำคัญต่อการออกแบบสิ่งก่อสร้างในทะเล และใช้ในการคำนวณการเปลี่ยนแปลงของคลื่นและชายหาด ในปัจจุบัน มีสูตรสำหรับคำนวณความสูงที่คลื่นแตกอยู่มากมายหลายสูตรด้วยกัน แต่สูตรเหล่านี้ส่วนใหญ่ได้ถูกพัฒนามาจากผลการทดลองในการทดลองขนาดเล็ก จึงเป็นที่น่าสงสัยว่าสูตรเหล่านี้จะสามารถใช้ได้หรือไม่ สำหรับเงื่อนไขการทดลองขนาดใหญ่ซึ่งมีสภาพใกล้เคียงกับสภาพจริงตามธรรมชาติมากกว่าการทดลองขนาดเล็ก ในการศึกษาครั้งนี้ ได้ทำการเปรียบเทียบสูตรสำหรับคำนวณความสูงที่คลื่นแตกที่มีอยู่แล้ว 29 สูตร ข้อมูลผลการทดลองที่ใช้ในการเปรียบเทียบได้จากข้อมูลคลื่นจากรางวัดคลื่นขนาดใหญ่ของ CRIEPI (1983) และ SUPERTANK (1994) จากการเปรียบเทียบพบว่า ค่าความผิดพลาดของสูตรที่ใช้มีค่าตั้งแต่ 8.7% ถึง 69.4% และสูตรที่ทำนายได้ดีมากสำหรับกรณีทั่ว ๆ ไป คือ สูตรของ Ostendorf and Madsen (1979), Larson and Kraus (1989), Gourlay (1992) และ Rattanapitikon and Shibayama (2000)

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The initiation of breaking wave height (or breaker height) has been a subject of study for a century due to its importance in design of coastal structures, as well as for the prediction of wave height transformation and beach deformation. During the past century, a number of studies and experiments have been carried out to develop the breaker height formulas. Owing to the complexity of wave breaking mechanism, any type of breaker height formula has to be based on empirical or semi-empirical formula calibrated with the experimental results. Therefore the validity of breaker height formulas may be restricted to the experimental conditions used in the calibration or verification. In order to confirm the validity of the formula, a wide range of experimental conditions should be used in the calibration or verification of the formula. As it is very difficult to measure the breaker height of each individual wave in the field, small-scale and large-scale experiments are the sources of quantitative information for verifying the breaker height formula.

Since most of the existing formulas were developed based on only the measured data from

small-scale experiments, it is doubtful whether those formulas are applicable in the large-scale experimental conditions, which are more representative of natural conditions. In spite of the great number of studies in the initiation of breaking, few have evaluated the validity of the existing formulas. Moreover, the few available comparisons are not based on the large-scale experiments. The aim of this study is to compare and find out proper breaker height formulas that predict well for large-scale experimental conditions.

This paper is divided into three main parts. The first part presents the existing breaker height formulas. The second part is a brief review of collected experiments used to examine the existing formulas. The third part is the examination of all formulas for identifying the proper ones.

Existing breaker height formulas

Many different formulas for computing breaker heights have been proposed during the past century. Among the existing formulas, the breaker height formulas of Miche (1944) and Goda (1970) are widely mentioned. The majority of the existing formulas represent a relationship

between the breaker height (H_b) and the variables at the breaking or deepwater conditions, i.e., still water depth at breaking (h_b), wavelength at breaking (L_b), local bottom slope (m), deepwater wavelength (L_o), and deepwater wave height (H_o). From preceding studies, the following formulas have been suggested to compute the breaker height.

a) McCowan (1894), hereafter referred to as MC94, derived a limit of breaking wave in water of constant depth based on solitary wave theory and proposed that the breaking will occur when

$$H_b = 0.78h_b \quad (1)$$

b) Miche (1944), hereafter referred to as MI44, developed a semi-empirical breaking criterion for periodic waves in finite water depth and proposed the limiting wave steepness as a function of water depth to wavelength ratio.

$$H_b = 0.142L_b \tanh\left(\frac{2\pi h_b}{L_b}\right) \quad (2)$$

Danel (1952) suggested changing the coefficient from 0.142 to be 0.12 when applying to the horizontal bottom.

c) Munk (1949), hereafter referred to as MU49, derived a breaker height formula based on the solitary wave theory. The formula was proposed to be

$$H_b = 0.3H_o \left(\frac{H_o}{L_o}\right)^{-1/3} \quad (3)$$

d) Le Mehaute and Koh (1967), hereafter referred to as MK67, proposed an empirical formula based on three sources of the experimental data (Suquet, 1950; Iversen, 1952; and Hamada, 1963). The experiments cover a range of $1/50 < m < 1/5$ and $0.002 < H_o/L_o < 0.093$.

$$H_b = 0.76H_o \left(\frac{H_o}{L_o}\right)^{-1/4} m^{1/7} \quad (4)$$

e) Galvin (1969), hereafter referred to as GA69, performed laboratory experiments with regular wave on plane beach and combined his data with the data of Iversen (1952) and McCowan (1894). The breaking criterion was developed by fitting empirical relationship between h_b/H_b and m .

$$H_b = h_b \frac{1}{1.40 - 6.85m} \text{ for } m \leq 0.07 \quad (5.1)$$

$$H_b = \frac{h_b}{0.92} \text{ for } m > 0.07 \quad (5.2)$$

f) Collins and Weir (1969), hereafter referred to as CW69, derived a breaking height formula from linear wave theory and empirically included the slope effect into the formula. The experimental data from three sources (Suquet, 1950; Iversen, 1952; and Hamada, 1963) were used to fit the formula.

$$H_b = h_b(0.72 + 5.6m) \quad (6)$$

g) Goda (1970), hereafter referred to as GO70, analyzed several sets of laboratory data on breaking waves on slopes obtained by several researchers (Iversen, 1952; Mitsuyasu, 1962; and Goda, 1964) and proposed a diagram presented criterion for predicting breaker height. Then Goda (1974) gave an approximate expression for the diagram as

$$H_b = 0.17L_o \left\{ 1 - \exp\left[-1.5 \frac{\pi h_b}{L_o} (1 + 15m^{4/3})\right] \right\} \quad (7)$$

h) Weggel (1972), hereafter referred to as WE72, proposed an empirical formula for computing breaker height from five sources of the laboratory data (Iversen, 1952; Galvin, 1969; Jen and Lin, 1970; Weggel and Maxwell, 1970; and Reid and Bretschneider, 1953). The experiments cover a range of $1/50 < m < 1/5$.

$$H_b = \frac{h_b g T^2 1.56 / [1 + \exp(-19.5m)]}{g T^2 + h_b 43.75 [1 - \exp(-19m)]} \quad (8)$$

i) Komar and Gaughan (1972), hereafter referred to as KG72, used linear wave theory to derive a breaker height formula from energy flux conservation and assumed a constant H_b/h_b . After calibrating the formula to the laboratory data of Iversen (1952), Galvin (1969), and unpublished data of Komar and Simons (1968), and the field data of Munk (1949), the formula was proposed to be

$$H_b = 0.56H_o \left(\frac{H_o}{L_o} \right)^{-1/5} \quad (9)$$

j) Sunamura and Horikawa (1974), hereafter referred to as SH74, used the same data set as Goda (1970) to plot the relationship between H_b / H_o , H_o / L_o and m . After fitting the curve the following formula was proposed.

$$H_b = H_o m^{0.2} \left(\frac{H_o}{L_o} \right)^{-0.25} \quad (10)$$

k) Madsen (1976), hereafter referred to as MA76, combined the formulas of Galvin (1969) and Collins (1970) to be

$$H_b = 0.72h_b(1+6.4m) \quad \text{for } m < 0.10 \quad (11)$$

Black and Rosenberg (1992) found that the formula of Madsen (1976) gives good predictions for individual breaker height in laboratory and field experiments.

l) Battjes and Janssen (1978), hereafter referred to as BJ78, modified Miche (1944)'s criterion by including an adjustable coefficient $\gamma/0.88$ into the formula. The formula calibration indicated that the coefficient $\gamma=0.8$ gave the best prediction.

$$H_b = 0.142L_b \tanh \left(\frac{0.8}{0.88} \frac{2\pi h_b}{L_b} \right) \quad (12)$$

m) Ostendorf and Madsen (1979), hereafter referred to as OM79, modified the formula of Miche (1944) by including the beach slope in to the formula. After calibrating to the laboratory

data, the Miche (1944)'s formula was modified to be

$$H_b = 0.14L_b \tanh \left[(0.8 + 5m) \frac{2\pi h_b}{L_b} \right] \quad \text{for } m \leq 0.1 \quad (13.1)$$

$$H_b = 0.14L_b \tanh \left[(0.8 + 5(0.1)) \frac{2\pi h_b}{L_b} \right] \quad \text{for } m > 0.1 \quad (13.2)$$

n) Sunamura (1980), hereafter referred to as SU80, conducted an empirical formula based on an analysis of various laboratory data (Iversen, 1952; Bowen *et al.*, 1968; Goda, 1970; and Sunamura, 1980) and obtained the following formula.

$$H_b = 1.1h_b \left(\frac{m}{\sqrt{H_o/L_o}} \right)^{1/6} \quad (14)$$

o) Singamsetti and Wind (1980), hereafter referred to as SW80, conducted a laboratory experiment. The experiments cover a range of $1/40 < m < 1/5$ and $0.02 < H_o/L_o < 0.065$. They proposed two empirical formulas based on their own data. The first formula is

$$H_b = 0.575H_o m^{0.031} \left(\frac{H_o}{L_o} \right)^{-0.254} \quad (15)$$

Equation (15) is referred to as SW80a hereafter. The second formula is

$$H_b = 0.937h_b m^{0.155} \left(\frac{H_o}{L_o} \right)^{-0.13} \quad (16)$$

Equation (16) is referred to as SW80b hereafter.

p) Ogawa and Shuto (1984), hereafter referred to as OS84, obtained the following formula from the same data sets as Goda (1970). The formula is limited to use for the range of $1/100 < m < 1/10$ and $0.003 < H_o/L_o < 0.065$.

$$H_b = 0.68H_o m^{0.09} \left(\frac{H_o}{L_o} \right)^{-0.25} \quad (17)$$

q) Battjes and Stive (1985), hereafter referred to as BS85, modified the formula of Battjes and Janssen (1978) by relating the coefficient γ with H_o / L_o as

$$H_b = 0.142L_b \tanh \left\{ \left[0.5 + 0.4 \tanh \left(33 \frac{H_o}{L_o} \right) \right] \frac{2\pi h_b}{0.88L_b} \right\} \quad (18)$$

r) Seyama and Kimura (1988), hereafter referred to as SK88, measured wave height deformation of individual wave of the irregular wave experiments and investigated the wave height to water depth ratio at wave breaking. The formula of Goda (1970) was modified to compute the individual wave breaking in irregular wave trains as

$$H_b = h_b \left\{ 0.16 \frac{L_o}{h_o} \left[1 - \exp \left[-0.8\pi \frac{h_b}{L_o} (1 + 15m^{4/3}) \right] \right] - 0.96m + 0.2 \right\} \quad (19)$$

They also found that the individual waves of irregular waves tend to break before satisfying the breaking criterion for regular waves. The reduction of the wave height to water depth ratio at the breaking point was found to be about 20%. Therefore the coefficient of (19) when applying to regular wave breaking should be changed to be 1.25 as

$$H_b = 1.25h_b \left\{ 0.16 \frac{L_o}{h_o} \left[1 - \exp \left[-0.8\pi \frac{h_b}{L_o} (1 + 15m^{4/3}) \right] \right] - 0.96m + 0.2 \right\} \quad (20)$$

s) Larson and Kraus (1989), hereafter referred to as LK89, developed a breaking criterion based on the large wave tank data of Kajima *et al.* (1983). The breaking height index H_b / h_b was related to the surf similarity parameter. $m / \sqrt{H_o / L_o}$. By using regression analysis, the breaker height formula was proposed to be

$$H_b = 1.14h_b \left(\frac{m}{\sqrt{H_o / L_o}} \right)^{0.21} \quad (21)$$

The correlation coefficient of Eq. (21) is 55%. Equation (21) is referred to be LK89a hereafter.

They also related the term H_b / H_o with the deepwater wave steepness (H_o / L_o). The regression analysis was used to obtain the equation. The regression equation obtained is

$$H_b = 0.53H_o \left(\frac{H_o}{L_o} \right)^{-0.24} \quad (22)$$

The correlation coefficient of Eq. (22) is 80%. Equation (22) is referred to as LK89b hereafter.

t) Hansen (1990), hereafter referred to as HA90, used the laboratory data from Van Dorn (1978) and unpublished data of ISVA to plot the relationship between H_b / h_b and mL_b / h_b and proposed the following empirical formula.

$$H_b = 1.05h_b \left(m \frac{L_b}{h_b} \right)^{0.2} \quad (23)$$

u) Smith and Kraus (1990), hereafter referred to as SK90, proposed 2 empirical formulas based on the analysis of 11 sources of laboratory data performed on plane beach conditions. The experiments cover a range of $1/80 < m < 1/10$ and $0.001 < H_o / L_o < 0.092$. The first formula is

$$H_b = h_b \left\{ \frac{1.12}{1 + \exp(-60m)} - 5.0[1 - \exp(-43m)] \frac{H_o}{L_o} \right\} \quad (24)$$

Equation (24) is referred to as SK90a hereafter. The second formula is

$$H_b = H_o (0.34 + 2.47m) \left(\frac{H_o}{L_o} \right)^{-0.30+0.88m} \quad (25)$$

Equation (25) is referred to as SK90b hereafter.

v) Kamphuis (1991), hereafter referred to as KA91, modified Miche (1944)'s formula by introducing the exponential form of the bottom slope into the formula and applied to compute the significant wave height of the irregular wave breaking. After calibrating to his irregular breaking wave data, the formula becomes

$$H_b = 0.095 \exp(4m) L_b \tanh \left(\frac{2\pi h_b}{L_b} \right) \quad (26)$$

He also found that the regular breaking height formula can be used for irregular wave to compute the significant wave height at the breaking but the coefficient have to be reduced to be about 0.75 of the proposed coefficient. Therefore the coefficient in Eq. (26) should be changed from 0.095 to be 0.127 when applying to the regular breaking waves as

$$H_b = 0.127 \exp(4m) L_b \tanh \left(\frac{2\pi h_b}{L_b} \right) \quad (27)$$

w) Gourlay (1992), hereafter referred to as GL92, proposed an empirical formula based on seven sources of laboratory data (Bowen *et al.*, 1968; Smith, 1974; Visser, 1977; Gourlay, 1978; Van Dorn, 1978; Stive, 1984; and Hansen and Svendsen, 1979). The experiments cover a range of $1/45 < m < 1/10$ and $0.001 < H_o / L_o < 0.066$. The data was used to plot the relationship between H_b / H_o and H_o / L_o , the curve fitting yields

$$H_b = 0.478 H_o \left(\frac{H_o}{L_o} \right)^{-0.28} \quad (28)$$

x) Rattanapitikon and Shibayama (2000), hereafter referred to as RS00, proposed 3 empirical formulas based on the re-analysis of existing breaker height formulas. The published experimental data from 24 sources were used to calibrate the formulas. The experiments cover a range of $0 < m < 0.44$ and $0.001 < H_o / L_o < 0.10$. The first formula is

$$H_b = (-2.06m^2 + 0.67m + 0.46) L_o \left(\frac{H_o}{L_o} \right)^{0.75} \quad (29)$$

Equation (29) is referred to as RS00a hereafter. The second formula is

$$H_b = 0.17 L_o \left\{ 1 - \exp \left[\frac{\pi h_b}{L_o} (16.21m^2 - 7.07m - 1.55) \right] \right\} \quad (30)$$

Equation (30) is referred to as RS00b hereafter. The third formula is

$$H_b = 0.1L_o \tanh \left[\left(-81.07m^2 + 35.27m + 7.88 \right) \frac{h_b}{L_o} \right] \quad (31)$$

Equation (31) is referred to as RS00c hereafter.

Experimental data

Two sources of large-scale experiments have been collected to examine the existing breaker height formulas, i.e., experiments of CRIEPI (Kajima *et al.*, 1983) and SUPERTANK (Kraus and Smith, 1994). The collected experiments were performed over the movable bed conditions. The experiments cover a wide range of wave and bottom conditions ($0.003 \leq H_o / L_o \leq 0.112$, and $0 \leq m \leq 0.29$). A total of 112 cases of

breaker height data are obtained from the experiments. Brief summary of each experiment is given below.

The experiment of CRIEPI was performed by Kajima *et al.* (1983) at Central Research Institute of Electric Power Industry (CRIEPI). The experiments were performed under the condition of regular wave and movable bed in a large wave flume (205 m long, 3.4 m wide and 6 m deep). Coarse sand ($D_{50} = 0.47$ mm) and fine sand ($D_{50} = 0.27$ mm) were used in the experiments. The wave heights were measured at various sections along the flume, covering both offshore and surf zone. Table 1 shows the CRIEPI experimental conditions that were used in this study. Run number in Table 1 is kept to be the same as the original.

The experiment of SUPERTANK Laboratory Data Collection Project (Kraus and Smith, 1994) was conducted to investigate cross-shore hydrodynamic and sediment transport processes,

Table 1. Summary of collected experimental data used to examine the formulas.

Sources	Run No.	No. of cases	H_o / L_o	m
CRIEPI (Kajima <i>et al.</i> , 1983)	2.1	6	0.028-0.030	0.06-0.21
	2.2	7	0.006-0.007	0.00-0.09
	2.3	6	0.046-0.052	0.00-0.03
	3.1	5	0.007-0.011	0.08-0.23
	3.2	7	0.017-0.022	0.06-0.18
	3.3	8	0.003	0.06-0.16
	3.4	9	0.105-0.111	0.05-0.29
	4.1	5	0.016-0.020	0.02-0.03
	4.2	7	0.031-0.039	0.03-0.17
	4.3	9	0.103-0.112	0.00-0.28
	5.1	5	0.006	0.00-0.02
	5.2	10	0.052-0.058	0.00-0.18
	6.1	6	0.043-0.045	0.15-0.21
	6.2	2	0.013-0.014	0.10-0.11
SUPERTANK (Kraus and Smith, 1994)	STG0	5	0.046-0.064	0.08-0.12
	STH0	4	0.013-0.063	0.10-0.13
	STI0	11	0.004-0.008	0.08-0.11
Total		112	0.003-0.112	0.00-0.29

during the period of August 5 to September 13, 1992, at Oregon State University, Corvallis, Oregon, USA. A 76-m-long sandy beach was constructed in a large wave tank of 104 m long, 3.7 m wide and 4.6 m deep. The 20 major tests were performed and each major test consisted of several cases. Most of the major tests were performed under the irregular wave actions. However, 3 major tests were performed under regular wave actions, i.e., test No. STGO, STHO and STIO. The wave heights were measured at various sections along the flume, covering both offshore and surf zone. Table 1 shows the SUPERTANK experimental conditions that were used in this study. Run number in Table 1 is kept to be the same as the original.

The breaking point is determined from wave height profile. The breaking point is defined as the point where the wave height is maximum. The breaker height (H_b) and depth (h_b) are the wave height and still water depth at the breaking point. The local bottom slope (m) is defined as the local slope measured seaward of the breaking point. If the bottom slope is adverse slope (negative value), it will be set to be zero.

Formulas examinations

The objective of this section is to examine the accuracy of the 29 breaker height formulas mentioned in the first section. A straightforward way to examine a formula is to compare the computed breaker height with the measured data. In order to evaluate the accuracy of the computation, the examination results are presented in terms of root mean square (*rms*) relative error, ER , which is defined as

$$ER = 100 \sqrt{\frac{\sum_{i=1}^n (H_{bci} - H_{bmi})^2}{\sum_{i=1}^n H_{bmi}^2}} \quad (32)$$

where i is the wave height number, H_{bci} is the computed breaker height of number i , H_{bmi} is the measured breaker height of number i , and n is the total number of measured breaker height. Smaller values of ER correspond to a better

prediction.

According to the bottom slope conditions in Eq. (5) and Eq. (13), the group of bottom slope may be classified to be $m \leq 0.07$, $0.07 < m \leq 0.10$, and $m > 0.10$. However some formulas (e.g., MK67, SH74, and SU80) are not valid for the bottom slope $m = 0$. Therefore, in this study, the bottom slope is classified into 4 groups, i.e., horizontal ($m = 0$), gentle ($0 < m \leq 0.07$), intermediate ($0.07 < m \leq 0.10$), and steep ($m > 0.10$). The total number of cases of the collected data for $m = 0$, $0 < m \leq 0.07$, $0.07 < m \leq 0.10$ and $m > 0.10$ are 4, 40, 24 and 44, respectively.

The computations of the breaker height formulas are carried out with 2 sources of collected data (see Table 1). Table 2 shows the *rms* relative error (ER) of each formula for 4 groups of bottom slope and all cases. The examination results from Table 2 can be summarized as follows:

1) The errors ER shown in Table 2 vary from 7.6 to 84.0. The formula of RS00c gives the best prediction ($ER = 7.6$) for the breaking wave on the bottom slope of $0.07 < m \leq 0.10$ while the formula of CW69 gives the worst prediction ($ER = 84.0$) for the breaking wave on the bottom slope of $m > 0.10$.

2) Some formulas are not valid for the horizontal slope ($m = 0$), i.e., the formulas of MK67, SH74, SU80, SW80a, SW80b, OS84, LK89a, and HA90. The formulas that give very good prediction ($ER < 12$) for the breaking wave on the horizontal slope are the formulas of MI44, GA69, CW69, MA76, SK88, LK89b and GL92.

3) The formulas that give very good prediction ($ER < 12$) for the breaking wave on the gentle slope ($0 < m \leq 0.07$) are the formulas of MI44, GO70, OM79, SW80a, LK89b, KA91, GL92, RS00b, and RS00c.

4) The formulas that give very good prediction ($ER < 12$) for the breaking wave on the intermediate slope ($0.07 < m \leq 0.10$) are the formulas of MK67, OM79, SW80a, OS84, LK89b, SK90a, SK90b, GL92, RS00a, RS00b, and RS00c.

5) Most of existing formulas seem to give unsatisfactory predictions for the breaking waves

Table 2. The root mean square relative error (*ER*) of each formula for four groups of bottom slope and all cases.

Formulas	$m = 0$	$0 < m \leq 0.07$	$0.07 < m \leq 0.10$	$m > 0.10$	All 112 cases
MC94 (Eq. 1)	13.1	31.2	29.2	30.3	30.1
MI44 (Eq. 2)	9.6	10.2	18.8	25.8	20.7
MU49 (Eq. 3)	34.5	28.6	24.7	21.4	24.7
MK67 (Eq. 4)	N.A.*	19.8	8.2	19.2	17.9**
GA69 (Eq. 5)	9.9	46.0	41.7	20.7	34.1
CW69 (Eq. 6)	9.9	52.1	52.3	84.0	69.4
GO70 (Eq. 7)	16.3	10.7	12.6	46.2	33.7
WE72 (Eq. 8)	13.1	13.8	12.2	13.7	13.5
KG72 (Eq. 9)	16.0	17.3	15.6	9.6	13.6
SH74 (Eq. 10)	N.A.*	18.1	16.9	40.8	31.6**
MA76 (Eq. 11)	9.9	46.6	44.4	66.5	56.7
BJ78 (Eq. 12)	12.9	13.6	24.5	31.3	25.6
OM79 (Eq. 13)	20.2	11.6	8.4	11.6	11.4
SU80 (Eq. 14)	N.A.*	31.3	25.1	19.3	24.6**
SW80a (Eq. 15)	N.A.*	8.8	9.1	13.2	11.3**
SW80b (Eq. 16)	N.A.*	29.9	25.5	19.9	24.4**
OS84 (Eq. 17)	N.A.*	13.8	8.7	17.5	15.1**
BS85 (Eq. 18)	16.4	25.4	37.3	36.8	33.5
SK88 (Eq. 20)	9.3	19.1	18.0	14.8	16.7
LK89a (Eq. 21)	N.A.*	28.3	24.1	21.4	24.2**
LK89b (Eq. 22)	11.2	10.0	9.0	7.9	8.8
HA90 (Eq. 23)	N.A.*	29.3	25.9	24.6	26.3**
SK90a (Eq. 24)	24.0	15.0	8.5	17.0	15.4
SK90b (Eq. 25)	32.3	18.1	9.5	11.2	14.2
KA91 (Eq. 27)	17.1	11.8	13.6	55.4	40.1
GL92 (Eq. 28)	10.9	7.9	11.6	12.3	11.0
RS00a (Eq. 29)	17.5	14.4	8.9	8.3	10.9
RS00b (Eq. 30)	14.5	9.7	8.7	8.9	9.2
RS00c (Eq. 31)	13.9	9.2	7.6	8.4	8.7

* N.A. = Not Applicable

** Exclude $m = 0$

on the steep slope ($m > 0.1$). The formulas that give very good prediction ($ER < 12$) for the breaking wave on the steep slope are the formulas of KG72, OM79, LK89b, SK90b, RS00a, RS00b, and RS00c.

6) The formula that gives very good prediction ($ER < 12$) for the four groups of bottom slope is the formula of LK89b.

7) The formulas that give very good prediction ($ER < 12$) for all cases are the formulas of OM79, LK89b, GL92, RS00a, RS00b, and

RS00c. The formula of SW80a gives very good prediction for the breaking wave on the slope $m > 0$.

8) The formula of RS00c gives the best prediction ($ER = 8.7\%$) over a wide range of experiments. However higher overall accuracy rating of a formula does not guarantee that the formula is superior to others under all conditions. The accuracy rating of a formula may vary depending on the bottom slope conditions. The best formulas for predicting the breaker heights on

the bottom slopes of $m = 0$, $0 < m \leq 0.07$, $0.07 < m \leq 0.1$, and $m > 0.10$ are the formulas of SK88, GL92, RS00c, and LK89b, respectively.

The comparison between measured and computed breaker height from the RS00c formula is shown in Figure 1. The solid line in the figure is the line of perfect agreement.

Conclusions

A total of 112 cases from 2 sources of large-scale experimental results were used to examine 29 existing breaker height formulas. The experimental data cover a wide range of wave and bottom conditions ($0.003 \leq H_o / L_o \leq 0.112$, and $0 \leq m \leq 0.29$). The examination results were presented in terms of root mean square relative error (ER). It was found that most previous formulas give a fair prediction for the breaking waves on the steep slope ($m > 0.1$). Overall, the formulas that give very good predictions are those by OM79, LK89b, GL92, and RS00. The formula of RS00c gives the best prediction ($ER = 8.7\%$) over a wide range of experiments. However higher overall accuracy rating

of a formula does not guarantee that the formula is superior to others under all conditions. The accuracy rating of a formula may vary depending on the bottom slope conditions. The best formulas for predicting the breaker heights on the bottom slopes of $m = 0$, $0 < m \leq 0.07$, $0.07 < m \leq 0.1$, and $m > 0.10$ are the formulas of SK88, GL92, RS00c, and LK89b, respectively.

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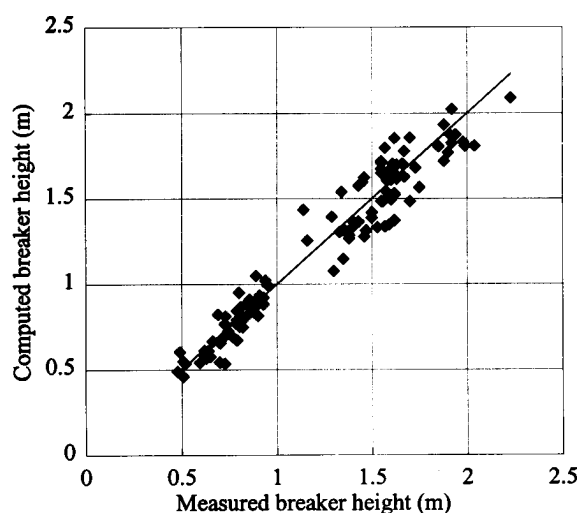


Figure 1. Comparison between measured and computed breaker heights from the RS00c formula (measured data from CRIEPI, 1983 and SUPERTANK, 1994).

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