CHAPTER 80

WAVE BREAKING OVER PERMEABLE SUBMERGED BREAKWATERS

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Abstract

A laboratory experiment was carried out in a wave tank to examine significant features of wave breaking over permeable submerged breakwaters and to determine the breaker height and depth indices. Submerged trapezoidal-shaped breakwaters were place on a 1/20 steel slope, and permeability of the breakwaters was varied.

The experiment showed that the breaker height and depth change with the breakwater permeability governing the strength of return flow over the breakwater. Breaker height index was developed in terms of the integrated parameter ξ_S'' proposed by Hara et al. (1992), which consists of the geometrical and structure properties of the breakwater as well as properties of incident waves. To determine the breaking position or depth, additional indices were also proposed. Validity of the computation scheme of the breaker height and position were confirmed by comparisons with the experiments.

INTRODUCTION

As is commonly known, permeable and submerged, low-crested rubble-mound, breakwaters force to break incoming steep waves and dissipate effectively the wave energy. Therefore, many breakwaters of this type have been built or planned at various locations to stabilize an eroded beach and to reduce damages of coastal and harbor structures due to severe wave actions.

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To meet requirements of the design and construction of the structures, many theoretical and experimental studies are extensively making to deepen understanding of the physics of wave breaking due to the submerged breakwater. The wave breaking may be sufficient to provide the principal control over the wave motion and resulting phenomena around the submerged breakwater, especially behind the breakwater, such as wave transmission, wave set-up, and so on. It seems likely that lack of a sound understanding of wave breaking over the submerged breakwater acts as a bottleneck of the physical and numerical examinations on the hydraulic function of the submerged breakwater.

A series of laboratory experiments was conducted to examine breaking wave properties over permeable submerged breakwaters and to determine the empirical relationships or breaker indices developed from measurements.

The results from the study will be useful for modeling the nearshore wave field around the breakwater and for predicting the evolution of the protected beach profile.

EXPERIMENTAL EQUIPMENT AND MEASUREMENTS

Experimental

Figure 1 shows the general arrangement of equipment. Experiments were carried out in a 20–m–long, 0.30–m–wide, and 0.55–m–high glass-walled wave tank, containing a steel beach of 1 on 20 slope. Monochromatic waves were produced by a reflection–absorbed wave maker of flap–type, installed at one end of the tank.

Six model breakwaters of same geometry, as shown in Fig. 2 and composed of the gravel materials or armor concrete blocks, were placed on the slope. Size and

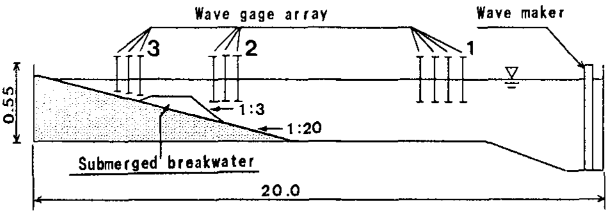


Fig. 1 General arrangement of equipment (units: m).

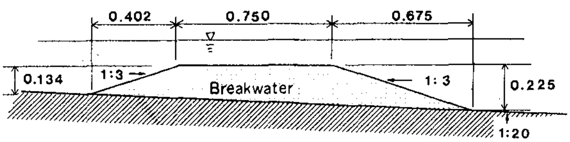


Fig. 2 Dimension of model breakwaters (units: m).

placing condition of the breakwater were determined based on actual breakwaters in Japan. The breakwaters had an upslope and downslope (tanθ) of 1:3, a 0.75m crest width (B), and a 0.225m height (d_s). The porosity (ε) were varied between 0.17 and 0.52 by changing the material size. In situ porosities were determined from the weight, volume and specific gravity of the materials used. Physical properties of the materials are listed in Table 1.

Table 1 Physical properties of materials used.

Porosity ε	Material Used	Material Size (cm)
0	Concrete	---
0.17	Gravel	1.7
0.25	Gravel	2.8
0.38	Gravel	4.0
0.50	Armor Block	7.5
0.52	Gravel	5.0

Measurements

As see in Fig. 1, water surface elevations were recorded at three wave gage arrays, which consist of either three or four capacitance-type gages. Wave array 1 was located at un uniform water depth section to resolve the incident and reflected wave heights using the method of Mizuguchi (1990). Wave array 2 was placed at the section of the seaward toe of structure slope to measure the incident wave height. Array 3 was set behind the breakwater to measure the transmitted wave height.

Wave data were collected for 2 minutes at 100 Hz, but only 10 successive waves were analyzed to obtain the wave height, mean surface elevation $\overline{\eta}$ and its variance η_{rms}. Wave profiles on and around the breakwater were recorded by a high-speed video of 200 frames per second. The wave properties were read from the still pictures, with aids of 1.0 cm square grid system attached on the sidewall glass. Incident wave parameters are listed as follows;

Incident Wave Height : H_I = 2.0 cm - 10.0 cm
Incident Wave Period : T = 0.8 s - 1.5 s
Water Depth
on Horizontal Bottom : h_I = 31.2 cm and 35.0 cm
above Breakwater Crest : R = 3.75 cm and 7.50 cm

INCIPIENT BREAKING

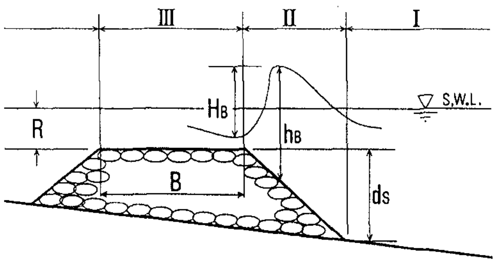


Fig. 3 Definition sketch of breaking wave and demarcation of breaker zone.

A schematie of a wave profile at breaking on the strueture seaward slope of breakwater is depicted in Fig. 3. H_B and h_B are the wave height and the water depth at breaking.

There are several ways of defining the break point. After careful inspection of the video pietures of breaking waves profile, we defined the breaking point as the point where the wave height is maximum. This definition ensured us stable judgement of the breaking point from video pictures. Breaker types observed over the submerged breakwater were basically the same to these over a plane sloping beach, spilling, plunging, and collapsing.

Breaking range of waves passing across the breakwater is demarcated into the three following zones, as shown in Fig. 3;

Zone I : on the offshore sloping beaeh in front of the breakwater,
II : on the strueture seaward slope, and
III : on the breakwater erest.

Thus we will examine eharacteristies of the wave breaking for each zone.

High-speed videos of the wave profile over the breakwater revealed that return flow over the crest and offshore slope of the breakwater influences the wave height and position at incipient breaking. In particular, a strong return flow over a impermeable submerged breakwater produces a variety of eollapsing breaker, whieh the wave crest remains unbroken and the lower part of the front face breaks just like a hydraulic jump due to rapid flows (Smith and Kraus, 1990; Katano et al., 1992). The effeets of the return flow on the breaker characteristics are weaken rapidly with decrease of the return flow strength, in other wards, with increase of the breakwater permeability.

BREAKER HEIGHT INDEX ON OFFSHORE SLOPING BEACH, ZONE I.

Due to the permeability and low crest of the submerged breakwater, wave reflection from the breakwater is low, but slightly higher than the plane sloping beaeh (Katano et al., 1992). As the result, experiments confirmed that the incipient breaker height in Zone I is predicted reasonably well by Goda's breaker index (1978), as given by Eq. (1), with a slight change of the value of empirical constant A from 0.17 to 0.15.

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

,in which H_B and h_B are the wave height and water depth at breaking, L_0 the wave length in deep water, and tan β the offshore beach slope. It is, therefore, considered that a steep wave approaching the breakwater is transformed principally by the shoaling effect caused by the plane slope of offshore beach.

BREAKER HEIGHT INDEX ON THE BREAKWATER, ZONES II AND III.

Integrated Parameter for Breaker Height.

Previous studies have been made on the wave breaking forced by low crested mound–type breakwaters as well as by barred and reef beaches. However, those have still failed to determine an appropriate breaker index as a function of the breakwater properties and the incoming wave parameters.

Hara et al. (1992) conducted extensive numerical experiments on the transformation of a solitary wave passing across an impermeable submerged breakwater of trapezoidal type, located on horizontal sea bottom. Based on regression analyses of the numerical computations, they propose a parameter for the breaker height index, ξ_s'', given by Eq. (2). It refers to a modified surf similarity parameter.

$$\xi_S'' = [\ \frac{B}{h_s} + \frac{(d_s/h_s)}{(3.5\tan\theta)^{0.2}}\ ]\ \frac{(d_s/h_s)}{(H_s/h_s)^{0.4}} \qquad (2)$$

,where H is the wave height, and subscript S denotes the quantity at the offshore toe of breakwater. The parameter comprises the physical properties and placing condition of the breakwater as well as incident wave properties. From this context, the parameter ξ_s'' is named the integrated parameter of breaker height.

Prior to employment of the integrated parameter, we will discuss briefly influences induced by differences in the experimental conditions of the present and Hara's studies, such as the character of incident wave, bottom profile, and permeability of the breakwater.

The experiments indicated that an incident periodic wave passing across the breakwater behaves almost like solitary wave. In addition, it was found that wave and current field in the vicinity of the breakwater display a very similar one produced in the numerical simulation, owing to the low wave reflection of the breakwater. As for the bottom slope, the wave shoaling on a plane slope was taken account by replacing the wave height in ξ_s'' with that at offshore toe of the breakwater.

Breaker Height Index as a Function of Integrated Parameter.

Complete analyses of the wave data on incipient breaking waves yield an empirical relation for the breaker height in terms of the integrate parameter ξ_s'', as given by Eq. (3).

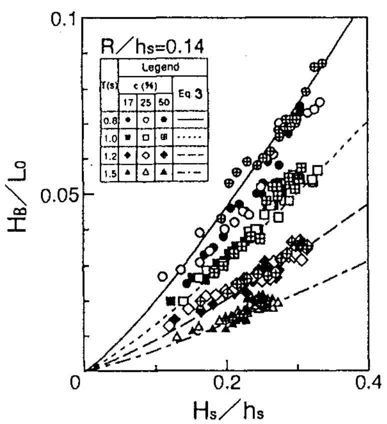
$$\frac{H_B}{L_0} = A_B\,(\varepsilon,\frac{R}{h_S})(\frac{2B}{5d_S})^3\,(\frac{h_S}{L_0})\;\xi_S'' \tag{3}$$

,where R is the water depth above the crest, and A_B is the empirical function and is written as

$$A_B\,(\varepsilon,\frac{R}{h_s}) = [1.0-0.12(\frac{R}{h_s})-0.6\varepsilon]\ \exp\ \varepsilon \tag{4}$$

, representing the permeability effect of total breakwater system. However, the value of A_B varies very slightly between 1.0 and 1.2 within limits of the experiments.

Figures 4 and 5 show plots of the breaking wave steepness, H_B/L_0 versus the relative wave height at seaward toe of the breakwater, H_s/h_s, to illustrate the ability of Eq. (3). It is noticed that the breaker height index, Eq. (3), describes surprisingly well the measurements.



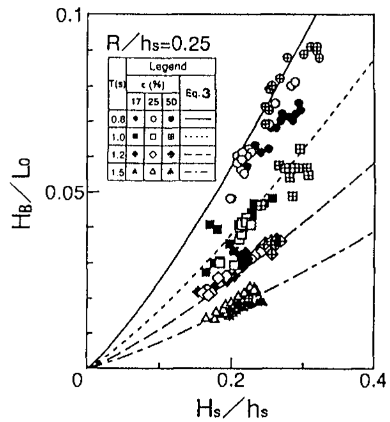
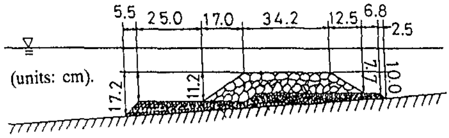


Fig. 4 Relation between H_B/L_0 and H_s/h_s. Fig. 5 Relation between H_B/L_0 and H_s/h_s.

Calibration of Eq. (3) is also made by using wave data of Izumiya et al. (1989). They carried out experiments of the wave transformation due to a two-layered submerged breakwater having rather complicated structure, as shown in Fig. 6. Porosity of the main breakwater body is 0.20. Figure 6 is an example of the comparison of Eq. (3) with their measurements. Although there is some scatter to the measurements, Fig. 7 shows reasonable agreements between the measured and computed breaker heights for their whole data.



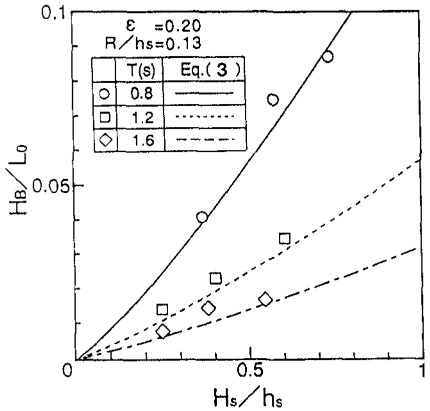


Fig. 6 Comparison of Eq. (3) with data of Izumiya et al. (1989).

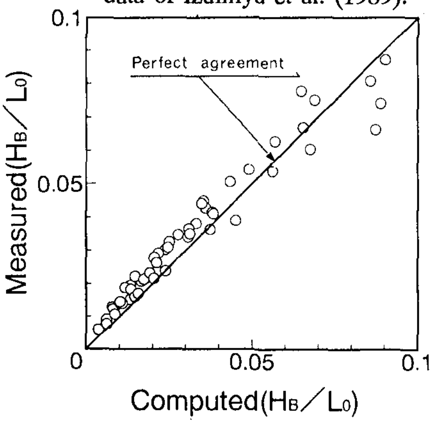


Fig. 7 Agreement of Eq. (3) with the whole data of Izumiya et al. (1989).

The agreements in Figs. (4) through (7) substantiate the validity and applicability of the proposed breaker height index Eq. (3). In addition to this, the integrated parameter ξ_s'' is likely to be very promising to other problems, such as wave breaking on barred and reef beaches. Using data of wave breaking over a triangle-shaped bar of Smith and Kraus (1990), breaker steepness H_B/L_0 is shown, in Fig. 8, as a function of the relative wave height at offshore toe of the bar. Equation (5), represented by lines in Fig. 8, agrees the data and follows their trend well.

$$\frac{H_B}{L_0} = 0.35 \left(\frac{h_S}{L_0}\right) \xi_S''^{\,-3} \qquad (5)$$

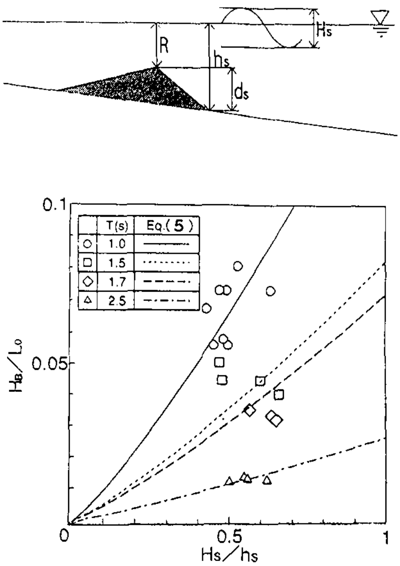


Fig. 8 Relation of H_B/L_0 to H_S/h_S, illustrating the ability of ξ_s''. Wave breaking over triangle-shaped bar. (Smith and Kraus, 1992)

Breaking Position or Depth on the Breakwater

Breaker depth h_B can not be calculated directly from the breaker height index, because Eq. (3) does not include explicitly the breaker depth. It is, therefore, required an additional index completely to determine the breaking condition on the breakwater. To do this, at first, we will examine the wave breaking on the breakwater crest, in Zone III, where the still water depth is very shallow and constant.

Following Goda (1964), the relative wave height H_B/R is plotted, in Fig. 9, as a function of the relative wave crest height h_c/R to determine the breaking position on breakwater crest. h_c and R are the wave crest height and the still water depth above breakwater crest. Plus and cross marks represent measurements for nonbreaking wave, and various solid and open marks for breaking waves. η_c is the wave crest height from still water level. The lines of η_c = 0.5H and H refer to relations for small amplitude wave and solitary wave, respectively. Broken line in Fig. 9 represents the bounds that incident waves pass across the breakwater without breaking.

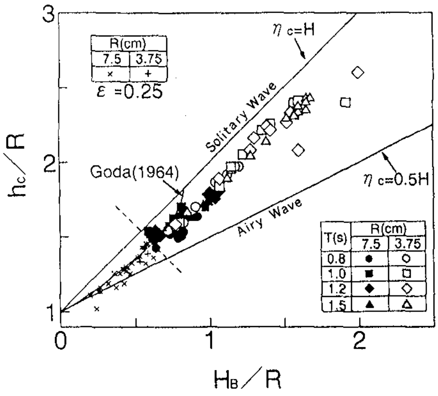


Fig. 9 h_c/R as a function of H_B/R for the incipient breaking on breakwater crest.

As noticed from Fig. 9, the breaker crest height approaches that of a solitary wave, as increasing the breaker height, $\eta_c \fallingdotseq 0.75H_B$. This indicates that the wave breaking on breakwater crest depends clearly on the trough depth of preceding wave and not on the still water depth above the crest, R. As a result, wave breaking on the crest is of a depth-limited wave, mainly controlled by the vertical asymmetry of incoming wave profile. Based on the results, the conditions under which waves break on the breakwater crest are examined by relationships between H_B/R and ε. In Fig. 10, solid circle and triangle marks represent the lowest wave height when breaking occurs on the crest. And open

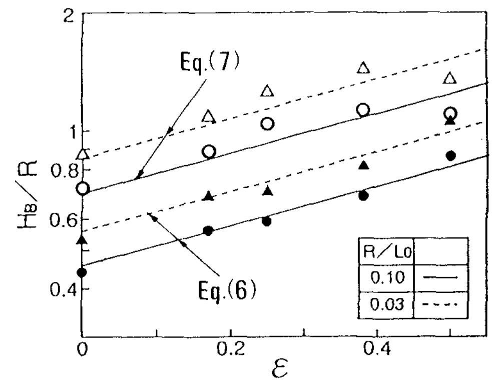


Fig. 10 Relation between H_B/L_0 and ε for determining the bounds of wave breaking on breaker crest.

ones show the breaker height at top of the structure slope. Two conditions of wave breaking on the breakwater crest can be determined as follows; (1) the lowest breaker height at the shoreward limit of wave breaking is given by,

$$\frac{H_B}{L_0} = \left(\frac{R}{L_0}\right)^{\frac{6}{7}} \exp(2.7\varepsilon - 1.8) \tag{6}$$

Therefore, Eq. (6) refers to the condition that if breaker height computed from Eq. (3) is lower than that from Eq. (6), the wave passes across the breakwater without breaking. And (2) the breaker height at top of the seaward structure slope is

$$\frac{H_B}{L_0} = \left(\frac{R}{L_0}\right)^{\frac{6}{7}} \exp(1.2\varepsilon - 0.8) \tag{7}$$

Visual analyses of the wave profile videos reveal that the breaker height changes exponentially with distance from top of the seaward breakwater crest, and that the shoreward limit of breaking position on the crest depends mostly on the breakwater porosity ε. Equation (8) is derived from the results with respect to the shoreward distance, x_{NB}, from top of the structure slope to the bound beyond which wave breaking does not occur.

$$\frac{x_{NB}}{B} = 0.5 - 0.75\varepsilon \tag{8}$$

Equation (8) indicates that the breaking position displaces toward the top of structural slope with increasing the breakwater porosity, this results in reduction of the return flow strength over the crest. The wave breaking on breakwater crest depends basically on the permeability rather than roughness of the crest surface.

By taking account of Eqs. (6) and (7), an empirical equation (9) for estimating the position of wave breaking on the crest is determined:

$$\frac{x}{B} = \frac{1}{2}\left[\ \ln\left\{\left(\frac{H_B}{L_0}\right)\left(\frac{R}{L_0}\right)^{-\frac{6}{7}}\right\} - 1.2\varepsilon + 0.8\ \right] \tag{9}$$

This relation refers to as the breaking position index.

Breaking Position or Depth in Zone II

As pointed out by the previous experimental and numerical studies (Rojanakamthorn et al.,1990), we also found experimentally that wave breaking on the seaward structural slope of the breakwater can be described reasonably well by a criterion, similar to Miche (1951) and Hamada (1951). Their criterion can be rewritten by using the dispersion relation of linear waves, as Eq. (10).

$$\frac{H_B}{L_0} = A_m' \tanh^2 (k_B h_B) \tag{10}$$

, in which k_B and h_B are the wave number and water depth at breaking. A_m' is the coefficient determined from the continuity condition of breaker height at top of the seaward structure slope (the boundary between Zones II and III). Using Eq. (7), A_m' is written as·

$$A_m' = [(\frac{R}{L_0})^{\frac{6}{7}} \exp(1.2\varepsilon - 0.8)] \;/\; \tanh^2 (k_R R) \tag{11}$$

, in which k_R is the wave number for the water depth above the crest. Figure 11 displays the range of the minimum and maximum values of A_m' as a function of the porosity ε, within the limits of the experiments. It is noticed from this figure that the value of A_m' in case of $\varepsilon = 0$ is almost the same to Miche's coefficient of A_m'=0.142 for a plane sloping beach.

To confirm applicability of the breaker height index Eq. (10), Fig. 12 shows predicted and measured values of H_B/L_0 as a function of $K_B h_B$. Equation (10) agrees with the measured breaker height on the seaward structure slope.

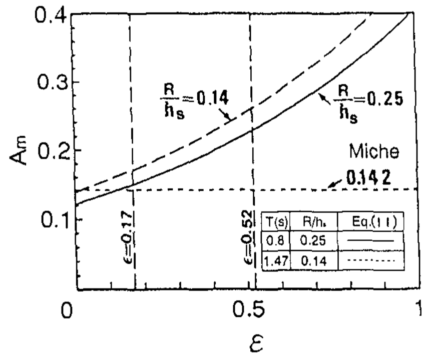


Fig. 11 Relation between A_m" and ε.

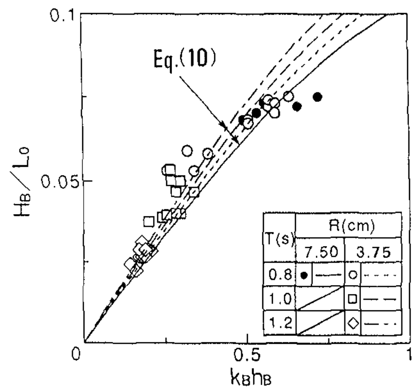


Fig. 12 H_B/L_0 as a function of $k_B h_B$, illustrating the validity of Eq. (10).

Comparisons Between Measured and Calculated Breaker Height over the Breakwater

In the two previous sections, the two additional breaker indices, Eqs. (9) and

(10), have been developed for the breaking zones II and III in order to determine the breaking position. Consequently, substitution of Eq. (3) into Eqs. (9) and (10) yields the distance of breaking position for Zone III and the breaking depth for Zone II, respectively.

Figures 13 and 14 are prepared to confirm this approach. Wave steepness H_B/L_0 at incipient wave breaking over permeable submerged breakwater is shown as a function of the relative distance , x/B, from top of the structure slope. It is noticed that synthetic trends generated by Eqs. (9) and (10) follow observed data trends very well. Discrepancies between predicted and observed values appear to result from variability inhering in the wave breaking.

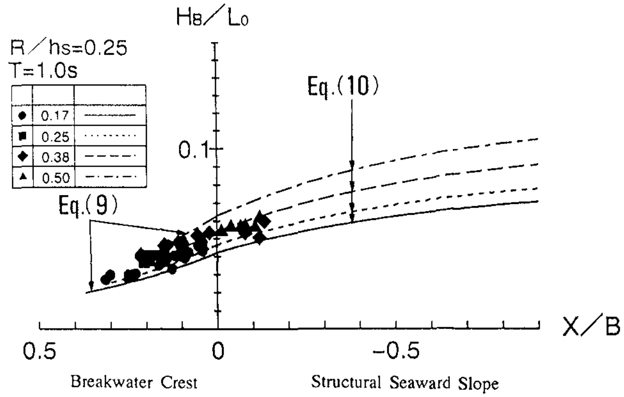


Fig. 13 Variation of H_B/L_0 as a function of x/B.

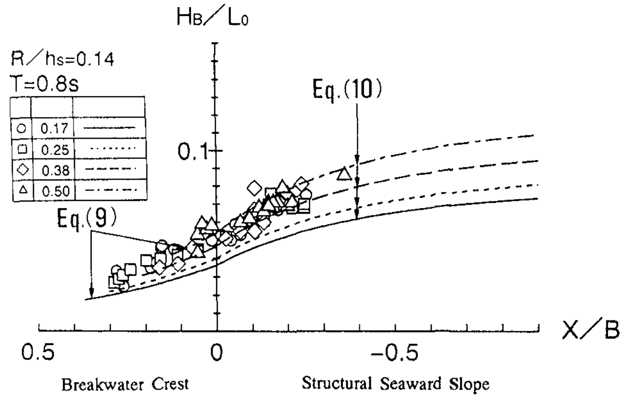


Fig. 14 Variation of H_B/L_0 as a function of x/B.

CONCLUDING REMARKS

A laboratory experiment was conducted to discuss and determine the conditions of incipient breaking over permeable submerged breakwaters. In this study, Brcaking range of waves passing across the breakwater was divided into the three following zones; Zone I: on the offshore sloping beach, Zone II: on the seaward structure slope of the breakwater, and Zone III: on the breakwater crest. Height and position of the breaking wave were examined for each zone, and the breaker height and position indices were developed from measurements.

Main findings are summarized as follows;

(1) Permcability of the submerged breakwater plays an important role in reduction of the strength of return flow over the breakwater. The return flow changes the breaker height and breaking position as well as the breaker type.
(2) The integrated parameter ξ_s'' of Hara et al. (1992) expresses remarkably well synthetic trends of observed data of the wave breaking over the breakwater. The parameter is versatile; it can be applied to cases of wave breaking over barred and reef beaches.
(3) Breaker height and depth for Zone I are calculated from Goda's breaker index, Eq. (1), by changing value of the empirical constant to A=0.15. Breaker height index, Eq. (3), for Zones II and III is determined as a function of ξ_s''.
(4) Additional indices, Eqs. (9) and (10), are developed to estimate the breaking position in Zone III and breakcr depth in Zone II, respectively.

In conclusion, the computation scheme of the breaker height and depth (position) on and around permeable submerged breakwaters is shown as follows;

Zone I: On the offshore sloping beach,
H_B and h_B, calculated from Eq. (1).

Zone II: On the seaward structure slope of the breakwater,

$$Eq.(1)\,|_{h_B=h_S} > \frac{H_B}{L_0}\Big|_{Eq.(3)} \geq Eq.(7)$$

H_B and h_B, calculated from Eqs. (3) and (10).

Zone III: On the breakwater crest,

$$Eq.(7) > \frac{H_B}{L_o}\Big|_{Eq.(3)} \geq Eq.(6)$$

H_B and x_B, calculated from Eqs. (3) and (9).

If wave height calculated from Eq. (3) is smaller than that given by Eq. (6), the wave will pass across the submerged breakwater without breaking.

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