人工 모래톱(ARTIFICIAL REEFS) 設置로 인한 越波量 低減效果

The Effects of Reduction Wave Overtopping Rate by the Use of Artificial Reefs

朴 相 吉*
Park, Sang Kil

要 旨

海岸防災의 새로운 工法으로 인공 모래톱(artificial reef)를 設置하여 海浜의 安定性을 維持하고 海岸을 利用하자는 構想으로 부터, 本論文은 海岸水理學的인 觀點에서 人工 reef의 特性을 밝히고 있다. 人工 reef 先端에서 強制碎波에 의한 碎波後의 波高變化를 豫測하는 model을 確立하고, 人工 reef上에서 波浪豫測의 方法中 波別解析法의 妥當性을 立證했다.

同時에 規則波와 不規則波를 利用하여 越波量 算定에 관한 weir model의 適用性을 檢證하고, 越波量 算定에 있어서 波別解析法을 適用하여, 人工 reef의 設置로 인한 越波量 低減效果를 數値計算과 實驗에 의해서 밝혔다.

Abstract

A wave overtopping rate from a sea dike of various toe depths is formulated based on a weir model in an unidirectional flow. To evaluate the wave overtopping rate from a seadike on an artificial reef by the weir model, a numerical procedure for predicting wave transformations including the effect of forced wave breaking on the reef is constructed. After confirming the applicability of the model by experiments with regular and irregular waves, the effect of artificial reef on wave overtopping is discussed. So-called individual wave analysis method is shown to be applicable to the wave overtopping caused by irregular waves.

1. Introduction

To cope with the wave overtopping over existing seawalls and seadikes, various kind of wave energy dissipating structures such as an offshore detached breakwater, armor blocks and so on have been used. The highest priority has given to the wave energy

*正會員 · 釜山大學校 工科大學 助敎授

dissipating function of these structures and utilization and the view of the coast have been left out of considerations.

In Japan, recently, artificial reef has been widely constructed as a multipurposed coastal structure to control coastal erosion, to reduce wave overtopping and to utilize coastal zone to the best advantage. The artificial reef usually consists of a submerged breakwater with broad crown width and an artificially nourished beach behind it. The main function of the artificial reef is to make incident waves break forcibly and reduce wave energy in the nearshore zone.

The primary objective of this study is to investigate the effects of artificial reef on the reduction of wave overtopping rate over the vertical seadikes when the artificial reef is constructed in front of them.

The wave overtopping rate over the sea walls and seadikes on an uniformly sloping beach has been studied under various conditions. Most results of these studies are analyzed by using wave conditions in deep water and crest elevations from the still water(e. g. Goda(1985)[1] and CREC(1984)[2]). Therefore, the effects of artificial reef on wave overtopping can not be discussed, based on these results because the incident waves in front of the seadikes are greatly altered by the reef.

In this study, I apply the weir model, in which wave heights in front of the seadike and the crest elevation of the seadike from the water level are directly taken into account, to investigate the effect of the reef on wave overtopping. To utilize the model, it is necessary to evaluate wave conditions in front of the seadike.

I also construct a numerical model for a prediction of wave transformation on the reef. After confirming the applicability of

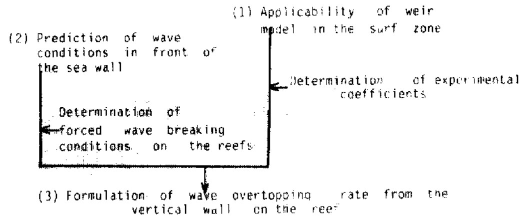

Fig. 1. A block diagram of the study

proposed model by experiments with regular and irregular waves, the effects of the artificial reef on the reduction of wave overtopping are discussed. A block diagram of this study is shown in Fig. 1.

2. Applicability of weir model in the breaker zone and determination of experimental constants of the model

The weir model was originally proposed by Kikkawa et al.(1967)[3] to estimate wave overtopping rate from the seadike in the region where the water depth at foot of seadike is deep enough for incident waves to form clapotis without breaking. They gave the following expression for the wave overtopping rate on the basis of weir discharge in the unidirectional flow :

$$Q=\frac{4\sqrt{2g}}{3}mK^{3/2}Hi^{3/2}\int_{t1/T}^{t2/T}[F(t/T)-\frac{Hc^{3/2}}{KHi}]d(t/T) \quad (1)$$

Where Q is the wave overtopping rate per unit time and width of the seadike, Hi is the incident wave height in front of the seadike, Hc is the crest height from the mean sea water level, η_{max} is the maximum elevation of the surface in front of the seadike, t_1 and t_2 are the times when the surface elevation becomes Hc and F(t/T) is the non-dimensional time variation of the surface elevation, $\eta(t)$, defined by $F(t)=\eta(t)/\eta_{max}$, $K=\eta_{max}/Hi$, Zo is the crest height from the still water level. m is the discharge coefficient ; in this

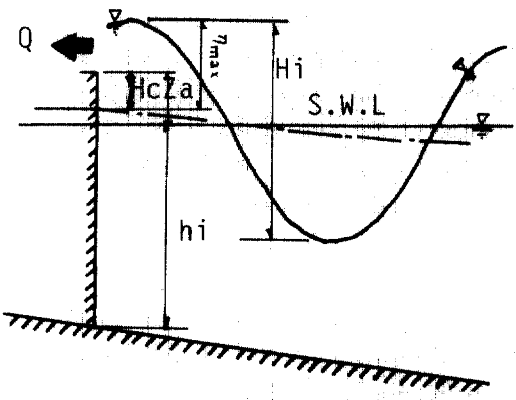

Fig. 2. Definition sketch of wave overtopping

study we assume that m will take the value about 0.5 according to Kikkawa et al.(1967)[(3)].

A definition sketch of wave overtopping together with notation used in this paper is shown in Fig. 2.

To evaluate wave overtopping rate by the model, the following three quantities must be given : the ratio of maximum surface elevation to incident wave height, K, the non-dimensional time variation of the surface displacement, F(t/T), and the incident wave height, Hi. In this tudy, I redefine η_{max} and Hc as the maxium surface elevation and the crest height of the seadikes from the mean water level as shown in Fig. 2 to refine the model. Therefore, besides those three quantities the mean water level, $\bar{\eta}$, is also required.

If I can find universal expression for K and F(t/T), it becomes possible to estimate wave overtopping rate based on the weir model(Eq.(1)). Of course, the incident wave height, Hi, and the mean water level in front of the seadike, shouid be given.

However, it is surely a hopeless work to formulate the non-dimensional time variation of the surface displacement, F(t/T), within the breaker zone. Firstly, I calculated the value of K from Eq.(1) by using the experiment results of wave overtopping rate conducted by many researchers(Ishihara et al. (1960)[(4)], Inoue et al.(1972)[(5)], Kikkawa et al. (1967)[(3)], Tominaga et al.(1970)[(6)], and Inoue (1973)[(7)]. Then, I conducted close investigations of the value of K by assuming that F (t/T) varies sinusoidally.

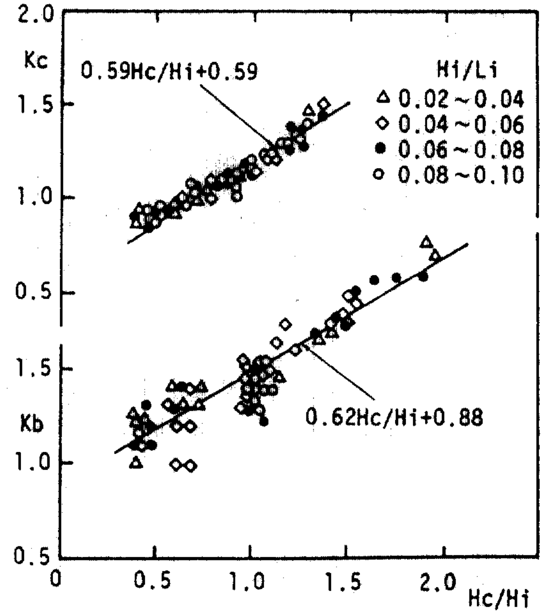

Fig. 3. K vs. Hc/Hi

The results are shown in Fig. 3. The upper part of the figure indicates the results obtained in the cases where clapotis without breaking was formed in front of the seadike. The reason is that the depth at the foot of the seadike was deep. The lower part of the figure shows the results in the cases where seadikes were located in the breaker zone. In the cases where no information about Hi and $\bar{\eta}$ was given, the values were estimated numerically. The detailed procedure for which is described in the following section.

The value of K in the clapotis region is uniquely determined by Hc/Hi and does not depend on Hi/Li where Li is the wave length in front of the seadike. This agrees with the results which have already pointed out by Tsuchiya et al.(1970)[(8)]. The solid line in the

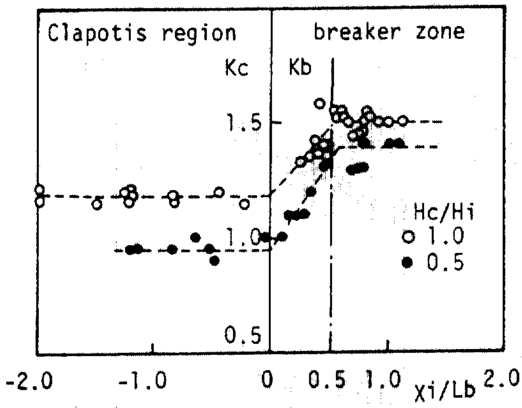

Fig. 4. Variation of K with Xi/Lb

figure is the regression of K in the clapotis region. In this region, K is hereafter referred to Kc, which is expressed by

$$Kc = 0.59Hc/Hi + 0.59 \qquad (2)$$

The value of K in the breaker zone also increases with the increase of Hc/Hi and does not depend on Hi/Li. However, some scatter can be seen when compared with K value in the clapotis region.

Fig. 4 illustrates examples of variation of K value in the breaker zone with the relative location of seadikes to the wave breaking point to investigate the reason of the scatter of K value in the breaker zone(Park et al. (1987))[9]. Xi in the horizontal axis is the relative distance between the location of seadikes and wave breaking point and is taken positive onshore wards. Lb is the wave length at the wave breaking point.

It is found that K is constant in the region of Xi/Lb<0 and Xi/Lb>0.5 in Fig. 4.

However, in the region of 0<Xi/Lb<0.5, K increases with an increase of Xi/Lb.

Sawaragi et al.(1986)[10] have already pointed out that when the vertical wall is located in the region of Xi/Lb<0, which is offshore region of the wave breaking point, clapotis without breaking forms in front of the wall. when it is located in the region of Xi/Lb>0.6, waves after breaking attack it. When the vertical wall is located in the region between 0<Xi/Lb<0.6, clapotis with breaking at the loopforms. The variation of K value with the change of Xi/Lb appears in Fig. 4 coincides with these situation of wave fields in front of the seadikes. However, the reason for the increase of K value in the region of 0<xi/Lb <0.5 is not found out.

A solid line in the lower part of Fig. 3 is the regression line of K calculated in the cases where Xi/Lb>0.5.

Hereafter, I refer K in this region as Kb, which is given by

$$Kb = 0.62Hc/Hi + 0.88 \qquad (3)$$

The value of K in the region where 0<Xi /Lb<0.5 becomes a function of Xi/Lb and can be evaluated by

$$K = 2(Kb - Kc)\ (Xi/Lb) + Kc \qquad (4)$$

3. Numerical model for the prediction of wave transformation on the reef

A series of experiment were carried out to investigate wave transformation including forced wave breaking on the reef. Based on the experimental results, a numerical model for predicting wave transformation on the reef was constructed.

3. 1 Two-dimensional experiments of the wave transformation on an artificial reef

Experiments were carried in a wave tank of 30m long, 0.7m wide and 0.9m high. An artificial reef made of polywood was placed on a model beach with a slope of 1/30. The slope of artificial reef was determined at 1/30 as suggested in the manual on the utilization of sandy beach(Port and Harbor Bureau (1979))[11]. The offshore slope of the reef was 1/2.

A sketch of the artificial reef used in the experiments is given in Fig. 5 together with the notation used in the following descriptions

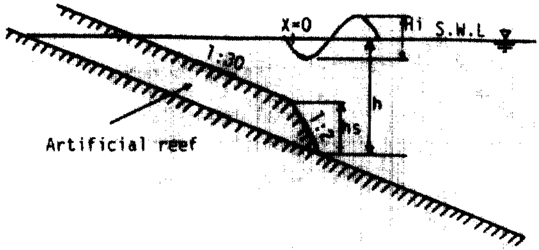

Fig. 5. Sketch of artificial reef used in the experiments

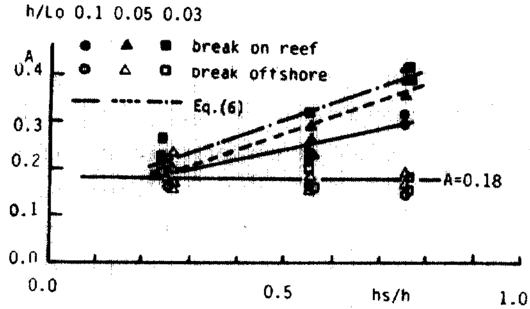

Fig. 6. Relation between A and hs/h

A water depth at a toe of the reef, h, was kept constant at 10cm and reefs of different relative heights of reefs($hs/h=0.25$, 0.55 and 0.75) were used. Periods of experimental waves were $T=0.8$sec, 1.1sec and 1.4sec. Wave heights at the toe of the reef, Hi, were adjusted to be $Hi/h=0.5$, 0.5*, 0.75, 0.75* and 0.9 where* indicates the case where waves had broken before they reached the toe of the reef. All the waves which reached the toe of the reef without breaking broke forcibly on the offshore slope of the reef. A breaker type of these waves was a typical plunger.

Water surface elevations were measured with six capacitance type wave gauges at an interval of 5 to 10cm around the artificial reef. The analogue output signals were digitized at the time interval of 1/20 sec. Mean water levels and wave heights were calculated from these digital data. A reflection coefficient was also calculated by the method proposed by Goda(1985)[1] to be 0.15 at maximum.

3. 2 Condition for forced wave breaking on an artificial reef

When waves reach an artificial reef, they break owing to an abrupt change in water depth. In this section, the condition for wave breaking on the artificial reef is investigate by applying Goda's breaking criterion(Goda (1985)[1], which explicitly takes into account the effect of bottom slope :

$$Hb/Lo = A[1-exp(-1.5(1+15\tan^{4/3}\theta)\pi h_b/Lo)] \quad (5)$$

Where Hb and h_b are the wave height and the water depth at the breaking point, Lo is the wave length in deep water, $\tan\theta$ is the bottom slope and A is the coefficient which will take the value between 0.12 to 0.18 for the waves which break on an uniformly sloping beach.

The applicability of Eq.(5) to the wave breaking on the artificial reef was examined by evaluating the coefficient A in Eq.(5) from measured Hb and h_b, where $\tan\theta$ was assumed to be the slope of the artificial reef(1/30). The results are shown in fig. 6. Open circles (○) in the figure indicate the cases of offshore breaking ; in this cases, the value of A shows almost constant(0.18). However, when waves breaker on the reef, A value increases with the relative height of the reef, hs/h, as shown by closed circles(●) in the figure. It is also seen that the value of decrease with increasing relative water depth at the toe of the reef, h/Lo.

From these results, the following approximate expression is obtained under the condition of $0.25<hs/h<0.75$ and $0.03<h/Lo<0.10$:

$$A = (-2.18h/Lo + 0.45)hs/h + 0.17 + 0.21h/Lo \quad (6)$$

The values of A estimated from Eq.(6) are also shown in Fig. 6.

3. 3 Applicability of the bore model on an artificial reef

Some examples of wave height distributions measured in the experiments are shown in Fig. 7 to 9 for the case of T=1.1sec and h/Lo=0.05. Fig. 7 and 8 correspond to the cases where incident waves broke on the offshore slope of the reef or on the reef. Fig. 9 represents the case where incident waves broke off the reef. In these figures, (a), (b) and (c) indicate the cases of hs/h=0.25, 0.55 and 0.75, respectively.

The decay of wave height after breaking in the figures becomes more rapid when the reef is higher regardless of the value of Hi/h.

The author applied the bore model to predicting the wave height and mean water level on the reef. The wave height in the offshore region was calculated by using the shoaling coefficient formulated by Shuto (1974)[12]. The wave height within the breaker zone was estimated from the bore model with the energy dissipation rate proposed by Mase et al.(1982)[13]. In the calculation, equations of energy flux conservation and time and vertically averaged momentum flux and mass flux.

Conservations were reduced to a system of difference equations and solved iteratively until the stable solutions are obtained.

The grid spacing was taken at 1/400 to 1/800 of the incident wave length to determine the breaking point exactly from Eq.(5) and Eq.(6).

Calculated wave heights are shown by the solid lines in Figs. 7 to 9. In the cases that the reef is relatively low(hs/h=0.55), predicted wave heights agree well with the measured wave heights. When the reef is relatively high(hs/h=0.75), the wave heights

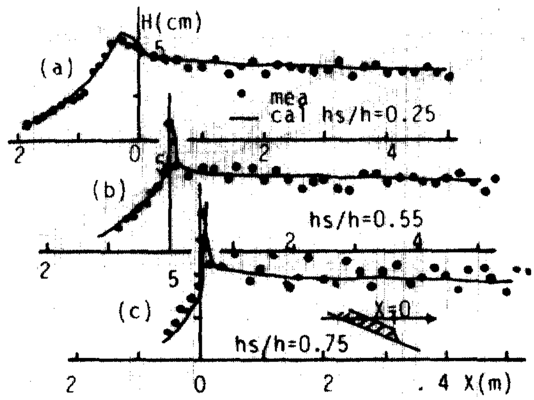

Fig. 7. Wave height distributions on the reef (Hi/h=0.5)

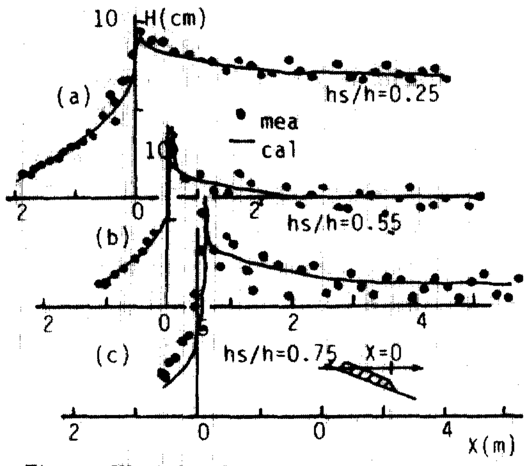

Fig. 8. Wave height distributions on the reef (Hi/h=0.9)

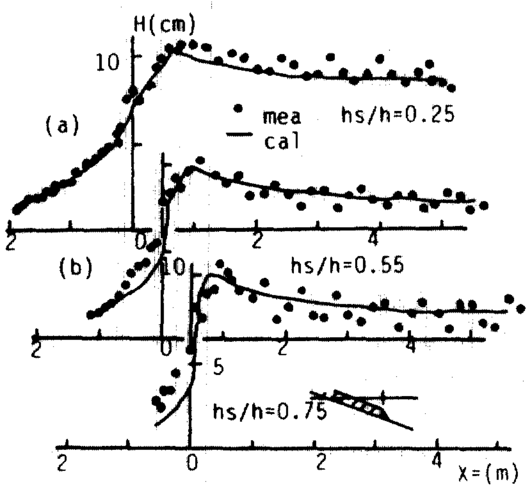

Fig. 9. Wave height distributions on the reef (Hi/h=0.75)

after breaking are slightly underestimated.

4. Wave overtopping rate from the seadike on the reef

Now, I was obtained all information to predict wave overtopping rate from the vertical seadike on the artificial reef.

In this section, the applicability of proposed procedure for predicting wave overtopping rate on the reef is examined by experiments.

Experiments were carried out in the same wave tank as used in the experiments of wave transformations. Horizontal reef set on the model beach with the slope of 1/30 was used and wave overtopping rate from the seadikes on various locations on the reef was measured. A water depth on the reef, hs, was varied between 4 cm to 8 cm and experimental waves of deep water wave heights, Ho, and periods, T, between 7cm to 11cm and 1.0sec to 1.5sec were used. Whereas, the height of the reef, hs, was kept constant (10cm).

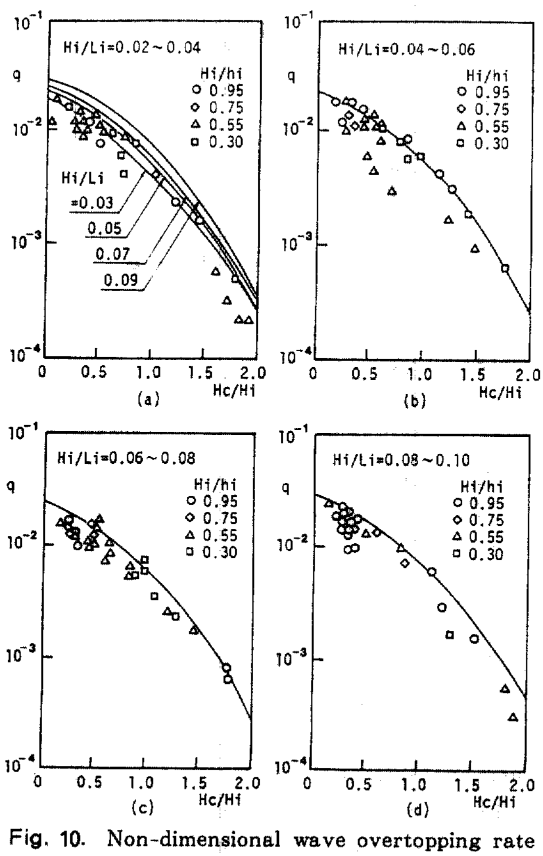

Fig. 10. Non-dimensional wave overtopping rate from the seadike on the reef

The total number of experimental runs was 150 in which the relative crown height of the seadike, Hc/Hi, ranged 0.3 to 2.0. The location of seadike, Xi/Li, was varied from 0.0 to 3.0, where Xi is the distance between the shoulder of the reef and the seadike and Li is the length of incident waves on the reef. In all the cases, all the incident waves broke forcibly on the shoulder of the reef.

Fig. 10 shows the comparison between measured and calculated non-dimensional wave overtopping rate, q,

$$q=\frac{Q}{\sqrt{gLiHi}} \tag{7}$$

Solid lines in the figure illustrate q estimated by Eq.(2). From the figure, it is found that measured wave overtopping rate decreases rapidly with the increase of Hc/Hi. It is also seen that predicted q covers upper limit of measured q and increases a little with Hi/Li.

This implies that the procedure for the prediction of wave overtopping rate from the seadike on the reef is adequate.

5. Effect of the artificial reef on wave overtopping

The applicability of model to the wave overtopping by the irregular waves is examined by conducting experiments on the assumption of actual state.

Further, the effect of artificial reef constructed in front of existing seadikes on wave overtopping in the irregular field is also discussed.

The experiments were conducted in the same wave tank as used in the previous two experiments. The slope of model artificial reef was 1/30. The length of reef, B, was 0.5, 1.0, 1.5 and 2.0m and the height of the reef, hs, was 4.5 and 7.0cm.

Experimental waves generated numerically to have Pierson≃Moskowitz spectrum were used. Significant wave period, Ts, was 1.21 sec and significant wave heights, Hso, in deep water were 8cm in the case of hs=4.5cm and 9.3cm in the case of h=7cm. the crown height of the seadike, Zo, from the still water level was adjusted to be Zo/Hso=0.5−0.6.

To predict wave overtopping rate by irregular waves, so-called "individual wave analysis method" is applied. That is, each volume of wave overtopping, q_k, brought about by individual waves which are defined by the zero-up-cross method in the irregular wave train is calculated from Eq.(2). Then, the time averaged wave overtopping rate, $\overline{Q}$, is estimated by summing up, q_k, as given by Eq.(8).

$$Q=[\sum_{K}^{N}(q_k\sqrt{g}H_k^2\, L_k T_k)]/(\sum_{K}^{N}T_k) \qquad (8)$$

Where N is the number of waves reached at the seadikes during the measurement of wave overtopping, $H_k L_k$ and T_k are the height, the length and the period of k-th wave respectively. The value of q_k in Eq(8) indicates the predicted volume of wave overtopping caused by k-th wave.

The individual wave analysis method for irregular wave transformation on the reef is applied on the assumption that there is no interaction between individual zero-up-crossing waves. This kind of analysis of irregular wave transformation on uniformly sloping beach has already been carried out by Mase et al.(1982)[13].

As mentioned before, wave overtopping rate depends on both Hc/Hi and Hi/Li. The joint distribution of wave height and period was given as a boundary condition at the offshore of the reef. To determine the wave breaking points of individual waves, Eq(5) and (6) are used. Based on these results, q_k caused by each wave is calculated by using empirical expression of K(Eqs. (2)−(4)).

Fig. 11 shows the comparison between measured and predicted time averaged wave overtopping rate on the reef by irregular

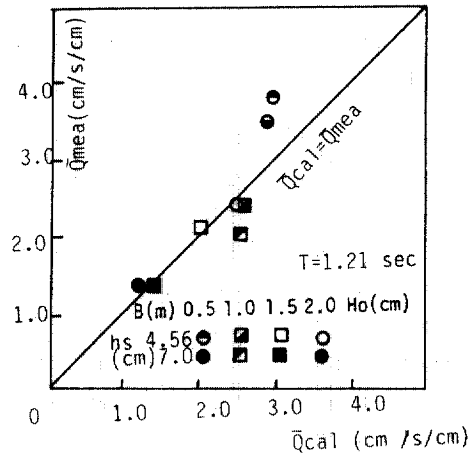

Fig. 11. Comparison of measured and estimated time averaged wave overtopping rate on the reef by irregular

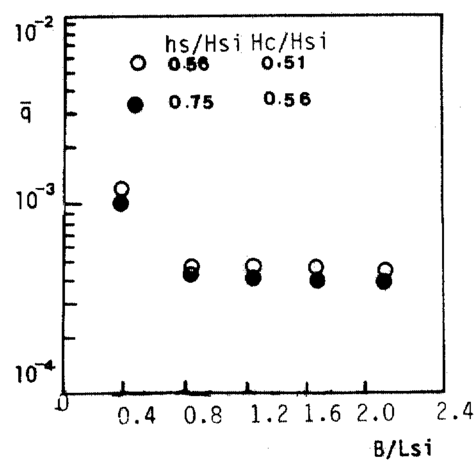

Fig. 12. Non-dimensional wave overtopping rate vs. non-dimensional length of artificial reef

waves. I can be judged that model can also applicable to the wave overtopping from the seadike on the reef by irregular waves.

Finally, Fig. 12 indicates the effect of length of the artificial reef on the reduction of wave overtopping. The vertical axis is normalized time averaged wave overtopping rate $\bar{q}(=\bar{Q}/\sqrt{gHsi^2\ Lsi})$ and the horizontal axis is the nondimensional length of ithe artificial reef, B/Lsi, where Hsi and Lsi are the significant wave height and length in front of the seadike. It can be seen that $\bar{q}$ decreases rapidly in the region of B/Lsi<0.8 and becomes almost constant beyond that range of B/Lsi.

When the artificial reef was constructed in front of the seadike, relatively large waves in the irregular wave train broke forcibly and number of higher waves of the wave train which reached in front of the seadike decreased.

Characteristics of the incident waves and dimensions of the reef determine the maximum waves which can transmit on the reef without breaking. However, the number of the waves which broke forcibly on the reef decreased with the increase of the length of the reef because the depth at the shoulder of the reef became deep. In such cases, the effects of the artificial reef appears in the point that it merely decreases the depth at the foot of the seadike.

This is the implication of the change of $\bar{q}$ shown in Fig. 12. In the case shown in Fig. 12, it can be said that the effective length of the artificial reef to break large waves significantly corre-sponds to 0.8*Lsi.

6. Conclusions

A procedure for estimating a wave overtopping rate from a seadike on an artificial reef is proposed, based on a weir model in an unidirectional flow by assuming that the surface displacement in front of the seadike varies sinusoidally. In the procedure, the crown height and the maximum surface elevation from the mean water level, and the incident wave height in front of the seadike are required to calculate the wave overtopping.

Among these, empirical expression for the ratio of the maximum surface elevation to the incident wave height is given as an increasing function of the ratio of the crown height to the incident wave height and mean water level in front of the seadike can be estimated numerically by using empirical criterion for the forced wave breaking on the reef proposed in the study.

So-called "individual wave analysis method" is applicable for the estimation of the wave overtopping rate in the irregular wave field.

It is also found that when the height of the reef in front of the seadike is given, a proper length of the reef exists to reduce the wave overtopping.

Reference

1. Goda, Y. "*Random seas and design of maritime structures*," Univ. of Tokyo Press, 1985, pp. 323−329.
2. Coastal Engineering Research Center, "*Shore Protection Manual*," Vol. 2, 1977, pp. 1−56.
3. Kikkawa, H., H. Shiigai and F. Khono, "Fundmental study on wave overtopping on seawall *14th Japanese Conf. on Coastal Eng.* 1967, pp. 118−122.
4. Ishihara, T., Y. Iwagaki and H. Mitsui, "Wave overtopping seawall," *Coastal Engineering in Japan*, 1960, Vol. 3, pp. 53−62.
5. Inoue, M. and T. Kikuoka, "Effect of bottom topography in front of the seadike on wave overtopping," *Proc. 19th Japanese Conf. on Coastal Engl.*, 1972, pp. 283−268.

6. Tominaga, M. and H. Hashimoto, "Wave overtopping on the seadike due to irregular waves," *Proc. 18th Japanese Conf. on Coastal Eng.*, 1970, pp. 265－268.
7. Inoue, M, "Mechanism of wave overtopping," *Proc. 20th Japanese Conf. on Coastal Eng.*, 1973, pp. 107－112.
8. Tsuchiya, Y. and M. Yamaguchi, "Characteristics of standing waves with wave overtopping," *Proc. 17th Japanese conf. on Coastal Eng.*, 1970. pp. 79－84.
9. Park, S. K, T. Sawaragi, I. Deguchi and Y. Inoue, "Effects of zonal protection system on the reduction of wave overtopping rate," *Proc. 34th Japanese Conf. of Coastal Eng.*, 1987, pp. 526－530.
10. Sawaragi, T., I. Deguchi and G. P, Hong, "Effect of rubble mound foundation of composite type breakwater on reduction of reflection," *Proc. 5th ADP-IAHR* 1986, pp. 361－368.
11. Port and Harbor Bureau, Min. of Transport, Japan, "*Manual of the construction of artificial reefs*," 1979, pp. 110.
12. Shuto, N, "Nonlinear long wave in the channel of variable section," *Coastal Eng. in Japan*, 1974, Vol. 17, pp. 1－12.
13. Mase, H and Y. Iwakaki, Wave heights distribution and wave grouping in the zone," *Proc. 18th ICCE*, 1982, pp. 58－76.

(接受 : 1989. 2. 8)