CHAPTER 23

WAVE RUN-UP AND OVERTOPPING ON COASTAL DIKES

by

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ABSTRACT

The experimental results of wave run-up and overtopping on coastal dikes with a steep seaside slope are presented. Wave run-up heights are calculated by regarding to the crest height of standing wave in none breaking zone and to the reflected bore height in breaking zone. The calculated values indicate good agreement with the experimental results. As for wave overtopping, the experimental results are mainly discussed with regard to the effect of wave breaker to overtopping phenomena.

INTRODUCTION

As for wave run-up and overtopping, a number of experimental studies have been carried out. But it seems that the data will not be sufficient with regard to the dikes with rather steep seaside slope. In Japan most of coastal dikes have steep seaside slope, such as nearly vertical, 1:05, 1:1 and so on. In this paper we present the experimental data of wave run-up and overtopping which have been obtained by the model test on coastal dikes with steep slope and discuss the several characteristics of the phenomena.

In front of dikes, there take place three types of wave; those are standing wave, partial standing wave, and breaker. Wave run-up and overtopping on coastal dikes will have close relation with the profile of standing wave in non-breaking zone, with the water depth in breaking zone, and also with the profile of partial standing wave in the intermediate zone.

S. Sato and T. Kishi (1954) made an analysis of wave run-up coastal dikes on the basis of the nearly same consideration as above stated. We have also made the detail analysis of the experimental results, and confirmed that wave run-up height will be predicted by the crest height of standing wave in non-breaking zone and the reflected bore height in breaking zone.

Concerning wave overtopping, we mainly discuss the effect of wave breaker on the phenomena. (Profile of wave breaker is shown in Fig.3) In Japan such a problem has been especially discussed after the occurrence of the damage due to

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the Ise-Wan Typhoon which hit Japan in 1959. It seems that the phenomena of wave overtopping have also close relation with the characteristics of water in front of dikes, but the phenomena should be complicate, and the precise analysis is still very difficult. As to this point, further investigation will be necessary.

EXPERIMENTAL PROCEDURES

The wave channels for the model tents are one of 112m long, 1.6m wide and 2.5 deep for wave run-up study and one of 35m long, 0.6m wide and 1.5m deep for overtopping study. The test condition are shown in table 1. (figures 1 and 2)

The models of beach and dike were made of wood. In order to investigate the effect of wave breaker of a dike on the phenomena of overtopping, two types of dikes were tested. The one with a wave breaker of 7.5cm in radius (type-II) and the other without a wave breaker (type-I) as shown figure 4.

The height and the period of incident wave were measured by resistance type wave gauges and recorded by pen-oscillographs. To measure the height and length of wave after breaking, 8mm cinecameras were used. The wave set-up was measured by a siphon arrangement (figure 3) and a resistance type level gauge. The measurement of the volume of overtopping water were made by a chest installed at the back of the dike.

WAVE CHARACTERISTICS IN FRONT OF COASTAL DIKES

There are two different types of run-up or overtopping waves, i.e. breaking and non-breaking. The breaking waves may be classified into two types: that which breaks before reaching the dike and that which breaks on or against the dike. These two types of breaking waves are distinguished by the breaking condition of standing wave and progressive wave. At first we investigate the breaking condition of progressive wave experimentally.

Many experimental and theoretical results have already been obtained on the breaking condition of progressive wave. In this study experiments were carried out for the breaking condition on 1:20 and 1:30 slope of beach as shown in figure 5. The experiments indicate that breaker index can be applied to the breaking condition of progressive wave.

However, regarding the breaking condition of standing wave formed in front of a dike, we have little information of the relationship between breaking condition and deep water wave characteristics. In order to estimate this relation experimentally, the measurements of standing wave height, its length and water depth in front of a dike were made, installing the vertical wall on 1:20 beach slope. These data are shown for the cases when the wave had not yet broken or had just broken. Figure 6 shows the experimental relationship of H/L and h/L for breaking wave and non-breaking wave. In this figure, H, L and h are the wave height, length and the depth of water respectively. It can be seen from figure 6 that Kishi's equation can be applied to the wave in front of dike. It is necessary to obtain the relationship between deep water wave characteristics and breaking condition. And it was investigated experimentally.

The changes of height and length of wave according water depth are shown in figure 7. These results are similar to the changes represented by the breaker index or the small amplitude theory.

Using Kishi's breaking condition of standing wave and breaker index or small amplitude theory, the relation between breaking condition and deep water wave is estimated here. Figure 8 shows a good agreement between the experimental results and calculated values. In order to estimate the deformation of wave height and its length according to the change of depth, it is possible to use the higher order solution. For example, the third order solution of standing wave by Tadjakhsh and Keller[3] leads the wave length as figure 8. In this figure, L_A is represented as follows:

$$L_A = L_0 \tanh \frac{2\pi h}{L_A}$$

where L_0 is the wave length in deep water.
In figure 9, H_0 and h_b are the wave height in deep water and the depth of water at breaking point. In figures 7 and 9, the wave height H is taken as a half of the measured value and is equivalent to the wave height of progressive wave.

WAVE RUN-UP

Run-up height is affected by the wave characteristics in front of dike. First we consider the wave run-up on a vertical wall and investigate the relation between run-up and wave characteristics. Second we treat the run-up on sloping dike.

Wave Run-up on vertical wall

For the region of standing wave, the wave run-up height may be equal to the crest elevation of standing wave above still water level. In order to estimate the relation between the crest elevation of standing wave and the deep water wave height and its length, it is necessary to know the change of the crest elevation with depth change. The second order solution of standing wave by Hamada[4] gives the height of the middle elevation of wave above still water level as follows:

$$\delta = \frac{A^2}{8} k(3\coth^2 kh - \coth kh + 2\coth 2kh) \qquad (1)$$

where δ : the height of the middle elevation above still water level, $k=2\pi/L$, A: amplitude of standing wave. According to Sainflou's equation, this height is expressed as follows:

$$\delta = 2kA^2 \coth kh \qquad (2)$$

Figure 10 shows the experimental results with the curves by equation (1) and (2). The experimental results are about 60% of the value from the equation (1), but the agreement with Sainflou's equation is not good. Taking account of the calculations by equation (1), it is possible to determine the wave

run-up height in the range of standing wave. The results of calculation are shown in figure 11, where R is the wave run-up height above still water level. In this case, the changes of wave height and its length with that of water depth are calculated by the small amplitude theory.

In the range of breaking wave, if the velocity distribution is assumed as constant vertically, the wave run-up may be considered as the reflection of a bore. The wave height after breaking may be determined by the water depth at the point and was measured on 1:20 and 1:30 beach slope as shown in figure 12. The experimental values are scattered because of the errors of measurement and the variation of wave height caused by turbulent water. In this paper, we treat approximately this relation as follows:

$$H = 0.78\ h. \tag{3}$$

Using equation (3) and Stoker's[5] relation, the reflected bore height above still water level is shown as follows·

$$R = 2.5\ h \tag{4}$$

where h is the water depth at the toe of dike.

This relation is applied to the case that the depth at the toe of dike is shallower than the breaking depth of progressive wave. From the equation (4) the wave run-up height is obtained and shown in figure 11. The breaking condition of progressive wave is represented by the solitary wave theory.

If the water depth is very small, the mean water level raises by the action of wave. According to the research by Longuet-Higgins and Stewart,[6] the depression of mean surface level (ζ) at breaking point was estimated as follows:

$$-\zeta = \frac{\pi}{2}\frac{H_b^2}{L_0}\cdot F\left(\frac{2\pi h}{L_0}\right)$$
$$F\left(\frac{2\pi h}{L_0}\right) \doteqdot \frac{1}{8\left(\frac{2\pi h}{L_0}\right)^{3/2}}, \qquad \frac{2\pi h}{L_0} \ll 1 \tag{5}$$

The comparison between experimental results and equation (5) is shown in figure 13. It is seen that the trend of the experiments is similar to that of the theoretical curve but the depression of the mean water level is greater than that predicted.

If the wave is in shallow water and is limited in height by breaking, wave set - up is predicted that

$$\frac{d\zeta}{dx} = -Q\frac{dh}{dx} \tag{6}$$

where Q is quantity of the order of 0.2, x is distance.

The measurements of mean surface level were carried out and the results indicate that the constant Q is 0.1 for 1:30 slope and 0.15 for 1:20 slope. This difference is caused by the difference of the energy dissipation in surt zone.

From the results stated above, the set-up at shore line is estimated and shown in figure 15. Then wave run-up at $h = 0$ is indicated that

$$R = 3.5\zeta \tag{7}$$

Figure 16 shows the experimental results and it may be seen that they differ slightly from the calculated values except the maximum of R/H_0. This difference occures in the case when the breaking wave is of standing wave type and it splashed at the wave crest. The calculated values of R/H_0 are compared with the experiment in figure 17. It may be seen that the agreement of them is fairly good.

Wave run-up On sloping dike

The result in the previous paragraph may be applied to the vertical or nearly vertical wall. It is interesting to investigate the limit of validity of this calculation and to estimate the effect of the slope of dike. As the slope becomes gentle, the wave characteristics in front of the dike changes and waves break on the slope. In the region of standing wave, the run-up becomes higher by surging, but, in the region of breaking wave, it becomes lower. Figure 18 shows the experimental results on various slope from 1:0.5 to 1:3 set on the beach slope of 1:20 and 1:30. The effect of the slope of dike appears with the increase of the depth of the toe. As shown in figure 19, when h/L_0 is 0.01, the effect can not be seen, but when h/L_0 is 0.05, it appears.

The effect of beach slope

As shown in figure 17 the effect of beach slope may be negligible when the water depth at the toe is sufficiently deep. However, $h/L_0 = 0$, the difference of R/H between the beach slope of 1:20 and 1:30 is obvious, see figures 17(a) and 17(b). Figure 19 shows the effect for the beach slope of 1:17[8], 1:20, 1:30 and 1:60[7] with the structure's slope of 1:2 and $h/L_0 = 0.01$. It is shown from this figure that the effect is negligible if the relative water depth h/L_0 is deeper than 0.01.

WAVE OVERTOPPING

The results of the experiment are shown in figure 20 in which the parameter H_c/h shows the effect of the height of dikes. (H_c; the height of the crown of dike above the still water level)

From the figure we can see the facts as follows;

The maximum values of run-up height and overtopping water occur at the same value of steepness H_0/L_0 and shallowness h/L_0; the maximum volume of overtopping water occur when wave breaks just at the front of dikes. The fact above suggests that the overtopping phenomena will be related to the type of wave in front of dikes as in the case of wave run-up.

The volume of overtopping varies largely with a change of steepness as shown in the figures. This cause that the relative height of coastal dikes H_c/H_o will vary with the change of steepness. The increase of the relative height makes the volume of overtopping water decrease sensitively.

The volume of overtopping water of the dike type-II is less than that of the dike type-I when they are in the same conditions. This represents the effect of a wave breaker.

The difference of the volume in these two types of dikes is notable when H_c/h takes bigger value. When H_c/h is large, waves run up to the top of dike along the slope of it and get back due to the wave breaker describing a parabola in the air. In this case the volume of overtopping water decreases considerably. On the contrary the action of a wave breaker will be not so effective when H_c/h is small, because in this case a wave breaker may be nearly submerged under the wave action.

Although a dike has a wave breaker and the volume of overtopping is little, conciderable quantity of water jumps up above the top of dike and when we try a case with wind blowing, the effect of a wave breaker will become less effective.

It seems that the overtopping phenomena will be related to the types of waves in front of dikes as stated before. But the phenomena is very complicate and further investigation will be needed.

CONCLUSIONS

From the series of experiments on wave run-up and overtopping, it may be concluded:

(1) For the standing wave, the run-up height is equal to the crest elevation of standing wave. The calculation can be made from the second order solution by Hamada.

(2) For the breaking wave, the run-up height is equal to the reflected bore height that is $R = 2.45\ h$.

(3) If the depth at the toe of dike is very small, the wave set-up must be considered.

For the dike with steep slope, there is a good agreement between the experimental value and the calculation except for the maximum of R/H_o. If the relative water depth h/L_o is deeper than 0.01, the change of beach slope gives no effect on wave run-up.

(4) The maximum values of run-up height and overtopping water occur at the same value of steepness H_o/L_o and the relative depth h/L_o.

(5) The volume of overtopping water varies sensitively with the relative height H_c/H_o as well as the steepness H_o/L_o.

(6) The effect of a wave breaker is notable when H_c/h is small.

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4) Hamada, T. : The secondary interaction of surface wave, Proc. 11th Conf. Coastal Eng. in Japan 1964. (in Japanese)

5) Stoker, J.J. : Water waves, 1957.

6) Longuet-Higgins, M.S. and R.W. Stewart, : Radiation stress and mass transport in gravity waves, with application to "surfbeats." J. Fluid Mech., 13, 1962.

7) Tang, F. : The wave run-up after breaking, Proc. 10th Conf. Coastal Eng., 1963. (in Japanese)

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Table 1 Experimental Condition

	Beach slope	Seaside slope of dikes	H_0/L_0	h/L_0
Run-up	1/20, 1/30	vertical, 1 : 0.5, 1 : 1 1 : 2, 1 : 3	0.006 ~ 0.06	0 ~ 0.1
Overtopping	1/30	1 : 1	0.01 ~ 0.1	0.03 0.05

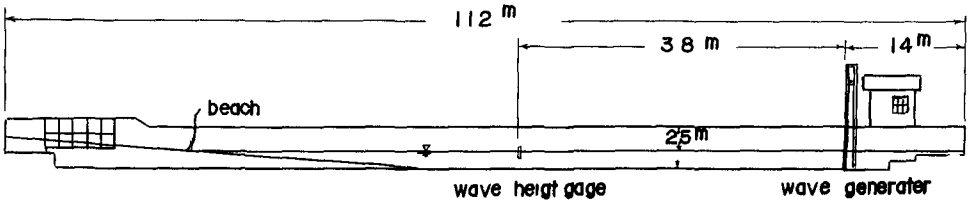


Fig 1 Wave channel

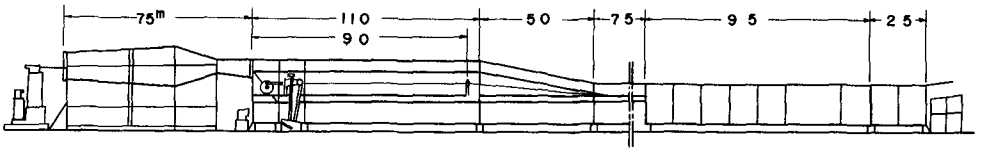


Fig 2 Wave Channel

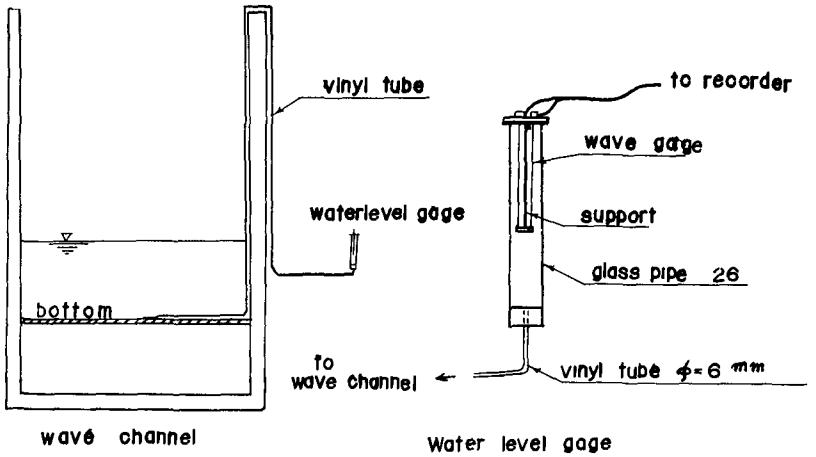


Fig 3 Siphon arrangement

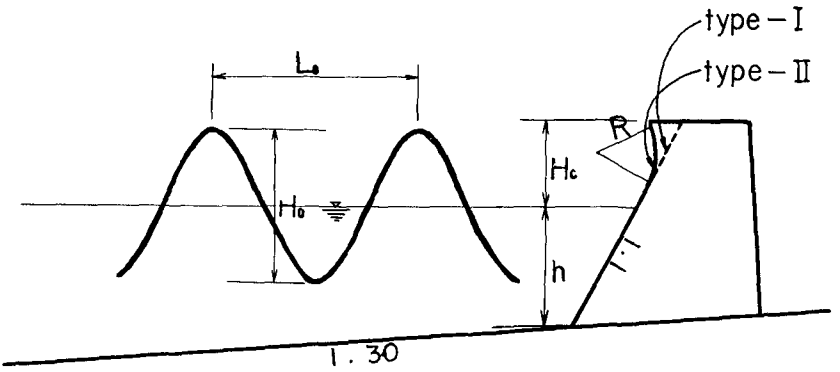


Fig 4 Dikes used in the overtopping experiment

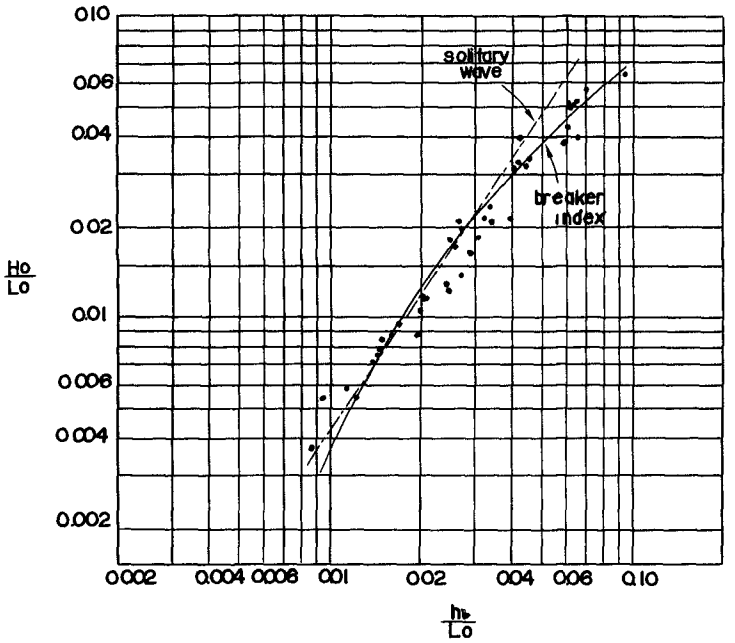


Fig 5 Breaking condition of progressive wave

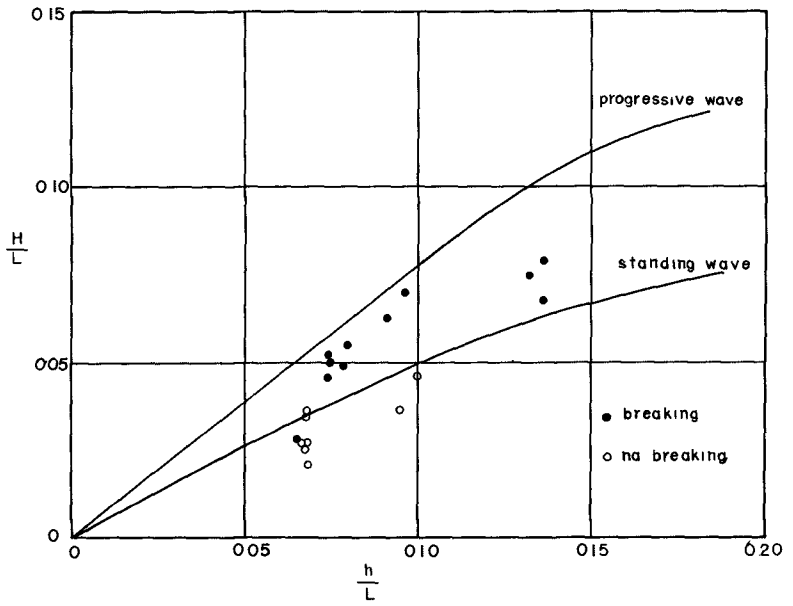


Fig 6 Kishi's breaking condition of standing wave

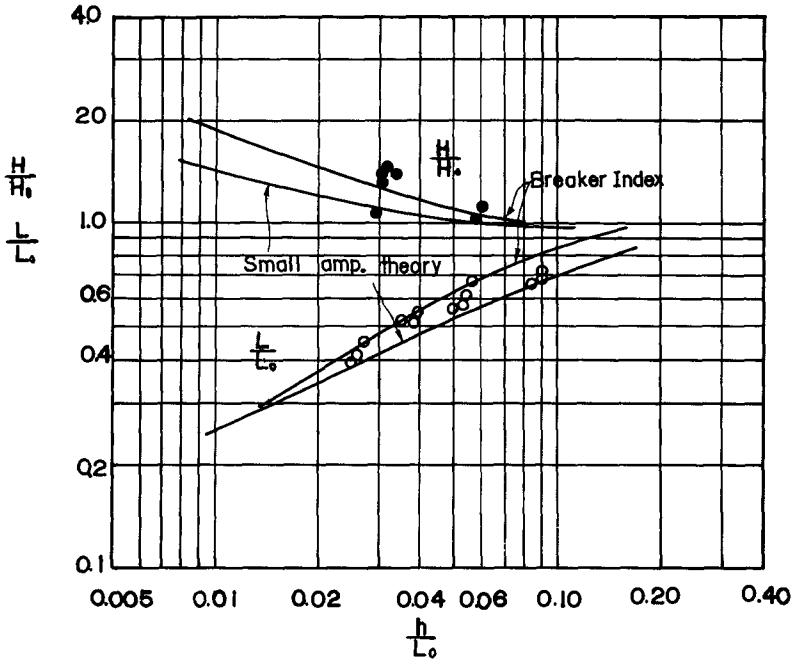


Fig 7 Wave height and length of standing wave

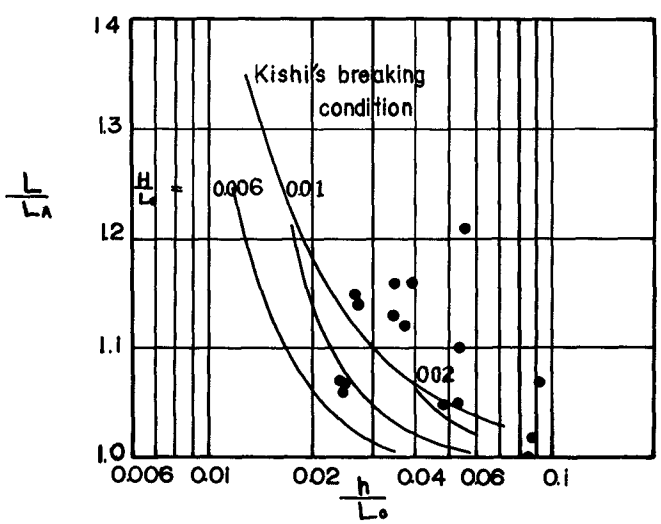


Fig 8 Wave length of third order solution

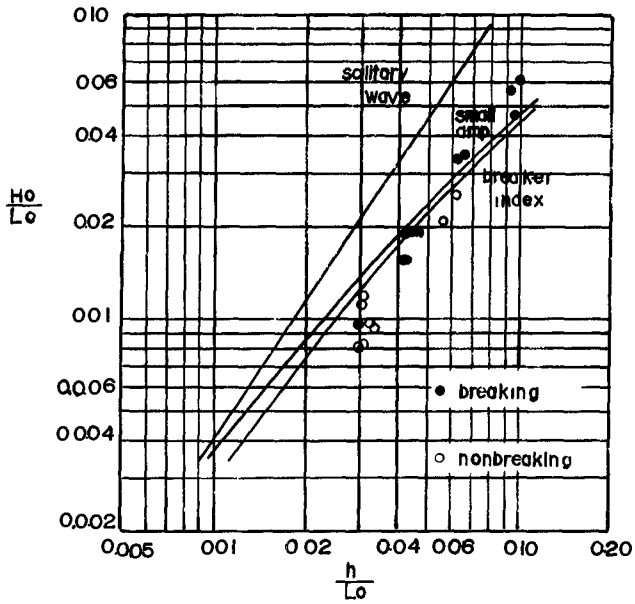


Fig 9 Breaking condition of standing wave

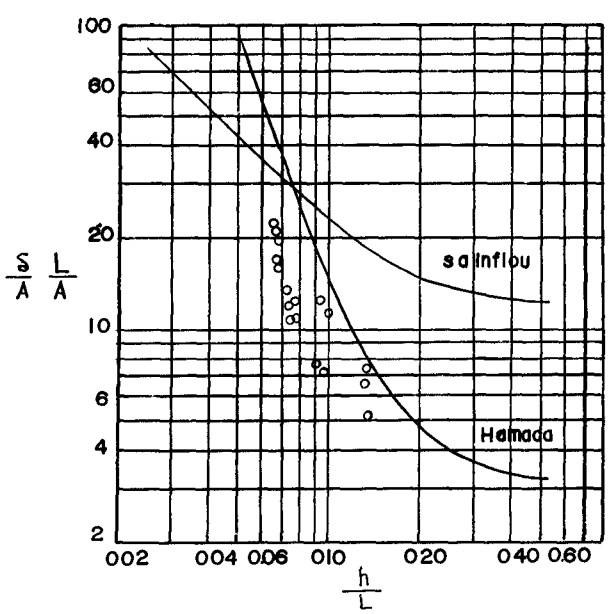


Fig 10 Height of the middle elevation above still water level

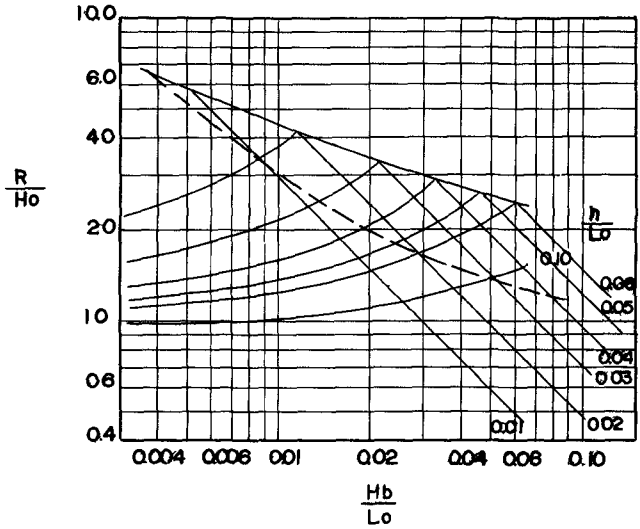


Fig 11 Run-up on vertical wall

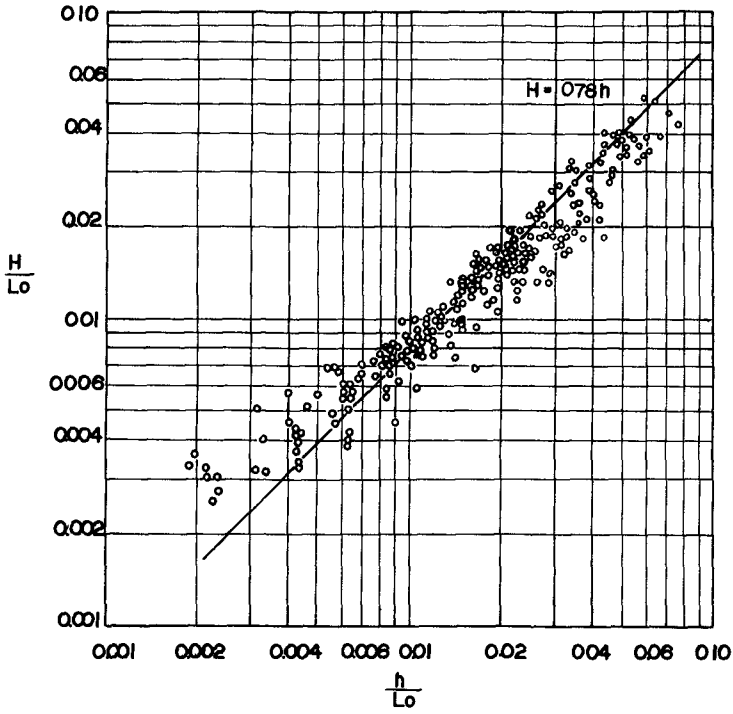


Fig 12 Wave height after breaking

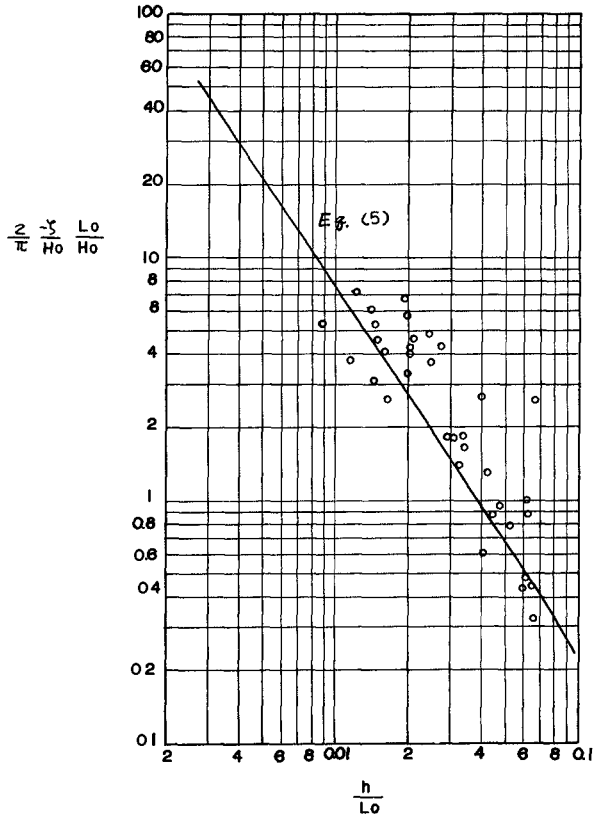


Fig 13 Wave set-up at breaking point

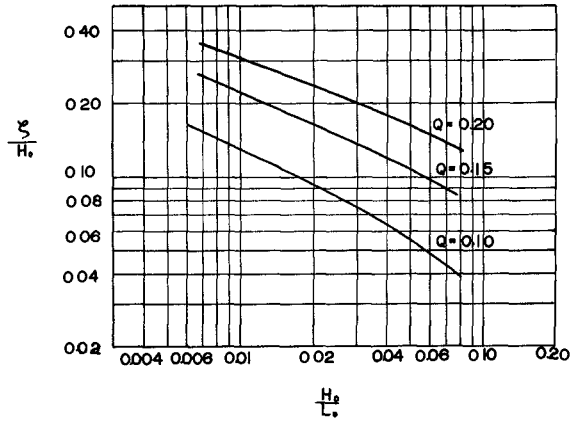


Fig 14 Wave set-up at shore line

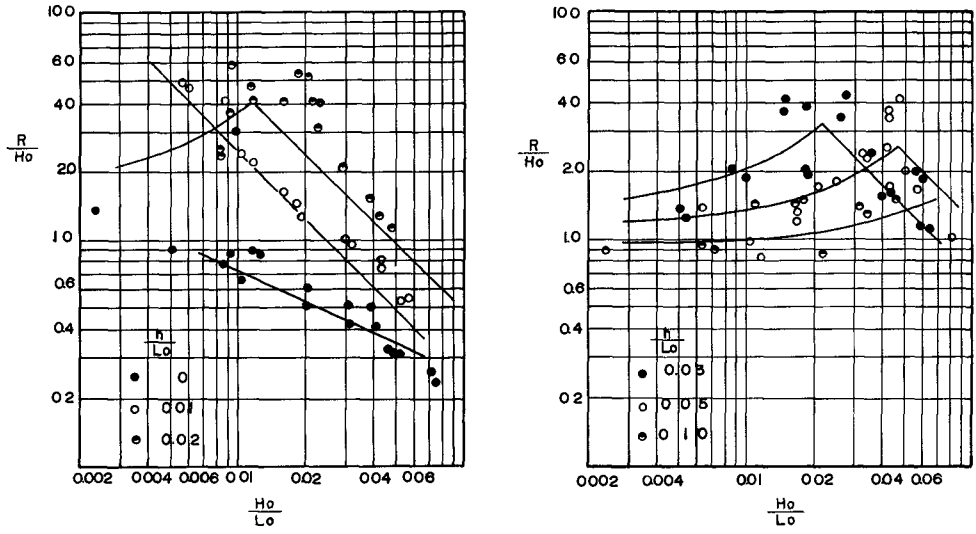


Fig 15 Experimental results of run-up on vertical wall

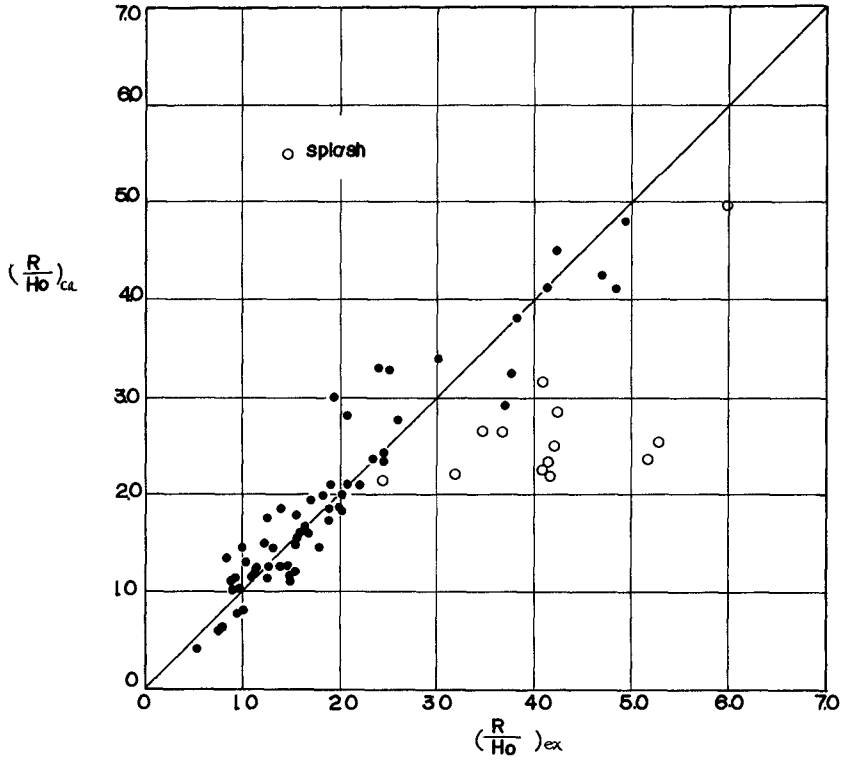
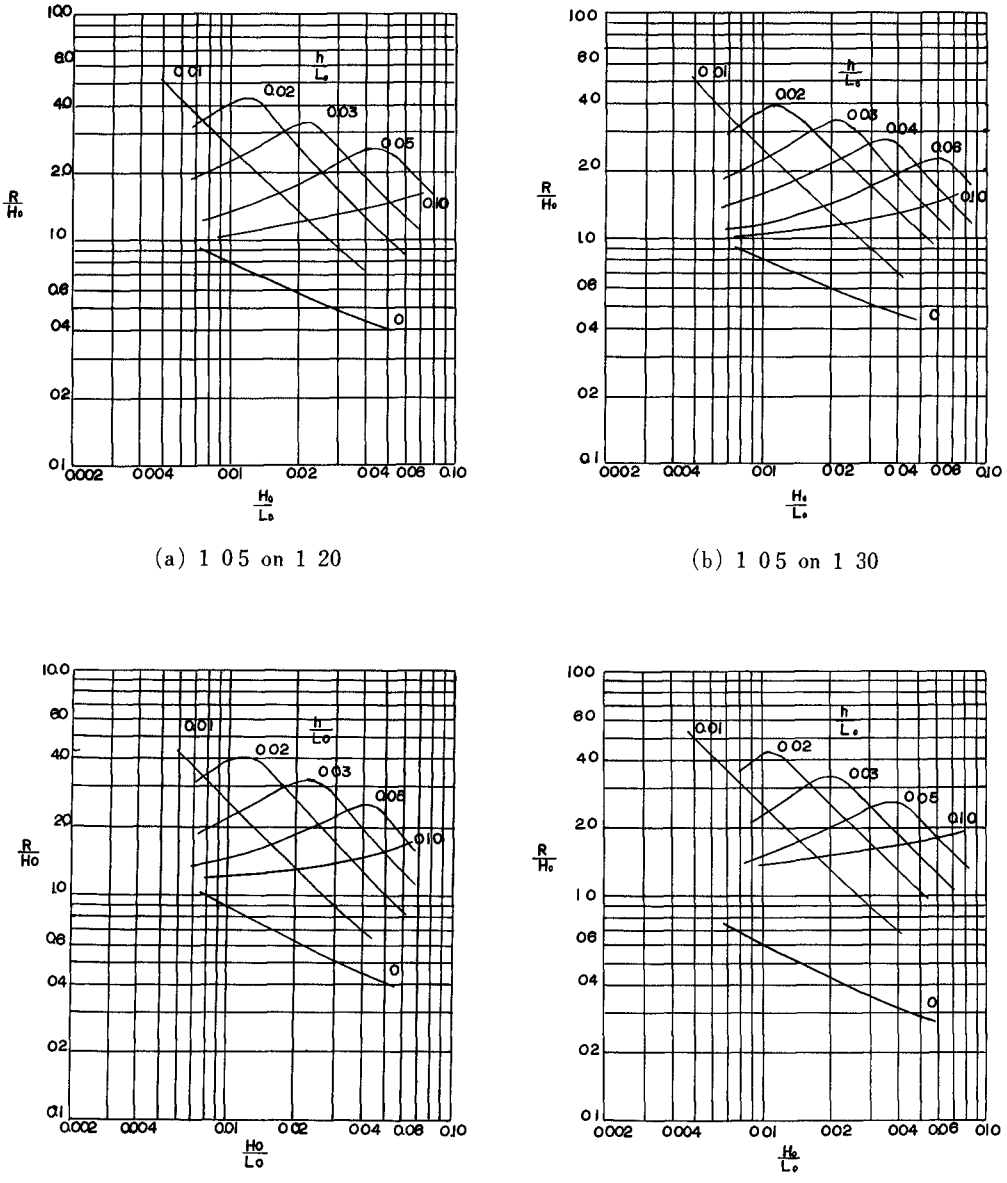


Fig 16 Comparison of calculation and experiment



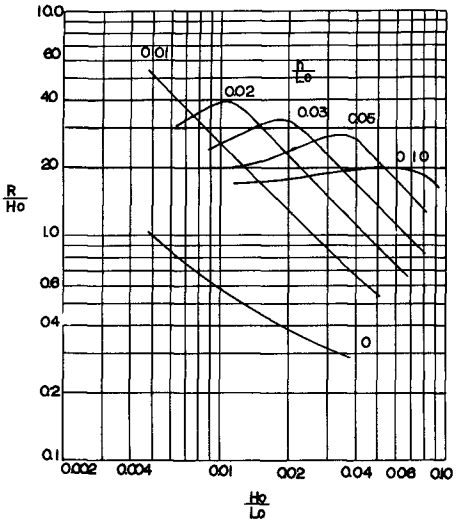
(a) 1 05 on 1 20

(b) 1 05 on 1 30

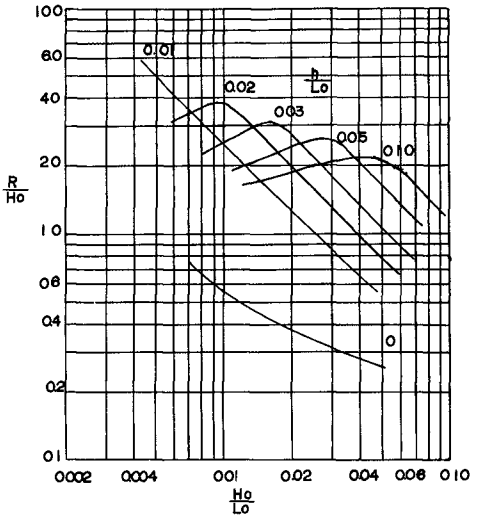
(c) 1 1 on 1 20

(d) 1 1 on 1 30

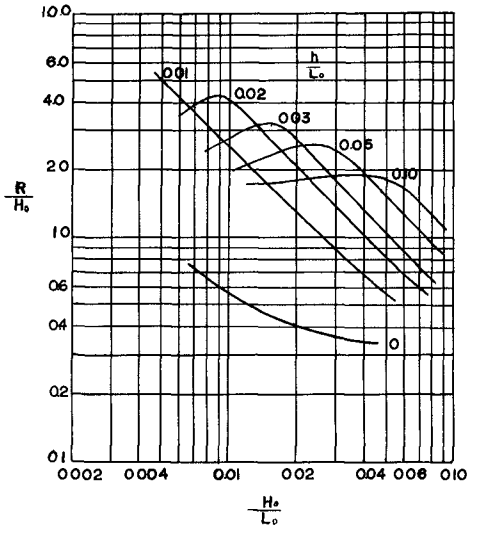
Fig 17 Wave run-up on sloping dike



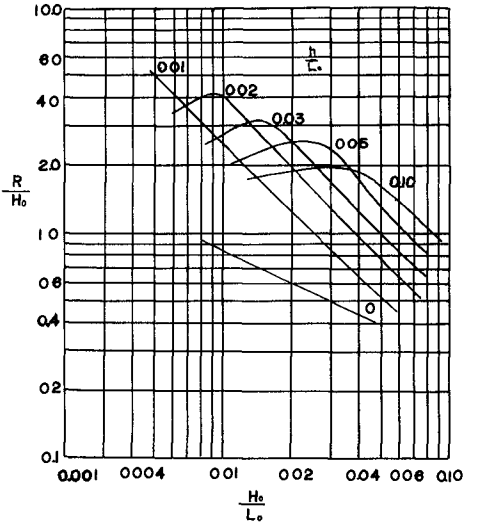
(e) 1 2 on 1 20



(f) 1 2 on 1 30



(g) 1 3 on 1 20



(h) 1 3 on 1 30

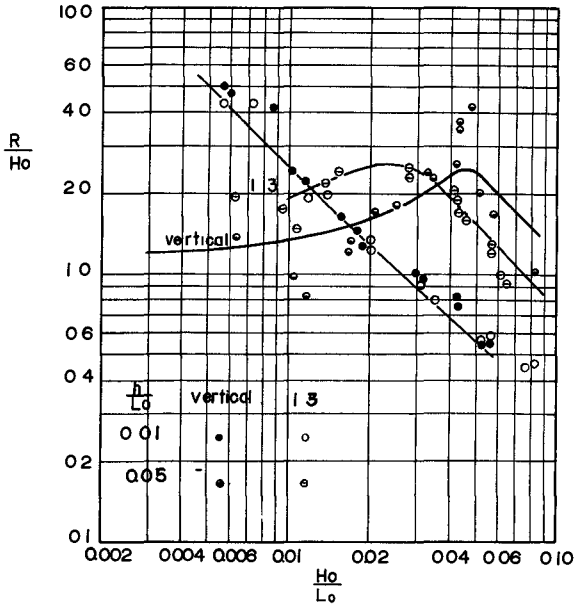


Fig 18 Effect of dike's slope

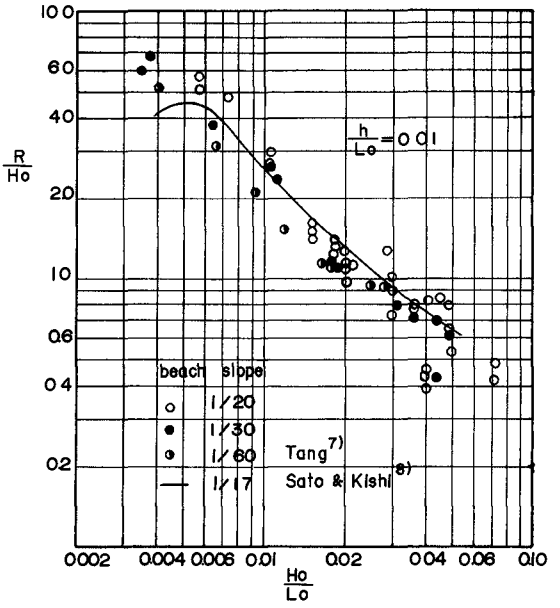


Fig 19 Effect of beach slope

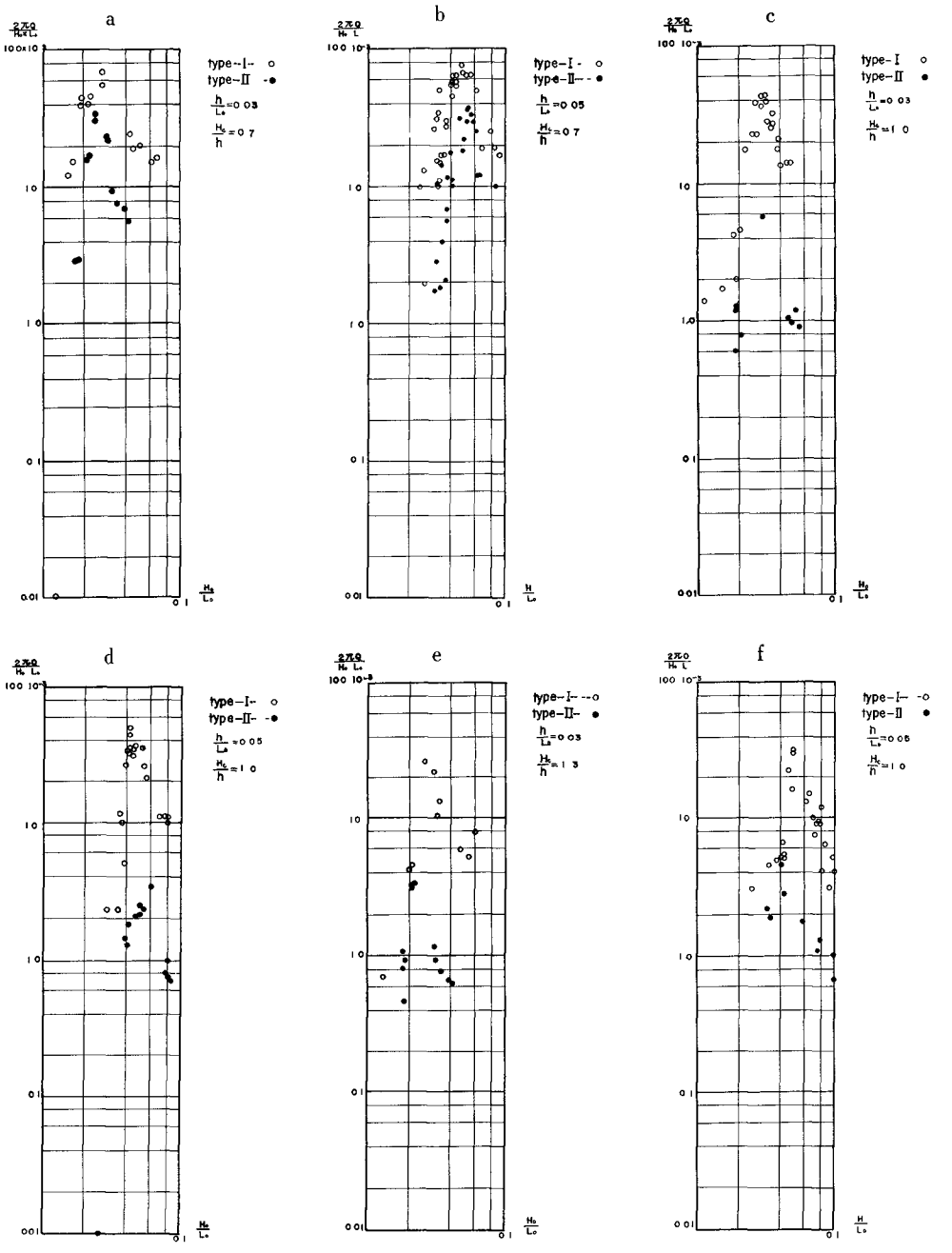


Fig 20 Experimental results of overtopping