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On the Effect of Wind on Wave Overtopping on Vertical Seawalls

By Yuichi IWAGAKI, Yoshito TSUCHIYA and Masao INOUE

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Synopsis

In designing seawalls and seadikes, it is very important to estimate the quantity of wave overtopping on them as exactly as possible. The estimation, however, is difficult because of complicated phenomena of wave overtopping, and in particular the effect of wind on wave overtopping is entirely unknown. With this in view, the authors have begun the study to disclose the effect of wind on wave overtopping quantitatively. As a first step of the study, the present paper describes some experimental results of wave overtopping on vertical seawalls for the wave steepnesses of 0.01 and 0.02, accompanied with wind created by a high-speed wind-wave tunnel, which is 0.8 m wide, 2.3 m to 4.0 m high and 40 m long, having a blower of 100 HP and a wave generator of submerged piston type with a motor of 10 HP.

The main results obtained from the experiments are summarized as follows.

1) Some experimental results on the wave overtopping on a vertical seawall in conditions of calm are described for the wave steepnesses of 0.01, 0.02 and 0.03, and compared with those by Ishihara, Iwagaki and Mitsui, and Saville.

2) When incident waves do not break in front of the seawall, the quantity of wave overtopping begins to increase suddenly with an increase in the wind velocity at a certain wind velocity. The increasing segment of quantity of wave overtopping by wind is considerable compared with other cases.

3) When incident waves break just in front of the seawall, the quantity of wave overtopping changes complicatedly with an increase in the wind velocity for the wave steepness of 0.01, and it becomes approximately constant over a low wind velocity for the wave steepness of 0.02.

4) When incident waves break before they rearch the seawall, the effect of wind on wave overtopping is not very great, and in particular when the seawall is constructed at the shoreline or on shore, the quantity of wave overtopping tends to decrease a little at a high wind velocity.

1. Introduction

In determining the design height of a seawall or seadike, the allowable quantity of wave overtopping on it should be estimated, based on the conditions of its hinterland, the structural type of the seawall and the drainage facilities[1]. Up to the present, the design height of a seawall or seadike has been decided by a simple method whereby the height is the sum of the design high water level, the height of wave run-up calculated from the design wave height, and an extra height for safety[2),3)]. The method for determining the design height of a seawall or seadike based on the quantity of wave overtopping has not been established yet. This is considered to be caused by very complicated phenomena of wave overtopping associated with many hydraulic factors, and the mechanism of wave overtopping has not been completely investigated.

With regard to the studies of wave overtopping on seawalls or seadikes, Saville and Caldwell[4] first carried out some experiments on wave overtopping on vertical seadikes in 1953, and consequently in 1955, many experiments for seawalls with various shapes were carried out by Saville[5]. In the same year, Sibul[6] tried a few experiments in the same manner for inclined seadikes. In 1956, Sibul and Tickner[7] carried out model experiments for seadikes with slopes of 1/3 and 1/6 put on a model beach with a slope of 1/10 to find the additional quantity of wave overtopping due to the action of wind, compared with conditions in calm weather. He concluded from the result of the experiments that the smaller the inclination angle of a seadike, the greater was the influence of wind on wave overtopping. Paape[8] made clear, by using a wind wave tunnel, that the irregularity of incident wind waves increases the quantity of wave overtopping considerably, compared with the results in the case of regular waves. However, the influence of wind on wave overtopping has not yet been made clear quantitatively.

In Japan, Ishihara, Iwagaki and Suzuki[1] asserted in 1955 that a design method considering the allowable quantity of wave overtopping to some extent, should be used for practical purposes, and Ishihara, Iwagaki and Mitsui[9] measured systematically the quantity of wave overtopping on vertical and inclined seadikes when there was no wind. They proposed a new dimensionless expression for the quantity of wave overtopping, which is different from the expression proposed by Saville. The details of the analysis of experimental results will be explained in Chapter 3.

Recently, Iwagaki and others[10],[11] discussed the effects of wave characteristics, water depth and water level on the quantity of wave overtopping on vertical seawalls, based on their experimental results, in addition to those by the Beach Erosion Board.

As mentioned above, most of the studies on wave overtopping on seawalls and seadikes are experimental as in U. S. A. and Japan, but in particular experiments in calm weather have produced considerable results. However, the phenomenon of wave overtopping associated with strong wind during storm has not been studied sufficiently.

For this reason, the authors have begun a basic study of wave overtopping by the high-speed wind-wave tunnel, newly constructed in 1961 at the Ujigawa Hydraulic Laboratory, to disclose the influence of wind on the quantity of wave overtopping. This paper is the first report of the study in which the experimental equipments used are described, and some results of the experiments for vertical seawalls in the case of the wave steepnesses of 0.01 and 0.02 are presented.

2. Experimental Equipments

(1) High-speed wind-wave tunnel

In 1961, the high-speed wind-wave tunnel was constructed to study the following three matters: firstly the hydraulic performance of seadikes and seawalls against waves during storm, secondly the generation and growth of wind waves, showing especially how the shearing stress with which high speed wind acts on a water surface, changes with increase of wind speed, and thirdly to study the wind resistance of structures. In this section, the wind wave tunnel, the blower and the wave generator are explained in outline.

(*a*) *Wind wave tunnel*

This wind wave tunnel is divided into three parts; the first is a so-called wind wave tank to study hydrodynamical characters of wind waves and mechanism of wave overtopping on seadikes, the second the smoke tunnel to study the wind resistance of structures and the third the wind tunnel to generate wind. A distinctive character of the high-speed wind-wave tunnel is that both the wind wave tank and the smoke tunnel can be operated by a blower. The wind wave tunnel consists of a wind blower, a wind tunnel, a wind wave tunnel and a smoke tunnel. The wind blower consists of an electric motor, a fan, moving vanes, fixed vanes, and an inner cylinder. The wind tunnel consists of a divergence tunnel, a baffle screen, a branch tunnel, and a nozzle. The smoke tunnel consists of a main tunnel, a baffle screen, an observation tunnel, and a nozzle. The downstream end of the wind tunnel is connected with a wave tank 40 m long, 2.3 m to 4.0 m high and 0.8 m wide. A part of the wave tank 0.3 m deep is submerged in the ground. Experiments on the wave overtopping are carried out at about 1.0 m in water depth. In this case, a model structure is put on a model sloping beach with a slope of 1/15

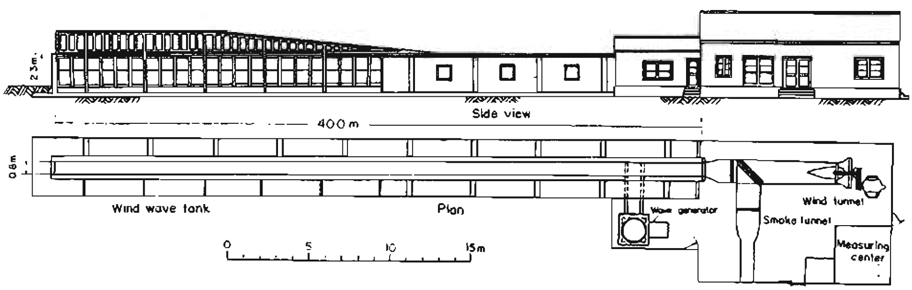


Fig. 1 Sketch of high-speed wind-wave tunnel.

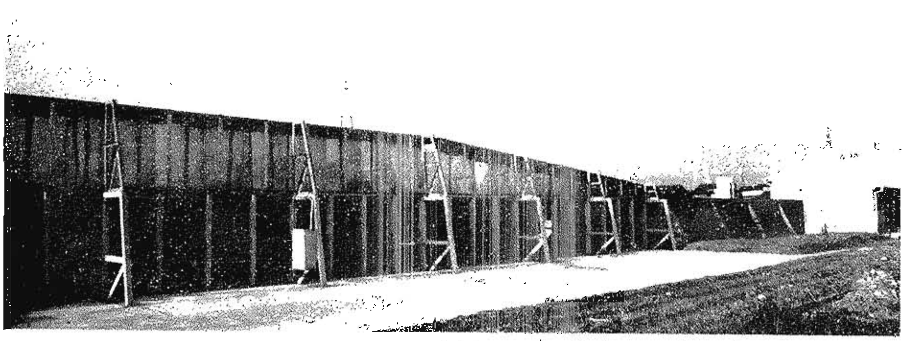


Photo. 1 General view of high-speed wind-wave tunnel.

at the end of the wave tank, so the height of ceiling made of aluminum was gradually varied.

A wave generator is set near the wave tank and connected with it, so that waves can be generated without operating the blower. Fig. 1 shows a sketch of the wind wave tunnel and Photo. 1 indicates a general view of the wind wave tank.

(b) Electric motor and blower

The motor is a varying speed commutator motor of three-phase current shunt type, 100HP, and the rotating speed can be adjusted continuously from 350 r.p.m. to 1,000 r.p.m. by remote control at two stations. The pitch angle of the moving vanes is changeable in the stop condition. The dimensions of the blower are summarized as follows: the type is of a single-suction axial flow, the diameters of inlet and outlet 1,200mm, the boss diameter 780mm, the air discharge 35 m^3/sec at maximum, the maximum rotating speed 1,800 r.p.m., and the numbers of

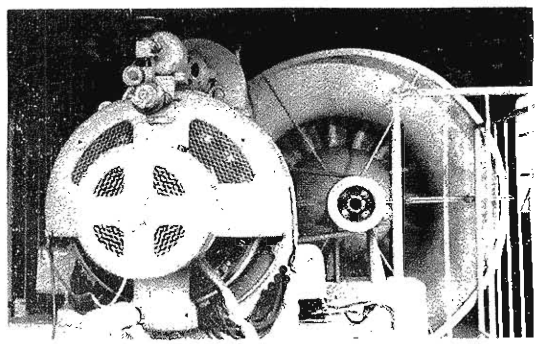


Photo. 2 View of electric motor and blower.

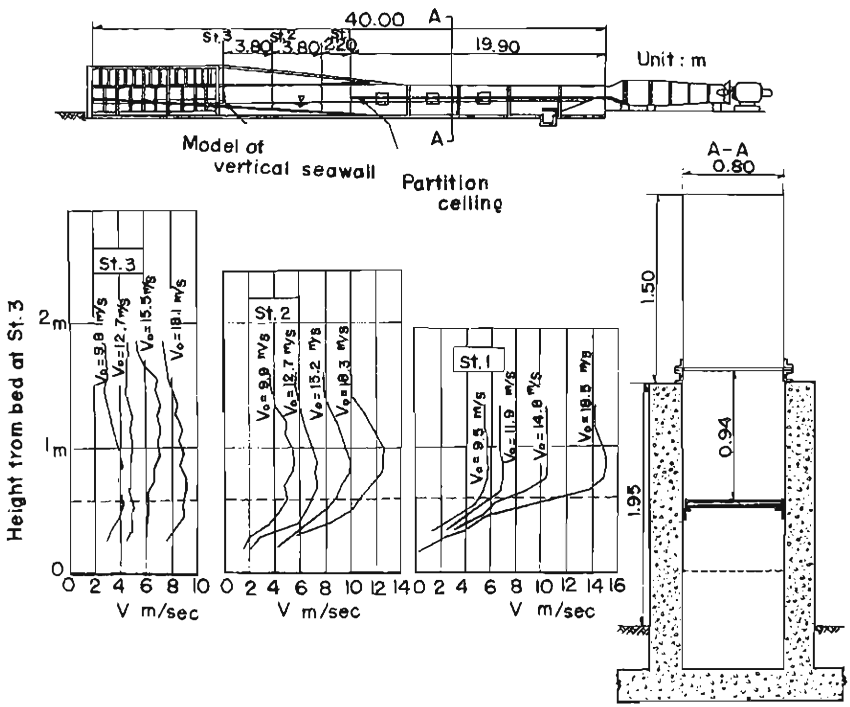


Fig. 2 High-speed wind-wave tunnel and vertical velocity profiles of wind.

moving and fixed vanes 16 and 11 respectively. Photo. 2 shows a view of the electric motor and the blower. The waves generated by the wave generator increase in height and become irregular when the blower sends wind to the wave tank, because the wind acts on the waves travelling in the wave tank. The authors found from the results of model experiments of the Yui seadikes[12] that irregularity of incident waves affects considerably the quantity of wave overtopping on the seadikes. Therefore, in this paper, the wave overtopping excluding the influence of irregularity of waves is investigated. For this purpose, a partition ceiling made of aluminum plate was set horizontally at about 20 m from the bottom of the nozzle of the wind tunnel as shown in Fig. 2, so the wind can act on the waves only in front of model seadikes. In addition, Fig. 2 shows some examples of vertical velocity profiles of wind at three stations in the case of such an experimental equipment.

(*c*) *Wave generator*

As described already, the purpose of the experiment is to investigate the wave overtopping on seadikes, so that wave reflection due to model seadikes may take place. Therefore, it is supposed that using wave generators of flatter and plunger types yields further reflection of waves due to them again. In order to prevent this phenomenon a wave generator of a new type was devised, which generates waves by sucking and spouting water periodically from a hole at the bottom of the wave tank, connected with a piston submerged in water. It was clarified from the recent theory on wave generation by such a method that the wave generator is adequate to generate shallow water waves and reflected waves by itself scarcely occur[13]. The wave height can be changed continuously by changing the stroke of piston of the wave generator, and periods can also be changed from 0.75 sec to 3.0 sec by a variator. The diameter of piston cylinder is 1,500 mm and the stroke of piston is 500 mm at maximum. Photo. 3 gives a view of the wave generator.

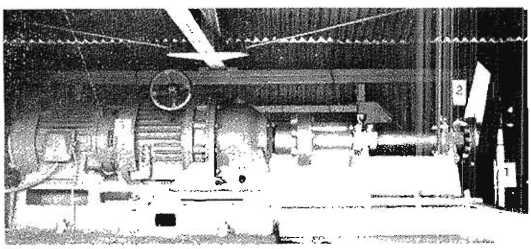


Photo. 3 View of wave generator.
(1) Piston (2) Crank (3) Motor

(2) **Measuring apparatuses**

In this article, an outline of measuring apparatuses used in this experiment is briefly described.

(*a*) *Wave gage*

This is of electric resistance type, and was connected with a recorder of auto-balanced strain meter.

(*b*) *Anemometer*

An anemometer of pitot tube type was used, and connected with the recorder described above through a differential pressure gage of 20 gr/cm^2 at maximum.

(*c*) *Measuring apparatuses and procedures for wave overtopping*

The overtopping water was collected by a small water tank set just behind a model seadike. The overtopping water collected in the water tank was led out of the wind wave tank through a tube to another water tank, and the rate of wave overtopping was found by measuring the rate of increase in the water depth in the tank, using a pressure gage of unbounded type when the rate of water overtopping was large, or measured directly by a mescylinder when it was small. On the other hand, in order to measure the horizontal distributions of the rate of wave overtopping, the quantities of water led into six vessels set at the positions of 75 cm, 105 cm, 140 cm, 185 cm, 245 cm and 335 cm back from the model seadike, were measured directly by a mescylinder in the same manner. Fig. 3 shows a schematic representation for the apparatus to measure the quantity of wave overtopping and notations.

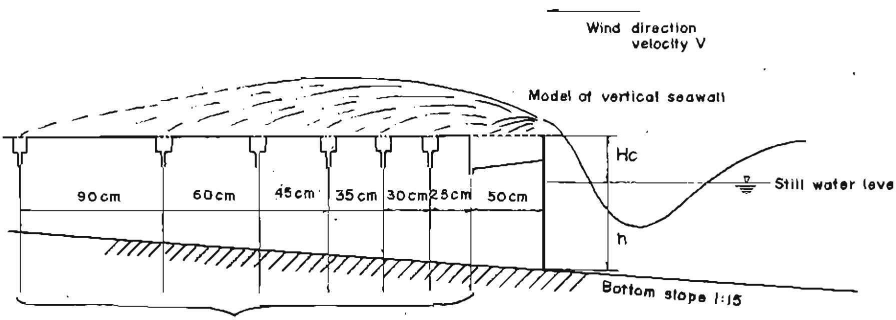


Fig. 3 Schematic representation for apparatus and notations.

3. Wave Overtopping on Vertical Seawalls in Calm Condition

As mentioned in the introduction, some interesting studies on the wave overtopping on seawalls in calm conditions were carried out by Saville and Ishihara, Iwagaki and Mitsui. In particular, Ishihara, Iwagaki and Mitsui performed systematically some basic experiments for vertical and inclined seawalls, and proposed a dimensionless expression for the rate of wave overtopping which is the ratio of the quantity of overtopping water per wave period to that of water moving on shore per wave period in deep water. Moreover, they plotted the experimental results obtained by themselves and Saville, based on the above expression, and found the relations between the characteristics of incident waves, the water depth at the toe of a seawall and the height of the seawall from still water level and the rate of wave overtopping.

However, the experiments were carried out only in the case of incident wave steepnesses of 0.03 to 0.08, but experiments for the wave steepnesses of less than 0.03 have not been carried out yet. For the reason mentioned above, the experiments of wave overtopping on vertical seawalls were first made in the case of incident wave steepnesses of 0.01, 0.02 and 0.03.

In this chapter the experimental procedure and the experimental results are described.

(1) Experimental procedure

The model of a vertical seawall made of steel plate was set on a beach of 1/15 slope described already in the preceeding chapter. With regard to the width of the model seawall, in order to measure the incident wave height as exactly as possible, the width of wave tank, 80 cm, was divided into two parts only near the seawall model, 30 cm and 50 cm, and the model was set in the part of 30 cm. The incident wave height was measured in the part of 50 cm where the waves are not reflected by the seawall.

The characteristics of incident waves used are summarized in Table 1. In this case, the water depth was kept always constant.

TABLE 1

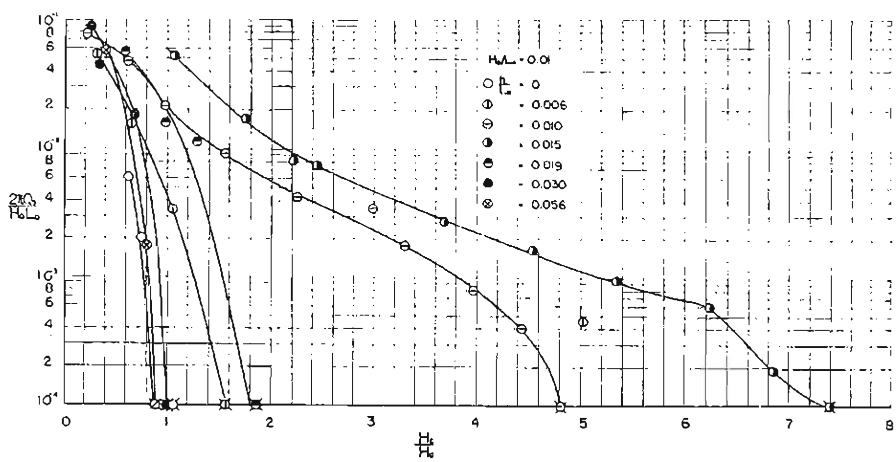
Characteristics of incident waves used.

No.	Wave height H_0(cm)	Wave length L_0(cm)	Wave period T(sec)	Wave steepness H_0/L_0
1	6.2	624	2.0	0.01
2	12.5	624	2.0	0.02
3	18.7	624	2.0	0.03

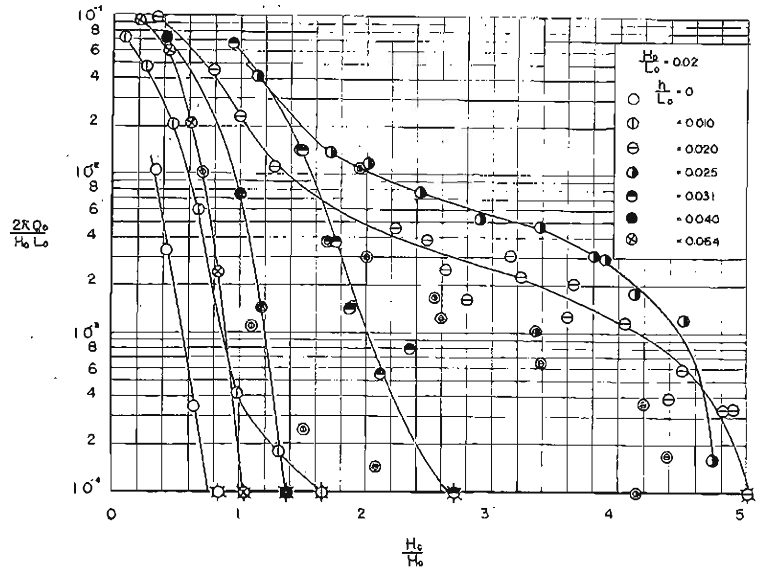
The quantity of wave overtopping was measured after the wave motion became steady. The measurements were repeated until the waves could not overtop on the seawall by increasing the height of the seawall. The water depth at the toe of the seawall was changed in six or seven cases for each wave steepness. The results described in this chapter are based on the experiments performed in 1963. There is a little difference between the experimental results on the quantity of wave overtopping carried out in 1963 and 1964.

(2) Experimental results and considerations

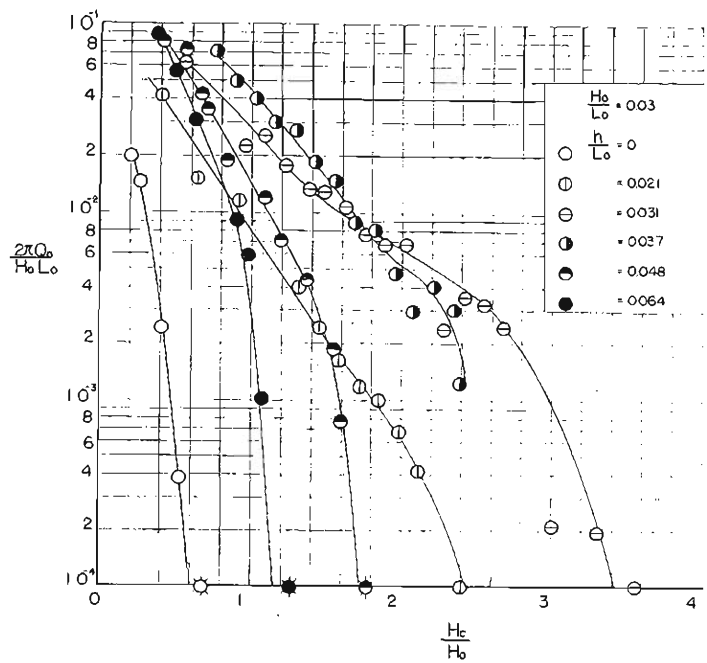
The state of wave overtopping is explained briefly, based on the observation



(a) Case when $H_0/L_0=0.01$



(b) Case when $H_0/L_0=0.02$

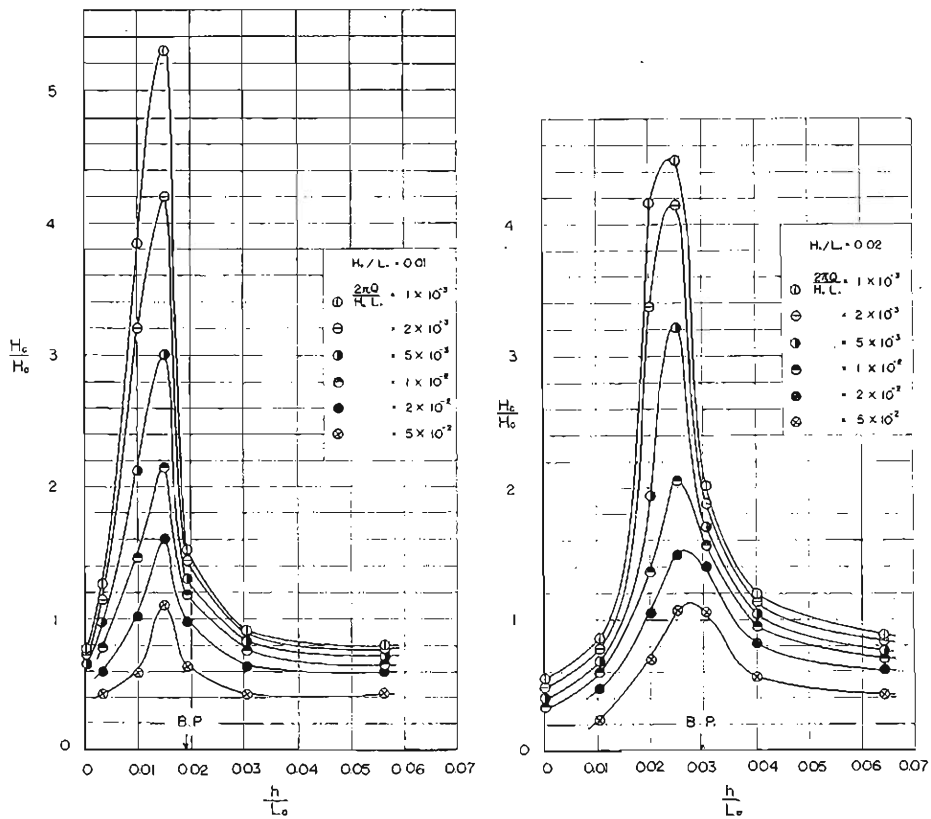


(c) Case when $H_0/L_0=0.03$

Fig. 4 Relations between dimensionless quantity of wave overtopping $2\pi Q/H_0L_0$ per wave period and relative crest height of seawall H_c/H_0 with a parameter of relative water depth h/L_0.

before describing the experimental results. The state of wave overtopping is divided into two types, firstly when incident waves have broken before they reach the seawall because the water depth at the toe of the seawall is shallow compared with the incident wave height, and secondly when the waves have not broken, because the water depth is deep. Furthermore, the former type is subdivided, firstly when incident waves break just in front of the seawall, and secondly when the waves reach the seawall after they have broken offshore and considerably dissipated their energy. In the former case, the waves generally splash up on the seawall with violent impact. When the water depth is deep, the waves generally form clapotis, and however, the phenomena of wave run-up begin to occur locally on the face of the seawall when the water depth at the toe of the seawall becomes shallow. Whenever the incident wave height is constant, the state of wave overtopping varies with the water depth at the toe of the seawall. Therefore, the water depth at the toe of the seawall was changed in six or seven cases in the experiments.

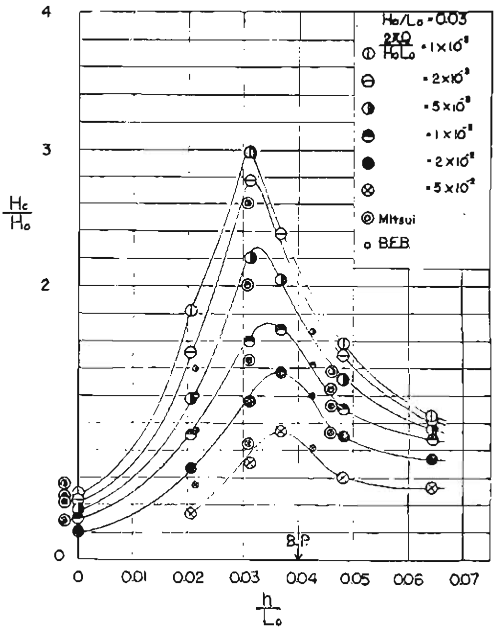
The experimental results were plotted in the same manner as in the study by Ishihara, Iwagaki and Mitsui. Fig. 4 shows the relations between the dimensionless rate of wave overtopping $2\pi Q/H_0L_0$ and relative height of the seawall H_c/H_0



(a) Case when $H_0/L_0=0.01$ (b) Case when $H_0/L_0=0.02$

with a parameter of the relative water depth h/L_0 for the three cases when wave steepnesses are 0.01, 0.02 and 0.03 respectively, in which Q is the quantity of wave overtopping per wave period, H_0 the wave height, L_0 the wave length, H_c the crest height of a seawall, and h the water depth at the toe of the seawall. The experimental results plotted with double circles in Fig. 4 (b) were obtained by the experiment made in 1964. In the following chapter these experimental results can be used in considering the effect of wind on wave overtopping.

The relations between the relative height of a seawall H_c/H_0 and the relative water depth h/L_c, which are obtained from rearranging the results in Fig. 4, are shown in Fig. 5 with a parameter of the rate of wave overtopping. The experimental results by Saville and Ishihara, Iwagaki and Mitsui are also plotted in Fig. 5 (c) for comparison. As is seen from Fig. 5 (c), the rate of wave overtopping obtained from the authors' experiments is less compared with these results, and this tendency is noticeable when the water depth at the toe of the seawall is shallower than the breaking water depth. It seems clear that this fact is due to the difference of the beach slopes which are 1/15 in the experiment by the authors and 1/10 in the experiments by Saville and Ishihara, Iwagaki and Mitsui respectively.



(c) Case when $H_0/L_0=0.03$

Fig. 5 Relations between relative crest height of seawall H_c/H_0 and relative water depth at toe of seawall h/L_0 with a parameter of dimensionless rate of wave overtopping $2\pi Q/H_0L_0$.

As is seen from Fig. 5, the maximum relative height of the wall appears at a rather smaller water depth than the breaking depth of water, which is denoted by B. P. in the figures obtained from the breaker index. Therefore, the rate of wave overtopping reaches a maximum when waves break a little offshore of the seawall.

The facts mentioned above were also found in the results of the experiment carried out on the beach with a slope of 1/10. Moreover, it is found that the effect of the water depth at the toe of the seawall on wave overtopping is remarkable when the wave steepness is small. However, as the effects of many factors except wind on wave overtopping have already been reported[11], these are not presented in this paper.

4. Experiment on Effect of Wind on Wave Overtopping on Vertical Seawalls

(1) Experimental procedure

The experiments were carried out in the same manner as those in calm conditions as follows: firstly, the quantity of wave overtopping was measured in calm conditions and secondly, the same measurements were taken in the case of wind. The characteristics of incident waves used are summarised in Table 2.

The water depth at the toe of the seawall was changed in five cases for each incident wave.

TABLE 2
Characteristics of incident waves used.

No.	Wave height H_0(cm)	Wave length L_0(cm)	Wave period T(sec)	Wave steepness H_0/L_0
1	6.2	624	2.0	0.01
2	12.5	624	2.0	0.02

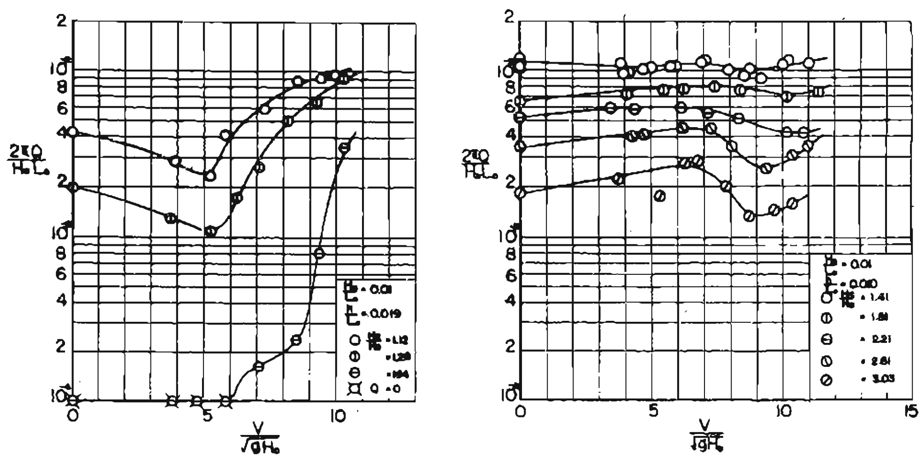
(2) **Experimental results and considerations**

The following relationship was obtained by means of the dimensional analysis concerned with the phenomena of wave overtopping with wind

$$2\pi Q/H_0L_0=F(H_0/L_0,\ H_c/H_0,\ h/L_0,\ V/\sqrt{gH_0})$$

The notations used here, except those already explained, are as follows: V is the wind velocity, g the acceleration of gravity and $V/\sqrt{gH_0}$ the dimensionless wind velocity.

Fig. 6 shows the relations between the rate of wave overtopping $2\pi Q/H_0L_0$ and the dimensionless wind velocity $V/\sqrt{gH_0}$ with a parameter of the relative height of the wall H_c/H_0 for each relative water depth h/L_0 when the wave steepness is 0.01. Fig. 7 shows the experimental results when the wave steepness is 0.02 in the same manner as in Fig. 6.



(a) (b)

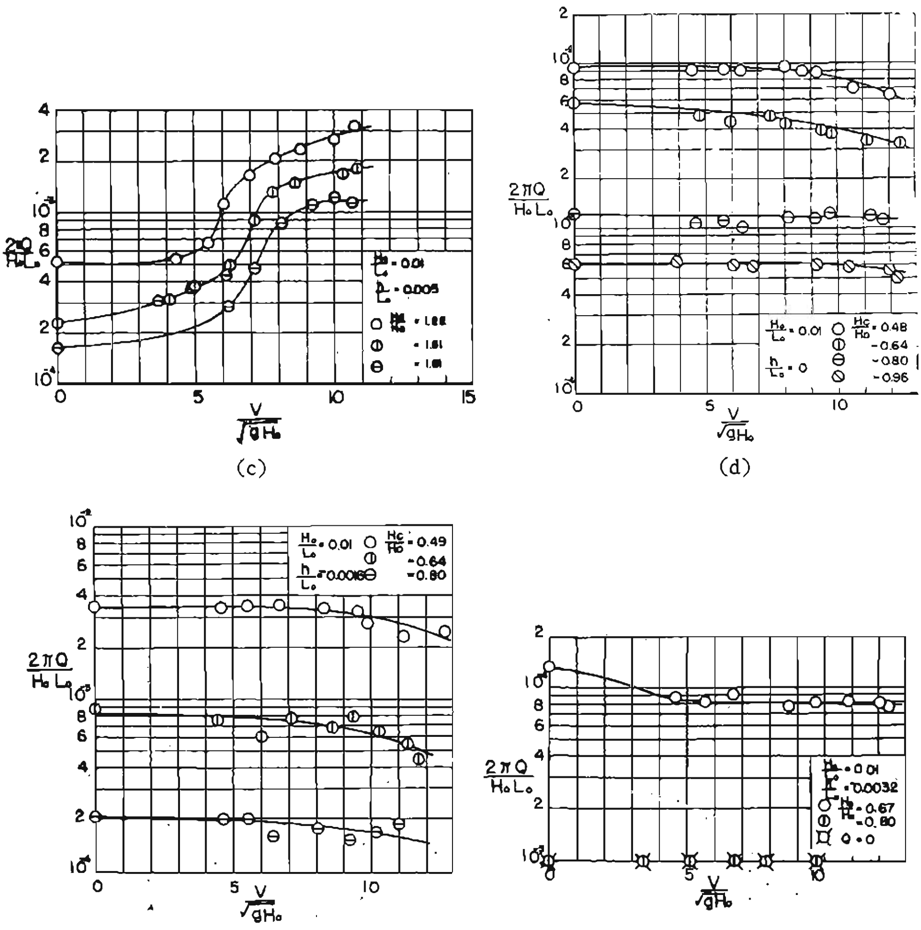
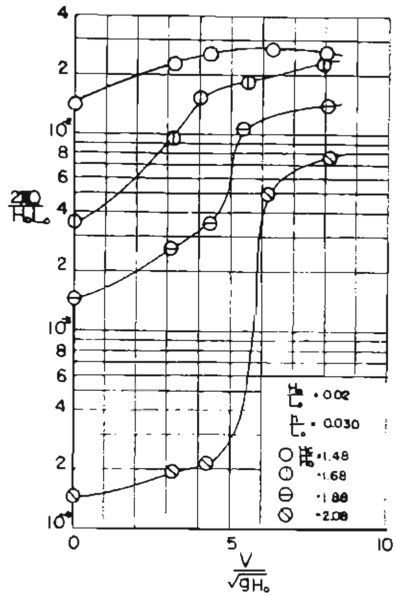


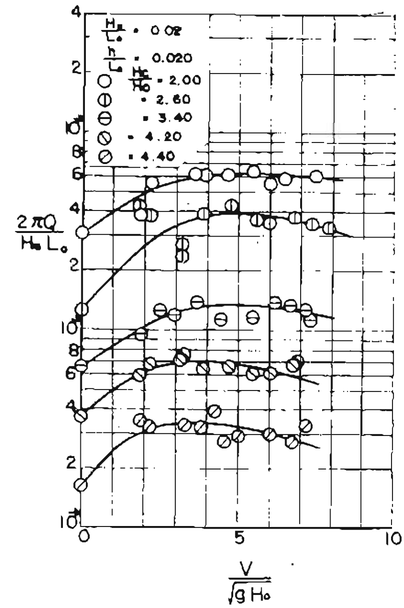
Fig. 6 Effect of wind on rate of wave overtopping when $H_0/L_0=0.01$.

Figs. 8 and 9 show the relations between the increasing segment of the rate of wave overtopping due to wind $2\pi Q_w/H_c L_0$ and the dimensionless wind velocity $V/\sqrt{gH_0}$, based on Figs. 6 and 7. The effect of wind on the wave overtopping is more clearly discerned in Figs. 8 and 9, where the wave steepnesses are 0.01 and 0.02 respectively. It can be seen from Fig. 7 that the effect of wind on wave overtopping varies considerably with the values of the relative water depth h/L_0 and the relative height of the wall H_c/H_0 if the wave steepness is constant.

In the case of Figs. 8(a) and 9(a), in which the water depth at the toe of the seawall is large compared with the incident wave height, the rate of wave overtopping increases rapidly at a certain value of $V/\sqrt{gH_0}$, and the increasing segment of the rate of wave overtopping is generally quite large. The values of $V/\sqrt{gH_0}$ when the rate of wave overtopping increases rapidly, are nearly equal to 6 to 7 when $H_0/L_0=0.01$ and 3 to 5 when $H_0/L_0=0.02$, and there is a little difference due to the relative height of the seawall H_c/H_0. This matter may be considered as follows: there are two actions in the effect of wind on wave overtopping. The first one is the local action of wind which gives somewhat horizontal components of velocity to the water rising high above the seawall, and makes the water splash as a results of the local action of wind. The second is the action which somewhat changes wave profiles in front of the sea-



(a)



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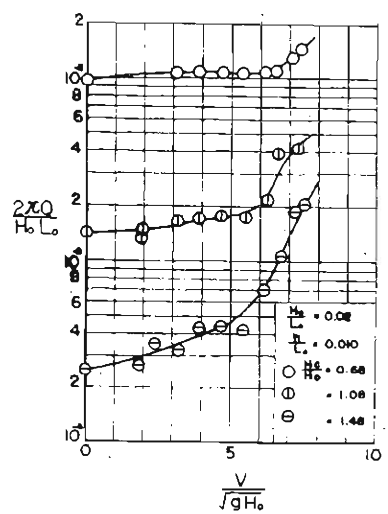
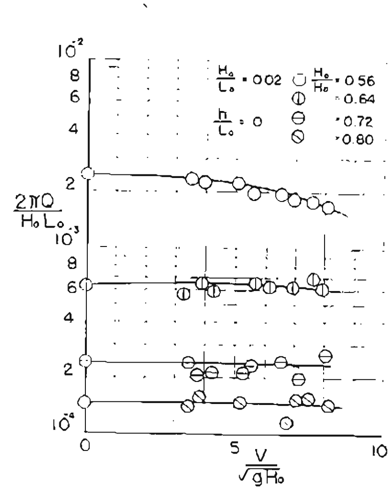


(c)



(d)

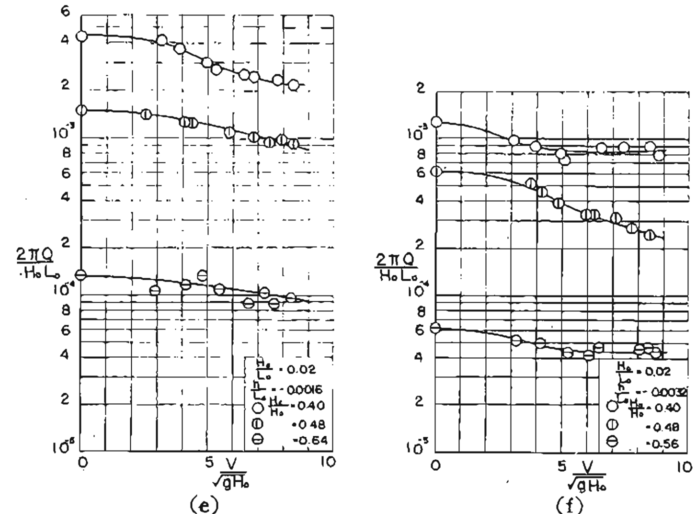


Fig. 7 Effect of wind on rate of wave overtopping when $H_0/L_0=0.02$.

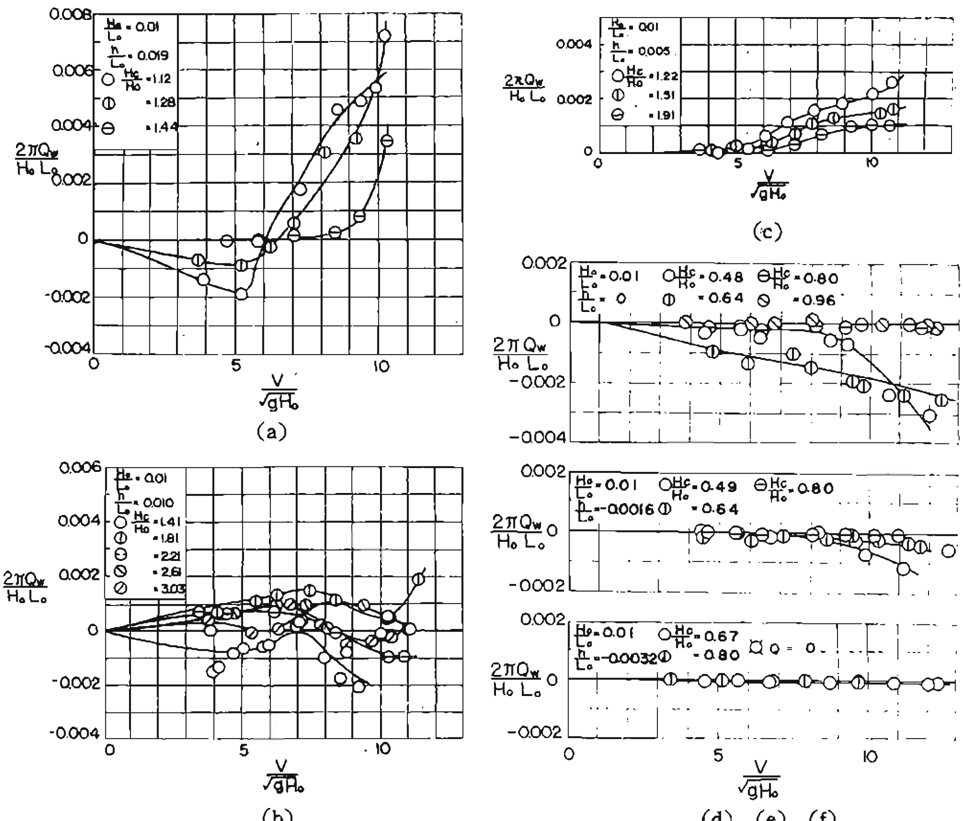


Fig. 8 Relations between increasing segment of rate of wave overtopping by wind $2\pi Q_w/H_0L_0$ and dimensionless wind velocity $V/\sqrt{gH_0}$ with a parameter of relative height of seawall H_c/H_0 when $H_0/L_0=0.01$.

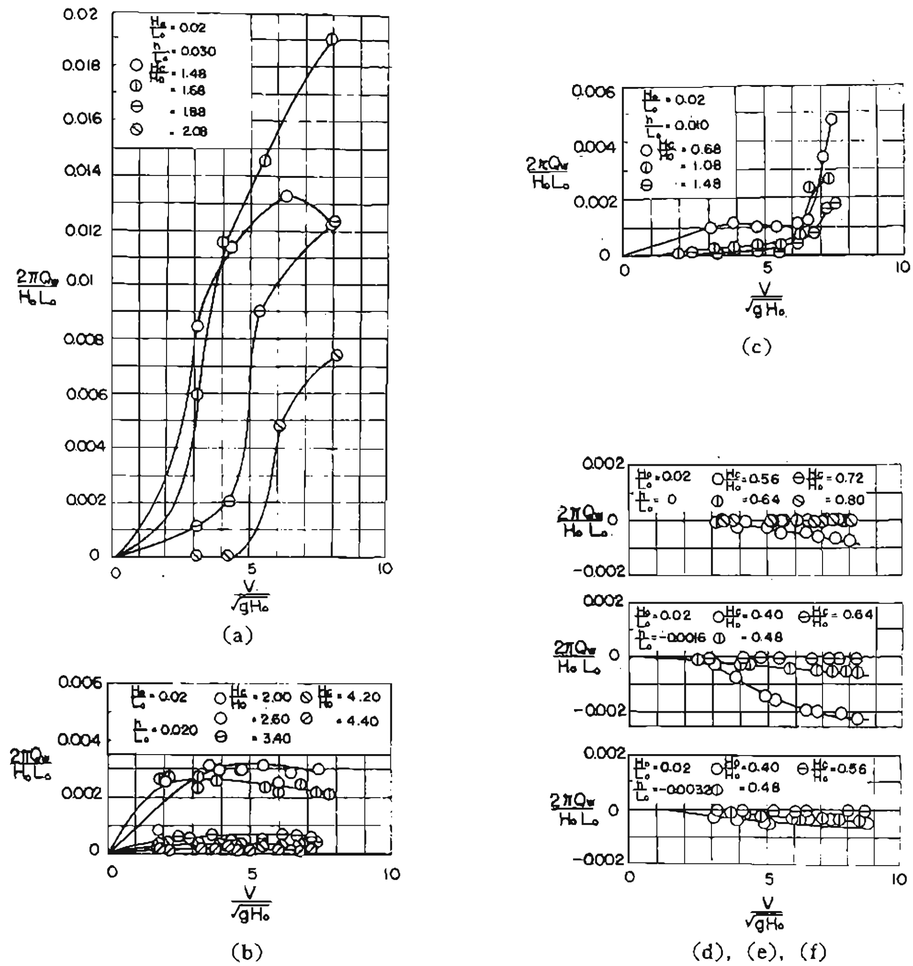


Fig. 9 Relations between increasing segment of rate of wave overtopping by wind $2\pi Q_w/H_0L_0$ and dimensionless wind velocity $V/\sqrt{gH_0}$ with a parameter of relative height of seawall H_c/H_0 when $H_0/L_0=0.02$.

wall and therefore changes the quantity of water overtopping itself. When the wind velocity is low, probably only the former action will be observed.

It seems, however, that both of the actions begin to occur when $V\sqrt{gH_0}$ exceeds the value mentioned above and the quantity of wave overtopping increases rapidly. Moreover, in Fig. 8(a), the rate of wave overtopping for the low value of $V/\sqrt{gH_0}$ is rather smaller than in the case of no wind. This is a very interesting phenomenon and it is considered from the observation that the phenomenon is due to the change of wave profile, especially a part of the wave crest due to wind action, but this has not been clarified in detail yet.

Figs. 8(b) and 9(b) deal with incident waves breaking just in front of the seawall, and water rising high above the seawall turns into fine drops of water. As is seen from Fig. 8(b), the quantity of wave overtopping changes complicatedly with the increase of wind velocity, and no definite tendency is found, but the change in quantity of wave overtopping is generally small. It is also seen from Fig. 9(b) that the rate of wave overtopping becomes constant at a point where the value of $V/\sqrt{gH_0}$ is 2 to 3. This may be due to the fact that the breaking waves become fine drops of water, as mentioned above, and most of the splashing water overtops on the seawall. In figs. 8(b) and 9(b) when the wind velocity becomes large and the value of $V/\sqrt{gH_0}$ exceeds nearly 5 to 7, the rate of wave overtopping decreases monotonously. This may be caused by the fact that the water rising high above the seawall becomes finer owing to the great wind velocity, so that the fine drops of water could not be collected in the tanks.

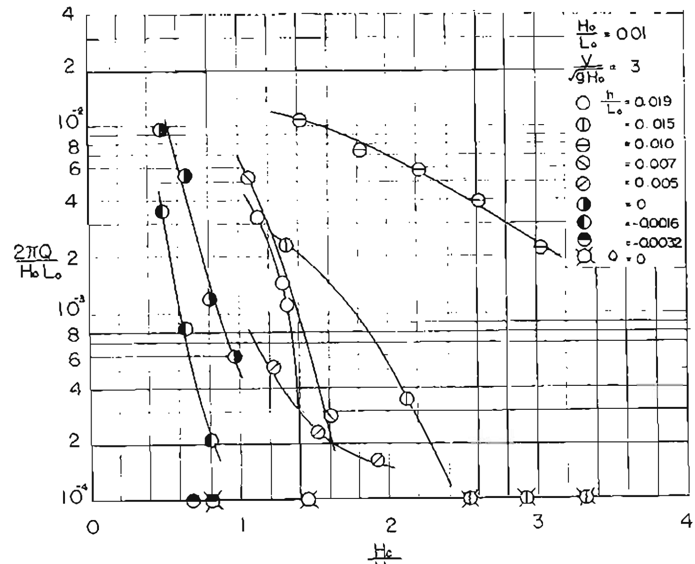
Figs. 8(c) and 9(c) refer to incident waves breaking offshore. The effect of the wind on the wave overtopping in this case differs from the above two cases. As is seen from these figures, the remarkable increase in the rate of wave overtopping due to wind can not be deduced until the value of $V/\sqrt{gH_0}$ exceeds about 6. The maximum increase of the rate of wave overtopping in this case is nearly equal to that of the case when the waves break just in front of the seawall within the limit of the experiment.

Figs. 8(d) and 9(d), Figs 8(e) and (f) and 9(e) and (f) are when the seawalls are set at shore line and on shore respectively. In these cases incident waves run up on the model beach after breaking and impinge on the seawall. There is a tendency that the rate of wave overtopping will decrease with an increase of wind velocity in both cases of Figs. 8 and 9, and the tendency is remarkable when the relative height of the seawall H_c/H_0 is small, and therefore the rate of wave overtopping is large. According to the observation, it is due to the fact that as crests of waves are disturbed by wind on breaking or in running up on the model beach after breaking, the wave energy decreases and the impinging action becomes weak when the wind velocity becomes high. In addition, in this case most of the overtopping water falls down into the 50 cm wide small water tank, just behind the seawall, even if the wind velocity becomes high, and it is found that there is little influence of wind on horizontal distributions of the rate of wave overtopping.

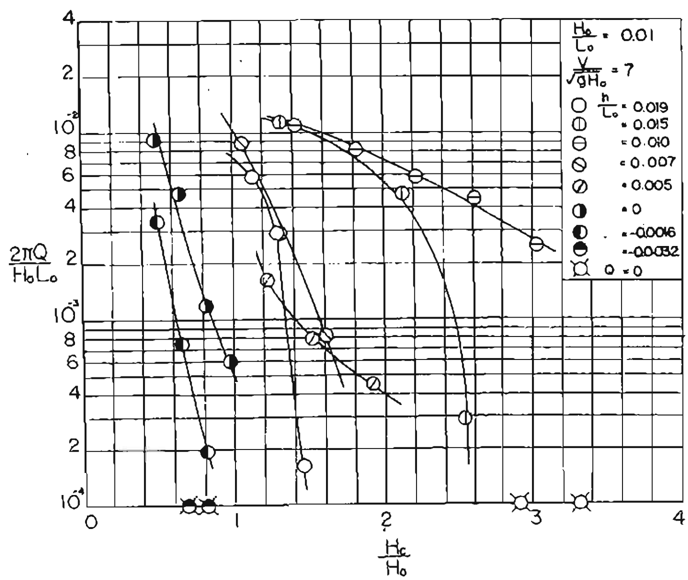
Figs. 10(a) and (b) are the relations between the rate of wave overtopping $2\pi Q/H_0L_0$ and the relative height of the seawall H_c/H_0 with a parameter of the relative water depth h/L_0, and show the effect of the crest height of the seawall on wave overtopping with wind. These figures deal with cases when the wave steepness is 0.01 and the dimensionless wind velocities $V/\sqrt{gH_0}$ are 3 and 7. From the figures, it is found that increasing the wall height is not so effective in decreasing the quantity of overtopping water when incident waves break just in front of the seawall, as when incident waves reach the seawall without breaking or after breaking offshore.

This is similar to cases in calm conditions. Fig. 11 shows the relations between the rate of wave overtopping $2\pi Q/H_0L_0$ and the relative height of the seawall H_c/H_0 with a parameter of $V/\sqrt{gH_0}$ to examine how the effect of the crest height of the seawall on the quantity of wave overtopping changes with increase in the wind velocity. (a), (b) and (c) in the figures correspond to

Figs. 6(a), (b) and (c) respectively. In the case of Fig. 11(a) in which the water depth at the toe of the seawall is deep compared with the incident wave height, when the value of H_c/H_0 are 1.1 to 1.3, the effect of the crest height of seawall on the wave overtopping is almost the same as in the case of no wind

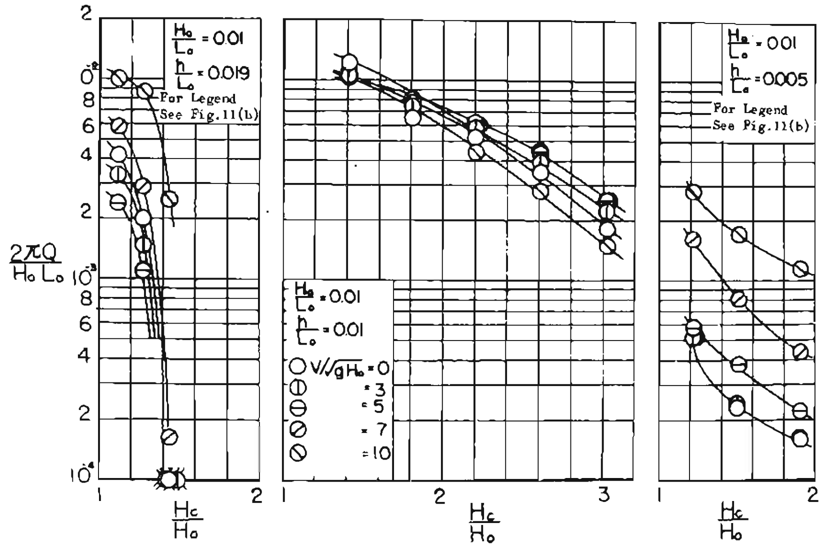


(a)



(b)

Fig. 10 Relations between rate of wave overtopping $2\pi Q/H_0L_0$ and relative height of seawall H_c/H_0 with a parameter of h/L_0 for case of $H_0/L_0=0.01$.



(a) (b) (c)

Fig. 11 Relation between rate of wave overtopping $2\pi Q/H_0L_0$ and relative height of seawall H_c/H_0 with a parameter of $V/\sqrt{gH_0}$ for case of $H_0/L_0=0.01$.

until the value of $V/\sqrt{gH_0}$ exceeds 7. But when the value of $V/\sqrt{gH_0}$ becomes as large as 10, the effect becomes less to some extent.

In the case of Fig. 11(b) in which incident waves break just in front of the seawall, it seems that the effect becomes less with an increase in the dimensionless wind velocity $V\sqrt{gH_0}$ until the value exceeds 7, but a remarkable difference of the effect between the wind velocities is not generally found. In the case of Fig. 11(c) in which waves approach the seawall after breaking, it does not vary greatly with an increase in the wind velocity.

Figs. 12(a) and (b) show the relations between the relative height of the seawall H_c/H_0 and the relative water depth h/L_0 with a parameter of the rate of wave overtopping $2\pi Q/H_0L_0$, obtained from Fig. 10. As is seen from the figures, when incident waves break just in front of the seawall, the quantity of wave overtopping reaches a maximum which is the same as in times of calm. With regard to the influence of the water depth at the toe of the seawall on the rate of wave overtopping, it is especially remarkable near the breaking point. Although the curves in the figures are not accurate because of insufficient experimental results, it may be noted that the gradients of curves become mild with an increase in the wind velocity. Consequently, when the wind velocity is very high, as during a typhoon, the quantity of wave overtopping becomes large within a wide range of the water depth compared with calm conditions. This may yield dangerous results in practical problems.

In this paper, as described above, the effect of wind on wave overtopping on the vertical seawall has been discussed in relation to the characteristics of incident waves, the crest height of the seawall and the water depth at the toe of the seawall, based on the results of experiments. However, the problem of the horizontal distribution of the quantity of wave overtopping has not been considered here, though it is important in designing seawalls. The authors wish to discuss the phenomenon another time after further investigations.

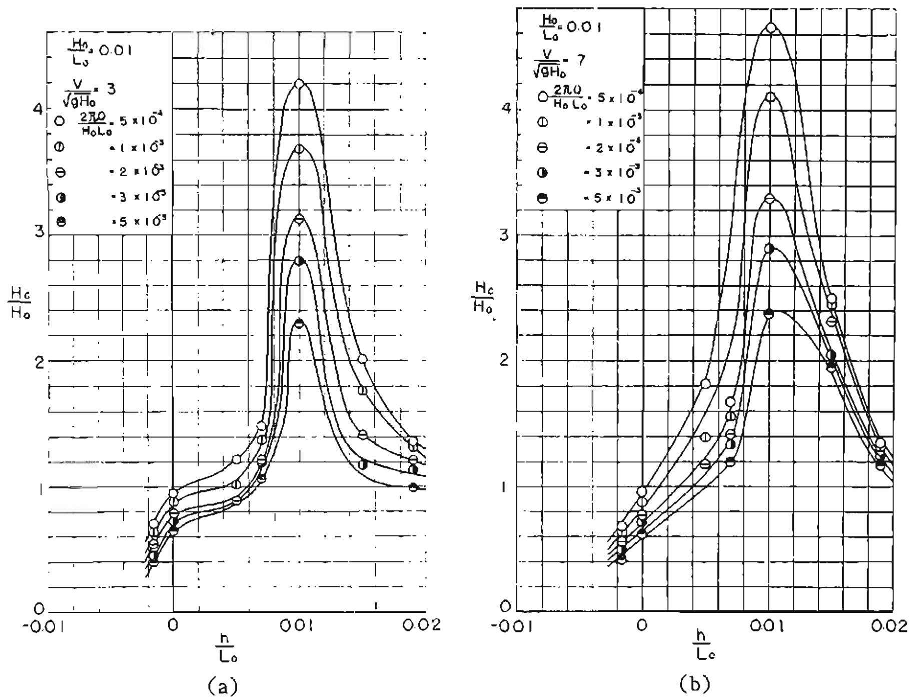


Fig. 12 Relations between relative height of seawall H_c/H_0 and relative water depth h/L_0 with a parameter of $2\pi Q/H_0L_0$ for case when $H_0/L_0=0.01$.

5. Conclusions

In view of the fact that it is very important to clarify the effect of wind on the rate of wave overtopping on seawalls and to estimate the quantity of wave overtopping as exactly as possible in designing seawalls, the authors have carried out some experimental studies on wave overtopping on a vertical seawall with a high speed wind wave tunnel for several years.

In the former part of this paper, some results of experiments on wave overtopping in calm conditions, in addition to the results already obtained by Saville, and Ishihara, Iwagaki and Mitsui, have been described and compared with them. In the latter part, some results of the direct effect of wind on wave overtopping have been presented. It is found from the results that the effect of wind on wave overtopping varies considerably with the relative water depth at the toe of a seawall, even if the incident wave steepness is constant. It is concluded, therefore, that in designing seawalls, the crest height of the seawall should be considered carefully from the view point of disaster prevention with the aid of basic results of investigation and detailed model experiments.

Since the results obtained by the experiment are only for the case of vertical seawalls and are not sufficient to apply the results to practical purposes, further studies will be carried out by more systematic experimental investigations to disclose the mechanism of wave overtopping in the future.

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