CHAPTER 116

ESTIMATION OF WAVE OVERTOPPING QUANTITY OVER SEA-WALLS

by

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ABSTRACT

This paper tried to formulate the wave overtopping quantity by using a model of overtopping mechanism. Namely, the author investigated the problem by applying the "Calculation method for discharge of overflow weirs" i.e. the method of Fukui et al. (1963)[1] and Shi-igai et al. (1970)[2].

INTRODUCTION

Actually it is very difficult to prevent perfectly the wave overtopping caused by irregular waves. Therefore, the sea-wall must be designed based on the conception of allowable wave overtopping quantity, on the premise that a drain system is constructed behind the sea-wall.

The conventional metbod of determining the crest height of sea-walls is based on the height of wave run-up. Recently, however, there is a tendency to introduce the wave overtopping quantity as the design criteria of sea-walls. Therefore, it is urgently required to establish a method of calculating the wave overtopping quantity.

According to previous researches, it has been disclosed that the wave overtopping quantity on a sea-wall has a close correlation with the spatial profile of wave run-up and the time history of surface elevation on a vertical sea-wall. At present, efforts are paid for finding out response functions of the above-mentioned factors and the quantity of the wave overtopping[1)~4)].

The author proposed the calculation formula of the wave overtopping quantity by using the spatial profile of wave run-up at the 13th Conference on Coastal Engineering in 1972[3)]. The said calculation formula comprise a controversial problem in the determination of the spatial profile of wave run-up for the complicated cross-sectional shape of sea-walls. Here, as a calculation formula that is free from any unreasonable point as a physical model and involves general applicable features, the author investigated the problem by applying the "Calculation method for discharge of overflow weirs" i.e. the method of Fukui et al.(1963)[1] and Shi-igai et al.(1970)[2].

Namely, overtopping waves on vertical sea-walls are regarded as complete overflows at sharp crest weirs[2)] and the characteristics of the discharge coefficient of overtopping waves to the vertical sea-walls were investigated empirically.

This paper tried to formulate wave run-up height and wave overtopping quantity on vertical sea-walls in the bottom slope of 1/10.

THE CALUCULATION FORMURA OF WAVE
RUN-UP HEIGHT ON VERTICAL SEA-WALLS

1. THE CLASSIFICATION OF THE WATER DEPTH AT THE TOE OF SEA-WALLS

The experiments made so far show that the water depth at the toe of sea-walls where causes the maximum run-up height corresponds nearly to the breaking point of progressive waves are approximately given by Eq.(1) proposed by Miche (1944)[5].

$$(H_b/L_b)_p = 0.142 \tanh 2\pi(h_b/L_b)_p, \tag{1}$$

for the sea-bottom slope of 1/10,

Where $(h_b)_p$ is the water depth of breaking of progressive waves, $(L_b)_p$ is the wave length at $(h_b)_p$ and $(H_b)_p$ is the wave height at $(h_b)_p$.

The calculated values of Eq.(1) are shown in the solid line of Fig.1. The solid line of Fig.1 shows the relation between the equivalent deep-water-wave steepness H_0'/L_0 and $(h_b)_p/L_0$.

When the wave after breaking hits a vertical sea-wall, however, there occur large amount of spray. The water depth at the toe of sea-walls where the spray height of wave run-up become a maximum for a given H_0'/L_0 value may be given by experiments as Eq.(2).

$$H_0'/L_0 = 0.21 \tanh (2\pi h_{R'max}/L_0), \tag{2}$$

for the sea-bottom slope of 1/10,

Where H_0' is the equivalent deep-water-wave height, L_0 is the wave length in deep water and $h_{R'max}$ is the water depth at the toe of a sea-wall where the spray height of wave run-up becomes a maximum.

The calculated values of Eq.(2) are shown in the dotted line of Fig.1.

2. THE CALCULATION FORMURA OF WAVE RUN-UP HEIGHT

By arranging the experimental values of wave run-up height with $(h_b)_p$ as boundary, the calculational formula may be such as follows.

2.1 The region of $h \gtrsim (h_b)_p$

In this region, the wave run-up height is thus nearly equal to the wave crest height of the standing wave. The wave crest height of the second-order approximation solution for finite amplitude standing wave is given by Eq.(3) proposed by Miche (1944)[5].

$$\frac{R}{H_0'} = \left[1 + \frac{\pi}{4}\frac{H}{L} \left\{ 3 \coth^3(2\pi\frac{h}{L}) + \tanh(2\pi\frac{h}{L}) \right\} \right] S, \tag{3}$$

Where R is the wave run-up height from the still water level, h is the water depth at the toe of a sea-wall, H is the incident wave height at h, L is the incident wave length at h, and S is the shoaling factor at h.

The S values are given by Eq.(4) from the small amplitude wave theory.

$$S = \frac{H}{H_0'} = \sqrt{\frac{(\sinh 4\pi\frac{h}{L})(\coth 2\pi\frac{h}{L})}{\sinh 4\pi\frac{h}{L} + 4\pi\frac{h}{L}}}\ , \tag{4}$$

The other hand, the relation between H_0'/L_0 and H/L, and the relation between h/L_0 and h/L can be expressed as Eq.(5) and Eq.(6) by the small amplitude wave theory, respectively.

$$\frac{H}{L} = \left(\frac{\sinh 4\pi\frac{h}{L}}{\sinh 4\pi\frac{h}{L} + 4\pi\frac{h}{L}}\right)^{1/2} (\coth 2\pi\frac{h}{L})^{3/2}\ \frac{H_0'}{L_0}, \tag{5}$$

$$\frac{h/L}{\tanh(2\pi\ h/L)} = h/L_0\ , \tag{6}$$

The calculated values of Eq.(3) either give wave run-up height close to the experimental values, or values somewhat over the experimental values[3),4)].

2.2 The region of $h = 0 \sim (h_b)_p$

(1) The essential run-up height of wave, R

In the region under researches, it is known experimentally that the R values are almost proportional to the h values[6)].

In consequence, if the R values on the vertical sea-walls are obtained, the calculational formula in this region will then be given as Eq.(7) by approximation.

$$\frac{R}{H_0'} = \left\{\frac{(R_b)_p}{H_0'} - \frac{R_0}{H_0'}\right\}\frac{h}{(h_b)_p} + \frac{R_0}{H_0'}\ , \tag{7}$$

where $(R_b)_p$ is wave run-up height on vertical sea-walls for $h = (h_b)_p$ and R_0 is wave run-up height on vertical sea-walls for beach line ($h = 0$).

The experimental values of R/H_0' for the sea-bottom slope of 1/10 is shown in Fig.2. The experimental values represented in the solid line, as shown, by approximation, may be expressed by Eq.(8).

$$R_0/H_0' = 0.18\ (H_0'/L_0)^{-1/2}\ , \tag{8}$$

for the sea-bottom slope of 1/10,

The $(R_b)_p/H_0'$ values can be calculated by Eq.(9) from Eq.(3).

$$\frac{(R_b)_p}{H_0'} = \left[\ 1 + \frac{\pi}{4}\left(\frac{H_b}{L_b}\right)_p \left\{3\ \coth^3 2\pi\left(\frac{h_b}{L_b}\right)_p + \tanh\ 2\pi\left(\frac{h_b}{L_b}\right)_p\right\}\right](S_b)_p, \tag{9}$$

Where $(S_b)_p$ is the shoaling factor for $h = (h_b)_p$ and can be calculated by Eq.(4). The $(S_b)_p$ values are also obtainable with Eq.(10).

$$(S_b)_p = \frac{(H_b)_p}{H_o'} = \frac{(H_b/L_b)_p}{H_o'/L_o} \; \frac{(h_b)_p/L_o}{(h_b/L_b)_p} \quad , \tag{10}$$

(2) The spray height of wave run-up, R'

a) The region of $h = h_{R'max} \sim (h_b)_p$

The calculated values of Eq.(3) were found to explain fairly well the experimental R' values in the region. Calculation of the R' values may thus be approximately by Eq.(11) from Eq.(3).

$$\frac{R'}{H_o'} = \left[1 + \frac{\pi}{4} \frac{H}{L} \left\{ 3\coth^3(2\pi\frac{h}{L}) + \tanh(2\pi\frac{h}{L}) \right\} \right] S \; , \tag{11}$$

b) The region of $h = 0 \sim h_{R'max}$

The results of author's experimental research show that in the region the R'/H_o' values are obtainable approximately by Eq.(12).

$$\frac{R'}{H_o'} = \left(\frac{R'_{max}}{H_o'} - \frac{R_o'}{H_o'} \right) \left(\frac{h}{h_{R'max}} \right)^2 + \frac{R'_o}{H_o'} \; , \tag{12}$$

Where R'_{max} is the maximum spray height of wave run-up for the wave of a given H_o'/L_o value. R'_{max} can be calculated by Eq.(13) from Eq.(11).

$$\frac{R'_{max}}{H_o'} = \left[1 + \frac{\pi}{4} \; (\frac{H}{L})_{R'max} \left\{ 3\coth^3 2\pi (\frac{h}{L})_{R'max} \right. \right.$$

$$\left. \left. + \tanh 2\pi (\frac{h}{L})_{R'max} \right\} \right] S_{R'max} \; , \tag{13}$$

where $S_{R'max}$ is the shoaling factor for $h = h_{R'max}$ and can be calculated by Eq.(4). The $S_{R'max}$ values are also obtainable with Eq.(14).

$$S_{R'max} = \frac{H_{R'max}}{H_o'} = \frac{(H/L)_{R'max}}{H_o' \,/\, L_o} \; \frac{h_{R'max}/L_o}{(h/L)_{R'max}} \quad , \tag{14}$$

where $(H/L)_{R'max}$ is shallow-water-wave steepness for $h = h_{R'max}$, and R_o'/H_o' is the spray height of wave run-up on vertical sea-walls for beach line (h = o).

The experimental values of R_o'/H_o' for the sea-bottom slope of 1/10 are shown in Fig.2. The experimental values represented in the dotted line, as shown, by approximation, may be expressed by Eq.(15).

$$R_o'/H_o' = 0.22(H_o'/L_o)^{-1/2} \; , \tag{15}$$

for the sea-bottom slope of 1/10,

(3) Adaptability of the calculational formula

Fig.3 shows the comparison between calculated values and experimental values[4),6)~8)]. The solid line is the calculated values of R/H_0' and the dotted line is the calculated values of R/H_0'. As described, the calculational formula exhibits good fitness to the experimental results. It is, therefore, well adaptable for actual problem.

In the region after breaking waves, the wave set-up has to be taken into consideration. This was, however, neglected in the present research. Taking account of the phenomenon, accuracy of the calculational formula should be improved still further.

CALCULATIONAL FORMURA OF THE WAVE OVERTOPPING QUANTITY OVER VERTICAL SEA-WALLS

1. APPLICATION OF THE WEIR DISCHARGE CALCULATIONAL METHOD[1),2)]

As indicated in Fig.4, the discharge calculational method for a sharp crest weir will be applied to obtain the quantity of wave overtopping[1),2)].

The quantity of wave overtopping Q of width B per a wave period is represented by Eq.(16) by using the method of Shi-igai et al. (1970)[2)].

$$Q = \int_{t_u}^{t_d} q(t)dt = \frac{2}{3}\sqrt{2g}\,B\int_{t_u}^{t_d} C(t)$$

$$\times \left[\left\{\eta^*(t) + h_a - H_c\right\}^{3/2} - (h_a)^{3/2}\right] dt, \tag{16}$$

where $q(t)$ is the discharge of wave overtopping per a unit time at time t, H_c is the crown height of a sea-wall from the still water level, $C(t)$ is the discharge coefficient of overtopping wave at time t, $\eta^*(t)$ is the time history of the surface elevation for a vertical sea-wall at the wave overtopping time, (h_a) is the water head of approach velocity, (t_u) is time when a wave of a given period start overtopping, (t_d) is the time when the overtopping is terminated, and g is the acceleration of gravity.

Here, for convenienc' sake of practical use, (h_a) is disregarded and the time history of surface elevation $\eta(t)$ on a vertical sea-wall for non-overtopping wave is used instead of $\eta^*(t)$, and erros caused from above assumptions are considered to be included in $C(t)$. On the other hand, assuming that an average value of times is used for $C(t)$ which is defined by a constant K, Q is given by Eq.(17), as proposed by Shi-igai et al. (1970)[2)].

$$Q = \frac{2}{3}\sqrt{2g}\;BK\int_{t_u}^{t_d}\left\{\eta(t) - H_c\right\}^{3/2} dt\ , \tag{17}$$

where K is the average coefficient of wave overtopping discharge.

Here, as shown in Fig.5, $\eta(t)$ is assumed to have approximately a trapezoidal profile, then Q is further given by follows, as proposed by the author (1972)[4)].

$$Q = \frac{2}{3}\sqrt{2g}\;BK\left[2\int_{t_u}^{t_d}\left\{\frac{(t - t_u)R}{(t_R)_u - t_u} - H_c\right\}^{3/2} dt\right.$$

$$\left. + \int_{(t_R)_u}^{(t_R)_d} (R - H_c)^{3/2}\,dt\right], \tag{18}$$

$$= \frac{4}{15}\sqrt{2g}\ BK(R - H_c)^{3/2}\left\{(1 - \frac{H_c}{R})(t_{oo} - t_{RR}) + \frac{5}{2}t_{RR}\right\}, \tag{19}$$

(t_{RR}) varies with H/L and h/L. Here, the values of (t_{RR}) are assumed to have approximately 0.05T. Therefore, the calculational formula of Q is expressed by Eq.(20), as proposed by the author (1972)[4].

$$Q = \frac{4}{15}\sqrt{2g}\ BK\ (R - H_c)^{3/2}\left\{(1 - \frac{H_c}{R})(\frac{t_{oo}}{T} - 0.05) + 0.125\right\}T, \tag{20}$$

where T is a wave period, and (t_{oo}) is shown in Fig.5.
The (t_{oo}) values are expressed by follows[4].

(1) The (t_{oo}) values for $h>0$

$$t_{oo}/T = (t_o/T)_d - (t_o/T)_u, \tag{21}$$

$$= 2(t_o/T),\ \text{for}\ \frac{1}{8}<t_o/T<\frac{1}{4}, \tag{22}$$

Here, the values of t_o/T are calculated from $\eta(t)$. Eq.(23) is $\eta(t)$ by the second-order approximation solution of finite amplitude standing wave.

$$\eta(t) = H\cos 2\pi\frac{t}{T} + \frac{\pi}{4}\frac{H}{L}H(3\coth^3 2\pi\frac{h}{L} - \coth 2\pi\frac{h}{L})\cos 4\pi\frac{t}{T} + \frac{\pi}{4}\frac{H}{L}H\coth 4\pi\frac{h}{L}, \tag{23}$$

with $\eta(t) = 0$ in Eq.(23), the values of t_o/T are calculated from Eq.(24).

$$\cos(2\pi\frac{t_o}{T}) = \frac{1}{\pi\frac{H}{L}}\left[\left\{1 + \frac{\pi^2}{2}(\frac{H}{L})^2 MN\tanh 2\pi\frac{h}{L}\right\}^{1/2} - 1\right], \tag{24}$$

where

$$M = \left\{3\coth^2(2\pi h/L) - 1\right\}\coth(2\pi h/L), \tag{25}$$

$$N = 3\coth^4(2\pi h/L) - 2\coth^2(2\pi h/L) - 1, \tag{26}$$

The (t_{oo}/T) values are then such as in Fig.6.

(2) The (t_{oo}) value for beach line ($h = 0$)

$$t_{oo}/T = 0.25, \tag{27}$$

2. EXPERIMENTAL RESULTS OF THE K VALUES

(1) The classification of the h values

By the experiments performed, the K values are known to differ largely with the (h) values[4]. The K values were thus studied for three regions, i.e. the region of $h > (h_b)_s$, the region of $h = (h_b)_p \sim (h_b)_s$ and the region of $h = 0 \sim (h_b)_p$, as shown in Fig.7.

Here, $(h_b)_s$ is the water depth of breaking for standing waves and can be calculated from Eq.(28) proposed by Kishi (1959)[10].

$$\left(\frac{H_b}{L_b}\right)_s = \frac{-\coth 2\pi \left(\frac{h_b}{L_b}\right)_s + \sqrt{\coth^2 2\pi \left(\frac{h_b}{L_b}\right)_s + 0.350 \operatorname{cosech}^2 2\pi \left(\frac{h_b}{L_b}\right)_s}}{0.592\pi \operatorname{cosech}^2 2\pi (h_b/L_b)_s}, \qquad (28)$$

where $(H_b)_s$ is the height of the incident wave which causes breaking of standing waves and $(L_b)_s$ is the wave length for $h = (h_b)_s$.

(2) Experimental results and the discussions

The K values were calculated with Eq.(29) from the Q_{exp} values and Eq.(20).

$$K = \frac{Q_{exp}(R - H_c)^{-3/2}}{\frac{4}{15}\sqrt{2g}\, B \left\{ \left(1 - \frac{H_c}{R}\right)\left(\frac{t_{oo}}{T} - 0.05\right) + 0.125 \right\} T}, \qquad (29)$$

where Q_{exp} are experimental values of wave overtopping quantity.

Here, for the R and (t_{oo}) values in Eq.(29), those by calculational formula mentioned were used.

Fig.8 (a) shows the relation between K_s and H_0'/L_0 for the region $h > (h_b)_s$. As in Fig.8 (a), the K_s values are not much influenced by H_0'/L_0. Though the experimental values are in considerable scattering, the average value can be taken approximately as $K_s = 0.38$. Therefore, the K_s values are smaller than the value of the discharge coefficient of sharp crest weirs ($K \doteqdot 0.65$).

Fig.8 (b) shows the relation between K_s and H_c/H_0' for the region of $h > (h_b)_s$. The K_s values are not much influenced by H_c/H_0', as shown in Fig.8 (b), and the K_s value in average is approximately 0.38.

Fig.9 (a) shows the relation between K_p and H_0'/L_0 for the region of $h = 0 \sim (h_b)_p$. The K_p values are not much influenced by the H_0'/L_0 values, as shown in Fig.9 (a).

Fig.9 (b) shows the relation between K_p and H_c/H_0' for the region of $h = 0 \sim (h_b)_p$. It is thus seen that, though the scattering in experimental values are fairly large, the K_p values become smaller with larger H_c/H_0' values. And the K_p values are generally smaller than the K_s values. If, then, the K_p values are represented by a solid line as in Fig.9 (b), the calculational formula for the K_p values is Eq.(30).

$$\log_{10} K_p = -\left(0.523 + 0.699 \frac{H_c}{H_0'}\right), \qquad (30)$$

(3) The calculation formula of the K values

From these experiment and the discussions, the K calculation formula are obtained by the following equations.

a) The region of standing waves $\left[h > (h_b)_s \right]$

$$K_s = 0.38 \ , \tag{31}$$

b) The region of transition into breaking waves waves $\left[h = (h_b)_p \sim (h_b)_s \right]$

$$K_b = (K_s - K_p)\left\{\frac{h - (h_b)_p}{(h_b)_s - (h_b)_p}\right\}^2 + K_p \ , \tag{32}$$

c) The region after breaking waves $\left[h = 0 \sim (h_b)_p \right]$

$$\log_{10} K_p = -(0.523 + 0.699 \frac{H_c}{H_0'}) \ , \tag{30}$$

for the sea bottom slope of 1/10,

(4) Adaptability of the K calculational formulas

Fig.10 shows the comparison between calculated values and experimental values[3),4),9)]. It is thus seen that, though the scattering in experimental values are fairly large, the calculated values indicate fairly accurately the tendency of the experimental values. However, it is for future study to improve the accuracy of these calculation formulas.

CONCLUSIONS

The author could experimentally obtain the calculation formulas both for wave run-up height and wave overtopping quantity on vertical sea-walls in the sea-bottom slope of 1/10.

The result obtained by the present study may be summarized as follows.

(1) In the region of $h > (h_b)_p$, the calculation formula of wave run-up height is given by Eq.(3).

(2) In the region of $h = 0 \sim (h_b)_p$, the calculation formula of wave run-up height is experimentally given by Eq.(7). And the calculation formulas of spray height of wave run-up are experimentally given by Eq.(11) and Eq.(12).

(3) The calculation formula of the wave overtopping quantity is given by Eq.(20).

(4) The average coefficients of wave overtopping discharge are generally smaller than the average value of the discharge coefficient for a sharp crest weir.

(5) The calculation formulas of the K values in Eq.(20) are given approximately Eq.(30)~Eq.(32).

ACKNOLEDGMENTS

As the author did not described carelessly that used the method of Fukui et al. (1963)[1] and Shi-igai et al. (1970)[2] in the paper of the author at "1974 Summaries" (Preprint, pp. 177 ~ 180) of the Conference, the author must have been misunderstood by fellow members. So, the author is very sorry to have done such a thing.

The author wish to thank Dr. H. Shi-igai (Asian Institute of Technology) for his helpful discussion and kind suggestions with respect to the format of this paper.

APPENDIXES

The method employed in this study is similar to those of Fukui et al. (1963)[1] and Shi-igai et al. (1970)[2].

The method of analysing the wave overtopping by approximating it with the steady weir overflow was originally presented by Fukui et al. in their study "On the Tsunami Wave Overtopping" (1963)[1].
Later, Shi-igai et al. (1970)[2], by applying this method to their study "On the Overtopping of Short-periodic Waves," investigated the characteristics of the virtual wave run-up, in which the time history curve of surface elevation of a triangular waveform and a constant discharge coefficient of wave overtopping were assumed.
With all the results these studies have attained, some important points still remain opened to further studies.

Namely:
1. The results are insufficient for the quantitative interpretation of the characteristics of the height of run-up, the time histories of surface elevation, and the discharge coefficient of wave overtopping.

2. A constant discharge coefficient of wave overtopping was assumed. Actually, however, it varies significantly with several parameters such as: the water depth at the toe of sea-walls; the crown height of sea-walls; wave steepness; sea-bottom slopes; the slope of sea-walls and others.

3. The formula for the wave overtopping calculation affords neither enough accuracy nor wide applicability.

4. The triangular approximation by Shi-igai et al. (1970)[2] for the time histories of surface elevation does not show good agreements with observations. Besides, in this study, the fundamental wave form assumes small amplitudes, which is inadequate for analysing such an involved phenomena as wave overtopping.

5. Shi-igai et al. (1970)[2] presented the virtual wave run-up concept and studied the characteristics of this phenomena. However, this approach could not permit positive utilization of the results of other studies previously performed.

Thus, intending to solve these problems, after examing extensive experimental results, the authors have presented the formula for the calculation of the height of wave run-up and the quantity of wave overtopping on vertical sea-walls.

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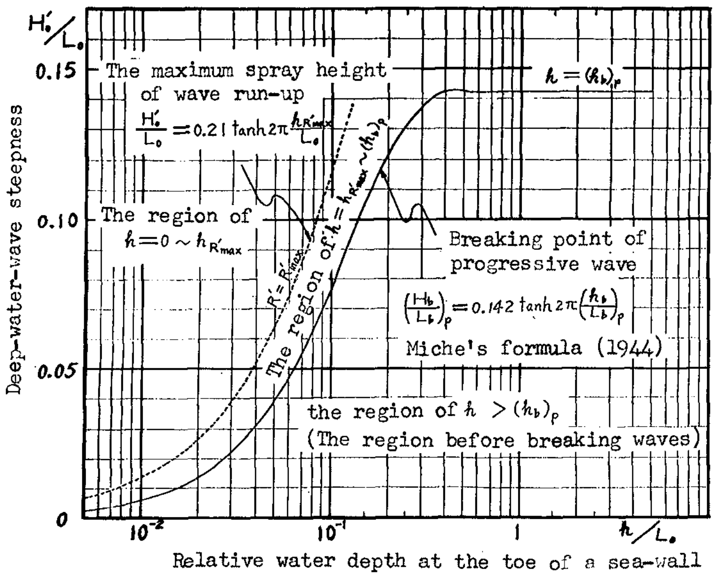


Fig. 1. The classification of the water depth at the toe of vertical sea-walls for the bottom slope of 1/10.

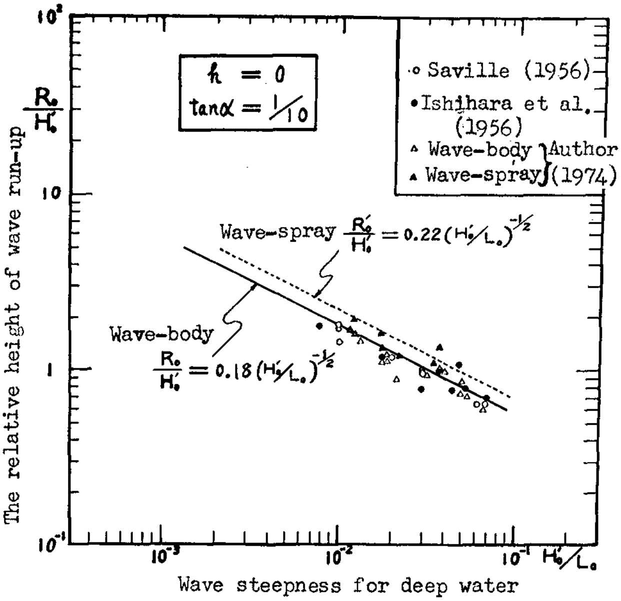
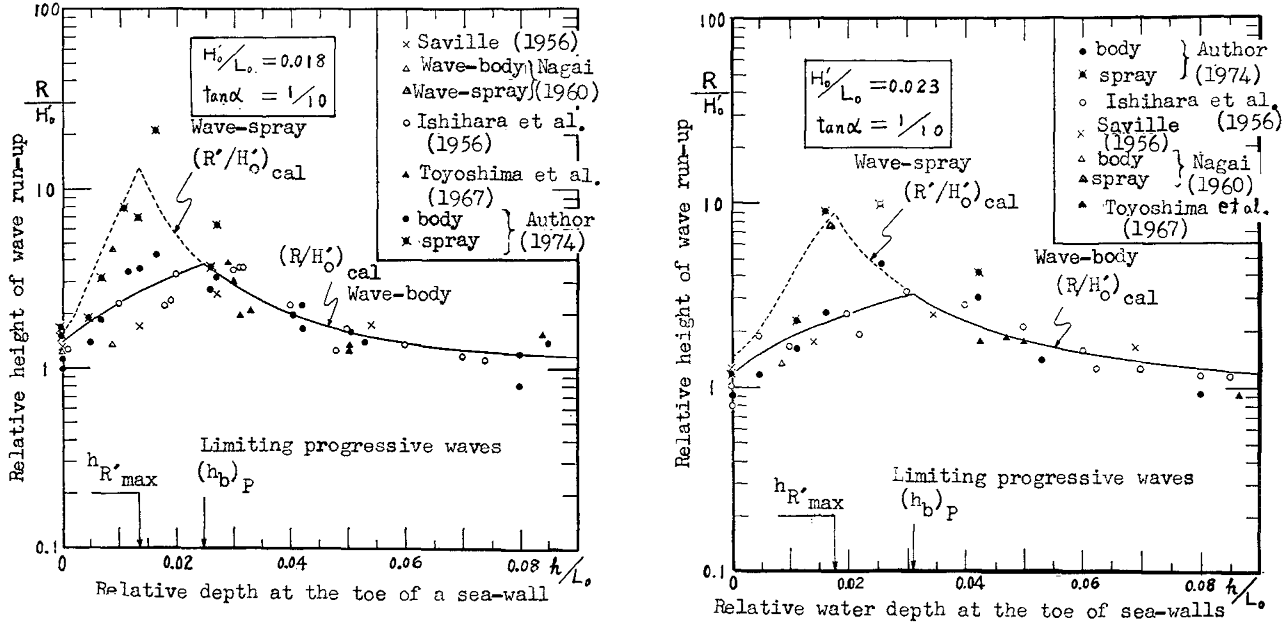


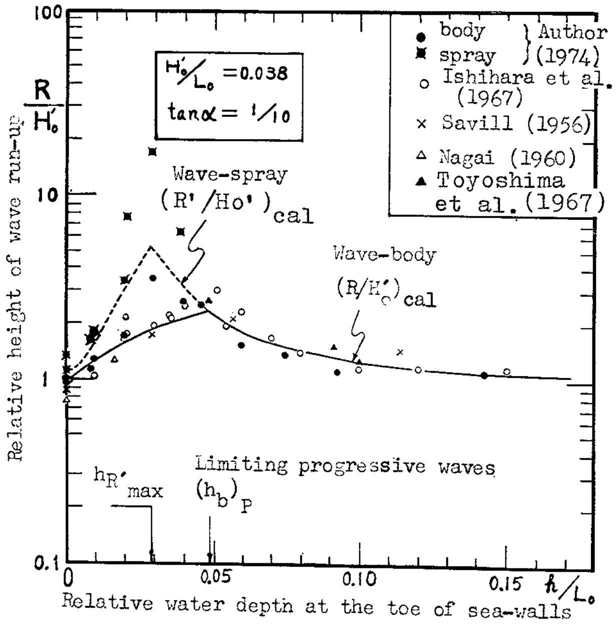
Fig. 2. Relations between R/H_0' and H_0'/L_0 for $h = 0$.



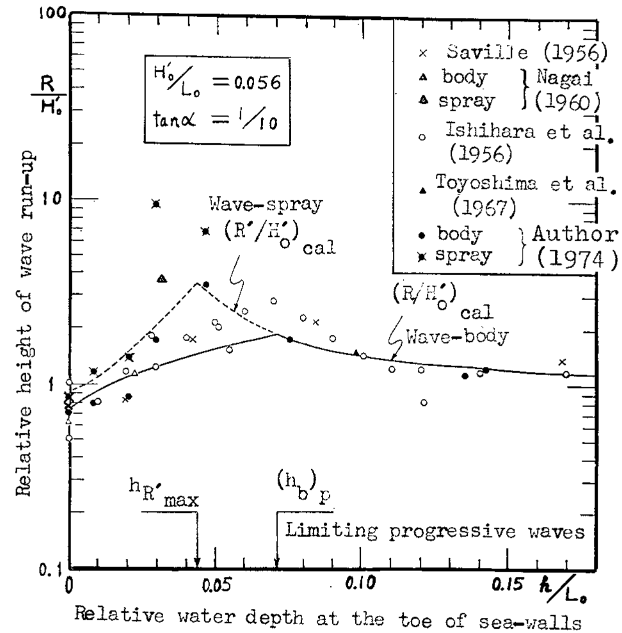
(a) Results for $H'_o/L_o = 0.018$ and the bottom slope of 1/10

(b) Results for $H'_o/L_o = 0.023$ and the bottom slope of 1/10

Fig. 3. Comparison between calculated and experimental values of the height of wave run-up for vertical sea-walls.



(c) Results for $H_0'/L_0 = 0.038$ and the bottom slope of 1/10



(d) Results for $H_0'/L_0 = 0.056$ and the bottom slope of 1/10

Fig. 3. Comparison between calculated and experimental values of the height of wave run-up for vertical sea-walls.

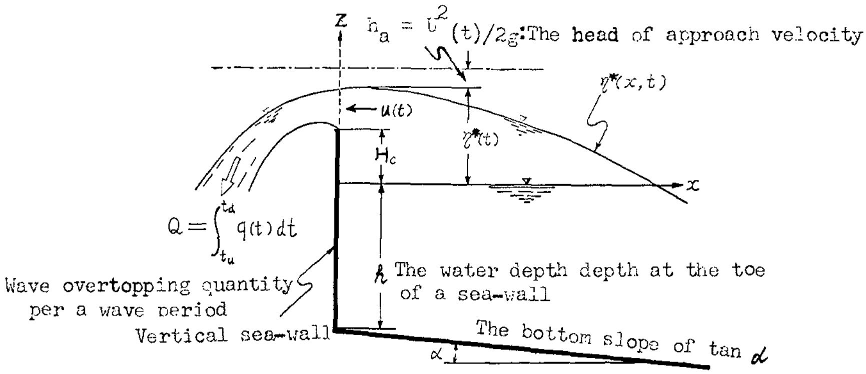


Fig. 4(a). Application of the discharge calculation method of the overflow weir for wave overtopping quantity.[2)]

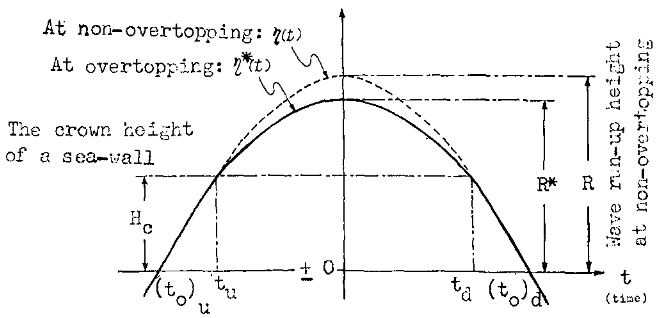


Fig. 4(b). Sketch of time history of the surface elevation at wave run-up.

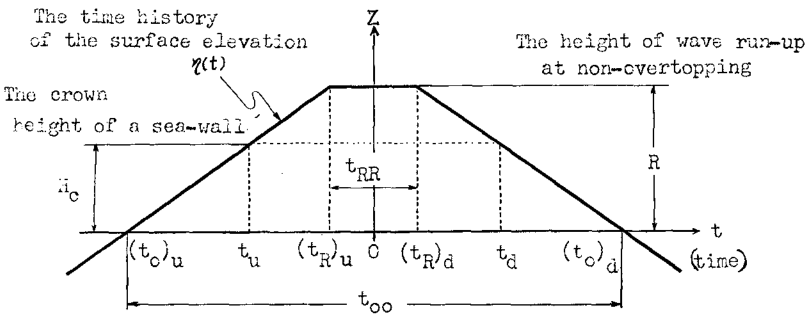


Fig. 5. The assumption of the time history of the surface elevation.

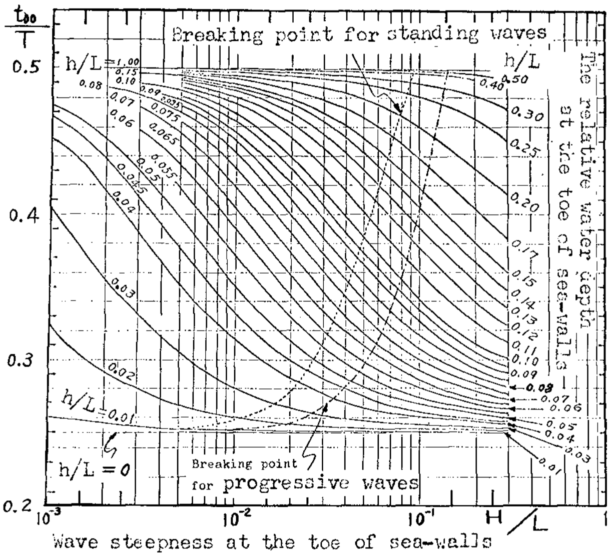


Fig. 6. Calculated value of t_{oo}/T.

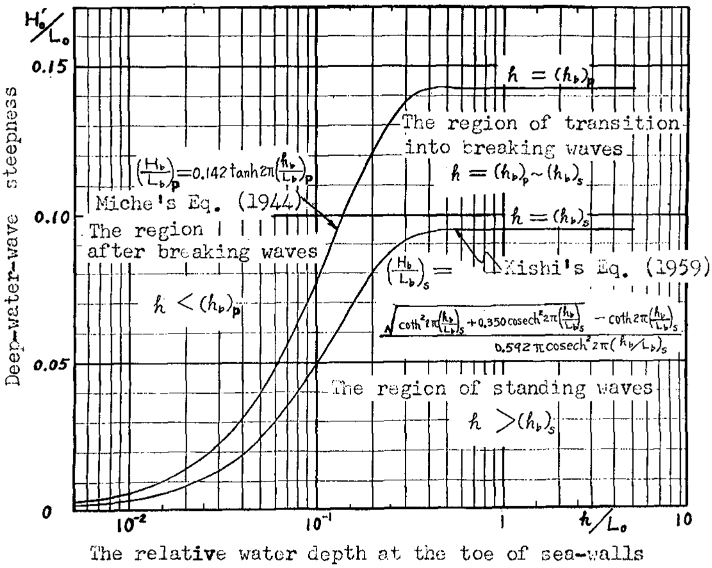
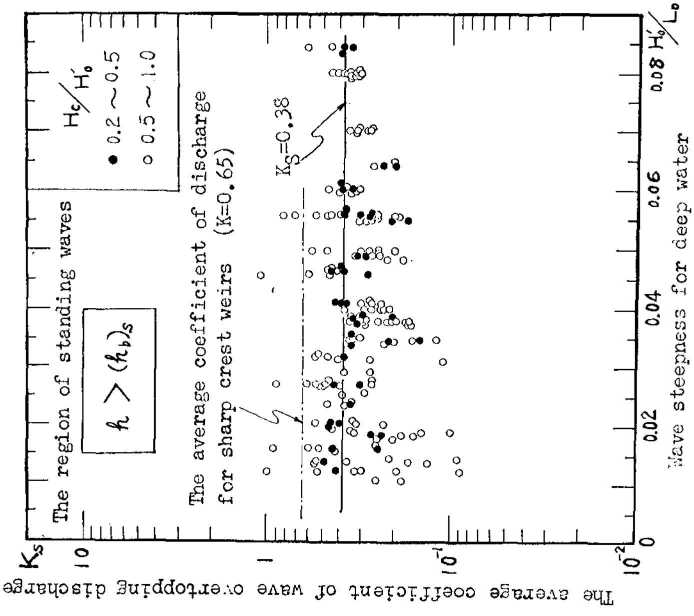
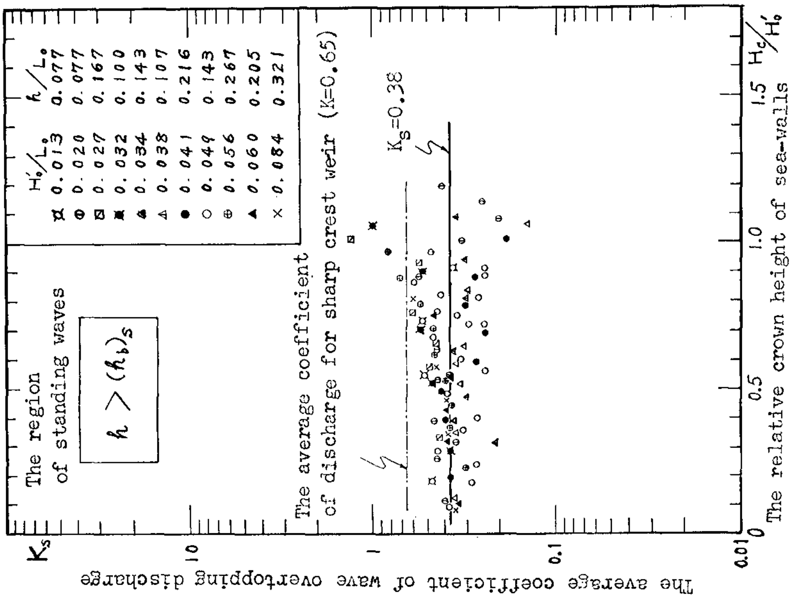


Fig. 7. The classification of the water depth at the toe of vertical sea-walls for the bottom slope of 1/10.

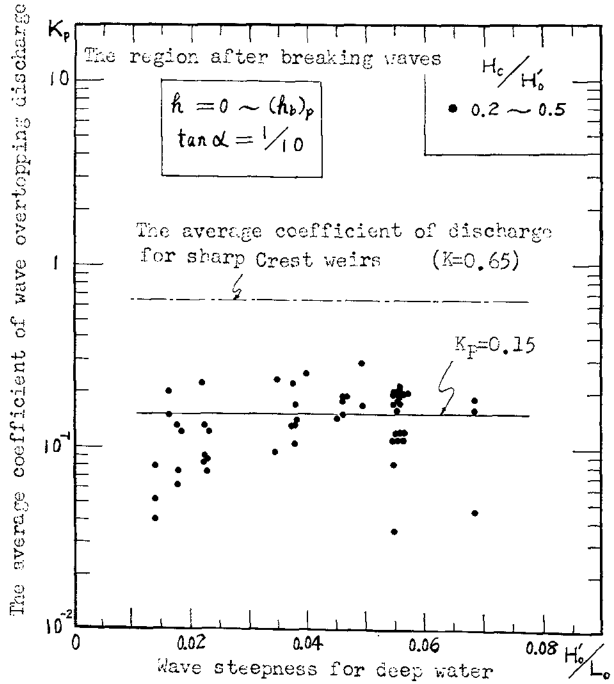


(a) Relations between K_s and wave steepness



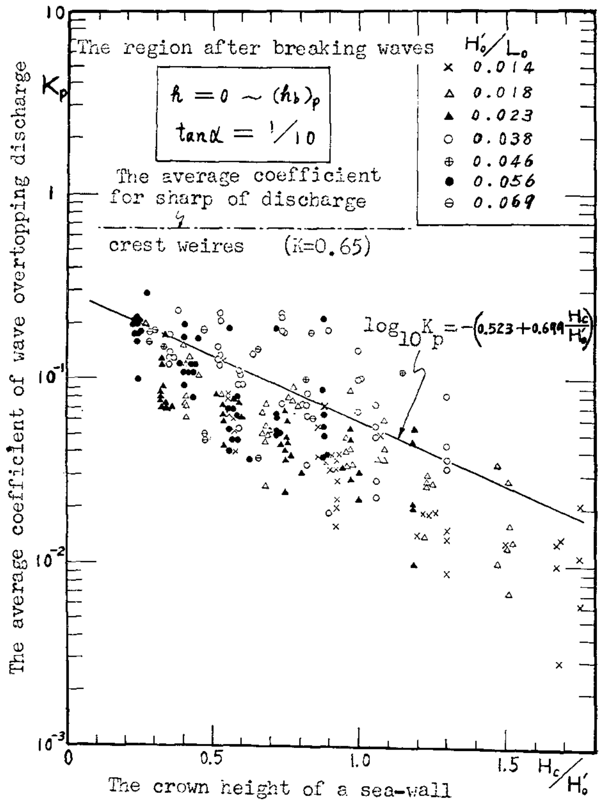
(b) Relations between K_s and the crown height of vertical sea-walls

Fig. 8. Experimental results of the average coefficient of wave overtopping discharge for $h \geqq (h_b)_s$.

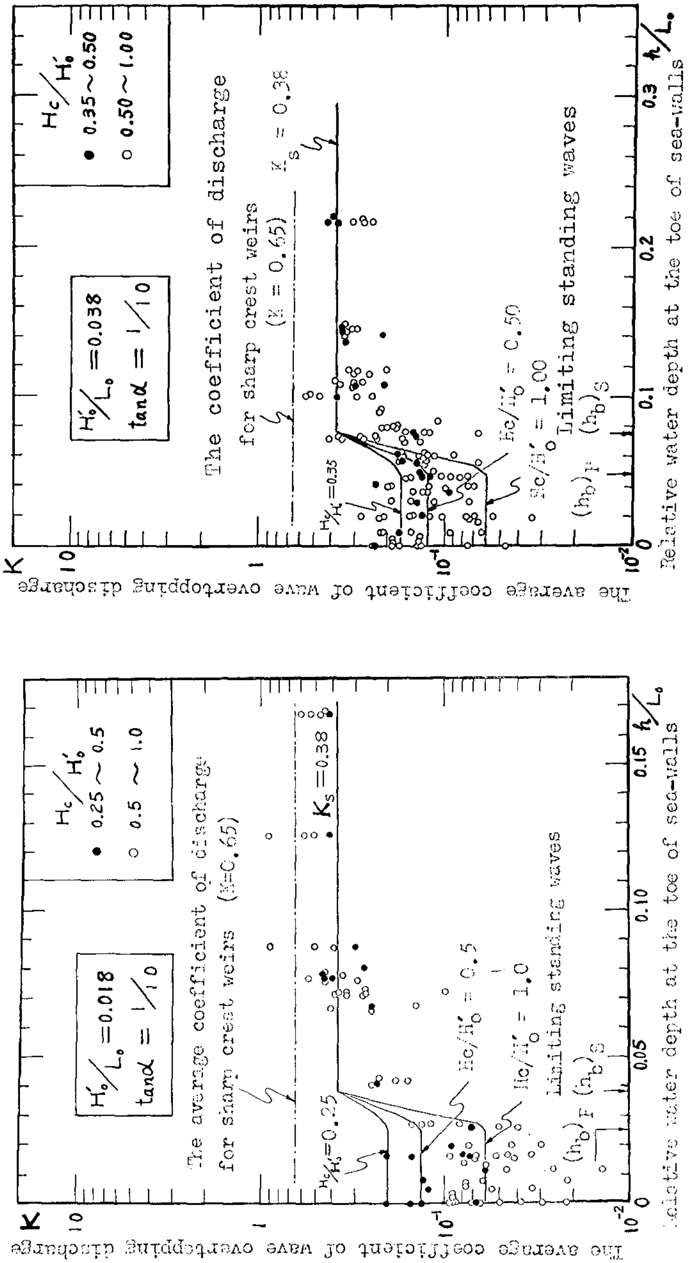


(a) Relations between K_p and wave steepness

Fig. 9. Experimental results of the average coefficient of wave overtopping discharge for $h = 0 \sim (h_b)_p$.



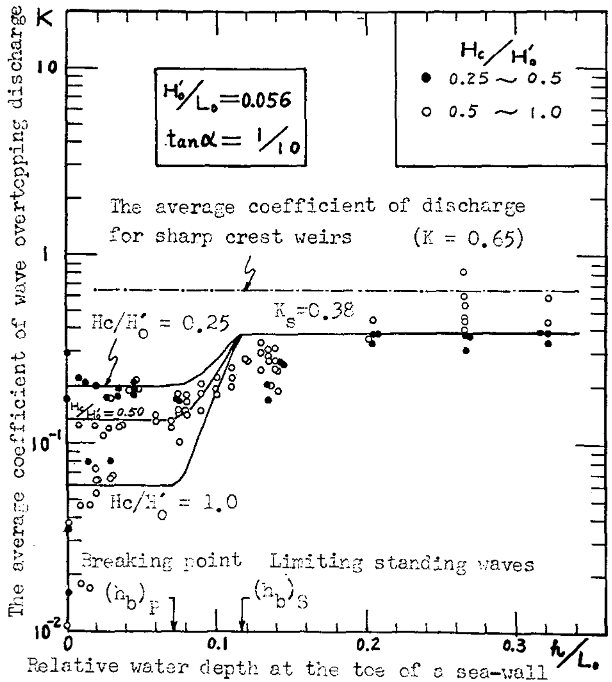
(b) Relations between K_p and the crown height of vertical sea-walls.



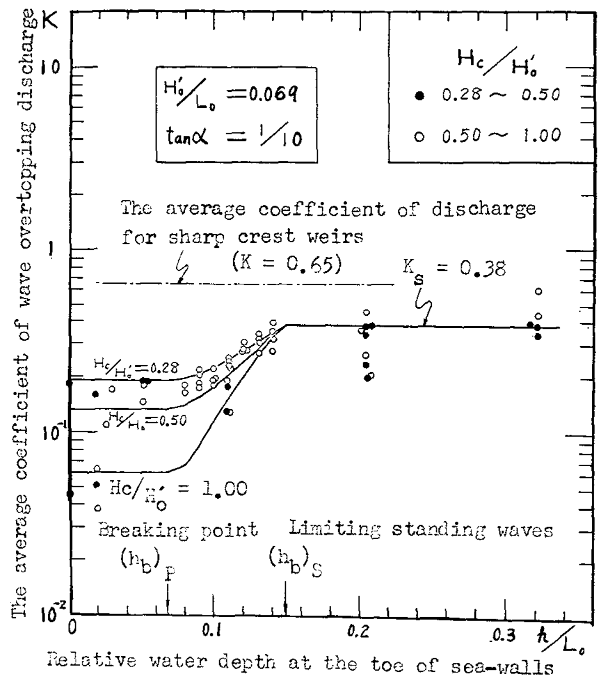
(a) Results for $H'_o/L_o = 0.018$ and the bottom slope of 1/10

(b) Results for $H'_o/L_o = 0.038$ and the bottom slope of 1/10

Fig. 10. Comparison between calculated and experimental values of the average coefficient of wave overtopping discharge for vertical sea-walls.



(c) Results for $H_o'/L_o = 0.056$ and the bottom slope of 1/10



(d) Results for $H_o'/L_o = 0.069$ and the bottom slope of 1/10

Fig. 10. Comparison between calculated and experimental values of the average coefficient of wave overtopping discharge for vertical sea-walls.