CHAPTER 123

SEAWALLS IN DEEP SEAS

by

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ABSTRACT

Features in wave overtopping of two new types of seawalls designed to be built in considerably deep sea conditions are presented herein. One of those is the seawall of concrete caisson with a parapet wall and armor blocks on the top of the caisson, and another one is the seawall with a slitted box-type wave absorber.

The former type of seawall has successfully been constructed in the Japan Sea and the Seto Inland Sea and is also to be constructed at a site directly exposed to an open sea of the Pacific Ocean in 1980 and 1981. The latter type of seawall was proposed in 1977 after numerous experiments and has been under construction in the Port of Osaka since 1978.

The results of the experiments on the wave overtopping over the slit-type seawall were compared with the calculated results, obtained by an analysis in which the wave overtopping over a parapet wall was considered similar to the phenomenon of flow over sharp-edged weirs having time-dependent overflow-head. The calculated curves obtained are in good agreement with the experimental results.

The designs of these two types of seawall are also presented herein.

INTRODUCTION

In recent two decades in Japan, a special type of seawall, in front of which a 1 : 1.5 slope covered with concrete armor blocks is built, has been constructed to protect reclaimed lands and coastal areas from overtopping of waves during typhoons. The water depths at the sites have been several meters to about ten meters or a little more. The heights of the design waves were several meters and the

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periods of them were 8 sec to 13 sec. Most of the seawalls, designed after experiments had been carried out at scales of 1/20 to 1/30, have been proved to be successful after attack of storm waves [1].

However, when the water depths where a seawall is built become so large as about 15 m to 25 m or more and the design waves are more than several meters in height and 13 sec to 15 sec in period, the section of the seawall mentioned above becomes very large; therefore its cost of construction becomes extremely high.

From such a reason, a new type of seawall was proposed in 1969 after numerous experiments had been carried out in the wave channel with a wind blower in our laboratory. This type of seawall is composed of a big concrete caisson with a parapet wall and concrete armors on the top. It has already been constructed at one place on the shore of the Japan Sea and one in the Seto Inland Sea, and has been under construction at a place on the shore of the Pacific Ocean since 1980.

In 1977 another type of seawall for deep seas was proposed. This type of seawall, called slit-type seawall, is composed of a concrete caisson and a slitted box-type wave absorber attached to it. It has been under construction in the Port of Osaka since 1978 [2].

CLASSIFICATION OF BEHAVIORS OF OVERTOPPING

As shown in Table 1, the behavior and quantity of overtopping waves over seawalls have been classified and judged in Japan the appropriateness of the seawalls by the relative overtopping quantity, q/q_0, in which q denotes the quantity of overtopping over the unit length of a seawall for a wave period and q_0 is the volume of water transported shoreward over the unit length of the seawall by a shallow water wave for a wave period ($= HL/2\pi$, H : wave height, L : wave length) [1].

As known from Table 1, the limiting relative overtopping quantity for a seawall is $q/q_0 = 5 \times 10^{-3}$, that is, when $q/q_0 \leqq 5 \times 10^{-3}$ the seawall can be effectively adoptable in the field.

TABLE 1.- Classification of Behaviors of Overtopping

Classification	Behavior of overtopping	q/q_0	Appropriateness
I	Only spray overtops (very well absorption of wave)	0 to 10^{-4}	Adequate for seawall
II	Lumps of water overtop (higher limit applicable to a seawall)	10^{-4} to 5×10^{-3}	
11I	A substantial part of wave overtops (imperfect absorption of wave)	5×10^{-3} to 10^{-2}	Inadequate for seawall
IV	Large volume of wave overflows (poor absorption of wave)	10^{-2} to 10^{-1}	

SEAWALL OF CONCRETE CAISSON WITH A PARAPET WALL AND ARMOR BLOCKS ON THE TOP

The latest seawall of concrete caisson with a parapet wall and armor blocks on the top has been under construction since 1980 at a site, Gobo, directly exposed to an open sea of the Pacific Ocean, as shown in Fig. 1, to protect a reclaimed land of about 350,000 m^2 for a thermal power station from wave overtopping during typhoons. Fig. 2 shows the cross-section of the seawall. The water depth at the site is about 18 m below Datum Line (D.L.), and the design wave height and period are $H_{1/3}$ = 9 m and $T_{1/3}$ = 13 sec at the design sea level of 3.6 m above D.L.. The sea-bottom in front of the seawall has a slope of 1/100. N-shaped blocks are used as the concrete armors to be placed on the top of the caisson because they have much greater stability against wave attack than other specially-shaped concrete armors, in addition to their distinguished ability for absorbing wave energy [3].

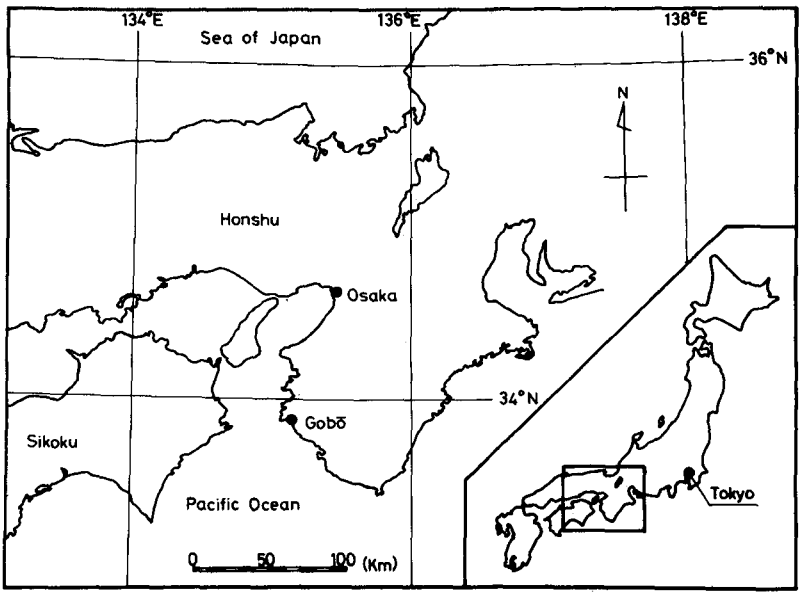

Fig. 1.- Location Map of Seawalls

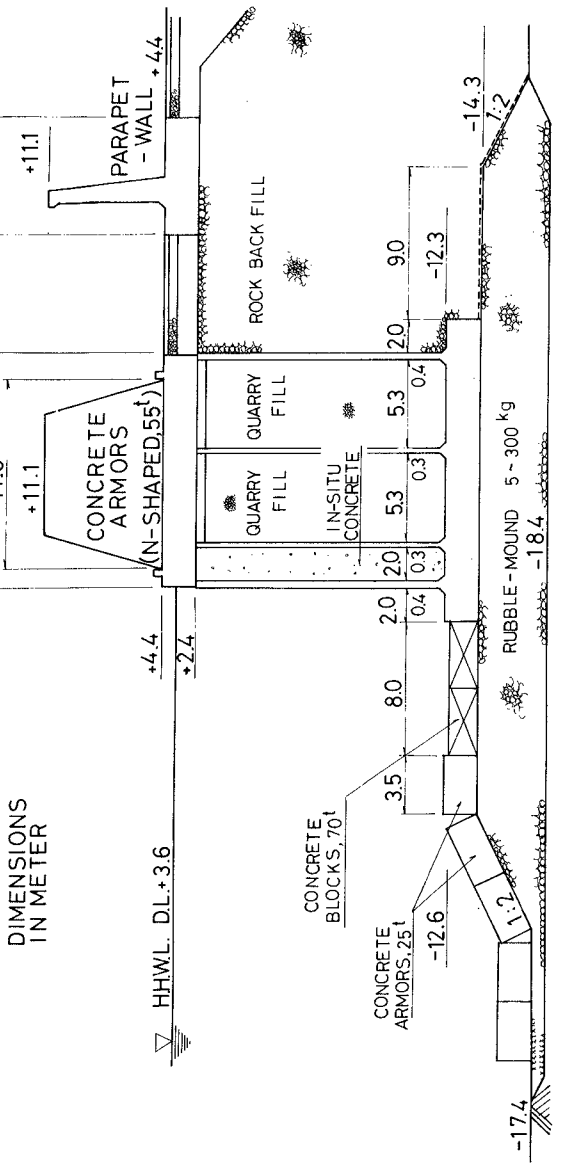

Fig. 2.- Seawall of Concrete Caisson with a Parapet Wall and Armor Blocks on the Top

Experimental Equipment and Procedures

In order to measure wave overtopping quantity over the seawall shown in Fig. 2 and to examine the stability of the concrete armors against wave attack, a great number of experiments were carried out at a scale of 1/35 using a wave channel with a wind blower, 100 m long, 1.2 m wide, and 2.0 m high, shown in Fig. 3.

The characteristics of the waves and winds used in the experiments are shown in Table 2.

Winds of velocities of 10 m/sec were blown in models over the waves in the wave channel to simulate the circumstances of the actual overtopping waves and sprays over the seawalls in the field.

Fig. 3.- Wave Channel (100 m long) with a Wind Blower

TABLE 2.- Characteristics of Waves and Winds in the Experiments

Wave characteristics (prototype)		Wind velocity (model)	Sea level (prototype)
Period T_p (sec)	Height H_p (m)	V_m (m/sec)	D.L. + (m)
13	8.7 to 12.4	10	3.6
10	8.5 to 12.6		
15	9.0 to 10.1		

As listed in Table 3, four conditions of the armor blocks were tested in the experiments. Fig. 4 shows the N-shaped block of 6 ton, and Fig. 5 shows the way of placing of the N-shaped blocks in two layers on the top of the caisson.

TABLE 3.- Conditions of the Armor Blocks on the Top of the Caisson

Cross-section	Armor blocks	Weight (ton)	Placing	Width of placing (meter)	Top of armor blocks (meter)	Top of parapet wall (meter)
I	N-shaped	28	2 layers (5,4) rows	15.8	D.L. + 9.5	D.L. + 11.1
II		28	3 layers (5,4,3) rows	15.8	D.L. + 11.5	D.L. + 10.1
III		55	2 layers (3,2) rows	11.0	D.L. + 11.1	D.L. + 11.1
IV		55	2 layers (4,3) rows	14.8	D.L. + 11.1	D.L. + 10.1

Fig. 4.- N-Shaped Block

Fig. 5.- N-Shaped Blocks in Two Layers

Experimental Results

Stability of the armor blocks was firstly examined using the cross-sections-I and -II with 28-ton N-shaped blocks in two or three layers. The results of the experiments for the waves used in the experiments showed that the N-shaped blocks of 28 tons were stable and the relative wave overtopping quantity, q/q_0, for both sections was about 1×10^{-3}, smaller than the limiting quantity of 5×10^{-3}, if they were placed on the top of the caisson in two or three layers.

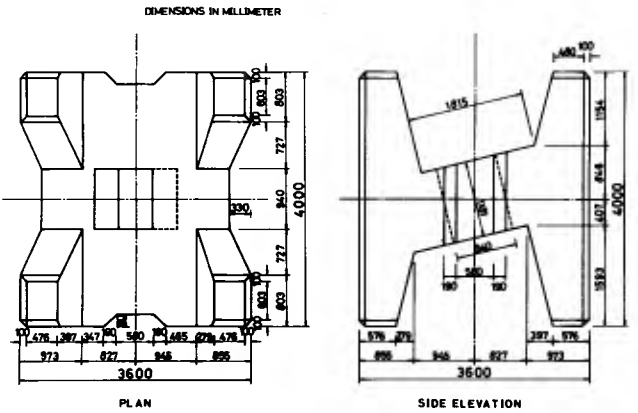

Fig. 6.- Detail of 55-Ton N-Shaped Block

Reinforced 55-ton N-shaped blocks, shown in Fig. 6, however, were decided to use in practice for more safety. Fig. 7 shows the results of q/q_0 as a function of wave height, H, for the seawalls with the 55-ton N-shaped blocks of the sections-III and -IV.

From Fig. 7 it may be stated that the overtopping quantities in the sections-III and -IV are almost same if the characteristics of the waves are same, and q/q_0 for the design wave of $T_{1/3}$ = 13 sec and $H_{1/3}$ = 9 m is about 1×10^{-3} in these two sections. Therefore, the seawalls with these sections are adoptable to the seas, as known from Table 1.

The section-III, shown in Fig. 2, was decided to adopt as the design section, because the width of placing of the armor blocks, 11.0 m, is smaller than the width of the caisson, 14.0 m.

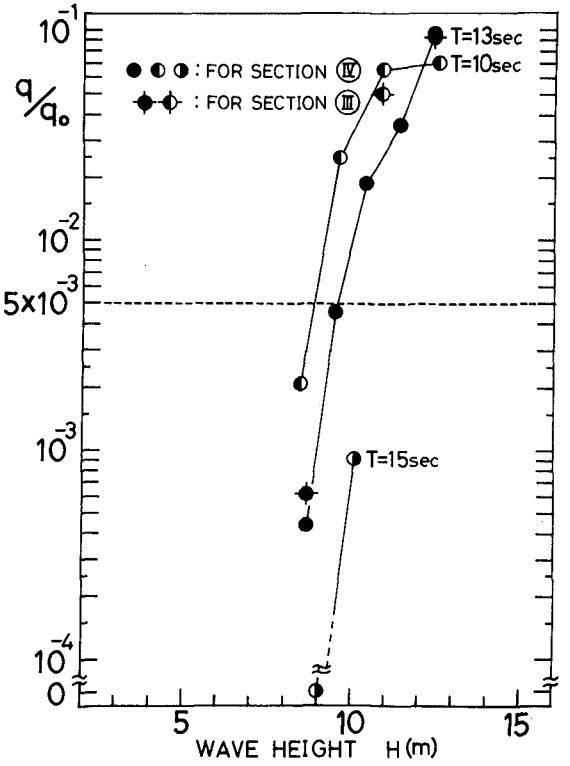

Fig. 7.- q/q_0 as a Function of Wave Height

SLIT-TYPE SEAWALL

The slit-type seawall, shown schematically in Fig. 8, is composed of a concrete caisson founded on a rubble mound and a box-type wave absorber, attached to the caisson, with a slitted vertical front-wall and a slitted horizontal bottom-wall. Experimental results have already proved that this type of structure has features of low reflection and distinguished reduction in wave pressures [4, 5], and also has an ability of reduction in wave overtopping to a considerable extent if it is used as a seawall.

Experimental Equipment and Procedures

The experiments were carried out at a scale of 1/25 by using a wave channel with a wind blower, 50 m long, 1.0 m wide, and 1.75 m high.

The heights and periods of the waves used in the experiments are H = 2.0 m to 6.0 m, and T = 6.0 sec to 12.0 sec. The velocity of wind used is constant V = 23 m/sec in prototype through the experiments. The widths of wave chambers of the slitted box-type wave absorbers are l = 3.75 m and l = 2.50 m in prototype. The void ratios of the vertical front-wall and horizontal bottom-wall are constant $\lambda = 0.24$ and $\lambda' = 0.14$, respectively, through the experiments. The depths of water where the seawalls locate are h = 12.2 m, 13.2 m, 14.2 m, and 15.3 m. The rubble mound on which the caisson is founded has a top width of B = 10.5 m in prototype and a sea-side slope of 1 : 2.

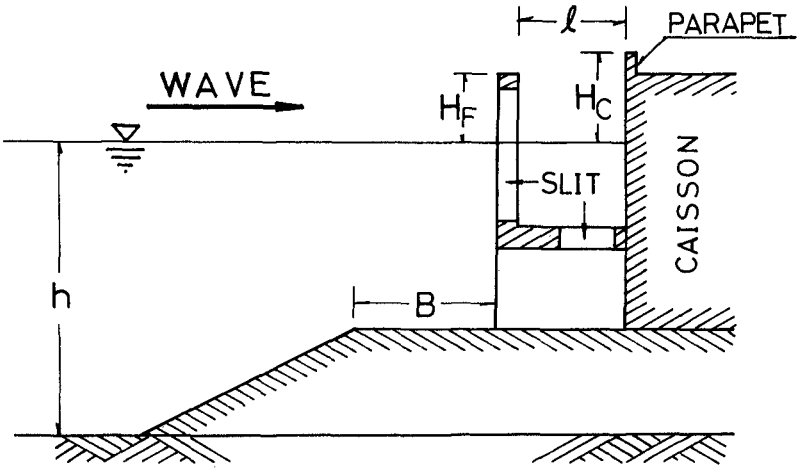

Fig. 8.- Schematic Cross-Section of the Slit-Type Seawall

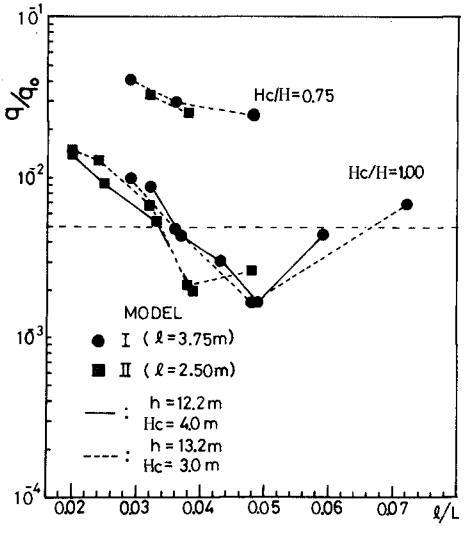

Fig. 9.- Relationship between q/q_0 and $1/L$

Experimental Results

The values of relative overtopping quantity, q/q_0, for the slit-type seawall depend mainly upon the relative wave chamber width, $1/L$ (wave chamber width/wave length). The minimum value of q/q_0 is obtained to be about 1×10^{-3} at the range of about 0.04 to 0.05 of $1/L$, if the relative parapet wall height $H_c/H = 1.0$, as shown in Fig. 9, in which H_c denotes the height of the top of the parapet wall above the design sea level. The range of about 0.04 to 0.05 of $1/L$ where the minimum value of q/q_0 is obtained does not vary even though H_c/H becomes larger than 1.0. The values of 0.04 to 0.05 of $1/L$ for the minimum relative overtopping, $(q/q_0)_{min}$, of the slit-type seawalls are less than half of 0.13 to 0.18 for the minimum reflection coefficient, $(K_R)_{min}$, of the slit-type breakwater or quay-wall [4]. Because the horizontal velocities of the waves plunging into the wave chamber are attenuated by making the value of the relative chamber width to be 0.04 to 0.05.

The relations between q/q_0 and H_c/H in association with the characteristics of waves may be much of interest in the design of the seawalls. Figs. 10 through 13 show the relationships between q/q_0 and H_c/H when the values of $1/L$ fall within the range of 0.04 to 0.05 for $(q/q_0)_{min}$. From these figures it can be seen that the values of q/q_0 and H_c/H are in a certain relation regardless of the incident wave heights, and the values of q/q_0 become smaller than the limiting relative wave overtopping quantity of 5×10^{-3}, if H_c/H is taken to be larger than 1.0 and H_F/H, in which H_F denotes the height of the top of the vertical front-wall above the design sea level, is taken to be larger than or equal to 0.70.

Comparisons of wave overtopping quantities of the slit-type seawalls with those of other types showed that the slit-type seawalls give much smaller values of q/q_0 in most cases [2].

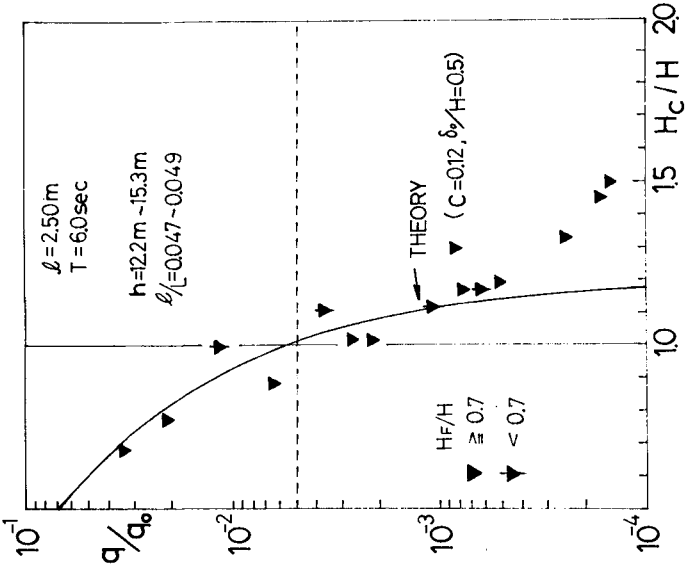

Fig. 10.- Relationship between q/q_0 and H_C/H

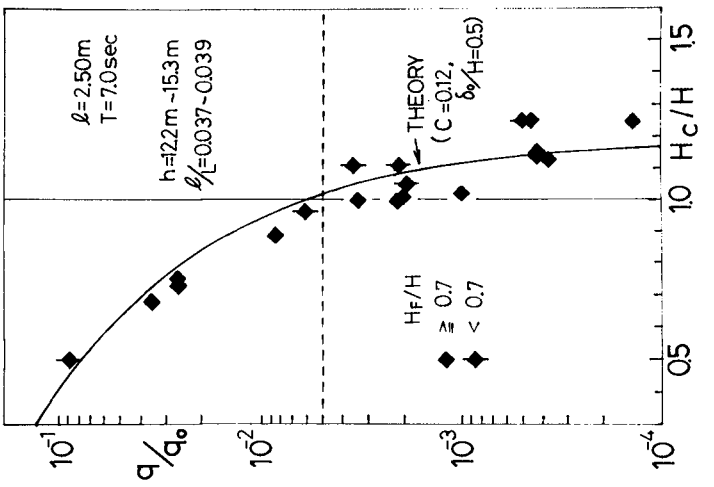

Fig. 11.- Relationship between q/q_0 and H_C/H

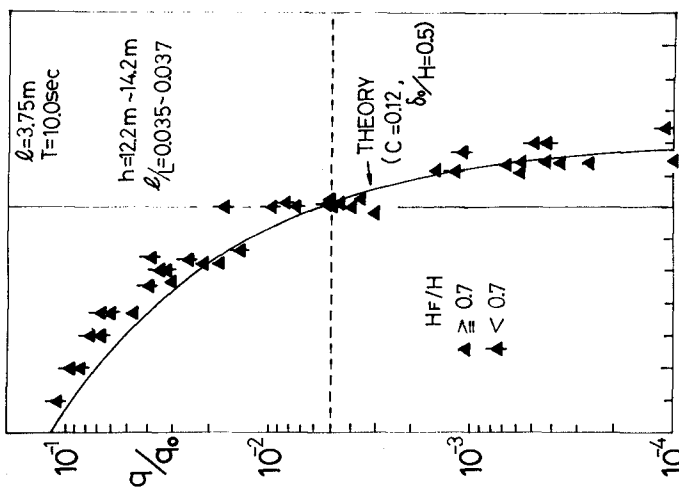

Fig. 13.- Relationship between q/q_0 and H_c/H

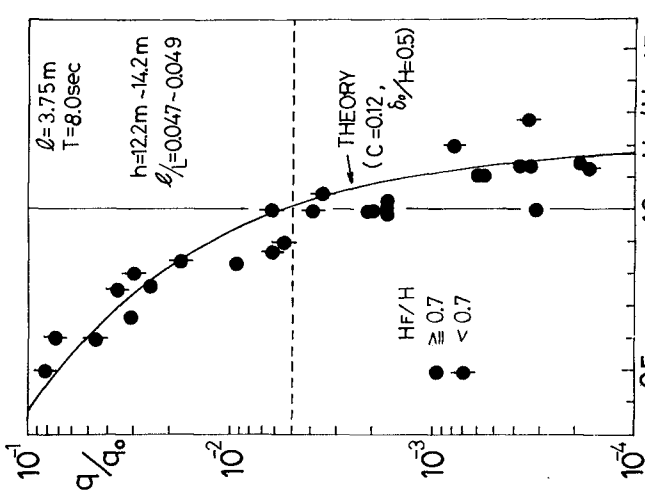

Fig. 12.- Relationship between q/q_0 and H_c/H

Calculations of Overtopping Quantities for the Slit-Type Seawall

When the water level inside the wave chamber of the slit-type seawall becomes higher than the top of the parapet wall, water flows over the parapet wall. The overflow was observed to occur calmly if 1/L was smaller than 0.06. This phenomenon implies that the analytical approach on wave overtopping over vertical seawalls [6] can also be useful for the analysis on the wave overtopping over the slit-type seawall with the values of 0.04 to 0.05 of 1/L.

(1) Assumptions and analysis

The surface elevation inside the wave chamber is considered to be a perfect standing wave with the wave height of $2\gamma_T \cdot H$, in which γ_T is the transmission coefficient of the perforated (slitted) walls of the absorber and H denotes the incident wave height, because it is composed of the transmitted wave, η_T, through the perforated wall and the reflected wave, η_{TR}, from the solid back-wall, as previously described [4].

Therefore the time history of the surface elevation inside the wave chamber can be written

$$\eta(t) = \gamma_T \cdot H \cdot \sin(2\pi t/T) + \delta_0 \tag{1}$$

in which T is the period of the wave, $\eta(t)$, and is identical with that of incident waves, and δ_0 is the mean water surface elevation from the still water level at the solid-back wall, which can be observed in the experiments and could be subject to the characteristics of the incident waves, water depths, wave chamber widths, and the profiles of the rubble mounds.

Supposing that the parapet wall of the seawall is a sharp-edged weir, and that the overflow-head for it is $\eta(t) - H_c$, varying with time, one gets the overtopping quantity over the unit length of the seawall for a wave period as

$$q = 2\int_{t_1}^{t_2} \frac{2}{3} \cdot C(t) \cdot \sqrt{2g}\,\{\eta(t) - H_c\}^{3/2} dt \tag{2}$$

in which t_1 is the time when $\eta(t)$ equals H_c, t_2 is the time when $\eta(t) = \eta(t)_{max} = \gamma_T \cdot H + \delta_0$, and C(t), termed the coefficient of wave overtopping in this paper, is the coefficient corresponding to the discharge coefficient used in the expression for the discharge of the flow over weirs.

Supposing that the coefficient of overtopping is constant with time, i.e., C(t) = C, and substituting Eq.(1) into Eq.(2), one can get

$$q = \frac{4\sqrt{2}}{3} \cdot C \cdot (\gamma_T \cdot H)^{3/2} \int_{t_1}^{t_2} \left\{\sin\frac{2\pi}{T} t - \frac{1}{\gamma_T}\left(\frac{H_c}{H} - \frac{\delta_0}{H}\right)\right\}^{3/2} dt \tag{3}$$

Dividing Eq.(3) by $q_0 = H \cdot L/2\pi$ to express Eq.(3) in the form of the relative overtopping quantity, and putting $t' = 2\pi t/T$ to express the integral term of Eq.(3) in non-dimensional form, one eventually obtains

$$q/q_0 = \frac{4\sqrt{2}}{3} \cdot C \cdot \gamma_T{}^{3/2} \cdot \frac{T\sqrt{gH}}{L} \int_{t_1'}^{t_2'} \{\sin t' - \frac{1}{\gamma_T}(\frac{H_c}{H} - \frac{\delta_0}{H})\}^{3/2} dt' \qquad (4)$$

in which $t_1' = \arcsin(\frac{H_c}{H} - \frac{\delta_0}{H})/\gamma_T$ and $t_2' = \pi/2$.

(2) Comparison with the experimental results

The full lines in Figs. 10 through 13 show the calculated results by Eq.(4). The value of $\gamma_T = 0.70$, which is the same value used in the calculations for the reflection coefficient of the box-type wave absorber [4], is used in the calculations. The values of C and δ_0/H in Eq.(4) are assumed to be $C = 0.12$ and $\delta_0/H = 0.50$ in order to fit the calculated results to the experimental results. The height of incident waves used in the calculations except the case of $T = 6.0$ sec is $H = 4.0$ m, which is the average value of the wave heights used in the experiments. For the case of $T = 6.0$ sec, $H = 3.0$ m is used to avoid the excessive wave steepness. The water depth used in the calculations is $h = 12.0$ m, which is about the same value as used in the experiments.

Figs. 10 through 13 show that the calculated curves obtained by the use of Eq.(4) with $C = 0.12$ and $\delta_0/H = 0.50$ are in good agreement with the experimental results. Most of the experimental results with the values of $H_F/H < 0.7$ in Figs. 10 through 13 are larger than the experimental results with the values of $H_F/H \geqq 0.7$ and the calculated curves. The reason is that the upper portion of the wave crest just outside the front-wall plunges into the wave chamber over the top of the front-wall, and then it strongly hit the back-wall, to cause large sprays.

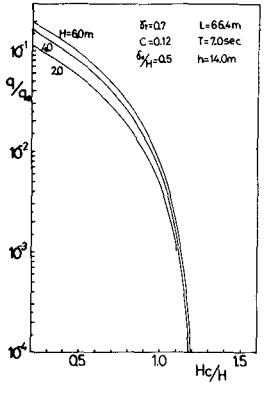

Fig. 14.- Effect of Wave Height

The calculated results also show that the effect of the incident wave heights on q/q_0 is not significant in the region of $H_c/H \geqq 1.0$, as shown in Fig. 14.

Slit-Type Seawall in the Port of Osaka [2]

The slit-type seawall of 3,700 m length, the cross-section of which is shown in Fig. 15, has been under construction in the sea in the Port of Osaka, where the water depth is about 10 m to 12 m below the D.L., and the height and period of the design wave are $H_{1/3} = 3.3$ m and $T_{1/3} = 7.0$ sec.

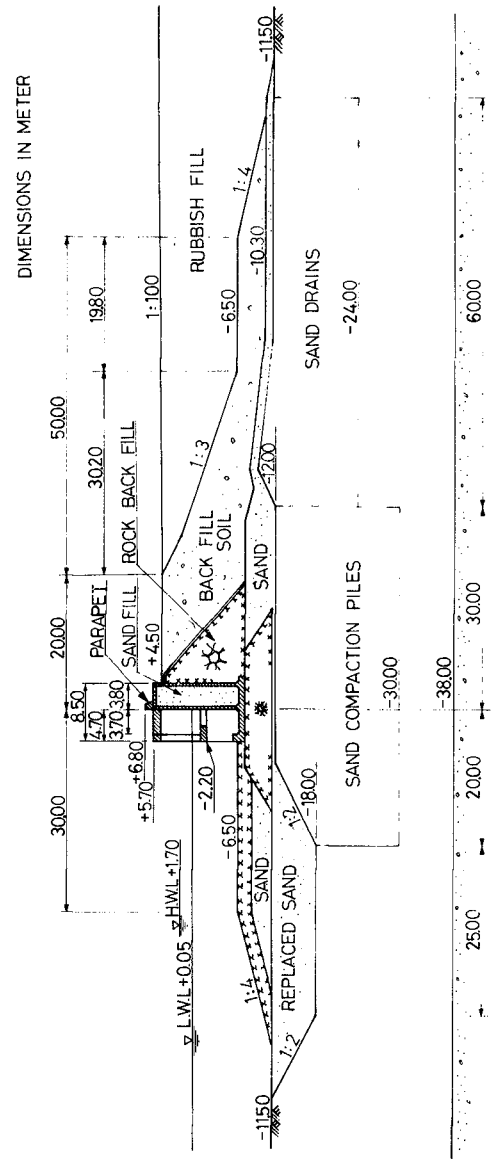

Fig. 15.- Cross-Section of Seawall in the Port of Osaka

The width of the wave chamber was taken l = 3.7 m to make the relative chamber width, l/L, equal to 0.15 for waves with a period of 4 sec, which occur most frequently when small fishing boats are in operation in the sea. Then the reflection coefficient takes the minimum values, $(K_R)_{min}$ = 0.10 to 0.20. The void ratios of the front-wall and bottom-wall were taken to be λ = 0.22 and λ' = 0.14, respectively. The height of the top of the parapet wall was taken D.L. + 6.8 m to make the relative wave overtopping quantity $q/q_0 \simeq 1 \times 10^{-3}$ for the design sea level of D.L. + 3.5 m and the design wave, by taking H_c/H = 1.0 and $l/L \simeq 0.05$, as shown in Fig. 9, for the wave period of T = 7.0 sec, which is the period of storm waves during typhoons.

Fig. 16 shows the completed caisson of the seawall, and Figs. 17 and 18 show the upper part and lower part of the seawall taken from the inside of the wave chamber.

Fig. 16.- Completed Caisson for Seawall

Fig. 17.- Upper Part of Wave Chamber of the Seawall

Fig. 18.- Lower Part of Wave Chamber of the Seawall

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