CHAPTER 151

PERMEABLE SEAWALL WITH RESERVOIR AND THE USE OF "WAROCK"

by

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Abstract

Interesting facts that a uniformly permeable seawall of vertical faces with appropriate reservoir has remarkable characteristics of absorbing wave energy even for long period waves in the same degree of usual sloped-face seawall and that these characteristics appear most clearly for permeable seawall of trapezoidal cross-section with backward-sloped reservoir wall are found theoretically and experimentally. Moreover, it is shown that a perforated wall with reservoir has similar characteristics to those for uniformly permeable wall with reservoir.

"Warock" is a type of concrete blocks which was invented in order to realize the wave absorbing seawall in practical works. Several examples of ever constructed wave absorbing seawalls, quaywalls and breakwaters by means of "Warock" in Japan are introduced.

I Introduction

A type of seawall with reservoir has been investigated by Jarlan (1961), Boivin(1963), Cote(1964), Terrett(1968), Marks(1968), Sawaragi (1973,1975) and others. And, they are concerned solely with perforated, thin wall and the effect of the width of the perforated wall in relation to the width of reservoir is entirely ignored. However, the width of permeable wall plays an important role to absorb the incident wave energy. In this paper, we are concerned with wide wall of uniform porosity and of perforated wall, and not only with permeable wall of vertical faces but also of sloped faces.

Since the ability for seawall to absorb incident wave energy is represented by the reflection coefficients, we are limited to the consideration on them. Moreover, since the wave absorbing ability appears clear-

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ly for relatively long period waves, we first introduce a simple analysis for vertical-face reservoir seawall of uniform porosity by long wave theory and then a precise numerical analysis for seawall of arbitrary cross-section by means of the authors' method proposed in the paper entitled " A Method of Analyses for Two-Dimensional Water Wave Problems", which is submitted to this Conference. Finally, comparing the perforated wall with uniformly permeable wall experimentally, we introduce " Warock " as a practical tool to realize the reservoir seawall in actual field.

II Theory and Experiment on The Vertical-Face Seawall with Reservoir

In Fig.2-1, suppose that ABCD is a vertical wall of uniform porosity with width ℓ , placed in front of impervious wall EF with reservoir space d and on bottom FDB of constant water depth h. The origin of coordinate system is taken at still water surface on foreside face AB and x-axis is in horizont, z-axis is vertically upwards. The incident wave is assumed to be long wave with frequency σ .

Dividing the fluid region into three parts (O) ($x \geq 0$), (I) ($0 \geq x \geq -\ell$) and (II) ($-\ell \geq x \geq -(\ell+d)$) and indicating the quantities in these regions by subscripts 0, 1 and 2, respectively, the mass and momentum equations and the resulting horizontal fluid velocity u and surface displacement ζ by long wave assumption are as follows:

Region (O):

$$\frac{\partial \zeta_0}{\partial t} = -h\frac{\partial u_0}{\partial x}, \qquad \frac{\partial u_0}{\partial t} = -g\frac{\partial \zeta_0}{\partial x} \tag{2.1}$$

Assuming incident wave of unit amplitude and reflected wave with complex reflection coefficient ψ_0 , the surface displacement ζ_0 is written as Eq.(2.2). Then, the fluid velocity u_0 and wave number k_0 are derived from Eq.(2.1) as Eq.(2.3) and (2.4).

$$\zeta_0 = (e^{ik_0x} + \psi_0 e^{-ik_0x})e^{i\sigma t} \tag{2.2}$$

$$u_0 = -\frac{gk_0}{\sigma}(e^{ik_0x} - \psi_0 e^{-ik_0x})e^{i\sigma t} \tag{2.3}$$

$$\lambda_0^2 = \sigma^2 h/g \qquad \text{where} \qquad \lambda_0 = k_0 h \tag{2.4}$$

Region (I):

Denoting the porosity as V, the linearized drag force coefficient for the porous material as μ and the mass force coefficient as ε , the mass and momentum equations are as follows:

$$\frac{\partial \zeta_1}{\partial t} = -\frac{h}{V}\frac{\partial u_1}{\partial x}, \quad \frac{1}{V}\frac{\partial u_1}{\partial t} = -g\frac{\partial \zeta_1}{\partial x} - \frac{\mu}{V}u_1 - \frac{\varepsilon(1-V)}{V}\frac{\partial u_1}{\partial t} \tag{2.5}$$

Taking the surface displacement ζ_1 as Eq.(2.6), the fluid velocity u_1 and wave number K_1 are derived as Eq.(2.7) and (2.8).

$$\zeta_1 = a_1\left[e^{ik_1(x+\ell)} + \psi_1 e^{-ik_1(x+\ell)}\right]e^{i\sigma t} \tag{2.6}$$

$$u_1 = -\frac{\sigma V a_1}{k_1 h}\left[e^{ik_1(x+\ell)} - \psi_1 e^{-ik_1(x+\ell)}\right]e^{i\sigma t} \tag{2.7}$$

$$\lambda_1^2 = \left[1+\varepsilon(1-V)-i\frac{\mu}{\sigma}\right]\frac{\sigma^2 h}{g} \qquad \text{where} \quad \lambda_1 = k_1 h \tag{2.8}$$

Region(II):

Eq.(2.1) is valid here, and putting the surface displacement ζ_2 as Eq.(2.9), the fluid velocity u_2 is provided by Eq.(2.10).

$$\zeta_2 = a_2\left[e^{ik_0(x+\ell+d)} + \psi_2 e^{-ik_0(x+\ell+d)}\right]e^{i\sigma t} \tag{2.9}$$

$$u_2 = -\frac{g k_0 a_2}{\sigma}\left[e^{ik_0(x+\ell+d)} - \psi_2 e^{-ik_0(x+\ell+d)}\right]e^{i\sigma t} \tag{2.10}$$

On the boundary EF ($x = -(\ell+d)$), horizontal fluid velocity u_2 must vanish, so that we have

$$\psi_2 = 1, \quad \zeta_2 = a_2\left[e^{ik_0(x+\ell+d)} + e^{-ik_0(x+\ell+d)}\right]e^{i\sigma t} \tag{2.11}$$

On the boundary CD ($x = -\ell$) and OB ($x = 0$), horizontal velocity and surface displacement should be continuous.

$$\begin{aligned} \zeta_1 &= \zeta_2 \quad \text{and} \quad u_1 = u_2 \quad \text{at } x = -\ell \\ \zeta_1 &= \zeta_0 \quad \text{and} \quad u_1 = u_0 \quad \text{at } x = 0 \end{aligned} \tag{2.12}$$

Accordingly, we have

$$a_1(1+\psi_1) = a_2(e^{ik_0 d} + e^{-ik_0 d}), \quad \alpha a_1(1-\psi_1) = a_2(e^{ik_0 d} - e^{-ik_0 d}) \tag{2.13}$$

$$1+\psi_0 = a_1(e^{ik_1\ell} + \psi_1 e^{-ik_1\ell}), \quad 1-\psi_0 = \alpha a_1(e^{ik_1\ell} - \psi_1 e^{-ik_1\ell}) \tag{2.14}$$

$$\text{where} \quad \alpha = \frac{V\Gamma}{\lambda_0\lambda_1} \quad \text{and} \quad \Gamma = \sigma^2 h/g \tag{2.15}$$

From Eq.(2.13) and (2.14), ψ_0 is obtained as follows:

$$\psi_0 = \frac{1-\alpha^2-\gamma(1+\alpha)^2+4\alpha e^{-2ik_0 d}}{(1+\alpha)^2-\gamma(1-\alpha^2)} \tag{2.16}$$

where $\gamma = e^{-2ik_0 d} + e^{-2ik_1 \ell} - e^{-2i(k_0 d + k_1 \ell)}$

The reflection coefficient K_r is given by the absolute value of ψ_0 .

$$K_r = |\psi_0| \tag{2.17}$$

Fig.2-2 is the calculated and measured reflection coefficients for various reservoir width d , when the permeable wall width ℓ is equal to water depth h and the incident wave frequency $\sigma^2 h/g$ is 0.25 (the depth to wave length ratio h/L is 0.083). Horizontal axis shows the ratio of total width X (= $\ell + d$) to depth h or to wave length L.

The model wall in experiments is made by armor blocks of 500 cm^3 with porosity V = 0.63 in wave flume of length 22 m with water depth h = 50 cm. The reflection coefficients are measured by Healey's method with incident wave height of 5 ~ 7 cm. Calculated values are obtained by Eq.(2.16)(2.17) with ε = 0, V = 0.40 and μ/σ = 1.1 .

From the figure, it is found that the reflection coefficient decreases with the increase of total width X and reaches the minimum 0.1 at X $\simeq$ 2.2h or X $\approx$ 0.18L and then increases gradually.

Fig.2-3 is the one for ℓ = h and $\sigma^2 h/g$ = 0.5 (h/L = 0.123).

Fig.2-4 is for ℓ = 0.5h and $\sigma^2 h/g$ = 0.50 (h/L = 0.123).

In both cases, the tendency of the change of reflection coefficient with the increase of reservoir width (or increase of total width X for fixed width of permeable wall) is entirely similar to each other and to the one in Fig.2-2, and the minimum coefficient appears at X = 0.18L in every cases.

From above results, it is clear that if a vertical permeable wall is equipped with a reservoir behind it, the reflection coefficient decreases remarkably and reaches minimum at an appropriate width of reservoir. And the total width of seawall at that most effective wave absorbing ability is about 0.18 times the wave length, when the width of permeable wall is half or equal to the water depth, more generally, when the width is the same order of water depth.

Above-described analysis is based on the long wave assumption. As for general waves, the problem has been analyzed by the author(1972) by the method of continuation of velocity potentials. Fig.2-5 is an example of calculated results by above method for ℓ = h and $\sigma^2 h/g$ = 0.25, 0.50 1.0 and 2.0, taking V = 0.5, μ/σ = 2.0 and ε = 0. From this figure, it is clear that the minimum reflection coefficient appears to each $\sigma^2 h/g$ but the minimum value itself is smaller for smaller $\sigma^2 h/g$, that is, for longer wave length. That is to say, the effect of reservoir to wave absorbing ability appears clearer for longer period waves than for shorter waves.

These minimum values of reflection coefficients are the same order of those which are attained by usual sloped-face seawall. That is, the permeable seawall with reservoir has a same degree of ability for absorbing incomming energy as sloped-face seawall, though it is limitted to some particular period wave, corresponding to the width of permeable wall and reservoir.

Above results of theoretical and experimental investigations are summerized as follows:

(i) Permeable vertical seawall without reservoir cannot absorb incomming wave energy effectively, even if the wall is sufficiently wide, that is, the wave absorbing ability of vertical seawall without reservoir is unsatisfactory for ordinary period waves and it is impossible to expect the same degree of absorbing effect as permeable sloped seawall, especially for long period waves. This is due to the fact that on general sloped surface the incident wave deforms gradually or abruply due to sudden decrease of water depth on the slope and accelerates the fluid velocity or otherwise breaks and dissipates the greater part of the energy, but on the contrary, for vertical permeable wall the incident wave penetrates partly into the wall without deformation or breaking, so that only a part of the energy is lost solely by turbulence in permeable wall. Consequently, in order to induce an effective energy dissipation in permeable wall, it is necessary to accelerate the fluid velocity inside the wall. The reservoir behind the permeable wall plays a role of accelerating the fluid flow across the permeable wall for ordinary or even for longer period waves. This situation is as follows: When a wave crest comes, the permeable wall dams up the flow of incomming wave in front of the wall and the reservoir stores the inflow water. And the water level in the reservoir rises up gradually with some lag following to the rising up of outside water level. When a trough comes, the situation is reversed. Such a difference of water levels along inside and outside faces of permeable wall and therefore, the surface slope of flow in permeable wall is always steeper than the one for flow without reservoir. This is the reason why the reservoir accelerates the flow across the wall and induces a large amount of energy loss. And, there exists the most effective width of reservoir for given width of permeable wall, wave period and water depth to induce the maximum amount of energy loss.

(ii) For ordinary or longer period waves, the reflected wave is minimized when the total width of seawall with reservoir (the permeable wall plus the reservoir width) is about 0.18 times the wave length, when the width of permeable wall is the same order of water depth. This total width is considerably shorter than the one for perforated, thin wall. Sawaragi(1973) has shown that the total width for the latter to provide the minimum reflection coefficient is 0.25L, that is, one-fourth of wave length. This is due to the fact that in case of thin, perforated wall the reflected wave from the backwall of the reservoir (EF in Fig.2-1) constitutes a standing wave system with the incident wave and the maximum horizontal fluid flow appears at nodal point (at the point of L/4 from EF) and that the maximum energy dissipation is induced by this flow through perforated wall. Therefore, the reservoir in this case does not play any particular role to accelerate the fluid flow through perforated wall.

(iii) The reflection coefficient attained by the reservoir seawall of above total width is sufficiently small in the same degree as the one by permeable sloped-face seawall. And at the same time, the surface wave elevation along the foreside face of wall is much smaller than the one for vertical permeable wall without reservoir, which results in the smaller amount of overtopping waves than the latter.

III Generalized Analysis for Reservoir Seawall of Arbitrary Cross-Section

In Fig.3-1, suppose that AA'B'B ia a uniformly permeable wall of arbitrary cross-section placed on impervious sea bottom CB'A'O' with variable water depth. The origin of coordinate system is taken at still water surface and is sufficiently distant from the seawall at constant water depth h. x-axis is in horizont and z-axix is vertically upwards. Then, fluid region is divided into four parts (O),(I), (II) and (III).

Assuming that the drag force for the porous material in region (II) is linearized to be proportional to fluid velocity, the fluid motion in region (II) has a velocity potential.

Then, the velocity potential in each region is represented in the form of Eq.(3.1) with potential function ϕ_0, $\phi^{(1)}$, ϕ^* and $\phi^{(3)}$, denoting the incident wave amplitude as ζ_0 and frequency as σ.

$$\Phi(x,z,t) = \frac{g\zeta_0}{\sigma}\phi(x,z)e^{i\sigma t} \tag{3.1}$$

After the same manner as the method proposed in our separate paper "A method of Analyses for Two-Dimensional Water Wave Problems", the boundary-values and its normal derivatives of potential functions for region (I), (II) and (III) are in the following relations, where potential functions on the boundaries are defined as shown in Fig.3-1:

Region (I):

On $\overrightarrow{OA}$: $\bar{\phi}_1^{(1)} = \Gamma\phi_1^{(1)}$ where $\Gamma = \sigma^2 h/g$ (3.2)

On $\overrightarrow{AA'}$: $\bar{\phi}_2^* = \bar{\phi}_2^{(1)}$, $\phi_2^* = \frac{1}{\beta}\phi_2^{(1)}$ where $\beta = \frac{\alpha}{\Gamma}$ (3.3)

On $\overrightarrow{A'O'}$: $\bar{\phi}_3^{(1)} = 0$ (3.4)

On $\overrightarrow{O'O}$: $\bar{\phi}_0 = i\lambda_0(1-\psi)A(kz)$, $\phi_0 = (1+\psi)A(kz)$ (3.5)

Region (II):

On $\overrightarrow{BA}$: $\bar{\phi}_1^* = \alpha\Gamma\phi_1^*$ where $\alpha = 1+\varepsilon(1-\Gamma)+i\mu/\sigma$ (3.6)

On $\overrightarrow{AA'}$: Same as Eq.(3.3) (3.7)

On $\overrightarrow{A'B'}$: $\bar{\phi}_3^* = 0$ (3.8)

On $\overrightarrow{B'B}$: $\bar{\phi}_4^* = \bar{\phi}_3^{(3)}$, $\phi_4^* = \frac{1}{\beta}\phi_3^{(3)}$ (3.9)

Region (III):

On $\overrightarrow{BC}$: $\bar{\phi}_1^{(3)} = \Gamma\phi_1^{(3)}$ (3.10)

On $\overrightarrow{CB'}$: $\bar{\phi}_2^{(3)} = 0$ (3.11)

On $\overrightarrow{BB'}$: Same as Eq.(3.9) (3.12)

Thus, the Green's identity formula for every region are as follows:

(i) Region (I)

$$-\phi^{(1)}(i) + \sum_{j=1}^{N_1^{(1)}}(\bar{E}_{ij} - \Gamma E_{ij})\phi_1^{(1)}(j) + \sum_{j=1}^{N_2^{(1)}}\left[\bar{E}_{ij}\phi_2^{(1)}(j) - E_{ij}\bar{\phi}_2^{(1)}(j)\right] + \sum_{j=1}^{N_3^{(1)}}\bar{E}_{ij}\phi_3^{(1)}(j)$$

$$+\ \psi\sum_{r=1}^{M} G_{ir}A(kz_r) = -\sum_{r=1}^{M} G_{ir}^* A(kz_r)$$

($i = 1 \sim N_1^{(1)}$, $1 \sim N_2^{(1)}$, $1 \sim N_3^{(1)}$, $(0,\ z_p)$ on $\overrightarrow{O'O}$) (3.13)

(ii) Region (II)

$$\Phi^*(i) + \sum_{j=1}^{N_1^*}(\bar{E}_{ij}^* + \alpha\Gamma E_{ij}^*)\phi_1^*(j) + \sum_{j=1}^{N_2^{(1)}}\left[\frac{1}{\beta}\bar{E}_{ij}^*\phi_2^{(1)}(j) - E_{ij}^*\bar{\phi}_2^{(1)}(j)\right]$$
$$+\sum_{j=1}^{N_3^*}\bar{E}_{ij}^*\phi_3^*(j) + \sum_{j=1}^{N_3^{(3)}}\left[\frac{1}{\beta}\bar{E}_{ij}^*\phi_3^{(3)}(j) - E_{ij}^*\bar{\phi}_3^{(3)}(j)\right] = 0$$

$$(i = 1 \sim N_1^* ,\ 1 \sim N_2^{(1)},\ 1 \sim N_3^* ,\ 1 \sim N_3^{(3)}) \qquad (3.14)$$

(iii) Region (III)

$$-\phi^{(3)}(i) + \sum_{j=1}^{N_1^{(3)}}(\bar{E}_{ij} - \Gamma E_{ij})\phi_1^{(3)}(j) + \sum_{j=1}^{N_2^{(3)}}\bar{E}_{ij}\phi_2^{(3)}(j) + \sum_{j=1}^{N_3^{(3)}}\left[\bar{E}_{ij}\phi_3^{(3)}(j) - E_{ij}\bar{\phi}_3^{(3)}(j)\right] = 0$$

$$(i = 1 \sim N_1^{(3)},\ 1 \sim N_2^{(3)},\ 1 \sim N_3^{(3)}) \qquad (3.15)$$

The notations used in above equations are the same as those in our separate paper(1976).

Eq.(3.13)(3.14)(3.15) are $(N_1^{(1)} + 2N_2^{(1)} + N_3^{(1)} + N_1^* + N_3^* + N_1^{(3)} + 2N_3^{(3)} + N_2^{(3)} + 1)$ linear equations with respect to the same number of unknown quantities $\phi_1^{(1)}$, $\phi_2^{(1)}$, $\bar{\phi}_2^{(1)}$, $\phi_3^{(1)}$; ϕ_1^*, ϕ_3^*; $\phi_1^{(3)}$, $\phi_2^{(3)}$, $\phi_3^{(3)}$, $\bar{\phi}_3^{(3)}$ and ψ . Solving above equations simultaneously, we obtain all of the unknowns and the potential values at points in every region are calculated by Green's theorem. The reflection coefficient K_r is given by the absolute value of ψ . In addition, the surface wave profiles are calculated as follows:

From C to B: $\zeta_3(j)/\zeta_0 = -i\ \phi_1^{(3)}(j)e^{i\sigma t}$, $j = N_1^{(3)} \sim 1$ (3.16)

From B to A: $\zeta^*(j)/\zeta_0 = -i\ \phi_1^*(j)e^{i\sigma t}$, $j = 1 \sim N_1^*$ (3.17)

From A to O: $\zeta_1(j)/\zeta_0 = -i\ \phi_1^{(1)}(j)e^{i\sigma t}$, $j = N_1^{(1)} \sim 1$ (3.18)

Above method is applied to reservoir seawall with various cross-sections, where the permeable wall is of rectangle, trapezoid and inverse trapezoid, and the backwall of reservoir is vertical or sloped, as shown in Fig.3-2. The width of rectangular wall is taken as h/2 and those of trapezoidal wall at still water level, half depth and bottom are taken as h/4, h/2 and 3h/4, respectively, so as to be of the same cross-sectional area as the rectangle. The slope of the backwall is taken as $\pm$ 60° to the horizontal bottom.

In Fig.3-2, the type (A) is of vertical backwall, the type (B) is of backward-sloped backwall and the type (C) is of foreward-sloped backwall. As shown in later, since the characteristics of the reservoir are represented by its width at still water level, the representative width of the seawalls is better to be taken as X, which is the distance from the half-depth point on the foreside face of permeable wall to the water line of the backwall of reservoir.

In numerical calculations, we take the geometrical surface OO' at the distance 3h from the seawall and $N_1^{(1)} = 15$, $N_2^{(1)} = 10$, $N_3^{(1)} = 12$, $M = 21$ for region (I), $N_1^* = 5$, $N_3^* = 5$ for region (II). As for the region (III), we take $N_3^{(3)} = 10$, and $N_1^{(3)}$, $N_2^{(3)}$ are taken as $6 \sim 10$, according to the variable width of the reservoir. The porosity V is taken as 0.7 and the coefficient μ/σ is as 0.9, ε is 0.

Fig.3-3 is the calculated reflection coefficients of the type (A) with respect to the ratio of total width X to the water depth or the ratio to the wave length L, for $\sigma^2 h/g = 0.50$ ($h/L = 0.123$). It is seen that in every wall, the minimum reflection coefficient appears at $X = 1.5h$ or $X = 0.18L$ and that the wave absorbing ability of the inverse trapezoidal wall is inferior to those of the others. Therefore, it will be resonable to exclude the inverse trapezoidal wall from further considerations.

Fig.3-4 shows the calculated reflection coefficients for the type (B) and (C), excepting the inverse trapezoidal wall, in comparison with the one for rectangular wall with vertical backwall. It is found that in every wall the minimum reflection coefficient appears at nearly the same value of X as before, and that for smaller values than that X, the type (B) provides lower reflection coefficients than those of the type (C). Therefore, it will be resonable to conclude that the rectangle or trapezoidal wall of the type (B) is better, of which the trapezoidal wall will be the most preferable, because of the smallest volume of the reservoir.

Above characteristics for various types of reservoir seawall based on the calculated results are prooved by experiment.

Fig.3-5 shows the measured reflection coefficients for the type (A). The model walls are made by quarry stones of mean diameter 5 cm with porosity $V = 0.53$ in wave flume with water depth $h = 50$ cm and length 22 m, and reflection coefficients are measured by Healey's method for incident wave height $H = 6.7$ cm. From the figure, it is clear that the minimum reflection coefficient appears at the same value as the one calculated before, and that the inverse trapezoidal wall shows the highest reflection coefficient.

Fig.3-6 is the measured reflection coefficient for the type (B). This shows that the rectanglar or trapezoidal wall is better.

Above results for various types of seawall are summerized as follows:
(i) As for the cross-section of permeable wall, the rectangular or trapezoidal wall is better than the inverse trapezoidal wall. As for the back-wall of reservoir, the backward-sloped one is better and foreward-sloped one is to be avoided.
(ii) The reservoir is characterized not by the volume but by its free surface width. And, the total width for the seawall to provide the minimum reflection coefficient is about 0.18 times the wave length and the value at that width is the same order of the one attained by permeable sloped-face seawall.

IV Characteristics of the Perforated, Wide Wall with Reservoir

In the uniformly permeable wall, the energy dissipation is induced by the turbulence of flow inside the wall. While, in the perforated wall, the energy is dissipated mainly by jet flow turbulence through the wall. Therefore, the situation seems to be quite different. However, the experiments on the perforated wall show that the wave absorbing characteristics of the permeable and perforated walls quite resemble to each other.

Fig.4-1 is the measured reflection coefficients of perforated walls with reservoir, where the water depth h is 50 cm, wave frequency $\sigma^2 h/g$ is 0.50 (h/L = 0.123) and incident wave height is $H_i = 4 \sim 6$ cm. The diameter of the circular holes of the wall is kept as D = 5.0 cm, average porosity is V = 0.33 and the width of the wall is varied as 4 , 10 and 20 in cm, that is, $\ell/h = 0.08$, 0.20 and 0.40.

From the figure, it is found that the minimum reflection coefficient appears at X/L = 0.25 for ℓ/h = 0.08 , at X/L = 0.20 for ℓ/h = 0.20 and at X/L = 0.18 for $\ell/h = 0.40$, that is, for wide wall the total width for minimum reflection coefficient is nearly 0.18L, which is the same value as the one for uniformly permeable wall and for thin wall the total width for minimum reflection coefficient approaches to L/4, which is also the same value as permeable wall.

Fig.4-2 is the measured reflection coefficients for constant width of perforated wall ℓ = 10 cm. Water depth is 50 cm and wave frequency is $\sigma^2 h/g = 0.50$, the incident wave height is $4 \sim 6$ cm. The diameter of horizontal holes varies as 3.2 cm 5.0 cm and 8.0 cm, with average porosity V = 0.33 . From this figure, it is seen that the reflection coefficients for larger diameter than incident wave height are higher than those for smaller diameter but the minimum values for every diameter appear at nearly the same value of $X/L = 0.20$.

From above results, it will be estimated that the perforated wall has similar characteristics on wave absorbing ability to the one of the uniformly permeable wall, though the situation of energy dissipation is quite different from each other. Therefore, it seems to be reasonable to replace the uniformly permeable wall by perforated wall without loss of the characteristics on wave absorption.

V The Use of " Warock " for Wave Absorbing Structures

The "Warock" is a type of concrete blocks to construct the seawall with reservoir. As shown in Fig.5-1 and Photo.5-1, it consists from the foreside part of hexagon column with franges at both ends and the rearside part of vertical slab, which are connected by horizontal beam. Placing the block in a row along the shoreline and piling up in several columns to the required height, a seawall with reservoir is constructed, where the foreside parts of blocks constitute the perforated wall of average porosity 0.48 and the rearside parts provide the backwall, between which we have reservoir of porosity 0.75 because of the existence of horizontal beams. Photo.5-2 shows a "Warock" hanged by crane in construction of a wave absorbing quaywall in actual place. The weight of this block is 20 tons, the length is 4.5 m, width is 2.0 m and the height is 1.7 m.

In order to oppose several period waves in various water depth, we have three sizes of blocks. The size A is 3.5 m in length, 1.6 m in width, 1.4 m in height and 10 tons in weight; the size B is as shown in Photo.5-2 and the size C is 6.0 m in length, 2.4 m in width, 2.0 m in height and 40 tons in weight.

Photo.5-3 shows the quaywall under construction by "Warock", piling up in four columns. The rightside of the figure constitutes vertical retaining wall, that is, the backwall of reservoir and lcftside constitutes a perforated wall and between them is the reservoir. Photo.5-4 shows the front view of a part of the quaywall.

In this way, various types of seawall, quaywall and breakwater with wave absorbing ability are constructed by "Warock".

Fig.5-2 is the cross-section of quaywall constructed at water depth 10.4 m at Muroran Harbour, in Hokkaido. "Warock" of 20 tons are placed in three columns on the foundation by cellar block and rubble mound.

Fig.5-3 is the quaywall of depth 3.0 m constructed at Ushibuka Harbour in Kyushu with four columns of "Warock" of 10 tons in weight. Fig.5-4 is the breakwater at depth 4.5 m,constructed against wave period 5.0 seconds and height 1.20 m at Odo Marina in Fukuoka City, by 20 tons "Warock" in three columns. Fig.5-5 is the breakwater of double rows in three and four columns of 20 tons and of 10 tons "Warock", constructed at depth 7.0 m at Hiakari harbour in the Port of Kita-Kyushu at North Kyushu. The outside face of the breakwater is agaist the open sea waves of period 5.2 seconds and height 1.70 m and the inside face is to absorb the induced waves in harbour.

The use of the "Warock" for reservoir seawall is limitted to the place where water depth is less than about 6 m and wave period is shorter than about 6 seconds. For larger depth and longer period waves, the seawall is better to be prefabricated in one body, transported by crane berge and placed on the site.

Fig.5-6 is the cross-section of breakwater by prefabricated reservoir seawall, constructed at depth 3.0 m at Tannawa Marina in Osaka Bay, against wave period 6.1 seconds and wave height 1.9 m. Photo.5-5 is the prefabricated body on the shore, whose length is 6.0 m, width is 5.6 m, height is 7.0 m and weight is 260 tons. Fig.5-7 is the seawall constructed at depth 7.0 m at the north coast of Kashima Harbour against open ocean waves of period 9 11 seconds and height 6.0 m. Photo.5-6 is the prefabricated body, whose widths of perforated wall and reservoir are 5.0 m and 6.0 m, respectively, the total width is 13 m, length is 13 m, height is 11 m and weight is 1800 tons.

VI Conclusions

The characteristics of the seawall with reservoir are summerized as follows:

(i) The uniformly permeable wall with reservoir has the best ability of wave absorption when the total wadth is about 0.18 times the wave length, if the width of permeable wall is the same order of water depth. If the permeable wall is thin, the total width of best ability approches to L/4.

(ii) The most effective cross-section for the permeable wall with reservoir to absorb wave energy is thought to be of trapezoidal wall with bavkward-sloped backwall of reservoir.

(iii) The perforated wall with reservoir has similar characteristics on wave absorption to the uniformly permeable wall with reservoir.

(iv) The permeable or perforated wall with reservoir in total width of about 0.18 times the wave length has the same degree of wave absorbing ability as the permeable sloped-face seawall, even for long period waves.

(v) Such a seawall with reservoir is realized by means of "Warock" for actual field. For larger depth and longer period waves, it can be realized by prefabricated perforated wall.

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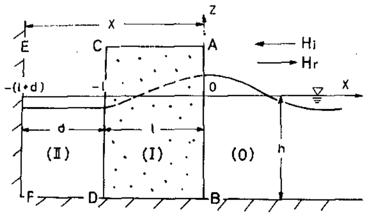

Fig.2-1 Permeable Seawall with Reservoir

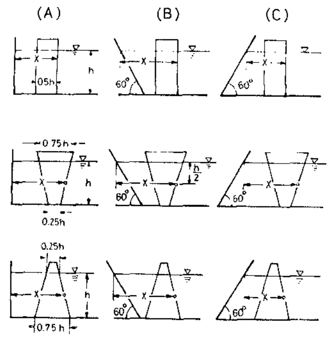

Fig.3-2 Various Types of Reservoir

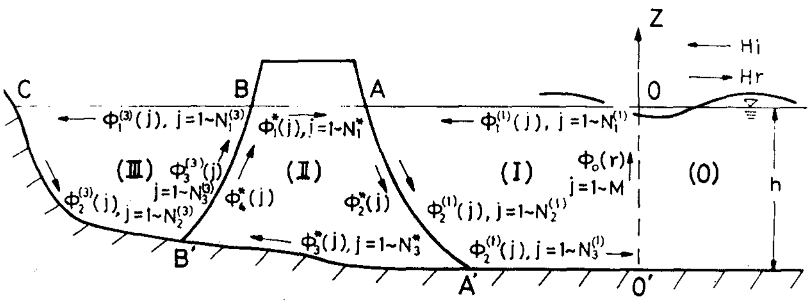

Fig.3-1 Definition Sketch for Reservoir Seawall

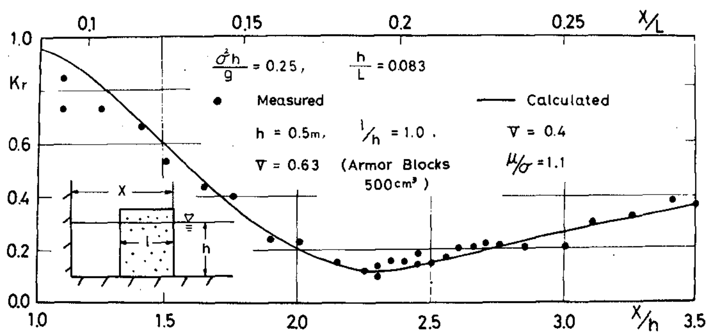

Fig.2-2 Ref. Coeff. for Reservoir Seawall

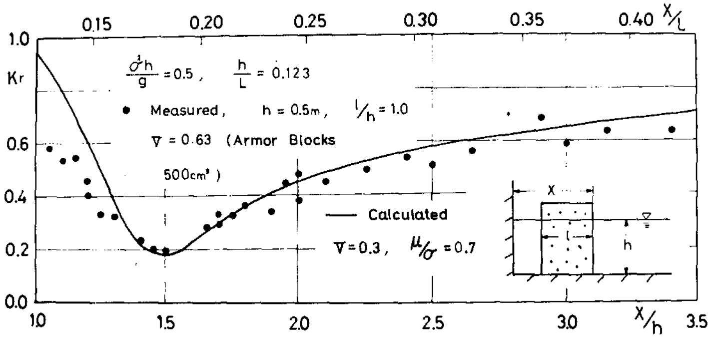

Fig. 2-3 Ref. Coeff. for Reservoir Seawall

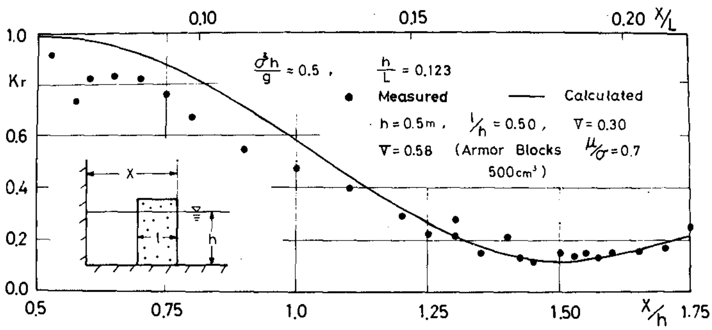

Fig. 2-4 Ref. Coeff. for Reservoir Seawall

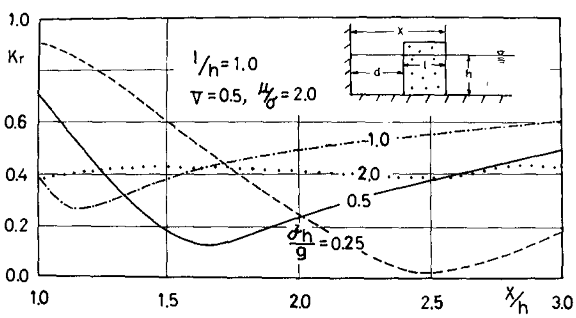

Fig. 2-5 Reflection Coefficient for Uniform Type Wall

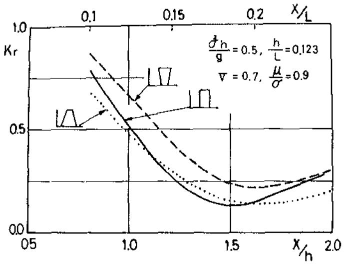

Fig.3-3 Ref. Coeff. for Vertical Back Wall (Type A)

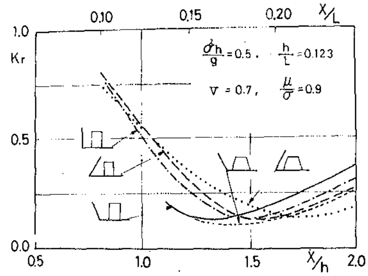

Fig.3-4 Ref. Coeff. for Sloped Back Wall

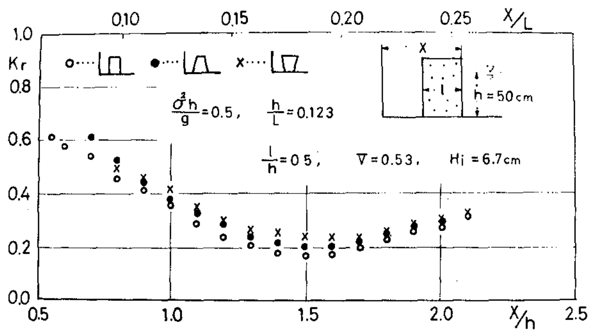

Fig.3-5 Ref. Coeff. for Vertical Back Wall (Measured)

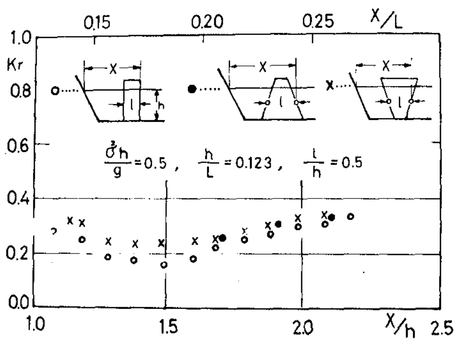

Fig.3-6 Ref. Coeff. for Sloped Back (Measured)

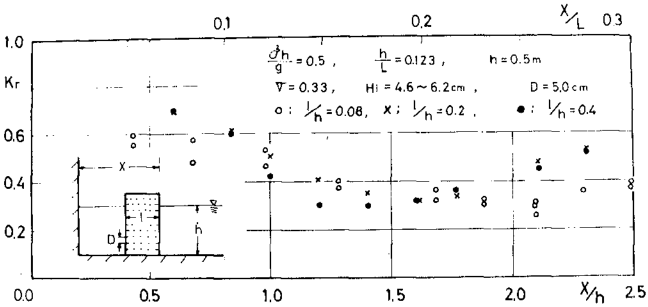

Fig.4-1 Ref. Coeff. for Solid Wall with Horizontal Holes

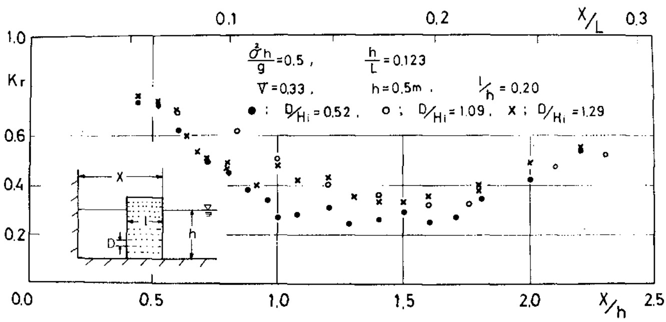

Fig.4-2 Ref. Coeff. for Solid Wall with Horizontal Holes

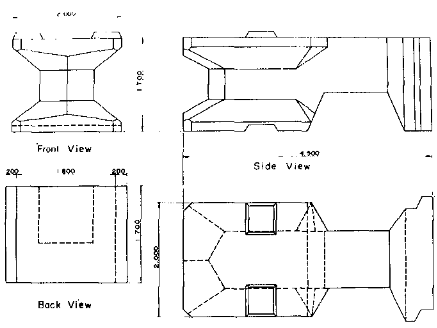

Fig. 5-1 Scheme of a "Warock" (20 tons) (Sizes in Meters)

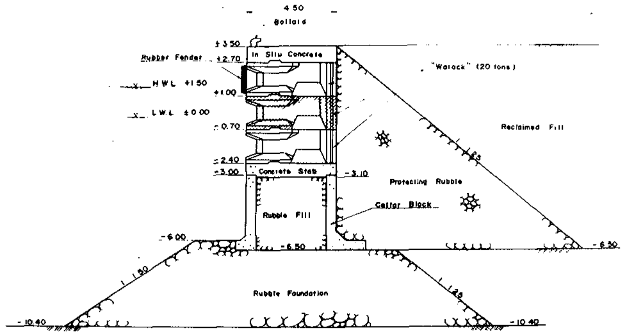

Fig 5-2 Cross-Section of Quaywall by "Warock" at Muroran Harbour
(Sizes in Meters)

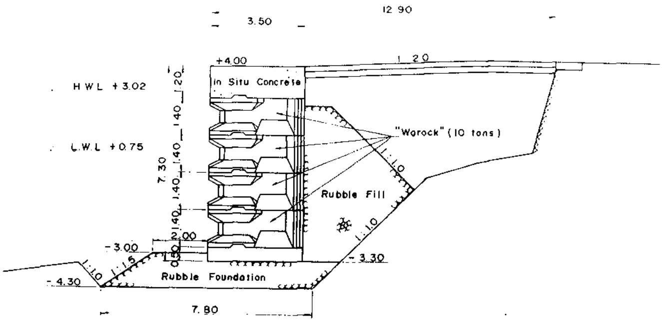

Fig. 5-3 Cross-Section of Quaywall by "Warock" at Ushibuka Harbour
(Sizes in Meters)

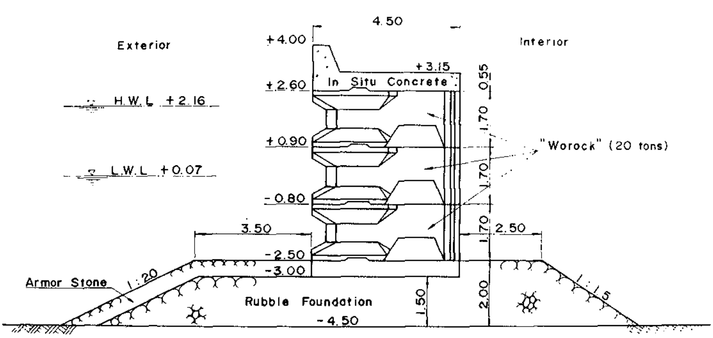

Fig. 5-4 Cross-Section of Breakwater by "Warock" at Odo Marina
(Sizes in Meters)

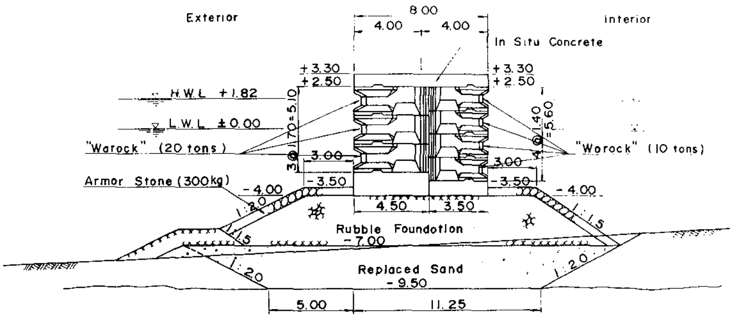

Fig. 5-5 Cross-Section of Breakwater by "Warock" at Hiakari Harbour (Sizes in Meters)

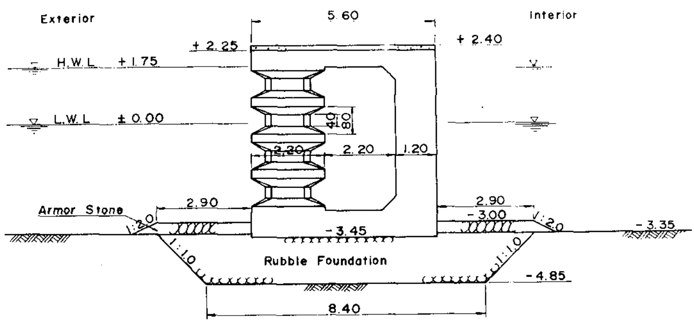

Fig. 5-6 Cross-Section of Breakwater by Prefabricated Reservoir Seawall at Tan-nawa Marina (Sizes in Meters)

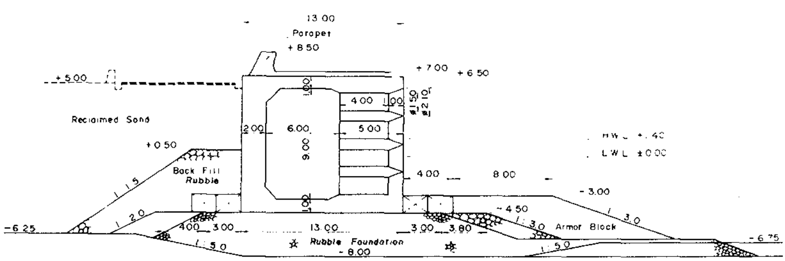

Fig. 5-7 Cross-Section of Seawall by Prefabricated Reservoir Seawall at the North Coast of Kashima Harbour (Sizes in Meters)

Photo.5-1: A "Warock"

Photo.5-3: Quaywall under Construction

Photo.5-2: A "Warock" hanged by Crane

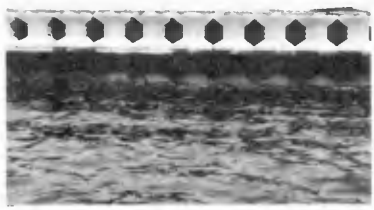

Photo.5-4: Front View of Quaywall

Photo.5-5: Prefabricated Body of Break-
water at Tannawa Marina

Photo.5-6: Prefabricated Seawall
at Kashima Harbour