CHAPTER 155

Analysis of Permeable Breakwaters

Hitoshi MURAKAMI*, Yoshihiko HOSOI** and Yoshitaka GODA***

Abstract

This paper discusses the characteristics of hydraulic and water exchange due to the wave action against vertical slit-type breakwaters. The theoretical solution of the reflection and the transmission coefficients for the breakwater models is compared with the experimental results. Furthermore, the water exchange discharge and the water concentration change through the gap of the permeable breakwater are examined experimentally. Finally the most effective geometry of the cross section is suggested for the breakwaters used here.

1. Introduction

With increasing pressure to conserve in a clean way the water quality in a harbor, a new breakwater should be devised. That means an effective breakwater for not only the reduction of the reflection and transmission of wave energy but also the increase of the water exchange discharge through a permeable wall.

Since Jarlan(1961) proposed the perforated vertical wall breakwater, many different kinds of permeable wall breakwaters have been designed(Kondoh et al.,1983). The hydraulic characteristics of these breakwaters have been examined experimentally for the most part. The theoretical solutions for the reflection and the transmission coefficients have been obtained only for the breakwaters with a comparatively simple cross section geometry.

Furthermore, the water exchange characteristics due to the wave action through a permeable wall has not been discussed sufficiently.

This study deals with both hydraulic and water exchange characteristics of the vertical slit-type breakwaters with some devised horizontal cross section geometries in a chamber of the breakwater, though they are very simple as shown in Fig.1. The purpose of this study is to obtain the necessary data to make a breakwater with a horizontal cross section geometry effective from those viewpoints mentioned above.

From here on, we shall call the models by their abbreviations S.P, G.C, G.E and so on.

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* Professor, Technical College, The University of Tokushima, Minami-jyosanjima, Tokushima, 770, Japan.

** Associate Professor, Technical College, The University of Tokushima.

*** Nikken Gijyutsu Cosultant Co., Ltd., Osaka, Japan.

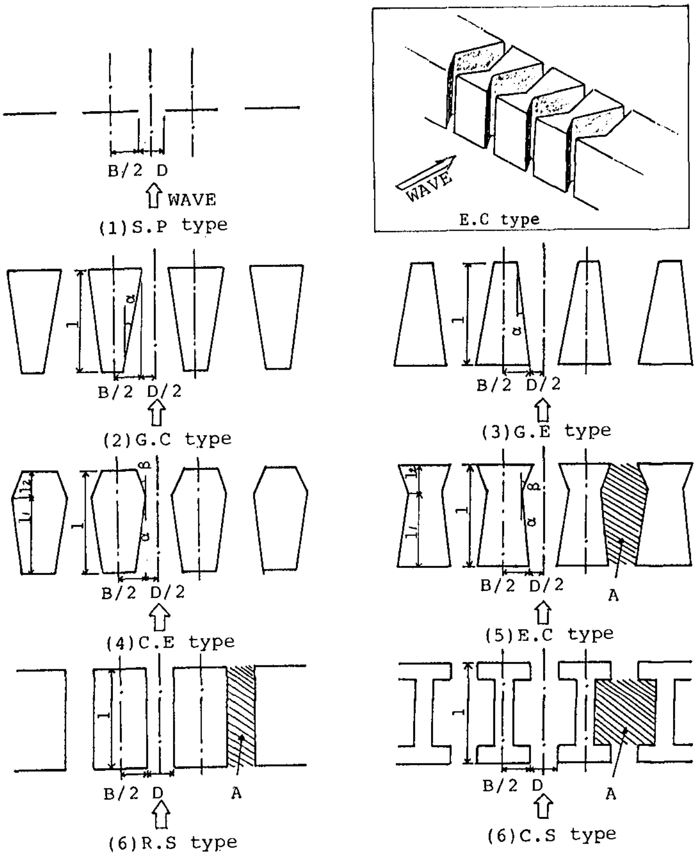


Fig.1 Horizontal cross sections of vertical slit-type breakwaters

2. Theoretical Solution of Reflection and Transmission Coefficients

Let us show as an example how to obtain the result of the reflection and the transmission coefficients for the C.E type breakwater in Fig.1-(4).

Fig.2 shows a coordinate system and a definition of the notation. For analysis, we consider a limited width of the breakwater (D+B) and divide the region into four parts. Then, we assume a small amplitude long wave coming perpendicular to the breakwater, the wave height along the breakwater not varying and the water depth being constant in all the regions.

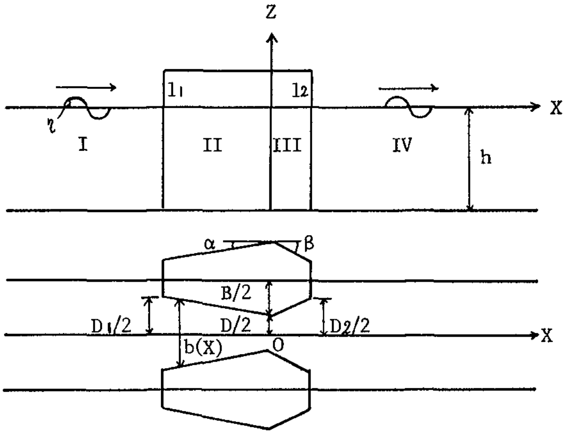


Fig.2 Coordinate system and definition of notations

A momentum and a mass equation at Regions II and III are expressed by eqs (1) and (2), respectively.

$$\partial u/\partial t + g\partial\eta/\partial x = 0 \qquad (1)$$

$$\partial\eta/\partial t + (h/b)\partial(bu)/\partial x = 0 \qquad (2)$$

$$b = D - 2x\tan\alpha , \qquad -l_1 \leqq x \leqq 0 \qquad (3)$$

$$b = D + 2x\tan\beta , \qquad 0 \leqq x \leqq l_2 \qquad (4)$$

where, η ,u and g are water elevation from still water, horizontal water particle velocity and gravity acceleration,respectively; b represents the gradually changing width between the wedges.

A mass equation at Regions I and IV are as follow:

$$\partial\eta/\partial t + h(\partial u/\partial x) = 0 \qquad (5)$$

The boundary conditions for each region which are energy and mass conservation laws are represented by eqs (6)-(11).

$$\eta_1 - \eta_2 = (C_A/g)\{(D + B)/D_1 - 1\}u_1|u_1| , \qquad x = -l_1 \qquad (6)$$

$$(D + B)u_1 = D_1u_2, \qquad x = -l_1 \qquad (7)$$

$$\eta_2 = \eta_3, \qquad x = 0 \qquad (8)$$

$$u_2 = u_3, \qquad x = 0 \qquad (9)$$

$$\eta_3 - \eta_4 = (C_B/g)\{1 - (D + B)/D_2\}u_4|u_4| , \qquad x = l_2 \qquad (10)$$

$$D_2u_3 = (D + B)u_4, \qquad x = l_2 \qquad (11)$$

In eqs (6) and (10), the energy loss coefficients are given as C_A and C_B, respectively.

By solving the above equations to satisfy the boundary conditions, we can obtain the result of the reflection and the transmission coefficients as eqs (12) and (13), respectively.

$$r_R = \frac{\sqrt{\{-1 + Eo - Gn + (\psi g/c)\}^2 + (Ep + Gm)^2}}{|1 + (\psi g/C)|} \tag{12}$$

$$r_T = \frac{\sqrt{(E's - G'r)^2 + (E't + G'q')^2}}{|1 + (\phi g/C)|} \tag{13}$$

where,

$$\left.\begin{aligned}
o &= h'm - jn \\
p &= jm + h'n \\
q' &= \frac{(Ao - Fn)A'a + (Ap + Fm)(A'b' + F')}{A'^2a^2 + (A'b' + F')^2} \\
r &= \frac{(Ap + Fm)A'a - (Ao - Fn)(A'b' + F')}{A'^2a^2 + (A'b' + F')^2} \\
s &= aq - b'r \\
t &= b'q + ar \\
h' &= (fd + eg')/(d^2 + e^2) \\
j &= (dg' - ef)/(d^2 + e^2) \\
m &= -2\underline{k}/(\underline{k}^2 + \underline{l}^2) \\
n &= 2\underline{l}/(\underline{k}^2 + \underline{l}^2) \\
\underline{k} &= \{1 + (\psi g/C)\}(D_1 Ij + D_1 M)/p - Eh' \\
\underline{l} &= -\{1 + (\psi g/C)\}D_1 Ih'/p - Ej - G \\
d &= -H'b'A - L'A - A'b'H - F'H \\
e &= H'aA + A'aH \\
f &= H'aF + A'a\underline{L} \\
g' &= H'b'F + L'F + A'b'\underline{L} + F'\underline{L}
\end{aligned}\right| \tag{14}$$

$$\left.\begin{aligned}
a &= \frac{\{1 + (\phi g/C)\}(D_2E'M'/p - D_2G'I'/p)}{\{1 + (\phi g/C)\}^2 D_2{}^2 I'^2/p^2 + E'^2} \\
b' &= \frac{-\{1 + (\phi g/C)\}^2 D_2{}^2 M'I'/p^2 - E'G'}{\{1 + (\phi g/C)\}^2 D_2{}^2 I'^2/p^2 + E'^2} \\
\psi &= C_A\{(D + B)/D_1 - 1\}|u_1|/g \\
\phi &= C_B\{1 - (D + B)/D_2\}|u_4|/g \\
C &= \sqrt{gh}
\end{aligned}\right\}$$

where,

$$\left.\begin{array}{ll}
A = J_0\left[kD/\gamma\right], & A' = J_0\left[kD/\gamma'\right] \\
E = J_0\left[k(l_1 + D/\gamma)\right], & E' = J_0\left[k(l_2 + D/\gamma')\right] \\
F = N_0\left[kD/\gamma\right], & F' = N_0\left[kD/\gamma'\right] \\
G = N_0\left[k(l_1 + D/\gamma)\right], & G' = N_0\left[k(l_2 + D/\gamma')\right] \\
H = J_1\left[kD/\gamma\right], & H' = J_1\left[kD/\gamma'\right] \\
I = J_1\left[k(l_1 + D/\gamma)\right], & I' = J_1\left[k(l_2 + D/\gamma')\right] \\
L = N_1\left[kD/\gamma\right], & L' = N_1\left[kD/\gamma'\right] \\
M = N_1\left[k(l_1 + D/\gamma)\right], & M' = N_1\left[k(l_2 + D/\gamma')\right] \\
\gamma = 2\tan\alpha, \quad \gamma' = 2\tan\beta, & k = 2\pi/L
\end{array}\right\} \qquad (15)$$

where, J_i and N_i are the Bessel and the Neumann functions of i-th order, respectively. L is a wave length.

The energy dissipation factor ε is expressed as follows:

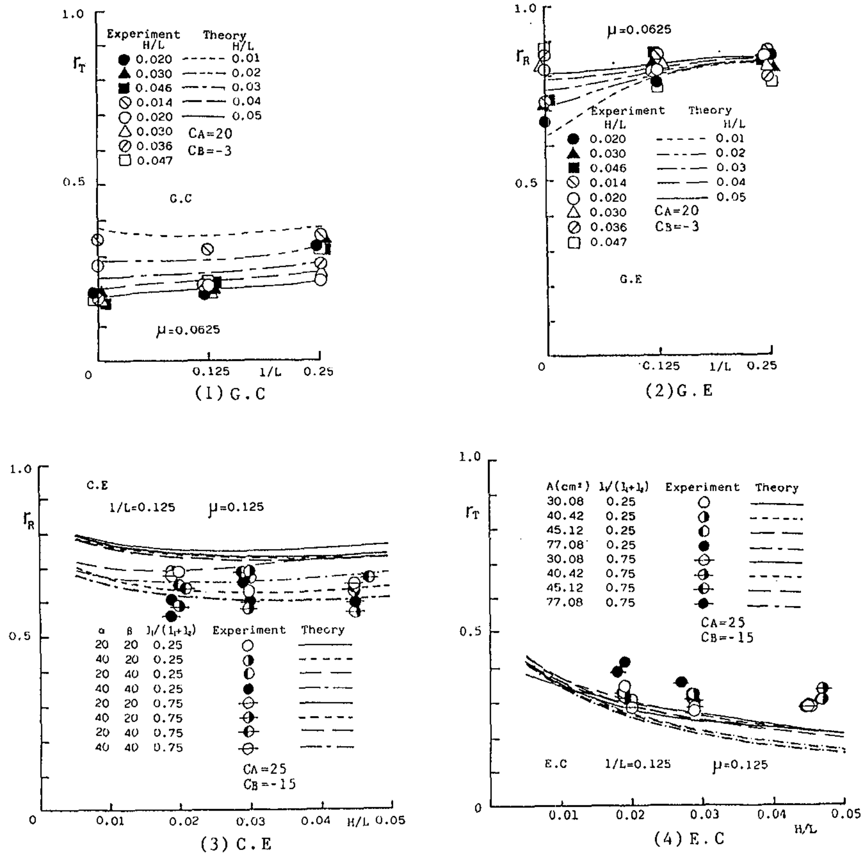
$$\varepsilon = 1 - r_R{}^2 - r_T{}^2 \qquad (16)$$

We can obtain the solution for any other breakwater by the same procedure (Murakami (1984,1985,1986)).

3. Experiments for Hydraulic Characteristics

The wave tank with a flap-type wave generator at an end, which is 15 cm long, 20 cm wide and 30 cm deep was used for measuring an incident, reflection and the transmission wave. The models were placed at a distance of 10 cm from the wave generator.

The water depth h and the wave period T were kept 15 cm and 0.75 sec, respectively. Incident wave steepnesses H/L were in the range of 0.01 to 0.05.

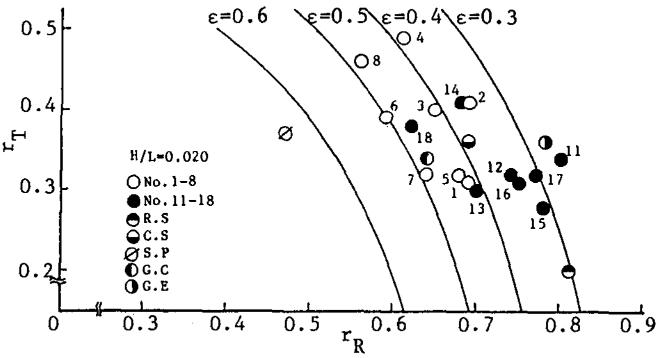


(1) G.C (2) G.E

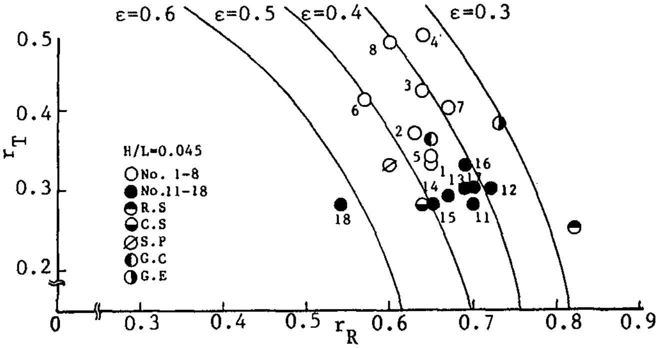
(3) C.E (4) E.C

Fig.3 Comparison of theoretical results with experimental data

Fig.3 shows some examples of the transmission and the reflection coefficients comparing theoretical results with experimental data. In figures, μ is the opening ratio D/D+B. It is found that the theoretical results coincide comparatively well with the experimental data, if appropriate values are assumed for the energy loss coefficients C_A and C_B.



(1) H/L=0.020



(2) H/L=0.045

Fig.4 Relation between reflection coefficients and transmission coefficients for each breakwater

Fig.4 illustrates, on the basis of the experimental results, the relation among the reflection coefficient r_R, the transmission coefficient r_T and the energy dissipation factor ε.

These experimental data are plotted for the relative breakwater width l/L = 0.125 and the opening ratio μ = D/D+B = 0.125. In the G.C type, the wedge angle α equals 19 degree. The experimental conditions of other types are shown in Table 1.

Table-1 Experimental Conditions

T=0.75sec, h=15cm, h/L=0.20, H/L=0.01~0.05

NO.	Type	$\mu=D/(D+B)$	$l=l_1+l_2$(cm)	$l_1/(l_1+l_2)$	$\alpha^{(\circ)}$	$\beta^{(\circ)}$	A(cm^2)
01	S.P	0.0625	0				
02		0.125	0				
03		0.25	0				
41	G.C	0.0625	9.4		19		
42		0.125					
43		0.25					
44		0.0625	18.8				
45		0.125					
46		0.25					
51	G.E	0.0625	9.4		19		
52		0.125					
53		0.25					
54		0.0625	18.8				
55		0.125					
56		0.25					
1	C.E	0.125	9.4	0.25	20	20	
2					40	20	
3					20	40	
4					40	40	
5				0.75	20	20	
6					40	20	
7					20	40	
8					40	40	
11	E.C	0.125	9.4	0.25	20	7	30.08
12					40	16	40.42
13					46	20	45.12
14					68	40	77.08
15				0.75	7	20	30.08
16					16	40	40.42
17					20	46	45.12
18					40	68	77.08
20	R.S	0.125	9.4				21.62
30	C.S	0.125	9.4				77.08

First, let us compare the values of three simpler types, S.P, G.C and G.E. The transmission coefficients of the three are almost the same, while the reflection coefficient becomes progressively larger from S.P through G.C to G.E.

For the R.S type, the reflection coefficient is largest in all the data, though the transmission coefficient is smallest.

The group of white circles is concerned with the C.E types. When we note the pairs of No.1 and No.2, No.3 and No.4 , No.5 and No.6 in order to discuss the effect of the wedge angle, the transmission coefficient has a larger value for the bigger number of the pair. On the other hand , the reflection coefficient does not change remarkably. This means that it is effective to make the wedge angle small for the breakwater in consideration of the hydraulic aspect. In the C.E type, the wedge angles α and β , the relative wedge length l_1/l_1+l_2 affect mainly the transmission coefficient.

The group of black circles is concerned with the E.C type. They have a chamber in each breakwater. The bigger the number, the larger the chamber area is. It is found that chamber area A and the relative wedge length l_1/l_1+l_2 do not remarkably affect the transmission coefficient, though an exception can be observed in the case of H/L = 0.02. Generally speaking, the transmission coefficients for the E.C type are much smaller than those for the C.E type. On the other hand, the reflection coefficients for the E.C type are nearly equal or a little bit larger than those for the C.E type.

The C.S type in this study has the same chamber area as those for the No.14 and No.18 of the E.C type. The transmission coefficients of both types are almost equal to each other for H/L = 0.045 and they are a little bit smaller in the C.S type for H/L = 0.02.

4. Experiments for Water Exchange Characteristics

4.1 Water exchange discharge

The horizontal water particle velocity at the smallest gap of a breakwater was measured by the propeller type current meter at the point of 7 cm from the water surface. The water exchange discharge per unit breakwater length through a gap caused by the wave action is expressed as follow:

$$q = \frac{4}{T}\int_0^{T/4} \frac{Dh}{D+B} V_{max} \cos\frac{2\pi}{T} t = \frac{2Dh}{\pi(D+B)} V_{max} \qquad (17)$$

where, V_{max} is the average value of maximum water particle velocities of two opposite directional flows at a gap.

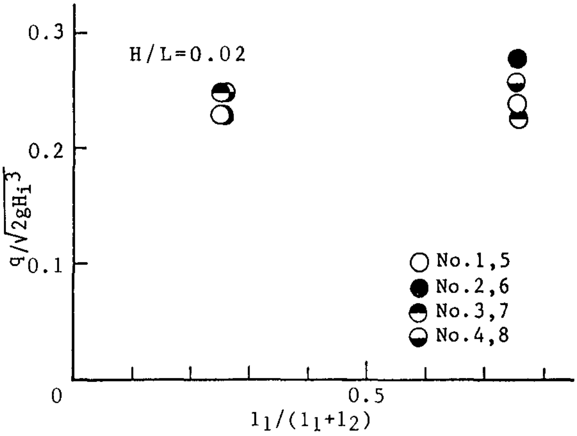
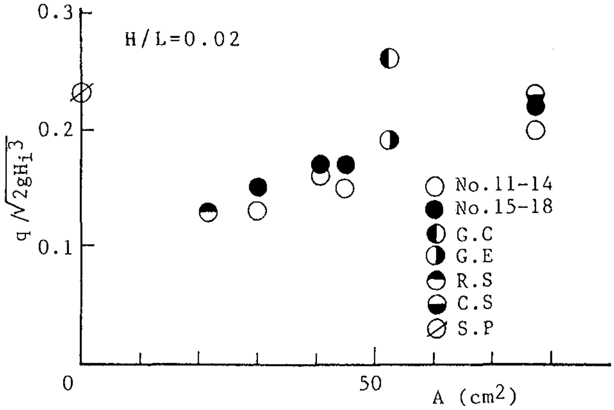


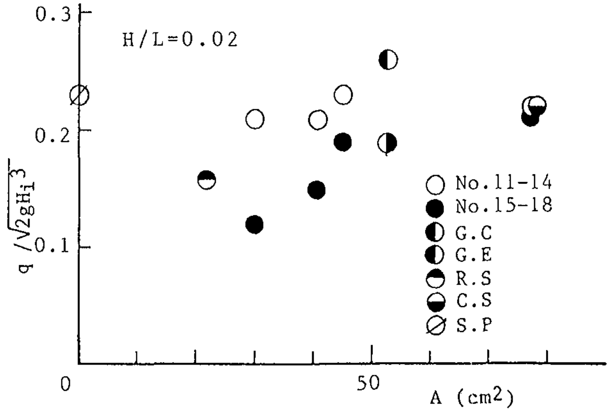
Fig.5 Relation between $q/\sqrt{2gH_i^3}$ and l_1/l_1+l_2

Fig.5 shows the relation between a nondimensional water exchange discharge and the relative wedge length for the C.E type. H_i in the vertical axis expresses an incident wave height. In this type, the water exchange discharge increases slightly with the increase of the relative wedge length l_1/l_1+l_2. However, such a relative wedge length and the wedge angles α and β do not remarkably affect the water exchange discharge.

To cite for reference, the values of $q/\sqrt{2gH_i^3}$ for the S.P, G.C and the G.E types are 0.23, 0.26 and 0.19, respectively. The water exchange discharge for the C.E type is nearly equal or bigger than those for the S.P and G.C types.



(1) front side



(2) rear side

Fig.6 Relation between $q/\sqrt{2gH_i^3}$ and A

Fig.6 is concerned with the E.C type. This type of breakwater has two gaps at the front and the rear. The abscissa of the figure represents a chamber area as shown by the shadow zone in Fig.1.

The exchange discharge increases slightly with the increase of chamber area A. The discharge at the rear side gap is large when l_1/l_1+l_2 is small, though the tendency is opposite at the front side gap. It seems that both values of discharge for the C.E and C.S types are almost equal, when the two chamber areas are equal. The R.S type breakwater is not effective for water exchange.

As a result of considering the water exchange discharge, we can say that the C.E type breakwater has the most effective cross section in these experiments.

4.2 Diffusion characteristics

Fig.7 shows the experimental equipment. The wave tank was sheltered by two sheets of thin plates from the rear of the breakwater to a distance of about 2 m in front. Salt water with a constant concentration was in this basin. Other regions of the wave tank were filled with fresh water. The sheltering plates were pulled up before an incident wave had just reached the posision of the front side plate. Then concentration changes at the three points of 1 cm, 2.5 cm and 4 cm from the bottom at a distance of 15 cm behind the breakwater were measured by the concentration meters for about 4 minutes.

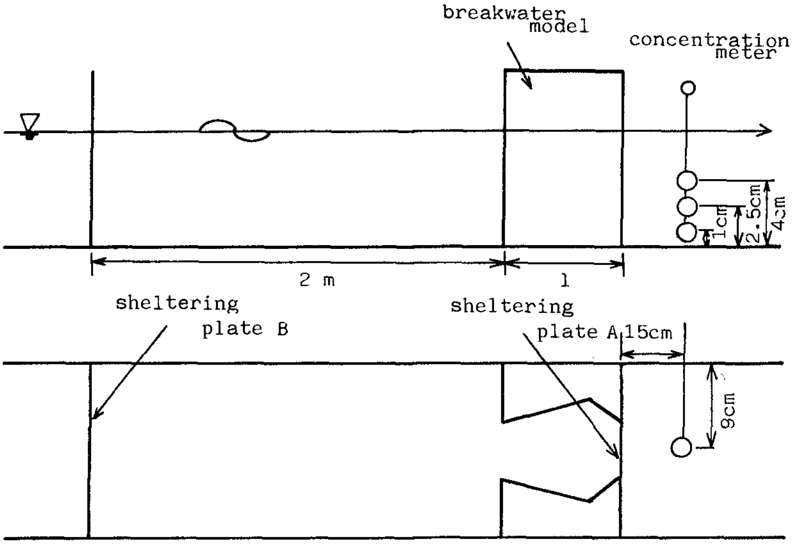
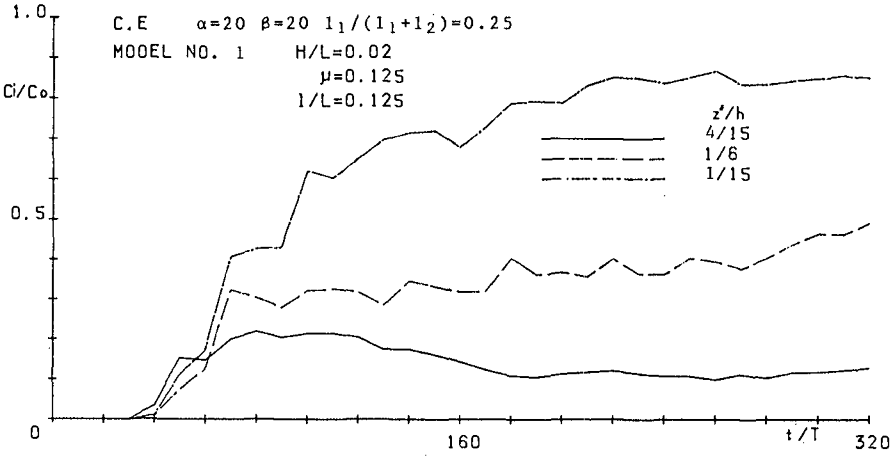
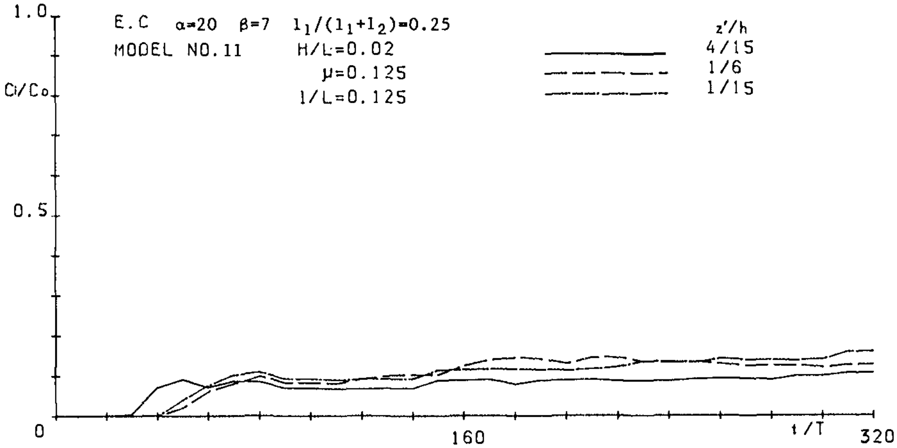


Fig.7 Experimental equipment for water concentration change through gap of breakwater



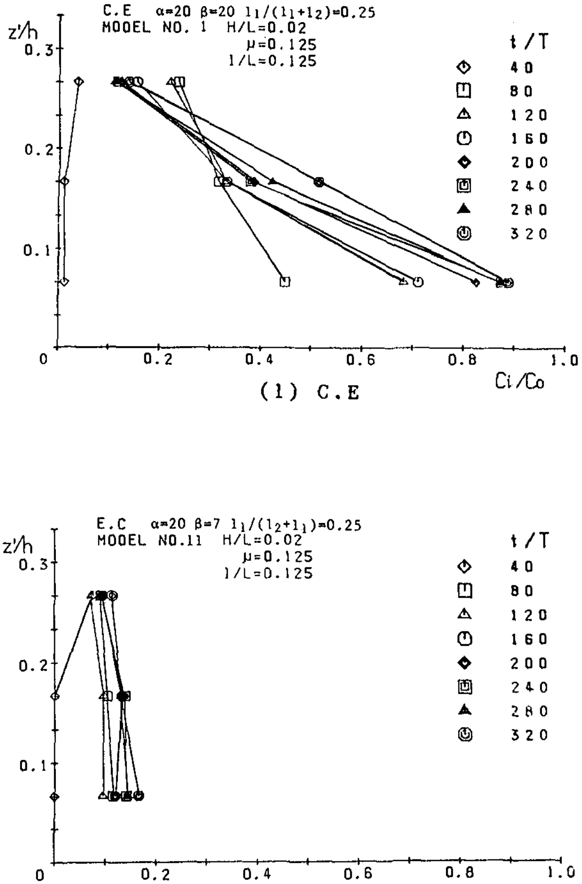
(1) C.E



(2) E.C

Fig.8 Nondimensional concentration change with time

Fig.8 shows two typical examples of nondimensional concentration changes with time t. C_0 is an initial concentration. T is a wave period. The concentration changes at the measuring points were remarkable for the G.E and R.S types as well as for the C.E type. On the other hand, the concentration did not change at the three points for the S.P, G.C and the C.S types, which are similar to the E.C type.



(1) C.E

(2) E.C

Fig.9 Vertical concentration distribution at regular time intervals

Fig.9 shows the vertical concentration distribution at regular time intervals for the C.E and E.C types. The ordinate z'/h is the nondimensional distance measured from the tank bottom. The parameter t/T represents the number of waves which penetrated through the slit after sheltering plates were pulled out. In the case of the C.E type, the concentration changes at the lower measuring points are more remarkable than at the upper point. The concentration near the bottom becomes almost the same as in the open sea after the 320th wave. In contrast, the vertical concentration distributions do not vary with time. Furthermore, all values of the concentration at each point are smaller than those for the C.E type.

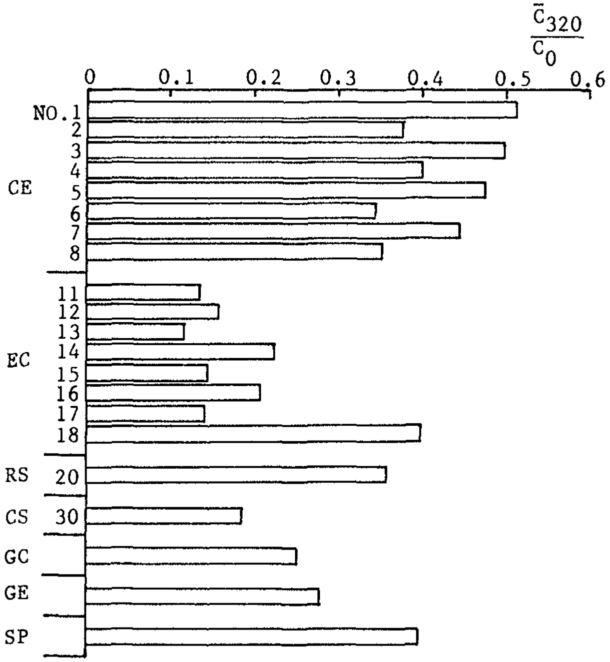


Fig.10 Comparison of average concentration after 320th wave for each breakwater

Fig.10 shows the comparison of the average concentration after the 320th wave for each breakwater. The values of concentration for the C.E type breakwaters are comparatively bigger than those for all other cases. Especially, in comparison of No.1 with No.2 or No.1 with No.5, the water mixes actively between the inside of the breakwater and the outside, when both the wedge angle α and the relative wedge length l_1/l_1+l_2 are small.

The nondimensional concentration for the E.C type is smallest in all experiments except the No.18. The value for the R.S type is much bigger, though the water exchange discharge was not bigger, than those for other cases. This means the characteristics of diffusion due to the setting up of the breakwater is not the same as those of the water exchange discharge due to the wave action.

5. Conclusion

The characteristics of the hydraulic and the water exchange due to the wave action against vertical slit-type breakwaters were discussed. Results are summarized as follows.

(1) We can estimate analytically the reflection and the transmission coefficients of the permeable breakwater with composition of the wedge shape parts for the horizontal cross section.

(2) We can find in this study that the C.E type breakwater is most effective as to both the hydraulic and the water exchange characteristics.

Acknowledgement

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