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WAVE PRESSURES ON VERTICAL WALL WITH POROUS ABSORBERS

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1. INTRODUCTION

Many laboratory studies and field practices have shown that a porous absorber facing the seaside of an impervious breakwater or seawall is remarkably effective to decrease reflected wave energy, wave run-up, and overtopping water quantity. Experiments have also shown that absorbers made of rubble types of material, such as quarry stone and artificial concrete blocks are effective to decrease the wave pressures on the wall faced with the absorbers under the limitted conditions[1)~5)]. They may be summarized as follows:

1) Wave pressure intensity without absorber, p_0, should be of aroused breaking waves such that the dimensionless pressure intensity, p_0/w_0H_i being greater than 1.5, where H_i is the incident wave height at the depth of wall, h.
2) The crown height of absorber above still water level should not be less than H_i.
3) Thickness of absorber at the crown should be wide enough to place no less than two armour units, which is originally a stability requirement.

Since the experiments have been performed for absorbers of rubble types of material, the effects of hydraulic characteristics of absorbers, such as porosity, loss coefficient, size of material, and thickness have not been investigated in details. That may bring underestimate or overestimate of the effects in the course of designing even conventional rubble types of absorber. Lack of knowledge about the effects precludes proper evaluation of the pressures for other types of absorber than conventional ones.

Therefore, a generalized method of predicting the pressures is desired for design purpose. Analytical and numerical approaches may be effective if the pressures were caused by waves of small amplitude[6)~8)]. However, for the pressures caused by waves of large amplitude including breaking waves concerned, which are important for design purpose, empirical approaches rather than purely analytical ones seem to be useful for predicting them because of their complex nature.

In this paper the effects of the thickness and of the size of material of absorbers on the wave pressures are studied with the employment of absorber of a simplified porous structure so as to find a method for predicting the pressures on the wall faced with porous absorber in general, for incident waves of large amplitude including breaking waves.

2. EXPERIMENTAL PROCEDURE

(1) Wave Channel

Tests were performed over sloping bottoms of 1/20 and 1/40 in a wave channel of 18.5 m long, 0.4 m wide, and 1.0 m deep. It was made of steel and was equipped with a series of glass panel for visual observation.

Waves were generated by a flap type wave generator. The sloping bottom was made of plain wooden boards on supports. Two kinds of water depth at the vertical wall employed were 8.2 and 13.2 cm for 1/40 slope tests.

Another depth of 10.7 cm was added for the 1/20 slope tests. Wave periods tested were 1.0 and 1.4 seconds except for the depth of 10.7 cm to which 1.2 sec. period was added. Incident wave heights were varied from few centimeters to the height with which waves broke before reaching the wall, if available. Fig. 1 shows general arrangement of the experiment on the 1/20 sloping bottom. The 1/40 sloping bottom was about 12 m long and the vertical wall was situated about 15 m leeward from the wave flap.

(2) Absorber

The experiment employed a simplified porous

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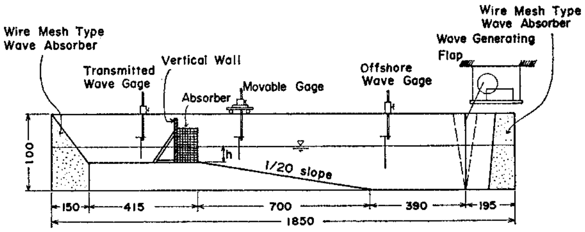

Fig. 1 General Arrangement of the Experimental Equipment for $S=1/20$. (unit of length in cm)

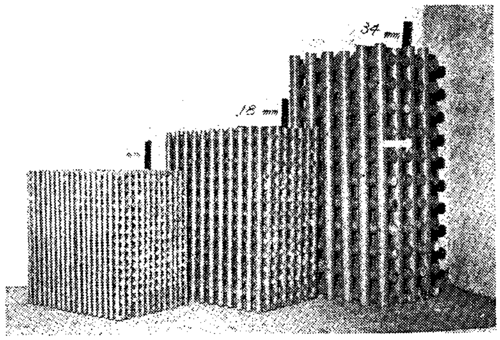

Photo. 1 Test Absorbers. (Arrow indicates the direction of wave advance)

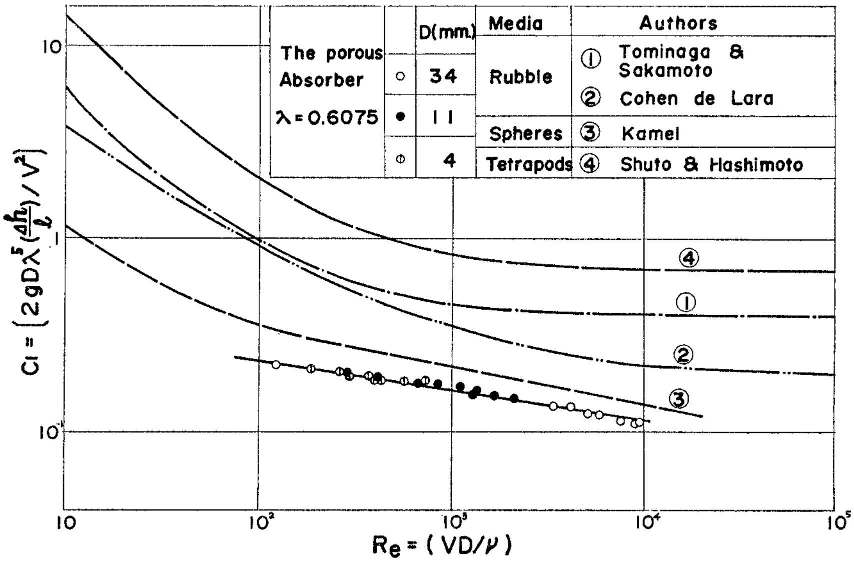

Fig. 2 Loss Coefficient.

material as wave absorber. It was a vertical-faced lattice made of circular polyvinyl chloride cylinders which were glued each other vertically or horizontally with a clearance of the diameter of cylinder, D [9), 10)] (Photo. 1).

The porosity of material, λ, in the hydraulic sense is computed to be 0.6075. Flow resistance of the material for steady flow to the direction of wave advance is shown in Fig. 2 [10), 11)]. The ordinate is a loss coefficient defined by

$$C_1=\frac{2gD\lambda^5}{V^2}\left(\frac{\Delta h}{l}\right) \quad \cdots\cdots(1)$$

where g is the acceleration of gravity, $(\Delta h/l)$ is the energy slope, and V is mean flow velocity in the material[12)]. The abscissa is a Reynolds number defined by

$$Re=\frac{VD}{\nu} \quad \cdots\cdots(2)$$

where ν is kinematic viscosity of water. In Fig. 2 loss coefficients of several materials, which have been calculated from published data, are added[10), 11), 13)]. Absorbers were high enough to preclude overtopping.

Three kinds of thickness of absorber employed mostly were 13.6, 27.2 and 54.4 cm, of which diameter was 34 cm. Absorbers of thickness of 6.8 and of 40.8 cm were used partly. Absorbers other than those of the diameter were of 1.8 and 1.1 cm for the thickness of 27 cm.

(3) Wave Height Measurement

Parallel-wire wave gages were used to measure wave heights. Incident wave height to a structure, H_i was usually determined as that measured at the location of structure in the absence of it. H_T, the transmitted wave height through absorber in the absence of wall was measured at the one quarter of wave length leeward from the rear face of absorber in 1/20 slope tests. H_T for 1/40 slope tests was determined, however, from the results of the former experiment performed in a 36 m long channel[10),15)], because of length limitation of the present channel. The output was amplified by an amplifier and recorded on a multi-channel oscillograph.

(4) Wave Pressure Measurement

Wave pressure was measured by the four pressure gages mounted on the wall which was a wooden board fixed on the bottom (Fig. 3). The pressure gage was a pressure converter of strain-gage type, a product of Kyowa Electronic Instruments Co. Ltd. (Fig. 4)[14)]. The output was amplified with a dynamic strainmeter and then recorded on another oscillograph.

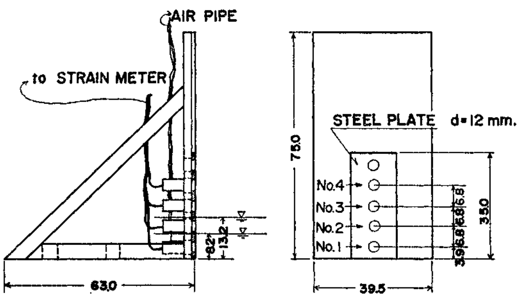

Fig. 3 Vertical Wall and Arrangement of Pressure Gages. (unit of length in cm.)

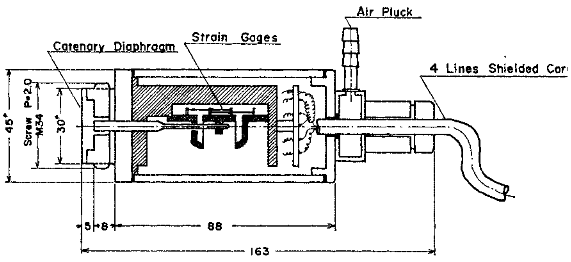

Fig. 4 Pressure Gage. (unit of length in mm.)

The method to determine a pressure intensity, p, is to draw a line on the record so that it represents an average of the maximum deviation by the stable several successive waves. The distance between that and the line to represent the records at still water is measured. Then p is computed by multiplying a caribration constant to the distance.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

A part of results of pressure measurement is presented in a direct manner in Figs. 5~7 and 9~14. Figs. 5 and 6 present examples of vertical distribution of p measured for various absorbers. Fig. 7 shows relationship between the maximum pressure intensity among those measured with

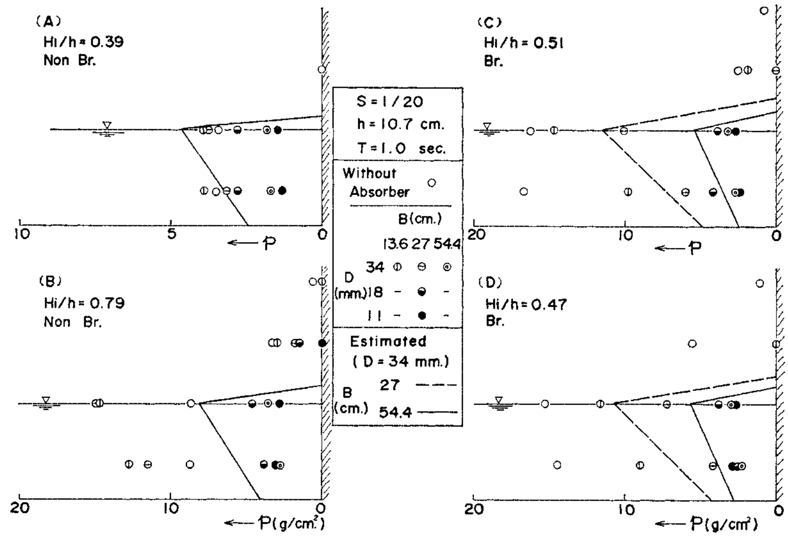

Fig. 5 Vertical Distribution of Pressure for Different H_i/h.

the four gages, p_{max}, and the incident wave height at deepwater, H_0'. H_0' was calculated from the incident wave characteristics at depth h or those of the breaking wave according to the cnoidal wave theory[20] or to the breaker index[21], respectively.

(1) Pressure on Wall without Absorber

Examples of vertical distribution of the pressure intensity on the wall without absorber, p_0, are shown with plain circles in Figs. 5 and 6.

The maximum pressures were obtained mostly at the No. 2 gage among the four ones for h of 10.7 and 13.2 cm, and at the No. 1 gage for h of 8.2 cm. No. 2 gage was the nearest one to the still water levels.

Though precise distribution cannot be expected due to limitted number of gages, the distributions are familiar ones[1]. Fig. 7 shows the relationship between H_0' and $p_{0,max}$, and Fig. 8 does that of between H_i/h, a relative wave height, and $p_{0,max}/w_0H_i$, a dimensionless pressure intensity, for 1/20 slope tests. Generally speaking, $p_{0,max}$ increases with H_0' gradually for waves of smaller height and then does sharply with it when waves begin to break on the wall. It continues to increase with H_0' though waves had broken before the wall, and H_i is decreasing with increasing H_0' for the broken waves. The pressure intensity is maximum for a wave which has already broken before it reaches the wall.

A linear relationship between H_i and $p_{0,max}$, which is known as a substantial one for complicated breaking wave pressure, is assumed as

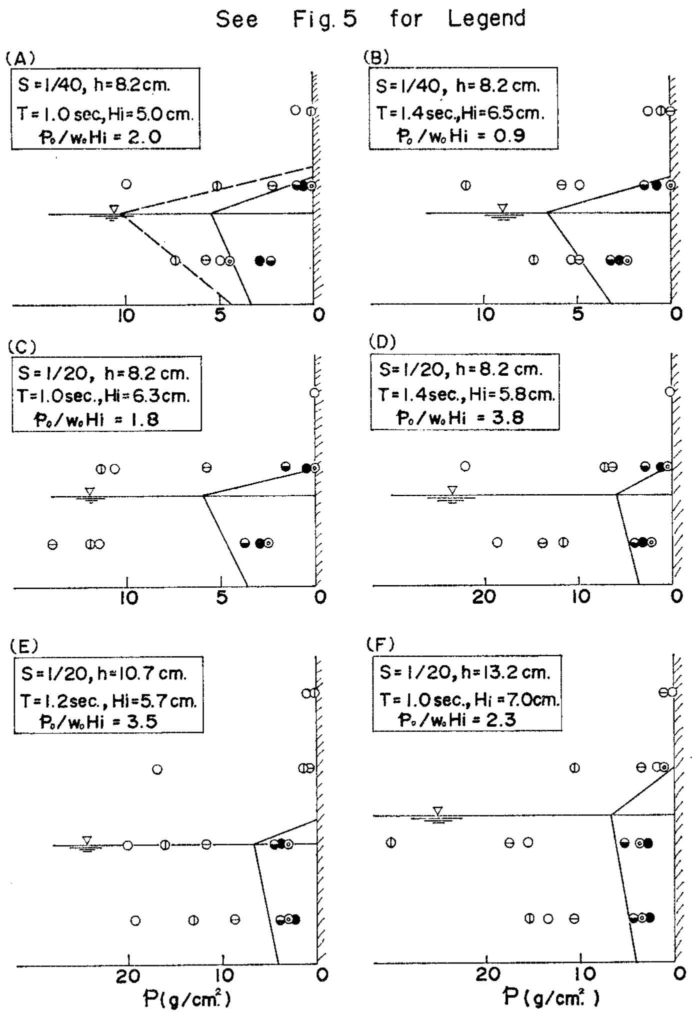

Fig. 6 Vertical Distribution of Pressure for Breaking Waves.

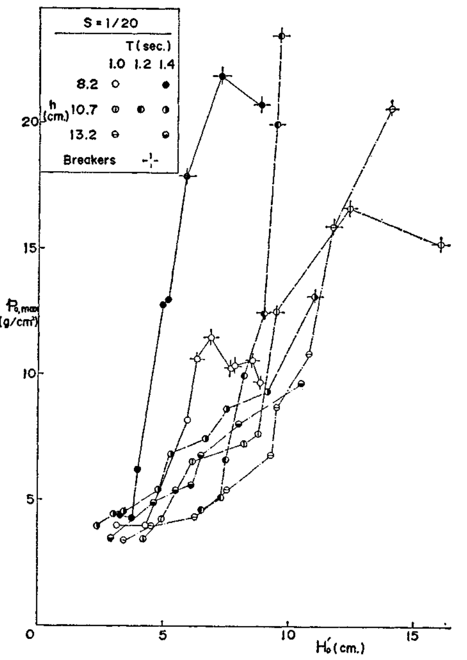

Fig. 7 The Maximum Pressure Intensity on Vertical Wall without Absorber.

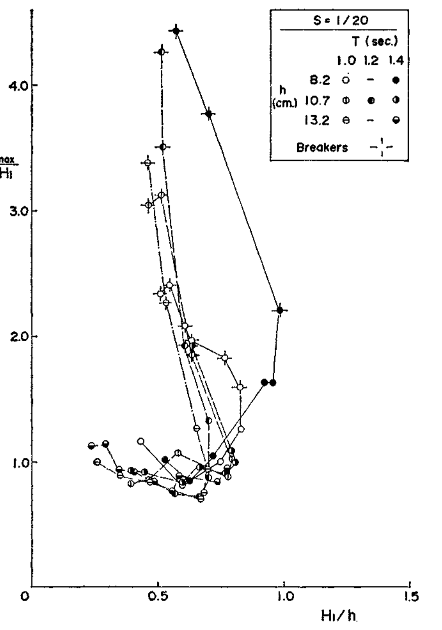

Fig. 8 $p_{0,\max}/w_0H_i$ versus H_i/h.

follows,

$$p_{0,\max}=\alpha_0 w_0 H_i \quad \cdots\cdots(3)$$

A dimensionless pressure intensity α_0 $(=p_{0,\max}/w_0H_i)$ may be a function of incident wave characteristics, bottom slope, and type and size of pressure gage. Values of α_0 for 1/20 slope test were almost less than 1.2 for non-breaking waves, and greater than 1.5 for breakers.

Values of α_0 for 1/40 slope tests were less than 2.5 and considerably lower than those for 1/20 slope tests were. This tendency stated above agrees with those obtained by several investigators[1].

(2) Vertical Pressure Distribution

The vertical distributions of pressure intensity on the wall with absorbers are shown in Figs. 5 and 6. Fig. 5 presents effects of wave height and state of breaking on the distribution, for four kinds of waves which are different only in their heights. Values of H_0' increases in order from A to D. Plots in the figure show that rate of damping of pressure is greater for breaking waves than for non-breaking waves.

Moreover, absorbers of smaller thickness are not effective for damping of pressures exerted by non-breaking waves.

Fig. 6 shows the distribution of several breakers of different periods, depths and slopes. The cases in the figure indicate that the pressure of higner α_0 is more easily decreased than that of lower α_0 is.

The pressure on the wall with absorber takes the maximum of it around the still water level and decreases rapidly upward and slightly downward. The distribution with absorbers of the largest thickness and of smaller diameters looks like that of a standing wave. A similar trend had been found for breakwaters with rubble types of absorber[4),5)]. These trends indicate that higher or dynamic pressures are more easily dissipated than lower or static ones are.

(3) Effects of Absorber Thickness on $p_{\max}$

Effects of the thickness of absorber, B, on $p_{\max}$ can be seen in Figs. 9~14. The region denoted by "Breaking Area" in the figures was determined from measurement of incident waves. The pressure could not be always decreased by installing an absorber unless α_0 was much large or B was much thick or D was small. Thin absorbers often brought greater pressures than $p_{0,\max}$ for non-breaking waves and waves breaking near the wall. This kind of increase of pressure with employment of relatively thin absorber has not been clearly acknowledged for rubble types of absorbers. The reason is that thickness of rubble absorbers cannot be decreased much because

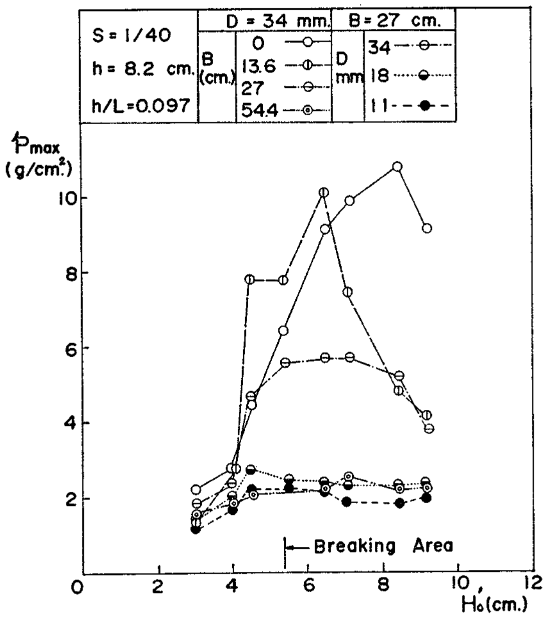

Fig. 9 Effects of B and D on p_{max}.

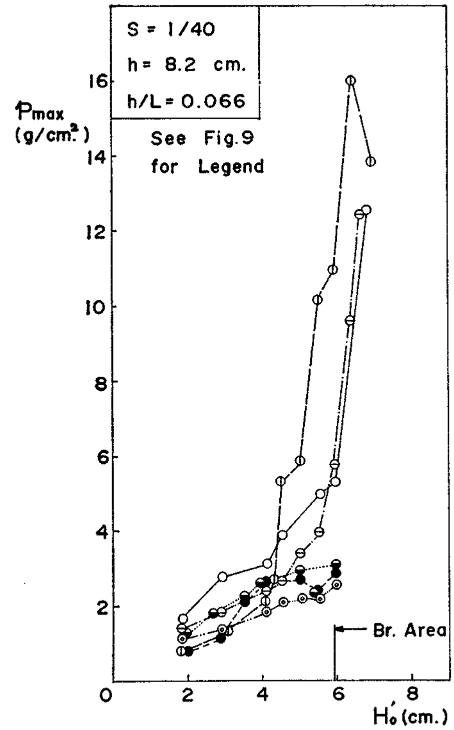

Fig. 10 Effects of B and D on p_{max}.

they have sloped front faces.

A remarkable trend associated with the above mentioned is that the deepwater incident wave

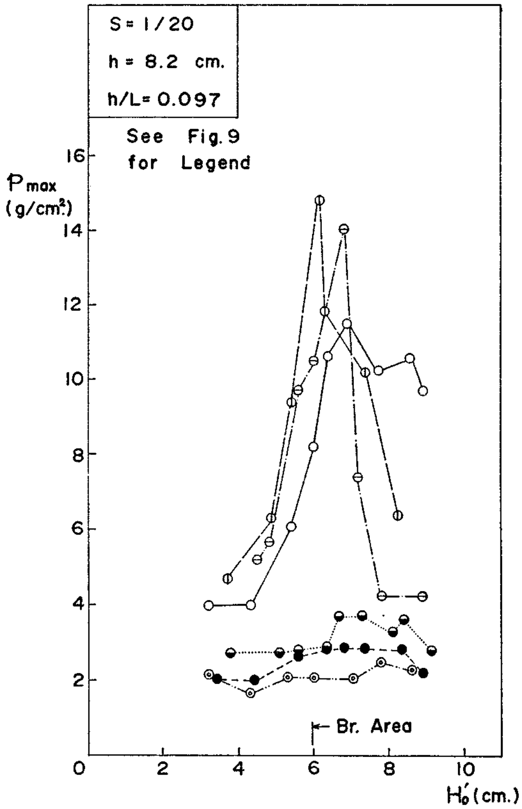

Fig. 11 Effects of B and D on p_{max}.

height which brings the greatest p_{max} under the condition of constant h, T, and structural arrangement, becomes smaller than that of without absorber, as seen in Figs. 9 and 12~14. A similar one had been found for overtopping quantity over the wall with rubble types of absorber[16].

Effects of B differ as incident wave dimensions, T and h, vary, which suggests importance of incident wave length, L, for the pressures. In Fig. 15, p_{max}/w_0H_i is plotted versus relative thickness of absorber, B/L, for three types of waves, namely, non-breaking, breaking just on the front face of absorber, and breakers. B/L has been known as a dominant parameter as far as wave reflection from and transmission through porous breakwaters concerned[9)~11), 15)]. Fig. 15 brings an idea that damping of pressure cannot be expected for the absorbers of B/L less than 0.25.

In order to investigate the cause of effect of B/L on the pressures, wave height within absorber was measured with small wave gages inserted in pores of it. Figs. 16 and 17 show wave height distribution for absorbers with B of 27 cm and 54.4 cm, respectively.

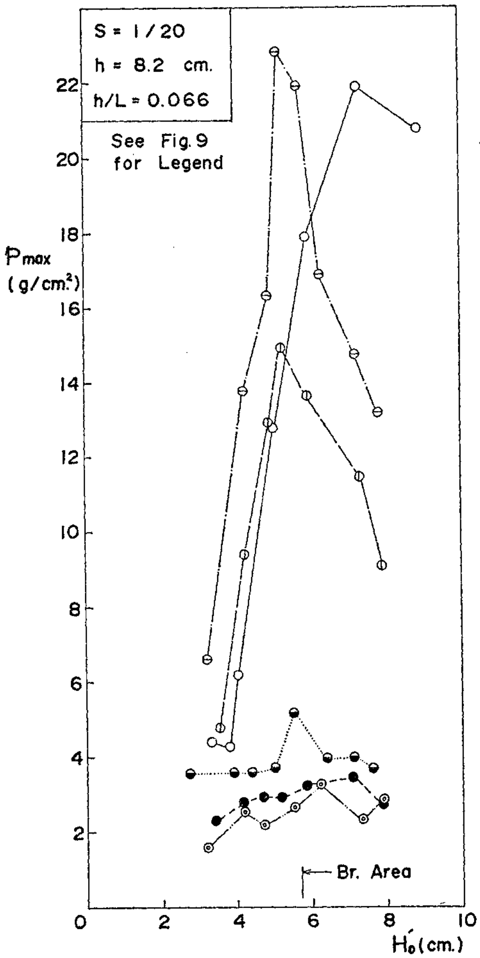

Fig. 12 Effects of B and D on p_{max}.

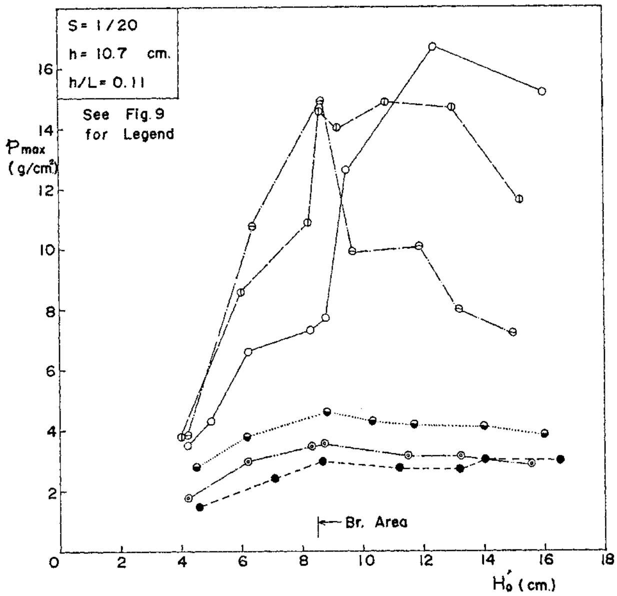

Fig. 13 Effects of B and D on p_{max}.

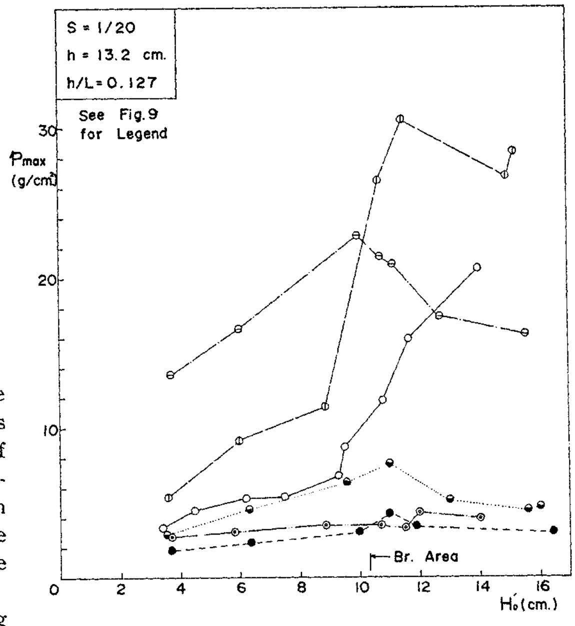

Fig. 14 Effects of B and D on p_{max}.

The distribution of non-breaking waves is more or less that of a partial standing wave which has at least two antinodes, one at the front face of absorber and another at the wall. The distribution is interesting when it is compared with the distribution in porous breakwater of the same material, in which case a node of standing wave was found at the rear face[10)~11), 15)].

As seen in Fig. 16, heights of non-breaking waves or the breaking waves on absorber sometimes become greater in absorber than at the front face.

The fact is explained as follows: Waves of B/L about 0.25 may bring the least reflected wave energy because phase lag between reflected wave from the front face of absorber and that of from the wall is about 180° provided fluid resistance in absorber is small. Then, the wave most progressively penetrates into the absorber, and may break in absorber and bring higher pressure. A similar phenomenon had been found for composite breakwater with relatively high rubble mound in front of it, in which case the relative length of the mound was important parameter[2)].

Since wave length within absorber is shortened

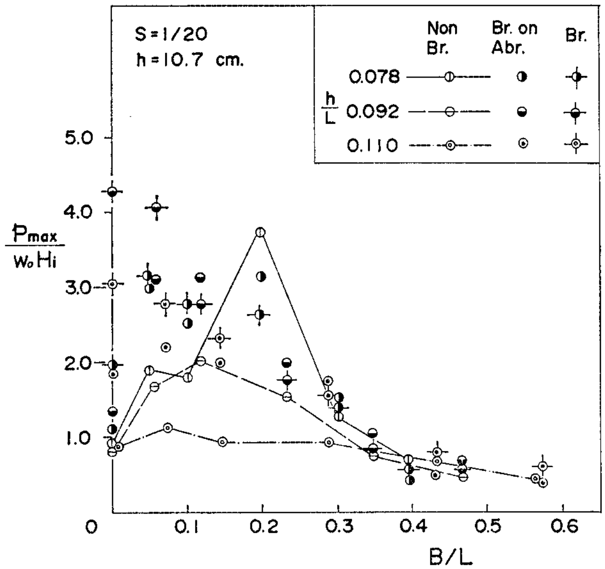

Fig. 15 p_{max}/w_0H_i versus B/L.

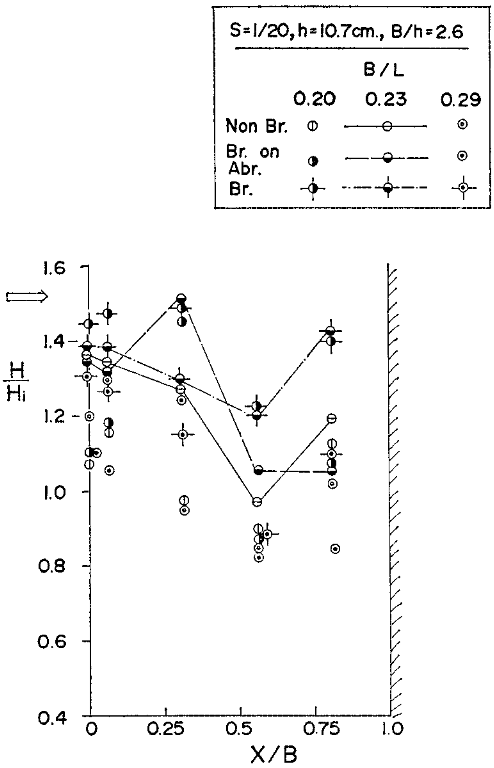

Fig. 16 Wave Height in Absorber. (B=27.2 cm.)

due to flow resistance of absorber[18], waves of B/L a little less than 0.25 brought higher pressures for the present experiment.

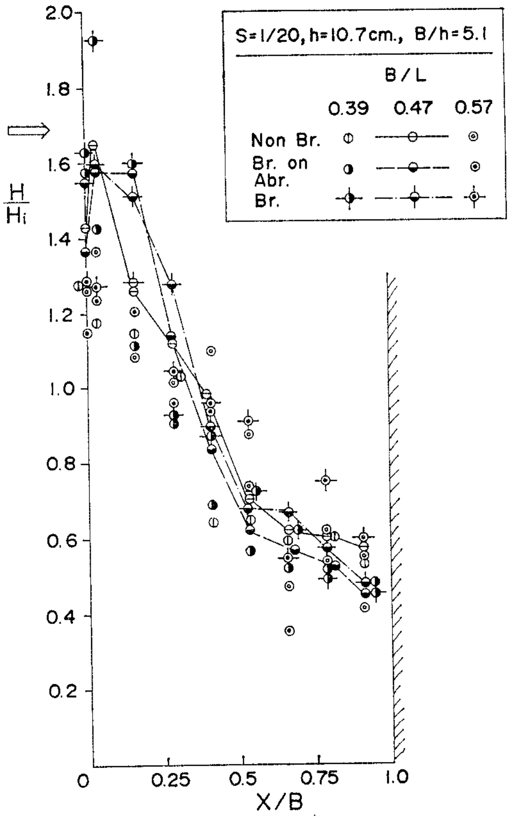

Fig. 17 Wave Height in Absorber. (B=54.4 cm.)

There is a nearly linear relationship between p_{max} and H_s which is wave height measured at location 5 cm seaward from the wall, as shown in Fig. 18. Two solid lines are drawn in it. The upper one was done so as to represent an average of breakers, while the lower one represents the equation,

$$p_{max}=\frac{1}{2}w_0H_s \qquad (4)$$

This may be the relationship for ordinally small amplitude long standing waves since H_s is approximated as twice of the incident wave height to the wall including cases with absorber. The pressure intensity p_{max} of non-breaking waves is higher for cases with absorber than those for without absorber under a constant H_s. Breakers, however, take almost the same p_{max} for both cases except for waves of small B/L.

(4) Effects of Size of Absorber Material

In order to investigate the effects of size of absorber material on the pressures, two kinds of absorber of different cylinder diameter D other

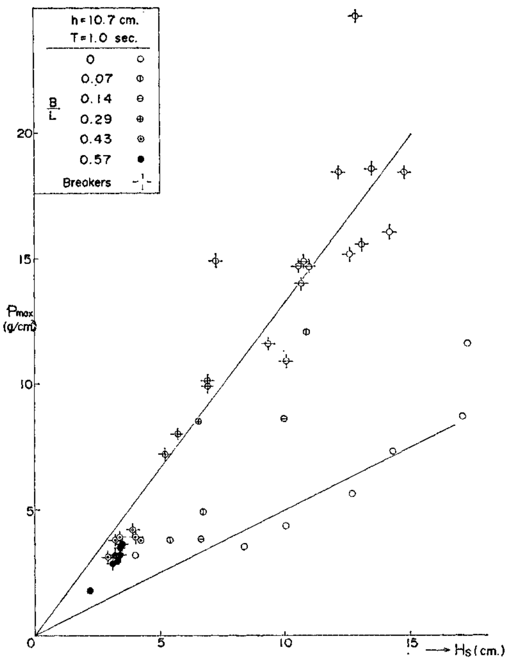

Fig. 18 p_{max} versus H_s.

than 3.4 cm were tested for absorbers of constant thickness of 27 cm. The diameters were 1.1 cm and 1.8 cm. The results are shown in Figs. 9~14, which reveal that the pressure decreases with decrease of the diameter size. The rate of decrease is higher for waves of greater height, shorter period, and of smaller depth. Decrease in the size is much effective to dissipate breaking wave pressures. With absorber of D of 1.1 cm, $p_{0,\,max}$ of breakers was decreased to value of between one third and one seventh of it according as α_0 ranges over between 1.0 and 4.0.

The cause of effect of size may be expected from the relationship by Eq. (1), which shows that for a material the rate of energy loss within absorber increases as size D decreases as well as velocity increases, for turbulent flow to which C_1 is constant.

(5) Relationship between p_{max} and the Transmitted Wave Height H_T

One of interesting properties observed from Figs. 9~14, is that when thickness becomes larger or D does smaller, the maximum pressure intensity is approximately the same and almost independent of H_0' and H_i.

A similar one had been found for the transmitted wave height through porous structures of the same material. The wave height, H_T, became nearly the same and did not depend upon H_i for larger waves including breaking ones[10), 11), 15)]. In such instances, the transmission coefficient K_T ($=H_T/H_i$) was almost inversely proportional to H_i.

Since the incident wave height H_i, is the dominant variable to p_0 for breaking waves, it seems to be reasonable to expect a similar relationship between the pressures on the wall with absorber and the transmitted wave height through absorber without wall. The linear relationship between p_{max} and H_s shown in Fig. 18 supports this assumption, because H_T is proportional to H_s.

When a similar equation to Eq. (3) is expressed as,

$$p_{max}=\alpha w_0 H_T\ . \quad \cdots\cdots(5)$$

Values of α are plotted against B/L in Figs. 19 and 20 in which data are classified according to α_0 and D. Fig. 19 deals with the data about waves of 1.0 sec. period with different H_i and h for absorbers of five kinds of B. On the other hand, the data in Fig. 20 are those of constant h of 10.7 cm. Both of them present a similar pattern of distribution

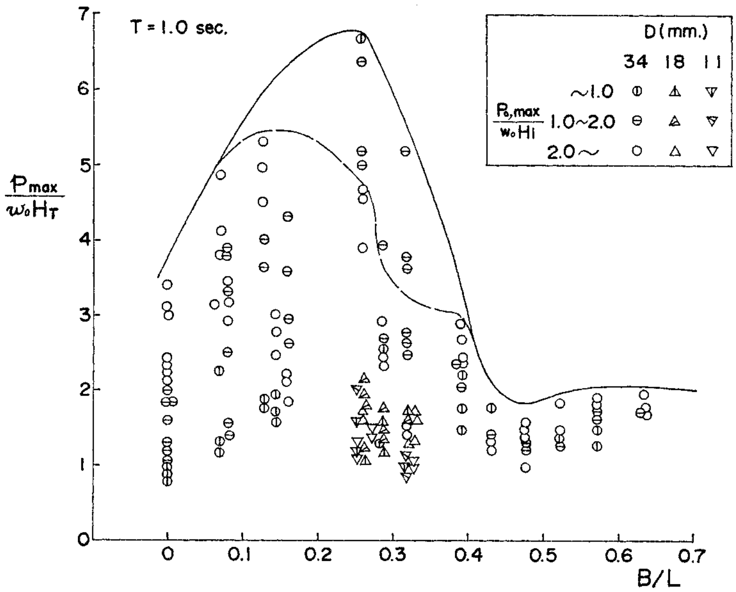

Fig. 19 p_{max}/w_0H_T versus B/L.

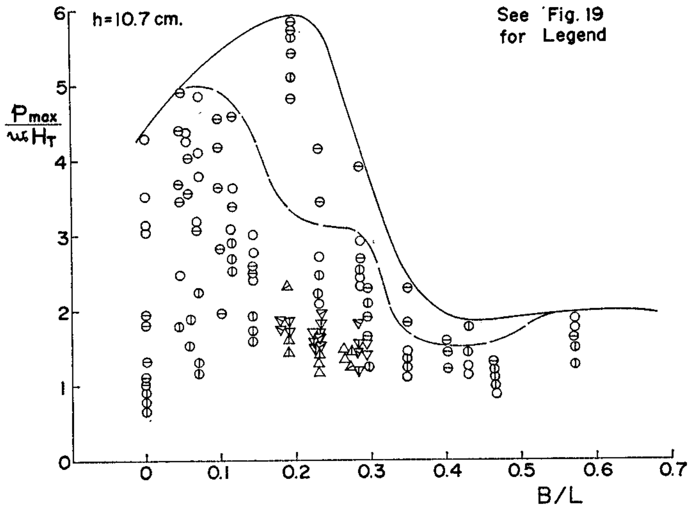

Fig. 20 p_{max}/w_0H_T versus B/L.

of plots. Though α varies considerably, it has much greater values at B/L around 0.20. Where B/L is larger than 0.45, α is less than 2.0 and independent from B/L and α_0. For the data of B/L less than 0.4, α is larger than α_0 for most cases. Two curves are drawn in the figures which indicate upper limits of all plots and of those for α_0 greater than 2.0, respectively. The latter one is appreciably lower than the former one is, for the range of B/L of 0.2~0.3. This trend may be a result of breaking phenomena within absorber mentioned in Section (3).

In the above dicussion wave length, L, of ordinary wave calculated on the basis of small amplitude theory is employed. Generally speaking, however, L should be replaced with L^* which is the wave length of wave progressing in water immersing porous materials[9),10),18)]. The ratio L^*/L was computed to find it being less than 1.0 for all and greater than 0.95, 0.90, and 0.85 for data of diameters of 3.4, 1.8, and 1.1 cm, respectively.

Thus, as far as data of D of 3.4 cm concerned, L instead of L^* can be used.

The maximum pressure intensity can be conservatively predicted for the present absorber with the following equations.

$$\alpha=3.0\,, \quad \text{for} \quad B/L^*\geqq 0.30 \quad \text{and} \quad \alpha_0\geqq 2.0 \qquad \cdots\cdots(6)$$

$$\alpha=2.0\,, \quad \text{for} \quad B/L^*\geqq 0.45 \qquad \cdots\cdots(7)$$

Prediction of the pressure for waves other than the above cited cannot be able because wider scatter of data, and possibly α is much greater than α_0.

The results discussed above suggest that an absorber with B/L^* less than 0.30 is not always successful in damping of wave pressure on vertical wall. In order to obtain greater B/L^*, decrease of L^* as well as increase of B should be considered. An absorber with a core made of material with greater flow resistance than that of the armour part of absorber, may be effective to obtain smaller L^*, and consequently to decrease the pressures.

4. A METHOD TO PREDICT THE WAVE PRESSURE

The maximum pressure intensity on vertical wall with the present absorber can be predicted with Eq. (5) for the waves satisfying Eq. (6) or Eq. (7), if H_T could be suitably estimated.

Analytical approaches to predict the transmitted wave height through a porous structure have been disclosed by several investigators, which are recognized to be useful[7),17)~19)]. The analytical values of K_T $(=H_T/H_i)$ for waves including breaking ones which were computed with an approach of the writer, had been compared with experimental ones for the present absorber. The comparison revealed usefulness of it for waves of h/L less than 0.1[10),11)]. Accordingly analytical estimation of p_{max} is possible.

Applicability of the present method to porous absorbers in general must be studied in detail in the future for practical purpose. An example of application has been tried for a rubble type absorber as follows:

A laboratory study on the wave pressures exerting on a reinforced concrete caisson with absorber made of tetrapods had been performed (Fig. 21)[4)].

The transmitted wave height H_T and the wave length have been computed by assuming the absorber being of rectangular form with thickness B_s (Fig. 22). Then, α is plotted versus B_s/L^* as shown in Fig. 22 together with α_0 which is done at B_s/L^* of zero. Inspecting the figure it can be said that the relationship between α and B_s/L^* approximately agrees to that of lattice absorber, though B_s/L^* of the data are almost less than 0.3.

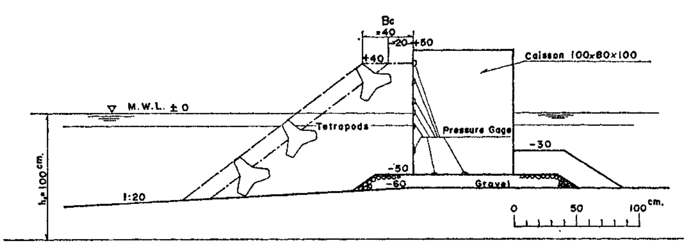

Fig. 21 Model Breakwater with Rubble Absorber for Pressure Measurements[4].

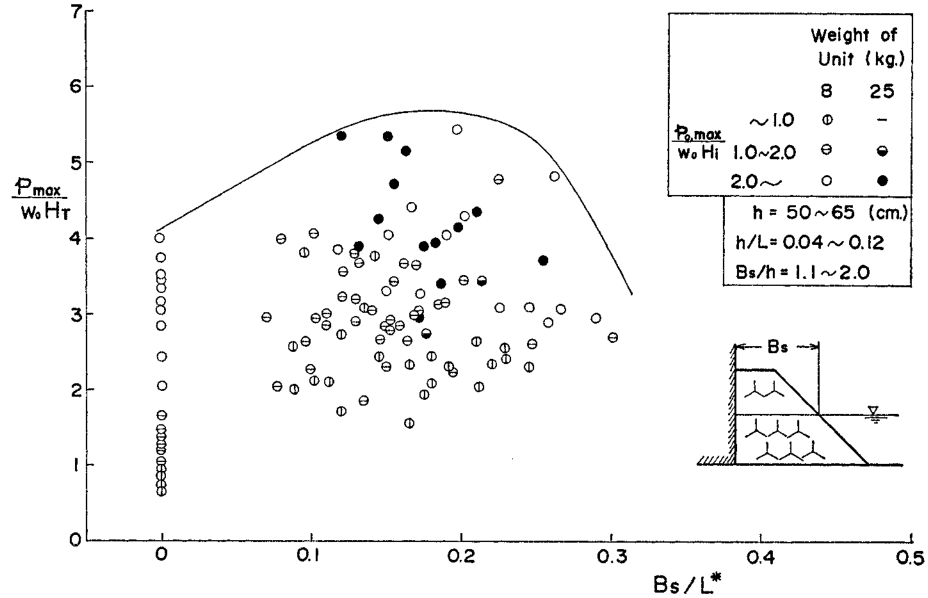

Fig. 22 p_{max}/w_0H_T versus B_s/L^* for Rubble Absorber Made of Tetrapods.

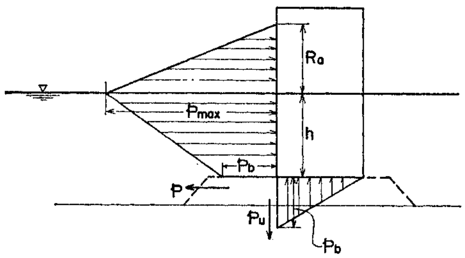

Fig. 23 A Proposed Pressure Distribution for Breakwaters with Porous Absorber[4].

Prediction of the total pressure per unit length of the wall requires further the vertical distribution of it. Inspection of Figs. 5 and 6, and the data of the rubble types of absorber[4] may bring an idea that the distribution of pressure after damped sufficiently with absorber is similar to that of a standing wave. On this line of thought, the distribution is approximated as depicted in Fig. 23. R_a in the figure is the highest elevation where pressure acts from the still water level, and p_b is the wave pressure intensity at the toe of wall. R_a and p_b must be estimated to obtain the total pressure. The value of R_a may be estimated conservatively by applying the wave run-up on the wall with absorber. That of p_b is approximated according to the case of without absorber, as,

$$p_b = 1.25 w_0 H_T \qquad (8)$$

Estimated p_{max} and the total pressures are shown in Figs. 5 and 6 with solid lines for B of 54.4 cm and with broken lines for B of 27 cm, of absorbers with D of 3.4 cm. Only the cases which almost satisfy conditions of Eq. (6) or Eq. (7) are drawn. In the course of computation, R_a was determined as $0.5H_s$. The estimated total pressures always exceed the experimental ones because of conservative determination of Eqs. (6) and (7), and of theoretical H_T being usually greater than experimental ones[11), 15)].

5. CONCLUSIONS

1) With employment of the lattice type of porous absorber, wave pressure on vertical wall cannot be always decreased by facing the wall with it unless the relative thickness of absorber, B/L, is greater than 0.25.
2) Non-breaking waves and waves breaking near the front face of absorber often exert much greater pressures on the wall with absorbers of B/L less than 0.25, compared with those on it without absorber, because the waves receive less seaward reflected energy and may be accelerated to break within absorbers. In connection with this property, the deepwater incident wave height which brings the greatest value of p_{max}, the maximum pressure intensity for a wave, while only wave height being varied, is smaller than that without absorber.
3) There are nearly linear correlations between p_{max} and the wave height transmitted through absorber in the absence of wall, for cases of B/L greater than 0.4.
4) The intensity, p_{max}, is predicted conservatively for the lattice absorber with Eqs. (6) and (7) by making use of analytic calculation of the transmitted wave height.
5) An investigation of the experimental data about composite breakwater with rubble type absorber shows similar properties to the lattice absorber, by employing the wave length travelling in absorber instead of L, the ordinal wave length, though more detailed study is needed for practical application.
6) Since the distribution of pressure decreased considerably looks like that of a standing wave, the maximum total pressure per unit length of wall is estimated according to Fig. 23.

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NOTATIONS

B	thickness of absorber
B_s	B at still water level for rubble absorber
C_1, C_2, C_3	loss coefficients for porous materials
D	diameter of absorber material
g	acceleration of gravity
h	water depth at the toe of absorber
H	wave height
H_i	incident wave height at h
H_0'	incident wave height at deepwater (computed)
H_s	H measured at about 5 cm seaward from wall in absorber
H_T	transmitted wave height through absorber without wall
K_T	transmission coefficient ($=H_T/H_i$)
L	wave length at h determined with usual small amplitude wave theory
L^*	wave length in porous material (computed)
p	pressure intensity (g/cm^2)
p_b	p at the toe of wall
p_{max}	the maximum of p values distributed vertically for a wave
p_0	p of without absorber
$p_{0,max}$	p_{max} of without absorber
R_a	highest elevation at which pressure acts
Re	a Reynolds number
S	tangent of angle of bottom slope
T	wave period (seconds)
V	mean steady flow velocity
w_0	unit weight of water (g/cm^3)
α	a coefficient represents a dimensionless pressure intensity
α_0	α for p_0
λ	porosity of porous material
ν	kinematic viscosity
$\Delta h/l$	energy slope

REFERENCES

1) Design manual of shore protection facilities (Revised), Japan Society of Civil Engineers, 1969 (in Japanese).
2) Kogami, Y. and K. Tokikawa: An experimental study on wave pressures on breakwater with absorbers for several stages of under construction, Proc. of 17th Conf. on Coastal Engrg. of JSCE, pp. 205-210, 1970 (in Japanese).
3) Horikawa, K. and Y. Noguchi: Relationships between breaking wave pressure on vertical wall and wave surfaces, Proc. of 17th Conf. on Coastal Engrg. of JSCE, pp. 177-188, 1970

(in Japanese).
4) Kondo, H.: Some considerations on absorbers made of artificial concrete blocks, Proc. of 18th Conf. on Coastal Engrg. of JSCE, pp. 197-202, 1971 (in Japanese).
5) Kubo, K.: Wave pressure damping by permeable layers, Proc. of 19th Conf. on Coastal Engrg. of JSCE, pp. 367-372, 1972 (in Japanese).
6) Lean, G. H.: A simplified theory of permeable wave absorbers, Jr. of Hydraulic Research, IAHR, Vol. 5, No. 1, pp. 15-30.
7) Ijima, T., Y. Eguchi and A. Kobayashi: Study on permeable breakwater and quay wall, Proc. of 18th Conf. on Coastal Engrg. of JSCE, pp. 121-130, 1971 (in Japanese).
8) McCorquodale, J. A.: Wave energy dissipation in rockfill, Proc. of 13th. Coastal Engrg. Conf., Vol. III, pp. 1885-1901, 1972.
9) Kondo, H. and S. Toma: Hydraulic properties of porous structures, Proc. of 17th Conf. on Coastal Engrg. of JSCE, pp. 155-162, 1970 (in Japanese).
10) Kondo, H. and S. Toma: Wave reflection and transmission for a porous structure, Proc. of 13th Coastal Engrg. Conf., Vol. III, pp. 1847-1866, 1972.
11) Kondo, H. and S. Toma: Hydraulic properties of porous breakwaters (2nd Rept.), Proc. of 18th Conf. on Coastal Engrg. of JSCE, pp. 131-136, 1971 (in Japanese).
12) Le Mehaute, B.: Permeabilite des digues en enrochments aux ondes gravite periodiques, La Houille Blanche, No. 6, 1957.
13) Shuto, N. and H. Hashimoto: Hydraulic resistance of artificial concrete blocks, Proc. of 12th Coastal Engrg. Conf., Vol. III, pp. 1587-1599, 1971.
14) Ishihara, T. and M. Honma, Ed.: Applyed Hydraulics, Vol. III, 1, Maruzen Co. Ltd., 1972 (in Japanese).
15) Kondo, H., S. Toma and J. Asano: Hydraulic properties of porous breakwaters (3rd Rt.), Proc. of 19th Conf. on Coastal Engrg. of JSCE, pp. 193-197, 1972 (in Japanese).
16) Tsuruta, S. and Y. Goda: Expected discharge of irregular wave overtopping, Proc. of 11th Conf. on Coastal Engrg., Vol. II, pp. 833-852, 1969.
17) Tominaga, M. and T. Sakamoto: Study of wave transformation by permeable structures, Proc. of 16th Conf. on Coastal Engrg. of JSCE, pp. 309-319, 1969 (in Japanese).
18) Kondo, H.: An analytical approach to wave transmission through permeable structures, Coastal Engrg. in Japan, Vol. 13, pp. 31-42, 1970.
19) Sollit, C. K. and R. H. Cross, III.: Wave reflection and transmission at permeable breakwaters, Rept. No. 147, R. H. Parsons Lab., MIT, 1972.
20) Iwagaki, Y.: Hyperbolic waves and their shoaling, Proc. of 11th Conf. on Coastal Engineering, Vol. I, pp. 124-144, 1968.
21) Goda, Y.: A synthesis of breaker indices, Proc. of the Japan Society of Civil Engineers, No. 180, pp. 39-49, 1970 (in Japanese).

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