COMBINATION EFFECT OF PNEUMATIC BREAKWATER AND OTHER TYPE BREAKWATER ON WAVE DAMPING

by

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ABSTRACT

This paper deals experimentally with combinations of the pneumatic breakwater and other type breakwaters in order to increase the effectiveness of wave damping.

Firstly, a submerged breakwater is picked up, and the wave damping effect of this combined type breakwater is examined. Results obtained in this experiment show that some improvements on the wave damping are found for low frequency waves that cannot be damped by the pneumatic breakwater only. The reason of appearence of the combination effect is explained that a part of energy of the transmitted waves over the submerged breakwater transfers to shorter period waves.

Secondly, a floating breakwater is combined with the pneumatic breakwater. Experiments show that the transmission factor for high frequency waves becomes smaller than that of the pneumatic breakwater only, while there is not so much wave damping effect for low frequency waves even when the floating breakwater is combined. In addition, a guide plate is set below the bottom of the floating breakwater in order to increase the horizontal flow velocity for a given air discharge. It is found that the velocity of horizontal surface flow by using the guide plate increases as much as about 1.3 times that in the case of the pneumatic breakwater only. As a result,a little improvement on the wave damping due to the guide plate is also found.

INTRODUCTION

The pneumatic breakwater is one of mobile breakwaters, so it has several specific characters of the mobile breakwater such as mobility, temporality,cheepness, etc. Besides these, it is pointed out as a special merit of the pneumatic breakwater from environmental point of view not to interrupt the exchange of water in harbors and facilities of air discharge are placed on the sea bottom.

However, existing studies on the pneumatic breakwater have clarified its defect that the effectiveness of wave damping suddenly disappears when the wave period becomes longer than a certain period. This property prevents it from practical use.

The horizontal flow velocity, which is strongly related to the wave damping, generated by the air bubble curtain, is proportional to 1/3 power of the air discharge, so it is not expected to increase the horizontal flow velocity by increasing the air discharge.

In the present paper, in order to increase the damping effect, an attempt that other type breakwaters are combined with the pneumatic breakwater is carried out. The submerged breakwater and the floating breakwater are picked up as combined breakwaters.

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DAMPING CHARACTERISTICS OF PNEUMATIC BREAKWATER ONLY[1)]

Experimental apparatus and procedure

A wave tank used for the test was 27m long, 0.5m wide and 0.7m deep. The power of a compressure used was 5.5kW, and the maximum pressure was $7kg/cm^2$. A pressure regulater was installed for reducing the pressure and keeping it constant. A pipe for discharging air set on the bottom was 47.5cm long and 1 inch in diameter. Nozzle holes of the pipe were 1mm in diameter and opened 6mm interval.

Experimental results

At first, characteristics of wave damping for monochromatic waves were examined. The result is shown in Fig.1. The transmission factor HT/HI (HT: transmitted wave height and HI: incident wave height) suddenly decreases with increase in the frequency of incident waves. A critical frequency, which is defined as the frequency of which waves are damped almost completely, shifts to lower frequency as the air discharge increases.

Secondly, experiments for random waves were carried out. The energy spectra of incident waves and transmitted waves are shown in Fig.2 as an example. As the air discharge increases, the power of the spectrum of transmitted waves decreases. This figure also shows that the powers of them increase reversely for the waves around 2Hz. This reason is considered that the air bubble curtain flow generates some disturbance of which frequency is around 2Hz on the water surface. The value of transmission factor for random waves shows close agreement with that for monochromatic waves, so it is concluded that the pneumatic breakwater has same characteristics for both waves.

COMBINATION WITH SUBMERGED BREAKWATER[2)]

Experimental apparatus and procedure

A schematic view of experimental apparatuses is shown in Fig.3. The wave tank is the same as described previously. In the experiment, the following four models were provided as submerged breakwaters.

1) impermeable type and smooth surface
2) impermeable type and with roughness on the upper surface
3) permeable type and made of stellersheet
4) permeable type and made of ripraps

The impermeable type submerged breakwaters were made of vinyl chloride and anchors were put in it not to be swayed by the wave motion. The roughness were made of glass sticks of 10mm in diameter and placed on the upper surface at 30mm interval. The void ratio of stellersheet and ripraps, which were used as the materials of the permeable type submerged breakwater, were 98% and 45% respectively. The diameter of ripraps was about 30 $\sim$ 60mm. The height of the submerged breakwater, Sh, was changed 30cm,35cm,40cm and 45cm for the impermeable type, 30cm,35cm and 40cm for the permeable type. Only for the impermeable and 30cm high model, the width Sw was changed 20cm,40cm and 60cm, and for others

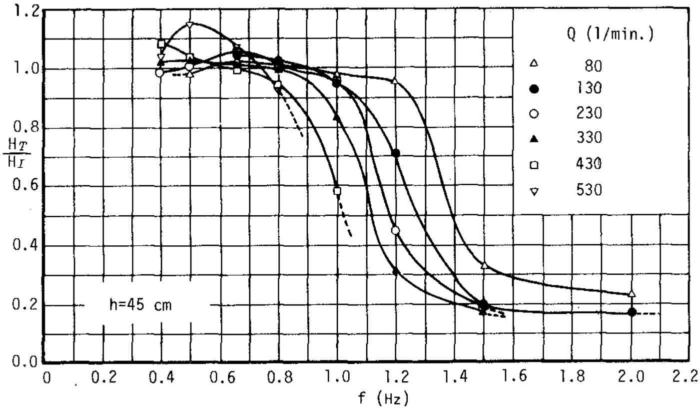


Fig.1 Relation between transmission factor of pneumatic breakwater and frequency of incident waves

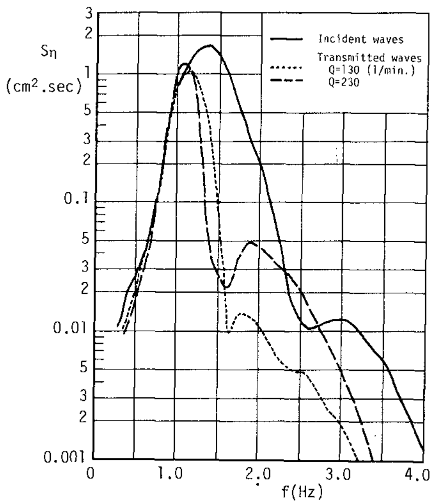


Fig.2 Damping effect of pneumatic breakwater for random waves

always Sw=20cm.

Experiments on the damping characteristics of the submerged breakwaters were carried out for monochromatic waves of 4cm $\sim$ 6cm in height and 0.4Hz $\sim$ 1.6Hz in frequency. The submerged breakwater was placed at the location where its front face was as far as 13m from the wave generater. Three wave gauges of electric resistance type were installed as shown in Fig.3. The first gauge was for incident waves, and other two were for transmitted waves. The reason why two gauges were installed was to examine the change of the transmission factor with measuring points.

Experiments of the submerged breakwater combined with the pneumatic breakwater were carried out for incident waves having the same characteristics as those used in the previous experiment. The air discharge was kept always constant 300 l/min, and this discharge corresponds to 7.09 l/sec.m under the condition of 0°C temperature and the atmospheric pressure.

Changing the distance between the air nozzle pipe and the submerged breakwater to 0cm,45cm,90cm,135cm and 180cm onshore and offshore sides respectively, the most advantageous arrangement was investigated. The experiment on the wave damping was carried out under this arrangement.

Damping effect of submerged breakwater

The purpose of this study is to examine the combination effect, so the damping effect of the submerged breakwater is not concerned with this purpose directly. But the combination effect cannot be discussed unless the damping effect of an individual breakwater is clarified. The experimental results on the transmission factor of several kinds of submerged breakwaters are shown in Fig.4. The variation of the transmission factor HT/HI with the height of submerged breakwaters Sh, and with the kind of materials are presented herein. The transmission factor decreases with increase of the height for the same type submerged breakwater,and becomes smaller in the order of the impermeable type of smooth surface, the impermeable type of rough surface, the permeable type made of ripraps and the permeable type made of stellersheet.

However, the most effective submerged breakwater on the wave damping is not always the most effective one for the combination type breakwater. It is assumed that the combination effect is caused by the energy transfer to shorter period waves which can be damped by the pneumatic breakwater. If this assumption is right, a submerged breakwater which can transfer more part of energy of transmitted waves to shorter period waves is the most effective as the combination type breakwater. From this point of view, it becomes important to investigate the characteristics of transmitted waves over the submerged breakwater.

Fig.5 shows the comparison of the transmitted wave amplitude spectrum over the submerged breakwater with the incident wave amplitude spectrum. In this case, the wave frequency is 0.4Hz, and the submerged breakwater is impermeable, 40cm high and 20cm wide. It is found that the wave height at the fundamental peak frequency fp, which corresponds to that of the incident monochromatic waves, decreases about 2cm, while the wave heights at the double and tripple frequencies of fp increase conversely.

Fig.6 shows the amplitude spectra of incident and transmitted waves

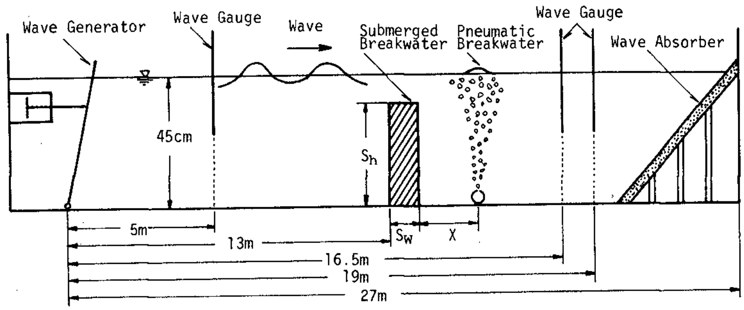


Fig.3 Experimental apparatus when submerged breakwater is combined with pneumatic breakwater

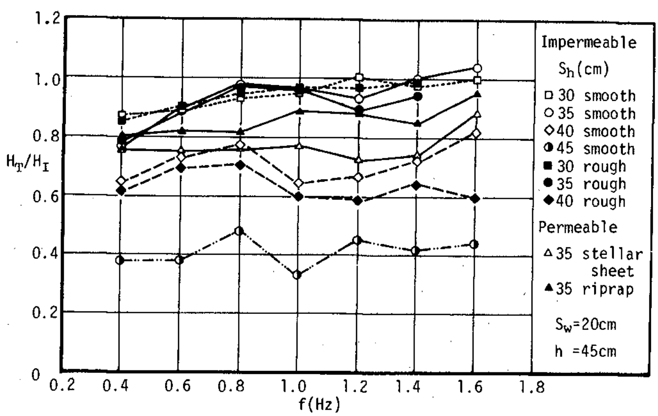


Fig.4 Relation between transmission factors of impermeable and permeable submerged breakwaters and frequency of incident waves

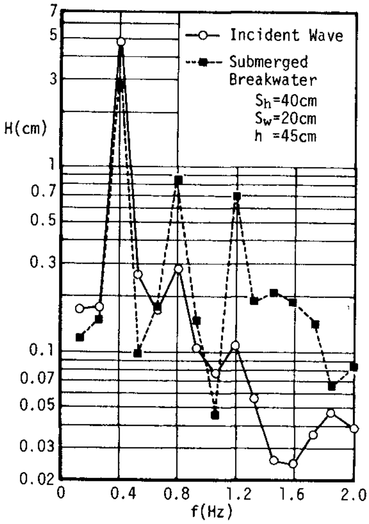


Fig.5 Comparison of amplitude spectra of transmitted waves over submerged breakwater and incident waves

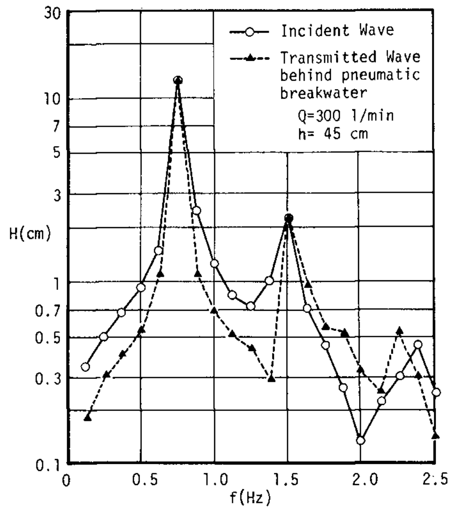


Fig.6 Comparison of amplitude spectra of transmitted waves through pneumatic breakwater and incident waves of finite amplitude with frequency of 0.77Hz

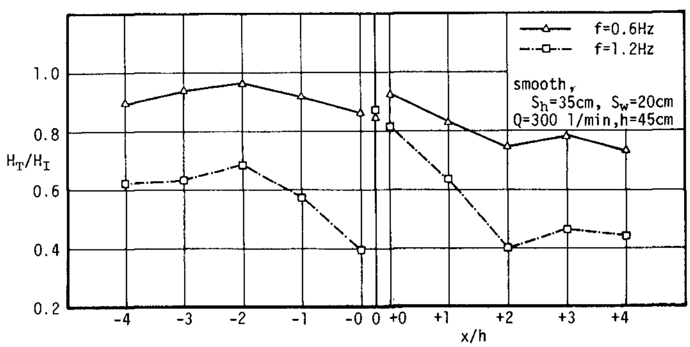


Fig.7 Variation of transmission factor with location of air nozzle pipe

through the pneumatic breakwater when incident waves are of finite amplitude and the frequency of 0.77Hz. It is found that the second harmonic component waves are not damped at all. That means that the pneumatic breakwater is not capable of damping bound waves of the second and third harmonics, even if their frequencies are in the region where the pneumatic breakwater is effective to wave damping. Therefore, it becomes important to clarify whether waves of the second and the third harmonics generated by passing over the submerged breakwater are free waves or bound waves.

A phase lag of component waves $\Delta\theta$ is obtained experimentally by calculating the phase spectrum from water surface variations measured at two points simultaneously. While a theoretical phase lag is calculated from the distance between recording points l and the wave length of component waves Lc, as follows

$$\Delta\theta = 2\pi l / Lc \qquad (1)$$

The comparison of the experimental phase lag with the theoretical one is shown in Table 1. Frequencies of waves used in this consideration are 0.586Hz and 0.781Hz. For free waves, the wave length Lc is calculated by the small amplitude wave theory, while for bound waves of the second harmonics Lc is assumed to be half of the wave length of fundamental component waves. The submerged breakwater used here is impermeable, smooth, 35cm and 40cm high and 20cm wide. The results of Cases 5,7 and 8 show that experimental values of the phase lag of the second harmonic component waves agree well with theoretical results of free waves. Therefore, it is reasonable to conclude that these waves generated by passing over the submerged breakwater are free waves.

Advantageous arrangement of pneumatic breakwater and submerged breakwater

Fig.7 shows the variation of the transmission factor with a location of the air nozzle pipe. The abscissa is the ratio of the distance between the air nozzle pipe and the submerged breakwater to the water depth, x/h, and the positive sign denotes the case when the air nozzle pipe is located onshore side. The submerged breakwater is in the section between $x/h=-0$, and $x/h=+0$. This figure shows the locations where the damping effect is remarkable are at $x/h\geq 2$ in the case when f=0.6Hz, and at $x/h=-0$ and $x/h\geq 2$ in the case when f=1.2Hz. From the results of two cases, the most advantageous arrangement is where the air nozzle pipe is located onshore side of the submerged breakwater apart more than twice the water depth. Accordingly, the location of the air nozzle pipe is determined to be at $x/h=2$ in the following experiment.

Damping effect of pneumatic and submerged breakwater

The wave damping effect of the combination type breakwater is examined by changing the size and material of the submerged breakwater. The results are shown in Fig.8. The transmission factor of the combination type breakwater decreases compared with those of the pneumatic breakwater only and of the submerged breakwater only. That is, for low frequency waves which cannot be damped by the pneumatic breakwater only, it decreases to some extent. But from the results in Fig.8, it is impossible to decide whethere the combination effect exists or not. Therefore, the

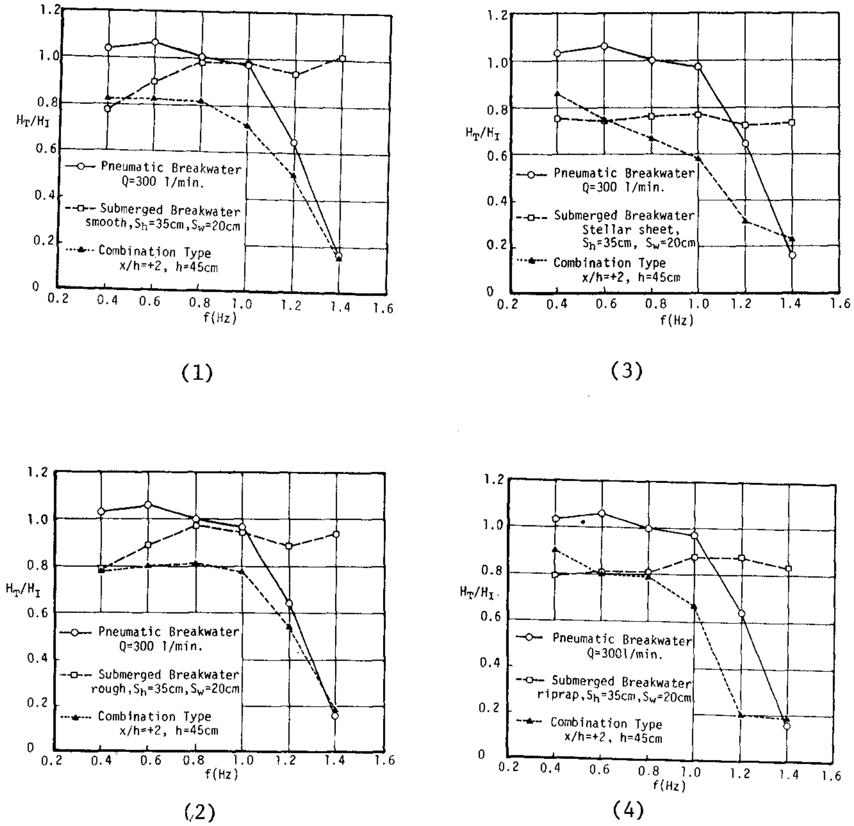


Fig.8 Transmission factors of pneumatic breakwater only, submerged breakwater only and combined breakwater

(1) Impermeable type and smooth surface
(2) Impermeable type and rough upper surface
(3) Permeable type and made of stellersheet
(4) Permeable type and made of ripraps

following equation is proposed as a quantitative expression of the combination effect:

$$ES=\left(\frac{HT}{HI}\right)_S\left(\frac{HT}{HI}\right)_P-\left(\frac{HT}{HI}\right)_{S+P} \qquad (2)$$

in which $(HT/HI)_S$ and $(HT/HI)_p$ denote the transmittion factors of submerged and pneumatic breakwaters only respectively. If the phenomenon is represented as a linear problem, the transmission factor of the combination type breakwater $(HT/HI)_{s+p}$ can be estimated as the product of each one. Consequently, the value of ES, which is the difference between the above mentioned product and the value of $(HT/HI)_{s+p}$, denotes the combination effect.

Fig.9 shows the transmission factors and the combination effects calculated by Eq.(2) for several kinds of combination type breakwaters. It is found from Figs.9 (a) and (b) that both the damping effect and the combination effect become remarkable as the height of the submerged breakwater increases. With regard to the width of the submerged breakwater, there is not so much difference of the damping effect as shown in Fig.9 (c). But in the case when Sw=60cm the curve of combination effect has a clear peak at the frequency of 0.6Hz. This phenomenon may be concerned with the effect of the width of the submerged breakwater on wave energy transfer to higher frequency waves. Fig.9 (d) shows the comparison between the effects by the materials constructing the submerged breakwaters.

It is concluded that the permeable type breakwater, especially made of stellersheet, is more effective on the damping effect than the impermeable type breakwater, but with regard to the combination effect, the impermeable type is more predominant than that of the permeable type.

In each case, it is found that existance of the combination effect is limited in the region of the frequency from 0.5Hz to 1.4Hz. The reason why the combination effect does not appear in the region $f<0.5$Hz is that the double frequency 1.0Hz of incident waves is a critical frequency for wave damping of the pneumatic breakwater. On the other hand, when $f>1.4$Hz, the combination effect also becomes negative because higher frequency waves are damped sufficiently by the pneumatic breakwater only.

COMBINATION WITH FLOATING BREAKWATER[3)]

Experimental apparatus and procedure

A schematic view of the experimental apparatus is shown in Fig.10. Floating bodies used as floating breakwaters were made of Lucite board, and 30 ∿ 90cm long, 48cm wide and 10cm high. The floating body was supported by anchor ropes which were $\sqrt{3}$ times as long as the water depth. A guide plate was set below the bottom of the floating breakwater as shown in Fig.11 to guide the horizontal surface flow in the opposite direction to wave propagation. The figure shows two ways of setting the guide plate.In the following,the guide plate shown in Fig.11(a) is named a vertical guide plate, and the other plate shown in Fig.11 (b) is named an inclined guide plate. The vertical guide plate was placed at the position dividing the length of the floating body into the ratio of 7:3, and the length of the vertical plate was 9cm. The angle of inclination

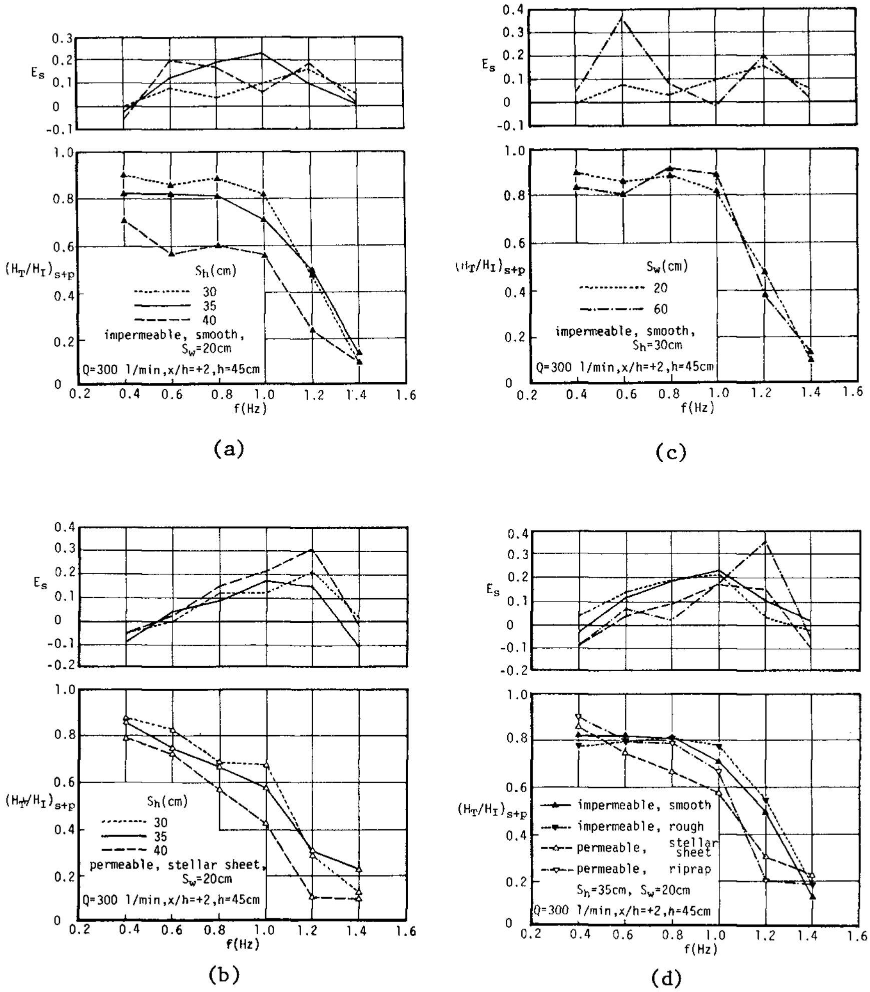


Fig.9 Combination effect and transmission factor of combination type breakwater

(a) Effect of height of submerged breakwater
(Impermeable type, smooth surface)
(b) Effect of height of submerged breakwater
(Permeable type, made of stellersheet)
(c) Effect of width of submerged breakwater
(Impermeable type, smooth surface)
(d) Effect of materials constructing submerged breakwater

Table 1 Phase lag of component waves

Case	f(Hz)	Wave	Freq.Compo.	Sh (m)	Experimental $\Delta\theta$ (rad)	Theoretical $\Delta\theta$ (rad)	
						Free Waves	Bound Waves
1	0.586	Transmitted	fundamental	0.35	1.04	0.985	—
2	0.781	Incident	fundamental	—	1.46	1.44	—
3	0.781	Transmitted	fundamental	0.35	1.50	1.44	—
4	0.781	Transmitted	fundamental	0.40	1.43	1.44	—
5	1.17	Transmitted	double	0.35	2.94	2.83	1.97
6	1.56	Incident	double	—	2.94	4.89	2.87
7	1.56	Transmitted	double	0.35	4.91	4.89	2.87
8	1.56	Transmitted	double	0.40	4.78	4.89	2.87

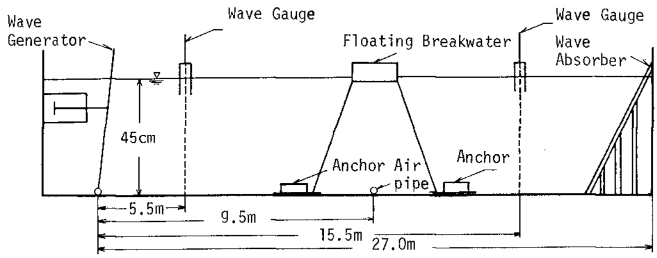
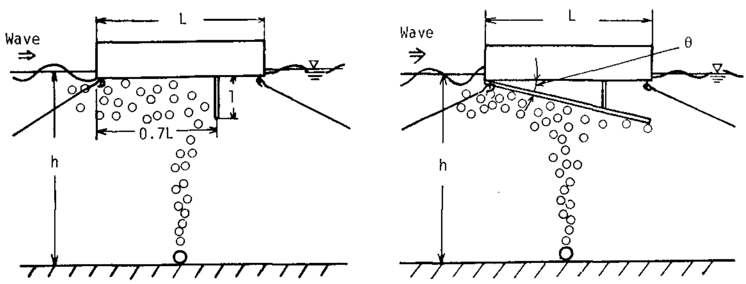


Fig.10 Experimental apparatus when floating breakwater is combined with pneumatic breakwater



(a) Vertical guide plate (b) Inclined guide plate

Fig.11 Setting ways of guide plate

of the inclined guide plate to the bottom of the floating body was kept constant 12°.

The water depth was 45cm,and the air discharge was 400 l/min throughout the experiments. This discharge corresponds to 15.15 l/sec.m under the condition of 0°C and the atmospheric pressure. Measurement of the horizontal flow velocity was carried out by a propeller type current meter of 18mm in diameter.

The draught depth of the floating body and the tension of anchor ropes are considered to affect significantly the transmission factor of the floating breakwater. Therefore, the draught depth was kept constant 2.5cm for the floating bodies which were 30cm,45cm and 60cm long, and 2.0cm for ones which were 75cm and 90cm long. The tension was not measured, but the experiment was made to keep the tension nearly constant.

Characteristics of horizontal surface flow velocity

Experiments were carried out in the following four cases:

Case-1 The pneumatic breakwater was used only.

Case-2 The floating breakwater without a guide plate was combined with the pneumatic breakwater.

Case-3 The floating breakwater with a vertical guide plate was combined.

Case-4 The floating breakwater with an inclined guide plate was combined.

Some examples of the velocity profile of the horizontal surface flow are presented in Fig.12. In this case, the velocity was measured at the section horizontally from the air nozzle pipe the same distance as the water depth. The length of the floating breakwater was 45cm. It is found that the velocity of the horizontal surface flow in the case of combination with the floating breakwater, especially with the vertical guide plate, increases as much as about 1.3 times that in the case of the pneumatic breakwater only. Regarding the thickness of the horizontal surface flow, the results in Case-2 and Case-4 show a little decrease of the velocity compared with Case-1 of the pneumatic breakwater only.

Damping effect of pneumatic and floating breakwater

At first, in the case of combination with the floating breakwater without a guide plate, the damping effect was examined. Fig.13 shows transmission factors in cases of the pneumatic breakwater only, the floating breakwater only and the combination of both breakwaters. Both the pneumatic and floating breakwaters have similar characteristics to be effective for the waves of higher frequency than a certain frequency. This characteristics remains same when both breakwaters are combined, but for the waves of higher frequency than a certain frequency the transmission factor becomes smaller than that in the case of simple use.

Change of the transmission factor with the length of the floating body is shown in Fig.14. The transmission factor of the floating breakwater only decreases a little as its length becomes longer. While, this tendency is not clear when the floating breakwater is combined with the pneumatic breakwater. This phenomenon is explained from the observation as follows. Incident waves increase in their height due to the horizontal

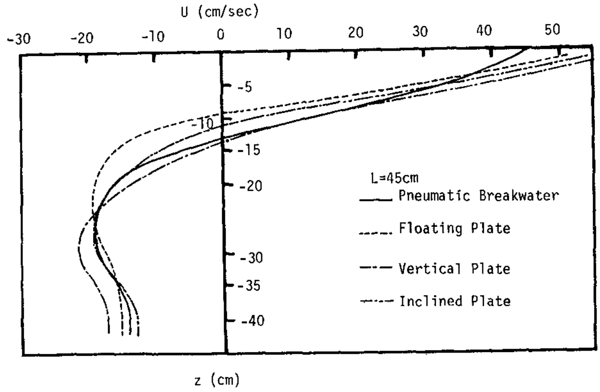


Fig.12 Velocity profiles of horizontal surface flow

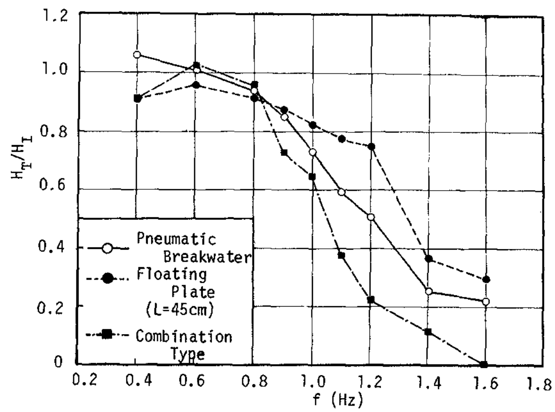
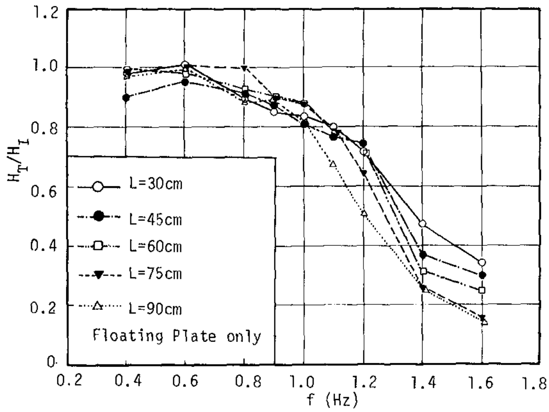
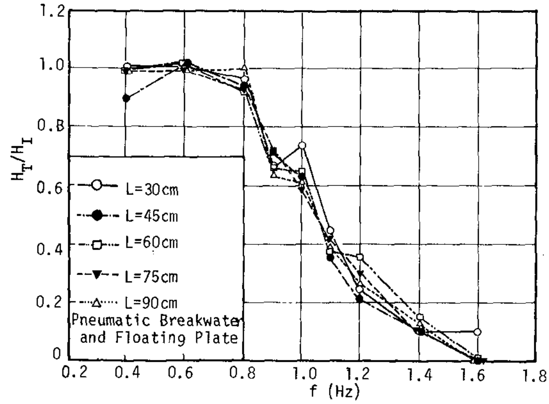


Fig.13 Transmission factors of pneumatic breakwater only, floating breakwater only and combined breakwater



(a)



(b)

Fig.14 Effect of length of floating body on transmission factor

(a) Floating body only
(b) Combination type breakwater

surface flow in the opposite direction, and wave energy is dissipated when waves clashes in front of the floating breakwater. This result is rather convenient in practical use of the combination type breakwater, because it is not necessary to lengthen the floating breakwater.

Fig.15 shows the comparison of the transmission factors between the combination type breakwaters without the guide plate and with the guide plate, and between with the vertical guide plate and with the inclined guide plate. It is shown clearly that the transmission factor decreases when the guide plate is placed, but there is not so much difference between using the vertical guide plate and the inclined one.

The variation of the transmission factor with the method of supporting is examined by changing the anchor support into the fixed support. The length of the floating body used was changed 30cm, 60cm and 90cm. Fig.16 (a) is the case of the floating breakwater only and (b) is the case of the combination type breakwater. A considerable improvement on the wave damping effect is achieved by changing the anchor support into the fixed support. It is also shown that the waves of higher frequency than 1.2Hz are damped almost completely when the fixed support floating breakwater is combined.

In the field, it is difficult to fix the floating breakwater, but it may be possible for the anchor support to make the damping effect strong as much as the fixed support by devising effective arrangement of the anchor ropes and making the spring constant of the anchor rope larger.

CONCLUSION

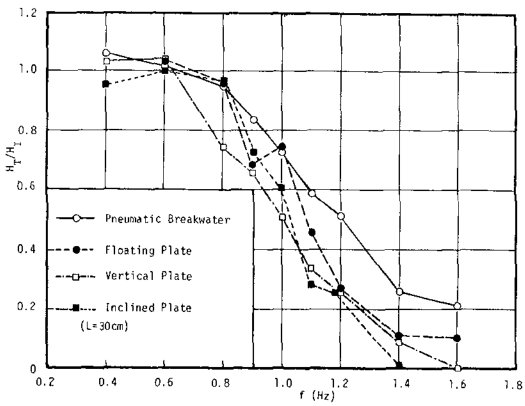
In the present paper, the improvement on the damping effect of waves by combining the submerged or the floating breakwater with the pneumatic breakwater has been investigated experimentally.

Main conclusions are as follows:

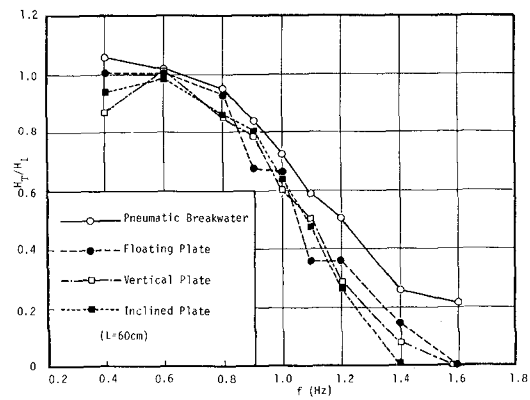
1) The combination type breakwater of the submerged and the pneumatic breakwaters is more effective on the wave damping than each breakwater only. The reason why the combination effect appears is explained as follows. When waves pass over the submerged breakwater, a part of the wave energy transfers to higher frequency waves which can be damped by the pneumatic breakwater. This phenomenon is confirmed by investigating the characteristics of waves passing over the submerged breakwater.

2) Four kinds of submerged breakwaters were provided for the tests. The permeable type submerged breakwater made of stellersheet is the most effective on the wave damping. However, concerning the combination effect, the impermeable type submerged breakwater is more effective than the permeable one.

3) The floating breakwater has similar characteristics to the pneumatic breakwater, so the weak point of the pneumatic breakwater is not improved at all for low frequency waves by combining the floating breakwater. But, for high frequency waves, the combination type breakwater is more effective than each breakwater only.



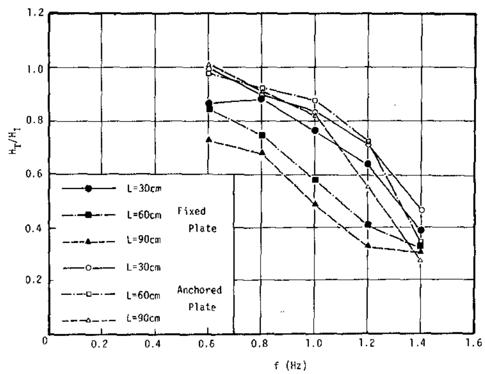
(a)



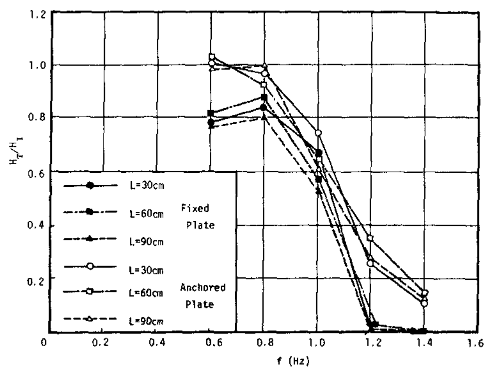
(b)

Fig.15 Comparison of transmission factors between combination type breakwaters with and without guide plates, and between with vertical and inclined guide plates
(L: length of floating body)

(a) Case when L=30cm
(b) Case when L=60cm



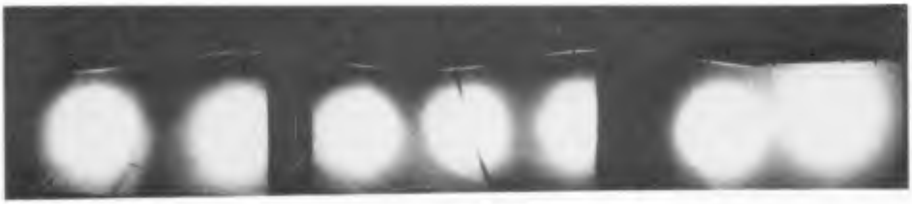
(a)



(b)

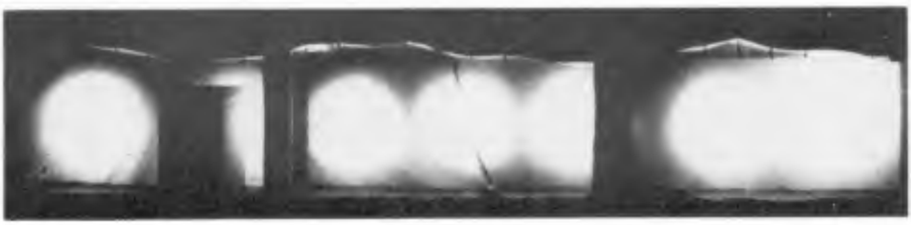
Fig.16 Effect of supporting method on transmission factor

(a) Floating breakwater only
(b) Combination type breakwater

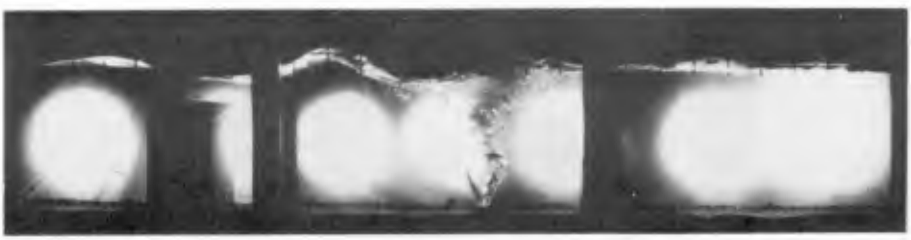


Incident Wave

Transmitted Wave behind Air Curtain



Transmitted Wave behind Submerged Breakwater



Transmitted Wave behind Combination Type Breakwater

Photo.1 Combination of submerged breakwater with pneumatic breakwater (impermeable type and smooth surface)

f=1.2Hz, Q=300 l/min, h=45cm, Sh=35cm, Sw=20cm

4) The guide plate was set below the bottom of the floating body to guide the horizontal surface flow in the opposite direction to wave propagation. It is found that the velocity of the horizontal surface flow increases by the guide plate. And the result on wave damping also shows the effectiveness of the guide plate.

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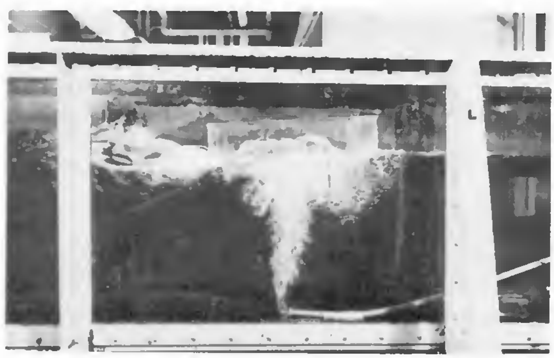

Photo.2 Combination of floating breakwater with vertical guide plate with pneumatic breakwater

f=1.2Hz, Q=400 1/min, L=45cm