CHAPTER 105

Wave Induced Flow around Submerged Sloping Plates

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Abstract

This paper deals with the hydraulic characteristics of two kinds of submerged plate type breakwaters. One is a plate with a gradual upward slope, the other is with a downward slope. The characteristics of the temporal and spatial wave induced flow and turbulence around a plate are discussed in detail on the basis of the result of the water particle velocity measured by the Laser Doppler Velocimeter. In addition, the effects of the plate length, the submerged depth of the crown and the inclination angle of a plate on the wave transmission, reflection and wave energy dissipation are discussed.

Finally it is suggested that a plate with a gradual upward slope is effective not only for the control of wave absorption but also for water purification.

Introduction

For improvement of a much better environment in the coastal zone, various kinds of breakwaters have been designed in full consideration of the conservation of water quality, sediment and non-injury to the land scape. The artificial reef is a typical example of the breakwater designed for this purpose. However, it has been known that its crown width should

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be constructed widely in eomparison with regular submerged breakwaters,if we expect the reduction of wave energy in an artificial reef. In covering the sea bed with the rubble mound in order to set up an artificial reef, the destruction of a good environmental condition of habitat would be a worry. Such fear will be removed in the case of submerged plate type breakwater.

In recent years, the characteristics of wave reflection and transmission in submerged sloping plate type breakwaters have been actively investigated experimentally and theoretically (Aoyama et al,1988,Takahashi et al,1989, Yu et al, 1989,1991, Yamashita et al,1990). Unfortunately, we have no information on the characteristics of wave induced flow and the turbulence around a plate, though it would be important to understand the motion of water particles and behavior of eddies not only from the hydraulic viewpoint but also from an ecological point of view.

Prior to this study, we have experimentally investigated the characteristics of the flow around both the vertical and horizontal plate type breakwaters (Murakami et al.,1992).

Two kinds of submerged sloping plate type breakwaters are chosen in this study. First, the characteristics of wave transmission, reflection and wave energy dissipation are investigated for the two kinds of breakwaters which comprise the plate with a gradual upward slope and one with a gradual downward slope. Second, based on the results of the two direction components of water particle velocities measured by the Laser Doppler Velocimeter, the characteristics of the flow and the turbulence around a plate are discussed.

Experimental Method

A wave tank with a flap-type wave generator at one end, which was 15m long, 20cm wide and 30cm deep, was used as shown in Fig.1. The submerged plate models were placed at a distance of 9.15m from the wave generator.

For convenience, the plate models with a gradual upward slope were named the A-type and ones with a gradual downward slope the B-type. The rear edge of the plate was in water. It did not touch the sea bottom in all of the experiments. The submerged depth d was defined as the water depth from the front edge of the plate. The water depth h and the wave period T were kept at a constant of 15cm and 0.65sec, respectively. Consequently, the wave length L was 60cm.

The wave heights were measured at the points **a**, **b** and **c** to obtain the reflection and the transmission coefficients.

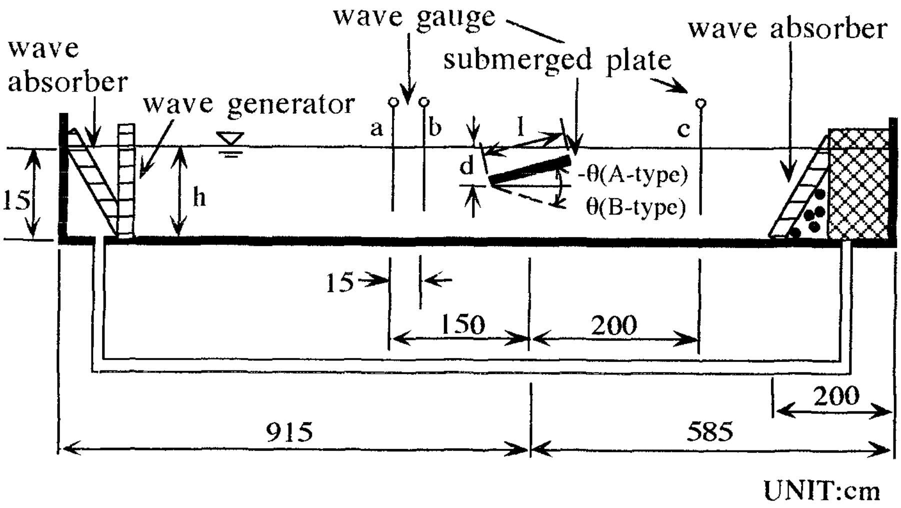


Fig.1 Experimental Apparatus

On the other hand, both the horizontal and the vertical water particle velocities were measured separately by the Laser Doppler Velocimeter (SYSTEM9100-3, KANOMAX) at 93-94 points around the plate. The change of water surface elevation was also measured at the same time above a measured point of the velocity.

Experimental conditions were shown in Table 1. In the table , the minus sign for the inclination angle of the plate θ was assigned to the A-type, a plus sign to the B-type.

Table 1 Experimental Conditions

T=0.65sec, h=15cm, L=60cm, h/L=0.25

1) Experiment of Wave Absorption

H/L	0.029	0.062	0.075
d(cm) d/h	1.5 0.1	3.0 0.2	4.5 0.3
l(cm) l/L	15 1/4	20 1/3	30 1/2
θ(°)	-10,-5, 0, 10, 20, 30, 40	-10,-5, 0 10, 20, 30	-5, 0, 10, 20

2) Experiment of Water Particle Velocity

H/L	0.062	
d/h	0.2	
l/L	1/3	1/2
θ(°)	-10, -5, 0, 10, 20, 30	10

The effect of the relative plate length l/L and the relative submerged depth d/h on the wave energy dissipation have already been discussed for the horizontal plate (Murakami et al,1992). The dimensions of the models were determined with reference to these studies in this paper.

Analytical Method

The incident and the reflected wave heights were separated by Goda's method from the wave record at point **a** and **b** in Fig.1 (Goda et al, 1976). Using these results and the transmitted wave height, the coefficients of the transmission k_T and the reflection k_R were obtained. The wave energy dissipation rate ε was calculated by the following equation.

$$\varepsilon = 1 - k_T^2 - k_R^2 \tag{1}$$

Let's describe how to obtain the water particle velocity and the turbulent intensity at a measured point.

From the data of each velocity component which consists of the horizontal velocity U and the vertical one V, the data corresponding to a train of 30 waves were used for the analysis. Each averaged velocity component (U,V) and each turbulent component ($u'=U-\overline{U}, v'=V-\overline{V}$) at an arbitrary phase of a wave period were obtained as mentioned hereunder.

First, one wave with T=0.65sec was divided into 50 phases, the components of the velocity and the turbulence at each phase were obtained by calculating the average value of 30 waves at each phase. Second, the velocity ($\sqrt{\overline{U}^2+\overline{V}^2}$) and the turbulent intensity ($\sqrt{\overline{u'^2} + \overline{v'^2}}$)at a measured point were obtained by the composition of each component.

Characteristics of Wave Absorption

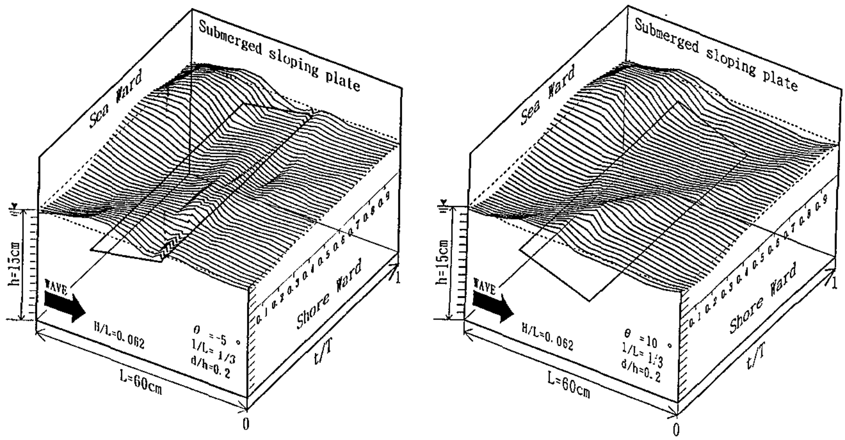
1) Wave Profile Transformation

Fig.2(1) shows only one example of the spacial wave profile transformation with time in the case of l/L=1/3, d/h=0.2, θ=-5° in the A-type.

With the installation of the plate, the wave profile gradually changes with regard to time. By the wave breaking on the plate, the wave height decreases immediately. After that, the wave induced flow rolls beneath the plate. Then, an eddy with air bubbles can be observed there. Such patterns are periodically repeated.

The transmitted wave height is attenuated from this figure.

Fig.2(2) shows this in the case of the B-type. When an incident wave reaches right at the front edge of the plate, the wave profile is compulsorily transformed there. Though the wave crest becomes sharp for a while, the wave does not break and the transmitted wave height does not decrease so much as in the A-type.



(1)A-type (2)B-type

Fig.2 Wave Profile Transformation

2) Characteristics of Transmission, Reflection and Wave Energy Dissipation

Fig.3 shows the characteristics of the transmission coefficients k_T in d/h=0.2. The results in the A-type and the B-type are plotted in the minus and the plus region of the inclination angle θ, respectively. The plate with $\theta=0°$ represents the horizontal plate.

In the A-type, the transmission coefficient k_T decreases with the increase of the inclination angle θ. Such a tendency is remarkable as this relative plate length l/L increases.

In the case of l/L=1/2, the value of the k_T could be controlled 0.1 even for $\theta=-5°$.

In the B-type, if the horizontal plate ($\theta=0°$) is inclined downward $\theta=10°$, the value of the k_T increases steeply. However the effects of the l/L and the θ on the k_T are not so remarkable in the range of $\theta \geqq 10°$.

Fig.4 shows the characteristics of the reflection coefficient k_R in d/h=0.2. It can be considered that there is no effect of the l/L on the k_R for eaeh type of plate .

In the A-type with a range of $-10° \leqq \theta \leqq 0°$, the k_R decreases with the increase of the θ ,because the wave is easy to break on at the plate as the θ increases. The k_R takes the small values 0.3-0.4 in this experiment.

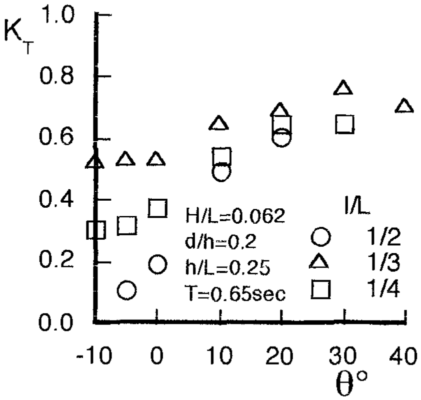


Fig.3 Transmission Coefficient

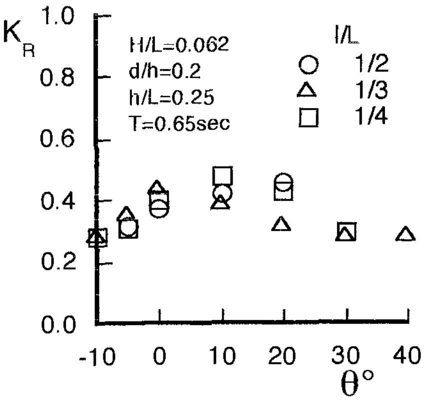


Fig.4 Reflection Coefficient

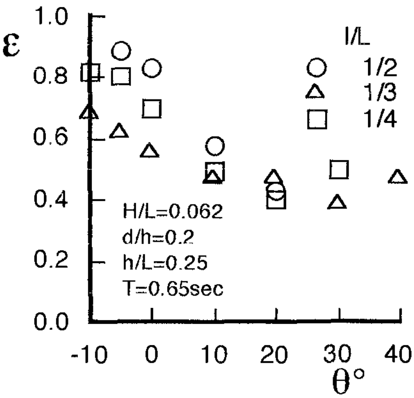


Fig.5 Wave Energy Dissipation Rate (d/h=0.2)

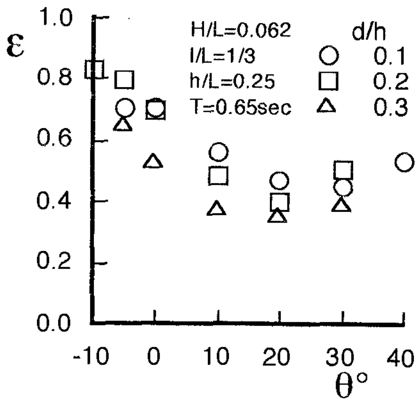


Fig.6 Wave Energy Dissipation Rate (l/L=1/3)

In the B-type, the k_R increases slightly with the increase of the θ for $l/L=1/2$. Contrary to this , the tendency of the k_R decreases slightly for $l/L=1/4$. In this experiment, the k_R takes the values 0.3-0.45. These values of the k_R are not so big in comparison with the reflection coefficients in some other types of breakwaters.

Fig.5 shows the characteristics of the wave energy dissipation rate ε in d/h =0.2.

In the A-type with the range of $-10° \leqq \theta \leqq 0°$, the ε increases with the increase of both the θ and the l/L. For θ=-5°, the incident wave energy is dissipated about 60% in the ease of l/L=1/4, 80% in l/L=1/3 and 90% in l/L=1/2.

It is effective for wave energy dissipation to incline the rear edge of the plate upward.

In the B-type with the range of $0° \leqq \theta \leqq 10°$, the ε decreases steeply with the increase of the θ and with the decrease of the l/L. However, the values of the ε in the range of $10° \leqq \theta \leqq 40°$ do not remarkably change regardless of the l/L . It means that effective dissipation of wave energy can not be expected regardless of the plate length, when the θ exceeds a given value.

Fig.6 shows the effect of the relative submerged depth d/h on the ε in the case of l/L=1/3. The values of the ε in d/h=0.3 are smallest of the three cases, the difference between the values of the ε in d/h=0.1 and in d/h=0.2 is not so big.

Characteristics of Wave Induced Flow and Turbulence

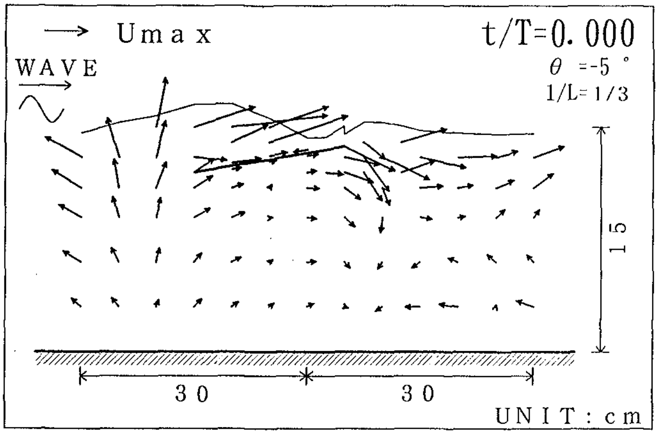
1)Spacial Distribution of Velocity and Turbulence at Arbitrary Phase

The spacial distribution of the mean velocity and turbulent intensity was obtained at every 1/50 phase of a wave period.

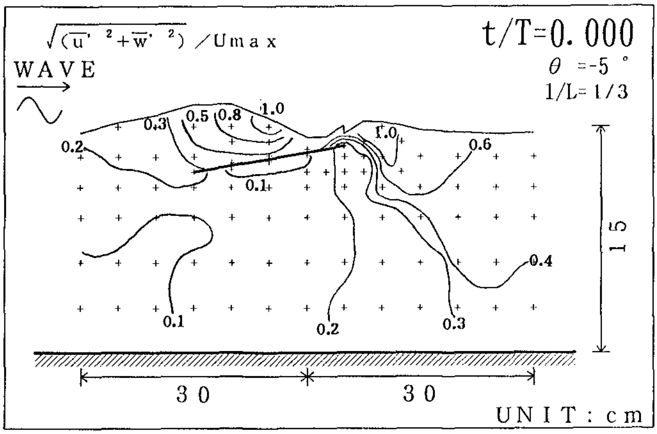
Fig.7 and Fig.8 show only two examples of the spacial distribution at the phases t/T=0 and 0.52 of in the case of l/L=1/3, d/h=0.2, θ=-5° in the A-type.

The U_{max} in a figure represents a maximum horizontal veloeity at the still water surface calculated by the small amplitude wave theory. The value of Umax= 19.6 cm/s is obtained in this experiment.

Pay attention to the upper figure of Fig.7. At this phase of t/T=0, the wave breaks intensely at the region from the front edge to the center part on the plate. Then the velocity at the forehead of the wave crest is about two times as large as the Umax. The wave induced flow plunges into the rear part of the plate, and the shoreward flow is generated at the upper part of the inner basin overtopping the plate edge. However, the velocity along the back of the plate is very small in contrast to the velocity at the upper part of the plate.



(1)Velocity

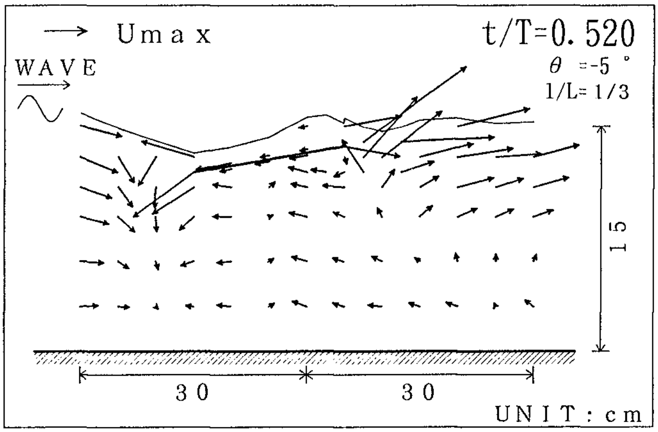


(2)Turbulent Intensity

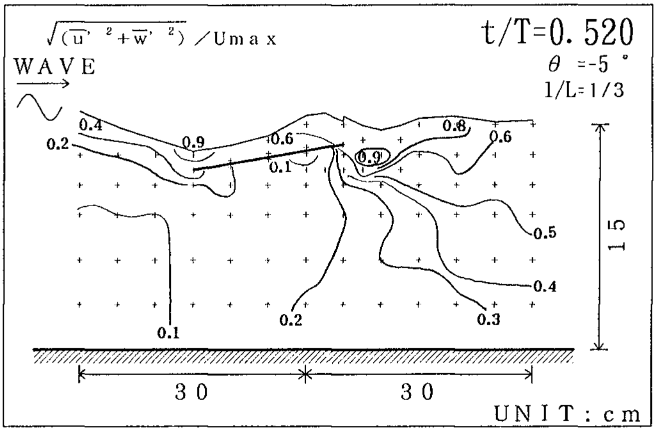
Fig.7 A-type(t/T=0)

The values of turbulent intensity are shown by the nondimensional expression in the lower figure. It can be found that the large value of turbulent intensity appears at the forehead of the wave crest and at the rear edge of the plate where the overtopping flow plunges into it.

At the phase after the time of a half of a wave period t/T=0.52, the surge after a wave breaking climbs up the slope and jumps over the rear edge of the plate as shown in Fig.8. So, the region with a large velocity can be seen at the upper part of the inner basin. On the other hand, the seaward flow with a small velocity is generated at both sides of the plate. The direction and the size of these velocities near both edges are very complicated. As a consequence, comparative strong turbulence is generated there as in the lower figure. Generally, we can say the turbulence at the under region of the plate is very weak at any phase in the A-type.



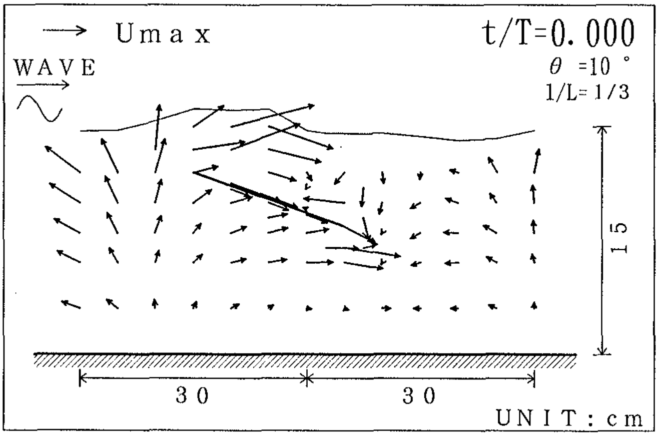
(1)Velocity



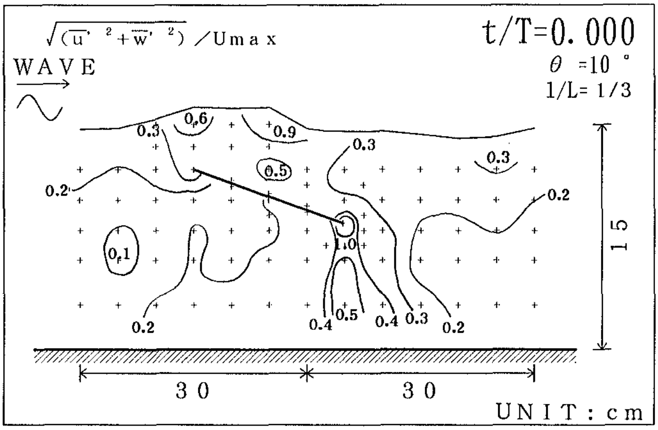
(2)Turbulent Intensity

Fig.8 A-type(t/T=0.52)

Fig.9 and Fig.10 show the spacial distribution in the case of 1/L=1/3, d/h=0.2, θ=10° in the B-type. At t/T=0 as shown in Fig.9, the region with a large velocity exists at the upper part of the front edge of the plate.



(1)Veloeity

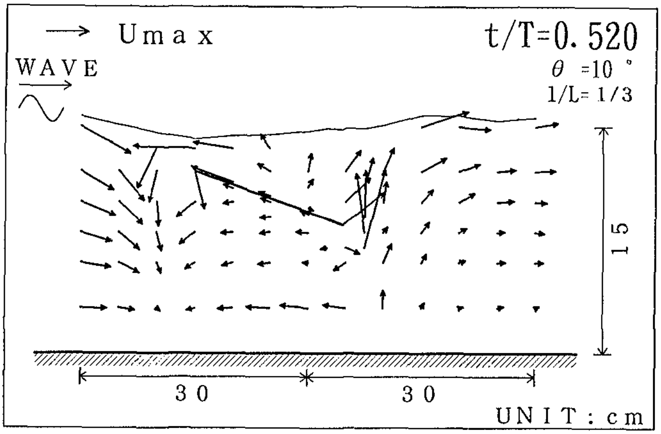


(2)Turbulent Intensity

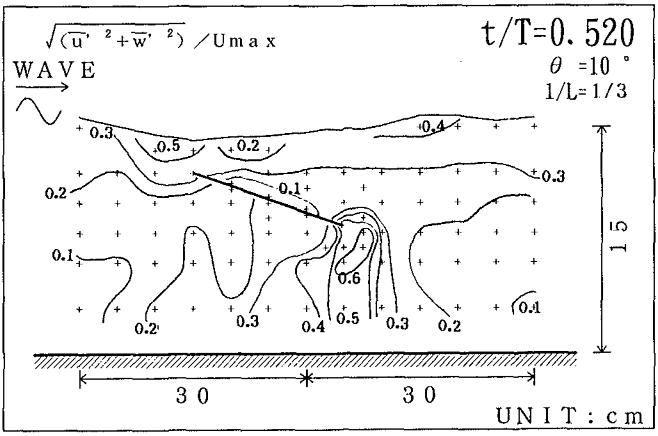
Fig.9 B-type(t/T=0)

As the velocities along both sides of the plate are different, the turbulence due to the strong eddy is generated at the rear edge of the plate as shown in the lower figure.

At t/T=0.52, the upward flow with a large velocity is generated at the rear edge as in Fig.10. It could be observed that the eddy existing at the lower part of the rear edge gradually expanded and moved upward. In the lower figure, we can see the result of the behavior of the eddy. It is noticeable that the influence of the turbulence extends to the lower part of the plate, though the turbulent intensity is not so strong.



(1)Velocity

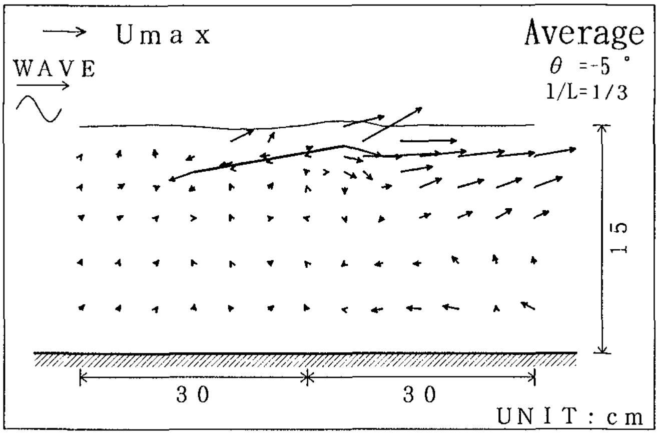


(2)Turbulent Intensity

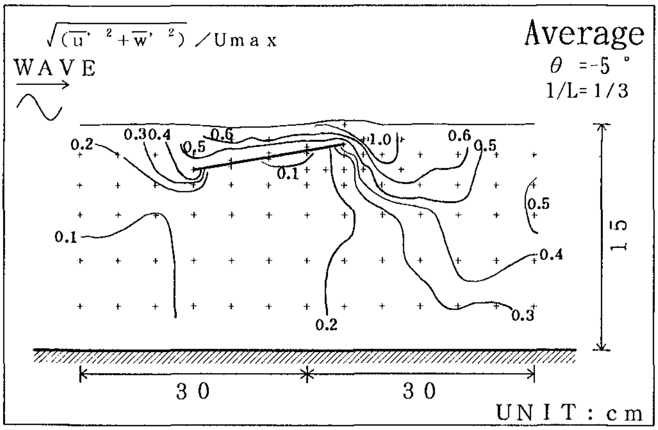
Fig.10 B-type(t/T=0.52)

2) Spacial Distribution of Averaged Value of Velocity and Turbulence of a Wave Period

Fig.11 shows the spacial distribution of both the averaged velocity and turbulent intensity of a wave period in the ease of l/L=1/3, d/h=0.2, θ =-5° in the A-type.



(1)Residual Velocity

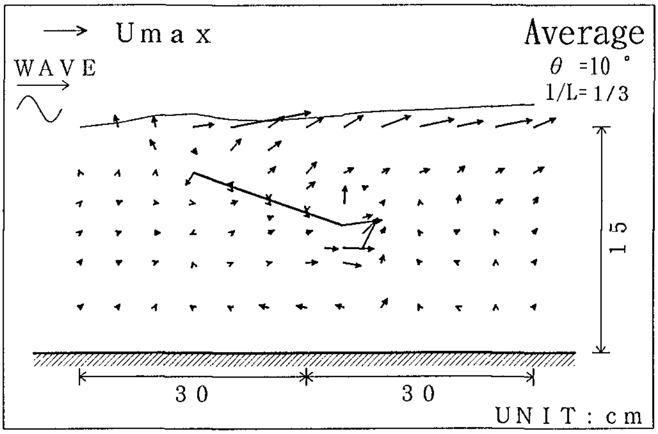


(2)Averaged Turbulent Intensity

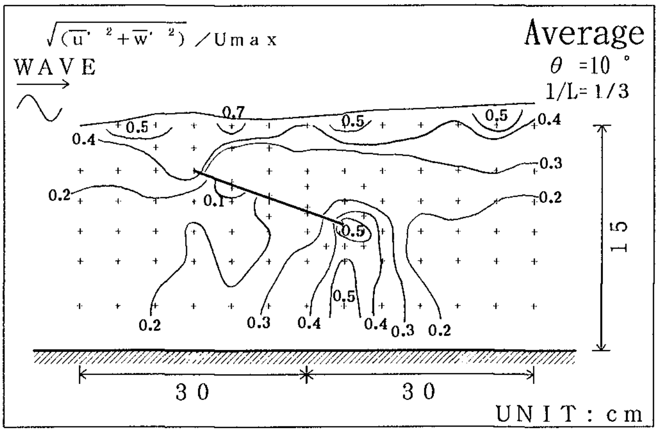
Fig.11 A-type

Each veloeity veetor in the upper figure means the residual velocity. The shoreward residual flow with comparative large velocities generated at the limited region of the upper part of the inner basin can be seen. Then,the strong turbulence ean be found at the rear edge of the plate as in the lower figure. However, it is clear that strong turbulence is not generated at the under region of the plate as already pointed out.

Fig.12 shows the case of l/L=1/3, d/h=0.2, $\theta=10°$ in the B-type.



(1)Residual Velocity



(2)Averaged Turbulent Intensity

Fig.12 B-type

The shoreward residual flow is generated only at the region of the water surface behind the front edge of the plate. Furthermore, the complicated residual flow can be seen at the rear edge of the plate. It can be found that weak turbulenee is scattered at the surface , the rear edge and at the bottom of the rear edge as shown in the lower figure.

Fig.13 shows the change of thc flow rate Q through a cross section of the rear edge of the plate in the case of l/L=1/3, d/h=0.2 in the A-type with θ=-5° and the B type with θ=10°. The Q was calculated by the product of the averaged velocity in 5-6 points of the cross section and the water depth from the water surface to the bottom. Though the seaward flow is generated for a short time at some phases in the A-type, the one directional shoreward flow is almost always generated in both types of plates. It means that scawater with pure water quality flows into the inner basin through these types of breakwaters. Furthermore, if we suppose the reflected wave at a seawall in the A-type again acts upon an A-type plate, the seawater in the inner basin must flow out smoothly into the sea through the breakwater by the seaward residual flow. This is because the reflected wave seaward in the A-type corresponds to the incident wave shoreward in the B-type.

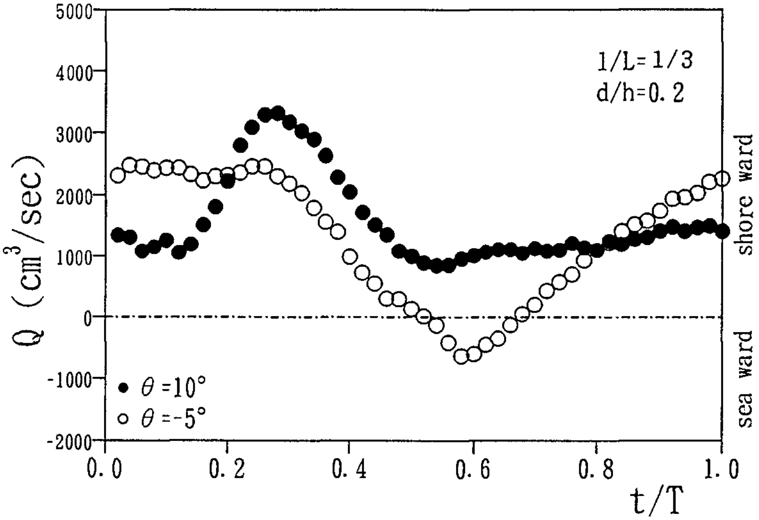


Fig.13 Change of Flow Rate

Conclusion

The mechanism of wave absorption and the characteristics of wave induced flow around two kinds of submerged plate type breakwaters were discussed experimentally.

Results are summarized as follows.

1) it could be certified that thc validity of a sloping platc type brcakwater for wave absorption, especially a plate with a gradual upward slope is

effective for the control of wave absorption.

2) The behavior of temporal and spacial water particle velocity and turbulence around a plate type plate breakwater could be understood.

3) The submerged sloping plate is effective for water quality purification producing a one directional flow, regardless of the raising and lowering of the rear edge of the plate.

Through this knowledge, we could give information to make a good environmental habitat for aquatic biota.

Ackowledgement

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