CHAPTER 12

WAVE HEIGHT DISTRIBUTION AROUND PERMEABLE BREAKWATERS

BY

Shintaro Hotta*

ABSTRACT

A phase lag phenomenon in which waves are delayed in transmission through a permeable breakwater was considered in an approximate calculation method using the superposition principle of Sommerfeld. Experimental verifications were carried out for a semi-infinite permeable breakwater. In addition, a field observation of wave height distribution around a small detached breakwater is reported.

PART 1

APPROXIMATE CALCULATION METHOD FOR WAVE HEIGHT DISTRIBUTION AROUND A PERMEABLE BREAKWATER WITH A PHASE LAG

INTRODUCTION

At the 16th International Conference on Coastal Engineering at Hamburg, 1978, the author reported a calculation method for the wave height distribution around permeable breakwater using the superposition method of Sommerfeld. The cases dealt with were a semi-infinite breakwater, a single relatively large gap in a long breakwater and an insular breakwater (or a single detached breakwater). As discussed in the last paper (Chapter 39, Proc. 16th ICCE, pp 695-714, hereafter referred to as I), the weak point of this method is that it is not strictly correct theoretically, that is, the boundary conditions are not completely satisfied, and the wave height becomes discontinuous on the x and y axis and on the lines which divide the calculation region considered. However, this method has some advantages, that is, the wave height distribution can be calculated very easily by addition and subtraction, if we have the Fresnel Integrals. Another advantage is that if the waves have a phase lag due to a time lag upon transmission through a permeable breakwater, the influence of this time lag can easily be taken into consideration in the equations, without any complication. That is, we can replace y with $(y \pm \Delta L)$ in the term which represents the transmitted waves. Here ΔL is related to the phase lag between the transmitted and free waves. In this paper, the equations with the phase lag are given,

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* Research Associate, Dept. of Civil Engineering, Tokyo Metropolitan University, Setagaya-ku, Tokyo, JAPAN

and the experimental verification of this method for semi-infinite permeable breakwaters are shown together with the case of no phase lag.

NUMERICAL CALCULATION OF WAVE HEIGHT DISTRIBUTION IN TRANSMISSION THROUGH THE PERMEABLE BREAKWATERS WITH PHASE LAG

As mentioned before, if waves are delayed in transmission through a breakwaters, the phase lag on the shoreside of the breakwaters can be expressed by replacing y with $(y \pm \Delta L)$ in the terms which represent the transmitted waves, namely

$$\alpha \{ e^{-ik(y + \Delta L)} f(u) + e^{-ik(y - \Delta L)} g(u) \} \text{ -------- } (1)$$

Calculations will be done using the same figures, symbols and coordinate systems described in reference I.

(1) A semi-infinite permeable breakwater

By replacing y with $(y \pm \Delta L)$ in the terms which represent the transmitted waves (See Fig. 5 - (3) in reference I) we have the final forms of these equations, with a phase lag accounted for in regions A and B1, as follows:

Region A $x>0$, $y>0$

$$\begin{aligned}
F_{2t}^{A} &= F_{0}^{A} + \alpha F_{1t}^{A} \\
&= e^{-iky} f(u_1) + e^{iky} g(-u_2) + \alpha \{ e^{-ik(y+\Delta L)} f(-u_1) + e^{ik(y-\Delta L)} g(-u_2) \} \\
&= (S_1 + S_2)\cos ky + (W_1 - W_2)\sin ky \\
&\quad + \alpha \{ (1 - S_1)\cos(k(y+\Delta L)) + S_2 \cos(k(y-\Delta L)) \\
&\qquad + (-W_1)\sin(k(y+\Delta L)) + (-W_2)\sin(k(y-\Delta L)) \} \\
&\quad + i[(W_1 + W_2)\cos ky + (-S_1 + S_2)\sin ky \\
&\qquad + \alpha \{ (-W_1)\cos(k(y+\Delta L)) + W_2 \cos(k(y-\Delta L)) \\
&\qquad\quad + (-1 + S_1)\sin(k(y+\Delta L)) + S_2 \sin(k(y-\Delta L)) \}] \text{ ---------- } (2)
\end{aligned}$$

Region B_1 $x<0$, $y>0$

$$F_{2t}^{B1} = F_0^{B1} + \alpha F_{2t}^{B1}$$
$$= e^{-iky} f(u_1) + e^{iky} g(-u_2) + \alpha \{ e^{-ik(y+\Delta L)} f(-u_1) + e^{ik(y-\Delta L)} g(-u_2) \}$$
$$= (1 - S_1 + S_2) \cos ky + (-W_1 - W_2) \sin ky$$
$$+ \alpha \{ S_1 \cos(k(y+\Delta L)) + S_2 \cos(k(y-\Delta L))$$
$$+ W_1 \sin(k(y+\Delta L)) + (-W_2) \sin(k(y-\Delta L)) \}$$
$$+ i [(-W_1 + W_2) \cos ky + (-1 + S_1 + S_2) \sin ky$$
$$+ \alpha \{ W_1 \cos(k(y+\Delta L)) + W_2 \cos(k(y-\Delta L))$$
$$+ (-S_1) \sin(k(y+\Delta L)) + S_2 \sin(k(y-\Delta L)) \}] \quad \text{---------} \quad (3)$$

To indicate the cases with a phase lag, a suffix t is added to the equivalent equations for no phase lag.

If we put $\Delta L = 0$ in Eqs. (2) and (3), they become Eqs. (23) and (24) in reference I, respectively.

(2) A single relatively large gap in a long permeable breakwater

As in section (1), replacing y with $(y \pm \Delta L)$ in the transmitted wave terms (See Feg. 6-(4) in reference I) the final forms of the equations in regions A1 and A2 for an opening in a breakwater become:

Region A_1 $0<x<b/2$, $y>0$

$$F_{3pt}^{A1} = F_3^{A1} + \alpha [F_{1t}^{B1} + F_{0t}^{A}]$$
$$= e^{-iky} f_r(u_1) + e^{iky} g_r(-u_2) + e^{-iky} f_l(u_1) + e^{iky} g_l(-u_2) - e^{-iky}$$
$$+ \alpha [e^{-ik(y+\Delta L)} f_l(-u_1) + e^{ik(y-\Delta L)} g_l(-u_2)$$
$$+ e^{-ik(y+\Delta L)} f_r(-u_1) + e^{ik(y+\Delta L)} g_r(-u_2)]$$
$$= (1 - S_{r1} - S_{l1} + S_{r2} + S_{l2}) \cos ky + (-W_{r1} - W_{l1} - W_{r2} - W_{l2}) \sin ky$$
$$+ \alpha \{ (S_{r1} + S_{l1}) \cos(k(y+\Delta L)) + (W_{r1} + W_{l1}) \sin(k(y+\Delta L))$$
$$+ (S_{r2} + S_{l2}) \cos(k(y-\Delta L)) + (-W_{r2} - W_{l2}) \sin(k(y-\Delta L)) \}$$
$$+ i [(-W_{r1} - W_{l1} + W_{r2} + W_{l2}) \cos ky + (-1 + S_{r1} + S_{l1} + S_{r2} + S_{l2}) \sin ky$$
$$+ \alpha \{ (W_{r1} + W_{l1}) \cos(k(y+\Delta L)) + (-S_{r1} - S_{l1}) \sin(k(y+\Delta L))$$
$$+ (W_{r2} + W_{l2}) \cos(k(y-\Delta L)) + (S_{r2} + S_{l2}) \sin(k(y-\Delta L)) \}] \quad \text{------} \quad (4)$$

Region A_2 $x > b/2$, $y > 0$

$$F_{3pt}^{A2} = F_3^{A2} + \alpha[F_{1t}^{A} + F_{0t}^{A}]$$

$$= e^{-iky} f_{r(-u1)} + e^{iky} g_{r(-u2)} + e^{-iky} f_{l(u1)} + e^{iky} g_{l(-u2)} - e^{-iky}$$
$$+ \alpha[e^{-ik(y+\Delta L)} f_{l(u1)} + e^{ik(y-\Delta L)} g_{l(-u2)}$$
$$+ e^{-ik(y+\Delta L)} f_{r(-u1)} + e^{ik(y-\Delta L)} g_{r(-u2)}]$$

$$= (S_{r1} - S_{l1} + S_{r2} + S_{l2}) \cos ky + (W_{r1} - W_{l1} - W_{r2} - W_{l2}) \sin ky$$
$$+ \alpha\{(1 - S_{r1} + S_{l1}) \cos(k(y + \Delta L)) + (-W_{r1} + W_{l1}) \sin(k(y + \Delta L))$$
$$+ (S_{r2} + S_{l2}) \cos(k(y - \Delta L)) + (-W_{r2} - W_{l2}) \sin(k(y - \Delta L))\}$$
$$+ i[(W_{r1} - W_{l1} + W_{r2} + W_{l2}) \cos ky + (-S_{r1} + S_{l1} + S_{r2} + S_{l2}) \sin ky$$
$$+ \alpha\{(-W_{r1} + W_{l1}) \cos(k(y + \Delta L)) + (-1 + S_{r1} - S_{l1}) \sin(k(y + \Delta L))$$
$$+ (W_{r2} + W_{l2}) \cos(k(y - \Delta L)) + (S_{r2} + S_{l2}) \sin(k(y - \Delta L))\}] \quad \text{--------} \quad (5)$$

Letting $\Delta L = 0$, Eqs. (4) and (5) become Eqs. (32) and (33) in reference I.

(3) A single insular permeable breakwater

Similar to the above, replacing y with $(y \pm \Delta L)$ in the transmitted wave terms (See Feg. 8 in reference I) the equations for regions A1 and A2 become:

Region A_1 $0 < x < b/2$, $y > 0$

$$F_{5t}^{A1} = (S_{r1} + S_{l1} + S_{r2} + S_{l2}) \cos ky + (W_{r1} + W_{l1} - W_{r2} - W_{l2}) \sin ky$$
$$+ \alpha\{(1 - S_{r1} - S_{l1}) \cos(k(y + \Delta L)) + (-W_{r1} - W_{l1}) \sin(k(y + \Delta L))$$
$$+ (S_{r2} + S_{l2}) \cos(k(y - \Delta L)) + (-W_{r2} - W_{l2}) \sin(k(y - \Delta L))\}$$
$$+ i[(W_{r1} + W_{l1} + W_{r2} + W_{l2}) \cos ky + (-S_{r1} - S_{l1} + S_{r2} + S_{l2}) \sin ky$$
$$+ \alpha\{(-W_{r1} - W_{l1}) \cos(k(y + \Delta L)) + (-1 + S_{r1} + S_{l1}) \sin(k(y + \Delta L))$$
$$+ (W_{r2} + W_{l2}) \cos(k(y - \Delta L)) + (S_{r2} + S_{l2}) \sin(k(y - \Delta L))\}] \quad \text{--------} \quad (6)$$

Region A_2 $x > b/2$, $y > 0$

$$F_{5t}^{A2} = (1 + S_{r1} - S_{l1} + S_{r2} + S_{l2}) \cos ky + (W_{r1} - W_{l1} - W_{r2} - W_{l2}) \sin ky$$
$$+ \alpha\{(-S_{r1} + S_{l1}) \cos(k(y + \Delta L)) + (-W_{r1} + W_{l1}) \sin(k(y + \Delta L))$$
$$+ (S_{r2} + S_{l2}) \cos(k(y - \Delta L)) + (-W_{r2} - W_{l2}) \sin(k(y - \Delta L))\}$$
$$+ i[(W_{r1} - W_{l1} + W_{r2} + W_{l2}) \cos ky + (-1 - S_{r1} + S_{l1} + S_{r2} + S_{l2}) \sin ky$$
$$+ \alpha\{(-W_{r1} + W_{l2}) \cos(k(y + \Delta L)) + (S_{r1} - S_{l1}) \sin(k(y + \Delta L))$$
$$+ (W_{r2} + W_{l2}) \cos(k(y - \Delta L)) + (S_{r2} + S_{l2}) \sin(k(y - \Delta L))\}] \quad \text{--------} \quad (7)$$

With $\Delta L = 0$, Eqs. (6) and (7) become Eqs. (39) and (40) in reference I.

EXPERIMENTAL FACILITIES AND PROCEDURES

Experiments were carried out using a small wave basin which was 2.4 meters in width, 6.0 meters in length and 0.5 meters in depth. The dimensions and the arrangement of the experimental facilities are shown in Fig. 1. Because of the limited wave basin width, only the case of a semi-infinite breakwater was treated.

As a model of a breakwater, a vertical homogeneous crob-style wall of 8 cm thickness, filled with 17 mm diameter glass balls, was used. Wave heights were measured with 18 capacitance-type wave gauges. Three of these were placed on a line extending from the breakwater axis ($x < 0$, $y = 0$) to measure the incoming waves and to synchronize three 6-channel paper oscillographs. The remaining 15 gauges were mounted on an arm having wheels at both ends, and which moved on rails fixed to both side walls of the basin. Using these wave gauges, wave heights at 15 locations could be simultaneously measured across the basin. To avoid wave interactions between the incoming waves and the waves reflected from the basin walls (of course a wave absorber was placed along the basin walls; See Fig. 1), the third wave height of each wave train generated was adopted as the height for comparison with the calculations. So, waves were generated from the still water state for each measurement on different transects parallel to the x-axis.

First, the experiments with no phase lag were carried out using wave periods of 0.7 and 1.2 seconds, and a water depth of 0.2 meters. Similar to the above, the experiments where the transmitted waves suffered a phase lag, due to the breakwater, were carried out using only one wave period (0.7 second) and the same water depth. In these experiments, it was difficult to obtain transmitted waves under the conditions of a phase lag. Instead of this, the waves generated in the region of the gap were forced to propagate ahead of the waves arriving at the breakwater by increasing the thickness of the wave generater flap in the former region. Then, to avoid the wave interaction between the two regions, the partition was placed as shown in Fig. 1.

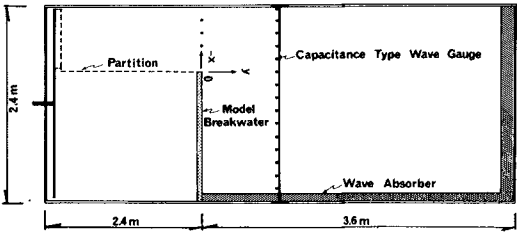

Fig. 1 Experimental facilities

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 2 shows the experimental results for no phase lag. The transmission coefficient was about 0.25. The water depth was 0.2 meters. In Fig. 2, the solid lines are the calculated values from equations (23) and (24) in reference I, and the solid and empty triangles show the experimental values for wave periods of 0.7 and 1.2 seconds, respectively. These figures show that the calculations agree with the experiments qualitatively. The experimental wave heights at the antinodes of the superimposed waves were a little smaller than the those in the calculations, and the experimental wave heights at the nodes became larger than those in the calculations. It is inferred that this is due to the interaction between the two waves, the transmitted and diffracted waves. Deviation of the experimental results from the calculations becomes larger according to the progress of the waves, especially in the case of the 0.7 second period. Perhaps this effect is due to an energy loss, since it is considered that the energy loss is greater for shorter waves.

Figure 3 shows the experimental results when the transmitted waves suffered a phase lag due to the breakwater. The wave period was 0.7 seconds and the water depth was 0.2 meters. In this experiment, the phase lag was 0.2 wave length, about 15 cm. In Fig. 3, the solid, dotted and broken lines show the calculated values from equations (2) and (3) for phase lags of $\Delta L = 0.1L$ and $\Delta L = 0.2L$, respectively. Here ΔL is the phase lag and L is the wave length. Solid rectangles show the experimental results for no phase lag and solid circles show the experimental results for a phase lag of $\Delta L = 0.2L$. From these figures, you can see a similarity with the experimental results for the case of no phase lag previously discussed. That is, first of all, the calculation agrees with the experiments qualitatively. Second, at the antinode the calculated wave heights are smaller than those in the experiments, and at the nodes we find the contrary. Thirdly with continued propagation, the wave interaction becomes larger, and the wave heights become constant.

From these results, we feel this method may be acceptable to roughly predict the wave heights distribution around permeable breakwaters. Furthermore, if we accept this method, then we have the possibility of expressing the wave height distribution around permeable breakwaters for irregular waves, by superimposing waves which have different incident wave angles and heights.

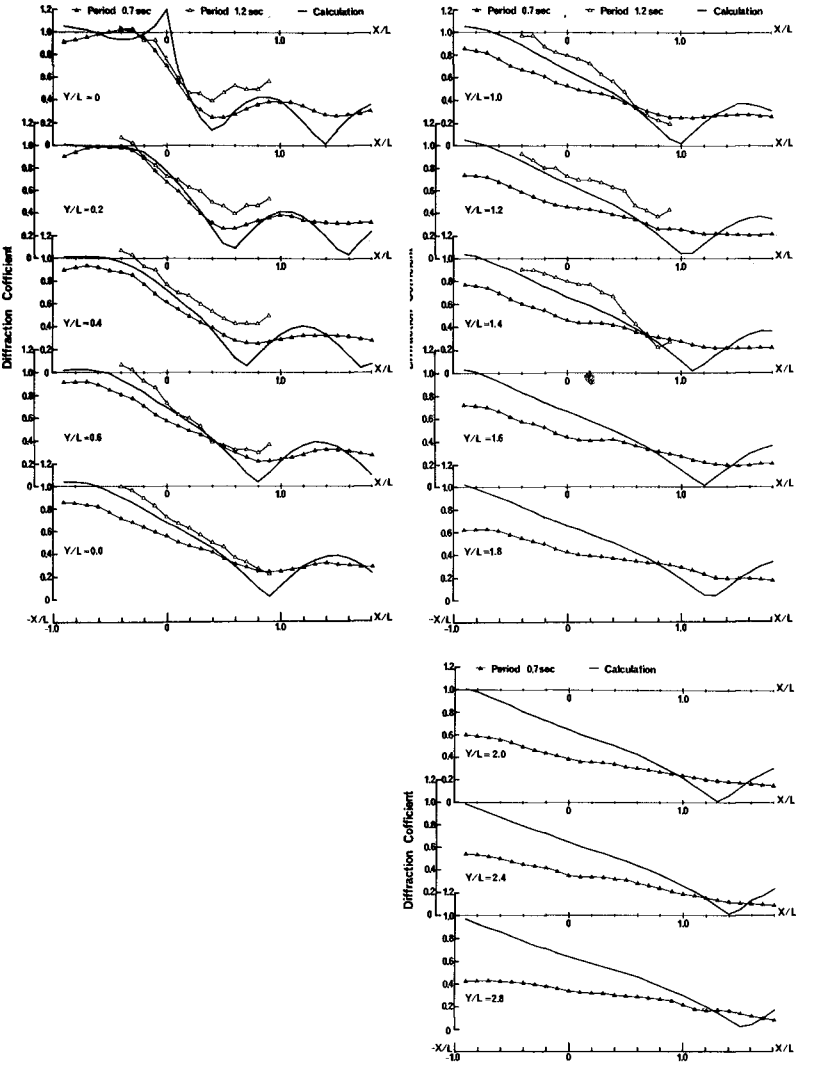

Fig. 2 Comparison of experimental results and calculations with no phase lag for semi-infinitive breakwater

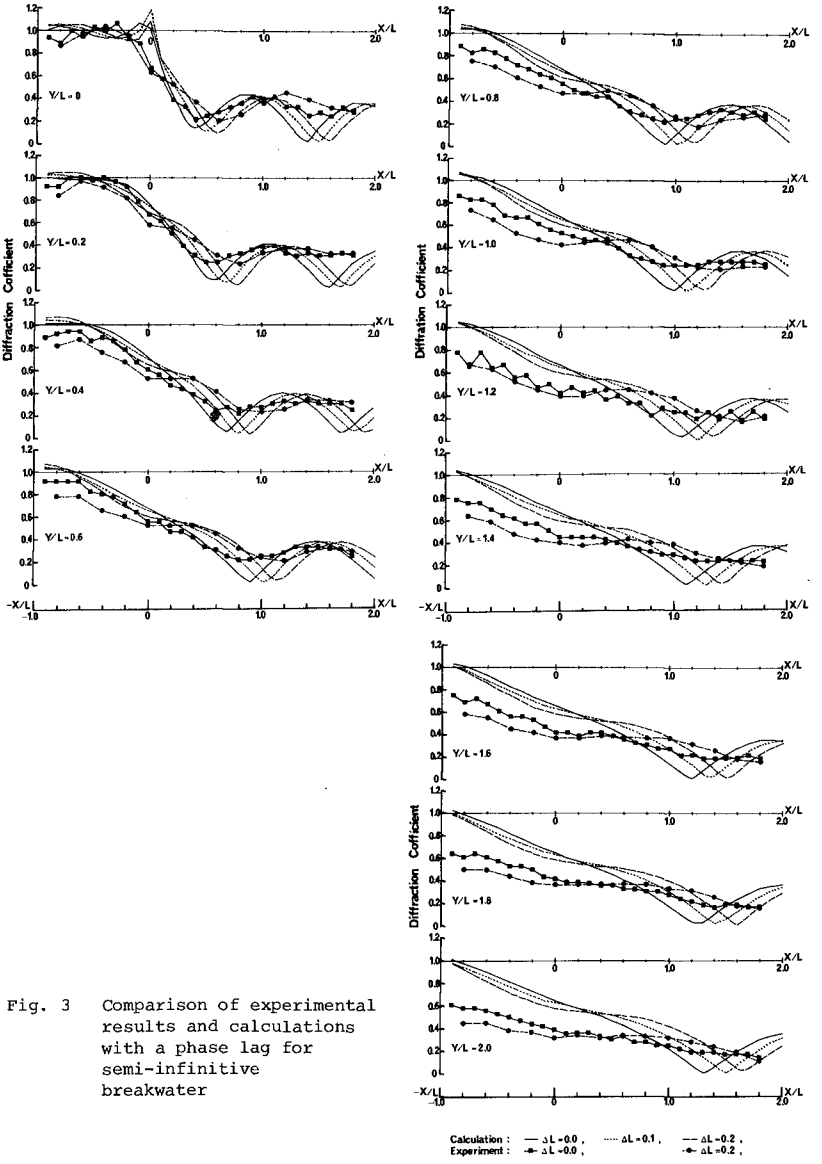

Fig. 3 Comparison of experimental results and calculations with a phase lag for semi-infinitive breakwater

PART II

A FIELD STUDY OF WAVE HEIGHT DISTRIBUTION AROUND A SMALL DETACHED PERMEABLE BREAKWATER

FORWARD

The field observation was carried out on September 4, 1979 at Oharai beach (See Fig. 4). Data are presently still under analysis. However, a part of the results are described and discussed here because of their interest which still remains to be expanded upon in a more detailed analysis and discussion. In the preceding section, the calculation and experiments were dealt with assuming regular waves, no breaking waves and a constant water depth. The field observation which will be described here was under the conditions that waves were irregular, had already broken and were on a sloping sea bottom. Because of these idealized constraints, this field observation is not considered as a verification of the calculation or experiments in the preceding section. However, it is expected that field wave data will give important information about the applicability of these calculations, or suggest an improvement of these calculation methods or development of new calculation methods in the future.

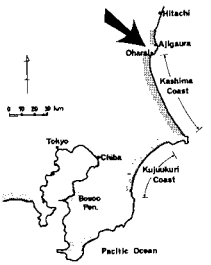

Fig. 4 Location of field observation site

FIELD OBSERVATION SITE AND INSTRUMENTATION

Field observation was carried out at Oharai beach where eleven small detached breakwaters had been constructed of hexalegs on the front of the seawall for defense from beach erosion. The detached breakwaters are about 20 m in length and situated with a 30 m spacing between each other, parallel to and 50 m from the seawall. Observation of wave height was done around the 5th detached breakwater counting from the North.

The wave height distribution at the shoreside of the detached breakwater was observed using a pole array and a 16 mm memo-motion camera system. This system is a photographic method of measuring waves on the sea water surface at poles placed in the sea, using several synchronized cameras. In this observation, 5 cameras were used and 25 poles were photographed. The arrangement of poles (station Nos.) shown in Fig. 5.

The tidal range of this beach was 1.1 m at the time, and at low tide the water depth of the breakwater site was about 0.2 - 0.3 m. At low tide, poles were erected in the sandy bottom using water jets, and wave heights were observed at high tide.

The data from 16 mm photographs of the water surface variations were transferred to paper tapes by using a 16 mm film analyzer and sonic digitizer graf pen system. Data on paper tapes were again transferred to magnetic tapes for convenient analysis by computer. Data station Nos. 12, 31, 32 and 63 were not recorded because it happened that these stations were out of the field of veiw. Three electromagnetic current meters were used to measure the current. However, the author has no intention of describing the current data in the present study.

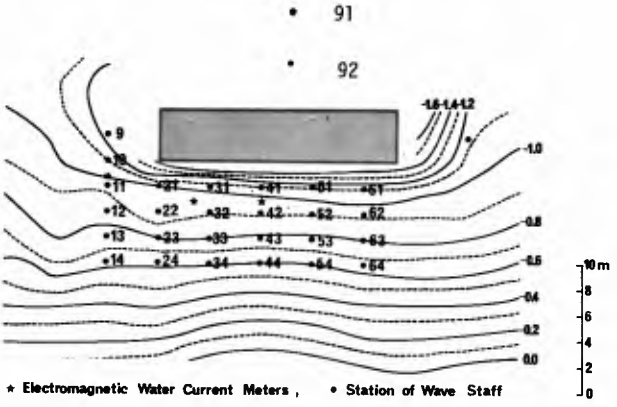

Fig. 5 Sea bottom topography and position of poles

DEFINITION OF WAVES

How are waves defined? The zero-up or zero-down crossing methods are one of the ways generally accepted at present. The field studies of waves in the surf zone being carried out by the author and coworkers (Hotta, Mizuguchi; and Isobe (1978, 1979, 1980)), using the same pole array and a 16 mm memo-motion camera system, have shown that many small amplitude waves could be defined by the zero-up or zero-down crossing methods for the waves in the surf zone. As a result, these small amplitude waves had small values of the representative wave statistics, for example, the one-tenth wave height and period ($H_{1/10}$, $T_{1/10}$) or the significant wave height and period ($H_{1/3}$, $T_{1/3}$). The same thing was found in this field observation. In studying the characteristics of the waves in the field it does not appear reasonable to take into consideration small amplitude waves. However, we have no evidence that smaller waves should be ignored. We have still not reached a conclusion yet, though we have extensively scrutinized and investigated this problem. One of the guidelines which the author wants to state, at least, is that the waves which have heights smaller than 3 times the minimum scale unit in reading water surface variations, should be ignored. This is concluded from checking the accuracy of our data (Hotta et al.(1980)). In this study the minimum scale unit was 2 cm, and time interval of photographing was 0.2 second. Then, the minimum wave which could be defined in this study was 6 cm in height and had a 0.6 second period.

We have other problem in the definition of waves. That is, as just mentioned above, we have ignored waves which were smaller than 6 cm and had period of less than 0.6 second. The problem is in choosing which way is more reasonable to add the small wave which we have ignored, to the main wave: to the previous main wave or to the next main wave? (See Fig. 6) This does not influence the height of the main wave, but influences the wave period. We have no idea which choice should be made. It seems that the zero-down crossing method might be good for defining waves in the surf zone, because it it considered that the elevation between the top of the propagating wave crest and the sea surface in front of the crest would characterized waves in the surf zone. Then, profiles of the waves defined by the zero-down crossing method would look good if the small waves ignored could be added to the trailing part of the main wave.

In this study waves were defined using the zero-down or zero-up crossing methods with W as shown in Fig. 6.

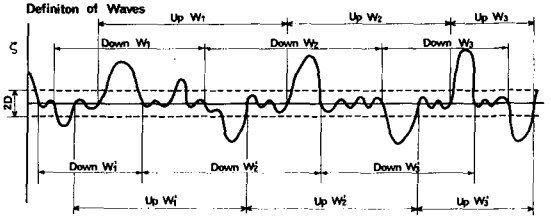

Fig. 6 Definition of waves

FIELD OBSERVATION RESULTS AND DISCUSSION

(1) Wave height distribution at the shoreside of the breakwater.

Figure 7A shows the significant wave height and period around a small detached breakwater. Fig. 7B shows a graph the same values along the section A-A, B-B and two other sections parallel to the former ones. From Fig. 7 we can point out the following. The significant wave height along section A-A, near the leeside of the breakwater, becomes smaller from the tip of the breakwater towards the center of the breakwater and at the center the wave height decreases by about 75% of that at the tip. Contrarywise, wave heights along section B-B, about 10 m from the breakwater, are getting large towards the center of the breakwater. This might depend on the superposition or convergence of waves, i.e. transmitted waves and waves diffracted from both sides of the breakwater.

Figure 8 shows part of the experimental results for wave height distribution around a permeable breakwater carried out by Horikawa, Isobe and Shiozaki(1980). Wave heights are shown in cm units. Experiments were carried out on a 1/20 sea bottom slope and the water depth at the site of the breakwater was 5.8 cm. The wave length at the site of breakwater and the length of the breakwater were about 72 cm and 90 cm, respectively. Noticing that this experiment and the field conditions were almost the same, we find the following fact. That is, we can see wave heights of 1.4 and 1.9 cm at the leeside of the breakwater and at positions about one-fourth of the breakwater length from both ends of the breakwater. These positions might be considered as nodes of three dimensional partial standing waves which were formed by the transmitted and diffracted waves. In the experiments described in part I, it was shown that the wave height at nodes of the partial standing waves became larger than the calculated values and it was imagined that this depended on energy transfer from antinodes to nodes by interaction of the two waves: transmitted and diffracted waves.

The same thing might have occurred the experiments of Horikawa et al. Comparing Fig. 7 and Fig. 8, we recognize that the energy transfer from the antinodes to the nodes of the partial standing waves in an irregular wave in the field becomes larger than that in regular waves in laboratory experiments. That is, to wave height averages at the leeside of the breakwater for regular waves is smaller than that for irregular waves. This is natural.

The significant wave period (See Fig. 7B) shows a tendency to become smaller at the leeside of the breakwater.

(2) Waves at the offshoreside of the breakwater.

Significant wave heights and periods at stations 91 and 92 were 113 cm and 8.7 sec. and 70 cm and 5.0 sec using the zero-up corssing method; and 119 cm and 9.4 sec, and 79 cm and 6.4 sec using the zero-down crossing method, respectively. The number of waves defined were 123 and 166. From the big difference between these two stations, we can predict that at the offshoreside of the breakwater, the partial

standing waves were formed by incoming waves and reflected waves. At the node the number of waves defined becomes larger than that at the anti-node, and the wave period beocmes smaller. (See Fig. 9)

(3) Wave height distribution at one location as a function of time.

Figure 10 shows the wave height and period distribution as a function of time at stations on the leeside of the breakwater. Fig. 10A shows the wave heights and period distribution at section C-C in Fig. 7. It is considered that waves on this section suffer little influence from the breakwater, and are almost the same as on a natural beach. Fig. 10B, 10C and 10D show the wave height distribution at each station on sections B-B, C-C and D-D, respectively.

In these Figures, histograms show the nondimensional wave heights, the ratio of wave heights and average wave height, $H/\bar{H}$. Solid circles show the nondimensional period, the ratio of wave periods and average period, $T/\bar{T}$. The distribution graph to the left side is that derived from the zero-up crossing method, and that to the right side is the one derived from the zero-down crossing method. These are distinguished by UP and DOWN, respectively.

Glancing at these figures, you can readily see that the nondimensional wave height distributions completely differ with the definitions of waves. Distributions defined by the zero-up crossing method become unimodal distributions, and those defined by the zero-down crossing method result in bi-modal distributions, except at stations 21, 41 and 51. This tendency is especially evident on section C-C. As mentioned before, waves on this section are not influenced by the existing breakwater so much, and we may consider that waves in this section are almost the same as on beaches with no structures. This phenomenon has often been observed by the author and his coworkers (1979 and 1980) on natural beaches.

The facts that the wave height distribution become uni-modal with its peak in the neighborhood of $H/\bar{H} = 1.0$, if we define the waves by the zero-up crossing method, and that the wave height distribution becomes bi-modal with two peaks located to the right and left side of $H/\bar{H} = 1.0$, if we define the waves by the zero-down crossing method, can be interpreted as follows. We shall consider defining waves for a case in which a relatively small wave follows a big wave, as shown in Fig. 11. Clearly, a large and a small wave are defined by the zero-down crossing method and two waves of almost the same height are defined by the zero-up crossing method. In addition to this, the average wave height and number of waves defined are the same in spite of the two different methods of definition. It is probable that these facts take place in the distributions shown in Fig. 10. No doubt, waves as shown in Fig. 11 exist very much in the surf zone on natural beaches. We can guess that the distribution for stations on the leeside of the breakwater change due to their dependence on the different positions of the waves.

Another thing to be pointed out from Fig. 10 is that the distribution of nondimensional wave periods roughly agrees with the wave height distribution. This means that the wave periods are roughly proprotional to the wave heights. This is not inconsistent with the general concept.

(4) Difference of representative waves statistics due to wave definitions.

Table-1 shows the wave heights and periods of the one-tenth and significant waves, and the number of waves defined. Wave heights show no difference between the zero-up and down crossing methods. However, wave periods defined using the zero-up crossing method become less large than those defined using the zero-down crossing method. This means that waves defined using the zero-down crossing method become steeper than those from the zero-up crossing method. There are relatively large differences in the numbers of waves defined. This relates to the differences of wave positions of the transmitted and diffracted waves, but this is not all. We can not offer exact answers or interpretations for the above results. Many things remain to be discussed in the future.

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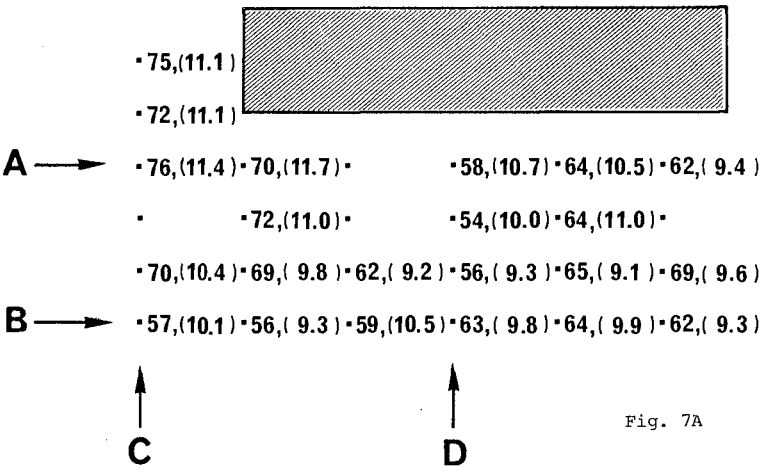


Fig. 7A

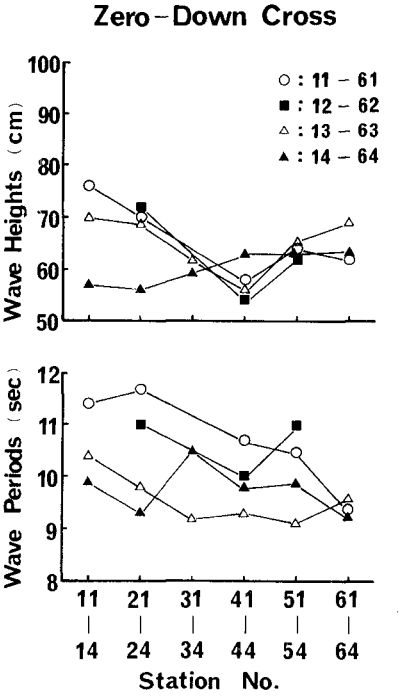


Fig. 7B

Fig. 7 Significant wave heights and periods around a small detached breakwater

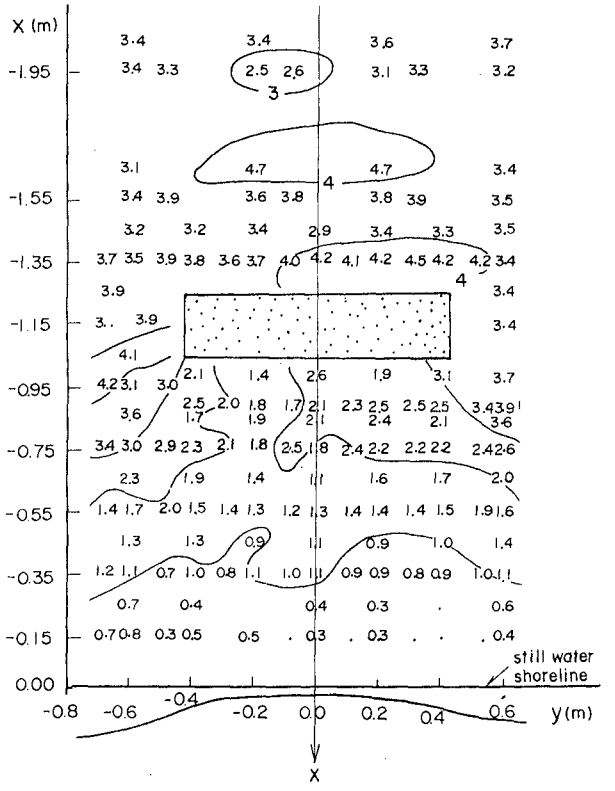


Fig. 8 Experimental wave height distribution around a permeable breakwater (after Horikawa, Isobe and Shiozaki)

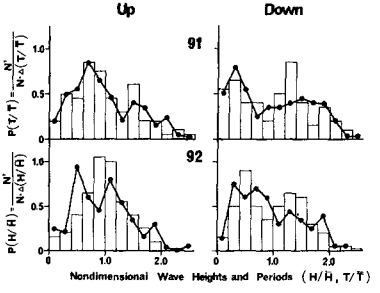


Fig. 9 Wave height distribution as a function of time at Station 91 and 92

Fig. 10A

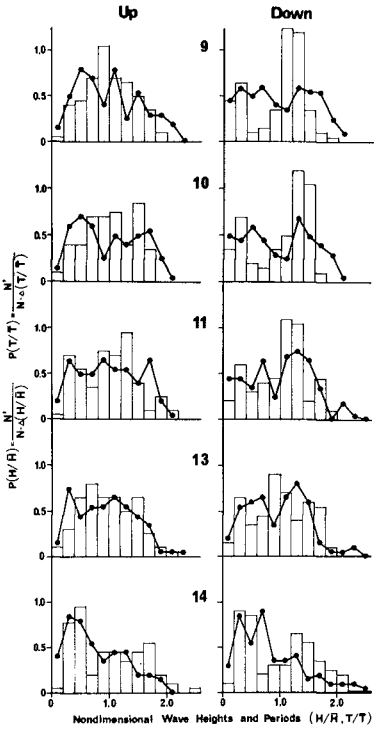


Fig. 10D

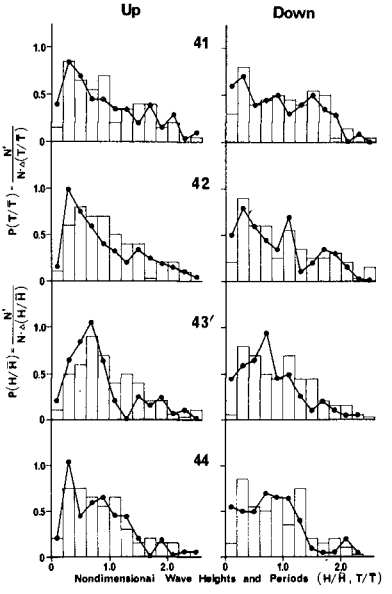
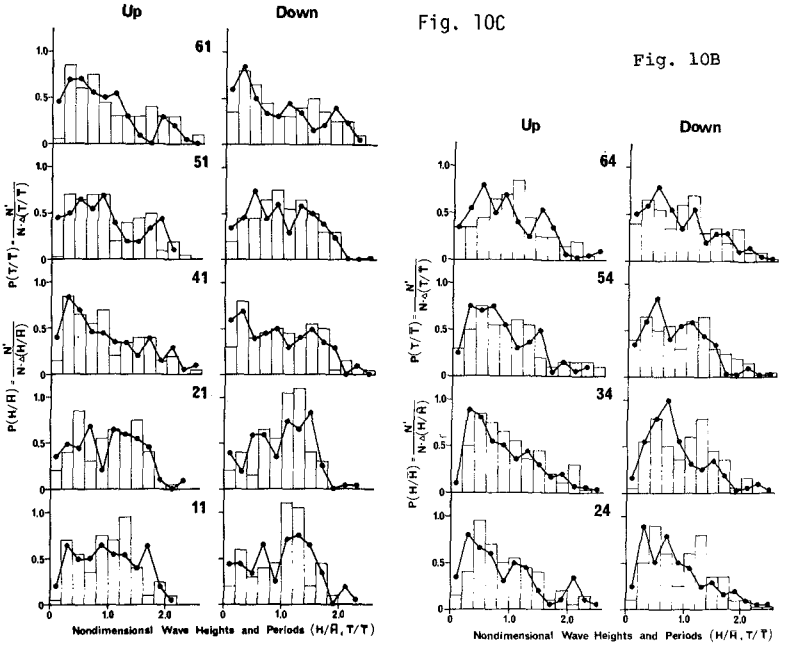


Fig. 10 Wave height distribution as a function of time at the leeside stations



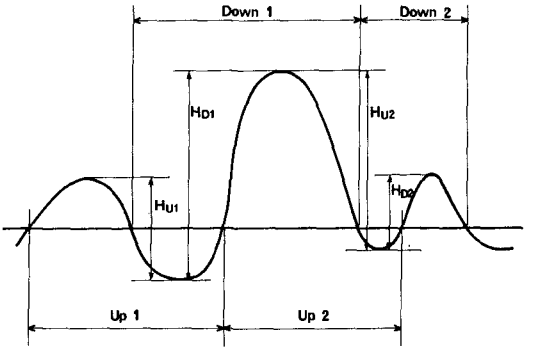


Fig. 11 Difference of wave heights due to methods of defining wave heights

Table - 1 Significant waves

St. No.	K	Height		Period	
		DOWN	UP	DOWN	UP
9	100	75	75	11.1	11.7
10	102	72	72	11.1	10.9
11	97	76	77	11.4	11.1
13	96	7	70	10.4	10.4
14	123	57	57	9.9	10.1
21	90	70	72	11.7	12.1
22	102	72	73	11.0	11.5
23	111	69	70	9.8	10.2
24	119	56	57	9.3	9.5
33	112	62	61	9.2	10.6
34	104	59	60	10.5	11.0
41	112	58	59	10.7	11.8
42	127	54	52	10.0	10.0
43	104	56	59	9.3	10.5
44	128	63	64	9.8	10.0
51	107	64	66	10.5	11.2
52	105	64	65	11.0	11.4
53	128	65	65	9.1	9.1
54	116	64	61	9.9	9.7
61	130	62	62	9.4	9.5
63	132	79	75	9.6	9.6
64	128	62	58	9.3	8.5

K: Number of waves defined

Wave Height (cm)

Wave Period (second)

REFERENCES

Hotta, S. (1979): Wave height distribution around permeable breakwater, Proc. 16th ICCE, pp 695-714, A.S.C.E.

Hotta, S. and M. Mizuguchi(1978): A field study of waves after breaking waves, Proc. 25th Conf. on Coastal Eng. in Japan, pp 151-154, J.S.C.E. (in Japanese).

Hotta, S. and M. Mizuguchi(1979): A field study of waves in the surf zone, Proc. 26th Conf. on Coastal Eng. in Japan, pp J.S.C.E. (in Japanese).

Hotta, S., M. Mizuguchi and M. Isobe(1980): A field study of wave characteristics in the surf zone, Proc. 27th Conf. on Coastal Eng. in Japan (in printing and Japanese).

Horikawa, K., M. Isobe and M. Shiozaki (1980): Laboratory investigation on the wave and current system induced by coastal structures, Annual Report of the Engineering Research Institute, Faculty of Tecnology, University of Tokyo. (in printing and Japanese)