CHAPTER 185

Regulation of Nearshore Circulation by Submerged Breakwater for Shore Protection

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Abstract

A submerged breakwater induces a circulation with onshore currents over the structure and offshore currents through gaps, resulting in sediment loss to the offshore region. A new submerged breakwater with inclined multiple blades is tested by laboratory experiments and numerical simulations. This breakwater can generate offshore currents over the structure and onshore currents through gaps suggesting onshore sediment supply.

1. Introduction

Submerged breakwaters and artificial reefs have been widely constructed to prevent coastal erosion without spoiling landscapes of coast. However, wave set-up induced in the onshore area of the structure by wave breaking often generates strong nearshore circulation. The directions of cross-shore currents of the circulation are onshore above the structures and offshore in their gaps (**Figure 1(a)**)(Browder, 1996; Uda, 1987).

These currents reduce the efficiency of shore protection, since the current crossing over the structure does not bring sediment onshore, while the offshore current takes sediment away to the offshore. If an opposite pattern of circulation, in which the direction of flow is onshore in the gaps of the structures (**Figure 1(b)**), can be formed, sediment will be supplied from offshore to onshore. In order to generate such current, it is need to develop a structure which dose not induce wave set-up in the onshore area. Authors have proposed such structures (e.g. Irie 1991).

This study aims at finding a technical solution which can meet the above requirement to control current's direction. To this end, a new

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submerged breakwater with multiple inclined blades shown in **Figure 2** is proposed.

In the study, experiments were performed to measure the wave set-up and patterns of the induced circulation around a structure in a wave flume and a wave basin. Numerical calculations using a two-dimensional model were also performed to simulate the nearshore currents around a structure. Finally, the functional capacity of these structures for shore protection was evaluated on the basis of the numerical simulation.

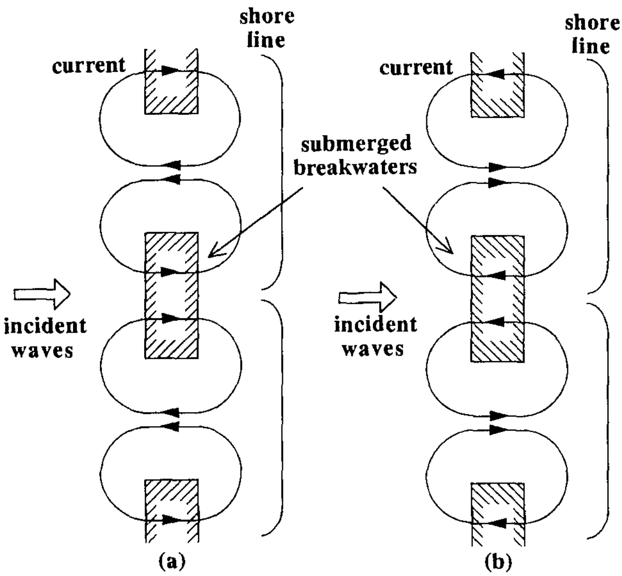


Figure 1 Patterns of nearshore circulation

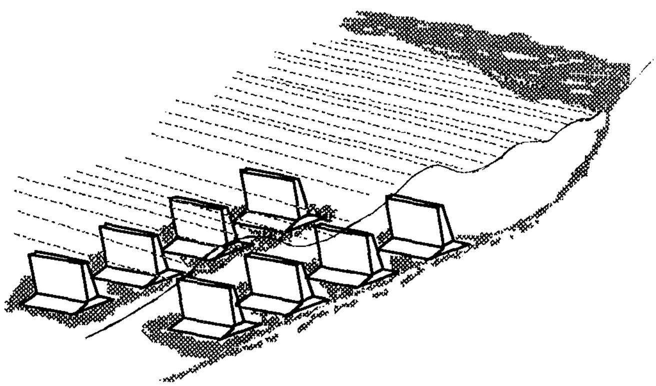


Figure 2 Sketch of a new submerged breakwater with multiple inclined blades

2. Methods of Experiments for Wave Set-up and Currents

Experiments were performed to examine the distributions of wave height and wave set-up and set-down around breakwaters under the condition of the uniform water depth(h=0.35m) in a wave flume whose length, width and height were 35m, 0.3m and 0.5m respectively. The structures examined were an artificial reef and four types of new submerged breakwaters with multiple blades; a type of blades was upright, and the others were inclined offshore as shown in **Figure 3**. The angle of blades was 15°, 30° and 45°. The height(D), spacing of the blades(B) and total length of the body(WT) was 0.5h, 2.0h and 6.0h respectively. Each structure was set in the flume at the point of 12m onshore from the wave maker. In each case, the condition of incident waves was 6.0cm in height, and 1.02, 1.27 and 1.83s in period. Fluctuations of water surface were measured around the structure at intervals of 7cm, i.e. 0.2h.

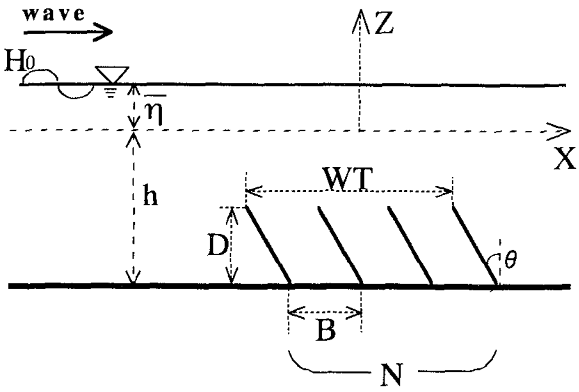


Figure 3 Scale of multiple blades

Another experiments were performed to measure currents around the breakwaters in a wave basin with a uniform water depth(h=0.1m). The basin was 246cm long, 170cm wide and 30cm high, and was equipped with a wave maker, wave absorber and filter as shown in **Figure 4**. In the experiments, models of detached breakwater (20cm×60cm), artificial reef (60cm×60cm, 6.5cm high) and multiple blades (60cm×60cm, 6.5cm high, θ= 30°, B=2.0h) were set in the center of the wave basin. The conditions of incident wave were 1.7cm in height and 1.1 and 0.76s in period.

To measure the patterns of currents, floats having a diameter of 1cm were used. The weight of the floats was adjusted so that they stayed in the surface layer and bottom layer respectively. The movement of the floats was recorded by a video camera, and traced at an interval of 5 or 20s.

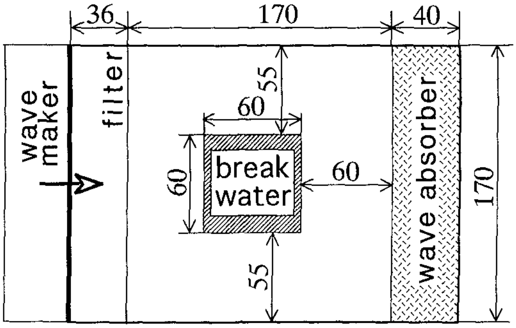


Figure 4 Experimental wave basin

3. Wave Set-up and Set-down Around the Multiple Inclined Blades

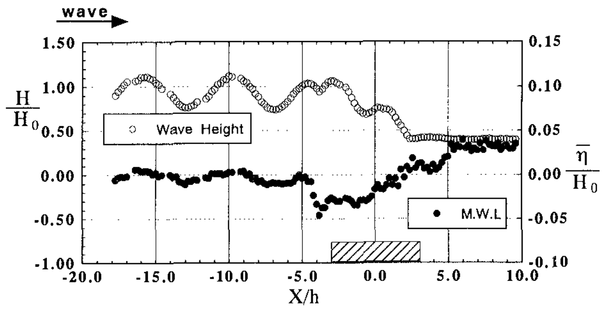
Figure 5 shows the distributions of wave heights and mean water level around the artificial reef **(a)** and multiple blades inclined by 30° **(b)**.

In the case of artificial reef, wave transmission coefficient is approximately 40% and standing waves is observed in the offshore side. On the other hand, for the multiple blades, the transmission coefficient is approximately 70% and no standing waves form. The coefficient changed from 60 to 70% with blade slant angle and wave period.

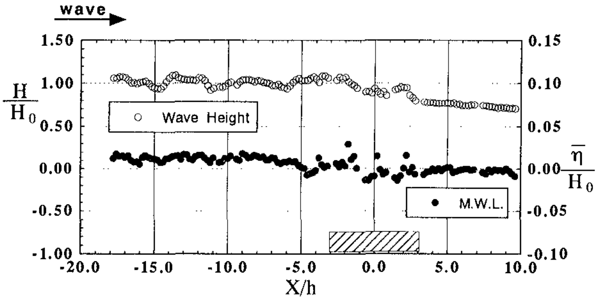
It was found by observation of the water motion that strong wave breaking occurred on the reef. On the other hand, at the top of the multiple blades, large eddies occurred. It can be concluded that the decreases in wave height were caused by wave breaking and reflection for artificial reef and eddy formation for multiple blades.

Regarding the mean water level distributions, wave set-up occurred in the onshore area in the case of reef. While, for the case of multiple blades, the mean water level decreased gradually in the onshore direction. Wave set-down occurred in the onshore area.

For all cases of blade's slope type and wave conditions, the mean water level is rather constant except just above the breakwater. **Figure 6(a)** shows the difference between the mean water levels of offshore and onshore sides around the five structures, respectively. Since the water depth is constant, it was taken as the reference level. The distribution of mean water level around the structure varies systematically depending on structure's type and the slope of the inclined blades. In the case of the reef, wave set-up occur in the onshore area. For the breakwaters with blades, the larger is the blade slope, the lower is the wave set-up in the onshore area. Even wave set-down takes place for the blade slopes of 30° and 45°.



(a) artificial reef



(b) multiple blades(θ=30°, T=1.1s)

Figure 5 Distribution of wave height and mean water level

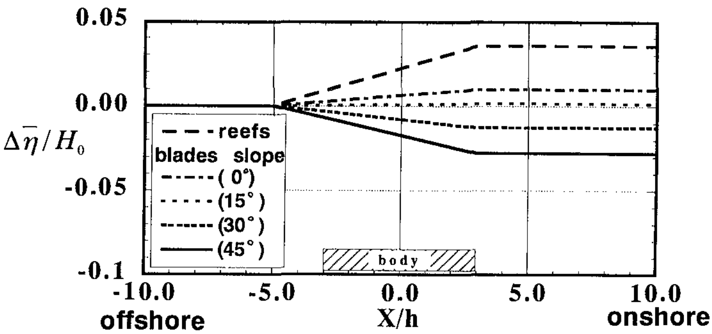


Figure 6(a) Difference in mean water level around the structure

The results of the cases with different wave periods are shown in **Figure 6(b)**. The horizontal axis is a wave period and the vertical the difference in mean water level. The same tendency as mentioned above was obtained; when the slant of blades is large, the wave set-down is also large. This tendency becomes more profound as the wave period becomes large.

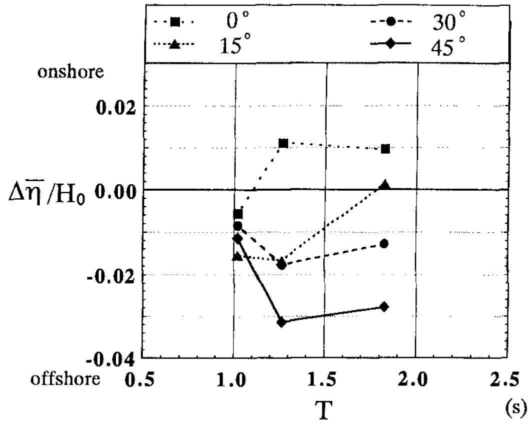


Figure6 (b) Difference of mean water level in all the case of multiple blades

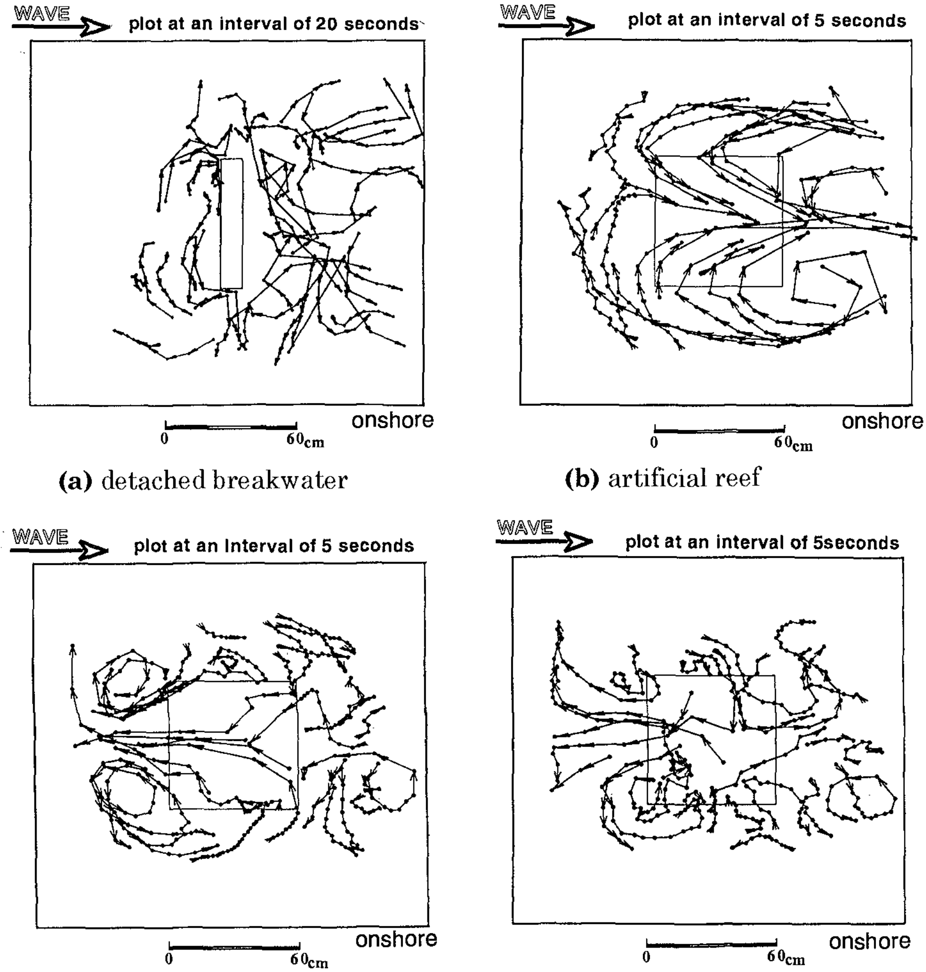
4. Experimental Results on Nearshore Currents

Figure 7 (a),(b),(c) show the currents at surface layer around the detached breakwater, the reef and multiple blades inclined by 30°. The wave conditions are H=1.7cm and T=1.1s. Filled dots in the figure indicate the location of floats at an interval of 5 or 20 seconds and the square in the center of figure shows the corresponding structure.

Around the detached breakwater (**Figure 7(a)**), the flow is so weak that a circulation is not very clear. At the side of the structure, onshore and offshore currents occur near the structure and far away from the structure.

For the case of the artificial reef (**Figure 7(b)**), a clear circulation is formed around the reef, in which currents flow in the onshore and offshore directions above the structure and on it's both sides, respectively. The directions of the circulation at the bottom layer were same as that of the surface layer.

A completely opposite pattern of circulation is generated for the case of breakwater with inclined blades by 30° as shown in **Figure 7(c)**; the current flows to the shore through the gaps, and juts out over the blades. In the bottom layer except above the structure, the flow is very weak and goes toward onshore. The case with different wave condition, which is 0.76s in wave period, is shown in **Figure 7(d)**. Though a pattern of circulation around the multiple blades was not so clear, the pattern of currents was same as that in the case of wave period which was 1.1s.



(a) detached breakwater

(b) artificial reef

(c) multiple blades (θ =30°, T=1.1s)

(d) multiple blades (θ =30°, T=0.76s)

Figure 7 Nearshore currents around the structure (experiment)

5. Evaluation of Functional Capacity of Currents for Shore Protection

In order to study the currents around the submerged breakwaters in detail, a numerical model was developed.

5-1. Government Equation

Equations of conservation of mass and momentum **(1)**, **(2)** and **(3)** for nearshore currents were used, with two additional terms to express special conditions imposed by the existence of the breakwater.

$$\frac{\partial \overline{\eta}}{\partial t}+\frac{\partial u\,(\overline{\eta}+h)}{\partial x}+\frac{\partial v\,(\overline{\eta}+h)}{\partial y}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+F_x-M_x+S_x+g\frac{\partial \overline{\eta}}{\partial x}=0 \tag{2}$$

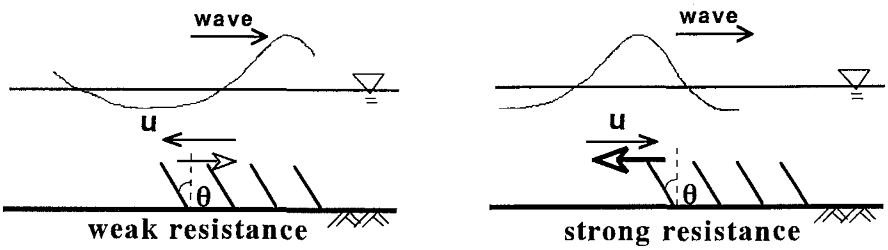
$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+F_y-M_y+S_y+g\frac{\partial \overline{\eta}}{\partial y}=0 \tag{3}$$

where, u, v are x and y components of the velocity, η mean water level, Fx, Fy bottom friction, Mx, My horizontal mixing terms, and Sx, Sy radiation stress term. The bottom friction was formulated according to Longuet-Higgins(1970) with the Manning roughness coefficient being $0.013[m^{-1/3}s]$. These equations were calculated by ADI method.

5-2. Special Term

The one of special terms is needed to express the onshore momentum transport due to strong wave breaking above the reef. If this effect is not introduced, the reproduction of the flow is insufficient (Sasaki,1990). In this study, this phenomenon was expressed by increasing the gradient of radiation stress at onshore side from wave breaking point.

The other special term is to express the mean resistance force of the inclined blades which appears as a residual stress over a period. This mean force was caused by the difference in the resistance force between the onshore and offshore directions. When the direction of water particle's motion is the same as the blade's inclination, the resistance force acting on the water mass is weak(**Figure 8(a)**). On the other hand, when the direction of flow is opposite to the blade inclination, the resistance force becomes strong(**Figure 8(b)**). Such a mechanism, therefore, can induce the difference of onshore and offshore resistance forces in a wave period. Since the offshore resistance force is stronger than onshore one, the blades exert offshore force on the water body and cause wave set-up on the offshore side.



(a) (b)

Figure 8 Generation of the offshore residual resistance force

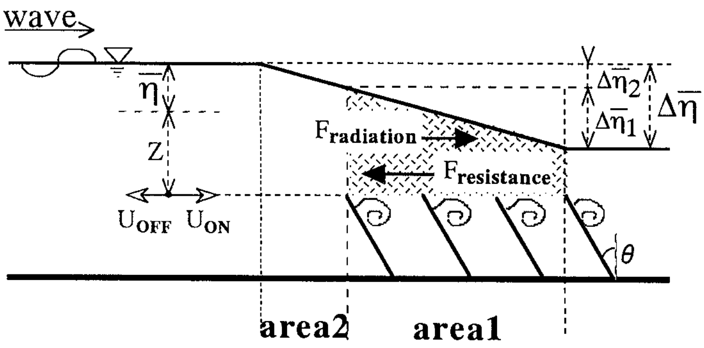


Figure 9 Balance of power around the multiple blades

It is assumed that the onshore and offshore resistance forces caused by blades are proportional to the square of the horizontal velocity of wave motion, and act in the direction opposite to the flow above the blades. It is also assumed that the resistance force integrated over the period of onshore or offshore flow is also proportional to the square of the maximum velocity in the corresponding period. The residual resistance force can be, therefore, evaluated by the difference in the square of maximum velocity. In this study, the horizontal maximum velocity was calculated by second-order stokes wave theory.

The three forces, which are the gradient of hydrostatic pressure, the gradient of radiation stress and the resistance force, balance near the multiple blades. This relation in area 1 shown **Figure 9** can be formulated as **Equation 4**.

$$g\ (\bar{\eta}+h)\ \frac{\Delta\overline{\eta_1}}{\Delta x}=-\frac{1}{\rho}\frac{\Delta S_{xx}}{\Delta x}+C_\alpha D\sum_1^N\ (u_{on(max)}^2-u_{off(max)}^2) \tag{4}$$

The left hand side is the gradient of hydrostatic pressure. The first and the second terms in the right hand side are the gradient of the radiation stress in the water column on the blades and the mean resistance force in a wave period, respectively. Cα is a kind of resistance coefficient and was obtained by a least squares method for the cases of different blades angle.

Mean water level varied even in the offshore area of the structure, which is indicated as area 2 in **Figure 9**. It is assumed that the resistance force also acts this area. The balance of forces in area 2 is, therefore, formulated in the same way as Equation (4) using a coefficient of Cβ instead of Cα, although the water depth is different from the area 1.

$$C\alpha=-0.010\times\theta-0.016 \tag{5}$$
$$C\beta=-0.013\times\theta-0.022 \tag{6}$$

here, the unit of θ is degree.

When the simulation of nearshore currents around the multiple blades was performed using the government equations with this resistance term, the velocities of flow became too strong. This is because the present model includes only the resistance force caused by wave motion, and dose not take into account that by the currents. The coefficient of $C\gamma$ which modify the coefficient of $C\alpha$, $C\beta$ was evaluated so as to reproduced the currents well.

$$C\gamma=1.2-0.88\times T \tag{7}$$

where, a range of a wave period, T, is from 0.76s to 1.1s for the water depth of 0.1m.

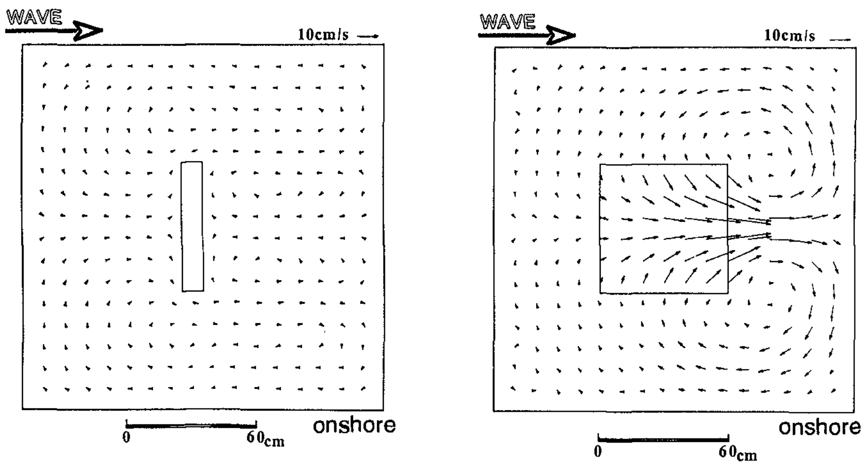
5-3. Results of Simulations for Nearshore Circulation

Figure 10(a) illustrate the currents around the detached breakwater. Very weak circulation flow occurred around the body.

For the case of artificial reef, a clear circulation was formed as shown in **Figure 10(b)**. The direction of circulation is onshore above the structure and offshore both sides of structure.

On the other hand, for the case of multiple blades, a completely opposite pattern of circulation was generated as shown in **Figure 10(c)**; the current flow to the shore through the gaps, and juts out over the blades. For the case with different wave period, the circulation was not much clear, but the same pattern appeared (**Figure 10(d)**).

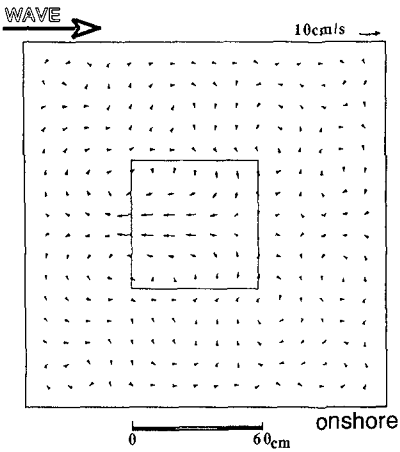
These results of simulations show fairly good agreement with those obtained by experiments.



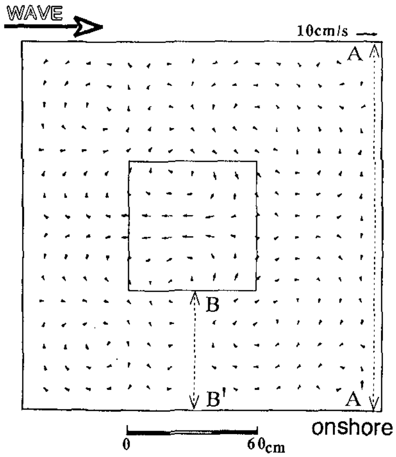
(a) detached breakwater

(b) artificial reef

Figure 10 Nearshore currents around the structure (simulation)



(c) multiple blades(θ =30°, T=1.1s)



(d) multiple blades (θ =30°, T=0.76s)

Continue Figure 10

5-4. Functional Capacity of Currents for Shore Protection

The effect of the induced currents for shore protection is evaluated on the basis of the result of the calculation. There are two disputed points; the one is wave set-up near shoreline, and the other is currents on the sides of breakwater. The examined structures were the detached breakwater, the artificial reef and the new submerged breakwater with multiple blades.

Wave set-up near the shoreline causes shoreline retreat, and the difference in wave set-up along the shoreline induces strong longshore currents which transport the sediments.

The wave set-up at line A-A' in **Figure 10(d)** are showed in **Figure 11** The horizontal axis is long shore distance and the square of the center indicates the position of the structure. For the case of reef, highest wave set-up appears. On the other hand, for the case of multiple blades and detached breakwater, wave set-up was low, and the difference of mean water level in longshore direction was small, that indicates the beach would be protected.

The offshore currents on the side of the structure bring sediment offshore, resulting in shore erosion. The flow rates across the line B-B' in **Figure 10(d)** are indicated in **Figure 12**. The vertical axis shows the cross-shore flow rates; a positive value indicated the onshore flow rates.

In the cases with detached breakwaters and multiple blades inclined by 15°, no or little currents occurred, so there are no bars on the graph. The case of artificial reefs shows strong offshore currents. For the case of multiple blades, with the blade angle, the onshore currents become stronger. For the case of multiple blades inclined by 45°, most strong onshore currents occur. It may be expected that the onshore currents supply sediment onshore.

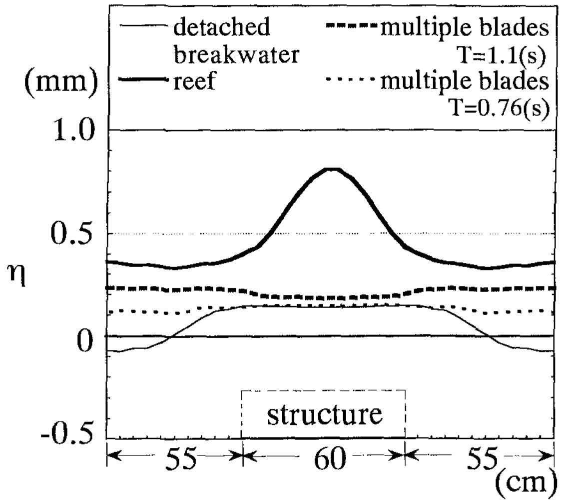


Figure 11 Wave set-up near the shoreline

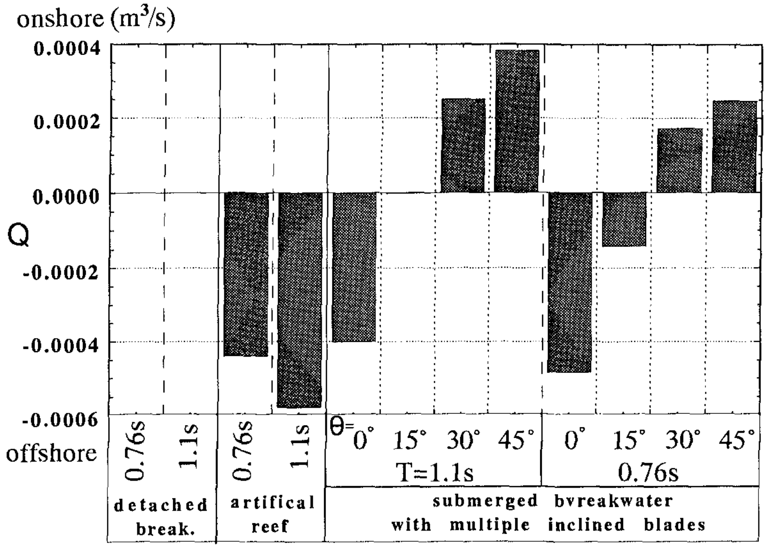


Figure 12 Cross-shore flow rates on the side of structure

6. Conclusions

This study confirmed the principle and effectiveness of a new type of breakwater with multiple blades to generate a preferable circulation pattern for preventing beach erosion. Three points should be emphasized as the conclusions of this study.

1. Wave set-down occurred in the onshore area of the new submerged breakwater with multiple inclined blades in laboratory experiments with a two-dimensional wave flume.
2. The direction of nearshore circulation around the multiple inclined blades is offshore above the structure and onshore on the sides of the structure. This pattern of the flows is opposite to that of nearshore circulation induced by artificial reefs.
3. The structure with multiple blades inclined by 45° caused the most strong onshore currents on the side of structure, which suggested that onshore transport of sediments was expected.

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