CHAPTER 208

BEACH EROSION CONTROL BY SUBMERGED FLOATING STRUCTURE

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ABSTRACT

This paper is to investigate experimentally the beach erosion control function of a submerged tension-moored breakwater. Two- and three-dimensional laboratory experiments are performed.

The single-peaked, double-peaked and triple-peaked cuspate spits are formed by placing the submerged tension-moored breakwater on an accreted-type or intermediate-type beach. When the submerged tension-moored breakwater is placed on an eroded-type beach, the shoreline denudation is stopped and the shoreline is restored to the original location.

The submerged tension-moored breakwater is concluded to be possibly one of effective measure works against beach erosion in an inner gulf area in which huge waves do not attack.

1. INTRODUCTION

So far, a semi-submerged bottom-seated offshore breakwater made with natural stones and concrete armour units

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have been constructed to protect beaches from severe erosion as well as to prevent the coastal zone from wave-caused disasters. The offshore breakwater has been verified to be an effective measure against beach erosion as well as an useful disaster prevention work, and Japanese coasts have been protected by many numbers of this kind of offshore breakwater.

Very recently, however, the bottom-seated offshore breakwater made with concrete armour units is pointed out to have some demerits such as (1) poor sea water exchange between the onshore and offshore side of the breakwater, (2) destruction of beautiful scenery and (3) bad barrier for marine sports. Therefore, research and development of new type of beach erosion control works is strongly requested in relation to re-development of urban water front in the bay area in which huge waves do not attack.

The artificial reef work utilizing a submerged sea-dike made with natural rocks are under construction, in some Japanese coasts, as a new measure work against beach erosion. All the measure works against beach erosion which have been put into practical use utilize bottom-seated structures. Another possible choice instead of the bottom-seated structure will be a moored-type structure. However, very few researches regarding the measure work using moored structures have been conducted.

With this background in mind, this paper deals with a submerged tension-moored breakwater from the view point of (1) good sea water exchange between onshore and offshore side of breakwater,(2) no destruction beautiful scenery and (3) no bad barrier for marine sports and discusses the beach erosion control function by means of two- and three-dimensional laboratory experiments.

2. TWO-DIMENSIONAL LABORATORY EXPERIMENT

1) Equipment and procedure

A wave tank in 1m width, 1.5m height and 50m length at Gikenkogyo Co.Ltd. was used to discuss 2-dimensional beach deformation. Experimental waves were all regular ones and thier wave steepness (Ho/Lo: Ho;deep water wave height,Lo; deep water wavelength) were 0.01,0.03 and 0.06, which were selected so as to produce the accreted-type, intermediate-type and eroded-type beaches without structures (Horikawa and Sunamura (1974)). Bed material was fine sand of 0.38mm medium diameter (d_{50}) and the initial bottom slope ($\tan\theta$) was 1/10. The floating breakwater was fixed to the bottom with tension using 4 stainless wires of 3mm diameter. The intitial mooring force (Fo) of one wire was about 7.2kg. The dimension of model breakwater was 10cm in height (D), 30cm in width (B) and 99cm in length (A). The schematic illustration of experimental set-up is given in Fig.1.

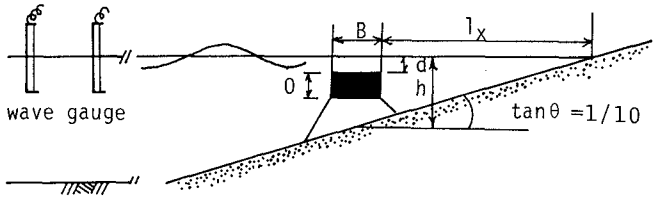

Fig.1 Schematic illustration of experimental set-up

The waves were generated for about 4 hours until the beach approached to an equilibrium state. The beach profiles at 0.5, 1, 2,3 and 4 hours from the initiation of wave generation were measured carefully with point gauges. The incident and partial standing wave in front of the breakwater were mesured with capacitance-type wave gauges. Experiments were carried out, changing the location and submerged depth of the breakwater. Table-1 shows experimental conditions and total experimental runs were 32.

Table-1 Experimental condition

T(s)	Ho/Lo	d/h	l_x/L	D/h	d_{50}/Ho
1.0	0.007	0	0.63	0.286	0.0039
1.8	0.019	0.288	∫	∫	0.0040
	0.030	0.333	∫	∫	0.0081
	0.060	0.358	2.46	0.833	0.0111

2) Dimensional analysis

The equilibrium beach profile is mainly dominated by the following dimensionless 6 parameters, due to a dimensional analysis;

$$\left(\frac{Ho}{Lo}, \frac{D}{h}, \frac{d}{h}, \frac{l_x}{L}, \frac{d_{50}}{Ho}, \frac{F_o}{\rho g d^2} \right) \quad \text{---------} \quad (1)$$

where, h is the stillwater depth at breakwater, d the submerged water depth, l_x the offshore distance of breakwater from shoreline, g the gravitational acceleration and ρ the fluid density.

There are so many leading factors, but the laboratory experiments are limitted. Therefore, the effect of l_x/L and d/h to beach deformation are mainly discussed here.

3) Result and discussion

Experiments showed, as a general feature, that the change of bottom configuration mainly takes place in shallower water depth than the setting location of the breakwater and the magnitude of bottom configuration change becomes smaller with increasing l_x/L and with decreasing D/h.

Figures 2 and 3 show some examples of bottom configuration change taken place by placing the breakwater. The bottom configuration shown in Figs.2 and 3 correspond to the equilibrium state beach. Figure 2(a) shows that the beach without the breakwater is eroded by the wave whoes

steepness is 0.06 (Ho/Lo=0.06). However, by placing the submerged tension-moored breakwater, the eroded beach was changed to the uneroded-type or a little accreted-type beach, as shown in Fig.2(b) and (c). The reason of this is that the steep incident wave is broken by the breakwater and the attenuated wave encouraged onshore sediment transport. On the other hand, in case of the accreted-type or intermediate-type beach, the bottom configuration change by the breakwater is not drastical. The intermediate-type and accreted-type beaches were never changed to the eroded-type beach by the breakwater. As shown in Fig.3, the intermediate-type beach was still intermediate-type ones even by placing the breakwater.

The bottom configuration is closely correlated with six dimensionless parameters as shown by Eq.(1). Among them, D/h, d/h and l_x/L were found to be significantly important parameters. With increasing of D/h and decreasing of d/h, the wave breaking-caused vortex and incident wave attenuation become larger, which bring larger change of bottom configuration. In the experiments, large change of bottom configuration was observed to take place under the conditions of $0.33 \leqq D/h \leqq 0.83$ and,

d/h=0 and $0.63 \leqq l_x/L \leqq 2.5$; $0 \leqq d/h \leqq 0.33$ and $0.63 \leqq l_x/L \leqq 2.2$
(for eroded-type beach)

d/h=0 and $0.63 \leqq l_x/L \leqq 2.5$; $0 \leqq d/h \leqq 0.33$ and $0.63 \leqq l_x/L \leqq 0.9$
(for intermediate-type beach)

The bottom around the submerged tension-moored breakwater was scoured in case that the clearance between the breakwater's bottom and beach was less than the breaker height. Material on onshore-bed of the breakwater is

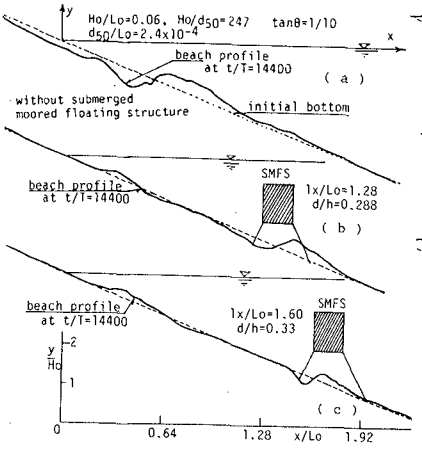

Fig.2 Bottom configuration change (eroded-type beach)

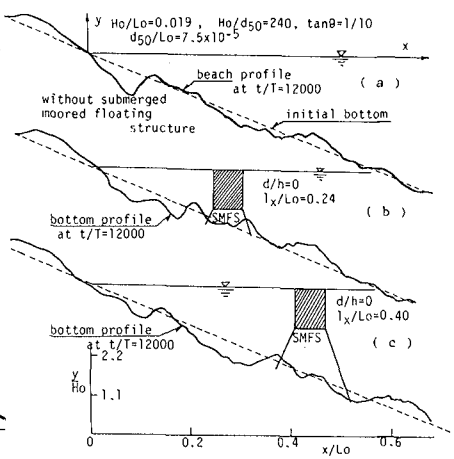

Fig.3 Bottom configuration change (intermediate-type beach)

suspended by wave breaking-caused vortex and is washed away mainly toward offshore ward by the return flow. This scouring was clearly observed in case of the eroded-type and intermediate-type beaches. The maximum scoured depth Δh is closely related to l_x and d, and the dimensionless maximum scoured depth $\Delta h/Ho$ is less than 0.65, as shown in Fig.4.

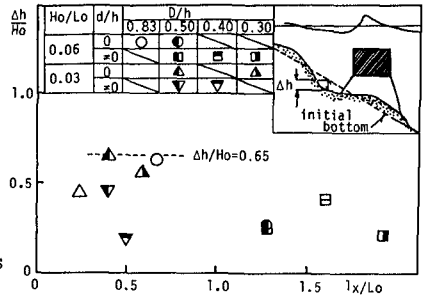

Fig.4 Nondimensional maximum scouring depth $\Delta h/Ho$

3. THREE-DIMENSIONAL LABORATORY EXPERIMENT

1) Equipment and procedure

A wave basin in 10m width, 0.65m height and 30m length at Nagoya University was used to investigate the combined effect of the transmitted and diffracted waves to beach profile. Three plywood breakwaters whoes dimensions are D=10cm, B=30cm and A=130cm, D=10cm, B=30cm and A=65cm, and D=5cm, B=30cm and A=130cm were employed, and they were fixed to the beach with tension by stainless wires of 0.3cm diameter. The bed material and initial bottom slope were quite the same as those of two-dimensional experiments. The stillwater depth at wave paddle was 40cm. Experimental waves were all regular ones and they were generated for about 6 - 12 hours until the beach approached to an equilibrium state. The incident wave was measured with capacitance-type wave gauges. Water particle velocities at bottom around the breakwater were measured with electro-magnetic velocimeters to study the wave-induced current. Particle velocities at 20 different locations were collected. Figure 5 illustrates an outline of experimental set-up. Experimental condition is given in Table-2. The total experimental run was 48.

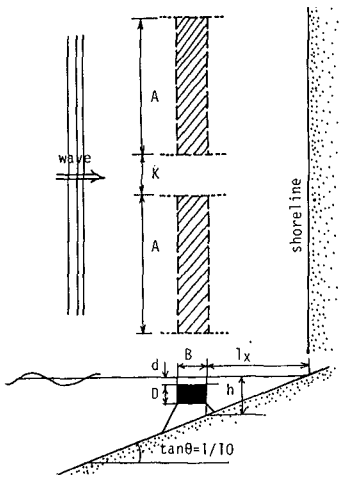

Fig.5 Sketch of experimental set-up

2) Dimensional analysis

The equilibrium beach profile is largely dominated by the following 8 parameters, due to a dimensional

analysis,

$$\left(\frac{Ho}{Lo}, \frac{D}{h}, \frac{d}{h}, \frac{lx}{L}, \frac{d50}{Ho}, \frac{A}{lx}, \frac{Fo}{\rho g d^2}, \frac{K}{A} \right) \quad \text{--- (2)}$$

Table-2 Experimental condition

Ho/Lo	d/h	lx/L	O/h	d_{50}/Ho	A/L	K/A
0.007	0	0.63	0.415	0.0040	0.22	0.25
0.030	0.10	∫	0.500	0.0081	∫	0.50
0.060	0.25	∫	0.588	0.0111	∫	1.00
	0.33	1.65	0.833		1.09	

where, K is the gap between two breakwaters as shown in Fig.5. When one breakwater is placed, the term K/A is neglected. The initial mooring force (Fo) was about 10kg for all experimental runs, although Fo differed a little from 10kg depending on experimental conditions. There are many leading factors which dominate the bottom configuration change. However, since the labotratory experiment runs are limitted like two-dimensional ones, the effect of D/h, d/h, lx/L A/lx and K/A to beach deformation are mainly discussed hereafter.

3) Result and discussion

3-1) Case of one submerged tension-moored breakwater

A) Intermediate-type and accreted-type beaches

Beach morphology was found, as a general feature, to be largely changed by nondimensional quantities relating to a setting location and dimension of the breakwater such as D/h, d/h, lx/L and A/lx.

The cuspate spit is generally formed by placing the breakwater on the intermediate-type and accreted-type beaches. Laboratory experiments revealed that the cuspate spit is classified into three types such as the single-peaked, double-peaked and triple-peaked cuspate spits, as shown in Fig.6. In Fig.6, Lc is the wavelength at the depth of h=40cm in front of the 1/10 bottom slope($\tan\theta$), and the bottom contour is depicted with 1cm depth interval. The beach morphology is an equilibrium state one.

The tombolo is well known to be formed by the bottom-seated structure. However, tombolo was not formed in our experiments. This is due to the reason that the incident wave breaks at the breakwater and the overtopped breaking wave suspends onshore-side sediment and stops the growth of the cuspate spit. This is a remarkable feature of the submerged tension-moored breakwater, which quite differs from the bottom-seated offshore breakwater made with concrete armour units whoes crown height is higher than the water level.

Fig.6(a) is one example of the single-peaked cuspate spit in case of d/h=0. The shoreline behind the breakwater is seen to advance offshore-ward. The diffracted wave dominates over the transmitted wave in this case, and then

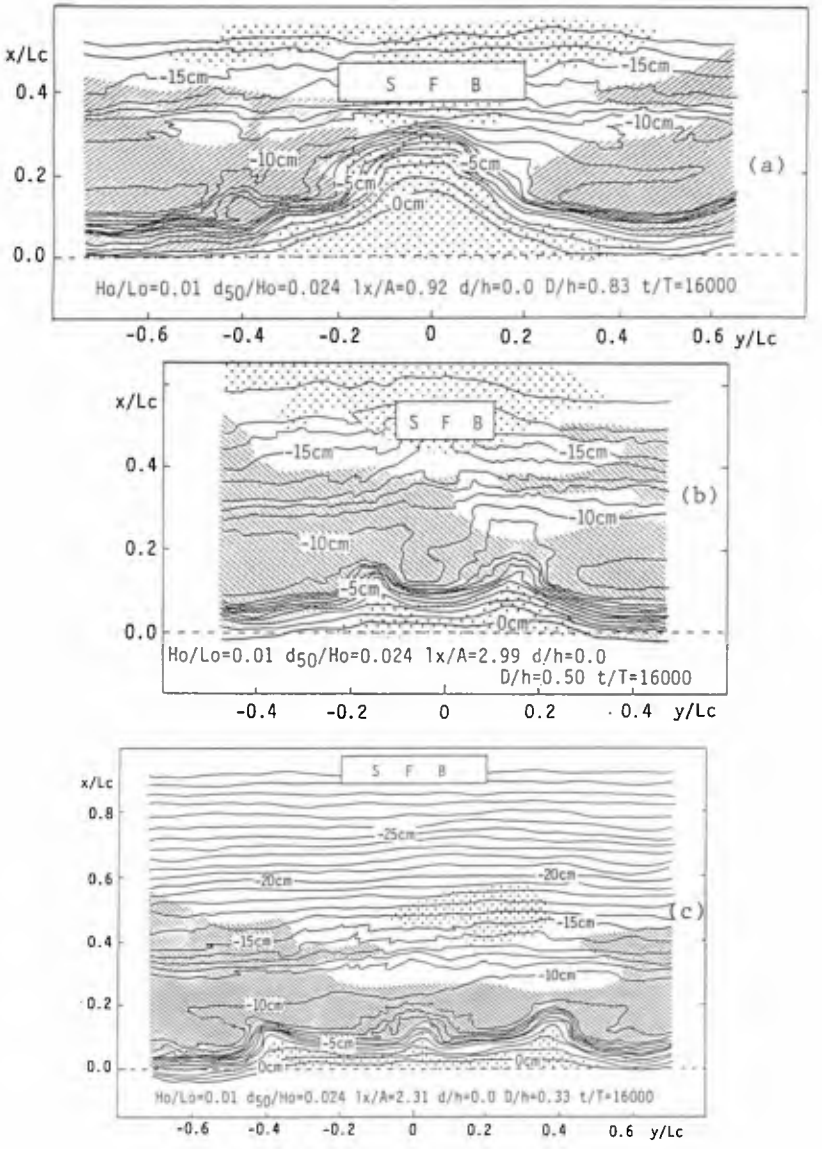

Fig.6 Examples of single-peaked, double-peaked and triple-peaked cuspate spits formed by the submerged tension-moored breakwater placed on accreted-type beach (▒▒; erosion, ⁘⁘; accretion)

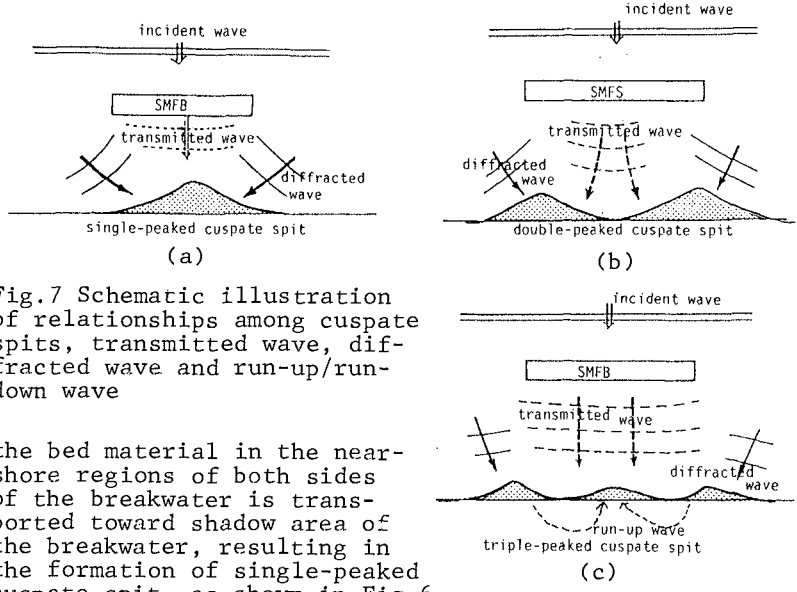

Fig.7 Schematic illustration of relationships among cuspate spits, transmitted wave, diffracted wave and run-up/run-down wave

the bed material in the nearshore regions of both sides of the breakwater is transported toward shadow area of the breakwater, resulting in the formation of single-peaked cuspate spit, as shown in Fig.6 (a) and Fig.7(a).

Fig.6(b) is one example of the double-peaked cuspate spit. Two peaks are formed behind the breakwater due to the combined effect of the transmitted and diffracted waves. With decreasing of D/h and A/lx, the triple-peaked cuspate spit is apt to be formed behind the breakwater. The amount of sediment accumulation around the shoreline is much less than that of the single-peaked and double-peaked cuspate spits. The mechnism of forming the triple-peaked cuspate spit is different from those of the other cuspate spits. As shown schematically in Fig.7(c), the run-up waves obliqely climbed on dry bed run down concentratedly to the same region corresponding to the trough area of double-peaked cuspate spit. The frequency of occurrence of the triple-peaked cuspate spit was very low in the experiments.

The cuspate spit shapes formed by the submerged tension-moored breakwater are very close to those formed by bottom-seated breakwaters made with concrete armour units and natural stones. However, the leading physical parameter which dominates the shapes is different between the two types of structures. lx/A (offshore distance/breakwater width) is the leading parameter in case of the bottom-seated breakwater, and the shoreline shape is classified by lx/A (Shinoda and Ikeda (1972)). However, in case the submerged tension-moored breakwater, D/h and d/h as well as lx/A change largely the morphology of the beach.

Figs.8(a),(b) and (c) show examples of change of equilibrium bottom configuration due to change of D/d and d/h.

Figure 8(a) shows the single-peaked cuspate spit in case of d/h=0. Only by increasing d/h from 0 to 0.17 with the other quantities fixed, the double-cuspate spit is formed as shown in Fig.8(b). This is due to the reason that the transmitted wave becomes larger with increasing d/h and then the transmitted and diffracted waves contribute a lot to beach deformation. d/h is an important parameter relating to the magnitude of wave breaking, as the magnitude of breaking wave-caused vortex tends to be smaller with increasing of d/h. Therefore, the local scouring around the

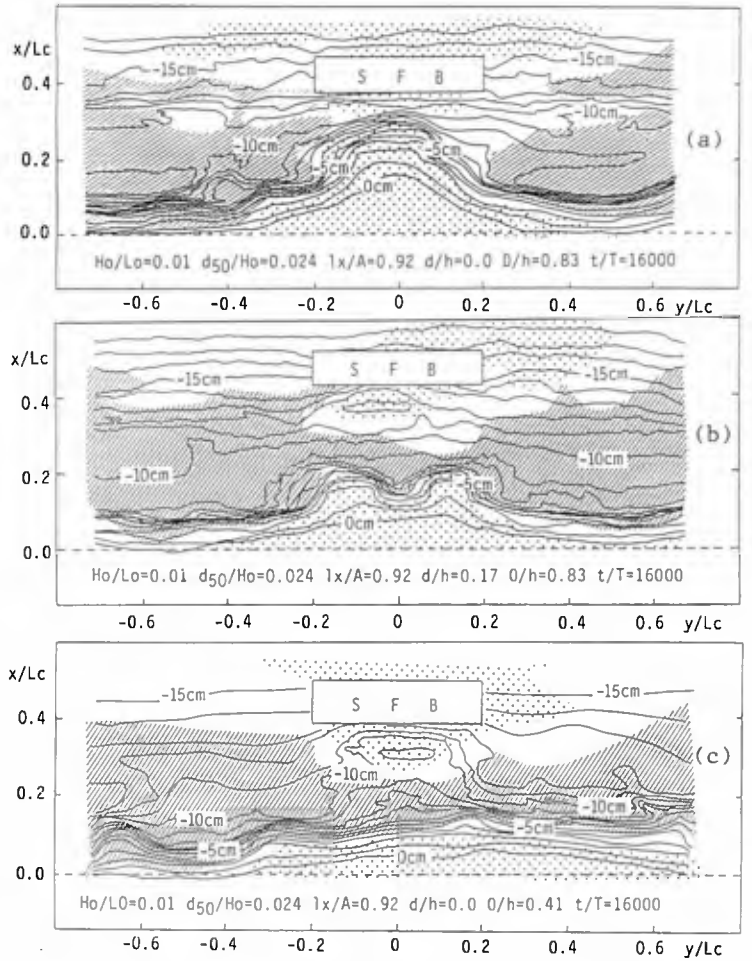

Fig.8 Effects of D/h and d/h to beach deformation (▨;erosion, ⁘;accretion)

diminishes generally with increasing of d/h, especially on eroded-type beach.

The dimensionless parameter D/h is more important than d/h, since D/h controls largely the diffracted and transmitted wave height. That is, increasing of D/h enlarges the diffracted wave height and diminishes the transmitted wave height. As shown in Figs.8(a) and (c), decreasing of D/h from 0.83 to 0.41 clearly diminishes the amount of sediment accumulation around the shoreline. This reason is that the diffracted wave in case of D/h=0.41 becomes smaller than the case of D/h=0.83 and becomes less effective to accumulate the sediment around the shoreline.

The other dimensionless quantities such as d_{50}/H_o and l_x/L are also important parameters which deform the beach. However, their effects to beach deformation cannot be discussed here in details due to the limitted laboratory experiments.

B) Eroded-type beach

In case of the eroded-type beach, the cuspate spit was not formed in the experiments. In the experiments, it was observed that the shoreline erosion (shoreline denudation) is stopped in the shadow area behind the breakwater, by placing the submerged tension-moored breakwater.

Fig.9 shows one example of change of beach comfiguration by placing the breakwater on eroded-type beach. The cross-sectional change at the section B located at y/Lc=-0.9 is very little, as in Fig.9(c). However, beach profile at section A located at y/Lc=0 (centerline) shows clearly that the shoreline denudation is stopped and the shoreline advances to the initial position.

Thus, it is clear that the submerged tension-moored breakwater has high function of protection of beaches from erosion in the shadow area of the breakwater. However, it should be noted that onshore-side bottom in front of the

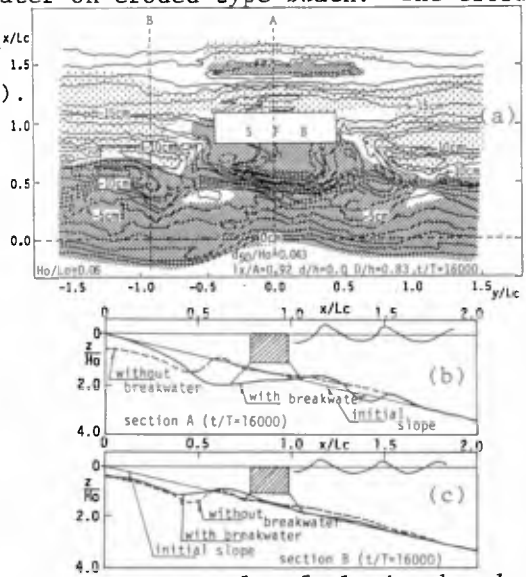

Fig.9 One example of placing breakwater on eroded-type beach (▨;erosion, ⁙;accretion)

breakwater is eroded by breaking wave-caused vortex, as shown in Figs.9 (a) and (b).

(C) Local scouring around the breakwater

The onshore-side bottom beneath the breakwater is always scoured on the eroded-type beach and sometimes scoured on the accreted-type and intermediate-type beaches. The maximum dimensionless scouring depth Δh/Ho obtained in the experiments is shown in Fig.10. Δh/Ho is seen to vary with d/h, D/h and lx/Lo. The maximum value of Δh/Ho is 1.1, which is larger than that of two-dimensional experiments. This may be caused by following reason. The moored structure in three-dimensional experiments has six-degree-freedom motions, different from three-degree-freedom motions in two-dimensinal experiments, and a lot of desiment are suspended and transported to both on-offshre and alongshore directions.

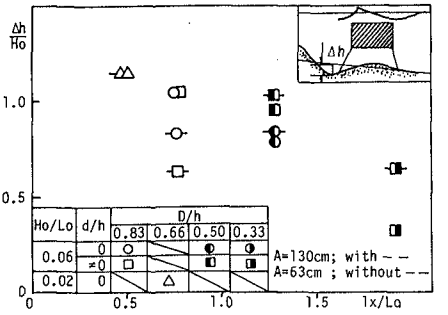

Fig.10 Dimensionless maximum scouring depth Δh/Ho

(D) Range forming cuspate spits

Drift and transportation of bed materials is largely controlled by the wave-induced current. In case of bottom-seated breakwater made with concrete armour units, a pair of current cells is known to be formed behind the breakwater.

On the other hand, the current cell was not formed clearly in case of the submerged tension-moored breakwater. The gap between breakwater's bottom and sea bed weakens forming the wave-induced current cells and encourage the return flow toward offshore, although the diffracted wave dominates over the transmitted wave with increasing of D/h and decreasing of lx/A and d/h. Figure 11 shows one example of velocity vectors of the wave-induced current, in which left-half of the breakwater is shown because velocity vectors in right-half is almost equal to the left-half. Figure 11 shows no clear current cell, although the return flow is observed.

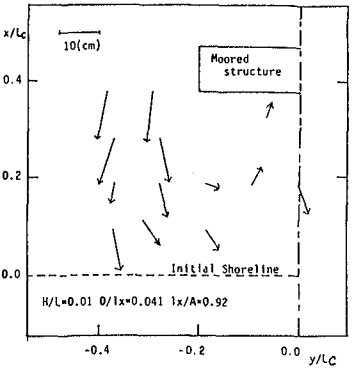

Fig.11 One example of velocity vectors of wave induced current

As already mentioned, three types of cuspate spits are

formed on the accreted-type and intermediate-type beaches. The outline of range in which three kinds of cuspate spits take place in case of d/h= 0 is shown in Fig.12, in which experimental results for bottom-seated breakwater made with concrete armour units are shown simultaneously(● and ■).

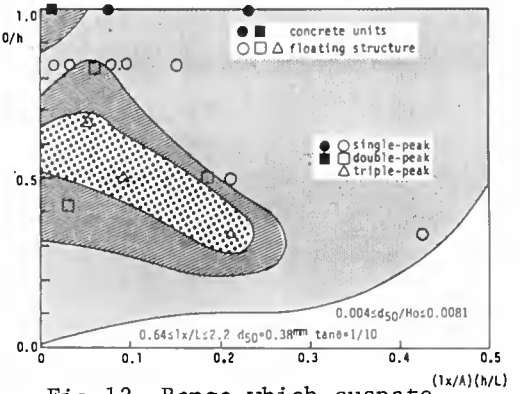

Fig.12 Range which cuspate spits are formed.(tanθ=1/10, d/h=0,0.64≦lx/L≦2.2 and 0.004≦ d50/Ho≦0.0081)

From Fig.12, it is seen that double- and triple-peaked cuspate spits are formed in the limitted ranges of D/A= 0.3 - 0.7 and (lx/A)(h/L) ≦0.27. On the other hand, the single-peaked cuspate spit is shaped under wider range of D/h and (lx/A)(h/L) than those of the double-peaked and triple-peaked cuspate spits.

3-2) Case of two submerged tension-moored breakwaters

When the natural beach is an accreted-type and intermediate-type beach, cuspate spits are formed by two submerged tension-moored breakwaters. The magnitude of the cuspate spits depends on K/A as well as D/h, d/h, lx/A and lx/L. Figures 13(a), (b) and (c) show examples of cuspate spits. It was found that the magnitude of the cuspate spit decreased with decreasing of relative gap between two breakwaters (K/A), as shown in Fig.13. Each shape of two cuapste spits formed behind the breakwater in case of K/A=1.0 is very smilar to that formed in the case of one breakwater. This would imply that when K/A is larger than 1, the coupling effect of two breakwaters to beach deformation is vanished and each breakwater deform independently the beach.

When two breakwaters were placed on the eroded-type beach, the shoreline denudation behind the breakwaters was stopped, as shown in Fig.14. Therefore, summarizing the above-mentioned, the submerged tension-moored breakwater is concluded to have a function of protecting beaches from erosion.

4. CONCLUDING REMARKS

In this paper, beach deformation by the submerged tension-moored breakwater is discussed experimentally.

The experiments have revealed that the single-peaked,

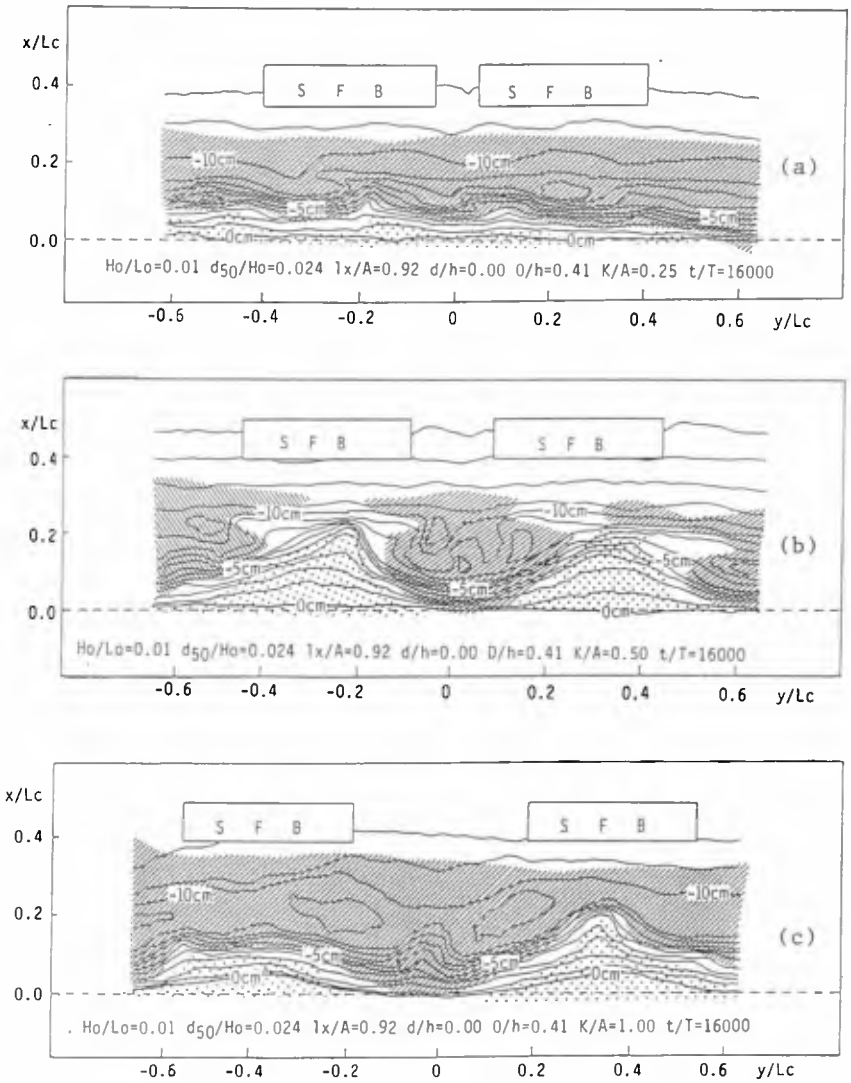

Fig.13 Some examples of beach deformation by two breakwaters placed on the accreted-type beach

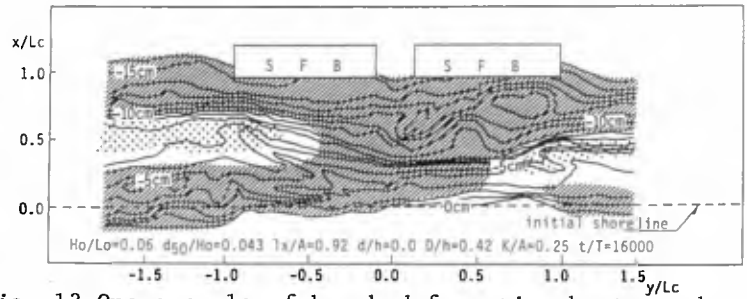

Fig. 13 One example of beach deformation by two submerged tension-moored breakwaters on eroded-type beach

double-peaked and triple-peaked cuspate spits are formed behind the submerged tension-moored breakwater on the accreted-type and intermediate-type beaches. The magnitude of three kinds of cuspate spits are largely controlled by the location and dimension of breakwater.

In the case that the submerged tension-moored breakwater is placed on the eroded-type beach, the shoreline denudation behind the breakwater is stopped.

Therefore, it is said that the submerged tension-moored breakwater has a high function of beach erosion control and is possibly one of useful measure works against beach erosion in an inner gulf area in which huge waves do not hit.

In this paper, the relationship between beach deformation and motions of breakwater is not discussed. The present authors are going to investigate this problem.

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