CHAPTER 92

APPLICABILITY OF SUB-SAND SYSTEM TO BEACH EROSION CONTROL

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ABSTRACT

We performed experiments in the laboratory under controlled conditions in order to determine the applicability of a sub-sand filter system to the beach erosion control work. The filter system is used to control a flow condition at the sediment-fluid boundary. In the foreshore, it increases the inflowing velocity into the beach and thus results in increasing the threshold of beach sediment movement. The sub-sand filter system accelerates accretion of much beach sediment in the foreshore through the development of a berm under normal wave conditions. When wave conditions change from normal to stormy , it is also applicable to stabilize the beach profile, and thus decrease loss of beach sediment from the foreshore to the offshore.

INTRODUCTION

As Duncan(1964) pointed out, during flood tide the water level rises faster than the water table within the beach, so that the seaward edge of the water table slopes shoreward. Because of this, most of the sediment transported up the beach face by the swash during flood tide is deposited at the top of the swash limit. During ebb tide the enhanced backwash removes the sediment and deposits it on the shoreward side, where the backwash collides with the incoming surf and loses its transporting capacity. This mechanism has been investigated by many researchers in the field of coastal geomorphology. In the foreshore, the thin and wedge shaped layer of water in the wave uprush /backrush moves the sediment up and down the beach face. The depth of the beach sediment layer over the water table can control the rate of infiltration of sea water accompanied with wave run-up. This leads to changes of swash movement of sediment along the beach. The sub-sediment filter system is used to control the flow condition at the sediment-fluid boundary. In the foreshore, the system increases the inflowing velocity into the beach and thus results in increasing the

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threshold of beach sediment movement. In the case of the laminar boundary layer, theoretical expression of the threshold of a sand under suction velocity is given by the authors (1984).

This protection technique has been developed by Chappell(1975) and Machemehl et al.(1976). In order to establish the sub-sand filter system as a means of beach erosion control, it is necessary to perform systematic experiments of beach changes under controlled conditions and to study increment of the threshold of sediment movement by the system. The objectives of this study are to investigate the effects of the system on the stability of beach profiles in the foreshore and to establish the applicability of the system to beach erosion control work.

EXPERIMENTS OF SUB-SAND FILTER SYSTEM

(1) Experimental apparatus

a) Solitary waves

The solitary wave tank shown in Fig. 1 is 21.6m long, 0.75m wide and 1.2m deep and has six trays in permeable slope to construct the sub-sand filter system. Suction pipes are connected to every tray and discharge rate is controlled by valves. Waves are generated automatically by a plunger with an eiectromagnetic cluch at intervals of 5 minutes 50 seconds. All experiments were run at a depth of 43.1cm. The permeable and impermeable beaches of slope 1/10 are constructed with sediment of mean diameter 0.350 mm. The experimental conditions are listed in Table 1, in which H is the wave height and u_s the suction velocity.

b) Monochromatic waves

Beach erosion control tests were carried out in a large wave tank (78m long, 1m wide and 1.5m deep) as shown in Fig. 2. A double hinged flatter type wave generator was used to generate regular waves. The wave period was varied by changing the running speed of the variable-speed drive unit thus enabling a continuous range from 0.5 s to 5 s. The wave height was changed with the eccentricity of the rod connecting the driving disk equipped at the generator. The test beach was 56m in length and was inclined at a slope of 1/30. The mean sediment diameter was 0.940mm. Sixteen pipes of diameter 5cm were used to construct the sub-sand filter system. They had a slit width of 1.5cm covered with fine mesh to prevent the passage of sediment. The header-pipe, of diameter 10cm, was coupled to the intake of a pump. The experimental conditions are listed in Table 2. Each run was further divided into two cases; a filtered experiment (hereafter referred to as A) and an unfiltered one (hereafter referred to as B).

(2) Measuring system

A capacitance type wave gauge and an ultrasonic depth sounder were attached to a movable carriage on the tank. This carriage moved at a speed of 10cm/s. The former was used to survey the bottom topography and the latter to determine the wave breaking point. The beach profile above still water level was obtained by using an improved point gauge.

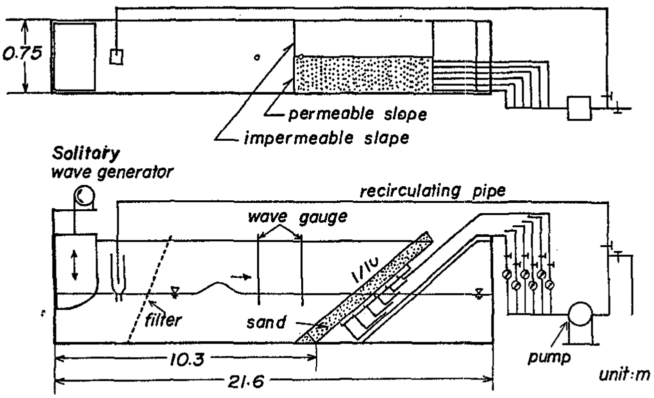

Fig. 1 Solitary wave tank and sub-sand filter system.

Table 1 Experimental conditions by solitary waves.

Run No.	H (cm)	u_s (cm/sec)	Run No.	H (cm)	u_s (cm/sec)
1—1	7.18	1.79×10^{-3}	2—3	8.75	1.79×10^{-3}
1—2	7.18	1.12	3—1	10.8	2.63
1—3	7.18	2.63	3—2	10.8	2.38
1—4	7.18	1.50	3—3	10.8	1.95
2—1	8.75	2.63	3—4	10.8	1.08
2—2	8.75	1.08	4	11.3	2.63

(3) Procedures

To estimate the effects of the sub-sand filter system on the stability of a beach profile, it is necessary to compare the changes in the profile of an unfiltered beach with those in the profile of a filtered beach.

Each run was conducted in the following manner. First, the desired wave characteristics were established. Secondly, the beach was raked into its initial profile (1:10 for solitary waves and 1:30 for monochromatic waves) and the beach profiles were recorded. The pump for the filter system was operated at a constant flow rate during all tests.

CHARACTERISTICS OF BEACH CHANGES

(1) Beach Profile Changes by Solitary Waves

Some examples of the beach changes with respect to the number of solitary waves when equalling 200, 400 and 600 are shown in Fig. 3, in which a solid line and a dotted one are the beach profiles with and without filter operation respectively. The processes of the beach changes by solitary waves are as follows. At the beginning of the experiments, the shoreline retreated rapidly. A berm was formed in the foreshore and a step was formed in the inshore. In the case of

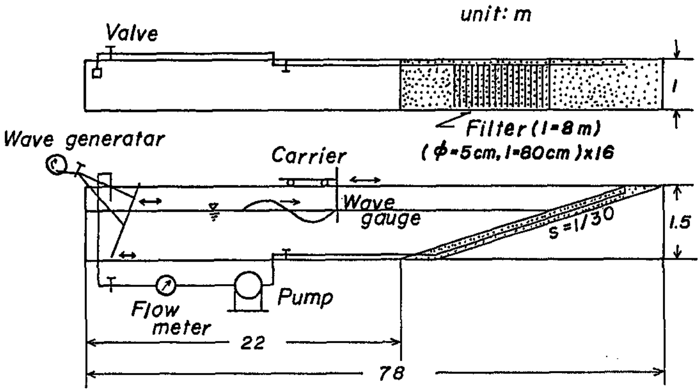

Fig. 2 Regular wave tank and sub-sand filter system.

Table 2 Experimental conditions by monochromatic waves.

Run No.		H (cm)	T (sec)	h (cm)	H_0/L_0	u_s (cm/sec)
5	A	29.8	1.77	90.0	0.0699	0.0231
	B	28.9	1.80	90.0	0.0630	
6	A	21.0	2.99	100	0.0155	0.0986
	B	20.1	3.00	100	0.0150	
7	A	27.0	1.99	100	0.0481	0.0932
	B	26.8	2.00	100	0.0470	
8	A	12.4	2.97	100	0.00932	0.0961
	B	11.8	2.96	100	0.00893	
9	A	29.3	2.03	100	0.0481	0.0932
	B	29.3	2.03	100	0.0481	

A: Suction, B: No suction

the larger wave heights such as in Run Nos. 3 and 4, ripples were generated on the step. Due to the sub-sand filter operation, the growth rate of the berm area with increment of the number of solitary waves was large in comparison with that under natural conditions. Therefore, the seaward slope of the berm with the filter became steep, and then the breaker scour formed at the onshore end of the step enlarged. Consequently, by the sub-sand filter operation, the deposition of sediment in the foreshore was developed, but the characteristics of the beach changes, such as shoreline recession and formation of a berm and a step, were not changed due to the filter operation.

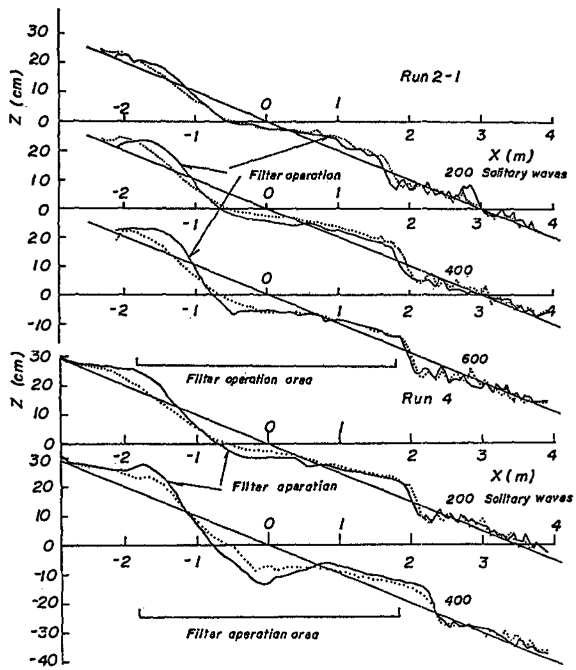

Fig. 3 Beach changes by solitary waves.

(2) Beach Profile Changes by Monochromatic Waves

Typical changes of beach profiles with time are shown in Fig. 4. From the experimental profiles in the nearshore zone in Run 7 (stormy wave condition), it was found that the beach profiles under filter operation are different to those under natural conditions. In the case of (B) (no filter operation), the small bar which was in the nearshore at t=5hr moved shoreward and developed, and changed to a large berm in the foreshore at t=10 hr. Finally, this berm came up to the beach crest and had two peaks. In the case of (A) (filter operation), the beach sediment movement in this area was not as simple as that in (B). Two small bars developed with time and moved shoreward, but the sizes and the moving speeds were very small in comparison with the former case. It was recognized that the sub-sand filter system reduces the sediment movement and stabilizes the beach changes in the nearshore zone.

In Run 8 (normal wave condition), from the view point of processes of berm development in the nearshore zone, existence of the sub-sediment filter system made no distinguishable difference to beach profile changes at t=7hr under natural conditions. After this time, the height of the berm in (A) was larger than that in (B), and then the shoreline advanced in the former case. From a budget of beach

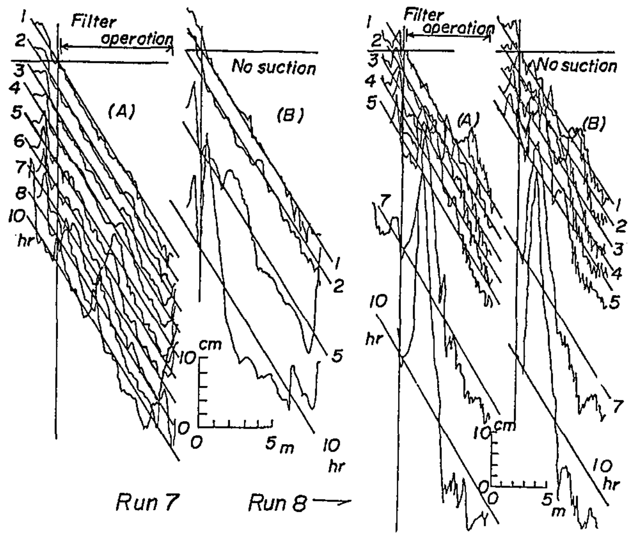

Fig. 4 Beach changes by monochromatic waves.

sediment in the nearshore zone, much sediment moved seaward in the offshore side of the berm and beach erosion occurred in the case of (B). Under the sub-sand filter operation, on the contrary, the accretion of beach sediment in the foreshore was found, because the seaward sediment movement was very controlled in the nearshore zone. It was also pointed out that under the filter operation, the beach profiles in the foreshore have a smooth surface due to the disappearance of ripples.

It is necessary to discuss whether the system is applicable or not when normal wave conditions change to stormy, because bottom roughness formed under the filter operation is very small. Under this bottom condition, incoming wave energy does not quickly dissipate and beach erosion will occur in the foreshore. Fig. 5 shows the results of the beach profile changes under the conditions mentioned above. The initial beach profile in Run 9 (stormy wave conditions) was the profile in which the filter was operated for ten hours in Run 8 (normal wave conditions). The changes of the beach profiles without the filter were very large in the foreshore, especially at the seaward slope of the berm, and much sediment moved seaward from this area. In contrast, the sub-sand filter system could stabilize the sediment movement, so that the changes of the beach profiles were smaller than those without the filter. It was found that the system is also effective, even if the wave conditions change to stormy.

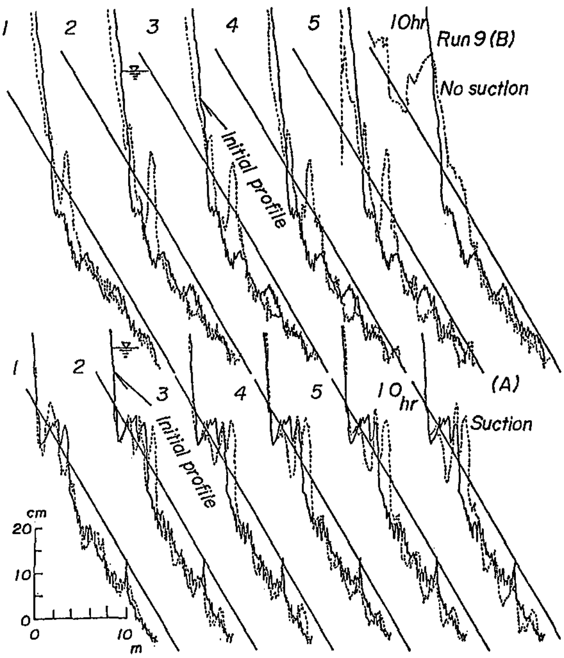

Fig. 5 Beach changes with changes of wave conditions from normal to stormy ones.

EFFECT OF SUB-SAND FILTER SYSTEM ON BEACH CHANGES

The development of a berm by solitary waves is shown as normalized beach profile A/A_a vs. H/h in Fig. 6, with the value of suction velocity u_s as a parameter. The symbol A is the area of the berm and A_a is the area of a right-angle triangle in which the length of the hypotenuse is the distance from a shoreline to a point of maximum runup height. It was found that in the range of the suction velocity, the effect of H/h on the berm size under the filter operation is about twice to four times greater than that under normal conditions. However, the growth rate of the berm with the increment of H/h is unaffected by any suction velocity in our experiments. The suction velocity which gives the largest value of A/A_a in the case of the experiments with 200 solitary waves does not coincide with the maximum velocity in any value of H/h.

The relationship between A/A_a and a dimensionless suction velocity u_s/w_f is shown in Fig. 7 with the value of H/h as a parameter. The symbol w_f is the settling velocity estimated by Rubey equation. In the case of H/h=0.250, the largest value of A/A_o is found at a moderate value of u_s/w_f both in 200 and 400 solitary waves. In other words, there is a most effective suction velocity in the growth of an underdeveloping berm. In the cases of H/h=0.167 and 0.203, the ratio A/A_a becomes nearly constant in the range of u_s/w_f of more than 0.25×10^{-3}. Under small wave conditions, the runup height and the rate of swash sediment transport are small, so that it is very difficult to make clear the effect of the filter. Consequently, the effect of the filter operation on the berm development depends on the runup height. Therefore, the most effective suction velocity will change with time.

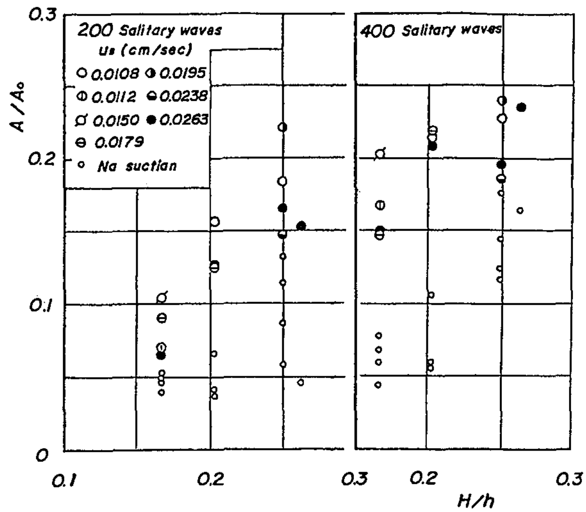

Fig. 6 Relationship between area of berm and ratio of wave height to water depth.

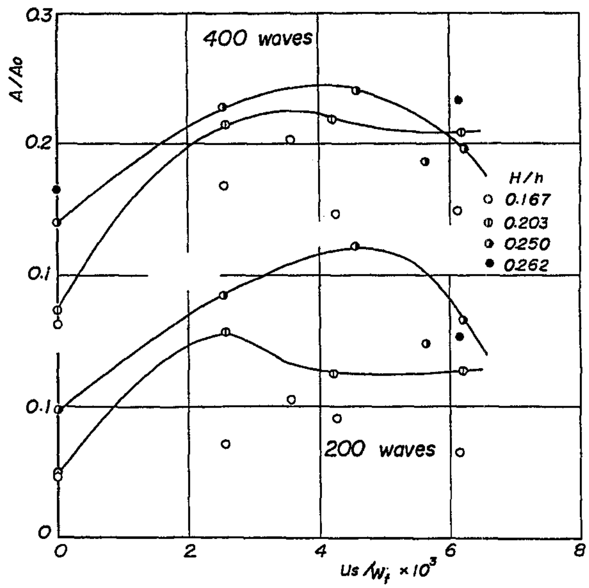

Fig. 7 Relationship between area of berm and suction velocity.

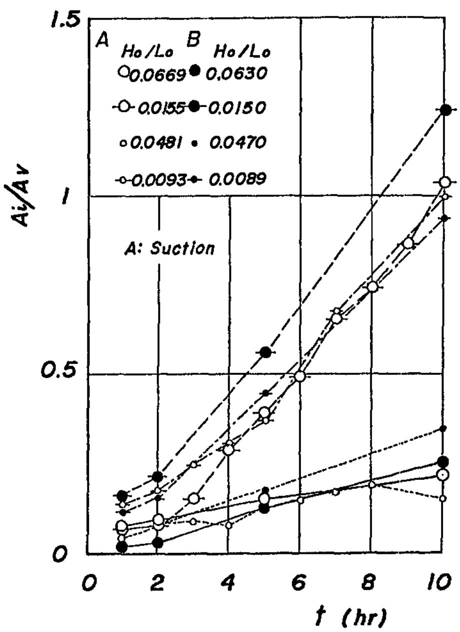

Fig. 8 Changes of budget of beach sediment in the foreshore with time.

The time development of the deviations of the dimensionless area A_i/A_v by monochromatic waves is shown in Fig. 8 with the wave steepness as a parameter. The symbol A_i is the amount of accretion and erosion areas (their absolute values) from the initial beach profile on the sub-sand filter system, and A_v is the area of a right-angle triangle in which the length of the hypotenuse is equal to that of the sub-sand filtered system. In our experiments with monochromatic waves, A_v is constant, because the length of sub-sand filter is 8m and the slope is 1/30, and so this value is 1.065 m^2. It is recognized that the changes of A_i/A_v with time in Run Nos. 6 and 8 (normal wave condition) are very large in comparison with those in Run Nos. 5 and 7 (stormy wave conditions), and this tendency continues until t=10hr. The values of A_i/A_v under the filter operation are smaller than those under natural conditions. This result is similar to that found by Machemehl(1976), though he defined the saturated and partially saturated zones (their boundary is a shoreline, and the area above still water level is defined as the saturated zone and the area below one is the partially saturated zone).

Fig. 9 shows the changes in the amount of accretion and erosion areas from the initial beach profile with time in Run 9. In this experiment, the initial profile was formed by the waves with a wave steepness of 0.0155. Even if the wave steepness changes from 0.0155 to 0.0481, the sub-sand filter reduces areas of accretion and erosion. The smaller value of A_i/A_v indicated that during the filter operation, the beach profile was more stable.

Fig. 10 shows the relationship between A_i/A_v and the wave steepness, with the duration of experiments as a parameter. As mentioned before, A_o in Machemehl's data is the saturated zone which is the area influenced with the filter below the still water level. It is found that the effect of the sub-sand filter system on the stabilization of the beach profile becomes very clear with the increment of the dura-

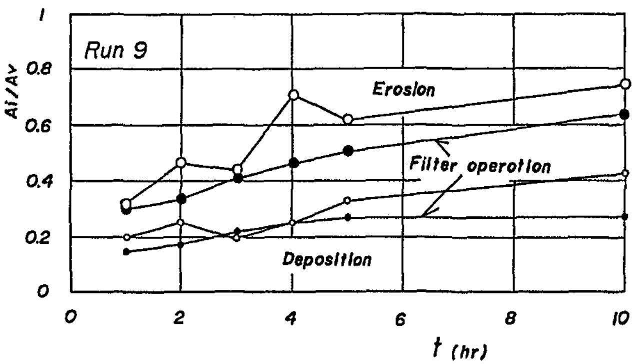

Fig. 9 Changes of budget of beach sediment in accompany with changes of wave characteristics

tion of the operation. Furthermore, the changes of A/A_o with time reduce and come to constant concomitantly with the increment of the wave steepness.

Above all, through our experiments concerning the effect of a sub-sand filter system on the stabilization of the beach profile, it is pointed out as follows: In cases of solitary waves and monochromatic waves with small wave steepness (swell wave conditions), the accretion in the foreshore grows very rapidly and leads to the formation of a berm under the filter operation. As the accretion area enlarged, the filter was not as effective so that a backrush did occur at the end of all our experiments. When the beach changes are caused by the waves with large wave steepness, the effect of the sub-sand filter system on the changes of accretion and erosion areas is not so

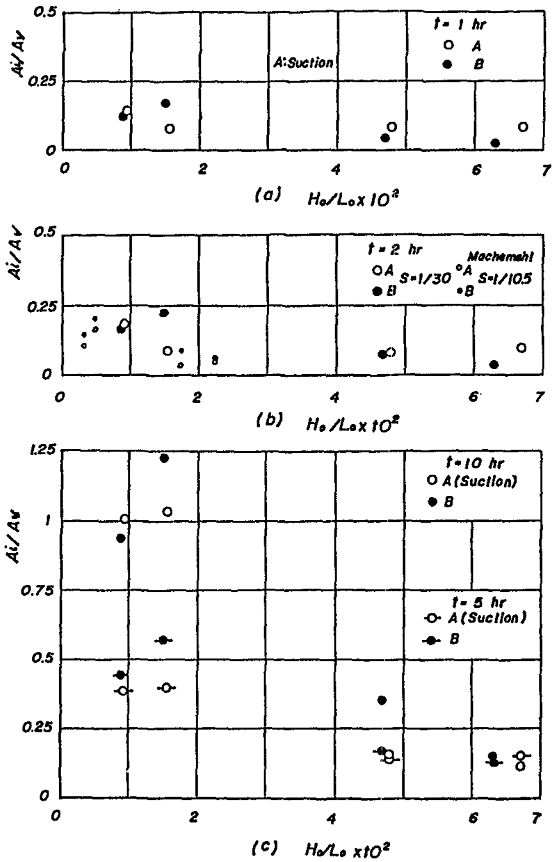

Fig. 10 Relationship between budget of beach sediment and wave steepness.

clear, but the filter did minimize the sediment movement in the area influenced by the filter in the nearshore zone. According to the experimental results of the beach changes under the filter operation, the roughness height become very small and it is very difficult to find ripples in the nearshore zone. In addition, the characteristics of beach profiles such as a stormy beach and a normal one do not change with the filter operation.

APPLICABILITY OF SUB-SAND FILTER SYSTEM

The most important point of the sub-sand filter systems in beach erosion control work is, of course, that the control work has high applicability to prevent or to mitigate beach erosion under any wave conditions. We discuss the applicability of the filter based on our experimental results. From Figs. 6, 7 and 8, the sub-sand filter system can accelerate accretion of much sediment in the foreshore through the development of the berm, so that it is accompanied by a shoreline advance. This characteristic shows the typical beach changes under normal wave conditions, so that this system encourages furthermore the beach changes with the duration of the wave action.

As is a well-known fact, the wave runup height become large with the decrease of the wave steepness. The swash movement of the beach sediment up and down the beach face can be largely controlled by the permeability of the beach, because the increased effective drag force creates a higher threshold for the sediment movement.

When wave conditions change from normal (swell wave) to stormy, the sediment of the berm in the foreshore moves seaward as the sediment in the offshore moves shoreward, and forms longshore bars, as shown in Fig. 4. Under the filter operation, the former sediment movement becomes inactive by the increment of the threshold. Therefore, the offshore sediment is greatly contributes to the formation of a longshore bar. In other words, loss of the sediment from the foreshore decreases. At the same time, the surface roughness mitigated by the filter operation in the foreshore does not lead to the enlargement of the beach erosion as shown in Fig. 9.

Our experiments were two dimensional in relation to cross-shore sediment transport, but saw-tooth movement of beach sediment due to waves with arbitrary wave angle will certainly be controlled by the system, so that the rate of longshore sediment transport is expected to reduce. As the results clearly show, the sub-sand filter system has high applicability to beach erosion control work.

CONCLUSIONS

We have developed the sub-sand filter system for beach erosion control work. The system has high applicability for stabilizing beach profiles in the foreshore, and consequently it is useful to reduce the offshore movement of beach sediment under any wave conditions.

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