CHAPTER 205

Field Experiment on the Effect of Gravity Drainage System on Beach Stabilization

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Abstract

To have a coastal protection work of high quality, we are developing a new beach protection system, that is a beach drainage system, in which the groundwater is naturally drained to the offshore through a permeable layer setting up under the beach. To examine the drainage function of the permeable layer and its effect on the beach stabilization, a field experiments have been conducted during storms. As a result, it is confirmed that the permeable layer drain the groundwater garvitationally into the surf zone and has a function of decreasing a speed of erosion in a storm, and the eroded foreshore is recovered quickly in a calm.

Introduction

As Japan has a long coastline and exposed to severe natural conditions, strong efforts on the coastal protection works such as detached breakwaters, jetties, seawalls are necessary to prevent the coastal disasters. However, these concrete hard structures keep the people away from the waterfront. The view of coastal regions are worse than they were. Over against this the demand for a better quality of protection gets greater, and multipurpose use of valuable coastal zone comes to be required.

In order to make the coasts what people currently desire to be, we started from the basic research on the changes of sandy beach in a storm because a sandy beach is fundamentally essential to create the desired coast. The series of researches have been reported in the ICCE (Katoh and Yanagishima, 1988,

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1990, 1992; Katoh, 1994). According to the results of basic researches, a shoreline rapidly recesses and a berm on the foreshore erodes in one or two days during a storm, which is due to the development of infragravity waves. When infragravity waves run up beyond the berm crest in the storm, the sea water stays for a good while on the horizontal area of berm, which accelerates infiltration of water into the beach. As a result, the water table becomes higher, and the water exfiltrate through the surface of foreshore. The seepage level of water corresponds to the critical level of berm erosion.

Taking these results into consideration, there are two kinds of measures for maintaining the sandy beach against the severe natural conditions. One is a construction of structure in the offshore such as detached breakwaters to diminish the wave energy and to suppress the wave run-up on the beach. Another is to lower the water table by some method. The system of lowering the level of water table by pumping, which is called the sub-sand filter system, has been tested in the laboratories and in a small scale field experiment in a calm (Chapell et al., 1979; Vesteby, 1991). There is a problem in this method, that is to say, a continuous pumping of the groundwater is required for lowering the water level. Then, an alternative drainage system is considered, in which the ground water is naturally drained to the offshore through a permeable layer setting up under the beach. We carried out an experiment on the function of permeable layer under the beach in a flume (Katayama et al., 1992), of which the final result is reported by Kanazawa et al. (1996). Davis et al. (1992) developed the prototype beach drainage system which incorporated an array of shore normal strip drains made of geotextile fabric enclosing a plastic core in an "egg-carton" configuration, and examined its function for lowering the water table and stabilizing the beach in the field. The results of these researches strongly suggest a possibility of gravity drainage system which enhances the stabilization of beach. If so it will be possible to maintain the beach of beautiful view without any artificial obstacles, because the whole system may be built under the ground.

To examine the drainage function of permeable layer under the foreshore and its effect on the beach stabilization, especially during a storm, a field experiment has been conducted.

Field experiment

1. Site of field experiment

The site of field experiment is an entirely natural sandy beach, being exposed to the full wave energy of the Pacific Ocean (see Figure 1). The foreshore slope is about 1/50, and the median diameter of sand on the beach is 0.18 mm which is nearly constant during the calm and storm conditions (Katoh and Yanagishima, 1995) . The tide range is about 1.5 m. According to the analysis of shoreline locations which were read from eleven aerial photographs taken during a period from 1947 to 1984, the shoreline advanced about 50 m during a period from 1975 to 1979, which was due to the construction of Kashima in 1974. However, it has been stable since 1979. On this beach, Port and Harbour Research Institute, Ministry of Transport, has constructed the Hazaki Oceanographical Research Station (HORS) in 1986 for carrying out field observation in the surf zone even under the sever sea conditions. The research pier is a 427 meters long concrete structure supported by 0.8 meter diameter concrete-filled steel piles in a single line, at 15 meters interval. Although the beach is stable, the field experiment is being carried out on this beach because the basic data obtained in HORS have been accumulated since 1986.

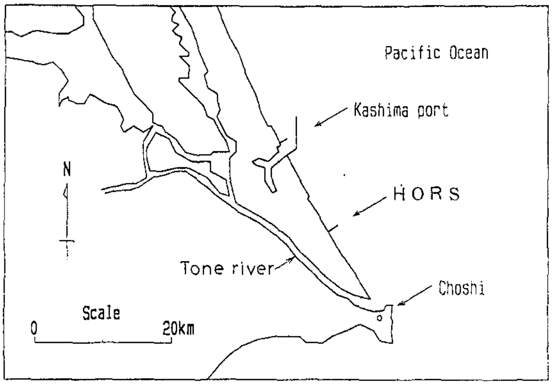

Figure 1 Site of Field Experiment.

2. Permeable layer and its execution

As the permeable material, the unit such as shown in Figure 2 is produced with the two sheets of corrosion-proof expanded metal in a factory, being wrapped with a geotextile fabric. A dimension of the unit is 1 meter wide, 2 meters long, and 20 centimeters thick. There is nothing inside the unit. The units can be connected by using couplers in the longitudinal direction. In August 1994 the permeable layer was set up under the beach in six columns from the foreshore to the backshore, being 30 meters apart in the longshore direction from the pier, as shown in Photo. 1. The elevation of permeable layer is about 3 meters below the beach surface, which is just below an envelope of the beach profiles overlapping for the last decade. The area is 88 meters in the cross-shore direction and 7.8 meters in width, which was enclosed by sheet piles when the permeable layer was being set. The pipe of 0.4 meter in

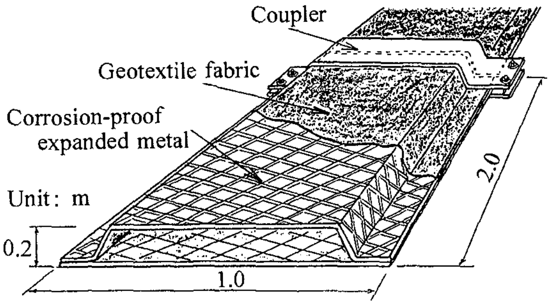

Figure 2 Permeable Layer.

Photo. 1 Execution of Permeable Layer.

diameter has been connected to the sea-side end of permeable layer to drain the ground water into the middle surf zone, 144 meters offshore from the shoreline. The pipe has been buried in the sea bottom with keeping the outlet in the sea. After setting, sand was put on the permeable layer so that we had the same profile as before. The sheet piles at the sea and land sides have been removed. The sheet piles along the longitudinal sides, however, were left without removing in order to make two-dimensional situation in the first experiment. In the second experiment, all the sheet piles were removed.

3.Items of measurements

In the first two-dimensional experiment, two representative measuring lines were taken into account in the cross-shore direction; one was coincided with the center line of the area where the permeable layer was buried, another was the line on the natural beach which was parallel to the first and 29 meters apart in the longshore direction. Along these lines, profiles of groundwater table and beach were surveyed once a day during a calm or every several hours in a storm, respectively. In the second three-dimensional experiment, a topography and plane distribution of water table were measured once a day in an area of 110 meters in the cross-shore direction and 75 meters in the longshore direction, including the area of permeable layer. The drained discharge through the pipe was continuously measured by a supersonic type discharge meter. Waves were measured near the shore line and the offshore.

<u>Result of the first two-dimensional experiment</u>

After about one month of setting up, on 18th September, 1994, a typhoon

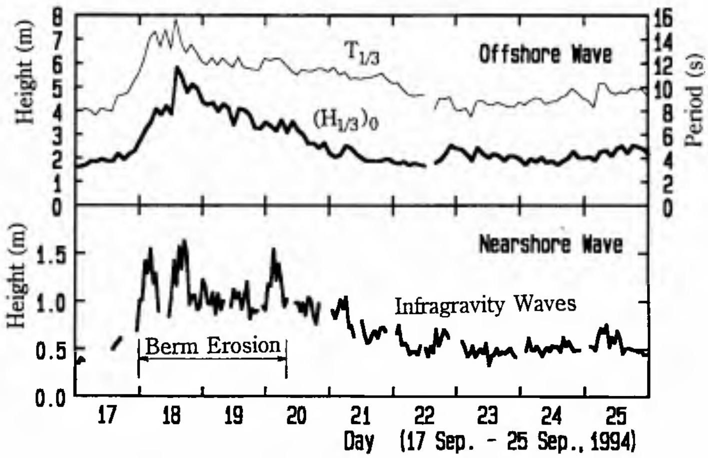

Figure 3 Waves in Typhoon No.9424.

attacked the experimental site. Waves at the offshore and infragravity waves near the shoreline are shown in Figure 3. The extreme value of significant wave height was 5.8 meters. The infragravity waves developed well, being about 1.5 meters in height near the shoreline, which run up to the backshore. The berm on the beach eroded during the days from 18 to 20, which is denoted in the Figure 3.

Photo. 2 was taken from the rooftop of laboratory at HORS on 19th September, on the second day of the storm, when an infragravity wave was running up on the drained beach. Small poles dug into the beach at the cross–shore intervals of 5 meters were arranged along a center line of the area where

Photo. 2 Infragravity Waves Running on the Drained Beach.

Photo. 3 Dried up Area on the Drained Beach.

the permeable layer was set up. Under this situation, sea–water infiltration into the beach was considered to be enhanced in the drained area, because on the drained beach we recognized a very interesting phenomenon that air bubbles came out actively from the ground through the surface of beach, which had never been seen in the laboratory. It is not difficult to infer the situation that the water was infiltrating into the beach because the effusion of air bubbles was a result of being replaced with the infiltrated water into the ground. Photo. 3 is a picture taken about one minute after the situation of Photo. 2, when the infragravity wave was running down to the sea. The beach surface of drained area, of which both sides were cut off by the sheet piles, was already dried up, while the surface of natural beach was still wetted.

Figure 4 is a comparison of profiles of water table between the natural beach and the drained beach, measured on the day of 18th September when the beach began to erode. Infragravity waves had already developed well, and run up to the high elevation denoted by an arrow which was higher than the usual H.W.L. of 1.4 meters. The elevation of groundwater table in the natural beach, which is denoted by triangles, rose up

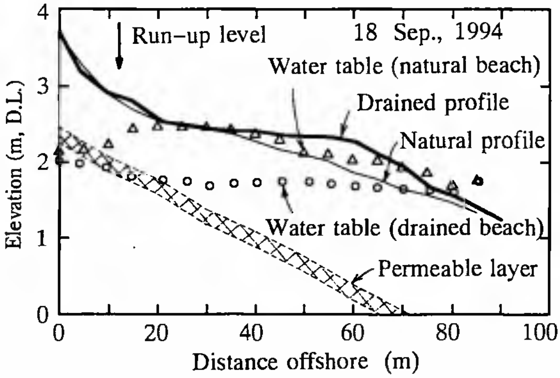

Figure 4 Comparison of Water Tables.

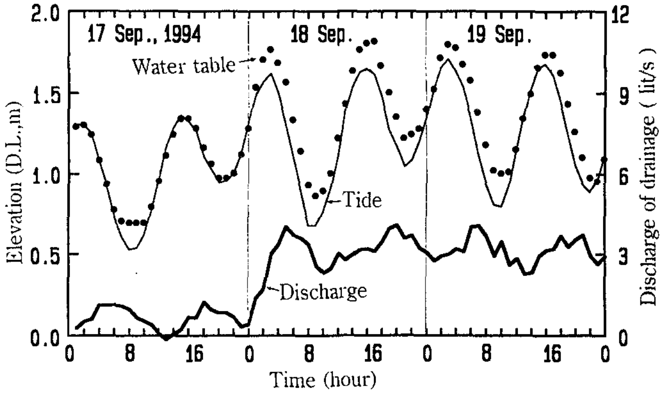

Figure 5 Changes of Tide Level, Water Table, and Drained Discharge.

to the beach surface. In other words, the ground was completely saturated with the water. On the other hand, that in the drained beach which is denoted by circles was 0.6 meter lower in maximum than the beach surface. The area between the beach surface and the water table in the drained beach was unsaturated, which means that the groundwater was gathered to the permeable layer and drained offshore through the drainage pipe.

Figure 5 shows the changes of a tide level at the outlet of drainage pipe, the water table at the point of -25m in the drained area, and a mean discharge in the drainage pipe for 20 minutes. On the day of 17th September, before the storm, the discharge was small. From the day of 18th September on, during the storm, The discharge was large, being about 30 lit/s. The groundwater level changed with a lag of about one hour behind the tidal change. As a result, the level difference between the groundwater table and the tide level became large during the ebb tide, which produced larger discharge.

Figure 6 shows the actual fluctuations of ground water level in the drained

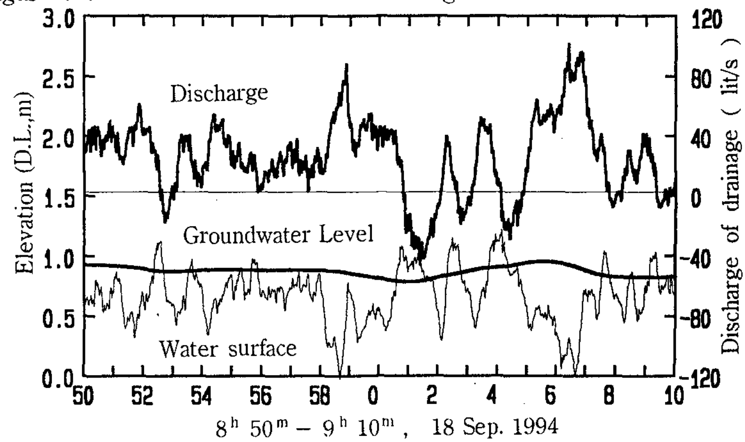

Figure 6 Fluctuations of Groundwater level, Water Surface, and Discharge.

beach and the drained discharge in the surf zone during the segment of twenty minutes in the storm. The level of water surface at the point of outlet in the surf zone, which is the result of running average with 10 seconds, is also presented in the same figure. These elevations were measured on the day of 18th September, the first day of storm. The fluctuation of groundwater level was smooth and small, while that of surface elevation was large, being 70 cm in amplitude and 1 to 2 minutes in period, which was due to the infragravity waves in the surf zone. As the surface level at the outlet was lower than the groundwater level in the better part of time, the water in the pipe usually flowed offshoreward with the discharge of 100 lit/s in maximum, which was equivalent to the mean velocity of 80 cm/s in the pipe. However, the surface level at the outlet was sometimes higher than the groundwater level when the crest of infragravity waves is passing over the point of outlet. When the surface level at the outlet was higher than the groundwater level, the water flows backward, or in the onshore direction.

In Figure 7, the mean discharges are plotted against the level difference between the ground water level and the surface level at the outlet. These values are the averaged ones for every 20 minutes before and during the storm. The averaged discharge was in roughly proportional to the difference of water level, which means that the water was gravitationally drained into the surf zone.

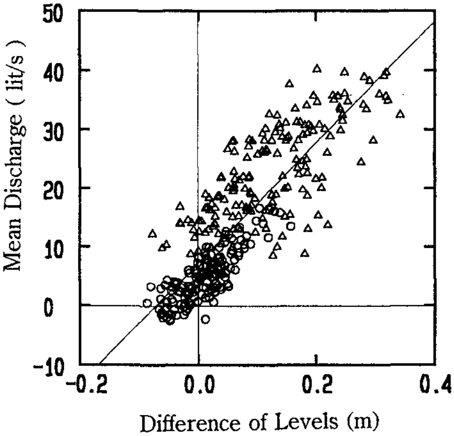

Figure 7 Relation between the Level Difference and the Drained Discharge.

Figure 8 shows the successive comparisons of beach profiles on the natural beach and the drained beach. On the two day before the storm, the day of 16th September, berms were formed on the foreshores of both the natural and the drained beaches (Figure 8, top) due to the relatively calm wave conditions during the three weeks before the storm. The berm on the drained beach was developed better, which is considered to be the effect of drainage. On the first day of storm, the berm on the natural beach eroded to the constant slope as seen in the middle figure, while the berm existed on the drained beach. In the bottom figure, one hour after, the berm still existed on the drained beach, which gradually eroded with time. Around 16 h of 18th, September, which was 13 hours after the time of profiles shown in the bottom figure, the tide level became highest and the height of infragravity waves also became the largest. Under this severe condition, the berm on the drained beach eroded completely to be the same constant slope as that of natural beach. In short, the effect of

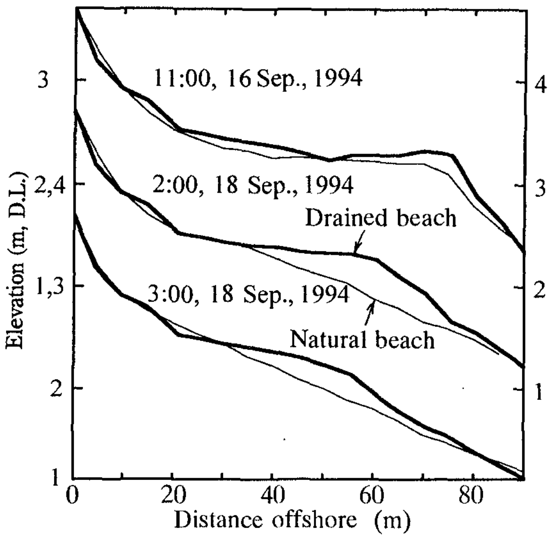

Figure 8 Comparisons of Profiles on the Natural and the Drained Beaches.

permeable layer is to decrease the speed of beach erosion in the storm.

Result of the second three-dimensional experiment

In the second field experiment, the sheet piles along the both sides of drained area had been removed. About one year after, on the day of 17 September 1995, a large typhoon No.9512 passed near the experimental site. Figure 9 shows the changes of the offshore significant waves and the height of infragravity waves near the shoreline. The extreme height of significant wave occurred at 14h on the day of 17th September, being 6.0 m. The height of infragravity waves near the shoreline increased from about 1.0m at 7th on the same day to 1.8m in maximum at 15h, which is the largest in the last 9 years

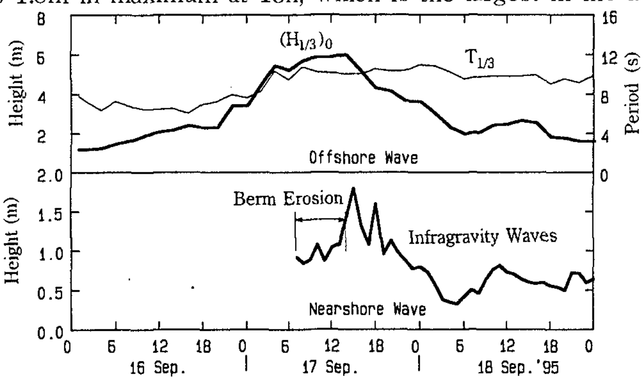

Figure 9 Waves in Typhoon 9512.

since the observation of infragravity waves have started at HORS in 1987.

Figure 10 shows a plane distribution of water table on the day of 16th, September. The water table above the permeable layer was lower than that of the circumference. Waves run up to the location of y=0m, where the water table was higher than 2.0 m in the areas apart from the permeable layer and lower than 1.5 m above the permeable layer.

Figure 11 shows the topography around the drained area, which was surveyed at 7h on the day of 17th, just before the storm. The slope is gentle in the area from y=−50m to 0m, while it is steep in the area offshoreward from y=0m, because a berm is formed on the foreshore. At this time, waves run up to the location of y=−55m, which was observed visually during surveying.

In order to survey the wide area in a short time, nine researchers took part in surveying. During the time from 7h to 14h, on the day of 17th September, however, we could not succeed in obtaining the data of topography because it was very dangerous for us to survey due to the large run−up of infragravity waves and a strong wind velocity of 29 m/s in average.

Figure 12 shows the topography around the drained area which was surveyed after the extreme condition, at 14h on the day of 17th. The foreshore has almost completely eroded to be a plane beach of the two dimensional state of 1/40 in slope. A contour line of 2m has recessed by 30

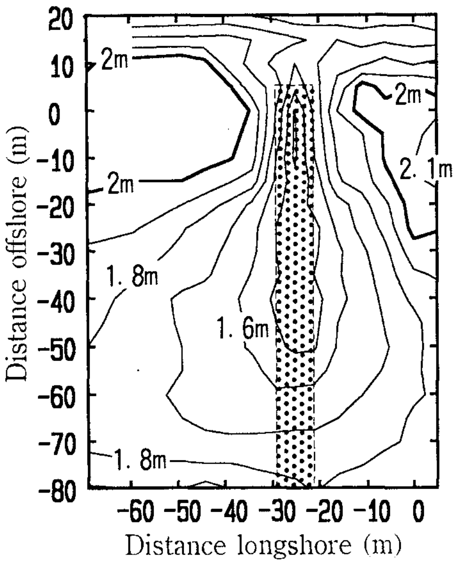

Figure 10 Water Table before the Storm (16th Sep., 1995).

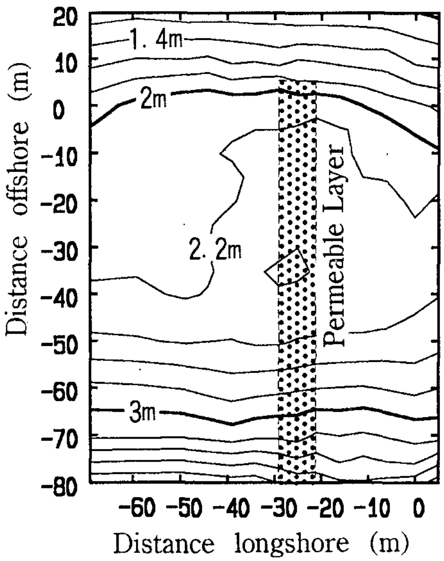

Figure 11 Foreshore Topography, just before the storm

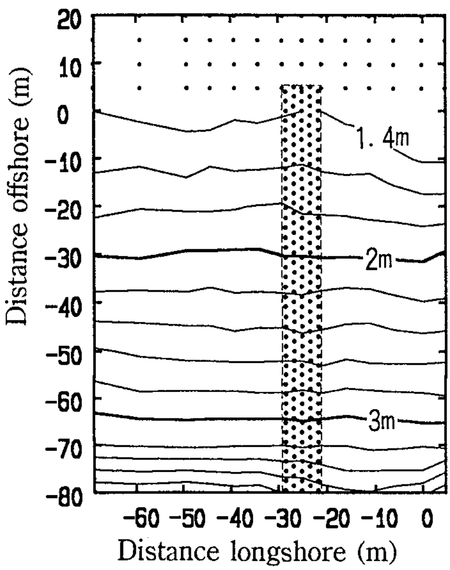

Figure 12 Foreshore Topography, after Erosion.

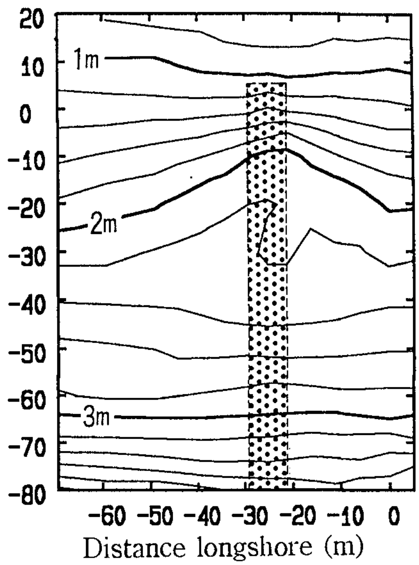

Figure 13 Foreshore Topography, One Week after the Storm.

meters from y=0m (in Figure 11) to y=−30m. No effect of permeable layer is observed in this topography. It is considered to be due to the narrow width of drained area, 7.8 meters, and the attack of extreme large waves. As the interruption of surveying was 7 hours, the effect of permeable layer on decreasing the speed of beach erosion was not confirmed.

After the storm, it was continued to survey the topography in the same area once a day. Figure 13 shows the topography on the day of one weak after the storm, 25th September. The contour lines of 1.4m to 2.2m advanced offshoreward, being convex in the area above the permeable layer. As a result, in the area above the permeable layer a slope was gentle in the area fihigher than 2m in elevation, while it

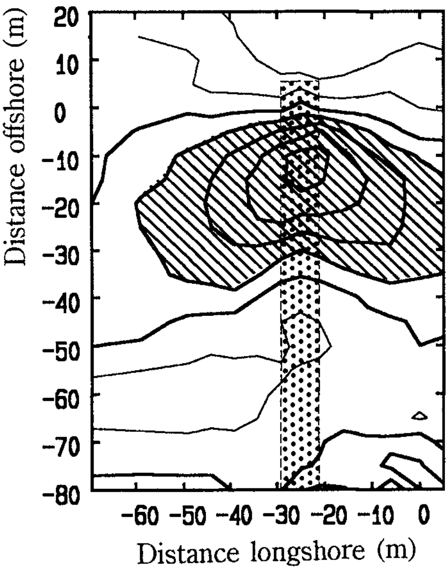

Figure 14 Change of Topography during one week.

was steep in the area lower than 2m. In short, a new berm was formed on the foreshore above the permeable layer.

The rate of sand accumulation during this one week has been calculated, of which result is shown in Figure 14. The area of sand accumulation more than 10 cm is hatched. In the middle of this area, on the drained beach, the thickness of accumulation is more than 40 cm. Then, it can be said that there was a quick recovery on the drained beach. The effect of permeable layer extended to the both lateral areas for about 20 meters, which suggests a possibility of beach protection by setting up the belts of permeable layers in stripes. On the lateral beaches where there was no permeable layer below, sand accumulated gradually and the berms were formed finally, being as the same topography as that before the storm (see Figure 11).

Conclusions

The effects of permeable layer set up under the beach are as follows:

(1)The permeable layer can drain the groundwater gravitationally through the drainage pipe into the surf zone even in a storm.

(2)It has a function of decreasing the speed of foreshore erosion in a storm.

(3)On the drained beach, the eroded foreshore is recovered quickly after a storm.

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