

## CHAPTER 115

### BEACH CHANGE AROUND DETACHED BREAKWATERS DUE TO ARTIFICIAL NOURISHMENT OF BYPASSED SAND

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#### ABSTRACT

Field experiment of sand bypassing was conducted on the Shimoni-ikawa Coast in Toyama Bay. The materials of 5900m<sup>3</sup> dredged on the updrift coast of the harbor were thrown into behind the detached breakwater. After the nourishment detailed surveys of the bottom topography around the breakwaters, wave observations and tracer tests using colored concrete blocks were carried out in order to investigate the movement of the nourished sand. Temporal and spatial changes of the shoreline positions and the sectional area of the beach in the shoreward zone of the detached breakwater are examined. It is found through the field experiment that the materials nourished behind the detached breakwater were carried slowly in the longshore direction by the westward littoral drift, dominating on the coast, without the outflow of sand through the openings of the breakwaters. It is concluded that the detached breakwater is useful to control the on-offshore sand movement and to retain the sand behind the detached breakwater.

#### I. INTRODUCTION

The Shimoni-ikawa Coast, located in Toyama Bay and formed by the fluvial sediment supply of the Kurobe River for an alluvial fan, has experienced severe beach erosion for a long time. On the east end of the coast Miyazaki Fishery Harbor has been constructed since 1947, and the balance of littoral transport directing westward was lost due to the presence of the breakwater. The shoreline advanced on the updrift side of the breakwater and the shoaling in the harbor entrance was caused by the sand movement around the tip of the breakwater, whereas the downdrift beach was eroded. In foreign countries sand bypassing method is frequently used to solve the beach erosion and accretion simultaneously, but in Japan the applied cases of the method are rather few.

Ministry of Construction and Fishery Agency performed a cooperative field study on the method to solve these problems, including sand bypassing system, in 1983 and 1984, taking the case of the Shimoni-ikawa Coast into a characteristic example.

This paper mainly summarizes the result of the field investigations conducted by Ministry of Construction. The aim of the study is to investigate the effectiveness of

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sand bypassing for a way which can solve the problems of the beach erosion and accretion near the harbor simultaneously through the field experiment. The second is to examine the function of the detached breakwater for a structure which can control the abrupt diffusion of the nourished sand by the field experiment.

## II. FIELD EXPERIMENT OF SAND BYPASSING

The field experiment was carried out on the Shimoni-ikawa Coast located in Toyama Bay (Fig. 1). The coast is one of the famous coasts eroded severely in Japan, and various countermeasure works against beach erosion have been conducted. In recent years the beach has still been eroded, and the settlement of the concrete armour units of the detached breakwaters and the scouring of the sea bottom in front of the sea wall are considerably large. Bottom contours around Miyazaki Fishery Harbor is shown in Fig. 2. Sandy beach extends on the east coast of the harbor, and to the contrary there is no sandy beach on the west coast. Instead, coastal revetments and many detached breakwaters are placed along the coastline to protect the coast. The coastlines east of Miyazaki Fishery Harbor and west of the river mouth of the Sasa River run almost in the east-west direction. Both coastlines have the discrepancy of the shoreline position of around 1km in the on-offshore direction at the downcoast of Miyazaki Fishery Harbor. The discrepancy of the shoreline positions is considered to be formed by the beach erosion. First, the position of the mouth of the Kurobe River historically moved westward and the sand supply of the river decreased on the coast, and hence the beach was eroded by westward littoral drift with the lack of the sand supply. Secondly, westward littoral drift was obstructed by the presence of the breakwater of Miyazaki Fishery Harbor.

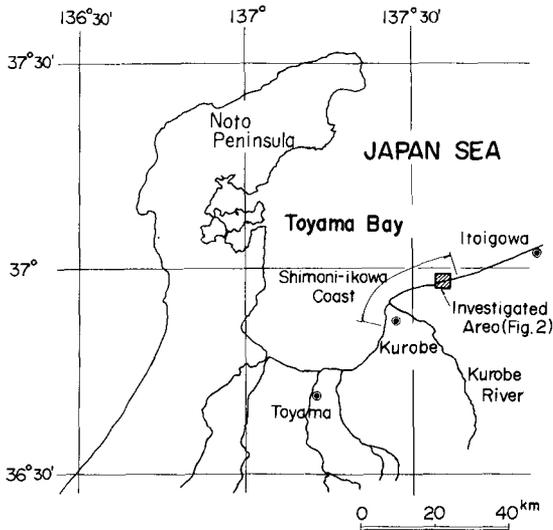


Fig.1 Location of Shimoni-ikawa Coast.

The transportation of sand was conducted by the following method. First, beach materials were dredged on the updrift site of the breakwater of Miyazaki Fishery Harbor, and were carried to 2.5 km downdrift location from the harbor by land (Fig. 2). The materials of 5900m<sup>3</sup> were thrown into behind the detached breakwater. For the transportation method, dump trucks of 11 tons were used, since the materials mainly consist of gravels and the transportation by sea is thought to be difficult because of high waves in winter, although various methods were examined at first. The transportation were carried out for 34 days from October 13 to December 7 in 1983. Artificial nourishments behind the detached breakwater were conducted 6 times dividedly between November 4 and December 7 in 1983 as summarized in Table 1.

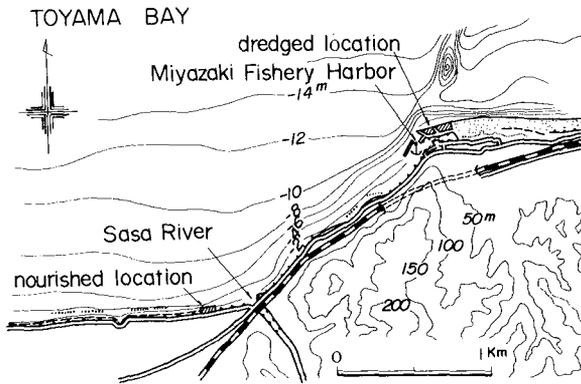


Fig.2 Bottom contours around Miyazaki Fishery Harbor.

Table 1 Nourished amount of sand.

Date	Nov. 4	Nov.10	Nov.16	Nov.17	Nov.29	Dec. 7
nourishd volume	1,050m <sup>3</sup>	1,100	1,100	530	1,060	1,060
accumulated volume	1,050m <sup>3</sup>	2,150	3,250	3,780	4,840	5,900

The location of the artificial nourishment was planned at the downdrift coast next to the fishery harbor at first, because of the short transportation distance. However, the nourishment was finally conducted behind the detached breakwater located about 2.5 km west of the harbor, considering the following two reasons. First, the nourishment at the location next to the harbor was anxious about the influence to the fishery, since the coast is a good fishing ground of production of the kelp. Second, the combined method of the construction of the detached breakwater and the artificial nourishment is considered to be effective in order to control the movement of the

The direction of the coastline is taken for the reference line of the figure. It is found that waves are frequently incident from clockwise direction to the normal of the shoreline. Under these conditions, westward longshore sediment transport should prevail.

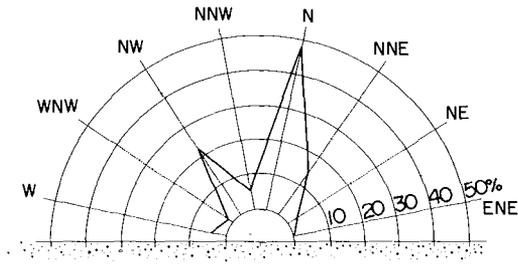


Fig. 4 Wave direction measured during November 4 through April 13, 1984 off the nourished location.

#### IV. FIELD TEST OF ARTIFICIAL NOURISHMENT

Here, the changes of the shoreline positions, beach profiles and sand volumes obtained by the field experiment of the artificial nourishment are described. First, the alignment of the survey lines of the sounding around the nourished location is shown in Fig. 5. The soundings of wide region were conducted at 40m intervals along 26 survey lines between a and z placed alongshore. The artificial nourishment was carried out behind the detached breakwater located at No.174. The sounding was carried out widely westward from the nourished location instead of ones centered at the nourished breakwater, because the predominant direction of littoral drift is westward and large beach change was expected in the west region. On the other hand, 40-m-interval of the sounding is considered to be too wide near the nourished location, because large beach change might be observed and therefore the soundings of 10 m intervals behind the nourished breakwater and 20 m intervals behind the adjacent breakwaters were selected.

Regarding the beach changes due to the artificial nourishment, bottom contours around the detached breakwaters are compared first. Figure 6 shows the bottom contours measured between October 13, 1983 and January 21, 1984 after the nourishment. The maximum depth behind the breakwaters was about 2 m below the mean sea level before the nourishment. The shoreline behind the detached breakwater protruded remarkably as shown in the bottom contours of December 7 after the completion of the nourishment, and at the same time it began to accrete behind the adjacent breakwater. Furthermore, it is found from the bottom contours until January 21 that the beach change at the openings is small and the tombolo behind the nourished breakwater began to be eroded. To the contrary behind the adjacent breakwater sand accumulated and the scale of the tombolo became large with time.

nourished sand and to prevent the outflow of sand toward the offshore zone, so that the field investigation of the system is valuable for the test of the future measure against beach erosion.

Calculating the actual cost of the transportation of the materials by the price in 1983, the total cost of the transportation and the nourishment was about 10 dollars/m<sup>3</sup> (1 \$≐162¥) . The rate of the transportation of the materials was 244m<sup>3</sup>/d, since 11-ton dump trucks ran between two locations 40 times a day. More frequent transportation between two locations was difficult because of the environmental influence produced by the passage of the dump trucks in a small town.

III. WAVE CONDITIONS DURING FIELD INVESTIGATIONS

Wave conditions during the field investigation of the artificial nourishment were observed at Tanaka Observatory located 5.6km west of the nourished location. Visual observation of wave direction off the nourished detached breakwater was also done. Temporal change of the daily mean of the significant wave height and wave period measured by an ultrasonic wave gauge placed at 15 m deep position off the coast is shown in Fig. 3. During the nourishment between November 4 and December 7 , fairly high wave ( $\bar{H}_{1/3}=2.5\text{m}$  and  $\bar{T}_{1/3}=12.9\text{s}$ ) attacked the coast on November 20. Besides, several high waves were observed after December 7 when the artificial nourishment was completed. For example,  $\bar{H}_{1/3}=2.30\text{m}$  ( $\bar{T}_{1/3}=5.8\text{s}$ ) on December 12 in 1983,  $\bar{H}_{1/3}=3.2\text{m}$  ( $\bar{T}_{1/3}=9.0$ ) on January 17 and  $\bar{H}_{1/3}=2.8\text{m}$  ( $\bar{T}_{1/3}=11.6\text{s}$ ) on January 18 in 1984. Regarding the seasonal change of wave conditions, wave height is high during November through April due to winter storms and calm between May and the midst of August, that is, the wave height becomes smaller than 0.5 m. Wave height and wave period show distinctive seasonal changes. Long-period high waves and short-period low waves appear in winter and summer, respectively.

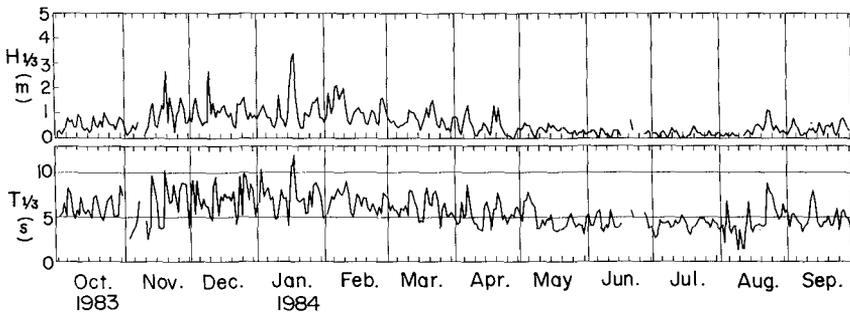
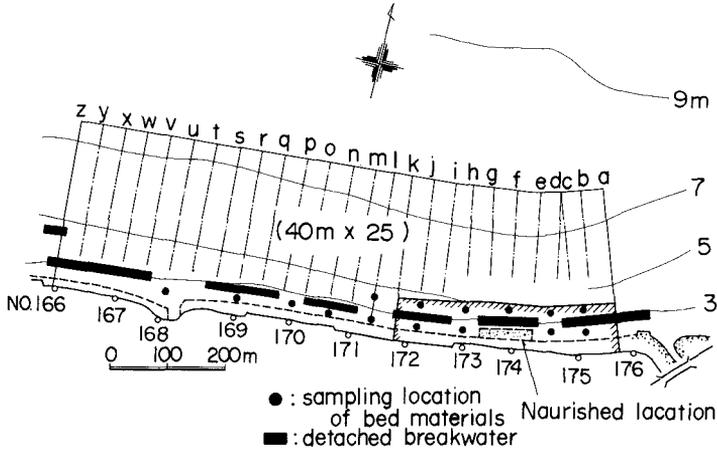
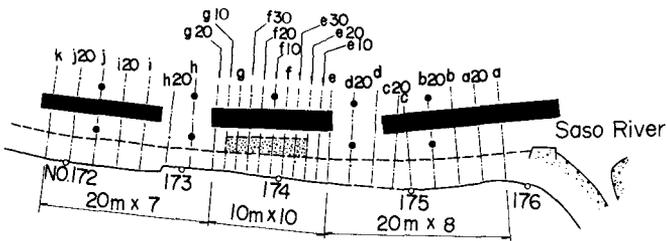


Fig.3 Temporal change of the daily mean of significant wave height and wave period measured at Tanaka Observatory.

Wave direction off the nourished location was visually measured during November 4, 1983 through April 13, 1984 from top of the coastal revetment (Fig. 4) .



(a) Sounding of wide region



(b) Sounding of narrow region

Fig.5 Scope of the soundings around detached breakwaters.

Figure 7 expresses the longshore changes of the shoreline positions and the sectional area of the beach at some survey lines near the nourished location. The reference date of these changes is selected on October 13, 1983 before the nourishment. The change of the sectional area,  $\Delta A$ , is calculated in the shoreward zone of the detached breakwater. Besides, the porosity inside the wave breaking works placed along the shoreline was assumed to be 50% in the calculation of the sectional area. The shoreline retreated at the nourished location, although once there was a large projection of sand, and the shoreline behind the adjacent detached breakwater advanced. It is found that the shoreline change is abrupt in the beginning of change, but soon it began to slow down with time. The change of the sectional area corresponds with that of the shoreline positions very well, so that it is understood that the shoreline position becomes a good parameter in expressing the change of the sectional area. However, some small differences are noted at survey lines located at

the openings of the breakwaters (for example at survey line h). The region where  $\Delta A$  is small is restricted to a narrow zone between the survey line i and h, although the region of small shoreline change is considerably wide. This means that sand can accumulate in a shallow zone in the openings of the detached breakwaters, even if the shoreline does not advance.

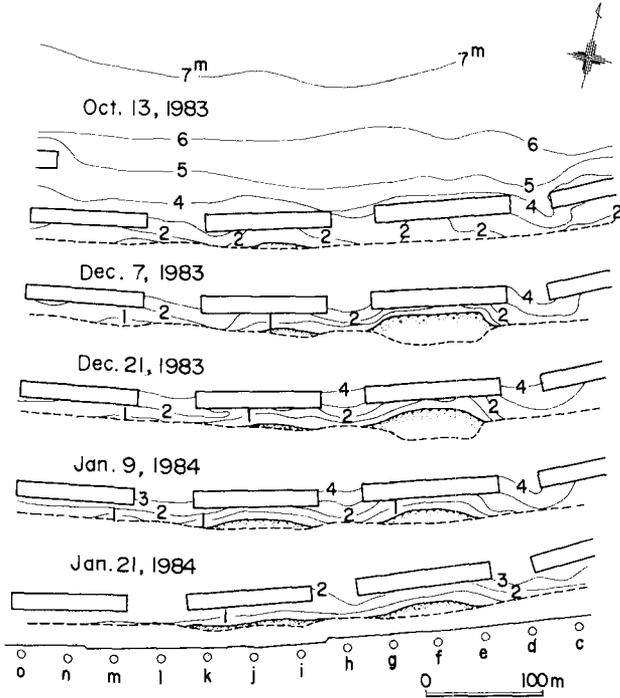


Fig.6 Comparison of bottom contours around detached breakwaters.

The characteristic change of the beach profiles corresponding to the changes of the shoreline positions and sectional area as described above is expressed in Fig. 8. The profiles of survey line f, located behind the nourished detached breakwater, is shown. In the profile of December 21, 1983, expressing the beach topography of 14 days after the nourishment, a large amount of sand accumulate in front of the wave breaking works to the onshore end of the detached breakwater, keeping mild slope. Then the beach, of which elevation is between 1.8 m and -1.5 m above the mean sea level, was eroded at this location. It is found that the maximum depth of the eroded beach was restricted within the shallow water zone behind the detached breakwater.

A good correlation is observed between the change of the shoreline positions,  $\Delta y$ , and that of the sectional area,  $\Delta A$ , as shown in Fig. 7, so that the relationship between  $\Delta y$  and  $\Delta A$  is examined as in Fig. 9. The solid and open circles are the data obtained in the eroded region behind the nourished breakwater and the accreted

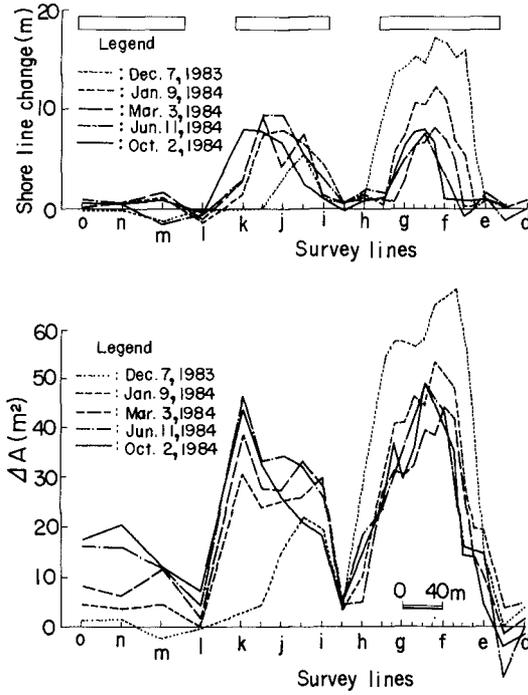


Fig.7 Longshore distributions of shoreline change,  $\Delta y$ , and change of sectional area,  $\Delta A$ .

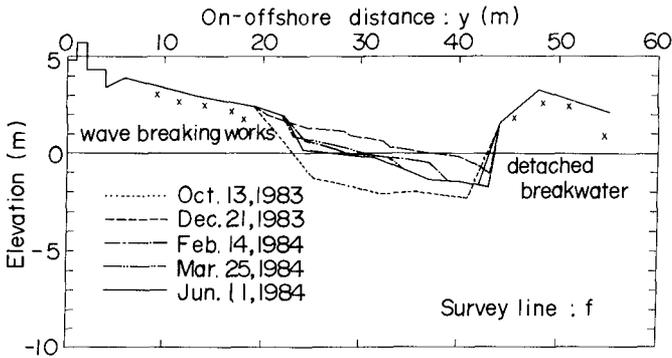


Fig.8 Change of cross section of the beach behind the breakwater (survey line: f) .

region next to the breakwater, respectively. A relation stands between  $\Delta A$  and  $\Delta y$  with the correlation coefficient of 0.97.

$$\Delta A = 2.6 \Delta y + 3.5 \tag{1}$$

where  $\Delta A$  and  $\Delta y$  have  $m^2$  and  $m$  unit, respectively. The regression coefficient of  $\Delta A$  and  $\Delta y$  is equal to the characteristic height of the beach changes due to littoral transport.<sup>1)</sup> Equation (1) shows that the areal change of a section of the beach can be expressed in terms of the change of the shoreline position, and that the characteristic height is equal to 2.6 m. The value is small compared with the one obtained on the other coast. For example, it is around 8 m on the Suruga Coast in Suruga Bay facing the Pacific Ocean.<sup>1)</sup> The reason is such that the beach changes are confined within the shallow water zone behind the breakwater in this field experiment.

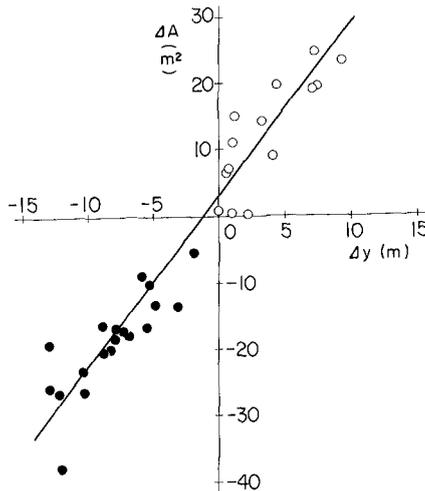


Fig.9 Correlation between the change of the sectional area,  $\Delta A$ , and that of the shoreline position,  $\Delta y$ .

Next, temporal changes of the shoreline positions and the sectional areas will be discussed in detail as shown in Fig. 10, since the overall relationship between these variables has already known. The abscissa shows the date of the sounding, and the ordinates are the change of the shoreline position in  $m$ -unit and that of the sectional area in  $m^2$ -unit, respectively. Changes at 26 survey lines between  $c$  and  $o$  are shown in the figure. Survey lines between  $e$  through  $g_{20}$  are located just on the nourished breakwater, and survey lines between  $i$  through  $k$  are located on the adjacent detached breakwater. The shoreline advanced abruptly between  $e_{10}$  and  $g_{20}$  during October 13 through December 7 due to the nourishment. At the same time the shoreline at  $i_{20}$  and  $j$  behind the adjacent detached breakwater advanced without the

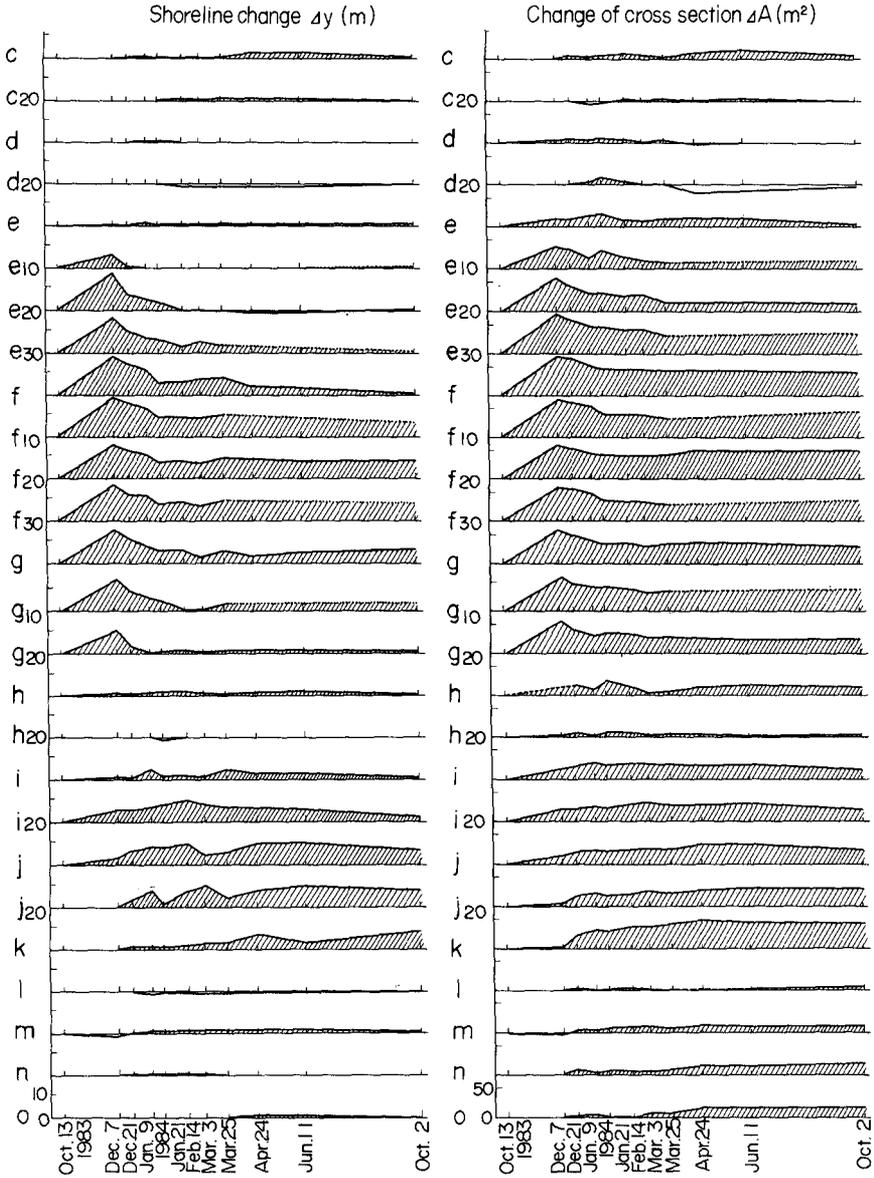


Fig.10 Temporal and spatial change of the shoreline position.

shoreline changes in the opening between the breakwaters. This means that part of the nourished sand were carried quickly westward by the longshore transport with the initiation of the artificial nourishment, and deposited behind the adjacent detached breakwater. Besides, it should be noted that the shoreline did not advance behind the detached breakwater located east of the nourished location, e.g. survey line c and c<sub>20</sub>. The shoreline change agrees well with the change of the sectional area, and the sectional area increases with the advance of the shoreline position. In the vicinity of the openings of the breakwaters, for instance at survey lines e, e<sub>10</sub>, g<sub>10</sub>, g<sub>20</sub>, i and i<sub>20</sub>, the sectional area is considerably large, although the shoreline change is comparatively small. It is found that sand accumulate below the sea surface without the advance of the shoreline. Moreover, the changes of the shoreline position and the sectional area since December 7 were rapid at first, and then the rate of changes decreased with time. Two reasons are considered. First, high waves attacked the beach under the winter storm condition at first, but gradually it became calm wave condition as shown in Fig. 3. Secondly, the rate of change of the nourished form was rapid in the beginning, since nourished sand had a projecting form, even if the artificial nourishment was conducted behind the breakwater.

#### V. RELATION BETWEEN VOLUME CHANGE AND LONGSHORE COMPONENT OF ENERGY FLUX OF WAVES

In the planning of the beach nourishment behind the detached breakwater, it is important from the technical point of view to know whether there is a possibility of outflow of sand through the openings of the detached breakwater toward the offshore zone or not. Because the sand amount to be needed for the creation of tombolo depends upon both the sand retained behind the breakwater and the loss of sand due to the on-offshore sand movement. Therefore the volume changes in various regions were calculated from the survey data and were summed up as in Fig. 11. In the figure the volume change in each period were normalized by the total volume change, 8152m<sup>3</sup>, between October 13, 1983 before the nourishment and December 7 right after the nourishment. In order to obtain the volume change the volume of the materials deposited inside the wave breaking works has to be counted, and for the purpose the porosity inside the wave breaking works was assumed to be 50%. The volume change until December 7 is 2252m<sup>3</sup> greater than the nourished volume of 5900m<sup>3</sup>, although both volumes should coincide each other. As for the reasons of the difference, several possibilities are considered such that the assumption of the porosity of 50% was not appropriate, the sounding on October 13 had some error, or the calculation of the total volume of the nourished sand had also some error. However, it is difficult to investigate the problem in detail, so that the volume change of sand is compared by the relative ratio with respect to the total volume change between October 13 and December 7.

Regarding the volume change of sand until October 2, 1984, it is understood that almost all amount of the nourished sand were retained behind the detached breakwaters and the loss of sand into offshore zone was small, taking account of the

total volume of sand from the nourished location to the second detached breakwater. Comparing the volume changes of sand in each region, the volume behind the nourished detached breakwater had about 80 percent of the total volume in the beginning, but soon it decreased with time. The rate of the volume change was large at first, and then became small. To the contrary the sand volume behind the adjacent breakwater increased rapidly. These changes are considered to be due to the cause that the sand were carried alongshore by the longshore sand transport directing westward in a shallow region behind the detached breakwater. Finally it is concluded that the nourished sand were retained behind the detached breakwater and were useful for the formation of tombolo.

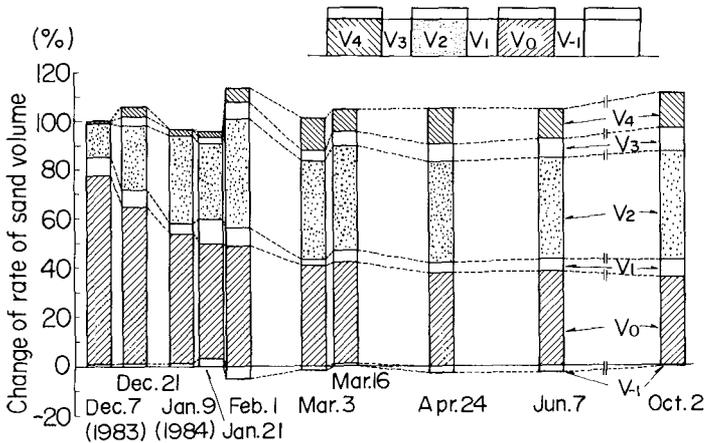


Fig.11 Temporal change of rate of nourished sand volume.

Next, the relationship between the longshore component of the energy flux of waves and the volume change of sand behind the nourished and west detached breakwaters are investigated as shown in Fig. 12. The energy flux of waves are evaluated at a depth of 5 m off the detached breakwater. The energy flux was obtained by the following method. First, wave height at the position of 15 m deep off the nourished location is calculated from the observed data of Tanaka Observatory, considering wave refraction due to the change of the bottom topography. Regarding the wave direction data, the results of the visual observation are assumed to be the input data at the same position, although the accuracy of the visual measurement may not be so high. If the visual observation data are lacking due to the difficulty of the observation under the storm wave conditions, the wave direction at the nourished location was estimated from the data of the visual observation of the wave direction at Tanaka Observatory. Due to the characteristics of wind velocity and the restricted fetch at Tanaka Observatory, the possibility of the generation of waves having longer period than about 5 seconds in Toyama Bay is very rare, so that waves, having

longer period than 5 seconds and being incident from the west of point of Noto Peninsula are assumed to be incident from the direction connecting Tanaka Observatory with the point of Peninsula. After the incident waves at a depth of 15 m were decided, wave shoaling between 15 m and 5 m off the nourished location was calculated, and finally the energy flux of waves was obtained.

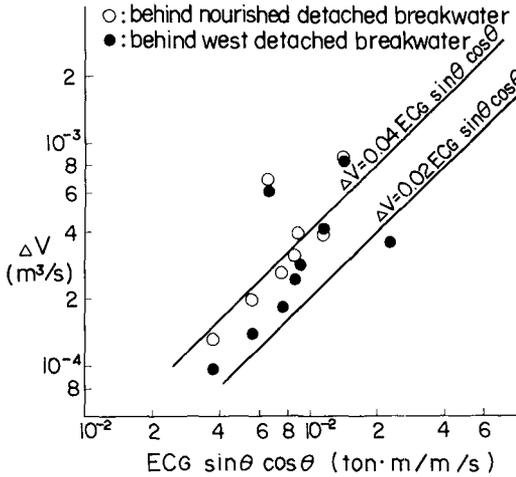


Fig.12 Relation between the longshore component of the energy flux of waves and volume change of sand.

In Fig. 12 the coefficient between the volume change of sand and the longshore component of the energy flux of waves was found to be 0.02-0.04, although it is difficult to compare the value with the past results of the coefficient directly because the longshore component of the energy flux of waves in Fig. 12 is not estimated at the breaking point. The value is one order smaller than the Savage coefficient. In the field experiment the beach changes were mainly confined within behind the detached breakwater, and the wave height behind the breakwaters is small compared with the exposed beach, so that the movement of the bed materials is restricted under the wave conditions and the coefficient is thought to become small.

**VI. RESULTS OF TRACER TEST**

In order to examine the direction of the littoral drift around the detached breakwater, tracer test using colored concrete blocks was conducted on December 7 in 1983 after the beach nourishment had just finished. Colored concrete blocks of around 30m<sup>3</sup> were placed on the surface of the nourished sand, and the movement was examined by the sampling test of 11 times until October 2, 1984. The number of the colored concrete blocks was counted directly along the shoreline. For the colored concrete, high strength concrete mixed with the red pigment was used in order to

confirm the easiness of the distinction of colored blocks along the shore and the abrasion resistance. The colored concrete blocks were broken into fine pieces of about 15 cm diameter. The compressive strength of these concrete was around  $900\text{kg}/\text{cm}^2$  at the field test.

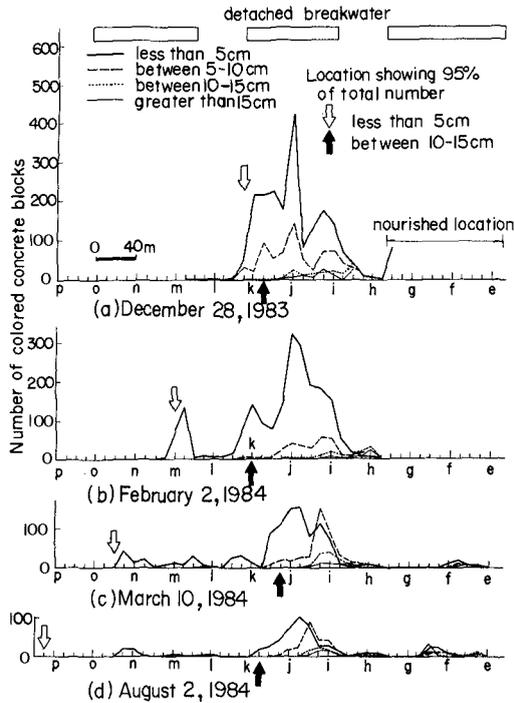


Fig.13 Longshore distribution of number of colored concrete blocks.

Longshore distribution of number of the colored concrete blocks is shown in Fig. 13 with the classification of each grain size of the recovered samples. The number is counted every 10 m intervals alongshore. The arrows in the figure designate the location showing 95% of the total number counted from the west end of the nourished position. Tracers of the grain size less than 5 cm moved westward definitely with time, and they reached to the point P distant about 350m from the nourished location. On the other hand the movement of tracers of larger grain size is slower compared with the case of the smaller grain size. The region where the tracers of the grain size smaller than 5 cm were recovered coincides with the one where large beach changes were observed, so that it is found that the maximum distance of the movement of the nourished sand during the observation period is about 350m.

## VI. CONCLUSIONS

In this study the field experiment of sand bypassing was done on the Shimoni-ikawa Coast in Toyama Bay. Finally the following conclusions were obtained.

(1) In the field experiment the sand nourished behind the detached breakwater were carried slowly in the longshore direction without the outflow of sand through the openings of the detached breakwaters. It is concluded that the detached breakwater is useful to control the on-offshore sand movement and to retain the sand behind the detached breakwater.

(2) On the Shimoni-ikawa Coast tombolos were not formed behind the detached breakwaters, because after the severe erosion of the coast the sand supply to the coast was small. It is found that they can be formed by the nourishment of sand bypassed from the updrift coast. The formation of tombolo is considered to be useful for the prevention of wave overtopping, because the depth near the shore becomes smaller due to the presence of tombolo.

(3) The coefficient between the volume change of sand and the longshore component of the energy flux of waves was found to be 0.02-0.04.

(4) The direction of littoral transport was confirmed to be westward due to the tracer test using colored concrete on the coast. It was also found that the fine tracer were carried more rapidly than coarser tracer.

## ACKNOWLEDGEMENT

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