CHAPTER 309

OBSERVATION OF NEARSHORE CURRENTS AND BEACH CHANGES AROUND HEADLANDS BUILT ON THE KASHIMANADA COAST, JAPAN.

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ABSTRACT

Nearshore currents and beach changes around headlands built on the Kashimanada coast facing the Pacific Ocean were investigated through the field observation. In order to confirm the effectiveness of headland system to stabilize sandy beach, nearshore current field and shoreline change around headlands were measured as well as the comparison of measured value with the results of numerical simulation of nearshore currents. Comparison of development of a rip current around a completed, anchor-type headland and a groin-type headland under construction was also made and superiority of anchor-type headland to suppress the development of a rip current in the vicinity of the structure was clarified.

I. INTRODUCTION

In recent years, a method to stabilize sandy beach by using headlands has been applying on several coasts in Japan in place of the detached breakwaters and the effectiveness has been confirmed. One of the examples is given on the Kashimanada coast as shown in Photo 1, where headland system was introduced to stabilize coastline(Uda et al., 1988). Now, construction of 40 headlands is underway with 1km intervals. The headland system to stabilize sandy shoreline was originally proposed by Silvester(1976). In his study headland system in which a headland of asymmetric shape is built on the sandy beach, was considered under the obliquely incident wave conditions. On many coasts, however, wave direction varies from season to season. In this condition, symmetric type of headland is more effective to stabilize the sandy beach. On the Kashimanada coast, therefore, headlands of a symmetric shape were built.

In the planning of headland system, due considerations must be paid to the shape and its effect to surrounding nearshore current field. For example, under

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the obliquely incident wave conditions, a rip current will be developed along the groin-type headland, whereas in case of the T-shape headland, development of a rip current is suppressed because of the sheltering effect of head-part of the headland. These differences deeply relate to the stabilization of sandy beaches between headlands. However, poor experience of constructing headland system on the real coasts prevents these understandings.

Photo 1 Aerial view of headlands on the Kashimanada coast (Dec.1993).

This study aims at the investigation of nearshore currents, beach changes around these headlands, and the confirmation of their effectiveness. To this purpose, the comprehensive field observations and the numerical simulation of nearshore currents were conducted. The study is composed of three contents as shown in Fig.1. First, the results of the field observation on nearshore currents around headlands are described. Field observations were carried out at three times from 1991 to 1993, in which aerial pictures were taken at a constant time interval from a helicopter to investigate diffusion of dyed water. In 1991, pre-observation was done in the vicinity of headlands, aiming at studying the difference between a groin-type and an anchor-type headland. In 1992, observations were done not only near the headland but also in the extensive area between two completed headlands in order to investigate nearshore currents and rip currents. In these observations, however, photographs were taken from a relatively low altitude. Therefore, in 1993, in order to simultaneously investigate current field in extensive area, high altitude photographs were taken from 1,000 m, as well as the bottom sounding.

In addition to these observations, beach stabilizing effect was investigated around a group of headland on the basis of several photographs and soundings, which have been carried out recurrently. Moreover, numerical simulation of nearshore currents was carried out and results of numerical simulation were compared with the observed nearshore current pattern. Current pattern was well agreed with the observed one.

Field Observation of Nearshore Currents

① **Dec.17, 1991** : Pre-observation in the vicinity of headlands
② **Dec.15, 1992** : Individual observation between two completed headlands
③ **Dec. 7 , 1993** : Simultaneous observation from high altitude

Beach Stabilizing Effects By Headlands

① Effectiveness of shoreline stabilization by a group of headland
② Cyclic shoreline changes around headland
③ Accretion in profile changes around headland
④ Vertical distribution of depth changes based on bottom soundings

Numerical Simulation of Nearshore Currents

① Calculation of nearshore currents under the condition observed in 1993
② Trial by both measured and smoothed topographies
③ Usage of irregular wave model
④ Calibrating wave direction by comparing with observed one

Fig.1 Outline of this study.

II. FIELD OBSERVATION OF NEARSHORE CURRENTS

2.1 GENERAL

Figure 2 shows the location of study site. The Kashimanada coast is located in the southern part of Ibaraki Prefecture facing the Pacific Ocean, where construction of 40 headlands with 1 km intervals is now underway. Construction works were begun in 1984, and by 1995, six sets of headlands were completed. Figure 3 shows the plane shape of the headland. Headland has an anchor-shape, of which offshore length is about 150 m and the head-part length is about 100 m. The head-part has a semi-circular shape and its offshore slope is as mild as 1/3 to reduce wave impact against the structure. The offshore surface of the headland is covered by armor units of 4 tons and the main part is built by natural stones of 1 ton. Field observations were carried out mainly between No.10 and No.11 headlands on the Ono-kashima coast located in the middle of the Kashimanada coast. The Ono-kashima coast is a sandy beach next to Kashima Port and beach slope is about 1/80, and the coastline length is about 12.5 km.

2.2 NEARSHORE CURRENT PATTERN AROUND THE COMPLETED HEADLAND

Photo 2 shows the nearshore current pattern around the completed headland measured on Dec. 17th, 1991, ① : right after the injection of dyestuffs to the foot part of a completed anchor-type headland No.10, ② : 6 minutes after the injection, and ③ : oblique aerial photo after ten minutes. In case of a anchor-type headland, it is realized from the comparison of successive aerial photographs that a nearshore circulation cell was formed on the south side of headland because of the wave dissipating effects of head-part. This is considered to be effective to contain the nearshore currents between headlands.

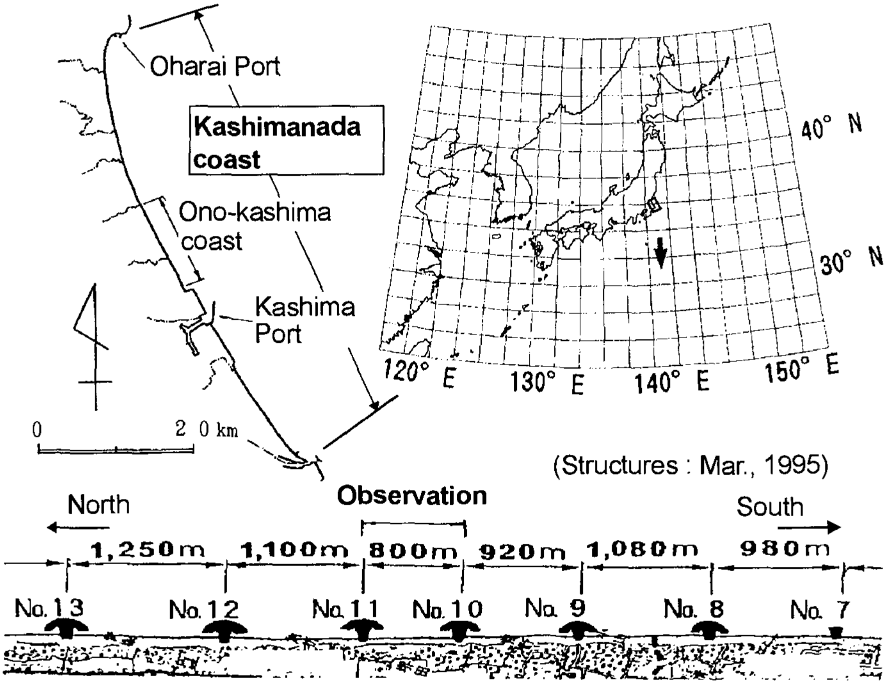


Fig.2 Location of study site.

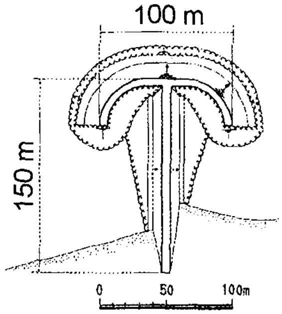


Fig.3 Plane shape of anchor-type headland.

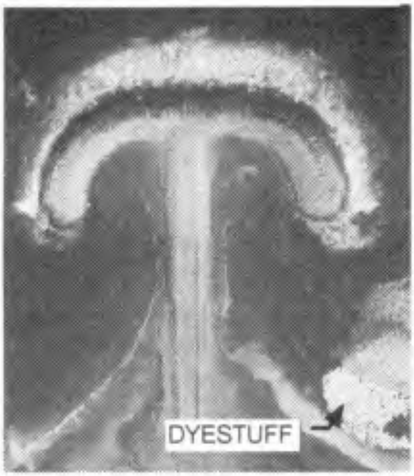
2.3 NEARSHORE CURRENT PATTERN AROUND THE GROIN-TYPE HEADLAND

Photo 3 shows the rip currents developed along the groin-type headland (No.9) under construction observed on Dec. 17th, 1991. In this case, dyed water injected to the foot of the groin-type headland was carried fast along the groin by the rip current. Then, dyed water spread out offshoreward and was diffused, implying that sand will be carried away to downcoast to accelerate the beach erosion on upcoast of the headland.

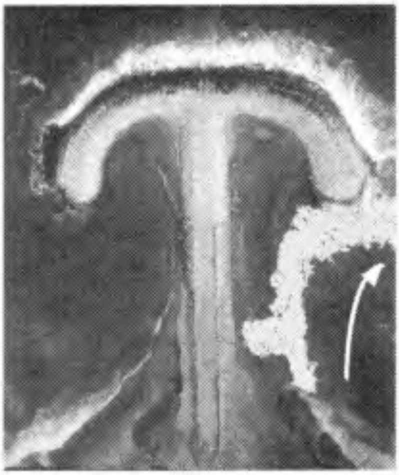
2.4 RESULT OF NEARSHORE CURRENT OBSERVATIONS IN 1992

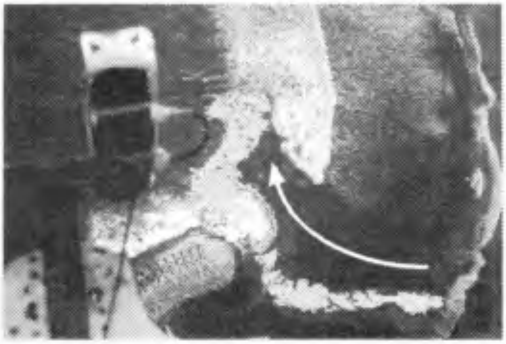
Figure 4 shows the nearshore current field observed on Dec. 15th in 1992 in the extensive region covering between No.10 and No.11 headlands . The figure shows changes in dyestuff clouds, their moving velocity and wave direction, which were measured from aerial photographs. Diffusion of injected dyed water was traced by the aerial photographing from the helicopter at 15 seconds interval, and the diffusion pattern of dyed water is traced at 1 minute interval.

① RIGHT AFTER THE INJECTION OF DYESTUFFS TO THE FOOT PART.



② 6 MINUTES AFTER THE INJECTION.





③ OBLIQUE AERIAL PHOTO AFTER 10 MINUTES.

Photo 2 Advection of dyed water around the completed headland of anchor-type (Dec. 17th, 1991).

During the observation, significant wave height was 1.3 m, and the period was 9.1 s due to the wave record measured off Kashima Port by an ultrasonic wave gauge. And also incident wave angle was read to be about 15 degree counterclockwise to the normal to the shoreline from the aerial photograph.

Because of the oblique wave direction, southward longshore currents are predominant and the circulation cell is formed on the north side of No.10 headland. On the other hand, on the north side of No.11 headland, a rip current occurs, which passes over head-part and flows out in the offshore direction. Furthermore, a rip current is occurred at a central part of the beach between No.10 and 11. The position of the rip current is located approximately 500m south of No.11 headland and is a little south from the center of headlands.

When mass flux by waves is considered, it is considered that the flux is mainly heading shoreward from between No.11 headland and the position of the rip current. And it returns to offshore by this strong rip current at central part of the beach. On the contrary, the longshore distance between the rip current in the central part and No.10 headland is short, so that the shoreward mass flux in this area is considered to be small and therefore the strength of the rip current just north of No.10 headland is weak.

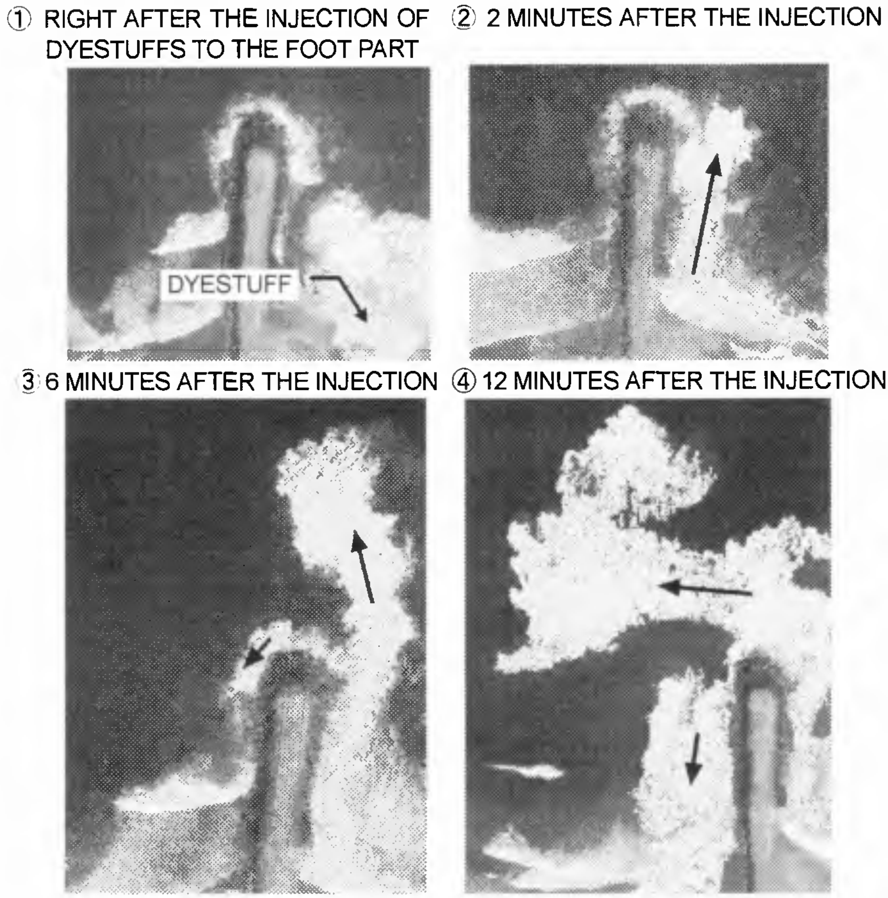


Photo 3 Advection of dyed water around the groin-type headland (Dec. 17th, 1991).

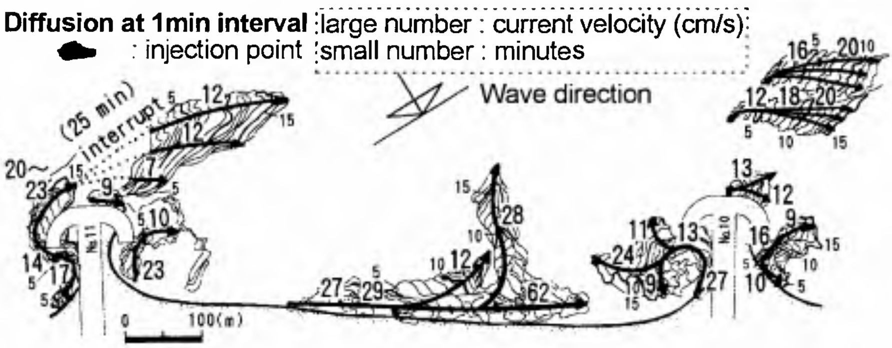


Fig.4 Diffusion of injected dyed water between No.10 and No.11 headlands (Dec. 15th, 1992).

2.5 RESULT OF THE HIGH ALTITUDE PHOTOGRAPHING IN 1993

Figures 5 and 6 show the diffusion process measured on Dec. 7th in 1993. The significant wave height and period were 1.6 m and 7.6 s, and waves were incident from clockwise direction in this observation period as shown in the figure. The condition of this incident wave angle contrasts to the wave characteristics in 1992.

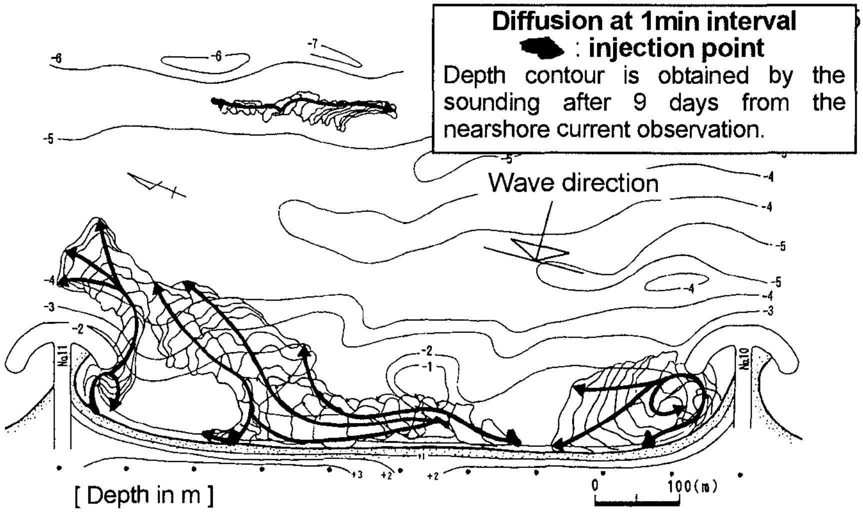


Fig.5 Diffusion of injected dyed water between No.10 and No.11 headlands(Dec. 7th, 1993).

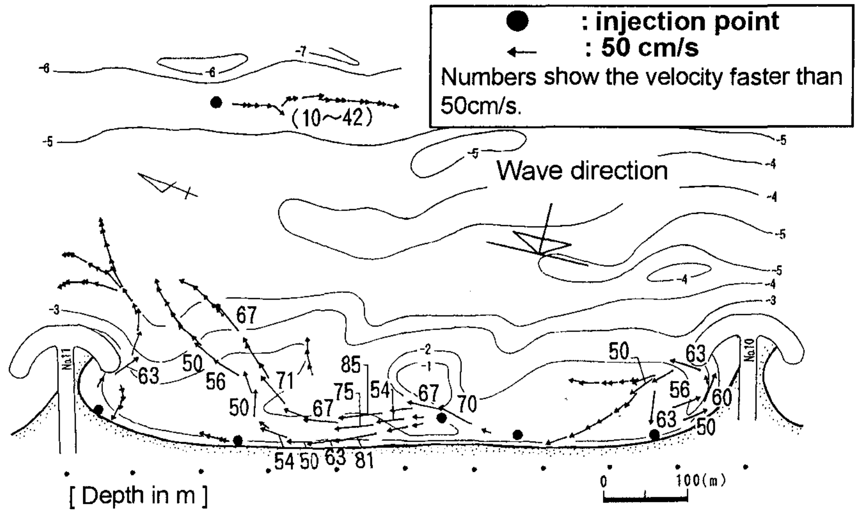


Fig.6 Velocity field of nearshore current determined from advection rate of dyed water front (Dec. 7th, 1993).

As a whole, northward longshore currents were induced, and counterclockwise circulation cell was observed in the vicinity of the north side of No.10. Furthermore, northward longshore currents developed next to this circulation cell. This longshore current is reduced to a rip current at a location of 300m distant from No.11 headland. On the south side of No.11 located on the downcoast, an another clockwise circulation cell was formed in the lee side of the headland. A part of this current reduces to the rip current and it superimposes the main rip current induced in the central part of the beach. In addition, about 400m off the shoreline, weak southward longshore currents were measured.

These results mean the formation of a large-scale clockwise circulation cell between headlands. Development of this circulation cell is considered to be effective to confine sediment between headlands, and to stabilize the sandy beach.

III. TOPOGRAPHIC CHANGES

3.1 SHORELINE CHANGE

Sea bottom surveys and aerial photographing for monitoring shoreline changes have been recurrently carried out on this coast. Figures 7 and 8 show the shoreline changes around headlands determined from the aerial photographs. As shown in Fig.7, the shoreline retreats in the southern part between headlands and a stepwise shoreline was formed due to the southerly wave incidence, which is the predominant wave direction on this coast. Near the headlands as shown in Fig.8, wide foreshore (tombolo) was formed behind the headland. All these show the effectiveness of headland system to contain sand between headlands, and to form dynamically stable beach between headlands. In this headland system, the interval between them is about 1 km, which is wide enough to keep the coastal scenic beauty on the natural sandy beach. Detached breakwaters are effective against beach erosion. But they have killed scenic beauty of the beach by the dense installation. Usually in Japan, the length is 100m and the opening width is 50m. In the headland system, however, the number of the headlands per unit distance is much less than that of detached breakwaters, thus this system is much more economical.

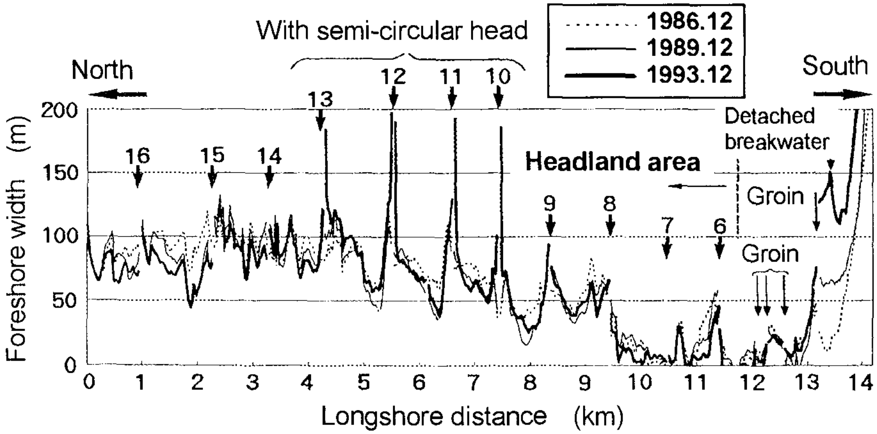


Fig.7 Changes in foreshore width between 1986 and 1993.

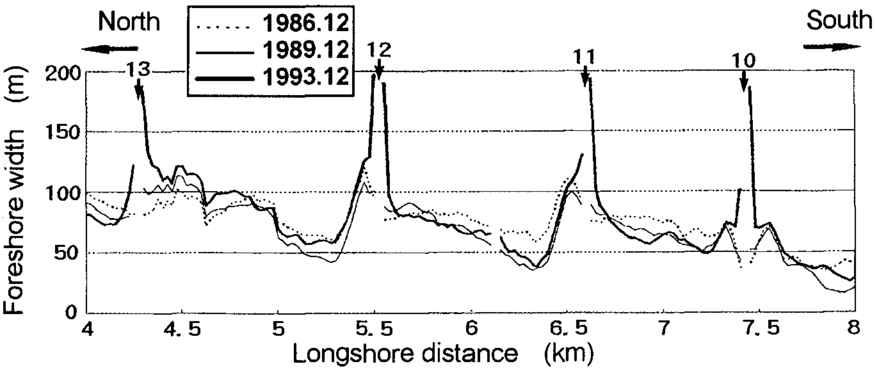


Fig.8 Shoreline changes around completed headlands between 1986 and 1993.

Figure 9 shows the temporal shoreline changes from 1986 to 1993 in the vicinity of No.11 headland. Surveys have been carried out in the same month of December in each year. In this figure, completion time of groin-part and head-part of the headlands are also shown. As shown in this figure, shorelines on the south side (S1~S3) of the headland No.11 change with the same phase, whereas on the north side (N2~N3) of the headland, the opposite mode of shoreline changes occur except the change at N1 located very close to headland and at the concave location. After the construction of the head-part in 1989, shoreline changes turn to the accretion tendency. It is understood that cyclic shoreline change occurs because of the seasonal change in wave direction in the zone next to the structure obstructing longshore sand movement. In short, the north side of headland is eroded and accretion occurs on the south side by southerly waves in summer, and then in winter, opposite phenomenon appears. Furthermore, it is realized that the accretion effect of headland overlaps on the above seasonal changes.

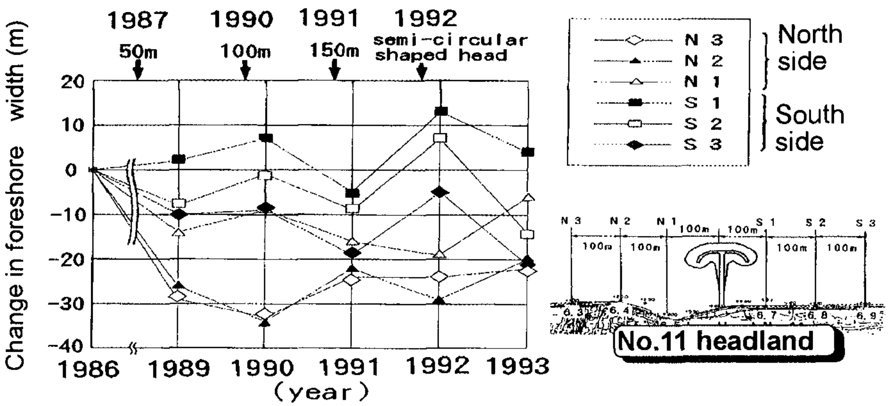


Fig.9 Temporal shoreline changes around headland No.11 between 1986 and 1993.

3.2 PROFILE CHANGES

Regarding the accretive effect of headland, it is also investigated by the bottom soundings along the survey lines arranged with 25m interval. Figure 10 shows the typical cross-shore profile changes around No.10 headland between July, 1987 and August, 1993. On the line of CN100, development of bar-trough topography was seen before the construction, but since 1992 when the head-part had been completed, bar-trough development becomes weak. On CN50 approaching 50m to headland further, because of the wave sheltering effect of the headland, accretion is seen at nearby the shoreline. Then, on CN0 nearest to the headland, a large amount of sand is accumulated to form a tombolo. The thickness of accreted sand at a distance of 100m offshore reaches to approximately 3m. On the other hand, a local scouring is not seen off the head, and a gentle slope of approximately 1/100 is formed. Thus, it is confirmed that accretive effect of headland is remarkable around No.10. because of the wave sheltering effect by its head.

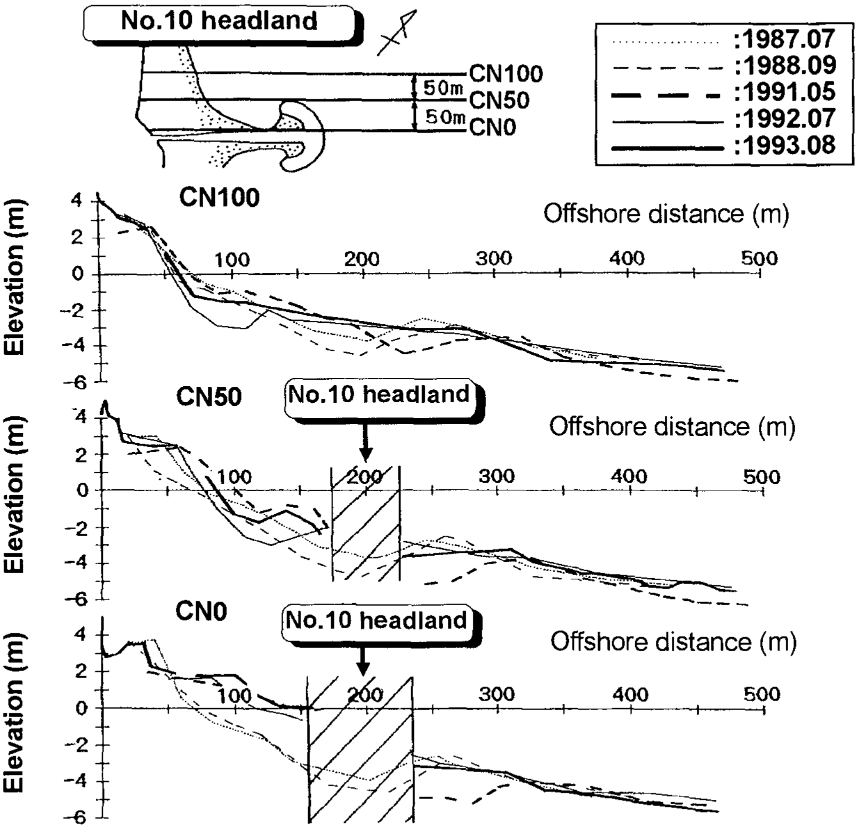
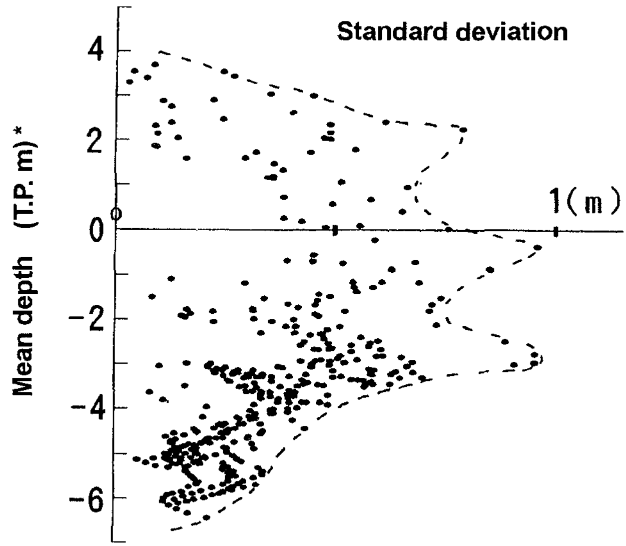


Fig.10 Typical profile changes in a period between July, 1987 and August, 1993.

3.3 VERTICAL DISTRIBUTION OF DEPTH CHANGES

On the basis of the sounding data, a vertical distribution of the standard deviation of the water depth change was examined. Fig. 11 shows the result. The vertical axis indicates the mean depth in meter. They were examined between No.10 and 11 headlands from 1987 to 1993.The significant topographic changes is occurred between -6m to +3m with two peaks at the shoreline and -3m. The peak of -3m is considered to be caused by the changes of bar-trough topography. This distribution shows a range of the remarkable topographic change. And the tip depth of the headland is approximately 3m depth. Therefore, the headland is located at a place which almost contains the range of the remarkable topographic change. This fact means the headlands on this coast is located at a offshore limit for demonstrating its effect.



* : T.P. is a datum level frequently used in Japan and equal to annual mean sea level.

Fig.11 Vertical distribution of depth change between No.10 and No.11.

IV. NUMERICAL SIMULATION OF NEARSHORE CURRENTS

4.1 NUMERICAL MODEL AND COMPUTATIONAL CONDITION

Numerical simulation for the nearshore currents was carried out to compare field data observed in 1993. Table 1 shows the computational condition. In the nearshore current simulation, wave field was first calculated by the irregular wave model Then, nearshore current field was calculated on the basis of the above wave field and with given some coefficients. On the other hand, regarding the sea bottom topography, two cases of the calculations as described in Table 1 and shown in Figs.12 (Chart 1) and 13 (Chart 2) were carried out. Chart 1 is the original topography data sounded on Dec. 16th, 1993, and Chart 2 is the smoothed one. The reason using also Chart 2 is why the bottom topography would be changed by the storm continued during 9 days since the above-mentioned nearshore current observation.

Table 1 Computational conditions.

Term	Condition
Computation area	Longshore 2,000 m × Offshore 1,000 m
Mesh size	$\Delta x = \Delta y = 10$ m
Initial topography	Chart 1 : Original bathymetric chart (Dec. 1993) Chart 2 : Smoothed bathymetric chart
Structures	Present (headland No.10 and No.11)
Sea wave conditions	Height and Period : decided from observation at Kashima Port on Dec. 7th, 1993. Direction : Trial in the range of observed direction
Tidal level	T.P.+0.806m
Computation time	1 day
Irregular wave computation	Dividing number of frequency : 5 Dividing number of direction :11 Directional concentration coefficient : $S_{max} = 25$
Nearshore current computation	Friction factor : $C_f = 0.01$, Lateral eddy viscosity : $25m^2/s$ Time step : $\Delta t = 0.5$ s, Boundary condition : Open

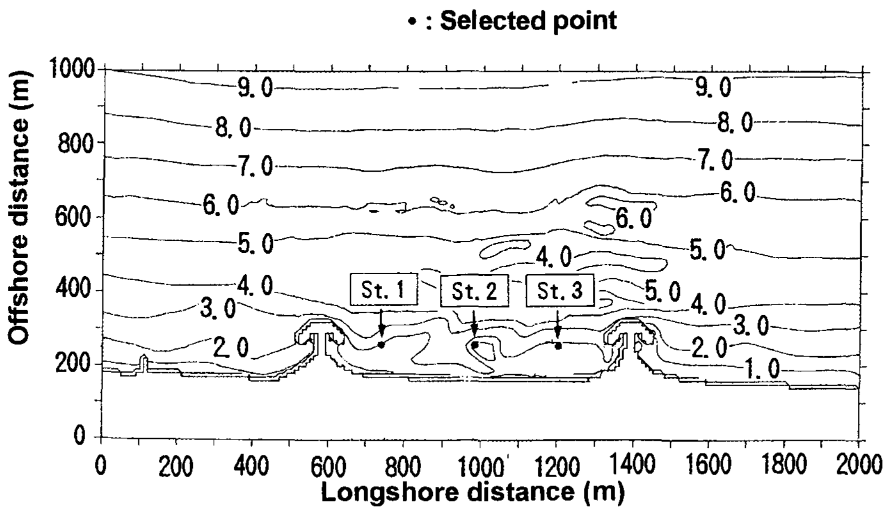


Fig.12 Original bathymetric chart (Chart 1) and selected point for verification of wave direction.

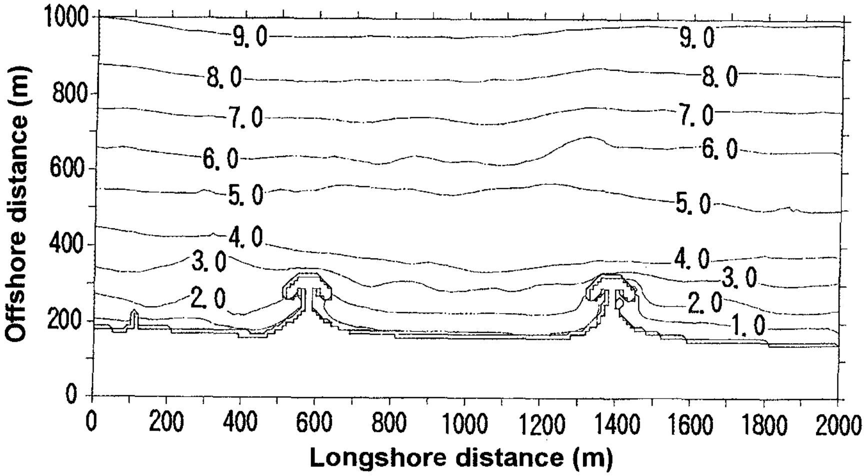


Fig.13 Smoothed contour chart (Chart 2).

4.2 VERIFICATION OF WAVE DIRECTION

First, the wave direction was verified. Table 2 shows the trial cases and results. Besides, as a representative point for verification, St.2 in Fig.12 was selected because it is located in the center, and therefore the influence due to the structures is small enough. As shown in Table 2, in total 8 cases of trials were conducted, and the best fit of the offshore wave direction to reproduce the measured wave direction resulted in -25 degree as case 7 or 8.

Table 2 Measured and calculated wave directions at selected points.

No.	Topography	Wave conditions				Wave directions		
		Height (m)	Period (s)	Direction	Tide level (T.P. m)	St.1	**St.2**	St3
1	Chart 1	1.57	7.6	-14.5°	0.806	-1.4°	**2.0°**	-7.4°
2	//	//	//	-20.0	//	-5.1	**-2.1**	-9.5
3	//	//	//	-35.0	//	-11.6	**-8.2**	-14.3
4	//	//	//	-40.0	//	-13.7	**-9.5**	-16.2
5	Chart 2	//	//	-20.0	//	-11.6	**-11.4**	-10.5
6	//	//	//	-30.0	//	-15.8	**-16.6**	-15.4
7	//	//	//	-25.0	//	-13.4	**-13.6**	-12.8
8	//	2.39	//	-25.0	//	-12.6	**-12.8**	-11.7
Mean angle measured						-13.7	**-13.3**	-5.1

4.3 RESULTS OF COMPUTATION

Figure 14 compares calculated current pattern with the observed one. Nearshore circulation cell on the downcoast of No.10, a rip current at the head of No.11, and a rip current at a location of longshore distance 900 m agreed considerably well. On the other hand, in case of using Chart1, a very strong onshore current occurred and discrepancy was large on the shoal located in the middle of the sandy beach.

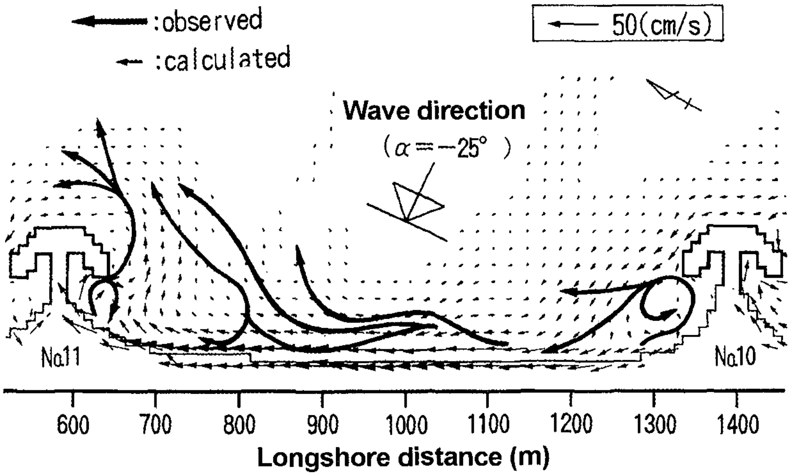


Fig.14 Comparison of observed and calculated nearshore current field.

V. CONCLUSIONS

Main conclusions in this study are summarized as follows :

① Nearshore current field with a longshore stretch of about 800m was measured. Development of nearshore circulation cell in the vicinity of headlands was confirmed. And, a rip current induced from the shoreward mass flux were also confirmed.

② Due to the shoreline changes around headlands observed by aerial photographs, the shoreline was stabilized to form a step-wise configuration responding to the oblique wave incidence. Furthermore, it was found that seasonal shoreline variation was superimposed to this shoreline to form dynamically stable shoreline.

③ Numerical simulation of wave field and nearshore currents were carried out. Results of numerical simulation agreed well with the observed one to show the effectiveness of the wave and current model.

④ This study summarizes field experiences regarding headland system in Japan. And this information is thought to be important for further application on the other coast in place of the detached breakwater.

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