CHAPTER 207

STABILIZATION OF COAST BY CONSTRUCTION OF HEADLANDS ON THE KASHIMANADA COAST, JAPAN

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ABSTRACT

Eleven artificial headlands were constructed on the Ohno•Kashima Beach facing the Pacific Ocean to prevent further extension of beach erosion and to form the dynamically stable beach. This paper summarizes the results of the follow-up study of the new works applied on the actual coast. Field investigations such as bottom sounding around headlands and aerial photographing were conducted. It was found that the periodic changes of the shoreline configuration correpsonding to seasonal change of the wave direction exist on this coast and these variations of the shoreline position can be reduced by the effect of these headlands.

I. INTRODUCTION

In recent years beach erosion has been considerably severe along Japan's coasts, so that various types of coastal protective measures have been carried out; seawalls, wave-dissipating breakwaters, groins or detached breakwaters have been constructed. Most of these facilities are constructed continuously or with small intervals along the shoreline. As a result of these works natural sandy beaches decrease year by year. Natural beach posesses not only prominent function of disaster prevention but also great advantages in view of landscape. Therefore, it is desirable for preventive works to be carried out while maintaining natural sandy beaches as much as possible.

Along the Kashimanada Coast in Ibaraki Prefecture, beach erosion has been severe in recent years (Uda et al., 1986 a,b). For a measure against beach erosion, construction of the artificial headland was planned by the Ibaraki Prefectural Government since 1983 on the

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Kashimanada Coast facing the Pacific Ocean, and a group of 11 headlands have already been constructed up to the present. Artificial headlands have been applied in Japan for the first time, and at present there remain some problems to be solved in its applications. This paper summarizes the results of the follow-up study of the new works applied on the actual coast. Present headlands have not been completed up to its final design, but further field investigations are to be conducted to attain the reasonable form of the headland system through actual field tests.

Regarding the headland system for the beach stabilization method some previous studies have been already conducted by Silvester (1976) or Tsuchiya (1984). These methods can be applied to the beach where waves obliquely approach to the shoreline with large angle. On the coasts in Ibaraki Prefecture, however, the direction of wave approach varies seasonably and periodically, so that their methods are not applicable. One of the authors has proposed a shoreline control method --artificial headland-- for the field with periodic changes of the incident wave direction (Uda et al., 1987). Since both methods have similar meaning with respect to a point that a long extensive beach is changed stable by separating into several segments by these works, the measures carried out in this study will be called by the same name-headland.

II. OVERALL FEATURES OF BEACH CHANGES ALONG THE KASHIMANADA COAST

The study site (the Ohno•Kashima Beach) is located on the north side of Kashima Port in the middle of the Kashimanada Coast (Fig. 1). On this beach the direction of longshore sediment transport is changing according to the seasonal changes of incident wave directions, but

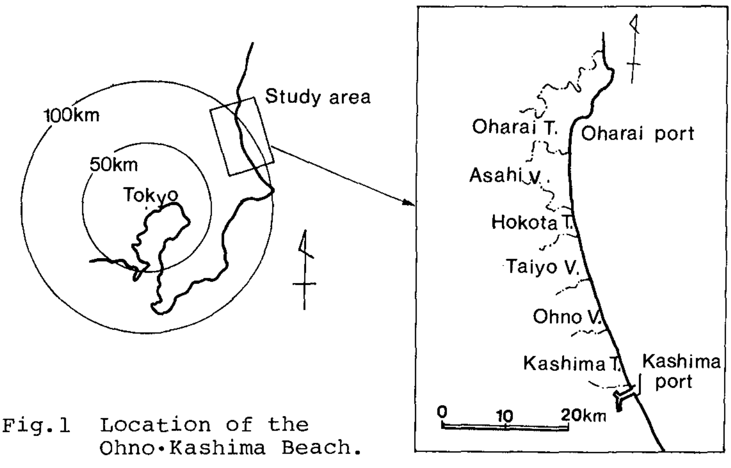


Fig.1 Location of the Ohno•Kashima Beach.

northward component of the wave energy flux dominates, so that severe beach erosion is observed on the north side of the Kashima Port, obstructing northward longshore sand transport (Uda et al., 1986).

The longshore distribution of the shoreline change, median diameter of beach materials and foreshore slope are shown in Fig. 2, illustrating the shoreline change until 1985 and 1987 with reference to the one measured in October, 1984. The abscissa is the longshore distance from the origin located at Oharai Port (refer to Fig. 1). In addition, median diameter and foreshore slope were measured both in 1985 and 1987. It is clearly understood that the shoreline has retreated considerably in recent years on the Ohno•Kashima Beach 25km to 39km south of the origin, and also beach materials and foreshore slope have become

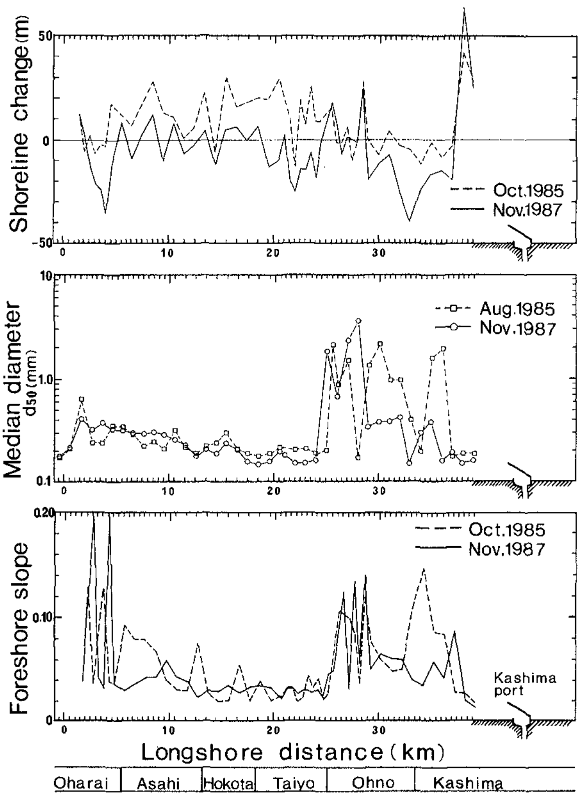


Fig.2 Longshore distribution of shoreline change, median diameter of the foreshore materials and foreshore slope along the Kashimanada Coast.

coarser and steeper at the same locations, respectively. The same characteristics as mentioned above are found on the south beach adjacent to Oharai Port. In order to prevent these beach erosions and to form stable beaches on this coast the construction of headlands was proposed.

III. CONSTRUCTION OF HEADLANDS

Headlands were constructed at the interval of about 1km based on the aerial photographs taken in August, 1984, assuming that the shoreline retreat should be less than about 30m, because the original shoreline width at the planning time had already been narrow enough and the shoreline retreat over 30m was not permissible for the stability of various coastal facilities. The construction sites of headlands were decided, based upon the simulation of the shoreline evolution by using one-line theory with the present shoreline data. The arrangement of each headland is shown in Fig. 3. Eleven headlands have already been constructed up to the present and the two are to be set in future. The construction of No. 1 and No. 4 headlands out of 11 headlands began in December, 1985 and were completed in March, 1986. The construction period of the remains is presented in Table 1. In addition, Fig. 4 represents details of headland plan; the crown width is 6m, the crown height is +2.2m above the M.S.L., its length is 100m and it was built by natural stones over 1 ton. The length of headland is about 80m at present.

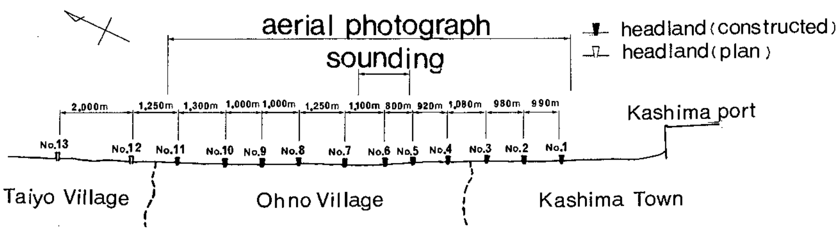


Fig. 3 Location of construction site of headlands on the Ohno·Kashima Beach.

Table 1 Dates of measurement of the bottom sounding and aerial photographs.

Date / Kind	1986				1987												1988
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.
Sounding	O			O	O	O		O			O		O		O		O
Aerial Photo		O		O	O	O		O			O		O		O		O
Construction Period of Headlands	←	No. 3, No. 5~7			← No. 8 ~10		→	→								← No. 2, No. 11	

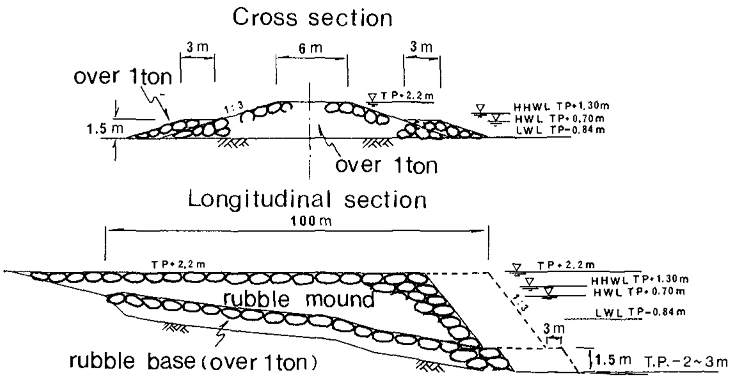


Fig. 4 Configuration of headland.

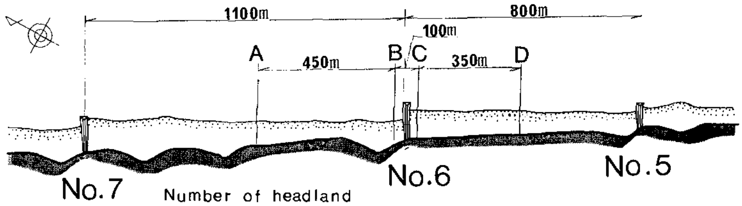


Fig. 5 Arrangement of survey lines of bottom sounding.

IV. METHOD OF FIELD INVESTIGATIONS

Field investigations consist of bottom soundings and aerial photographing, whose schedules are summarized in Table 1. Bottom soundings were carried out 9 times in total. Both observations were tried to be conducted at the same day, but there was a little time lag in execution due to the weather conditions.

The soundings were carried out along 20 survey lines of 200m in length, covering the sites of No. 5 to No. 7 headlands. The investigation of the profile changes were conducted in detail only with the representative 4 survey lines such as the north lines (A, B) and the south ones (C, D) of No. 6 headland as shown in Fig. 5, because beach changes caused by the construction of headlands can be well examined by the comparison of beach profiles near the structure with those far from that. Comparison with the beach profiles along the survey lines B and C near the structure enables to evaluate the influences of the headland for the surrounding beach topography.

Figure 6 represents the wave data during the field survey in terms of significant wave height ($H_{1/3}$) and wave

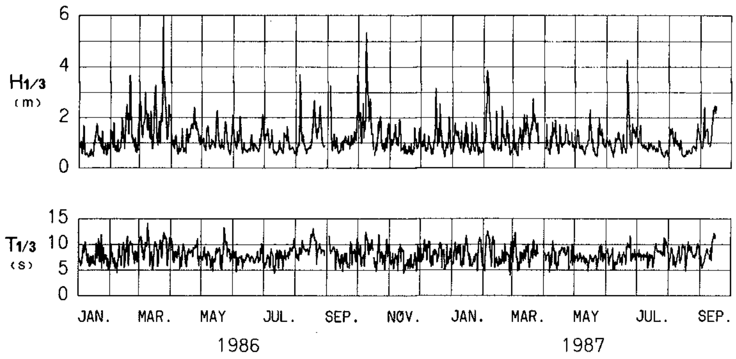


Fig. 6 Temporal changes of significant wave height and wave period off Oharai Port.

period ($T_{1/3}$) observed at a location of 21m deep off Oharai Port in January, 1986 through September, 1987. Wave condition of this coast is usually rough in February, March and October. On the contrary, from April to August calm sea condition generally prevails. There exists a weak correlation between significant wave height and wave period as shown in Fig. 6, and wave period tends to be longer with the increase of wave height.

At Oharai Port wave directions have been observed. The joint distribution of significant wave height and wave direction is summarized in Table 2, in which the data are summed up separately in 1986 and 1987. On both tables four predominant direction with high wave energy level are apparent, and in addition these wave directions are roughly divided into two groups of NE, ENE and SE, SSE. Assuming the same wave incidence at a location off the Ohno•Kashima Beach, the longshore sediment transport on this site

Table 2 Joint distribution of significant wave height and wave direction.

Jan. 1986 ~ Dec. 1986 (%)

$H_{1/3}$(m) \ Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	Total
0.00 ~0.49										
0.50 ~0.99		0.6	9.0	11.3	4.8	0.3	1.0			27.0
1.00 ~1.49		0.6	7.7	15.1	1.9	2.3	6.8	3.9		38.3
1.50 ~1.99		1.0	4.2	7.1	2.9		5.8	1.3		22.2
2.00 ~2.49		0.3	0.6	1.6	1.3	0.6	2.6	0.3		7.4
2.50 ~2.99				0.6	1.3	0.6	0.3			2.9
3.00 ~3.49				0.3	0.3		1.0			1.6
3.50 ~3.99							0.3			0.3
4.00 ~				0.3						0.3
Total		2.6	21.5	36.3	12.5	3.9	17.7	5.5		100.0

Jan. 1987 ~ Sep. 1987 (%)

$H_{1/3}$(m) \ Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	Total
0.00 ~0.49				0.6			0.6	0.6		1.7
0.50 ~0.99		1.1	8.0	10.9	2.3		1.1	5.1	0.6	29.1
1.00 ~1.49			14.3	9.7	1.7		1.7	10.9	0.6	38.9
1.50 ~1.99			5.7	5.7				7.4		18.9
2.00 ~2.49			1.7	1.1				4.0		6.9
2.50 ~2.99			1.1					0.6		1.7
3.00 ~3.49								1.1		1.1
3.50 ~3.99			0.6							0.6
4.00 ~										
Total		1.1	31.4	28.0	4.0		3.4	30.9	1.1	100.0

dominates southward by wave incidence from NE, and northward from SE or SSE, respectively because the direction normal to the mean shoreline is ENE. As is mentioned, this coast is characterized by seasonal changes of wave direction and to this reason typical changes of the beach configurations can be seen around coastal structures.

V. RESULTS OF INVESTIGATION

5.1 Shoreline Evolution

Shoreline changes around headlands between September 8, 1986 through January 7, 1988 are expressed in Fig. 7. In this figure comparisons are made with subsequent shoreline configurations. The locations of No. 1 through No. 7 headlands are also shown at the bottom of the figure. From September 8 to October 28, the shoreline retreated on almost all area except adjacent part north of No. 1 and No. 4 headlands which had been already constructed at that time. This recession of the shoreline is thought to be caused mainly by the cross-shore sediment transport by high waves which attacked the beaches with the significant wave height over 5m on October 9 as shown in Fig. 6. On the other hand, the local advance on the north part of No. 1 and No. 4 headlands may be caused by the accretion due to the southward longshore transport by waves approaching from counterclockwise direction

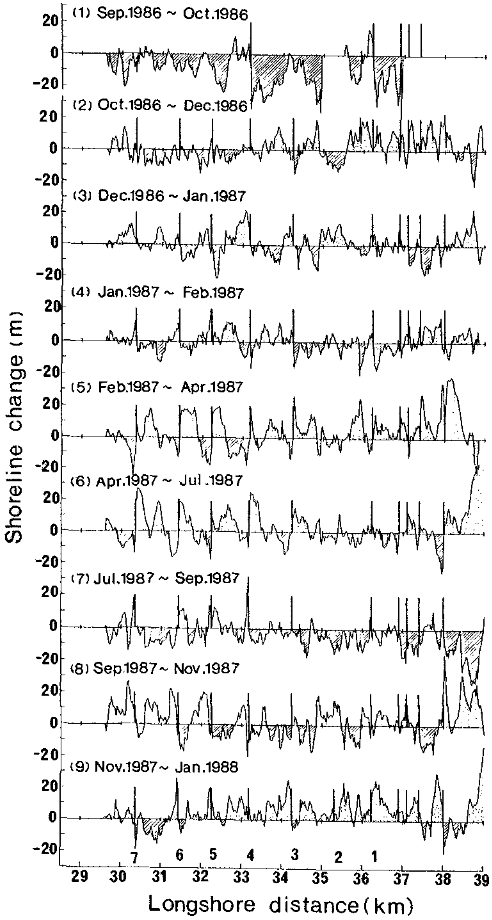


Fig. 7 Shoreline change between September, 1986 and January, 1988 measured from the aerial photographs.

to the normal of the shoreline. Between October 28 and December 24, any typical feature of shoreline evolution did not appear, only accompanying with some local erosion or accretion. From December 24 to January 17, as seen especially around No. 3, No. 4 and No. 7 headlands, the shoreline retreated on the south side in contrast to the advance on the north side of these headlands. These phenomena of the shoreline change were induced by the southward longshore sediment transport resulting from the wave incidence from the counterclockwise direction to the normal of the shoreline, corresponding to the wave approach from NE to ENE on the study coast. On the contrary, the shoreline changes occurred between February 13 and April 13, and between April 13 and July 23 are entirely reversed to the above, i.e., the shorelines advanced greatly on the south (right) side but retreated on the north side of each structure. This is due to the wave approach from the predominant direction of SE to SSE through spring to summer. Then, remarkable changes of the shoreline did not appear between July 23 and September 12, but from September 12 to November 6 the shoreline advanced again on the north side and retreated on the south side of each structure. These characteristics of shoreline changes are the same as the ones between December 24, 1986 and January 17, 1987. Consequently, it is found that the shoreline between headlands are dynamically stable with periodic fluctuations of the amplitude of about 40m.

The above-mentioned periodic fluctuations of shoreline configuration between headlands are recognized on the north coast in the same Ibaraki Prefecture (Uda et al., 1986 a,b). Taking into consideration of these facts, it is considered that this shoreline evolution represents a general features along the Ibaraki Coast facing the Pacific Ocean.

A reversal mode was observed on south and north sounding lines near a certain headland. This change is due to the periodic change of incident wave direction. In the following these phenomena will be examined in detail on the basis of temporal change of shoreline position on both survey lines of 25m away from No. 6 headland (Fig. 8). In the figure solid and open circles represent the shoreline positions on the south and north lines, respectively, including the shoreline position before the construction plotted as a broken line. There is little difference in the shoreline change before the construction on both lines, whereas the shoreline position advanced on the north side and retreated on the south side between January and February, 1987 after the construction of the headland. Then, the opposite mode of the shoreline change was observed until August resulting in large advance of the shoreline on the south side. Moreover, between August and December appeared again the recession of the shoreline position on the south side. The reasons of above mentioned cyclic shoreline changes could be explained as follows; from autumn to winter the southward longshore sand

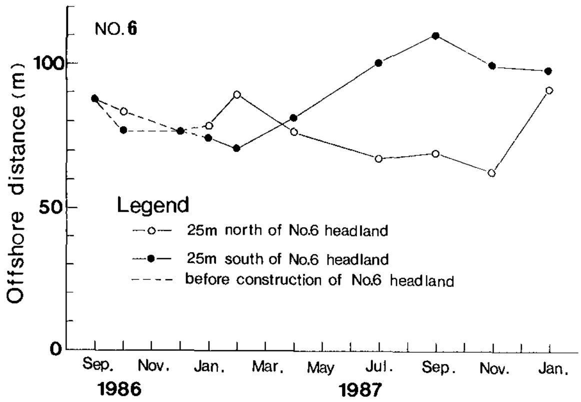


Fig. 8 Temporal change of shoreline position in the vicinity of No.6 headland.

transport prevails by the incident waves approaching from NE or ENE to this coast and then the obstruction of longshore sediment transport by the structures produces the progression of the shoreline on the north side. On the contrary, from spring to summer northward longshore sediment transport is caused by the predominant waves from SE or SSE, which is clockwise to the normal of the coastline. Then shoreline position progrades on the south side of the structure.

5.2 Comparison of Aerial Photographs Around Headlands

Shoreline configurations will be investigated in detail, selecting No. 7 headland as a typical example. Aerial photographs were taken five times between January 17 and September 12, 1987 around No. 7 headland.

The shoreline on January 17, 1987 is shown in Photo 1. Taking into account of the headland length of about 80m, it is seen that the sea is very calm and the surf zone width is narrow. This calm wave condition coincides with the characteristics observed in Fig. 6. Comparing the shoreline configuration on both sides of the headland, the shoreline on the right (south) side retreats a little more than that on the left (north) side. It shows a resultant beach change caused by the weakly-oblique wave incidence from the counterclockwise direction to the normal of the shoreline. On February 13 wave conditions turned rough and the whole picture were covered by the surf waves (Photo 2). This photograph is thought to represent a typical rough wave condition in winter, because wave height in February is high as shown in Fig. 6. In addition, the shoreline south of the headland retreats greatly compared with that north of headland. This fact indicates the same feature

Photo 1 Aerial photo of No.7 headland (January 17, 1987)

Photo 2 Aerial photo of No. 7 headland (February 13, 1987)

Photo 3 Aerial photo of No.7 headland (April 13, 1987)

Photo 4 Aerial photo of No.7 headland (July 23, 1987)

Photo 5 Aerial photo of No.7 headland (September 12, 1987)

observed in Photo 1. In other words, incident wave approaches from counterclockwise direction to the normal of the shoreline.

Two month later (Photo 3), the shoreline configuration on both sides became almost symmetry to the headland, and there disappeared the distinct shoreline retreat on the south side in Photo 2. It shows that the direction of incident wave turned clockwise with respect to the normal to the shoreline during these two months. In addition, low waves are supposed to be approaching to the coast judging from the occurrence of narrow surf zone. Actually low wave conditions appeared in April as shown in Fig. 6, so that Photo 3 is thought to show the typical state of the shoreline form in this season. On the other hand the shoreline on July 23, 1987 (Photo 4) represents remarkable changes; great advance on the south side and recession on the north side. The characteristics of the shoreline changes on this date are totally opposite to those on February 13. Furthermore, the wave conditions are also calm and the swell waves are clearly noticeable to approach in the offshore zone of the headland from a clockwise direction. Finally it is found that morphological changes between April and July are caused by the clockwise wave incidence.

Photo 5 represents the beach circumstances on September 12. Entire region of the photograph is covered by the surf waves, thereby high waves were clearly incoming to the beach at that time. Also in the offshore of the headland the waves approach clockwise at an angle of about 12° to the normal of the shoreline and even the tip of the headland locates within the surf zone. Since the northward longshore sediment transport dominates under the wave climate, the shoreline advanced on the south side, whereas the shoreline retreated on the north side of the structure. Consequently, it is concluded that the periodic variations of the incident wave direction throughout a year determine the direction of the longshore transport on this coast. This means that the seasonal changes of wave directions are the most important factor to consider beach deformation on this coast. Having seen in Photos 2 and 5, the tip of the headland becomes contained occasionally within the surf zone under high wave conditions. It is, therefore, possible for the longshore sediment to turn around the tip of the structures to the adjacent beaches. This means that the headland of present dimension can reduce the rate of sediment, but can not prevent from the decrease of sand volume between headlands. Taking the present situation into account, it is necessary to elongate the headlands in future.

5.3 Beach Profile Changes

Here will be described time series of the beach profile changes based on the data surveyed almost at the same time as the shoreline changes as shown in Fig. 7. Figure 9 expresses the beach profiles along the section A, where the influence of the existence of the headlands is minimum because it is located in the middle of No. 6 and No. 7 headlands. Since this section is located far from the structure, the characteristics of topographic changes due to cross-shore sediment transport can be investigated in detail.

First, from September 8 to December 24, 1986 the foreshore was eroded to form a bar-trough topography off the coast. According to Fig. 6, very high waves beyond $H_{1/3}$ = 5m attacked the coast on October 9, so that the bar-trough topography might be formed due to the offshore sand movement. Thereafter the beach had not changed so greatly untill April 14, but changed remarkably between April 14 and July 8; offshore bar receded as well as sand accumulated on the foreshore. This topographic change has a reverse mode against the pattern occurred between September 8 and December 24. Furthermore the critical depth to which the erosion or accretion occurs near the foreshore agrees well with about 3m in both cases. During the period between April and July mainly calm sea conditions continued with the significant wave height less than about 2m except on June 19 with the height of $H_{1/3}$ = 4.3m. Considering these calm wave conditions, it may be concluded that the profile change illustrated in the figure was caused by the onshore sand transport. After that, the whole beach profiles tend to retreat slightly until November 6.

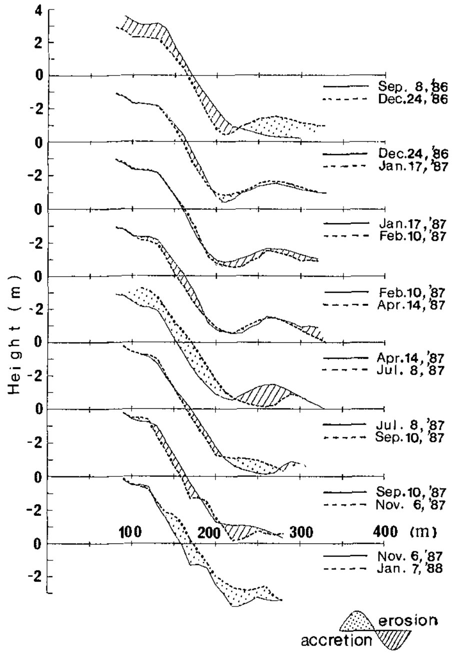
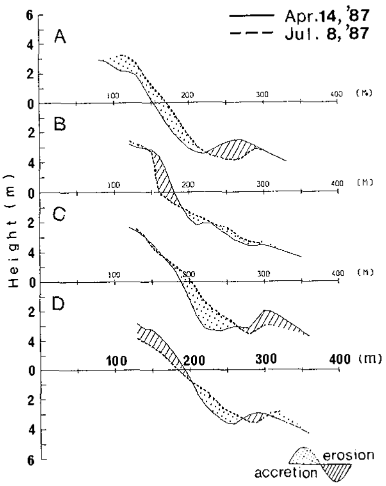


Fig. 9 Temporal profile change along section A.

Comparing the profile on September 8, 1986 with the one on September 10, 1987, both shoreline positions and beach profiles are almost the same each other and therefore it is found that the eroded beach retrieved into the previous state after one year. It should be noted that on this



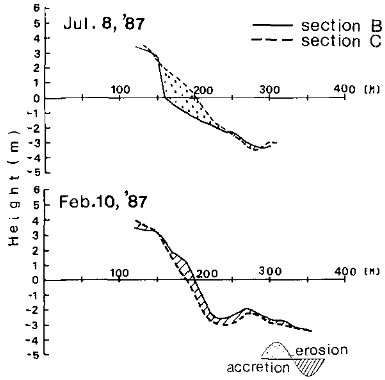


Fig. 11 Comparison of beach profiles on both sides of No.6 headland between February and July in 1987.

Fig. 10 Spatial and temporal profile changes along section A through D measured between April and July in 1987.

coast the following two types of sand movement can be observed; the variation of the longshore sediment transport caused by the periodic changes of wave direction and the change of cross-shore sediment transport due to wave climate change.

As shown in Fig.7, the shoreline on the north side of the structure retreated between April 13 and July 23, 1987. The typical profile changes in this period are illustrated in Fig. 10. On the section C just south of the headland of No. 6, sand accumulated near the shoreline to form the gentle slope of the foreshore, and in addition the accreted area extends to the depth of about 3m. On the contrary, on the section B located in the symmetric position with respect to the headland, the area shallower than the water depth of 1m was eroded to form a steep slope of the foreshore, whereas beach slope of the offshore zone becomes mild. These accretion-erosion pattern of topographic changes having opposite features on both sides of the headlands indicate that the beach changes are caused mainly by the longshore transport. On the other hand, on the section D, 375m south from No. 6 headland, the foreshore was eroded to form a gentle slope similar to the section C.

In order to examine the extent of the obstruction of longshore sand transport by the headlands, it is preferable to compare the spatial profiles on both sides of the structure rather than to examine the temporal changes of profiles as shown in Fig. 10. Because the influences of the structure to surrounding topography can be well understood by superimposing each others, since the two sections next to the headland should have the same profile before the construction of the headlands.

Figure 11 represents the superimposed profiles the sections B and C measured on February 10 and July 8, 1987. The former date is in the period when the southward longshore sediment prevails as shown in Fig. 7. The shoreline position on the section B north of the headland advances more than that on the section C, and the sand obviously accumulates in the region shallower than the depth of 3m deep, but at further offshore zone both profiles nearly coincide with each other. Taking the tip depth of about 2m into account, the above accretion shows that the effect of the headland extends to the region somewhere offshore from the tip of headland.

The similar comparison will be made with regard to the profiles on July 8, when the northward longshore transport was predominant. The shoreline position on the section C south of the structure is located further offshore than that on the section B, resulting in the quite opposite to the case of February 10. The foreshore slope on the section B is steeper than that on the section C, and also the region shallower than 2m deep is eroded, but almost coincides with the section C in further offshore zone.

Consequently, it is concluded that the headlands on this coast are effective for controlling sediment movement in a zone shallower than 2m because the tip of the headland is about 2m, although sediment may pass through around the tip of the headland. Nevertheless, it can be said that this headland is useful at present stage in reducing the longshore sediment transport rate.

VI. CONCLUSIONS

(1) Eleven headlands were constructed in order to prevent further extention of beach erosion and to form the dynamically stable beach on the Ohno·Kashima Beach. The variation of the shoreline position can be reduced by the effect of the construction of these headlands in the field where seasonal change of the wave direction dominates.

(2) The periodic changes of the shoreline configuration corresponding to seasonal change of the wave direction have been observed along the other coast facing Pacific Ocean in Ibaraki Prefecture such as the Joban Coast or the Ajigaura Beach. From these facts, the characteristics mentioned above may be considered as a typical example of the beach changes along the Eastern Coast of Japan.

(3) The depth at the tip of the headland is about 2m. Comparing beach profiles on both sides of headland, there exist differences in the region shallower than about 3m. Therefore the region where longshore sediment transport is remarkably obstructed by the

headlands is thought to be the region up to a location of about 3m deep.

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