ANALYSIS OF BEACH EROSION AROUND LARGE-SCALE COASTAL STRUCTURES

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ABSTRACT

The coast of Ibaraki Prefecture, facing the Pacific Ocean, has an alongshore stretch of 181 km. On this coast many structures associated with harbors have been constructed since early 1960s. Since then 25 years have passed, and some notable beach changes due to the influence of the construction of the coastal structures have been observed. This study aims to examine the actual situation of the beach change around large-scale structures and the damages of the coastal structures selecting the coast of Ibaraki Prefecture as the study area. For the purpose aerial photographs were taken along the coast, and the topographic surveys and measurements of median diameter of beach-face materials were made. Data of the soundings having been conducted once a year since 1975 around Oharai Port and Hazaki Fishery Harbor were collected in order to study the beach changes around the large-scale coastal structures. For the analysis of these data the comparison of the shoreline changes were performed by using four sets of aerial photographs since 1947 to the present. Moreover, temporal and spatial changes of the beach topography were investigated by the sounding data.

I. INTRODUCTION

In recent years beach erosion is severe in Japan due to the influences of the decrease of the fluvial sediment supply from rivers and the construction of various large-scale coastal structures built on the coast. Generally the beach should change its form to attain to the new equilibrium condition because the movement of littoral drift is restricted, when coastal structures are built on a coast dominating littoral drift. For the countermeasures against beach erosion concrete armour units have been frequently placed along the coastlines. Furthermore, they have been often placed at the downdrift side of the most severely eroded location, and sometimes deep consideration of keeping the stable beach is lacking. Continuous placement of concrete blocks along the coast brings about the disappearance of the natural sandy beach. These situations can be seen on many Japanese coasts.

The aim of the study is to examine the actual situation of the beach change around large-scale structures and the damages of the coastal structures selecting the Ibaraki Coasts as the study area. On the coast many structures associated with harbors have been constructed since the early 1960s. Since then 25 years have passed, and some notable beach changes due to the influence of the construction of the harbor structures

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have been observed. In this study the actual situation of the beach erosion on the Ibaraki Coast is investigated using the topographic survey data, aerial photographs and coastal pictures taken in the past.

II. METHOD OF INVESTIGATION

The investigated region of 181.4 km long extends from Ohtsu Fishery Harbor to the mouth of the Tone River (Fig. 1). The region is separated into two coasts: Joban Coast north of Oharai Port and Kashimanada Coast south of the port. First, aerial photographs were taken along the coast, and the soundings and the samplings of beach-face materials were conducted between Oharai Port and the mouth of the Tone River. Second, the sounding data in the past were gathered in order to compare the past with the present state of the beach at three locations around Ohtsu Fishery Harbor (①), Oharai Port (②) and Hazaki Fishery Harbor (④) as expressed in Fig. 1, where the beach was recently eroded to a large extent. The changes of the shoreline positions along the coast were measured from the aerial photographs having been taken 4 times between 1947 and 1984. Temporal and spatial changes of the shoreline positions were also examined at locations where sounding data in the past were obtained. On the north coast of Kashima Port (③ in Fig. 1), pictures of the beach taken in the past were gathered in order to examine the beach condition qualitatively.

III. BEACH EROSION ALONG THE JOBAN COAST

The shoreline changes between Ohtsu Fishery Harbor and Hitachi Port along the Joban Coast are investigated. The shoreline positions were degitalized at 50 m intervals continuously from the aerial photographs, and the changes of the shoreline positions during each subsequent period are calculated (Fig. 2). Regarding the general condition of the coastal landform, there protrude some capes between Ohtsu Fishery Harbor and Unomisaki Cape, and the sandy beaches extend between these capes. The coasts south of Unomisaki Cape generally consist of the coastal cliffs, but locally there exist narrow sandy beaches. For instance, the sand spit is formed around Kawarago Port because of the shelter effect of the offshore rocks[1]. The shoreline changes at locations north of Unomisaki Cape are comparatively larger than those between Unomisaki Cape and Ohse Fishery Harbor, which is mainly due to the types of the coast. The former coast consists of the sandy beach, and the latter one the cliff coast, so that the shoreline change is small. Here, the region between Ohtsu Fishery Harbor and Unomisaki Cape, showing the large shoreline changes, should be discussed in detail. In the region there are three capes, Tenpisan Cape at the mouth of the Ohkita River, Takado and Unomisaki Capes. The existence of the rocky head of the capes, projecting offshore, prevents the longshore sand movement across the head, and thereby some characteristic shoreline changes are noted.

First, it is seen from Fig. 2(a) that the shoreline retreats south of Ohtsu Fishery Harbor and it advances north of Tenpisan Cape. To the contrary the shoreline south of the cape retreats, and again the shoreline north of Takado Cape advances except the adjacent part of the cape. In addition to these changes, the same features can be observed between Takado and Unomisaki Capes. The shoreline changes as described above have a distinct feature that the shoreline north of the cape advances and that south of it retreats. The shoreline change is due to such reason that the southward longshore drift caused by incident waves from northeast was obstructed at the capes. On the other hand, it is found in Fig. 2(b) that the shoreline changes are totally reversed. Due to the field observation of wave direction having been conducted over 10 years at Ajigaura Beach located south of Joban Coast, southeastern wave direction prevails in summer and northeastern wave direction in the other seasons, and the wave direction has a periodic feature of one year[2]. Taking these features into account, it is concluded that Figs.2(a) and 2(b) designate the shoreline changes after the northeastern and southeastern wave incidences prevailed, respectively. Figure 2(c) shows the different feature from those in Figs.2(a) and 2(b). Between Tenpisan and Takado Capes the shoreline in a region next to the capes retreats and the shoreline advances at the central part of each stretch of the coast. Between Takado and Unomisaki Capes the influence of the river mouth jetty of the Hananuki River to the adjacent beach is newly observed, and the beach is eroded south of the capes and the coastal structure, and vice versa

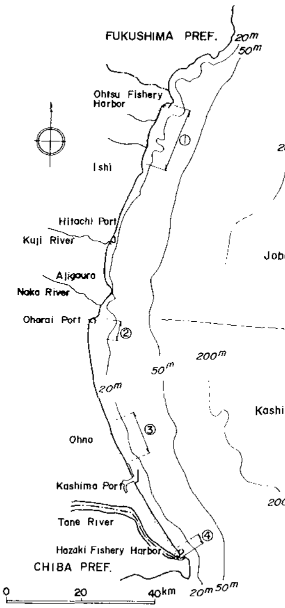

Figure 1 Investigated region along coasts in Ibaraki Prefecture.

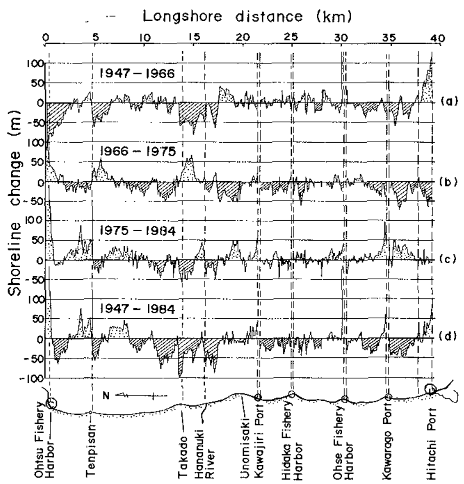

Figure 2 Shoreline changes between Ohtsu Fishery Harbor and Hitachi Port during 37 years from 1947 to 1984.

north of them. The pattern of the shoreline change differs each other. This might be mainly due to the difference of the overall direction of the shoreline configuration, assuming that the incident angle of the waves at far offshore zone is relatively small and takes almost the same value along the coast.

Regarding the shoreline change in Fig.2(d) between 1947 and 1984, the shoreline advances to a great extent on the south side of Ohtsu Fishery Harbor, whereas it retreats far from the harbor. The main cause is considered to be the influence of the construction of the breakwater as described in the following section. In addition, the shoreline retreats in south and north regions around Takado Cape, but the cause of the extensive beach erosion is not known at present.

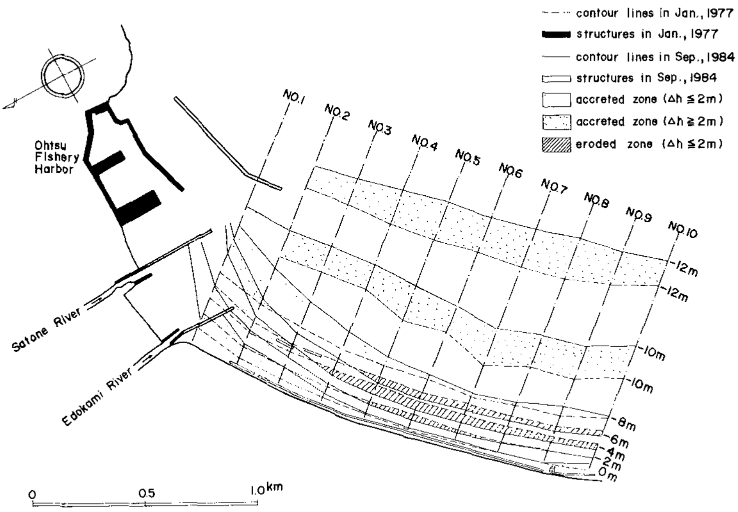

Figure 3 Changes of some contour lines around Ohtsu Fishery Harbor.

Since it is found that the shoreline change is large around Ohtsu Fishery Harbor, the change of the bottom contours is compared as shown in Fig.3, using the sounding data obtained in 1977 and 1984. The construction work of the offshore breakwater finished in 1974, and thereafter large amount of sand accumulated on the southwest side of the harbor. On the other hand, the beach up to 6 m deep below the mean sea level was eroded at No.5 through No.10. The beach erosion at No.7 is so severe in recent years that the coastal revetment fell down in 1983. In the same figure the contours of 10 and 12 m deep have a large change, but they are thought to be the error accompanied with the bottom sounding and not to be the significant change of the beach, considering that large onshore-offshore change of the contours could be observed at a small depth change at the mild slope beach, and that the contours advanced in all region without the difference of the locations. The beach changes stated above are considered to be caused by the influence of the construction of the breakwater, taking the facts into consideration that sand accumulate inside the harbor and the beach far from the breakwater is eroded. Namely, the nearshore circulation directing toward inside the harbor from outside the shadow zone of the breakwater may develop due to the existence of the offshore breakwater, and the current induces the sand movement toward the lee of the breakwater[3].

In constructing the harbor structures it is necessary to perform the countermeasure works rapidly to prevent the adjacent beach from being eroded. It is ineffective to place the wave breaking works after the initiation of the beach erosion. There are some countermeasure works to be selected. For example, some groins can be constructed to prevent longshore sand movement from outside the harbor and to form a stable shoreline, of which tangent is at right angles with the incident wave direction.

IV. BEACH EROSION ALONG THE KASHIMANADA COAST

The shoreline change along the coast is expressed in Fig.4 with reference to that in 1947. Since there exists Kashima Port at the central part of the coast, the shoreline changes around the port are not shown in the figure. The construction of the breakwater of Kashima Port began in 1963[4], and almost completed in 1976. Regarding the shoreline changes between 1947 and 1965, the beach at 3-4 km south of Oharai Port was eroded locally, and the shoreline tends to advance to the location, of which longshore distance is around 26 km. In further south the shoreline has a tendency to be eroded

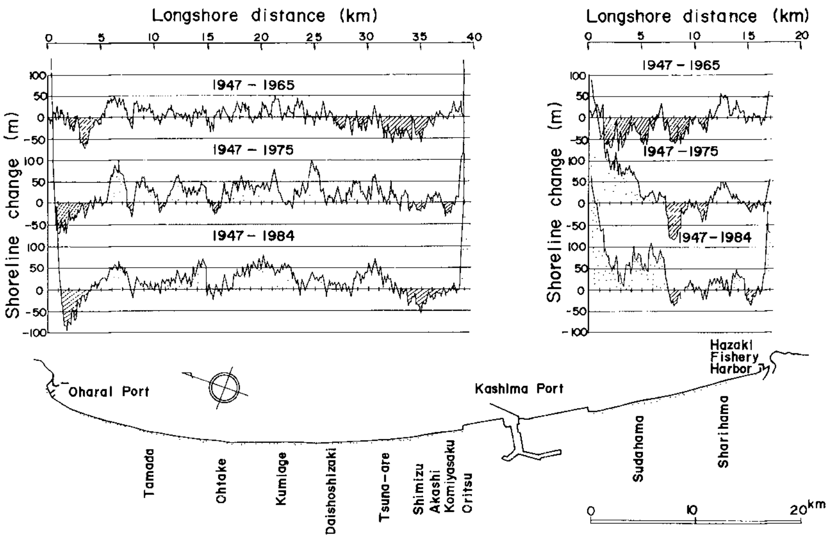

Figure 4 Shoreline changes along the Kashimanada Coast during 37 years from 1947 to 1984.

except the vicinity of Kashima Port and the region between Hazaki Fishery Harbor and the location 5 km north of the harbor. The construction work of Kashima Port began in 1963, and therefore littoral drift could move up and down alongshore freely before 1963. As a result, it may be concluded that for an overall feature of the beach erosion the coasts between Oharai Port and 5 km south of it, and the coasts far south of the longshore distance of 26 km were eroded, and the coasts between the longshore distance of 5 through 26 km were accreted. On the shoreline change around Kashima Port some local changes due to the influence of the existence of the breakwater may be considered to superimpose over the large-scale beach changes as described above.

Comparing the shoreline changes in 1947 and 1975, it is found that the shoreline advanced around 300 m on the south side of Kashima Port. This is due to the artificial nourishment of sand produced by the excavation of the Harbor[4]. Regarding the shoreline changes between Oharai and Kashima Ports, the shoreline tends to advance generally, whereas the shorelines south of Oharai Port and in the vicinity of Kashima Port retreat.

On the shoreline changes between 1947 and 1984, the amount of the retreat increases at the south coast of Oharai Port and the north coast of Kashima Port. Between Kashima Port and Hazaki Fishery Harbor part of sand nourished on the south side of the harbor may have moved southward, and the shoreline inside Hazaki Fishery Harbor advanced to a great extent. Consequently, it is concluded that the littoral cell along the coast was separated into two portions by the existence of the breakwater of Kashima Port, although before the construction of the harbor there existed a northward longshore drift south of the location, of which longshore distance is about 26 km.

In order to study the cause of the shoreline change, wave directions measured at Oharai and Kashima Ports are investigated (Fig.5). The wave gauges of both positions are placed at a depth of around 20 m off the coast as shown by the solid circles in the figure. At Oharai Port the wave data from January, 1980 to February, 1982 are referred[5),6)], and at Kashima Port those in 1980 are used[7)]. The ratio of the period when the wave data were obtained to the total period at Oharai Port is 24%, considering the significant wave height over 1 m, and that at Kashima Port is 97% with regard to the total period. It is clearly understood from Fig.5 that the dominant wave direction is from ENE at both locations. This means that waves are incident from counterclockwise direction with respect to the normal to the coastline in the vicinity of Oharai Port and from clockwise direction near Kashima Port. These wave incidences induce southward and northward longshore transport, respectively, at both locations.

Next, seasonal changes of significant wave height and wave period are examined based on wave observation data of Onahama Port, Ajigaura Beach and Kashima Port during January, 1980 and February, 1982[8),9),10)]. Mean wave height ($\bar{H}1/3$) and wave period ($\bar{T}1/3$) averaged monthly are expressed in Fig.6. Significant wave height measured at Kashima Port is slightly larger than those at two other locations, but almost similar seasonal changes of wave height are observed at Onahama Port and Ajigaura Beach. In summer and winter $\bar{H}1/3$ takes on around 1 m, and in spring and autumn it increases to about 1.4 m. The difference of wave period between three locations is relatively small, and dominant wave period is about 7-8 sec.

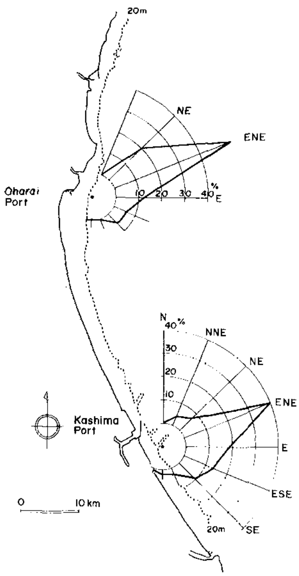

Figure 5 Wave directions at Oharai and Kashima Ports.

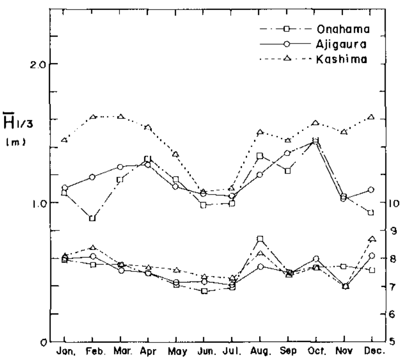

Figure 6 Monthly change of the averaged significant wave height and wave period at Onahama Harbor, Ajigaura and Kashima Port.

In the present study the topographic surveys and the sampling of beach-face materials along the Kashimanada Coast have been carried out. Corresponding to the advance or retreat of the shoreline position, the foreshore slope and the median diameter of the bed materials on the foreshore have also changed to a great extent. Using the topographic survey data, the foreshore slope, defined by the mean slope between 1 m above the mean sea level and 1 m below it, is calculated (Fig.7). The foreshore slope is steep between Oharai Port and the Tamada Coast. On the south of the coast mild slope of around 1/70 continues to the Daishoshizaki Coast, and again the beach slope steepens near Kashima Port. On the south of Kashima Port the beach slope is mild, but again the slope steepens in the vicinity of Hazaki Fishery Harbor. Comparing the foreshore slope with the shoreline changes between 1947 and 1984 shown in Fig.4, it is found that the foreshore slope steepens in the eroded region and it becomes mild in the accreted region. In the comparison between the shoreline change and the foreshore slope, it should be noted that the region of steep foreshore slope is wider than the one where the shoreline actually retreated. This may be partly due to the relatively low accuracy of measurement of the shoreline position, and partly due to the fact that actually the foreshore slope begins to steepen before the change of the shoreline position accompanying with the beach erosion.

The longshore distribution of the median diameter of beach face materials sampled along the shoreline is also expressed in Fig.7. The median diameter takes a

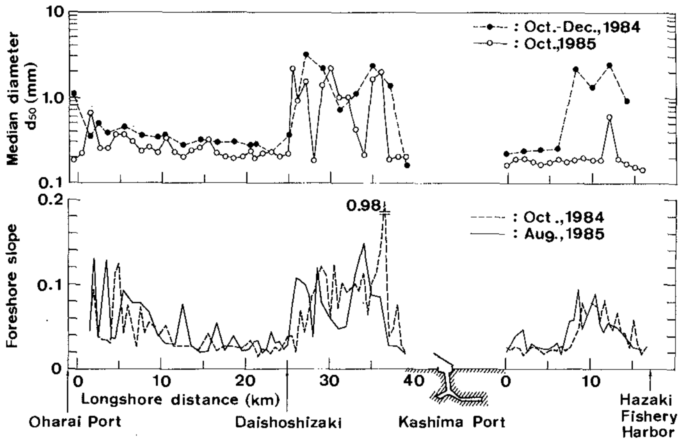

Figure 7 Longshore distribution of median diameter (d_{50}) and foreshore slope along the Kashimanada Coast.

large value between Oharai Port and 5 km south of the port, and the same between the Daishoshizaki Coast and Kashima Port. The median diameters between these areas are fine, that is, $d_{50}=0.2$-0.3 mm. Coaser materials are found between Hazaki Fishery Harbor and the location 10 km north of the harbor, and on further north coast fine materials are seen again. It is found from Figs.4 and 7 that the longshore distribution of the median diameter corresponds well with that of the shoreline change, because large and small grain sizes are found on the eroded and accreted beaches, respectively. It is also understood from Fig.7 that coaser materials can be found on steep beaches. This reason is given by the sorting effect of bed materials due to waves, in which finer materials are carried away first and coarser materials are left on the eroded beach. Furthermore, the region of steep foreshore slope extends in the longshore direction through 1984 and 1985. This means that the eroded region extended in the longshore direction, taking the fact into consideration that the foreshore slope steepened on the eroded beach. It is clear that the foreshore slope and the median diameter on the foreshore become good parameters on judging whether the beach has been eroded or not.

V. DETAILED ANALYSIS OF BEACH CHANGES AROUND COASTAL STRUCTURES

In previous chapter the overall features of beach changes along the Kashimanada Coast were discussed. In the analysis some notable beach changes were observed in the vicinity of Oharai and Kashima Ports, and Hazaki Fishery Harbor. In the following the beach changes of each region will be studied in detail.

5.1 Beach changes around Oharai Port

Oharai Port has been annoyed with the deposition of sand for a long time[3]. The extent of the beach change increased with the completion of the offshore breakwater having been constructed until July, 1984 in order to enlarge the port facility. The shoreline changes of each year with reference to the shoreline positions in April, 1978 are shown in Fig.8. On the coast the wave incidence from ENE dominates as in Fig.5 and in the lee of the breakwater the breaker height lowers, so that clockwise nearshore circulation may develop behind the breakwater and sand accumulate from outside of the port to inside of it. Particularly the accreted zone has expanded southward since the beginning of the construction work of the offshore breakwater in September, 1981. At the same time the beach south of No.9 was eroded. A large part of the eroded sediment may be considered to be transported toward the harbor, taking into consideration that the retreat of the shoreline position decreases with the distance from the port. Moreover, it is found from Fig.8 that the retreat of the shoreline position is much

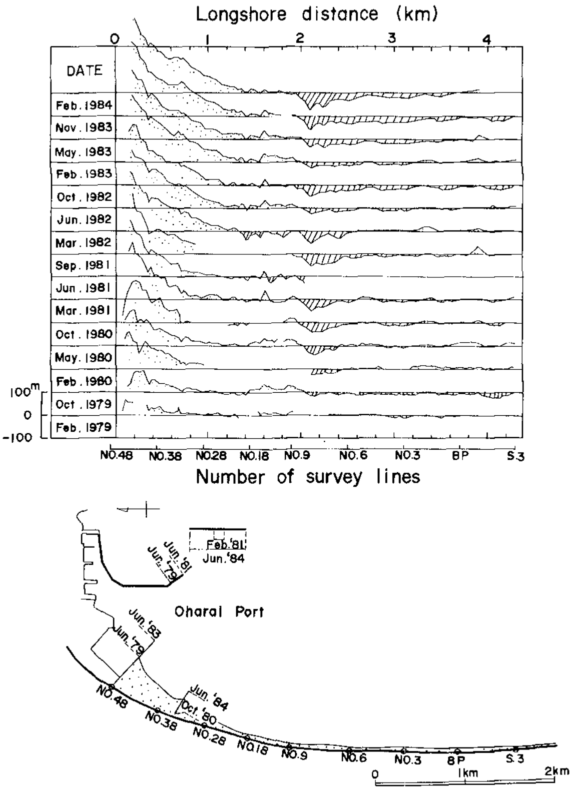

Figure 8 Temporal and spatial change of shoreline position around Oharai Port.

smaller than the advance. This may be interpreted by the reason that high beach cliff was formed by the erosion and therefore the sand supply from the cliff into the sea was large enough not to bring large retreat of the shoreline. The beach erosion is severe between No.9 and No.3 in Fig.8. The coastal revetment fell down over around 300 m long at No.6 in the midst of the region since 1984 due to the beach erosion.

Finally the actual situation of beach erosion will be studied using pictures taken on the coast. Due to Picture 1 taken on the south of Oharai Port in July, 1984, a large amount of sand accumulate inside the harbor accompanying with the construction of the offshore breakwater. In June, 1984 there was a wide beach in front of the coastal revetment at No.6 south of Oharai Port, so that the revetment was stable (Picture 2). Then abrupt change occurred, the foreshore totally disappeared on October 5 in the same year, and the foot of the coastal revetment was exposed to the wave uprush (Picture 3). Finally on February 27, 1985 the revetment fell down (Picture 4) and beach cliff of around 5 m high was formed on the natural sandy beach next to the position of the revetment. It is understood that the coastal revetment may be fallen down easily when the foreshore disappears due to the beach erosion.

Picture 1 Aerial photogragh of Oharai Port taken in July, 1984.

Picture 2 Situation of the beach at survey line No.6 in June, 1984.

Picture 3 Same location as Picture 2. The picture was taken on October 5, 1984.

Picture 4 Same location as Picture 2. The picture was taken on February 27, 1985.

5.2 Beach changes north of Kashima Port

The north coast of Kashima Port has been eroded and particularly the beach erosion was severe in the summer and autumn of 1986, because high waves generated by the tropical storms attacked the coast frequently. In this study many pictures, showing the historical changes of the beach since 1938, were gathered. In order to examine the beach condition qualitatively, the pictures are compared. Picture 5, taken in July, 1980, shows the situation of the beach at the Akashi Coast (For location, see Fig.4) adjacent to Kashima Port. At this stage wide foreshore extends in front of the coastal revetment, and the vegetations can be seen on the foreshore, expressing that the beach has been stable for a fairly long time. On September 15, 1986, the foreshore totally disappeared as shown in Picture 6 due to the beach erosion. These change may be attributed to the beach erosion caused by the imbalance of the littoral transport. Because at the south of the coast a large breakwater of Kashima Port is located, and the northward longshore sediment transport is obstructed at this location.

Picture 5 Situation of the beach of the Akashi Coast north of Kashima Port in July, 1980.

Picture 6 Same location as Picture 5. The picture was taken on September 15, 1986.

5.3 Beach changes around Hazaki Fishery Harbor

The construction work of the breakwater of the fishery harbor began in 1974 at Hazaki next to the mouth of the Tone River. The breakwater was elongated year by year, and until 1984 south and north breakwaters had been completed (Fig.9). With the elongation of the breakwater sand accumulated inside the harbor, and at the same time the north coast of the harbor was eroded. The temporal and spatial changes of the shoreline positions can be examined as shown in Fig.9 because the topograghic surveys around the harbor have been conducting twice a year since 1974. In September, 1976 the lengths of the north and south breakwaters were elongated until about 470 m and 360 m respectively. During the period the shoreline advanced in the vicinity of both breakwaters. On the other hand, the beach between No.12 and No.26 north of the breakwater was eroded. Thereafter both breakwaters were further elongated in the offshore direction until January, 1981 and simultaneously the shoreline inside the harbor gradually advanced. Furthermore, the eroded region extended north over No.0. The

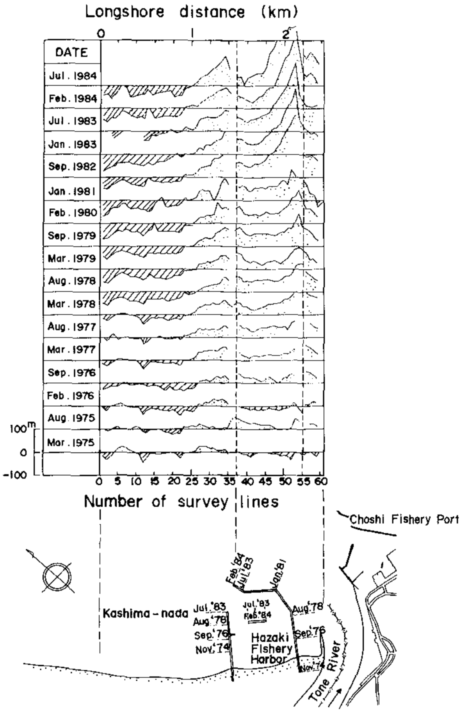

Figure 9 Temporal and spatial changes of shoreline position around Hazaki Fishery Harbor.

breakwater was elongated normal to the direction of the shoreline until January, 1981. During 1981 and 1984 the parallel part of the breakwater was constructed and the north breakwater was also elongated. With these construction works, the shoreline inside the harbor advanced to a great extent to reach to 263 m at maximum. The shoreline on the north side of the harbor advanced with the elongation of the breakwater, but the amount of the advance is smaller than that inside the harbor. The cause may be given by the following reason. First, the predominant direction of the littoral transport is considered to be northwestward at the coast, judging that the eroded zone extended in the northwest direction. In other words, the diminant wave is incident from clockwise with respect to the normal to the initial shoreline. Under such a condition of wave incidence, longshore current directing southeast develops in the lee of the breakwater, and sand accumulate on the north side of the breakwater. Regarding the cause of the beach changes inside the harbor, not only the littoral drift turning around on tip of the breakwater due to the mechanism, but also the deposition of a part of the sediment outflow from the Tone River is thought to be important. Because it is not until 1981, when wave condition inside the harbor was getting calm by the construction of the offshore breakwater, that the shoreline advanced quickly.

VI. DISCUSSIONS

In the previous chapters the actual situation of large-scale beach erosion along the Ibaraki Coast were studied. The types of the beach erosion are separated into two groups. The first is the case, in which the distributions of wave height and wave direction vary due to the influence of the construction of the breakwater first, and hence the beach changes are induced by the littoral drift corresponding to the changed distributions of wave height and wave direction. The second is the case, in which beach change is caused by the obstruction of the longshore drift accompanying with the construction of the coastal structure on a coast, where dominant littoral drift in one direction exists. The former includes the beach changes around Ohtsu Fishery Harbor or Oharai Port, and the latter is the case around Kashima Port or Hazaki Fishery Harbor. Comparing both types, it is considered in the first case that the beach erosion might be confined in a comparatively narrow region, and the construction of a structure to control littoral drift such as a groin is effective for the measures against the beach erosion, if the structure is built in time. To the contrast in the second case the countermeasure work is considerably difficult. If a structure obstructing littoral drift is built along the coast of a long stretch, where littoral transport is dominant and the continuous movement of littoral drift is cut, then there is a high possibility that its influence expands extensively in a long term. In this case the shoreline will change its form to attain to the equilibrium state, in which the normal to the shoreline becomes paralell with the wave direction at the breaker line.

In Japan the sand bypassing method is conducted only experimentally for the measures to ensure the continuity of littoral drift. It is not used for a general method, and therefore it is impossible to maintain the continuity of littoral drift artificially at present. Instead of the sand bypassing method, groins and detached breakwaters are widely used for the countermeasure works against the beach erosion. In other case concrete armour units or coastal revetments are merely set along the shoreline. In selecting the former method, if once a structure is built along the coast to obstruct the littoral drift, the beach erosion will extend to the downdrift coast. In order to prevent further beach erosion many structures of some longshore intervals have to be built along the coast. Furthermore, the selection of the latter case is not effective only for maintaining the sandy foreshore. The sandy coast of a long stretch will disappear and the sandy beach will be finally replaced by the concrete armour units, since the eroded region extends alongshore gradually. Taking these points into account, fundamentally it is important to consider the method to ensure the continuity of littoral drift. However it is difficult to select the plan for the present because the sand bypassing method is not acknowledged for the countermeasure works in Japan. In addition, it should be noted that the eroded region will extend further with the time elapsing. For the second selection of the measures, a method is considered, in which some coastal structures are built on the coast and the coast is altered to such a coast of stable planform, even if the littoral drift from downdrift end of the structure located on the updrift side becomes zero. At least wider beach could be kept by the method compared with the way using concrete armour units setting along the shoreline.

VII. CONCLUSIONS

Main results of this study are summarized as follows:

(1) Cyclic beach changes of accretion or erosion were observed on both sides of the headlands located between Ohtsu Fishery Harbor and Unomisaki Cape. The cause is considered to be due to the fact that the predominant wave direction changes seasonally from northeast to southeast on the coast.

(2) Severe beach erosion and accretion were caused by the elongation of the offshore breakwater at Ohtsu Fishery Harbor and Oharai Port.

(3) Along the Kashimanada Coast beach erosion is severe at the south site of Oharai Port, the north of Kashima Port and Hazaki Fishery Harbor. It is found quantitatively that the slope of the beach face becomes steep and the armouring of the bed materials on the shore is under way on the eroded beach on the downdrift side of the structure.

(4) A large amount of sand accumulated inside Hazaki Fishery Harbor with the elongation of the breakwater. Especially the shoreline advanced very much after the completion of the construction work of the parallel offshore breakwater with respect to the shoreline. Regarding the cause of the beach changes inside the harbor, the deposition of a part of the sediment outflow from the Tone River is considered to be important because of the formation of the calm water inside the harbor.

(5) The types of the beach erosion along the Ibaraki Coast are separated into two categories. The first is such a case that the beach changes are produced by the littoral transport induced by the longshore changes of wave height and wave direction, which are caused by the influence of the construction of the breakwater. The second is the case, in which the beach change is caused by the obstruction of littoral drift due to the construction of the coastal structure. For the first case, the construction of a coastal

structure to control littoral drift like a groin is effective for the measures against beach erosion, if the structures are built in time. For the second case fundamentally it is important to consider a method to ensure the continuity of littoral drift, and if not, a method to form the shoreline of stable configuration against wave attack by the construction of a structure should be considered.

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