CHAPTER 92

CHANGES OF SEA BED DUE TO DETACHED BREAKWATERS

Osamu Toyoshima
Director, Public Works Research Institute, Akabane Branch
Ministry of Construction
Ex-Director, Sea Coast Division, River Bureau
Ministry of Construction, Japan

INTRODUCTION

Since most of the coast lines of Japanese Islands are faced on the open sea and are always attacked by severe waves, beach erosion is one of serious problems in the coastal engineering field. Although Japan has all types of coastal land-forms except the glacial shoreline, remarkable recessions of coast line have been observed at sea cliffs and sandy beaches. The recession of sea cliffs has been found at several districts in Japan since old times. But, beach erosion has become increasingly severe since the early 1950's. The main causes of beach erosion are the reduction in sediment supply from rivers and the interception of the longshore paths of sediment. The former is caused by the river improvement works and by the construction of dams and debris barriers or Sabô works. The later is caused by the coastal structures, such as jetties, groins, breakwaters, and flood-control outlets. In addition a new type of beach erosion has been observed at the coast where coast protection works such as seawalls and bulkheads exist.

The beach erosion defence works are being executed at more than 300 sites in Japan. Considerable number of the works were commenced in the 1960's.

The author proposed ten years ago a detached breakwater system to develop the sand deposition behind the breakwater. Up till now, about fifty or more works of the detached breakwater system have been constructed under the guidance of the author, and most of them have brought about succesful results. The details of the design method about a detached breakwater system were presented by the author at the fourteenth International Conference on Coastal Engineering, titled "Design of a detached breakwater system".

The paper takes an example in Kaike coast, and describes the changes of coastal protection works against beach erosion and the changes of sea bed after the construction of the detached breakwaters.

OUTLINE OF THE KAIKE COAST

Kaike, one of the most famous hot spring resorts, located on the root of the Yumiga-hama Peninsula which has been believed to be a sand spit formed by sand deposition discharged from the Hino River that fed sand to this coast.

Rough waves from the east- northeast is refracted in Miho Bay as a result of the offshore topography and configuration of the coast as shown in Figure 2. These refracted waves give rise to the longshore current in the western direction along the Yumiga-hama Peninsula.

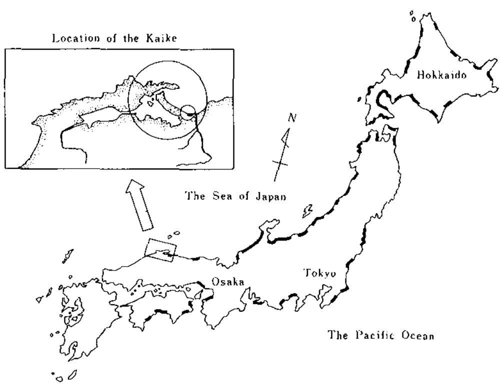

Fig.1 Location map showing the Kaike coast and sites where beach erosion has been comparatively severe.

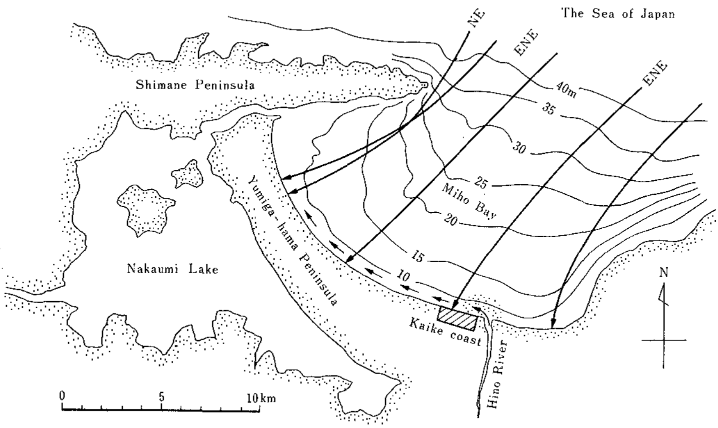

Fig.2 The longshore current formed the Yumiga-hama Peninsula in ancient times, and now-a-days it erodes the Kaike coast on account of reduction of sand supply from the Hino River.

In the early 1870's, a fountainhead of hot spring was discovered by fishermen in shore of the Kaike coast by chance. In those days, the shoreline of the Kaike coast had been advancing offshorewards year by year. In the 1910's, the former sea bed where the fountainhead of hot spring was discovered, changed into backshore, and the first spa was built on the beach. At that time, Kaike had sandy beach of width of more than 200 meters.

About 1920, iron sand collecting for Japanese traditional steel making was abandoned in the upper reaches of the Hino River. In addition to this, a number of Sabô dams and agricultural weirs were constructed along the Hino River. These facts brought a remarkable reduction in sediment supply from the Hino River and the advancing tendency of the Kaike coast turned into the receding one. The shoreline at Kaike has receded more than 200 meters during the last half century.

CHANGES IN COASTAL PROTECTION WORKS AT THE KAIKE COAST

In the face of acute construction material shortage during the World War II, an attempt was made to weaken the rate of beach recession by means of primitive crib works using pine logs which had commonly used in the river bank protection works in Japan.

Unfortunately almost of the works were destroyed soon after their completion by very strong actions of stormy waves.

Fig.3 In 1942, people in the seabord tried to weaken the longshore current by means of primitive crib works using pine logs, but these works were destroyed soon.

In 1947, after the War, Tottori Prefecture organized a research committee on the littoral drift control with experts and engineers representing the universities and central and local governments. There have never been any attempts to organize the technical and research committee concerning with the problems in the coastal engineering until the establishment of this committee.

Before the establishment of this committee, Tottori Prefecture had constructed an experimental groin composed of rubble stones on the Kaike coast. But this groin subsided under the sea water level soon after its completion.

In paralleling with the committee's research work, between 1949 and 1950, the local government constructed more five experimental groins which composed of large scale concrete blocks.

Figure 4 indicates the change in the shoreline configuration during that period together with locations of constructed groins. It is noticed from this figure that groins resulted in accretion on the updrift side and in erosion on the downdrift. However the shoreline in front of Kaike Spa advanced seawards in comparison with that before the scheme commenced. The fountainhead of hot spring, indicated in the figure, was the No. 3. Nos. 1 and 2 fountainhead, located more offshore side than the No.3, had been destroyed by the heavy beach erosion, and vanished under the sea bed before 1940.

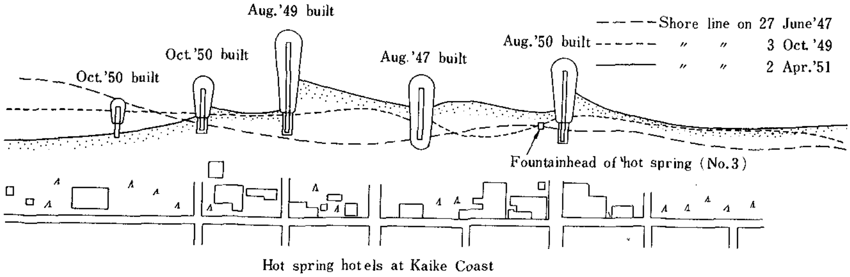

Fig.4 Five groins were constructed between 1947 and 1950 in front of the Kaike Spa. Their performances in the initial stage were very effective and shoreline advanced seaward compared with that before the construction.

Based on the proposal of the research committee and the success in the construction of groin system, Tottori Prefecture decided to construct eight groins in addition to that previously constructed. As seen in Figure 5, the function of groin system gave the satisfactory effect in 1954.

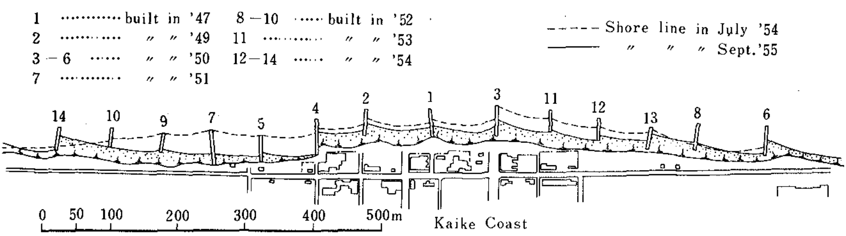

Fig.5 In the next summer after the completion of the construction of the groin system, August 1955, the Kaike coast was eroded again.

In August 1955, the Kaike coast was heavily eroded by rough waves caused by Typhoon and the shoreline was in full retreat.

Immediately after the heavy erosion due to Typhoon, Tottori Prefecture constructed seawalls along the shoreline to withstand severe wave actions. Based on the technical consideration in those days, concrete stepped face seawalls illustrated in Figure 7 have been adopted as a suitable prevention structures against beach erosion in Japan. The construction of the seawalls had been made between 1955 and 1961.

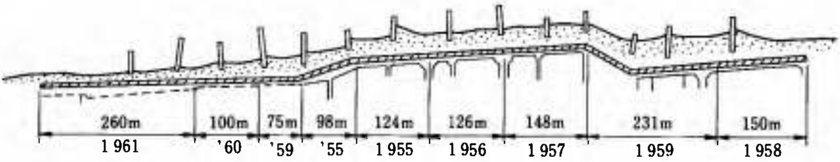

Fig.6 The seawalls have been constructed between 1955 and 1961, and most of the Kaike Spa have been protected from the severe waves by the seawalls in length of about 1300 meters.

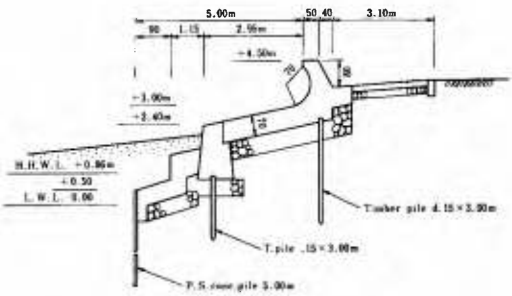

Fig.7 Concrete stepped face seawall was adopted in 1955.

For several years after the completion of the seawalls, the Kaike coast had been seen like a stable beach, where very wide sandy beach extended in front of the seawall.

Fig.8 In 1957, the Kaike beach had been seen a stable wide sandy beach. The berm height of sandy beach in front of the seawall was nearly equall to that of the crest of the seawall.

Even when the Kaike coast was seemed to be stable, a large amount of beach sediment carried offshoreward with every attack of severe wind waves in winter. As the result of wave attacks groins and seawalls on the Kaike coast were damaged locally in January 1961.

Fig.9 In December 1960, most of the sandy beach were vanished. The arrow mark on the center of the picture shows the fountainhead No.3 shown in Figure 4.

Fig.10 In January 1961, the stepped face seawall had been partly destroyed by the winter strong wave force. Waves had scoured beach at the foot of the seawall, and the body of the seawall had been scattered. The seawall had been reconstructed at once.

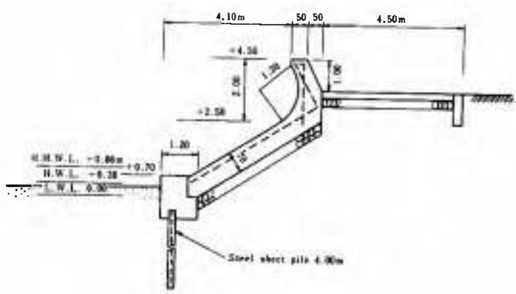

Fig.11 Reinforced inclined-face type seawall was adopted as the restored seawall.

The profile of seawall restored by the local government was an inclined-face type seawall with sandtight cutoff wall by steel sheet pile as shown in Figure 11.

After a lull in beach retrogression Kaike coast begun to retreat again in the early 1960's. Incident waves directly struck seawalls and overtopped. In order to reduce wave overtopping, wave defence works composed of artificial concrete blocks were constructed in front of the seawalls.

Fig.12 As the wave defence works, armour concrete blocks, named Hexaleg block, were piled up in front of the seawall. But a number of these blocks have sank under the sea bed (photo in 1970).

As severe waves have repeatedly hit the Kaike coast, the combination system of groins and seawalls with wave defence works has shown its inadequacy in the protection function against beach erosion. When incident waves approach normally to the shoreline, some portions of incident wave energy are reflected from the seawall.

This wave reflection results in considerable scour in front of seawalls and receding waves take away beach sediment seawards. Due to these unfavourable effects by the seawall, groins and wave defence works settled and scattered. Therefore the local government often faced to restore and reinforce the protection works on the Kaike coast. In the early 1970's, the Kaike coast severely eroded again.

Then, the author proposed to construct detached breakwaters as a countermeasure against beach erosion.

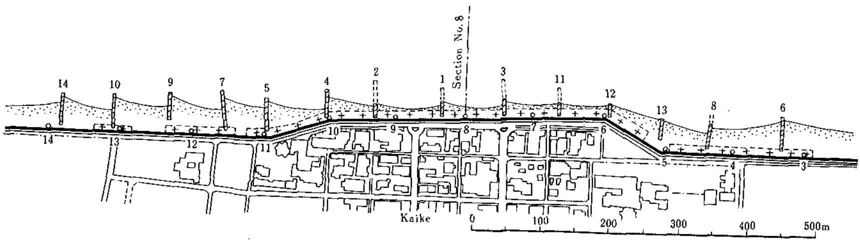

Fig.13 The shoreline of the Kaike coast in 1970.

PROPOSAL OF A DETACHED BREAKWATER SYSTEM

For more than twenty years, in Japan, as a countermeasure against beach erosion, many preventive constructions, such as seawalls and groins, have been built. However, it turned out that the seawalls and groins are not necessarily effective measures to prevent beach erosion, and that they have even accelerated beach erosion in some cases. Then the author proposed a detached breakwater system ten years ago.

This system has two major functions. One is the dissipation of incident wave energy, by which beach erosion due to wave actions can be stopped. The other is generation of diffraction waves, by which development of a tombolo, sand deposition behind a breakwater, is encouraged. A detached breakwater system consists of a group of breakwaters, parallel with the shoreline, and is usually located in the surf zone.

The first experimental work of this system was carried out at Ishizaki coast Hokkaido Prefecture under the direction of the author in 1966. Soon after the completion of the work, the tombolo was formed behind the breakwater, and the system were effective in the restoration of shoreline. Further twenty or more experimental works had been carried out on another coasts, and most of them have been successful.

Although a considerable experimental works were carried out, this system is comparatively new and there are fewer examples compared with groins. Generally, of cause, construction work of the detached breakwaters is not easy and maintenance cost is also high, when they are constructed on steep and deep sea bed.

CONSTRUCTION OF THE DETACHED BREAKWATERS AT KAIKE

The detached breakwaters at Kaike were positioned in water considerably deeper than that where the previous experimental breakwaters constructed. Therefore, the adoption and its positioning were determined after long series of field surveys and researches.

In June 1971, the construction of the first breakwater at Kaike was commenced under the direct administration of the Ministry of Construction, and was completed in September the same year. The breakwater with the length of 150 meters was constructed at the water depth of about 5 meters where was 110 meters offshoreward from the seawall. The breakwater as seen in Figure 14 was comprised of rubble stones and armoured by tetrapods.

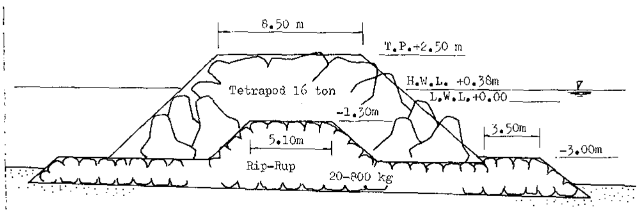

Fig.14 Cross-section of the detached breakwater at Kaike.

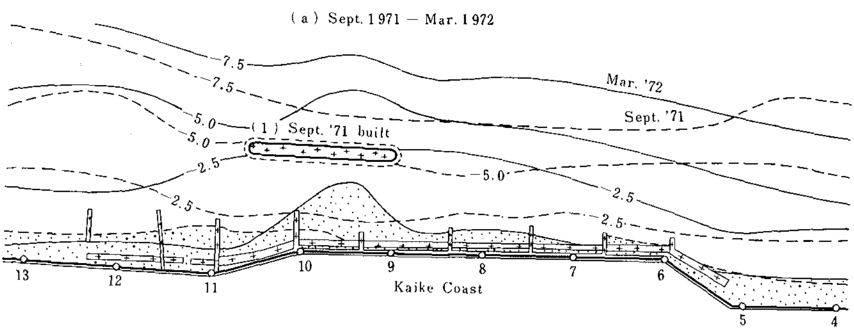

Fig.15 Changes of shoreline and equi-depth line before and after the construction of the No.1 detached breakwater at Kaike.

After the construction of the first breakwater, the tombolo was formed in front of the seawall, and every equi-depth line around the breakwater greatly advanced offshoreward in comparison with that before the construction. The thickness of deposit sand was about 4 meters at the apex of the tombolo, and about 2 meters in front of the seawall.

According to the changes of sea bed before and after the construction of the breakwater, it was estimated that most of the deposit sand was carried from the offshore sea bed at a depth of more than 12 meters.

Encouraged by the successful result of the first experimental detached breakwater, the No.2 breakwater was constructed in the following year, on the updrift side of the No.1 breakwater. The No.2 breakwater was also effective in bringing back sand transported from offshore zone and in forming a large scale tombolo behind it.

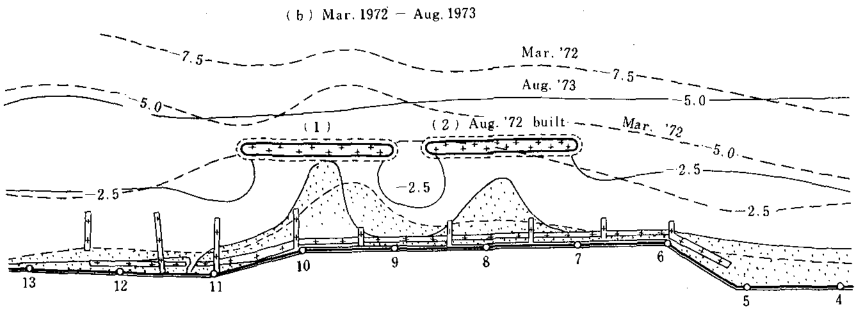

Fig.16 Changes of sea bed after the construction of the No.2 breakwater.

In progress of No.2 breakwater construction it was observed beach retrogression in the downdrift zone of No.1 breakwater. To eliminate the undesirable effect by Nos. 1 and 2 breakwater, No.3 breakwater was sited on the downdrift side of No.1 breakwater. The No.4 breakwater was in the updrift side of the No.2 breakwater in order to increase the covering area.

These two breakwaters were constructed in the following two years, and were positioned at equall spaces of 50 meters.

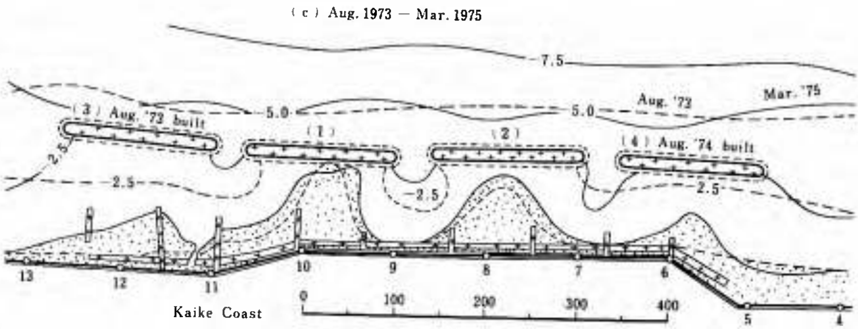

Fig.17 Changes of sea bed after the construction of the Nos. 3 and 4 breakwater.

Before the construction of the breakwaters, the shoreline has usually been retreated by attacks of strong waves in winter. But after the construction, the sand depositing action of the breakwaters has continued and tombolos have become larger in their sizes even under the severe wave condition.

At the Kaike coast, the progress of the construction of the breakwaters and changes in shoreline features have frequently been recorded by means of the radio controled model plane. From the sequential aerial photographs, we can see the development of the tombolos and the refracting wave patterns due to the breakwaters.

Fig.18 Aerial view of the Nos. 1 and 2 breakwater and tombolos by means of a radio controled model plane.

1) July 27 '72
No.2 breakwater is under the construction.

2) Aug. 24 '72
Just after the construction.

3) Sept. 11 '72
Small tombolo appears.

4) Sept. 29 '72
The tombolo grows larger gradually.

5) March 9 '73
Strong waves attack the breakwaters and tombolos.

6) April 25 '73
The tombolos are stable.

CHANGES OF SEA BED DUE TO DETACHED BREAKWATERS

In order to investigate the changes of sea bed, the survey of beach profile on each section have been made since 1958. Before the construction of the breakwaters, there were considerable changes in the sea bed configuration. However, since the construction, the changes of the sea bed have become very little.

Figure 19 are a typical example of survey results for the section No.8 which is located at the center of the Kaike Spa. There had been severe erosion on the sea bed between March 1963 and August 1963, and it had continued. After the construction of the detached break-water (No.2), large amount of sand deposition have accumulated on the shore.

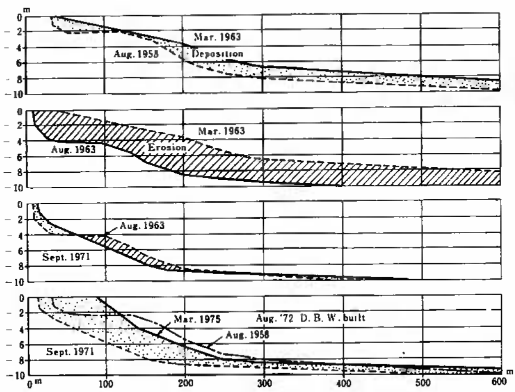

Fig.19 Changes of sea bed on the section No.8.

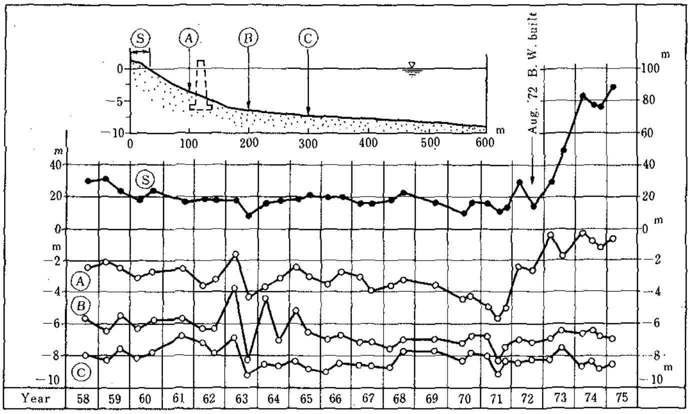

Fig.20 Annual changes of shoreline and sea bed on the section No.8.

Figure 20 shows the annual changes of the sea bed on the same profile line No.8. In this figure, (S) represents the horizontal distance of shoreline from the seawall, and (A), (B) and (C) the water depth from the still sea water level at the points of 100, 200 and 300 meters distant from the seawall. The No.2 breakwater was constructed on the profile line No.8 in August 1972, and it was very effective for depositing sand. After its construction, the sea bed at the point (A) indicated a remarkable shoaling, and the shoreline (S) greatly advanced.

Above-mentioned severe erosion are also expressed in this figure, and the point (B) indicates remarkable change of sea bed three times during the period from 1962 to 1965.

Similar changes of sea bed occured at the same time within the nearby area. Figure 21 also shows the annual changes of sea bed at the points of 200 meters distant from the seawall (like point (B)) on each profile line. We can see remarkable erosion of sea bed in 1963 on the profile lines No.6 to No.12. On the other hand, there were violent rise of sea bed on the profile lines No.2 and 4 in 1966, and we cannot find out significant changes of sea bed in 1963 on these profile lines such as the profile line No.8.

There are furthermore noticeable facts in this figure that, every sea bed have been going to rise since 1971, after the first detached breakwater was built, in spite of those offshoreward situation.

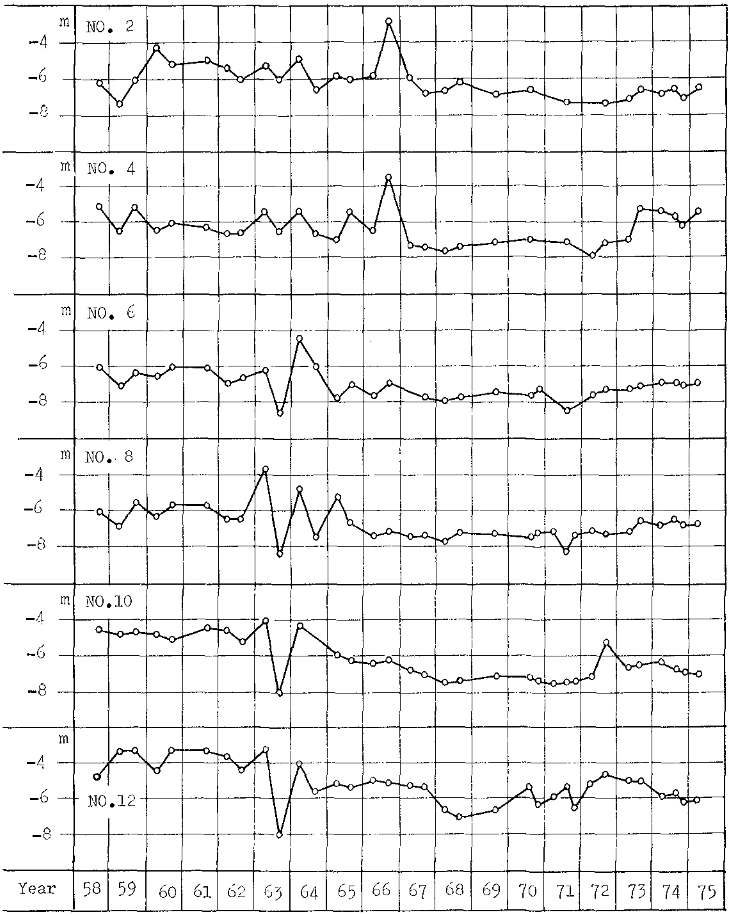

Fig.21 Annual changes of sea bed at the points of 200 meters distant from the seawall on each profile line.

The survey of sea bed, that is sounding, have been made within the limits of about 600 meters offshoreward from the seawall. After the construction of the detached breakwaters, a lot of sand were transported from offshore zone to the nearby area of the detached breakwaters not only onshore side but also offshore side of the breakwaters. However, we cannot find out the eroded zone as the source of the sand supply to the onshore zone.

Table 1 Volumetric changes in the sea bed after the construction of the detached breakwaters at the Kaike Coast.

Unit : cubic meters

Number of breakwater	Onshore side of breakwater	Offshore side of breakwater	Total volume
No.4 break-water zone	+ 41,260	+ 61,845	+ 103,105
No.2 break-water zone	+ 39,790	+ 99,770	+ 139,560
No.1 break-water zone	+ 35,835	+ 101,575	+ 137,410
No.3 break-water zone	+ 1,200	+ 45,265	+ 46,465
Total	+ 118,085	+ 308,455	+ 426,540

Table 1 shows volumetric changes in the beach profiles calculated from the survey results during the period from September 1971, before the construction, to March 1975, after the construction of the fourth breakwater. It is noticed from this table that a considerable volume of sand has been deposited on the sea bed in the onshore and offshore zones of the breakwaters since the construction scheme of detached breakwaters commenced. And now, the Kaike coast has gained a stable sea bed by virtue of this detached breakwater system.

CONCLUSION

The detached breakwater system at the Kaike coast is one of the symbolical work in the countermeasure against the beach erosion in Japan. It is very effective in the shoreline protection, however, some problems involved this system still remain to be solved. The most important problem is subsidence of the breakwaters. Up to now, the subsidence of the breakwaters on the Kaike coast is considered to be moderate, but it is urgently needed to develop methods by which the speed of subsidence can be minimized.

Hereupon, our efforts must be continued without a break, so that the re-created beach may not be lost again.

Fig.22 The latest aerial view of the Kaike coast (in 1975).

Reference:

Osamu Toyoshima, Design of a detached breakwater system, Proceedings of the Fourteenth International Conference on Coastal Engineering, Vol.II pp. 1419 - 1431, 1975.