CHAPTER 118

BEACH CHANGES BY STORM WAVES

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ABSTRACT

Monitoring of beach profiles was carried out during one-year period at two sites located 3 km apart along a Pacific beach, Japan. These two sites are composed of beach sand with different grain size: 0.76 mm and 0.26 mm. It was found that the shoreline did not move even in storm wave events at the site with 0.76-mm sand, where the "seesaw mode" profile change took place in the subaerial portion of the beach. It was also found that the shoreline was not always retreated by storm waves at the 0.26-mm sand site, where the "parallel mode" profile change dominated, at the time of presence of bars working as a submerged breakwater to protect the beach from erosion.

INTRODUCTION

It is generally considered that storm waves erode beach material and transport offshore causing shoreline recession on a coast with dominant cross-shore sediment transport. In some cases, however, no shoreline retreat occurs even in the event of storm waves. There have been few systematic studies on such a phenomenon. The present study purposes to investigate this problem based on one-year consecutive monitoring of beach changes and incident wave characteristics.

STUDY AREA AND DATA ACQUISITION

Beach monitoring was carried out at Naka Beach, Ibaraki Prefecture, Japan (Fig. 1). The beach, facing the Pacific Ocean, is an approximately straight coast with a north-south oriented shoreline 5 km long. The beach sediment is

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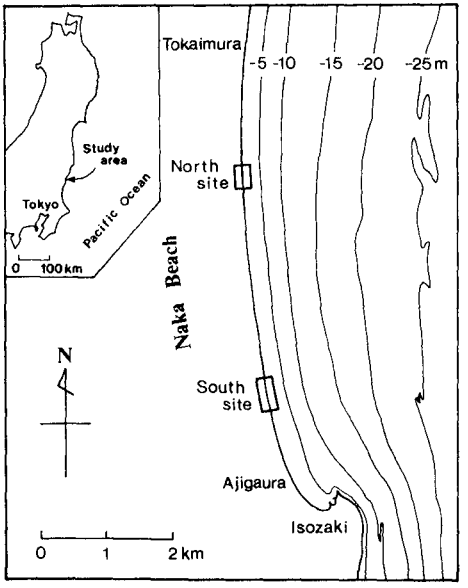

Fig. 1 Study area and two monitoring sites.

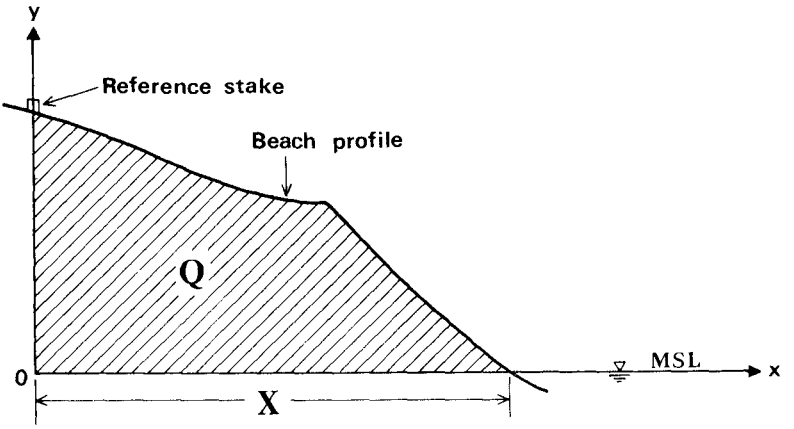

Fig. 2 Schematic diagram showing beach width and subaerial beach sediment volume

composed of coarse sand in the northern part of the beach and fine sand in the southern part (Takeda, 1984). The shoreline of the study area is stable on a long-term basis (Tanaka et al., 1973). The direction of long-term longshore sediment transport would be southward, but cross-shore sediment transport dominates for short-term beach changes. No man-made coastal structures have been constructed on the beach.

An outer bar is always located nearly parallel to the shoreline, and an inner bar only develops under certain physical conditions. The average bottom slope is 0.011 to a water depth of 20 m, and is almost constant along the beach. No significant alongshore difference in incident wave characteristics has been observed. The beach is in a microtidal environment, a maximum tidal range is 1.4 m and a mean is about 1 m.

Two monitoring sites, 3 km apart, were established along this beach (Fig. 1). They are called North Site and South Site. North Site has an alongshore length of 300 m and South Site has a 500 m length. The mean grain size of the beach material was 0.76 mm at North Site and 0.26 mm at South Site. Reference stakes were installed along the shoreline on the highest part of the beach. Sixteen stakes were set up at an interval of 20 m at North Site and eleven stakes were installed at 50-m interval at South Site.

Beach profiles were surveyed perpendicular to the general shoreline trend from each stake to the surf zone using a telescopic level, a surveyor's rod, and a tape. The survey was conducted at an interval of once or twice per week for a period of one year beginning August 28, 1980.

Based on the beach survcy results, the beach width and the subaerial beach sediment volume, defined in Fig. 2, were calculated. In this figure, the x-axis extends offshore on mean sea level from the origin which is located at the intersection with the y-axis extending upwards through a reference stake. The beach width, X, is the horizontal distance between the origin and the point at which the beach profile meets the x-axis. The subaerial beach sediment volume, Q, is the cross-sectional area (hatched area) bounded by the beach profile, the x-axis, and the y-axis. Averaged values of X and Q over 16 survey lines for North Site and 11 lines for South Site were obtained, and they were denoted by $\bar{X}$ and $\bar{Q}$, respectively.

The two quantities, $\bar{X}_*$ and $\bar{Q}_*$, are defined as:

$$\bar{X}_* = \bar{X} - \bar{X}_0 \quad (1)$$

$$\bar{Q}_* = \bar{Q} - \bar{Q}_0 \quad (2)$$

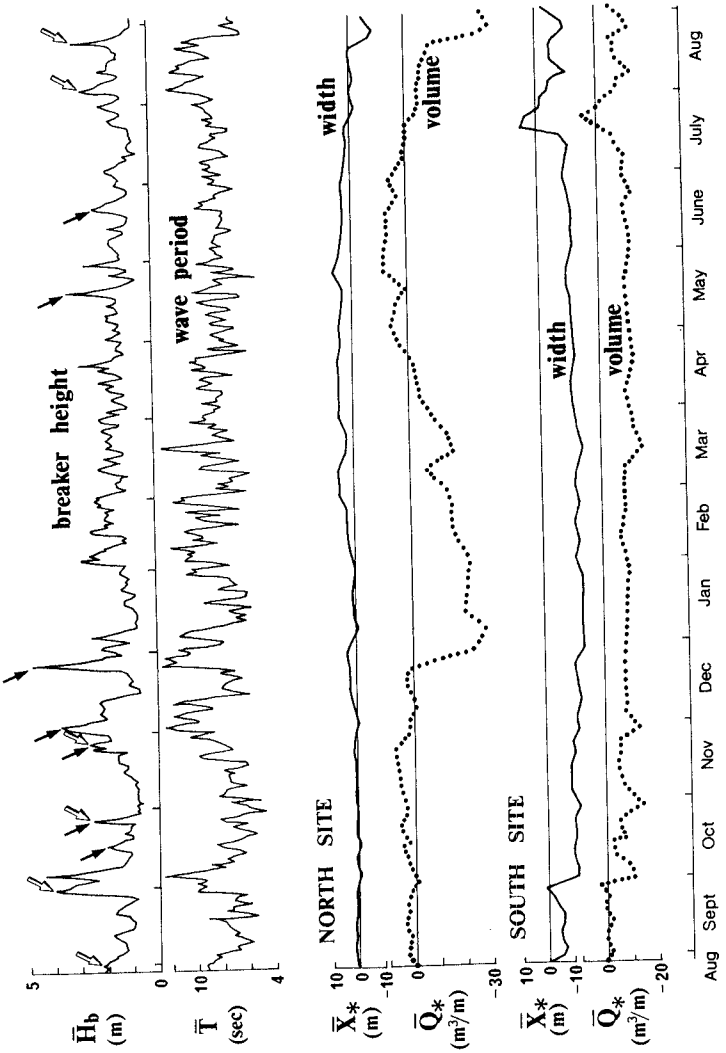

Fig. 3 Time-series data of waves and beach characteristics.

where $\bar{X}_0$ and $\bar{Q}_0$ are values of $\bar{X}$ and $\bar{Q}$ of August 28, 1980, the first day of the investigation, respectively.

Waves were measured by an ultrasonic-type wave gage installed about 10 km south of the study area at a water depth of 21 m. Continual wave records obtained over 20 minutes for every two hours were available. Based on the wave records, daily averages of deepwater significant wave height and period were obtained. Daily averages of significant breaker height, $\bar{H}_b$, were calculated using the following relationship (Sunamura, 1982):

$$\frac{H_b}{H_0} = (\tan \beta)^{0.2} \left(\frac{H_0}{L_0}\right)^{-0.25} \quad (3)$$

where H_b is the breaker height, H_0 and L_0 are the deepwater wave height and length, respectively, and $\tan\beta$ is an average nearshore bottom slope.

Time-series data of $\bar{X}_*$, $\bar{Q}_*$, $\bar{H}_b$, and daily averages of significant wave period, $\bar{T}$, are shown in Fig. 3.

RESULTS AND DISCUSSION

Beach Erosion Pattern

The time-series data of $\bar{X}_*$, $\bar{Q}_*$, and incident waves (Fig. 3) illustrate that the characteristics of subaerial beach change in the event of storm waves is different between the two sites. Namely, the pattern of change in $\bar{X}_*$ is the same as that in $\bar{Q}_*$ at South Site, while the change pattern of $\bar{X}_*$ is different from that in $\bar{Q}_*$ at North Site.

At South Site, storm waves simultaneously decreased both $\bar{Q}_*$ and $\bar{X}_*$. This change pattern was observed at storm events shown by open allows in Fig. 3, i.e., storms in late September, 1980; late October, 1980; late November, 1980; early and late August, 1981. Such a subaerial beach change is schematically shown in Fig. 4-(A); that is, storm waves decrease the beach width and the subaerial beach sediment volume at the same time, and the "parallel mode" profile change takes place.

A typical example of this type of profile change actually observed at South Site is shown in Fig. 5. The solid line indicates the profile before the storm waves (with a maximum of $\bar{H}_b$ = 2.7 m) in late November, 1980. The step had a height of about 0.3 m. The dashed line shows the after-storm profile. As shown in Fig. 5, the storm wave action decreased both the subaerial beach sediment volume as well as the beach width.

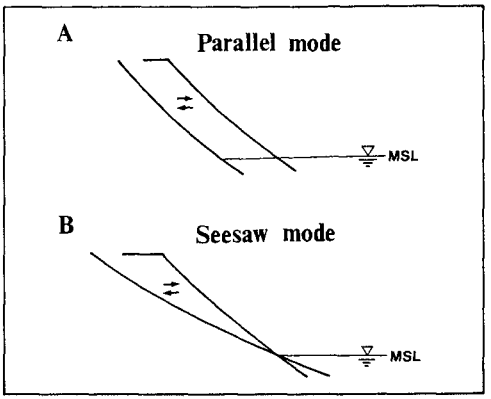

Fig. 4 Schematic diagram showing subaerial beach changes.

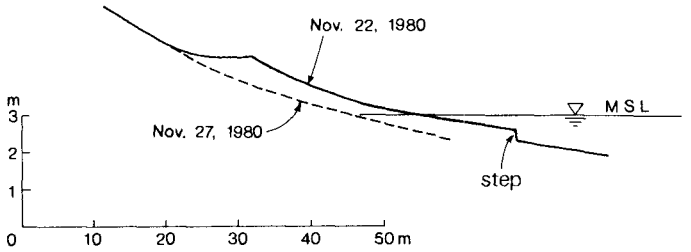

Fig. 5 Typical beach erosion pattern observed at South Site.

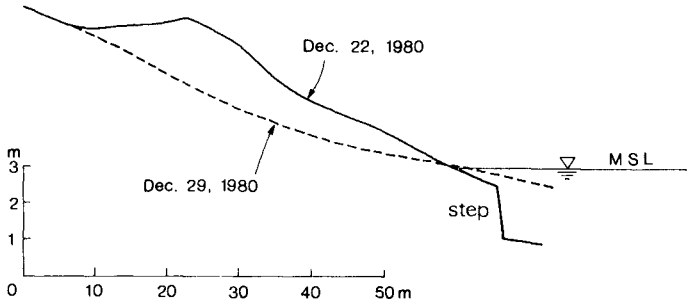

Fig. 6 Typical beach erosion pattern observed at North Site.

On the other hand, storm waves decreased $\bar{Q}_*$ but they did not decrease $\bar{X}_*$ at North Site. This change pattern was observed at storm events shown by solid allows in Fig. 3, i.e., storms in middle and late October, 1980; late November, 1980; early and late December, 1980; middle May, 1981; and late June, 1981. This subaerial beach change is shown in Fig. 4-(B). In spite of that subaerial beach material is eroded away by storm waves, the shoreline advances or does not change, and the "seesaw mode" profile change occurs in the subaerial portion of the beach.

Figure 6 shows an actual example of the seesaw mode profile change occurred at North Site due to the storm waves with $(\bar{H}_b)_{max}$ = 4.8 m on December 25, 1980. The pre-storm profile (solid line in Fig. 6) had a step with a height of about 1.5 m. The storm waves markedly decreased the subaerial beach sediment volume, whereas the shoreline position did not retreat but advanced. The surf zone could not be surveyed due to high waves, but it was observed through wading that the eroded subaerial beach material deposited near the shoreline.

The difference in the two patterns of beach profile changes are due to the scale of a step formed under calm-sea conditions before the attack of storm waves. Larger steps usually developed at North Site, where beach material eroded by storm waves was not transported offshore but deposited just in front of the step, and no shoreline retreat occurred as schematically shown in Fig. 7-(B). The height of steps formed at South Site was much smaller. Eroded material was not deposited near the shoreline, but transported seaward to build up an inner bar in the surf zone, and the shoreline retreated [Fig. 7-(A)].

Beach Response of South Site to Storm Waves

It was often observed that the South Site beach also was not always eroded by large storm waves. For example, the beach was severely eroded by the action of storm waves in late September, 1980, but the beach was not significantly eroded by the storm in late December, 1980, which was the highest storm waves during the one-year survey period (Fig. 3). A similar phenomenon could also be recognized at the storm events in early February, late April, and middle May, 1981. Figure 3 shows that this phenomenon always occurred when the beach had a low $\bar{Q}_*$-value, that is, the beach was poor in the subaerial beach sediment volume. Beach material eroded from the subaerial portion of the beach had been transported offshore and formed an inner bar in the surf zone as schematically shown in Fig. 7-(A). It can be considered that such an inner bar is closely related to the condition for beach erosion.

Moreover, if the inner bar effects the condition for beach erosion, the outer bar also probably affects beach erosion. Because energy of waves arriving at the beach is greatly influenced by the position and water depth of a bar (Carter and Balsillie, 1983). The position of the outer bar in this study area was greatly changed by the action of the largest storm waves on December 25, 1980. The bar, located 70 to 120 m offshore before this day, was moved further offshore and thereafter its location was kept between 150 to 250 m in offshore distance. The time-series data (Fig. 3) were split into two parts on this day for the purpose of examining the critical condition for beach erosion.

In order to express the existence or nonexistence of inner bar, a dimensionless parameter, Q_R, is introduced, which is defined as:

$$Q_R = \frac{\bar{Q}_* - Q_{min}}{Q_{max} - Q_{min}} \tag{4}$$

where Q_{max} and Q_{min} are the maximum and minimum values of $\bar{Q}_*$ during the one-year investigation period, respectively. The parameter Q_R, which shows a relative subaerial beach sediment volume, is a value ranging from 0 to 1. A berm-developing beach state (fully accretionary state) has larger Q_R-values compared with an inner-bar forming beach state (erosional state), and a bar-welding beach state takes intermediate values.

The magnitude of storm waves can be expressed by a dimensionless coefficient, k, in the following equation (Sunamura, 1984; Takeda, 1984):

$$\frac{H_b}{gT^2} = k\frac{D}{H_b} \tag{5}$$

where D is the grain size of beach material, and g is the gravitational acceleration.

Because (1) wave climate changes in time and (2) beach change is most sensitive to larger waves during one interval of two consecutive beach profiling, $(\bar{H}_b)_{max}$ and $\bar{T}_{max}$ were substituted for H_b and T in equation (5), respectively:

$$\frac{(\bar{H}_b)_{max}}{g\bar{T}_{max}^2} = K\frac{D}{(\bar{H}_b)_{max}} \tag{6}$$

where $(\bar{H}_b)_{max}$ is the maximum value of daily average breaker height during one interval between surveys, $\bar{T}_{max}$ is the average wave period of the day giving $(\bar{H}_b)_{max}$, and K is a dimensionless coefficient. The larger value of K means the

higher wave-intensity resulting in net offshore sand transport in the surf zone (Sunamura, 1984).

Using two parameters, Q_R and K, the critical condition for beach erosion was examined. Figure 8 is a plot of data obtained before December 25, 1980 (the outer bar was located near the shoreline). Beach accretion or erosion is determined by the change in subaerial beach sediment volume $\bar{Q}_*$ during one survey interval, i.e., an increase in $\bar{Q}_*$ is defined as accretion, while a decrease in $\bar{Q}_*$ is defined as erosion. In Fig. 8, the open symbol indicates accretion and the solid symbol denotes erosion. Data showing small change in $\bar{Q}_*$ less than 1.0 m^3/m were excluded from the plot. Although some overlapping of the data points is seen, the erosion-accretion demarcation can be described by the solid curve. The figure shows that no erosion takes place even for the case of larger K-value when the beach has lower Q_R-value. Namely, the beach is not likely to be eroded even by the large storm waves when an inner bar develops. This suggests that the inner bar protects the beach acting as a submerged breakwater.

Figure 9 is a plot of data obtained during the period when the outer bar was located further offshore. A similar tendency to the former case is found. These two results show that the existence or nonexistence of an inner bar is closely related to the critical condition for beach erosion.

Comparison of Figs. 8 and 9 indicates the influence of the outer bar on beach erosion. The demarcation curve in Fig. 9, compared with Fig. 8, is plotted in the lower-left area. This suggests that less severe storm waves can erode the beach when the outer bar is located offshore. The water depth of bars increases with increasing offshore distance (Keulegan, 1948). Because the outer bar located closer to the shoreline has smaller water depth, such an bar is likely to protect the beach acting as a submerged breakwater like the above-mentioned inner-bar case. On the other hand, the outer bar located offshore can not effectively work as a submerged breakwater to protect the beach from erosion.

CONCLUSIONS

The data of beach monitoring shows that the seesaw mode profile change dominates at the coarse sand beach (North Site) and the parallel mode profile change takes place at the fine sand beach (South Site). In the case of seesaw mode profile change, little significant shoreline retreat occurs in the event of storm waves. It is found that the presence of inner bar and the location of outer bar greatly influence the subaerial beach change occurring on the fine sand beach.

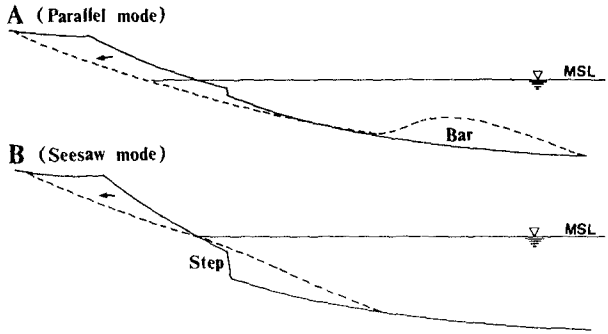

Fig. 7 Schematic diagram showing beach erosion patterns.

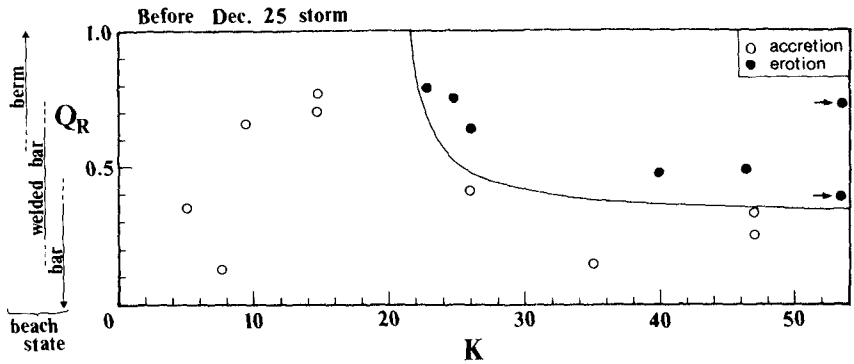

Fig. 8 Critical condition for beach erosion at South Site (Aug. 28, 1980 - Dec. 24, 1980).

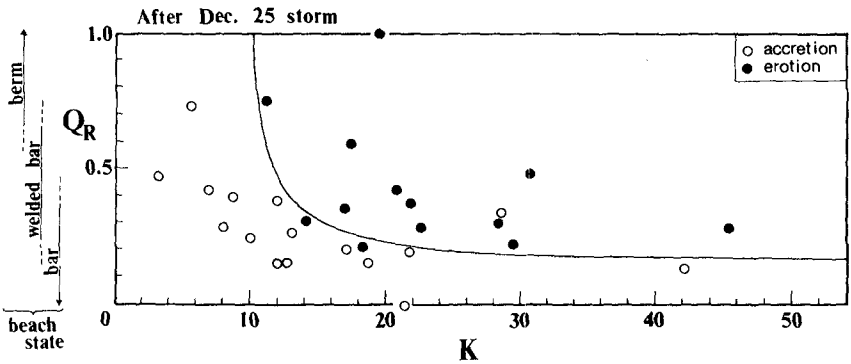

Fig. 9 Critical condition for beach erosion at South Site (Dec. 25, 1980 - Sept. 1, 1981).

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