Bull. Disas. Prev. Res. Inst., Kyoto Univ., Vol. 32, Part 3, No. 292, September, 1982

Long-term Changes in Beach Profiles at Ogata Coast

By Yoshito TSUCHIYA, Toru SHIRAI and Takao YAMASHITA

(Manuscript received July 31, 1982)

Abstract

To investigate the characteristics of beach profile changes, continuous observations of nearshore topography have been carried out at Ogata coast along an observation pier since 1973. Systematically analized are the data of beach profiles collected for more than eight years, to find out the role of beach changes.

An outline of the characteristics of the coast is described, and characteristics of beach profiles in the time-space coordinates are elucidated. A relationship between beach slopes and shoreline changes was found, and an explanation of beach changes is also made by the method of empirical eigenfunction by Winant et al., from which how to select each period of the data to be analyzed is considered from the seasonal wave conditions. Continuous beach erosion at the coast is recognized from the annual changes in sediment volume in averaged beach profiles for the period of observation, in which two remarkable beach changes are included in the periods from 1973 to 1974 and from 1978 to 1980, respectively.

1. Introduction

Classifications of coastal topography have been made by geomorphologists and coastal engineers, especially by D. W. Johnson[1], Shepard[2], Cotton and Valentin[3]. From the engineering view point, it is important in studying the role of beach processes and the methods of their prediction that we understand long-term changes in coastal topography by the appropriate classification with relation to sediment transportation, which is considered separately to be the sediment movements perpendicular and parallel to the shoreline. Needless to say, the two kinds of sediment movements are closely related to each other. Longshore changes in beach topography, especially shoreline changes have been investigated by the so-called one-line theory[4], which is a one-dimensional approach based on the local balance of longshore sediment transport. The time and space-independence of beach profiles is required in the one-line theory. To estimate the changes in beach profiles as well as shoreline changes practically, the so-called two-line theory is proposed. It requires however an expression of the distribution of longshore sand transport.

Changes in beach profiles have been studied by stochastic analyses and methods of schematization of equilibrium beach profile recognizing the existence of two types of beach profiles such as longshore bar and step types by a number of wave tank experiments and field observations. Previous stochastic analyses of beach profile data have been made to investigate changes in beach profile configuration as a Markov process[5,6]. These studies made the applications of the stochastic analyses possible in order to clarify both subaqueous and subaerial beach profiles[7]. Winant et al.[8] proposed a method of empirical eigenfunction in studying beach profile changes, and concluded that most of the variation in beach profile configurations can be accounted for by three eigenfunctions with the three largest eigenvalues. The largest one corresponds to an eigenfunction which is called the mean beach function and the second and the third ones are called the bar-berm and terrace (step) functions, respectively. A few data of long-term beach changes have been used for such investigations. But the period of the observed data is not so long, usually several years, that precise conclusion of beach changes and applicability of the method of empirical eigenfunction have not yet been completed.

Recently, Swart[9] investigated how to schematize equilibrium beach profiles and proposed the so-called D-profile (developing profile) for the equilibrium state in developing areas under wave action. This idea is applicable for estimating the rate of offshore sediment transport if there are long-term reliable data of waves and beach profiles.

In order to investigate changes in beach profiles as one of the beach processes by wave action, continuous observations of nearshore topography are required, but difficulty in such observations is usually expected. At Ogata coast facing the Japan Sea, as shown in **Fig. 1**, there is an observation pier, 315 m in length, which belongs to the Teikoku Oil Company Ltd.. At the Ogata Wave Observatory, Disaster Prevention Research Institute, continuous observations of beach profile have been carried out since 1973. The beach profile has been measured once a week along the observation pier at intervals of 2 m. The sounding in the nearshore area has also been

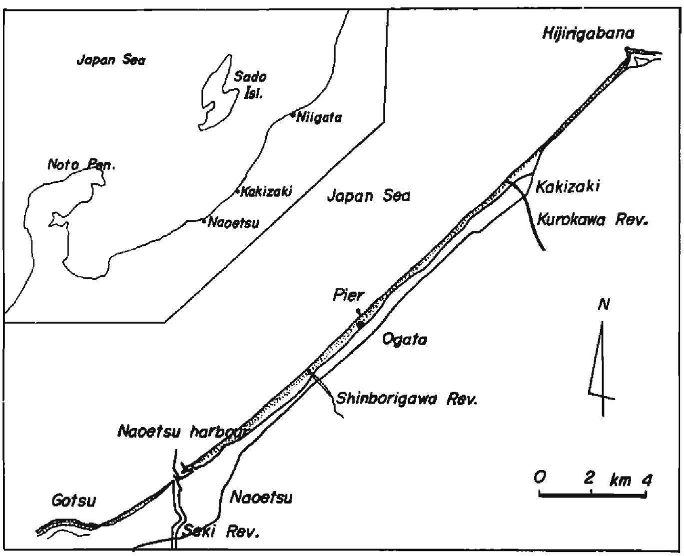


Fig. 1 Location of Ogata coast and the observation pier.

performed at intervals of a few years. The observed data of beach profiles would be helpful so that the long-term changes in beach profiles can be investigated to find out the role of beach changes by wave action. The period of the observation is more than ten years at the present so that the data of beach profiles can be analyzed by various procedures to make understanding of the beach changes by means of the so-called Eularian description, supposing that one has been standing at the end of the observation pier and looking at the beach changes seaward along the pier for the period. From this point of view, we first describe an outline of the Ogata coast, and then investigate characteristics of beach profiles, such as the role of beach profile change, and the relationships between beach slope and shoreline change, and also explain the beach changes by the method of empirical eigenfunction.

2. The Present Conditions of Ogata Coast

The Ogata coast is a straight sandy beach with parallel contours, extending north-eastward 25 km from Gotsu which is located south-east of Naoetsu as shown in **Fig. 1**, to Cape Hijirigabana which is located north-east of Kakizaki. The main source of coastal sediment at this coast was formally the Seki river flowing into Naoetsu, before the extension of the west breakwater of Naoetsu harbour about 20 years ago, but the input of sediment to Ogata coast was suddenly stopped after the completion of the breakwater in 1974. Beach erosion at Ogata coast has been remarkable since the late 1960's as seen in **Fig. 2**, in which temporal changes in shoreline position measured with aerophotographs are shown.

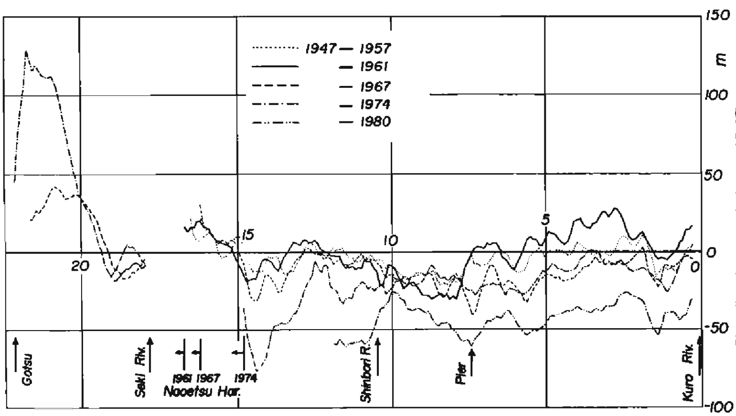


Fig. 2 Shoreline changes along the Ogata coast.

Wave observations have been carried out at the Ogata Wave Observatory, Disaster Prevention Research Institute since 1966 and at Naoetsu harbour, Ministry of Transport since 1963. The general characteristics of incident waves have been investigated by these continuous observations of waves, and they showed that the dominant direction of incident waves at this coast is NW and most of wave energy flux is due to the waves incoming during the period between December and the following March of every year. The sea state is usually calm during the period between April and September, but it becomes rough with high waves if a typhoon passes over The Japan Sea or the neighbouring coastal areas. These characteristics of the incident waves indicate that changes in beach profiles occur in winter seasons.

On the other hand, the characteristics of longshore sediment transport have been investigated by the authors[10] by the analysis of sedimentological properties of beach sediments along the coast. It has been made clear that there is a singular point in the sedimentological properties, near the observation pier as seen in **Fig. 3**, showing properties of the sediment such as phi median diameter $M_{d\phi}$, phi standard σ_ϕ, phi skewness α_ϕ, and content of rock fragment, igneous rock, sedimentary rock and volcanic rock. From this we conclude that the direction of longshore sediment transport may change at this point, but it is not remarkable.

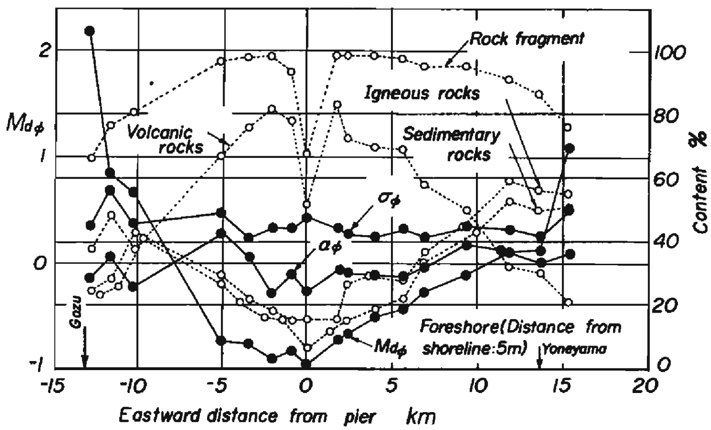


Fig. 3 Alongshore distribution of sedimentological characteristics along the Ogata coast.

3. Beach Profile Data

The beach profiles have been measured since 1973, by lead soundings at 154 points of intervals of about 2 m along the observation pier. These data sets are kept in the files of the Information Processing Center for Disaster Prevention Studies, Disaster Prevention Research Institute. Moreover, the bottom topography around the pier has been measured at intervals of a few years with sonic-fathometers and sounding leads. Bottom topographies measured in July, 1967, 1969, 1972 and 1979 respectively are shown in **Fig. 4**. Cresent-shaped bars, well-known as a rhythmic bar pattern, are formed in the surf zone. Shoals associated with small bars are located at intervals of 300 m to 900 m along the shore. The 7 m-bathymetry in 1979 changes shoreward, especially at the position of the pier, and shoals are nearly equal-spaced for this period.

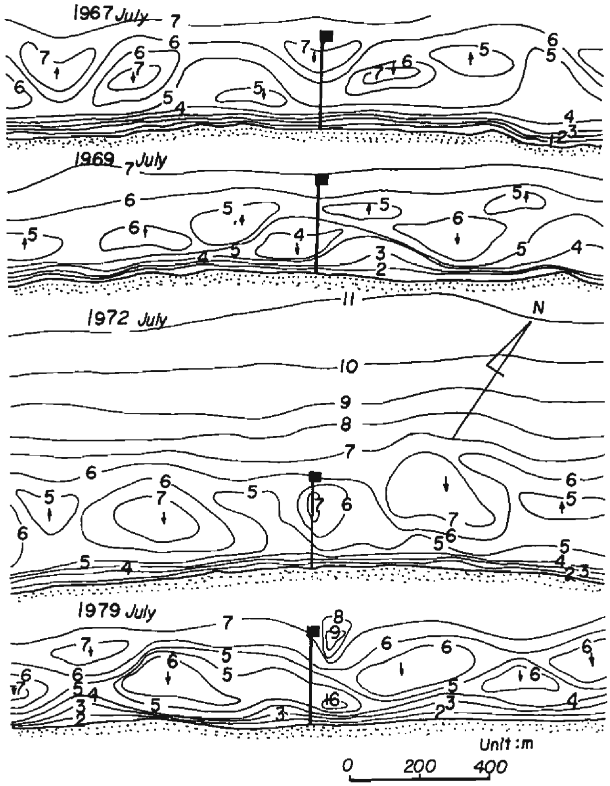


Fig. 4 Changes in the bottom topographies and the observation pier.

On the other hand, the beach profile data are averaged at intervals of a month or a season (a winter period of three months, for example, is defined between December and following February) to discuss the long-term changes in beach profiles along the pier. The changes in seasonally averaged beach profiles are shown by net-display in **Fig. 5**, where the vertical and x-axis show the depths of water and seaward distance from the end of pier, respectively and the other horizontal axis shows the time. The net in the figure is formed with beach profiles and lines connected with every fourth measuring point. The changes in monthly averaged beach profiles are also shown in **Fig. 6**, by the same method used in **Fig. 5**, in which the time axis shows the monthly scale. The broken line in 1973 indicates the lack of data. In both figures, the pronounced changes in beach profile configurations occurred during the winter seasons in 1974 and 1978 respectively. With these changes, remarkable bars are also formed. To explain it in more detail, the contour display for the subaqueous beach profiles in time-space coordinates is shown in **Fig. 7**, in which the arrows taken upward and downward indicate a convex (shoal) and concave (dip) respectively. Seasonal and long-term changes in configurations of beach profiles are considered to be a process of generation and migration of winter bars by incoming waves. In the changes

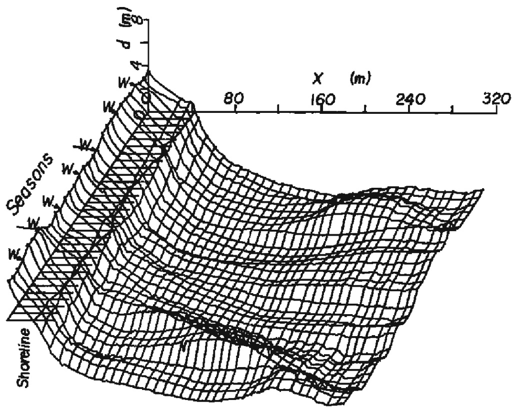


Fig. 5 Changes in seasonally averaged beach profiles.

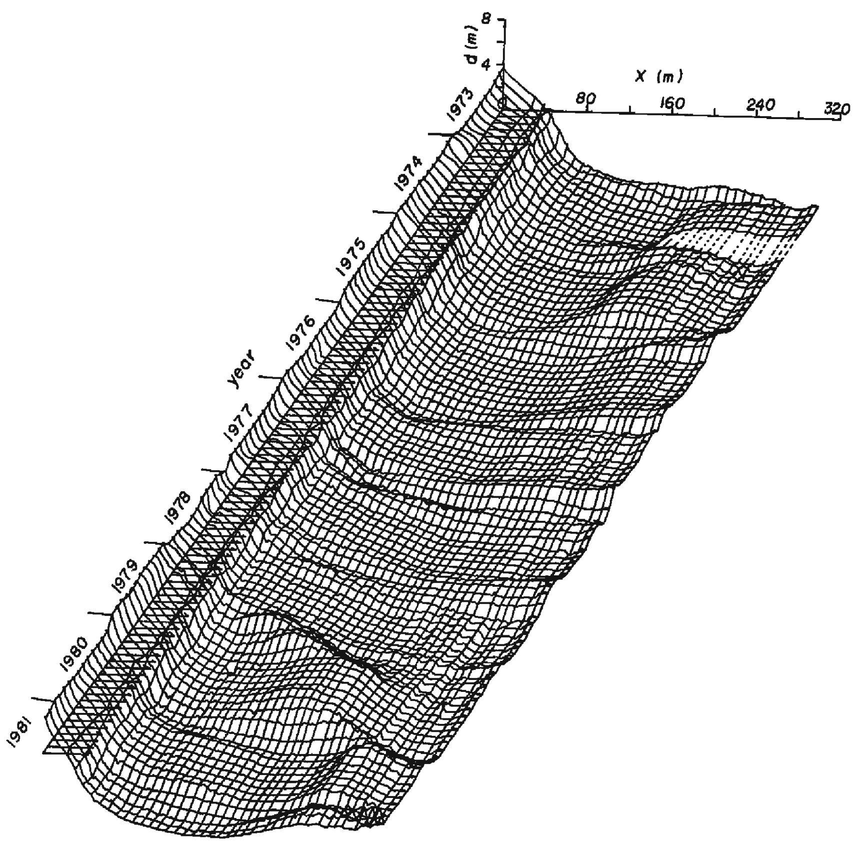


Fig. 6 Changes in monthly averaged beach profiles.

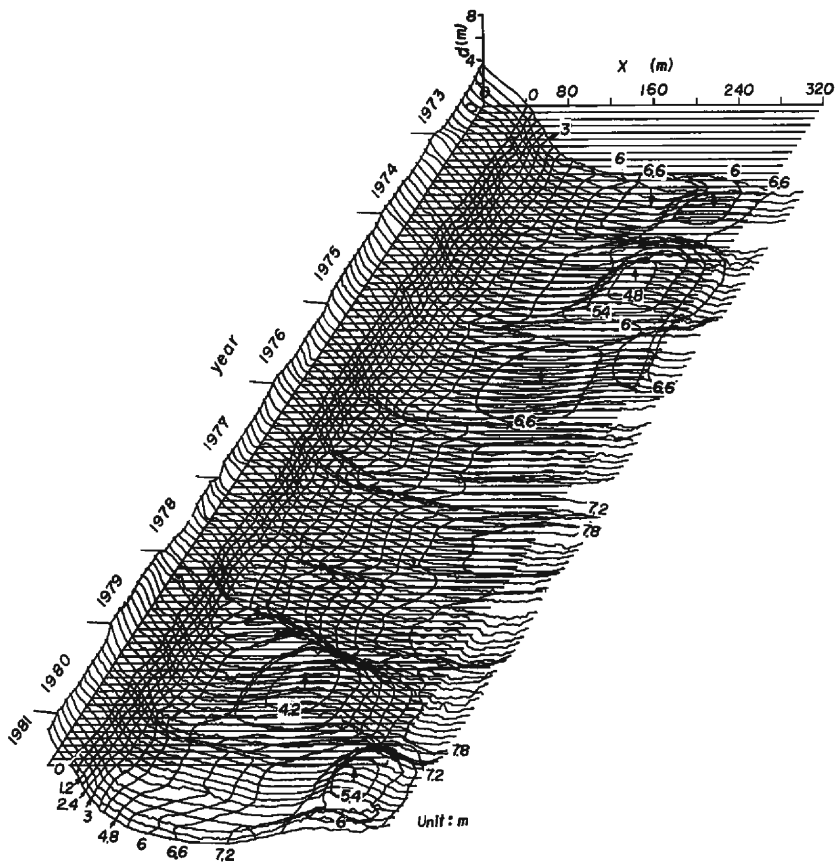


Fig. 7 Contour display of subaqueous beach profiles in time-space coordinates.

in beach profiles for this period, there appears two remarkable bars, one appeared in 1973, so is called the 73-bar in this paper, while the other was generated in December, 1978, and is called the 78-bar.

The 73-bar and the 78-bar were generated in winter in the periods between 1973 and 1974, and 1978 and 1979, respectively. Both the bars migrated offshoreward in winter or spring and were in a stable state in other seasons. In the case of the 78-bar, a small bar was first formed at the offshore position of 80 m, at a depth of about 3 m. And then it migrated offshoreward to the position of 160 m, and further in next winter, resulting in the retreat of the shoreline and changing the bar to a dip in the beach profile.

Long-term changes in beach profiles are related to sediment transport, which is usually considered separately to be onshore-offshore and longshore movements. We assume here the longshore sediment transport is negligible compared with the onshore-offshore transport along the Ogata coast. The annual changes in beach profiles are shown in **Fig. 8**, which was obtained by averaging the data over the intervals from July to the next June, except for that measured from July, 1980 to February, 1981. In the figure, the shaded areas show positive variation from the beach profile averaged over all the data. It is observed that the two remarkable bars, 73-bar and 78-bar, temporally migrated offshoreward, and every beach profile above the level of the water depth of 3 m was translated in the onshore direction. The annual changes in sediment volume per unit width of shoreline are shown in **Fig. 9**, where Q_{aer} and Q_{aqu} indicate the sediment volumes in subaerial and subaqueous beach profiles within the length of the pier, respectively. Both values of sediment volume decrease monotonically until 1977, and they increase due to the large de-

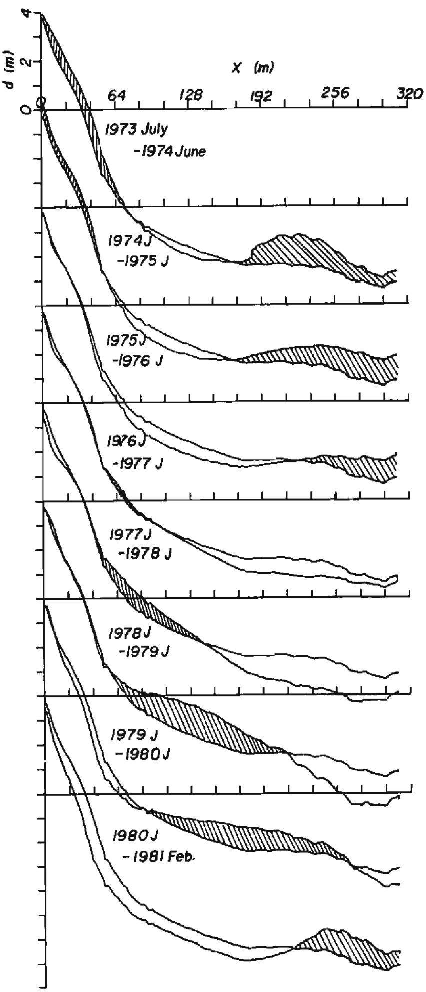


Fig. 8 Comparison between annual beach profiles and the beach profile averaged over all the data.

formation of the beach profile by great wave action, while they began to decrease again. This tendency of temporal changes in these values is similar to that of shoreline changes with a lag of about one year, which is referred to in the next chapter. This implies that there is a linear relation between the shoreline position and the sediment volume per unit width of shoreline, in the averaged beach profile, especially above the level of 3 m in water depth. This fact may support the idea of the so-called D-profile by Swart[9].

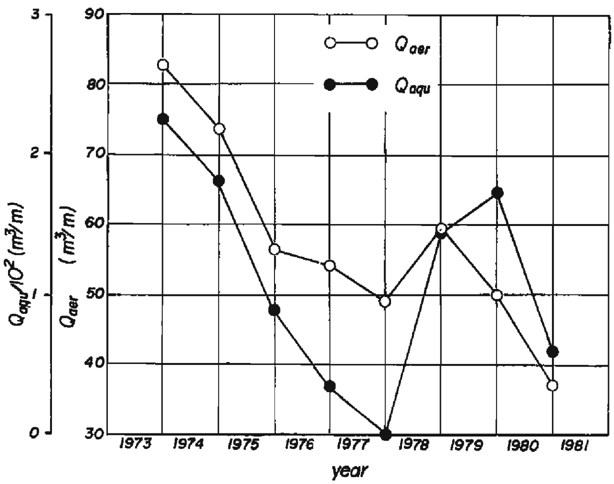


Fig. 9 Annual changes in sediment volume per unit width of shoreline (Q_{aer}: sediment volume of subaerial beach, Q_{aqu}: sediment volume of subaqueous beach).

4. Changes in Beach Slope and Shoreline Position

As already described, beach erosion has been occurring at Ogata coast. This may be significant in studying the mechanism of beach change to find out a relationship between the retreat of shoreline and the beach profile. It is of course closely related to wave conditions, but the steeper the beach profile becomes, the more the waves reflect remarkably against the beach. As the efficiency of the beach wave energy dissipation decreases, the beach erosion may be accelerated. From this viewpoint, we may suppose that increase in beach slopes have influence on the retreat of shoreline, as seen in **Fig. 10**, where i_b and i_3 are the beach slopes in the subaerial and the subaqueous beach profiles in the region shallower than 3 m in water depth. These beach slopes were calculated by a least square method. In this figure, i_b, i_3 and y_0 are the movable-averaged values of $\bar{i}_b$, i_3 and $\bar{y}_0$, respectively. It can be recognized from this figure that the shoreline retreated about 20 m during the period of eight years and three months, showing a similar tendency of the annual changes in sediment volume in the subaqueous and subaerial profiles, as shown in **Fig. 9**. The recent subaerial beach slopes have become very steep, nearly twice of those in 1973, that

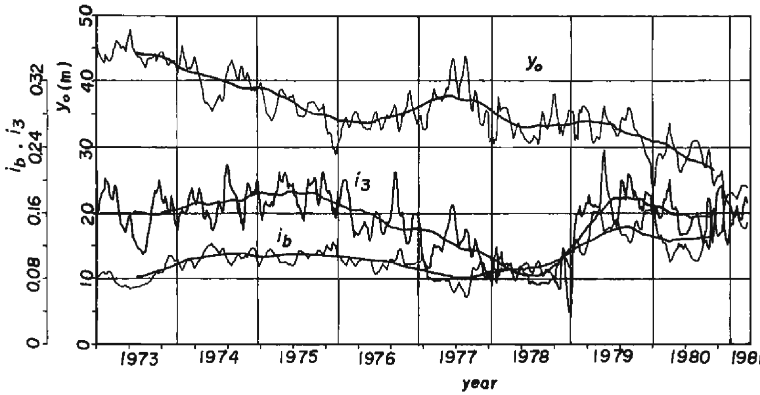


Fig. 10 Temporal changes in beach slopes and shoreline position (i_b, $\bar{i}_b$ beach slopes in subaerial beach profiles, i_3, $\bar{i}_3$: beach slopes in subaqueous beach profiles in the shallower region than 3 m in water depth).

is, these values are about 0.08 and 0.16, respectively. This fact may give an inverse-proportional relationship between the shoreline retreat and the beach slope i_b. It is, however, postulated that the beach slope i_3 is not remarkably influenced by the change in shoreline. The relations between $\bar{i}_b$ and $\bar{y}_0$, and $\bar{i}_3$ and $\bar{y}_0$ are shown in **Figs. 11** and **12**, respectively, where the arrows signify their time dependence. It is recognized that there is an apparent correlation between $\bar{i}_b$ and $\bar{y}_0$, presenting the temporal resumption. The relationship between $\bar{i}_3$ and $\bar{y}_0$, however, doesn't show a remarkable correlation.

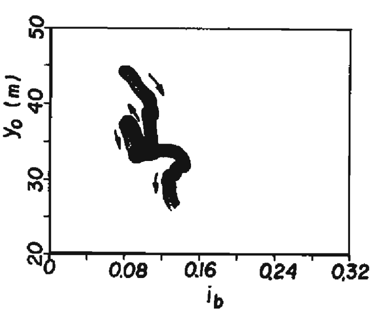


Fig. 11 Relations between $\bar{i}_b$ and $\bar{y}_0$.

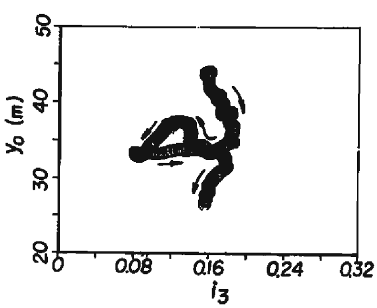


Fig. 12 Relations between $\bar{i}_3$ and $\bar{y}_0$.

The relation between the beach slopes and shoreline position which was obtained by the annually averaged data of beach profiles, is shown in **Fig. 13**. It can been seen from **Figs. 11**, **12** and **13** that the relationships between beach profiles and the shoreline position were resumed in 1977 and disturbed by wave action in 1978 and 1979. And the shoreline began to retreat again with the increase of the beach slope $\bar{i}_b$. The time dependence of the beach slope $\bar{i}_3$ is steady except for that in 1977 and 1978, so that the beach slope $\bar{i}_b$ rapidly approaches $\bar{i}_3$ in the recent beach profiles.

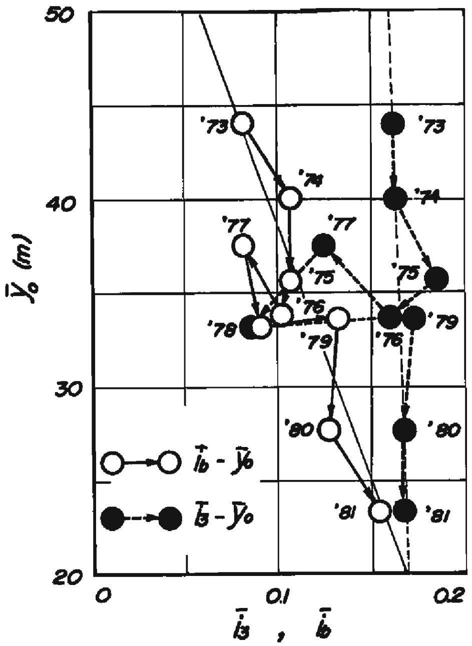


Fig. 13 Relations between beach slopes and shoreline positions which were calculated with annually averaged data.

This process of the changes in beach slopes may explain the fact that the wave reflection increases with increase of the beach slope i_b, and the offshore sediment transport then becomes remarkable to result in the shoreline retreat. On the other hand, the beach slope i_3 is constant except for the period when remarkable disturbances in the relationship occurred in 1977, and in 1978 and 1979, during which the shoreline position $\bar{y}_0$ remained unchanged, but the relevant beach slope i_3 decreased. We conclude that the beach profiles in the shallower region than 3 m in water depth are directly influenced by incident wave action, and the subaerial ones are affected by dynamical conditions in swash zones.

5. Empirical Eigenfunctions

The monthly averaged beach profile data shown in **Fig. 6** are used to generate sets of empirical eigenfunctions, which was originally proposed by Winant et al.[8], to analyze statistically variations in beach profile configuration. In this analysis, a linear combination of functions of the time and the distance normal to the beach is assumed for investigating temporal and spacial dependence of beach profile data.

The beach profile h (x, t) is represented for a given range as h_{xt}, where the subscript x is an index ranging between 1 and n_t, being the total number of points along the beach profile (here $n_x=154$), and the subscript t an index which varies between

1 and n_t, being the total number of times at which profiles are recorded ($n_t=31$), by

$$h_{xt}=\sum c_{nt}e_{nx} \quad\cdots\cdots(1)$$

$$\sum e_{mx}e_{nx}=\delta_{mn} \quad\cdots\cdots(2)$$

where, δ_{mn} is the Kronecker delta, the e_{nx} form a set of eigenfunctions. To generate these eigenfunctions, a symmetric correlation matrix $\boldsymbol{A}$ can be formulated with the elements,

$$a_{ij}=\frac{1}{n_x n_t}\sum_{t=1}^{n_t} h_{it}h_{jt} \quad\cdots\cdots(3)$$

The matrix $\boldsymbol{A}$ processes sets of eigenvalues λ_n and their corresponding eigenfunctions e_{nx} which are defined by the matrix equation,

$$\boldsymbol{A}e_n=\lambda_n e_n \quad\cdots\cdots(4)$$

If the sets of eigenfunctions e_{nx} is selected, the coefficients c_{nt} are evaluated using the orthonormal property of Eq. (2) by

$$c_{nt}=\sum_{x=1}^{n_x} h_{xt}e_{nx} \quad\cdots\cdots(5)$$

yielding

$$\sum c_{mt}c_{nt}=\delta_{mn}\lambda_n n_x \quad\cdots\cdots(6)$$

Defining $c_{nt}^*=c_{nt}/\sqrt{\lambda_n n_x n_t}$, the functions c_{nt}^* result in an orthonormal relation

$$\sum_{t=1}^{n_x} c_{mt}^* c_{nt}^*=\delta_{mn} \quad\cdots\cdots(7)$$

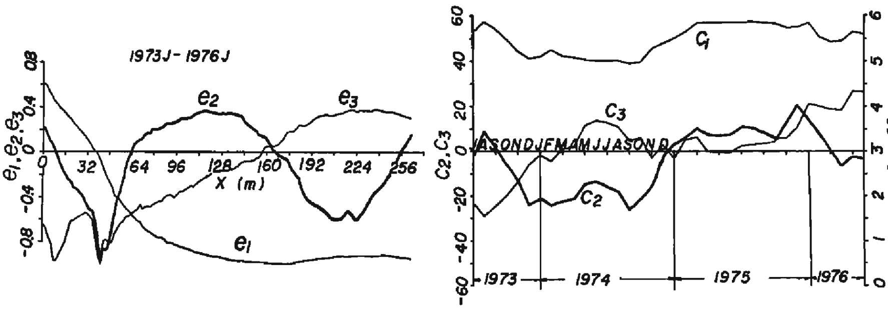
so that the other symmetric correlation matrix $\boldsymbol{B}$ formulated with the elements

$$b_{ij}=\frac{1}{n_t n_x}\sum_{x=1}^{n_x} h_{xi}h_{xj} \quad\cdots\cdots(8)$$

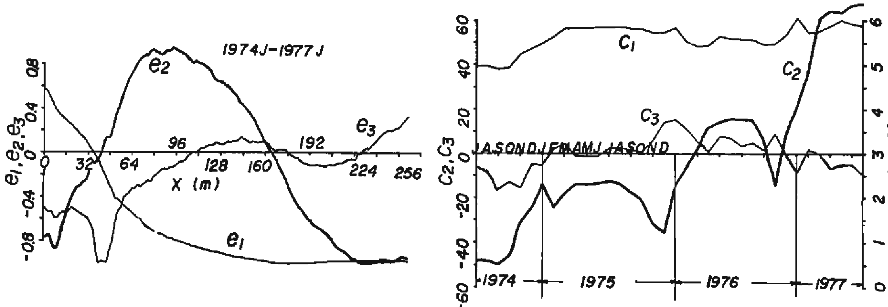
Temporal and spacial empirical eigenfunctions are computed by the method described above for the monthly averaged data of beach profiles. The eigenfunctions with the three largest eigenvalues, according to Winant et al.[8], represent the characteristics of the changes in beach profile configurations. The eigenfunction with the largest eigenvalue shows the mean beach profile, and the second function, called the bar-berm function, shows variations in winter bars and summer berms. The third function represents the changes in terrace (step), which is called the terrace function. Moreover, the temporal coefficients corresponding to these three spatial eigenfunctions show the time dependence of mean beach profile, bar-berm and terrace, respectively. In the sense of factor analysis, an other eigenfunctions are related to smaller variations in beach profiles, which are compared with the three typical eigenfunctions and coefficients mentioned above.

We have applied this method to the monthly averaged data of beach profiles to make clear the physical meanings of the three eigenfunctions and related coefficients, and then discussed the characteristics of the time dependence of beach profile changes by this method. Two types of data sets are made by the different periods of wave conditions, one consists of the monthly averaged data for a successive period of three years starting from July of the first year to June of the last year (we call it JJ-data), the other type is the data for three years arranged by the calender year (C-data). These different divisions of data are avialable for discussing the effect of the two remarkable bars on the beach changes as well as for specifying the physical meanings of these functions, by the long-term data. As already described, the first eigenfunction shows the mean beach profile, but the minimum of the second function indicates the existence of bar or berm, and the maximum of the third one shows the location of a terrace (step). Empirical eigenfunctions and their related coefficients of the beach profile by the JJ-data are shown in **Fig. 14**, in which e_1, e_2 and e_3 denote the eigenfunctions and c_1, c_2 and c_3 the related coefficients, respectively. The first eigenfunction e_1 in any figure, is obviously understood to show the mean beach profile. The generation and migration of the 73-bar can be seen in **Fig. 14**. The minimum of e_2 in **Fig. 14(a)** indicates the existence of the 73-bar at the position where $x=224$ m, as can also be seen in **Fig. 7**. The large negative value of c_2 describes the generation of the 73-bar in winter, 1973, as well as keeping its state during summer, 1974. Moreover, the increase of c_2 in 1975 indicates the migration of the 73-bar, but its direction is not able to be judged only from this figure. The values of e_2 and c_2 shown in **Fig. 14(b)** and **(c)** explain the migration or vanishing of the 73-bar, because of the minimum value of e_2 which can be found to move offshoreward from these figures. While the value of c_2 increased in time with the periodic seasonal changes. The generation of the 78-bar is found at the position where $x=192$ m in **Fig. 14(d)** and **(e)**, as also seen in **Fig. 7**. Decrease in c_2 in 1979 represents processes of the generation and migration of the 78-bar. Considerations of c_2 shown in these figures make clear that the 78-bar was generated in January, 1979, remained during the summer, and then migrated in winter between 1979 and 1980. This agrees with the changes in beach profile shown in **Fig. 7**.

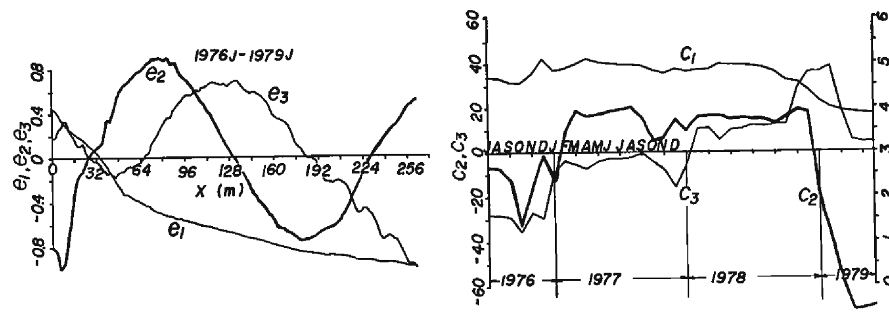
On the other hand, it is difficult to discuss the physical meanings of the third function e_3 and its coefficient c_3 by the data of beach profiles at the coast, where we rarely observed terraces. We therefore consider the third function to correspond to terrace-shaped beach profiles. Any broad maximum of e_3 can be seen at the onshore position of the bar in **Fig. 14**. The terrace-shaped beach profile is considered to be a flat beach profile in **Fig. 7**, from the comparison between **Figs. 7** and **14**. We may therefore understand the physical meaning of the three empirical eigenfunctions from the results of the JJ-data. By comparing the results of the JJ-data with those of the C-data, as shown in **Fig. 15**, influences of the remarkable bars on these eigenfunctions are considered. The influence of the 78-bar, for example, on the second eigenfunction can be seen **Fig. 15(a)**, resulting in an inverse tendency of e_2 and c_2 which were obtained by the different divisions of data. The function e_2 obtained by the JJ-data shows non-existence of a bar, but the function introduced by the C-data



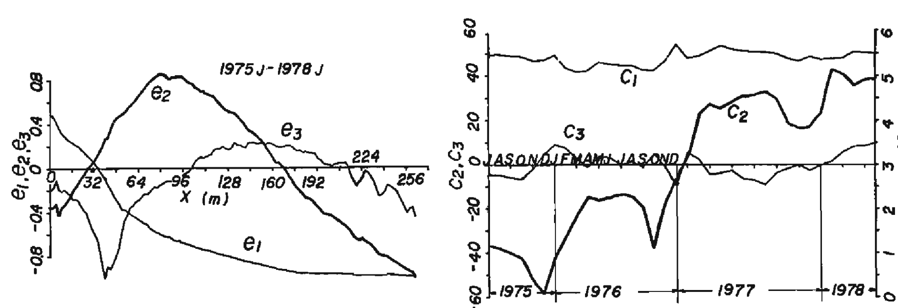
(a) From July, 1973 to June, 1976



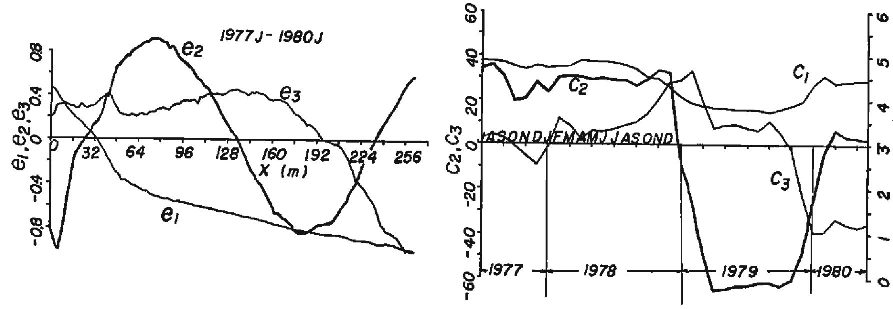
(b) From July, 1974 to June, 1977



(c) From July, 1975 to June, 1978

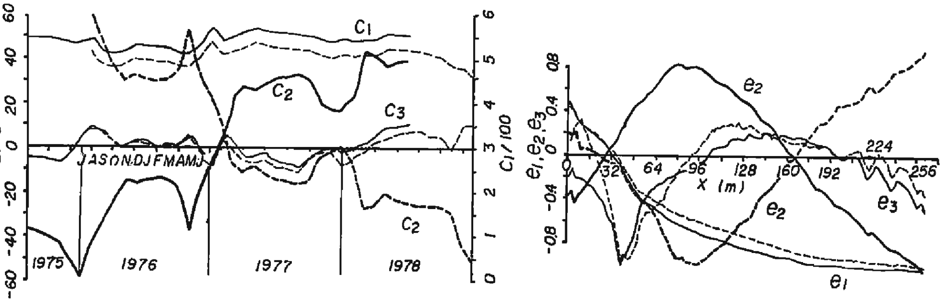


(d) From July, 1976 to June, 1979

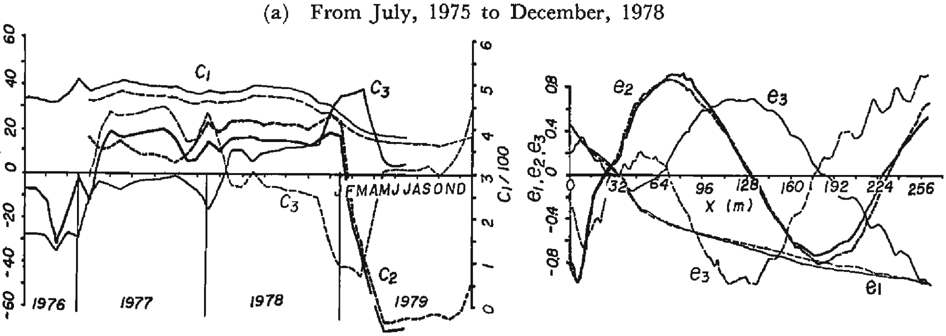


(e) From July, 1977 to June, 1980

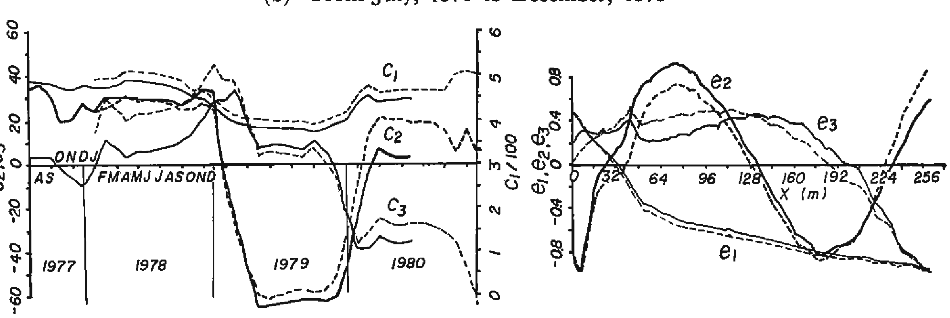
Fig. 14 Empirical eigenfunctions and their related coefficients.



(a) From July, 1975 to December, 1978



(b) From July, 1976 to December, 1979



(c) From July, 1977 to December, 1980

Fig. 15 Comparison of empirical eigenfunctions and their related coefficients calculated with JJ-data (thick lines) and C-data (thin lines).

indicates the existence of the remarkable bar at the position where $x=96$ m, corresponding to the just generated 78-bar, as seen in **Fig. 7**. The 78-bar also influences the third eigenfunction as shown in **Fig. 15(b)**. Clearly found is an inverse tendency in this figure, such as the function e_3 obtained by the JJ-data, showing the existence of terrace-shaped beach profile at the position where $x=128$ m, but the other e_3 gives an inverse result. This is explained by assuming that the 78-bar causes the function e_3 to be cancelled with the effect of the terrace-shaped profile. This assumption can be justified by the results shown in **Fig. 15(c)**, which represents the comparison between the results including the 78-bar both in the JJ-data and C-data. Apparently, there is no remarkable difference between them in this figure.

From the above discussion, the properties of the empirical eigenfunctions are summarized:

1) The method of empirical eigenfunction can be employed in studying characteristics of beach profile changes quantitatively and explaining their time dependence.

2) The physical meanings of the first and second functions are well specified as the mean beach profile and the bar or berm, but those of the third function can not be clarified.

3) The remarkable changes in beach profile, such as the 73-bar and the 78-bar, however, so greatly influence the second and third eigenfunctions that careful determination of the division of period of data of wave conditions is required.

5. Conclusion

Long-term changes in beach profiles have been studied in this paper by use of the data observed at Ogata coast for the period of eight years and three months. The most significant conclusions are summarized:

1) During the observation period, two remarkable beach changes occurred in the processes of the generation and migration of bars as well as those of the shoreline retreat. One occurred in the period from 1973 to 1974 and the other from 1978 to 1980. Continuous beach erosion along this coast was observed from the changes in sediment volume in the annually averaged beach profiles, except for the temporal occurrences in 1979 and 1980, respectively.

2) The relationships between the shoreline position $\bar{y}_0$ and the beach slopes $\bar{i}_3$ and $\bar{i}_b$ were determined to show that the beach slope in a subaerial beach $\bar{i}_b$ becomes steeper with the retreat of shoreline $\bar{y}_0$. While recently, the beach slope $\bar{i}_b$ has approached that of $\bar{i}_3$. The beach slope of a subaqueous beach profile in the region shallower than 3 m $\bar{i}_3$ is constant except for the period of great changes in beach profile such as those of 1978.

3) Since the physical meanings of the first and second empirical eigenfunctions have been specified, as done by Winant et al., the method of empirical eigenfunction can be employed in investigations of the changes in beach profiles. Remarkable changes in beach profile, however, so greatly influences the second and third empirical eigenfunctions, that the division of periods of data has to be carefully determined

in wave actions.

Further investigations will be carried out to find out any relationship between changes in beach topography and incident wave characteristics from the viewpoint of sediment transport in rough conditions.

Acknowledgement

We thank Mr. K. Uchiyama, Technical Officer, Ogata Wave Observatory, Disaster Prevention Research Institute, Kyoto University for his kind help in carrying out the continuous observation of beach profiles.

References

1) Johnson, D. W.: Shore processes and shoreline development, Hafner Pub. Com., 1965, p. 584.
2) Shepard, F. P.: Longshore-bars and longshore-trough, U.S.Army Corps Engrs., Beach Erosion Board Tech. Memo., No. 15, 1950, p. 32.
3) Valentin, H.: Die kueste der erde, Petermanns Geog. Mitt. Ergaenzungheft, Vol. 246, 1953.
4) Bakker, W. T., E. H. J. Klein Breteler and A. Roose: The dynamics of a coast with a groin system, Proc. 12th Conf. on Coastal. Eng., ASCE, 1970, pp. 1001–1020.
5) Sonu, C. J. and J. L. Van Beek: Systematic beach changes on the outer banks, Jour. Geology, Vol. 79, No. 4, 1971, pp. 416–425.
6) Sonu, C. J. and W. R. James: A Markov model for beach profile changes, Jour. Geophys. Res., Vol. 78, No. 9, 1973, pp. 1462–1471.
7) Nordstorm, C. E. and D. P. Inman: Sand level changes on Torrey Pines Beach, California, U.S. Army Corps Engrs., Beach Erosion Board Tech. Memo., 1975.
8) Winant, C. D., D. L. Inman, and C. E. Nordstorm: Description of seasonal changes using empirical eigenfunctions, Jour. Geophys. Res., Vol. 80, No. 5, 1975, pp. 1979–1986.
9) Swart, D. H.: A schematization of onshore-offshore transport, Proc. 14th Conf. on Coastal Eng., ASCE, 1974, pp. 884–900.
10) Shirai, T. and Y. Tsuchiya: Characteristics of beach configuration of Ogata coast, Coastal Eng. in Japan, JSCE, Vol. 71, 1974, pp. 141–154.