CHAPTER 93

Predictive model for daily changes of shoreline

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Abstract

Beach profiles have been being measured every day on sandy beach at the Hazaki Oceanographical Research Facility, facing to the Pacific Ocean. Based on the data obtained during the period from March 12, 1986 to September 11, the relation between the daily changes of shoreline position and energy flux of incident waves is analyzed. A tentative predictive model of the short-term shoreline changes is proposed. A combination of this model and the one-line theory is examined.

1. Introduction

A shoreline changes due to the longshore sand transport in a long-term. A practical numerical simulation model, the one-line theory can predict the long-term shoreline changes. The shoreline also changes due to the cross-shore sand transport in a short-term. There is, however, no reliable method to calculate the short-term ones during and after a storm, mainly because of lack of information on the actual changes of shoreline.

The authors have measured the beach profile every day for 184 days. Based on the data obtained, the relation between the short-term shoreline changes and the energy flux of incident waves are examined. Furthermore, a black box model for predicting the short-term changes are developed.

2. Field observation (on beach profile)

The site of field observation is a entirely natural sandy beach. It is facing to the full wave energy of the Pacific Ocean (see Figure 1). A foreshore slope is mild, about 1/50, and the mean diameter of sediments on a beach is 0.18mm. According to eleven aerial photographs taken

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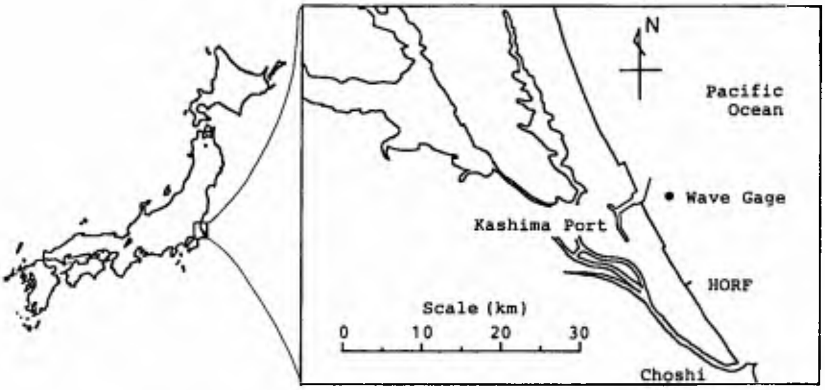

Figure 1 Site of field observation

Photo. 1 Hazaki Oceanographical Research Facility

during a period from 1947 to 1984, the location of shoreline has been stable since 1979. On this beach, Port and Harbour Research Institute, Ministry of Transport, has constructed the Hazaki Oceanographical Research Facility (HORF) in 1986 for carrying out field observation in the surf zone even under sever sea conditions. The research pier is a 427 meters long concrete structure supported by 0.8 meter diameter concrete-filled steel piles in a single line, at 15 meters interval. The pier deck is 2.5 meters wide and 7 meters above L.W.L.(Photo. 1).

Beach profiles of 500 meters from the tip of pier to the backshore were measured with an interval of 5 meters once a day during 184 days from March 12 to September 11, 1986. The sea bottom profile was surveyed with a sounding lead

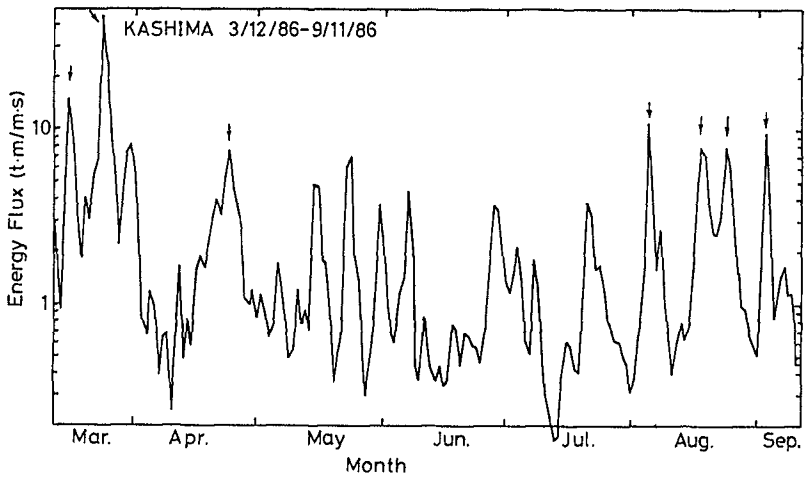

Figure 2 Changes of daily mean wave energy flux

Table 1
Representative high waves

Month :Day	Energy Flux (tm/ms)	Maximum waves	
		$H_{1/3}$ (m)	$T_{1/3}$ (s)
3:16	15.4	4.04	9.3
3:24	45.9	6.76	10.7
4:24	7.8	3.06	10.1
8: 5	11.0	4.12	9.1
8:18	8.0	3.12	11.9
8:24	8.2	3.10	9.2
9: 3	9.6	3.35	10.9

from the pier deck. The land survey of the backshore and foreshore was done by using a transit and surveyor's staff.

The offshore waves have been measured near Kashima Port (see Figure 1) during twenty minutes of every two hours at the depth of 22 meters below the datum line. The daily mean energy flux has been calculated with the significant wave data of every two hours.

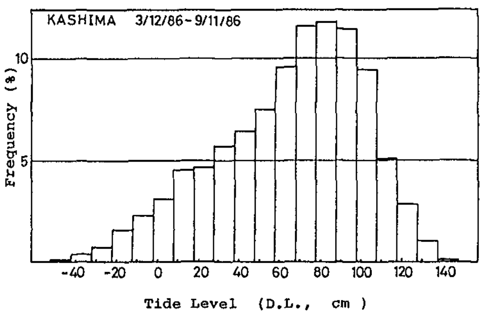

Figure 3 Frequency of tide level

Figure 2 shows the daily mean energy flux of incident waves during the period from May 12 to September 11, 1986. The energy flux was small in the months from May to July, while it was large in the other months. Storms larger than 3.0 meters in the significant wave height occurred seven times on days denoted by arrows in Figure 2. The daily mean energy flux, the maximum significant wave height and period on the storm day are listed in Table 1. The tide level is being observed every hour in Kashima Port. Figure 3 shows the distribution of frequency of tide level.

3. Daily changes of shoreline position

3.1 Outline of profile changes

Figure 4 shows the mean profile during observation relative to the datum line. The on-offshore reference coordinate is inherent in HORF. Beach slope above the datum line is nearly constant, 1/50. Sunken places of 15 meters interval in offshore side of reference point 150m are the local scour around the piers.

The dotted points in Figure 4 are the standard deviation of profiles at every measuring point from the mean profile. The standard deviations of sea bottom levels have a general tendancy to increase in the offshore direction. However, it has the minimum value at the reference point 25m, where the mean level is +0.28 meter above the datum line. Then, the level at the minimum value point is not apt to change.

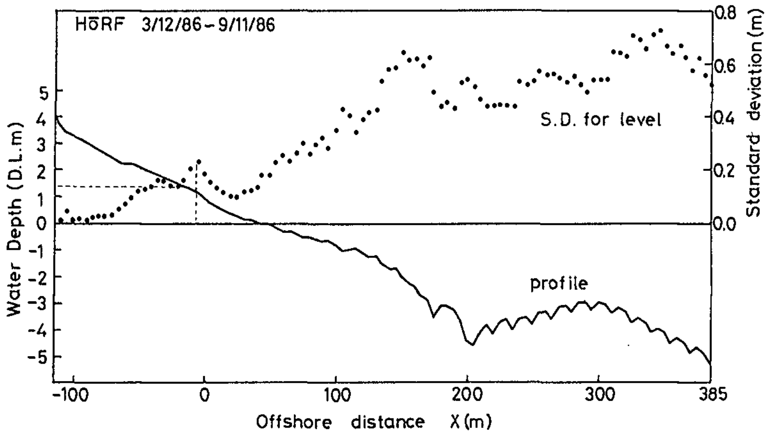

Figure 4 Mean profile and standard deviation of profiles

According to the authors' visual observation on the beach and from the pier deck, the shallow water area and the beach was nearly plane.

3.2 Feature of shoreline changes

The changes of foreshore profile was maximum at the mean level of +1.4 meters above the datum line, as seen in Figure 4. This level is corresponding to the maximum water level during observation. In this paper, the shoreline position is defined at an intersection of beach profile and a level of +1.4 meters above the datum line. The shoreline positions was calculated by interpolating the beach profile data of 5 meters interval.

Figure 5 shows the daily on-offshore changes of shoreline position. The shoreline was in onshore-side in the high energy flux months of March, April and August, while it was in the offshore-side during the low energy flux period from May to July. Then, a whole trend of shoreline changes are

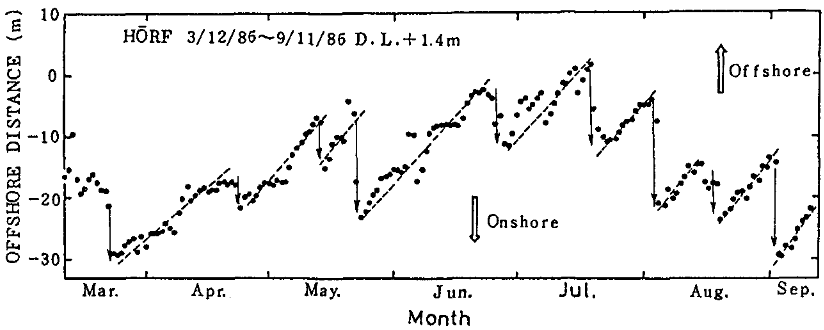

Figure 5 On-offshore changes of shoreline position

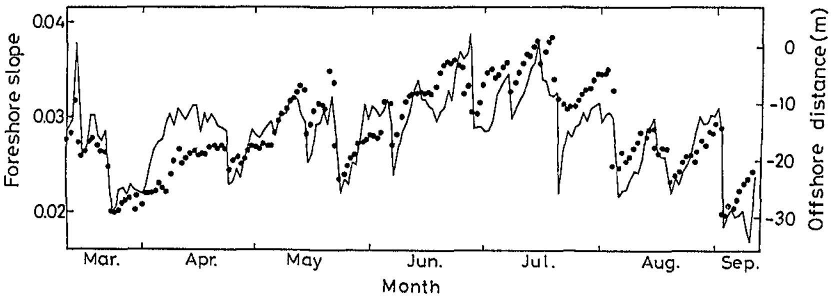

Figure 6 Changes of foreshore beach slope

roughly corresponding to the changes of incident energy flux.

The shoreline positions shifted in the offshore direction, independent of wave energy flux, in the accretionary process. Nine broken lines in Figure 5 approximate the accretionary process. The broken lines are nearly parallel each others, which means that the shoreline advanced with almost constant speed. The inclinations of the broken lines give the value of 0.68 meter/day for the speed of progression in average. On the other hand, the shoreline rapidly recessed in one or two days in erosional process as shown by arrows in Figure 5. The rapid recession have occurred even in the low energy flux months such as May, June, and July.

The solid line in Figure 6 shows the changes of mean foreshore slope calculated by the least square method with the data from the reference point -20m to +25m. The shoreline position are also plotted in this figure. The changes of the slope and the shoreline position have a same tendancy, although there is a some discrepancy between them. The foreshore slope suddenly became to be mild when the shoreline rapidly recessed in the erosional process.

4. Relation between shoreline position and energy flux

Sunamura(1984) proposed the following semi-empirical relation among the foreshore beach slope ($\tan\beta_f$), sediment grain size (d), and the waves:

$$\tan\beta_f = 0.12[H_B/(g^{\frac{1}{2}}Td^{\frac{1}{2}})]^{-\frac{1}{2}}, \quad (1)$$

where H_B is the wave breaker height and T is wave period. The wave breaker height in Eq.(1) can be eliminated by using a following relation (Sunamura and Horikawa,1974),

$$H_B/H = (\tan\beta)^{0.2}(H/L)^{-0.25}, \quad (2)$$

where $\tan\beta$ is mean bottom slope, H and L are offshore wave height and wave length, respectively. Then, we will have Eq.(3) instead of Eq.(1),

$$\tan\beta_f = 0.19d^{1/4}(\tan\beta)^{-0.1}(L^{1/3}/H)^{3/8}. \quad (3)$$

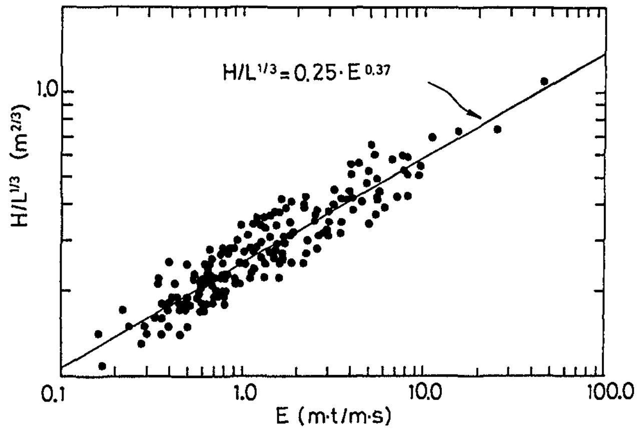

Figure 7 Relation between $H/L^{1/3}$ and energy flux

Figure 7 shows the relation between $H/L^{1/3}$ and the daily mean energy flux during the observation. The wave length was calculated by the small amplitude wave theory with the daily mean significant wave period. The height was reversely calculated based on the daily mean energy flux and mean wave period. As seen in Figure 7, there is a strong relation between them, a solid line in the figure, which is expressed as

$$H/L^{1/3} = 0.25E^{0.37}, \quad (4)$$

where E is the daily mean energy flux. By substituting Eq.(4) into Eq.(3), we have

$$E = [0.32d^{0.25}(\tan\beta)^{-0.1}]^{7.19}(\tan\beta_f)^{-7.19}. \quad (5)$$

Next, a simple relation between the foreshore slope and the shoreline position will be introduced. Let the

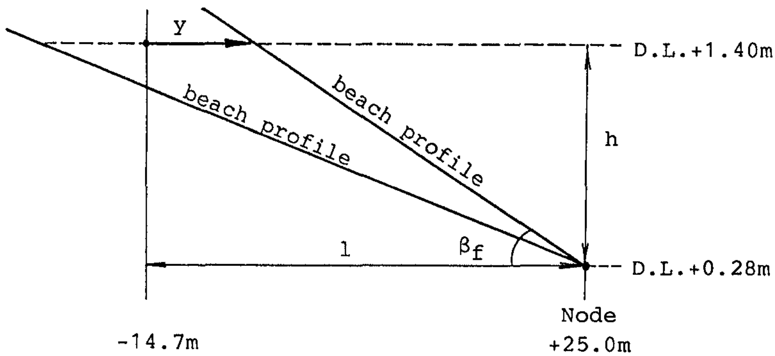

Figure 8 Relation between foreshore slope and shoreline position

reference point 25m be a node since the standard deviation of level changes at this point was minimum as seen in Figure 4. The mean level of reference point 25m is +0.28 meter above the datum line. Figure 8 illustrates the relation between the foreshore slope and the shoreline position. A symbol l is the horizontal distance from the node to the time averaged shoreline position, 39.7 meters. A symbol h is the vertical distance from the node to the level of shoreline, 1.12 meters. A symbol y is the location of shoreline, taking the origin at the mean shoreline position and being positive in the offshore direction. From this concept figure, the foreshore slope is represented by

$$\tan\beta_f = h/(l-y). \tag{6}$$

By substituting Eq.(6) into Eq.(5), and by introducing the actual values of d=0.18mm and $\tan\beta=1/60$ in the study site, and by normalizing the daily mean energy flux with the mean value of energy flux during the observation, 2.48tm/ms, we have

$$\hat{E} = 4.19\times10^{-10}[(l-y)/h]^{7.19}, \tag{7}$$

where $\hat{E}$ is the dimensionless energy flux.

Figure 9 shows a plot of the dimensionless wave energy flux ($\hat{E}$) versus the shoreline position (y) for 184 cases (days). Essentially speaking, the cross-shore component of energy flux must be considered. The measurement of wave direction, however, is not being done in Kashima Port. Then, the absolute energy flux are utilized without any further calculation. This approximation will introduce a little error of less than 3% when an angle of wave incidence to beach is less than ±10 degrees. The curved line in Figure 9 is Eq.(7) with the slightly modified constant of 7.15×10^{-10} and an exponential index of 6.0, which can be approximated on the figure by a straight broken line as

$$y = -16.0 \log\hat{E} + 1.63, \tag{8}$$

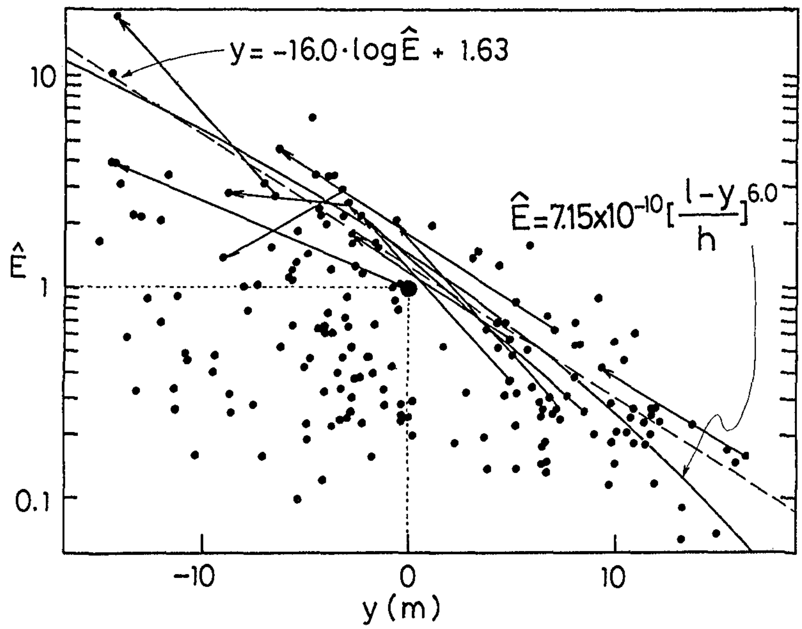

Figure 9 Relation between energy flux and shoreline position

where log is a common logarithm and a unit of y is in meter.

In Figure 9, the rapid recessions more than 5 meters in a day are connected with arrows. The direction of arrows are the same as those of shoreline changes, that is leftward in the figure. It is recognized that the arrows lie parallel near the straight broken line of Eq.(8). According to Figure 9, the shoreline position rapidly recesses by the lower energy flux when the more it is being advanced.

On the other hand, almost all data in the accretionary processes are plotted in the lower side of the broken line in Figure 9.

Furthermore, a relation between the averaged shoreline position (y=0) and the mean energy flux ($\hat{E}$) is just near the broken line, a larger closed circle. This situation is interesting and will be discussed later.

5. Tentative predictive model for daily shoreline changes

The shoreline advances with the constant speed in the accretionary process, while it rapidly recesses in one or two days in the erosional process. Then, without taking into account the time lag of shoreline changes behind the external force, the authors have developed an empirical predictive model for the daily shoreline changes as follow.

The shoreline position and the dimensionless energy flux on the i-th day are denoted by y_i and $\hat{E}_i$, respectively.

[**Step 1**] By assuming the accretionary process, the shoreline position on next day can be predicted by a following equation:

$$y_{i+1} = y_i + 0.68 \quad \text{(meter)}. \qquad (9)$$

[**Step 2**] The assumption in Step 1 must be confirmed by plotting the data of (y_{i+1}, $\hat{E}_{i+1}$) in Figure 9. If it will be plotted in the lower side of the broken line, that is,

$$y_{i+1} < -16.0 \log\hat{E}_{i+1} + 1.63 \quad \text{(meter)} \qquad (10)$$

y_{i+1} predicted by Eq.(9) is decided to be the shoreline position.

[**Step 3**] If it will be in the upper side of the broken line, it will be in the erosional process. Then, the shoreline position rapidly recesses along the broken line. A new position of y_{i+1} depends on $\hat{E}_{i+1}$ according to the following equation:

$$y_{i+1} = -16.0 \log\hat{E}_{i+1} + 1.63 \quad \text{(meter)}. \qquad (11)$$

The above procedure from Eq.(9) to (11) is expressed in one equation as

$$y_{i+1} = \min[\, y_i + 0.68,\ -16.0 \log\hat{E}_{i+1} + 1.63 \,], \qquad (12)$$

where the symbol min[a,b] gives the smaller of a or b.

Figure 10(a) shows the relations between the dimensionless energy flux and the shoreline position during the

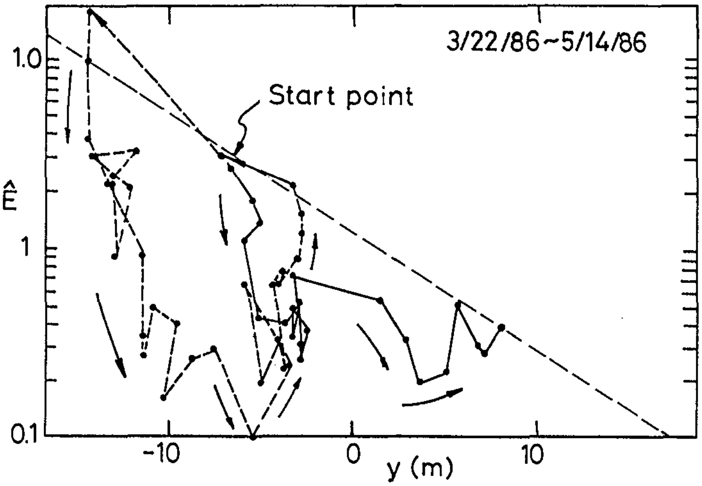

Figure 10(a) Relation between $\hat{E}$ and y (March 22 to May 14)

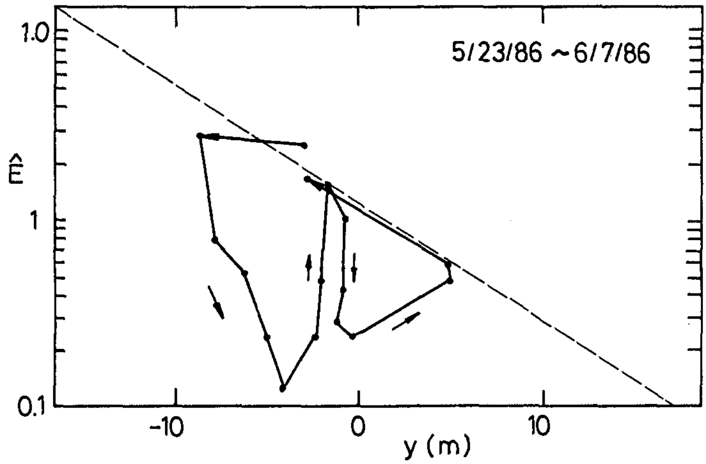

Figure 10(b) Relation between $\hat{E}$ and y (May 23 to June 7)

period from March 12 to May 14, 1986. Broken lines connect the time series data for the first half period and solid lines for second one. A broken straight line in this figure is corresponding to Eq.(8). At first, a rapid recession occurred along Eq.(8) when the value of energy flux was large. After that, the shoreline position gradually advanced with a decrease of wave energy flux up to be y=-5m. In turn, the wave energy flux became to be large, which eventually made the relation between the energy flux and the shoreline position to be on the broken line of Eq.(8). On that day, another rapid recession occurred again along the broken line. Next day, the shoreline position started to advance again under the lower energy flux.

Figure 10(a) shows the time series data during the period from May 22 to June 7, 1986, in the same manner as Figure 10(a). A rapid recession occurred also in this case at first. Subsequently, the shoreline position gradually advanced. During the accretionary process, there was temporary increase of wave energy flux, just reaching to the broken line. The rapid recession, however, did not occur. The shoreline position continued to advance, because the relation between the wave energy flux and the shoreline position on the next day was in the lower side of the broken line. On the last day, the wave energy flux became to be beyond the broken line and another rapid recession occurred along the broken line.

By using Eq.(12), the shoreline position have been successively predicted with the time series data of wave energy flux (see Figure 2). A result of prediction is shown with solid lines in Figure 11 by comparing with the dotted data of actual shoreline position. In calculation, an initial condition is the measured position of shoreline on May 12. As seen in Figure 11, the predicted shoreline

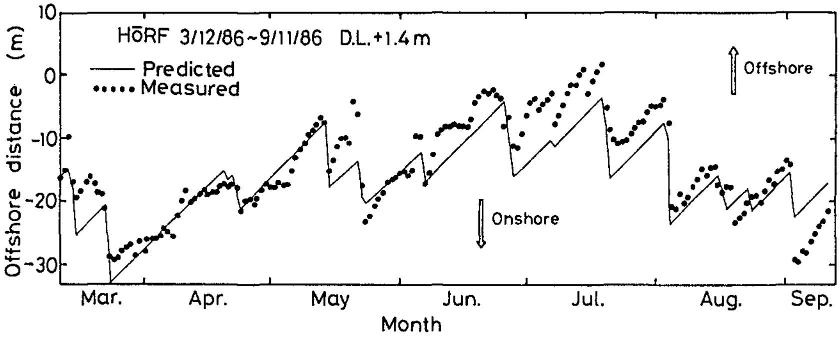

Figure 11 Comparison of changes of shoreline position predicted and those observed

position almost agree with the measured ones.

6. Possibility of combination of the present model and the one-line theory

For practical purpose of predicting the short-term shoreline changes, the present model must be combined with the one-line theory. For this purpose, any mutual contradiction between both models are not basically allowed. Concerning to this problem, the following four items are pointed out:

(a) Both models treat the mechanism of sand transport and the other phenomena in the surf zone in a black box. Therefore, both modeling accuracies of phenomena are almost the same each other.

(b) The external force in the present model is the cross-shore component of energy flux. That in the one-line theory is the longshore one. Therefore, there is no physical contradiction between the models.

(c) The time series data of energy flux are utilized in the present model, while the time averaged energy flux during a objective period is usually utilized in the one-line theory. Fundamentally speaking, the time series data have to be utilized also in the one-line theory. However, it will take much computer processing time for calculating the wave deformation. Usage of averaged energy flux in the one-line theory is only for convenience.

(d) The one-line theory can predict the long-term shoreline changes by inputting the mean energy flux. As shown in Figure 9, the relation between the time averaged energy flux (E=1) and the averaged position of shoreline (y=0) is just near the broken line, along which the rapid recession of shoreline position occurs. In short, the shoreline position predicted by the one-line theory with the averaged energy flux practically satisfies the relation of Eq.(8). Therefore, the shoreline position predicted by both models agree at the basic point.

The above consideration shows that there will be no problem in combining them into a new model. The combined model will be able to predict not only the long-term shoreline changes but also the short-term one. The present model, however, is the empirical one, and has the following incomplete points which must be studied further:

(1) The definition of shoreline position with the level of +1.4 meters above the datum line is not general.

(2) The effect of changes of sea bottom topography such as bars and troughs on shoreline changes is unknown.

(3) The changes of tide level is not taken into account in the present model.

(4) The mechanism of shoreline changes in the short-term has not been known.

7. Conclusions

The conclusions obtained in this study are as follows:

(a) The shoreline advanced with the constant speed of 0.68 meters/day in the accretionary process.

(b) In the erosional process, the shoreline rapidly recesses in one or two days. The rapid recession of shoreline depends not only on large energy flux of waves but also on the position of shoreline. In other words, the shoreline recesses by the lower energy flux when the shoreline has advanced, while it advances by the higher energy flux when it has recessed.

(c) The empirical criterion of an occurrence of rapid shoreline recession is obtained.

(d) Based on the results of data analyses, the authors have proposed a tentative predictive model of the short-term shoreline changes. This model can predict the shoreline position in order with the time series data of wave energy flux.

(e) The present model can be combined with the one-line theory without any contradictions.

References

(1) Sunamura,T. and K.Horikawa(1974): Two-dimensional beach transformation due to waves, Proc. of 14th ICCE, pp.920-938.
(2) Sunamura,T.(1984): Quantitative predictions of beach-face slopes, Geol. Soc. Am. Bull., Vol.95, pp.242-245.