

CHAPTER 143

PREDICTION OF 3-D BEACH CHANGES ON THE FUJI COAST

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ABSTRACT

Beach changes around Tagonoura Port on the Fuji Coast were investigated by using the topographic survey data collected in the 15 years between 1968 and 1983. Temporal and spatial changes of the offshore distance from a reference point to certain contours were analyzed to elucidate the actual situation of topographic changes on the Fuji Coast, and the littoral transport rate on the downdrift coast of Tagonoura Port was found to be about $1.17 \times 10^5 \text{ m}^3/\text{yr}$ on the average between 1973 and 1983. It is concluded that a large amount of sediment eroded from the downdrift beach of Tagonoura Port is carried away toward a zone deeper than 20m. A numerical model predicting three-dimensional beach changes was also developed, taking account of both the vertical distribution of littoral transport and the effect of the wave-dissipating breakwaters.

1. INTRODUCTION

In recent years beach erosion has become severe along Japan's coasts. The Fuji Coast, surrounding Suruga Bay and formed by the fluvial sediment supply from the Fuji River, is one of these eroded coasts. Since the early 1960s sediment supply to this coast has decreased due to the influence of extensive excavation of the river bed, eroding the coast around the river mouth. Since 1959 the breakwater at Tagonoura Port has been constructed in the middle of the coast, and then the downdrift beach of the harbor was further eroded. As a countermeasure against beach erosion, wave-dissipating breakwaters, composed of concrete blocks parallel to the shoreline, have been constructed since 1973 on the downdrift coast of the harbor. The beach erosion on the Fuji Coast seems to be a typical example of beach erosion occurring along Japanese coasts from a caused point of view. For this reason, it is of primary importance to investigate the actual situation of the beach erosion and the effectiveness of the countermeasures along this coast in order to understand the beach erosion problems in Japan.

Along this coast, topographic surveys have been conducted once a year since 1968. This study aims to investigate beach changes around the harbor in the 15 years between 1968 and 1983 by using the topographic survey

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data. In order to analyze the field data, temporal and spatial changes of the offshore distances from a reference point to certain contours are studied. The validity of this method has been proved when applied to the analysis of beach profile changes on the Suruga Coast (Uda and Takeuchi, 1985) and Kochi Coast (Uda et al., 1986).

The temporal and spatial beach changes on the Fuji Coast are elucidated through this study, and the littoral transport rate on the downdrift coast of Tagonoura Port is evaluated. In particular, it is concluded that a large amount of sediment eroded from the downdrift beach of Tagonoura Port is carried away toward a zone deeper than 20m. The second aim of this study is to develop a numerical model which can predict three-dimensional beach changes. For this purpose, a model in which the vertical distribution of littoral transport is taken into account and the effect of the wave-dissipating breakwaters on the beach changes can be evaluated is developed.

II. METHOD OF INVESTIGATION

The Fuji Coast surrounds Suruga Bay facing the Pacific Ocean to the south (Fig.1). The water depth of Suruga Bay is so deep that the Fuji Coast has a steep slope as shown in Fig.1. At a location about 5.5km east of the mouth of the Fuji River lies Tagonoura Port, which was constructed in 1959. Topographic surveys have been conducted once a year since 1968 in the region between survey line No.0, adjacent to Numazu Port, and No.85, next to the mouth of the Fuji River. The survey line interval for the bottom sounding is 250m. In this study the bottom sounding data obtained over the 15 years between 1968 and 1983 are analyzed in order to investigate the beach changes on the Fuji Coast. For this purpose, temporal and spatial changes of the offshore distance from the reference point to certain contours between 2m above and 30m below the MSL are investigated.

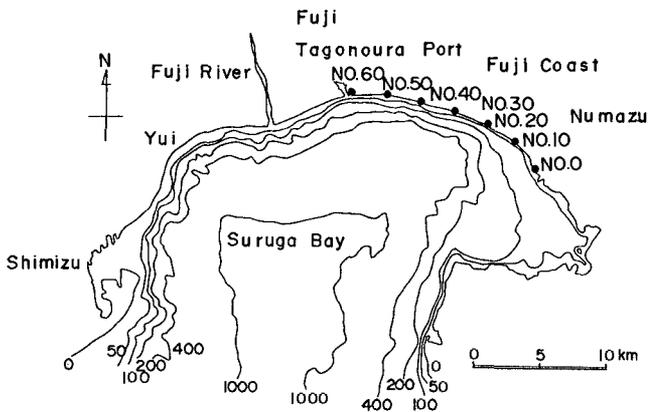


Fig.1 Location of the Fuji Coast

III. BEACH EROSION ON THE FUJI COAST

3.1 Spatial and temporal changes of shoreline configuration

First, the actual situation of the beach erosion on this coast will be studied focusing on shoreline changes before advancing the detailed analysis with respect to the movement of bottom contours in the shallow water zone. The changes in the shoreline configuration on the Fuji Coast are shown in Fig.2. The abscissa is taken for the number of the survey lines set along the coastline, in which No.0 and No.85 are located next to Numazu Port and the Fuji River, respectively. The locations of various facilities are denoted by the serial number in the figure. Since the interval of the survey lines represents 250m, the entire distance in Fig.2 includes 20.25km of shoreline. The ordinate expresses the change of shoreline positions measured in each year since 1968 until 1983 relative to the shoreline configuration in 1968.

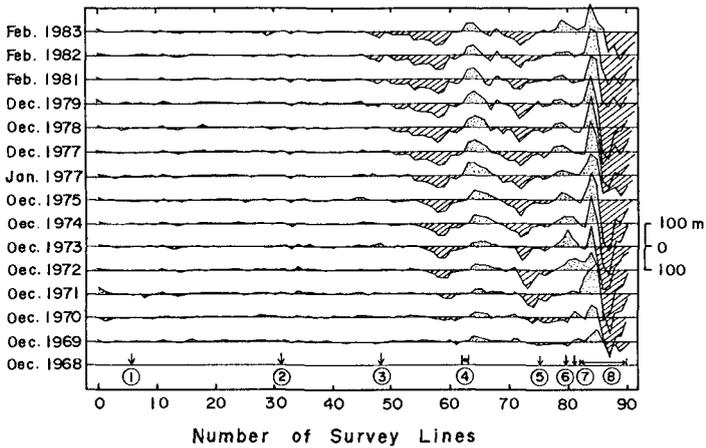


Fig.2 Temporal and spatial changes of the shoreline position on the Fuji Coast (1: Shinnakagawa Flood Way, 2: Showa No.2 Flood Way, 3: Showa Flood Way, 4: Tagonoura Port, 5: Nyudo Drainage channel, 6: Motofuji No.2 Drainage Channel, 7: Motofuji Drainage Channel, 8: Fuji River).

After the construction of the harbor breakwater in 1959, the east coast of the harbor has been gradually eroded. The eroded region extended from No.62 up to No.49, or 3.5km, until 1983. These features of the shoreline retreat in a region next to the harbor breakwater obstructing littoral transport show that the dominant direction of littoral drift on this coast is eastward. As the beach was eroded, wave-dissipating breakwaters, composed of the concrete blocks, have been constructed to counteract beach erosion, and at present, the whole coastline between Tagonoura Port and Showa Flood Way is covered by the concrete blocks. However, many concrete blocks have been scattered in this region due

to the scouring at the foot of the breakwaters and due to the wave action on the blocks(Kohno et al., 1986).

As is clearly understood in Fig.2, beach erosion was observed between Tagonoura Port and Showa Flood Way. Nevertheless, the shoreline configuration between Showa Flood Way and Numazu Port at No.0 has been of stable form during the same period. This implies that the eroded materials from the updrift coast were carried away in the offshore direction. This offshore movement of sand is important when studying the littoral drift on the Fuji Coast, so that this point will be discussed in detail in the later section. Furthermore, it is found from Fig.2 that beach erosion is also severe next to the mouth of the Fuji River. Just west of Tagonoura Port, where the shoreline has advanced in recent years in contrast with the shoreline retreat on the east coast, littoral sand has been lost partly by the offshore movement in front of the tip of the breakwater, and partly by the excavation of sand for use in the construction industry.

Figure 2 is useful to understand the spatial changes of the shoreline configuration, but in order to realize the time lag in shoreline changes existing between survey lines, it is favorable to take time as the independent variable. Therefore, the temporal changes of the shoreline positions between No.62 and No.45 located on the downdrift site of Tagonoura Port are shown in Fig.3. Time is taken as the abscissa and the ordinate is the change of the shoreline positions relative to the one measured in December, 1968 for the initial value. In addition, the sign(\square) in the figure expresses the time when the wave-dissipating breakwater was constructed at each survey line. The first one was built in 1973 at survey line No.58, and until 1978, 17 wave-dissipating breakwaters have been constructed along the shoreline. It should be noted that the construction time of the breakwaters corresponds to the shoreline retreat at each survey line fairly well, indicating that the construction site was extended eastward with the continuous shoreline retreat. Maximum shoreline retreat was observed at No.58 and it reaching about 50m in two years between 1971 and 1973. Thereafter the rate of the shoreline retreat became small by virtue of the wave-dissipating breakwater constructed in 1974. It is found that there exists a time lag in the initiation time of the shoreline retreat with the distance from No.62 next to Tagonoura Port. It was not until 1979 that the shoreline retreat began at No.48. In addition, it is understood that the rate of the shoreline change at the initial stage tends to decrease with the distance from the port, when compared with the shoreline changes observed at two survey lines located far from the port such as No.48 and in the vicinity of the port such as No.58.

3.2 Numerical simulation of change of shoreline configuration

Some features of the changes of the shoreline configuration observed on the coast just east of Tagonoura Port can be predicted by using the one-line model of

shoreline evolution as described in the following, if simple assumptions were made. First, it is assumed that the beach changes are caused only by the imbalance of littoral transport and do not depend on cross-shore sand transport. The definition sketch and the initial conditions are shown in Fig.4. Secondly, it is assumed that there exists a vertical wall totally obstructing littoral transport, like a jetty, at the righthand side of the region, and that the distance from the initial shoreline to the wave-dissipating breakwater of continuous type is equal to ℓ . Furthermore, the wave incidence is assumed to be from clockwise direction as shown in Fig.4. In the calculation, the diffraction effect of the jetty is neglected.

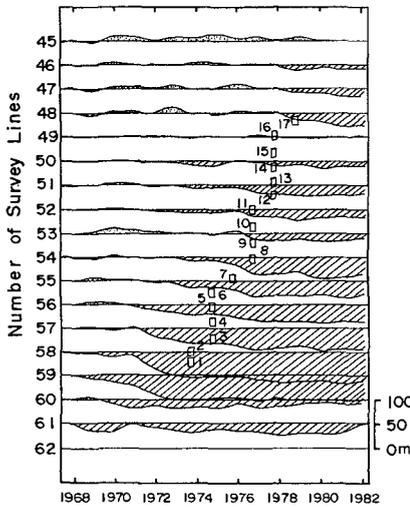


Fig. 3 Temporal changes of the shoreline positions in the region east of Tagonoura Port.

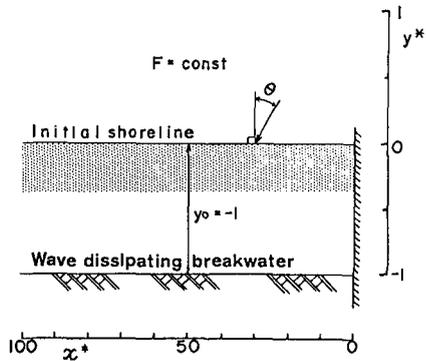


Fig. 4 Definition sketch of shoreline simulation model.

Fundamental equations of the one-line model of the shoreline evolution are expressed by Eqs. (1) and (2).

$$\frac{\partial q}{\partial x} + h \frac{\partial y}{\partial t} = 0 \tag{1}$$

$$q = F \left(- \frac{\partial y}{\partial x} + \tan \theta \right) \tag{2}$$

Where q : littoral transport rate, h : characteristic height of beach changes caused by littoral transport, x : longshore distance, t : time, F : coefficient depending upon the wave characteristics. In this study coefficient F and h are assumed to be constant in order to understand the essence of the phenomenon as easily as possible. Next, in order to simplify the analysis some dimensionless variables are introduced as follows:

$$y = \ell y^*, \quad x = \ell x^*, \quad t = \frac{\ell^2 H}{F} t^*, \quad \varphi = F \varphi^* \quad (3)$$

where ℓ is a characteristic length scale, and variables with the asterisk denote the dimensionless forms. Substituting these forms into Eqs. (1) and (2), then dimensionless forms of the equations are obtained.

$$\frac{\partial \varphi^*}{\partial x^*} + \frac{\partial y^*}{\partial t^*} = 0 \quad (4)$$

$$\varphi^* = - \frac{\partial y^*}{\partial x^*} + \tan \theta \quad (5)$$

In this calculation it is assumed that the shoreline does not retreat if the shoreline position coincides with the location of the wave-dissipating breakwater, and the breaker angle normal to the shoreline is equal to 10° . The results of the simulation of the shoreline evolution are expressed in Fig.5 showing the x^*-t^* diagram of the shoreline changes. The vertical axis and the abscissa are taken for the dimensionless longshore distance x^* and the dimensionless time t^* . The initial shoreline and the wave-dissipating breakwater are located at $y^*=0$ and $y^*=-1$, respectively, and the base line of y^* axis is moved upwards. It is found from Fig.5 that the beach downdrift of the jetty was rapidly eroded by the influence of the jetty, and that the time when the shoreline begins to retreat has a time lag with the longshore distance from the jetty. Furthermore, it is found that the duration required for the shoreline position to retreat to the location of the wave-dissipating breakwaters increases with the distance from the origin. These features obtained in the simulation are in good agreement with the field data shown in Fig.3, and it is concluded that the fundamental phenomenon of the shoreline changes caused by the obstruction of littoral transport can be understood through the present simple model.

3.3 Temporal and spatial changes of offshore distances

In the previous section, only the temporal and spatial changes of the shoreline configuration were discussed. In this section, temporal and spatial changes of the offshore distances from the reference point to some contours are studied in detail. First, the longshore distribution of the offshore distances from the reference points, which were determined along the foot of the coastal dike, to some contours selected at 5m intervals are shown in Fig.6. It can be clearly seen from Fig.6 that the bottom slope is steep between No.5 and No.25 because of the small intervals of the offshore distance to each contour, and that there exists a comparatively mild slope between No.25 and No.45. Beyond No.46, the contours have irregular shapes, expressing the irregular bottom topography.

Next, the changes of the offshore distance at some typical survey lines are investigated. For the typical survey lines, No.54 and No.58, located east of Tagonoura Port where the beach was eroded severely in recent years, are selected. Figure 7 shows the temporal change of the offshore distance from the reference point to some contours

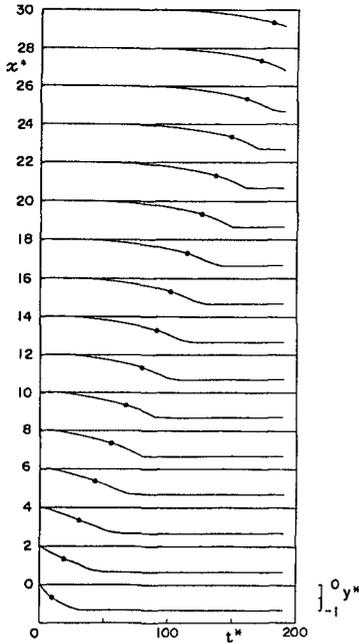


Fig. 5 x^*-t^* diagram of change of shoreline position.

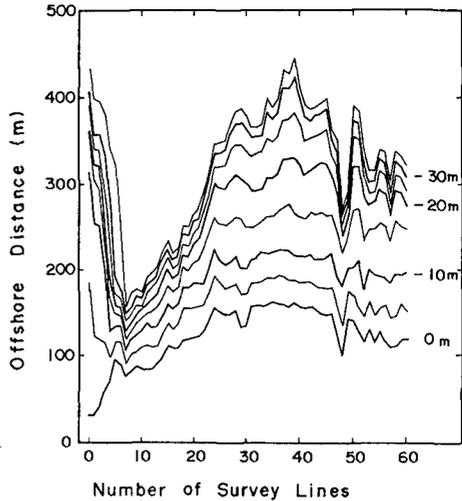


Fig. 6 Longshore distribution of offshore distance to some contours.

at No.54. The abscissa is the elapsed time, and the vertical axis is the offshore distance. The shoreline position began to retreat rapidly from Dec., 1975 and the contour lines between 2m above and 10m below the MSL retreated simultaneously with the shoreline change. This means that the beach profile in this region has changed its shape as a whole. By contrast, the change in offshore distance to contours deeper than 16m is small, except for the tendency of a gradual advance in the region deeper than 20m. This fact implies that part of sand eroded from the nearshore zone was carried away in the offshore direction, and therefore net loss of sand was caused on this beach, although the mechanism of the movement of sand is not known at present.

Similarly, the temporal changes of the offshore distance at survey line No.58, located 1km west of No.54 and 1km east of Tagonoura Port, are shown in Fig.8. It is found that the shoreline retreat at No.58 began faster than that at No.54 when Figs.7 and 8 are compared. Rapid retreat of the shoreline position began in 1971, 4 years earlier than that at No.54. The reason that the beach changes at No.58 were observed faster than the changes at No.54 is because of the proximity of survey line No.58 to the harbor structure obstructing littoral transport. The existence of the time lag in shoreline change shows that the beach erosion on this coast mainly depends upon the littoral transport. Further-

more, it is found from Fig.8 that the offshore distance defined between 2m above and 10m below the MSL gradually decreased, whereas the offshore distance to contours deeper than about 16m gradually increased, expressing the possibility of the offshore sand movement of part of the eroded sand.

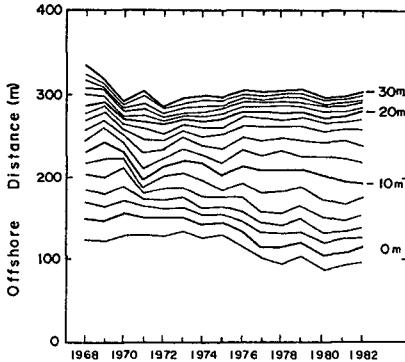


Fig.7 Temporal changes of offshore distance at survey line No.54.

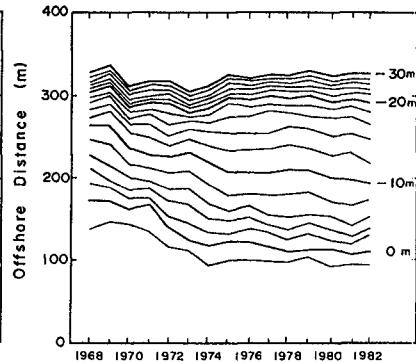


Fig.8 Temporal changes of offshore distance at survey line No.58.

Knowledge of the offshore movement of bed materials is of vital importance in order to formulate a plan to counteract beach erosion on this coast, because this movement results in the net loss of sand in the nearshore zone, and the beach will be eroded to a large extent in the long term. For the purpose, the cumulative value of the area surrounded by the contours and the abscissa in Fig.6 is calculated first, and then the change in the cumulative value (ΔS) with reference to the one measured in 1974 is obtained (Fig.9). For the calculation, 1983 bottom sounding data is selected, and the origin is set at No.60.

Cumulative area corresponding to the shoreline change shows the net loss in area in the longshore direction, and ΔS decreased about $5 \times 10^4 \text{ m}^2$ in 9 years up to No.0, adjacent to the breakwater of Numazu Port. Between No.60 and No.45, the rate of the decrease of ΔS is large, but thereafter it becomes small. In Fig.9, the changes in the area surrounded by the 5-m-interval contours are shown as well. It is found that ΔS corresponding to 5 and 10m deep contours undergoes a change similar to that corresponding to the shoreline. Namely, the absolute values of ΔS increase abruptly between No.60 and No.45, and they show a net loss in area at No.0. The losses of the areas attain about $7 \times 10^4 \text{ m}^2$.

On the contrary, the changes of the area surrounded by the 20, 25 and 30m deep contours contrast sharply with those measured in shallower zone. In the offshore zone ΔS increases with the distance from No.60, whereas ΔS in the shallow zone decreases. However, it should be noted that the eroded area in the shallow zone increased rapidly between No.60 and No.45, while the accreted area in the offshore

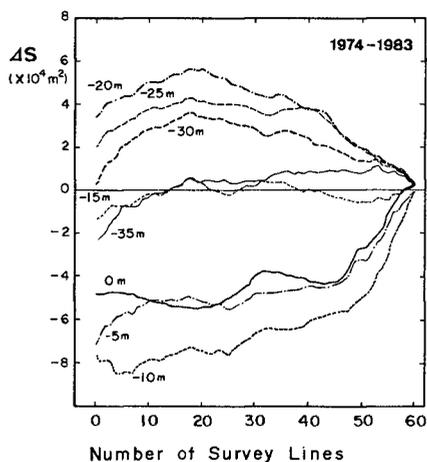


Fig.9 Longshore distribution of change of cumulative value of the area surrounded by offshore distance to some contours as shown in Fig.6.

zone tends to increase gradually from No.60 up to No.18. The increase rate of ΔS is especially large in the region where mild bottom slope was observed in the offshore zone as shown in Fig.6. These features indicate that a large amount of the sediment eroded on the downdrift beach of Tagounoura Port will be finally carried away toward the zone whose depth is between 20 through 30m. This kind of offshore sand movement along this coast was also confirmed through field investigations, using a radioactive tracer (Shuto et al., 1977). The results of the present study agree well with the findings of this field test.

3.4 Characteristic height of beach changes and littoral transport rate

On the east coast of Tagounoura Port, where beach erosion has been mainly due to the imbalance of littoral drift in recent years, temporal changes in the beach sections have been measured once a year so that the relationship between the changes in the sectional area and those of the shoreline position can be investigated. The calculation is carried out between No.61 and No.45, where beach changes caused by littoral transport are more dominant than those caused by cross-shore transport, judging by the movement of contours shallower than 10m which are very similar to each other, and the amount of sand carried in the offshore direction being comparatively small in this region, as shown in Fig.9. The characteristic height of beach changes caused by littoral transport can be determined empirically from the relationship between the change in the sectional area and that of the shoreline position. If the change in the sectional area (ΔA) can be expressed in terms of the change in shoreline position (Δy) for a linear relationship, then the regression coefficient becomes equal

to the characteristic height of beach changes caused by littoral transport (Uda et al., 1986). When the regression coefficient is calculated by using the data set, whose absolute values are small enough, the accuracy of the prediction in determining the regression coefficient will be lowered. Therefore, the profile data between No.52 and No.59 are used, where large beach changes are observed. In addition, the profile data at No.60 and No.61 are neglected, because these survey lines are located in the vicinity of the harbor structures, so that the local influences are considered to be predominant. The region of the calculation of the sectional area extends from the backshore to the 20m-deep location. As a result, the following relation stands between both variables with the correlation factor of 0.80.

$$\Delta A = 13.3 \cdot \Delta y + 150 \quad (6)$$

Where ΔA and Δy have the units of m^2 and m , respectively. The regression coefficient between ΔA and Δy is equal to the characteristic height of beach changes (h). Due to the relation in Eq.(6), h becomes 13.3m.

Next, littoral transport rate at a typical location east of Tagonoura Port will be evaluated based upon the field data of beach changes. The littoral transport rate can be evaluated on the basis of the continuity relation of sand volume by analyzing the temporal change of the total sand volume of the eroded beach located on the downdrift side of the coastal structure obstructing the continuous longshore movement of sand (Uda et al., 1986). First, the contour map on the downdrift coast of Tagonoura Port is shown in Fig.10.

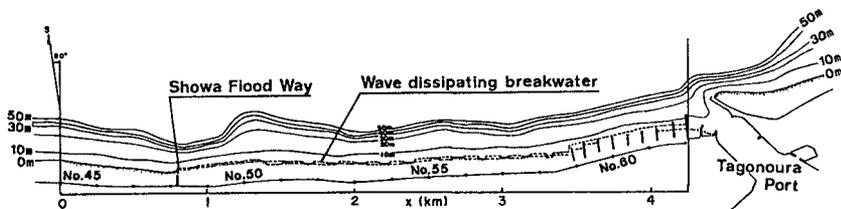


Fig.10 Contour map on the downdrift coast of Tagonoura Port and coordinate system for shoreline simulation.

There are 11 groins and 17 wave-dissipating breakwaters along the shoreline. In this map the region between No.45 and No.62 is selected for the calculation zone. It should be noted that at survey line No.45, far from the harbor, the littoral transport rate has kept constant to the dominant wave incidence on this coast, because at this site the shoreline configuration has not changed since 1968, as shown Fig.3. On the other hand, the littoral transport rate rounding the tip of the breakwater of Tagonoura Port is assumed to be negligibly small, because the water depth at the entrance channel to the harbor is sufficiently deep like as about 10m as shown in Fig.10. The total amount of littoral transport passing through No.45 is approximately equal to the volume change of sand in the test area between

No.45 and No.62. Strictly speaking, there may be a small amount of sand movement toward the offshore zone. If this is correct, such loss of sand should be added to the volume change to give the exact transport rate. However, in this study, it was impossible to measure this value reliably because of the relative low accuracy of the bottom sounding data in the far offshore zone, so that in the present study this is assumed to be negligible.

The change in the total sand volume in the eroded area can be approximately obtained from the change of the plane area in the eroded zone multiplied by the characteristic height of beach changes ($h=13.3m$). Because the characteristic height of beach changes is the vertical height of the rectangle whose sectional area and horizontal scale are equivalent to the measured sectional area and the change of the shoreline position, respectively. Therefore the multiplication of this vertical height by the change in the plane area in the eroded region results in the volume change. The result of this calculation is shown in Fig.11. The total volume of sand eroded has increased with time, although there is some scatter. The time derivative of the total sand volume approximately becomes equal to littoral transport rate at the downdrift end of the area examined as shown in Fig.10. The time derivative of the sand volume change becomes $Q=1.17 \times 10^5 m^3/yr$ between 1973 and 1983. This value is equal to the average littoral transport rate at No.45 in a period between 1973 and 1983.

IV. PREDICTIVE MODEL OF THREE DIMENSIONAL BEACH CHANGES

In this section a new one-line model of shoreline evolution is developed in order to predict three-dimensional beach changes with some improvements on the former model (Uda and Saito, 1987). In this model the vertical distribution of littoral transport is taken into account, and not only the change of the shoreline position but also the change of the offshore distance to certain contours are predictable by using this vertical distribution of littoral transport. The vertical distribution can be determined from the beach profile changes measured with time at a site, assuming that the beach slope is sufficiently small and the vertical distribution of beach changes during a short period is similar to that of littoral transport. For example, Figure 12 shows the results. To determine the distribution, the reference years selected are 1970 at No.58 and 1973 at No.54. Then, the changes in the offshore distance are divided by the change in the shoreline position to obtain the normalized distribution. There is scatter to some extent, but the vertical distribution of horizontal changes in the beach topography has a triangular shape, taking a maximum value at the MSL and decreasing monotonously above and below the MSL as shown in Fig.12. This distribution of littoral transport is approximately equal to the vertical distribution of littoral transport under the assumption that the vertical distribution of littoral transport does not vary so much, even if the beach profile changes are caused by the littoral transport over a short period.

In the calculation, the equation given by Savage was used for the littoral transport formula. The Savage coefficient is assumed to be 0.2. The littoral transport rate was vertically divided at each depth relative to the average of the normalized vertical distribution as shown in Fig.12 except above the MSL, where the maximum value was used to obtain the best fit with the measured beach changes.

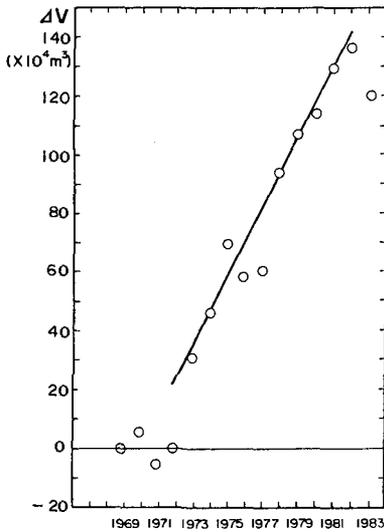


Fig.11 Temporal change of total eroded volume of sand on the downdrift coast of Tagonoura Port.

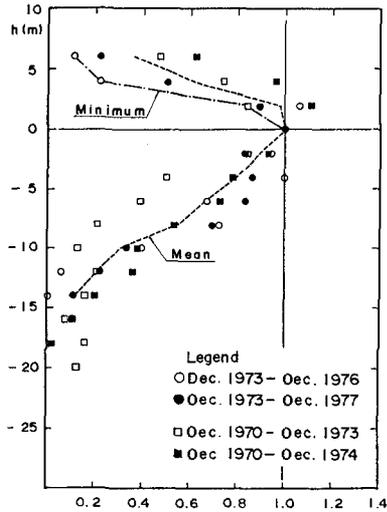


Fig.12 Vertical distribution of normalized horizontal distance in each depth.

On the Fuji Coast there are wave-dissipating breakwaters placed along the shoreline discontinuously as shown in Fig.10, and therefore a model of beach changes around the wave-dissipating breakwater is required as follows. First, in the simulation, the wave-dissipating breakwater is assumed to be of continuous type because the longshore distance in the opening is narrow compared with the longshore length of the wave-dissipating breakwater. Then the depth at the foot of the wave-dissipating breakwater is determined from the given beach profiles, because the location of the breakwater is already known. The wave-dissipating breakwaters, as shown in Fig.3, have been built since 1973, and therefore the total length of the wave-dissipating breakwater from No.62 was chosen so as to satisfy the actual situation of the construction. As is mentioned in Fig.10, between No.59 and No.62 there are groins but the coast between them is covered with the concrete blocks. Therefore the physical condition at this site can be assumed to be the same as at the wave-dissipating breakwater.

If a wave-dissipating breakwater is constructed along the coast, the beach behind the wave-dissipating breakwater is usually protected against beach erosion, and therefore littoral transport rate at this site will be reduced depending upon the location of the wave-dissipating breakwater. Here, the reduction of the littoral transport rate, named by the cutting ratio of littoral transport, is taken into account. The cutting ratio of littoral transport can be obtained, assuming that the littoral transport rate decreases with the ratio of the area above the depth of the tip of the breakwater with respect to the total area in the vertical distribution of littoral transport. The greater this point depth is, the more the littoral transport rate decreases. The beach changes are assumed to be observed only in the zone deeper than the point depth of the wave-dissipating breakwater, and the horizontal change of the beach topography is calculated from the vertical distribution of littoral transport.

For the initial condition, the bottom topography measured in 1970 was used, and the beach changes until 1983 are predicted. It is assumed that the incident wave height and period at the far offshore zone are equal to $H=0.85\text{m}$ and $T=9\text{sec}$, and the waves are incident from $\alpha=513^\circ\text{W}$ based upon the field observation conducted on the coast. Secondly, the longshore distributions of wave height and wave direction at a location of 10m deep along the coast are evaluated by wave refraction calculation using this incident wave. Furthermore, wave height and wave direction at the breaking point are calculated, assuming that the bottom contours in the shallow water zone are parallel at each location. Wave refraction calculation was performed repeatedly in a shallow water zone under the assumption that the incident wave at a location of 10m deep did not vary as much, even if beach changes occurred in the zone.

As the beach erosion proceeds, the bottom profile gradually tends to reach a stable profile, which is mainly determined by wave characteristics, bottom slope and grain sizes of the bed materials. In this study this stable profile is empirically determined. The beach profile at No.58 measured in 1982 may be selected for such a profile approximately, because the eroded beach section next to Tagonoura Port should approach the stable profile more rapidly. If the beach profile during the initiation time of the construction of the wave-dissipating breakwater has retreated compared with the stable beach profile, and if a part of the beach profile differed from the stable beach profile due to the difference of the bottom profile, their part of the retreated profile was used instead of the stable beach profile. After the beach profile reached to the stable form, it was assumed that the littoral transport rate is equal to the input data at the updrift end, and the same amount of sand can pass through the site with the stable profile.

The predicted changes of the offshore distance to some bottom contours after 4 and 8 years from the beginning are compared with the measured values in Figs.13 and 14. The

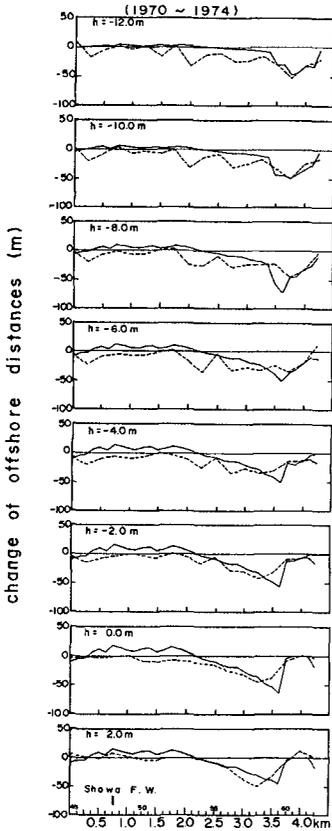


Fig.13 Comparison of measured and predicted changes of offshore distance after 4 years from the beginning.

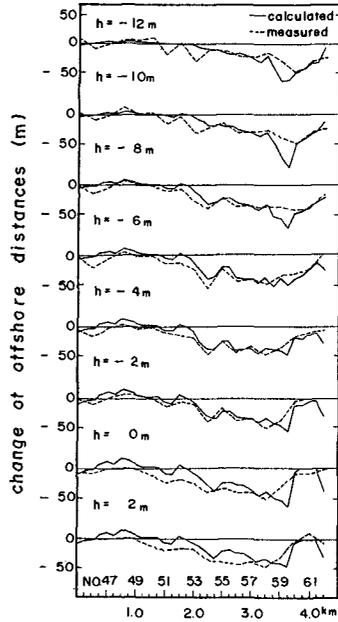


Fig.14 Comparison of measured and predicted changes of offshore distance after 8 years from the beginning.

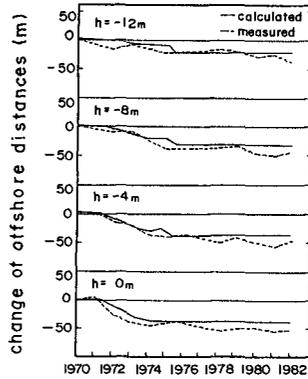


Fig.15 Comparison of temporal changes of measured and predicted offshore distances.

longshore distance along the coast is taken for the abscissa, and the changes in the offshore distances are compared. It is found that the predicted and measured changes of the

offshore distances to some contours agree well. It is difficult to understand the process of the temporal beach changes from Figs.13 and 14 alone, although they are useful in understanding the spatial beach changes. Therefore, temporal changes of the offshore distances to some contours are expressed in Fig.15, where survey line No.58 is selected as an example. It is concluded that the process of beach changes is well predicted from the point of view of temporal beach changes.

V. CONCLUSIONS

1) The littoral transport heading eastward was obstructed due to the construction of the breakwater of Tagonoura Port located in the middle of the Fuji Coast, and the downdrift coast of the harbor was severely eroded. The maximum retreat of the shoreline between 1968 and 1983 was about 60m at survey line No.58.

2) Beach erosion was severe between No.60 and No.45, and recently, retreat of the shoreline is tending to decrease. This is due to the decrease of the littoral transport itself on the coast and due to the effect of the construction of wave-dissipating breakwaters.

3) The littoral transport rate passing through No.45 located east of Tagonoura Port was found to be about $1.17 \times 10^5 \text{ m}^3/\text{yr}$ on an average between 1973 and 1983.

4) It is found that large part of the sediment eroded on the downdrift beach of Tagonoura Port is carried away toward the offshore zone, whose depth is between 20 through 30m.

5) A predictive model of three-dimensional beach changes was developed, in which the vertical distribution of littoral transport is taken into account and the effect of wave-dissipating breakwaters on beach changes can be evaluated. The predicted beach changes were in good agreement with observed ones.

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