CHAPTER 11

FIELD OBSERVATION OF MOVEMENT OF SAND BODY DUE TO WAVES AND VERIFICATION OF ITS MECHANISM BY NUMERICAL MODEL

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ABSTRACT

Bottom sounding data collected from 1983 to 1993 on the Shizuoka coast were analyzed. The results reveal the existence of a sand body moving downcoast at a velocity of about 233m/yr. It is the first time that this kind of phenomenon was observed in the quantitative sense including the spatial and temporal changes in longitudinal profile of the beaches, and this propagation mode is a very interesting phenomenon. In this study, sand movement shoreward and offshoreward of the detached breakwaters is modeled, and a model to predict successive contour line changes is developed, taking into account of time lag caused by the obstruction effect of longshore sand transport due to the detached breakwater. The new phenomenon observed on the Shizuoka coast is well explained by the present model. The propagation velocity of the sand body reproduced by this model is 230m/yr and it is well in agreement with the field observation value.

I . INTRODUCTION

Recently, beach erosion has proceeded at many coasts in Japan. According to the analysis of beach erosion, many of the beach deformations are caused by the imbalance of the longshore sand transport by the obstruction of continuous longshore sand transport due to breakwater, etc., decrease in sediment supply from rivers/sea cliffs, or change in wave field due to the construction of a large-scale harbor breakwater. In all these cases, the basic principle itself of beach deformation is already known, but there still remain many unknown points regarding the quantitative evaluation of the longshore sand transport and an external force of the topographic change, especially the research is insufficient on the change in mechanism of the longshore sand transport associated with the installation of shore protection facilities against erosion such as detached breakwater and headland. This leads to the decreased accuracy in predicting the beach deformation when countermeasures against erosion are taken, and in order to enhance the accuracy of the prediction, this kind of problem must be clarified.

Of the beach deformations due to the above three factors, this study

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focuses on the beach deformation due to a sharp decrease in sediment discharge from a river and the Shizuoka coast facing Suruga Bay is selected as the case study area. Through the analysis recent recovery process of the sandy beach due to the increase of the sediment discharge is discussed. As for beach deformation of the Shizuoka coast, Uda et al.(1994) found out that the sediment supplied from the Abe River was moved downdriftward by the longshore sand transport while forming a large mass of sediment (hereinafter called sand body) along the coastline. Tsuchiya(1995) also discussed erosional waves on the Shizuoka coast on the basis of the field data of Toyoshima et al.(1981). As for the shoreline change, this phenomenon is classified into the longshore sand waves recently discussed by Thevenot-Kraus(1995)or can be classified as a type of phenomenon in which the wave-like shoreline propagates alongshore while keeping its form. In addition, there are various names for the longshore sand waves. Sonu(1968) calls them cusp-type sand waves, Bruun(1954) and Grove et al.(1987) migrating sand humps, Inman(1987) accretion and erosion waves, and Verhagen(1989)simply sand waves. Of these studies, especially the accretion and erosion waves by Inman(1987)are produced when a coastal structure such as a groin is installed or the sediment supply from a river or the source of littoral drift, is sharply increased due to flood, and they propagate along the coastline while being accompanied by weak diffusion.

On the Shizuoka coast, the erosion waves were produced from the beginning of the 1970s to around 1983 before the movement of the sand body, and propagated alongshore, and this is completely the same phenomenon as the erosion waves mentioned by Inman(1987). On the Shizuoka coast, seawalls, many wave dissipating armour units and detached breakwaters were installed on the eroded beach after the erosion waves were gone, and the foreshore was almost completely lost. Subsequently, the movement of the sand body started. Such a characteristic change has shown that the sediment was accumulated only when the leading portion of the sand body arrived. In all the past studies, the sand waves propagated alongshore on the coast with a continuous sandy beach. And in this respect, the longshore sand waves subject to this study are remarkably different from others. In this study, a soliton, instead of many waves, propagated alongshore while being accompanied by weak diffusion, and so this may be called by the movement of a sand body different from other types and its occurrence mechanism will be discussed.

As to the theoretical study on the longshore sand waves, Thevenot• Kraus(1995) numerically solved a diffusion equation including the advection term on the shoreline change, and they well explain the propagation of the longshore sand waves on Southampton Beach, New York, U.S.A. But their study is on the predictive model of shoreline change and has not reached the level of predicting the three-dimensional beach deformation. On the Shizuoka coast a number of detached breakwaters have been installed, and they are considered to be closely related to the movement of the sand body, which suggests the necessity of modeling of the obstruction effect of littoral transport by the detached breakwaters. For this reason, in this study, contour line change model which can predict three-dimensional topographic changes by assuming the depth distribution of the longshore sand transport rate, is applied to the Shizuoka coast to clarify the movement of the sand body.

II. OBSERVATION OF MOVEMENT OF SAND BODY ON SHIZUOKA COAST

(1) General

The Shizuoka coast is located on the west shore of Suruga Bay and is a sandy beach extending 7.8km northeastward from the Abe river mouth, as shown in Fig.1, Fig.2 shows the sea bottom contours off the Shizuoka and Shimizu coasts. On the Shizuoka coast as well as the Shimizu coast, it is very steep as 1/10 near the shoreline. In the offshore zone ranging from 10m to 30m depth, a continental shelf of mild slope of 1/150 spreads, but the bottom slope at the tip of the Mihono-matsubara sand spit is steep at about 1/5.

During the Jomon Transgression of the sea level, it is considered that hill side of Mt. Kuno was eroded to supply sediment toward the Mihono-matsubara sand spit, but at the present sea level, the only supply source of sediment to the sand spit is the Abe River. In the Abe River, the river bed excavation was carried out extensively before 1967, causing sharp decrease of the sediment discharge of this river and then serious beach erosion was triggered from near the river mouth and spread out northeastward. Presently, the most severely eroded portion of the beach is approaching the tip of the Mihono-matsubara sand spit. Much sediment supplied from the Shimizu coast is transported from the northeast end of the Mihono-matsubara sand spit into submarine canyons.

The study area ranges from No. 0, 7.8km away northeastward from the Abe River mouth, to No. 78 of the Abe river mouth, as shown in Fig. 2. The interval of the measuring line is 100m. On the Shizuoka coast, bottom soundings have been done along these measuring lines once a year. According to the sampling test of bottom materials conducted at 9 points in 1km intervals alongshore from the Abe River mouth on February 20, 1989, the median diameter of the beach materials near the shoreline of the Shizuoka coast is around 7.5mm

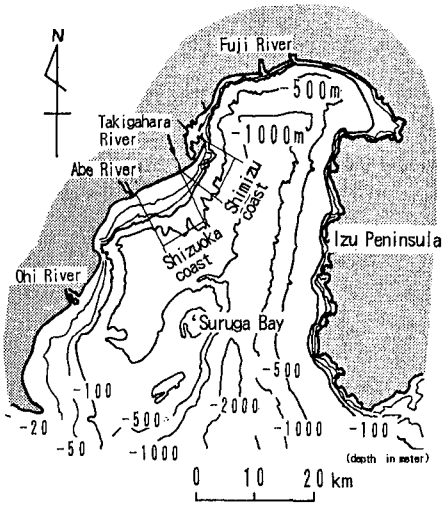

Fig.1 Location of Shizuoka coast in Suruga Bay.

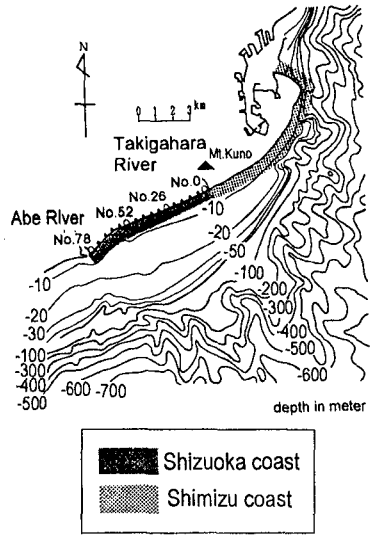

Fig.2 Sea bottom contours of Shizuoka and Shimizu coasts and alignment of measuring lines.

(2) Change in Shoreline Position and Longitudinal Profile on Shizuoka coast

On the basis of the bottom sounding data, the change in shoreline position by selecting 1989 as the reference year, is shown in Fig. 3. In the figure, No. 78 is located next to the left bank of the Abe River mouth, and the origin of the longshore distance is set at 7.8km east-northeast from the river mouth. On the top of the figure, approximate locations of various shore protection facilities (detached breakwater, seawall, groin, wave dissipating armour units and jetty) are shown.

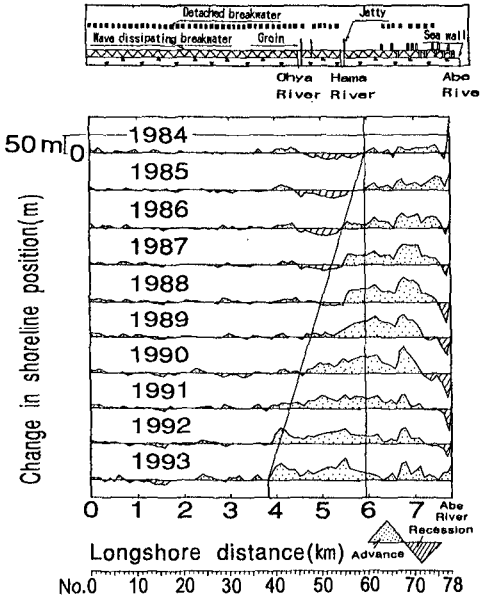

Fig.3 Change in shoreline position on Shizuoka coast (referrence year:1983)

The main change in shoreline position started near the Abe River mouth, the source of the littoral drift on the Shizuoka coast. In the beginning, the erosion concentrated on the south side of the jetty of the Hama River as the boundary, but after 1990, the erosion spread fast northward of the jetty of the Hama River. Simultaneously with the northward spread of the accretion area, the shoreline retreated fast in the areas (e.g. section between No. 66 and No. 70 in 1987) where the shoreline had been remarkably advancing in the beginning, and as a whole, the aggregate of sediment (sand body) moved northward with mild deformation. In 1993, north of No. 38 where the leading edge of the sand body seems to have arrived, the shoreline hardly moved in comparison with the southern side, indicating that the beach was completely eroded and there is no sediment to move because the area is totally covered with seawalls and wave-dissipating armour units and no foreshore exists. From Fig. 3, the propagation velocity of the leading edge of the sand body between 1984 and 1993 is calculated to be 233m/yr.

The profile change of the beach associated with this sand body movement is investigated in two sections : No. 67 between breakwaters in the area where the shoreline greatly advanced until 1988 but retreated subsequently, No. 62 without breakwaters.

Fig. 4 shows the profile change of No. 67. Until 1988, the accretion took place in the area shallower than -4m, but subsequently the accretion occurred in a wide area shallower than 7m depth. Taking into account of the fact that the breakwaters were installed at a depth of 3m in this area, it is found that the accretion occurred shoreward of the breakwaters until 1988, but after that the area was filled with sand, littoral drift started to pass through the offshore side of the breakwaters, causing the accretion in that area. In the period between 1983 and 1993, remarkable profile changes were seen mostly in the area shallower than -7m.

As to the profile change of No. 62 shown in Fig. 5, much sediment

accumulated in the area shallower than -4m until 1989, but subsequently an erosion occurred. In this profile, too, the topographic changes were seen mostly in the area shallower than -7m, but the bottom fluctuation between -5m and -7m was small in contrast to the remarkable bottom changes between -5m and -7m at No. 67 located between breakwaters.

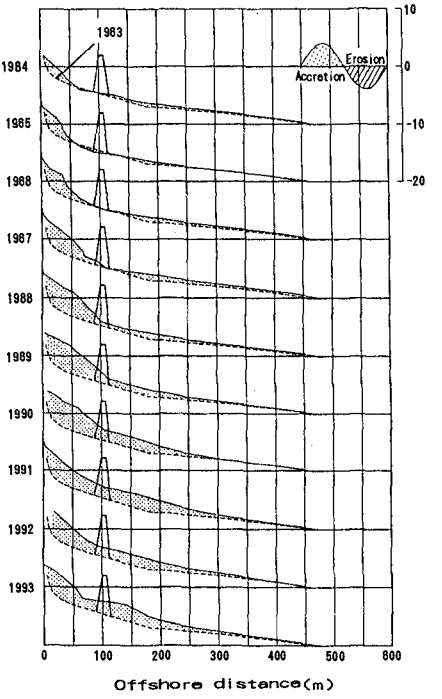

Fig.4 Change in longitudinal profile along measuring line No. 67 on Shizuoka coast.

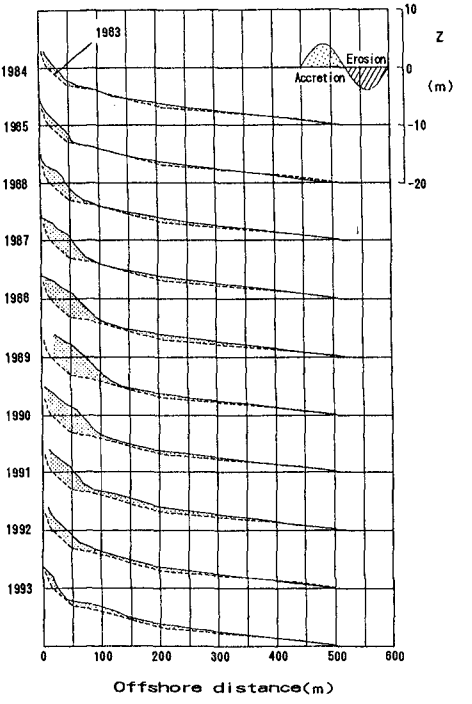

Fig.5 Change in longitudinal profile along measuring line No. 62 on Shizuoka coast.

(3) Littoral Drift and Propagation Velocity of Center of Gravity of Sand Body

As to beach deformation of the Shizuoka coast, it was found that the sea bottom slope greatly changed with the accretion of sediment. As an index of the change in cross-sectional area, the change in cross-sectional area of the beach between +5m and -3m equivalent to the water depth at the shore end of the detached breakwaters, and between +5m and -7m equivalent to the critical depth for sand movement were determined and their spatial and temporal changes were investigated.

The sand volume shallower than -7m was increasing with the elapse of years, but the longshore stretch where the remarkable volume change was observed was limited in each year. Therefore, the region shown in Table 1 was selected in each year, and the volume change was calculated and the time change in sand volume together with the change in the foreshore area is shown in Fig. 6. From this, it is realized that on the average from 1983 to 1993, the total sand volume increased at the rate of $10 \times 10^4 m^3/yr$, though some fluctuation existed. In this area, as a whole, the

northeastward littoral drift is dominant, and the only sediment supply source is the Abe River. On the northeast side of the tip of the sand body, seawalls and wave-dissipating armour units have been installed, and no beach deformation has been observed, and in fact, the littoral drift rate is considered as 0. Therefore, the increase rate of the total sand volume shown in Fig. 6 should be equal to the littoral transport rate supplied to this area from the Abe River mouth. Uda・Yamamoto(1994) estimated, on the basis of the time change in beach topography, that the littoral transport rate on the Shimizu coast was about $13 \times 10^4 m^3/yr$. Before the Shizuoka and Shimizu coasts were eroded, almost the same littoral transport rate was considered to exist over the entire area, and therefore the littoral transport rate in this area is also assumed to be about $13 \times 10^4 m^3/yr$. The littoral transport rate after 1983 is about 77% in comparison with this.

Table 1 Integration region of sand volume and location of center of gravity of sand body.

Meesured yeer	Integretion region	Longshore distance of accretion zone(m)	Longshore distance(m) of center of grevity from No.78
1984	No.60~No.78	1,800	471
1985	No.60~No.78	1,800	508
1986	No.55~No.76	2,100	997
1987	No.55~No.76	2,100	1,247
1988	No.55~No.75	2,000	1,376
1989	No.46~No.72	2,600	1,586
1990	No.46~No.72	2,600	1,773
1991	No.38~No.72	3,400	2,078
1992	No.39~No.72	3,300	2,263
1993	No.38~No.78	4,000	2,373

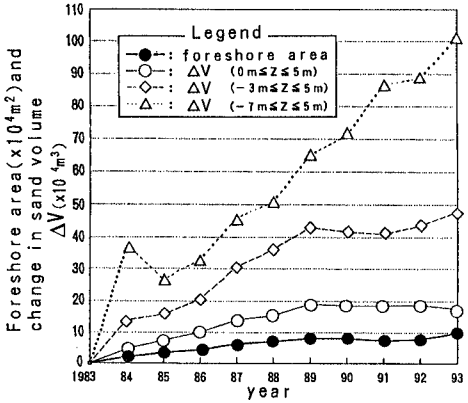

Fig.6 Time change in sand volume and foreshore area of the beach (referrence year:1983)

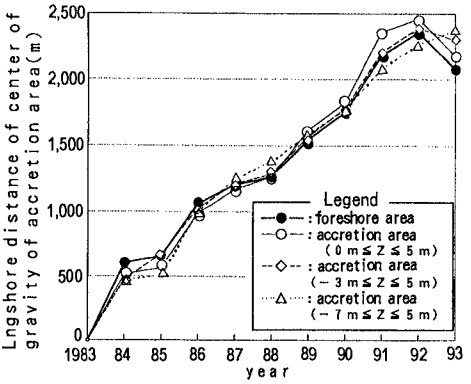

Fig.7 Movement of center of gravity of sand body.

The foreshore area and total sand volume in the zone higher than 0m and shallower than -3m shown in Fig. 6 increased until 1989, but thereafter they remained almost at certain values, implying that although the accretion seems to have stopped in view of the change in sand volume shoreward of the detached breakwaters, actually the accretion continues in the offshore zone.

Fig. 7 shows the time change of the longshore distance from No.78 of the center of gravity of the accretion area. In all cases except the period of 1983-1984, the center of gravity of the sand body moved monotonously northward and the average propagation velocity of the center of gravity is 235m/yr. The fact that the propagation velocity of the center of gravity is identical in all three types of integration regions means that almost the

same propagation velocity of the center of gravity existed at any place. While the sand volume of the beach shoreward of the detached breakwaters saturated in 1989, the center of gravity moved with keeping almost the same velocity. This means that although the sand volume shoreward of the detached breakwaters does not change, it, as a whole, is also moving at the same velocity. Uda•Yamamoto(1994) estimated from the shoreline changes that the phase velocity of the erosion wave before the construction of the detached breakwaters was 0.5 to 0.8km/yr. In comparison with this value, it is realized that the propagation velocity was reduced to 0.47-0.29 times due to the installation of the detached breakwaters.

III. REPRODUCTION OF PROPAGATION PHENOMENON OF SAND BODY BY CONTOUR LINE CHANGE MODEL

(1) Contour Line Change(CLC) Model

Uda-Kawano(1996) developed a model which can predict the spatial and temporal changes of the contour line by assuming depth change in littoral transport rate. This model is designed for a coast with a steep slope near the shoreline and without the existence of bar/trough topography and it can model the effects of coastal structures such as groin, seawall and breakwaters. But in the former study it was difficult to model the permeable detached breakwaters installed in the breaker zone. For this reason, here modeling of the permeable breakwaters is carried out.

The Shizuoka coast has a steep slope near the shoreline and has no bar/trough, suggesting that the beach deformation is caused only by the action of the littoral transport even around the breakwaters. From this, the CLC model to predict the topographic changes due to the littoral transport may be applicable for reproducing the propagation phenomenon of the sand body. With the CLC model, it is possible to predict the three-dimensional topographic changes including the profile changes of the beach by assuming the depth change in littoral transport rate.

The fundamental equations of the model is shown below. If the breaker angle of waves is assumed to be sufficiently small using the Savage formula, Eq.(1) stands.

$$Q = F_0(\tan \alpha_0 - \frac{\partial y_s}{\partial x}) \qquad (1)$$

Where Q: littoral transport rate, F_o: a coefficient of littoral transport rate dependent on wave energy flux, α_o: breaker angle, x: longshore distance, and y_S: shoreline position measured normal to x axis. Eq.(1) is established under the assumption that the beach profile makes parallel movement in time and space.

Now a region is divided by n contour lines, and the littoral transport rate at each water depth corresponding to k=1 ... n is set to be q_k and if a similar relationship is assumed to be satisfied between the contour line position y_k and q_k in analogy with Eq. (1), the following equation is obtained.

$$q_k = F_{0k}(\tan \alpha_0 - \frac{\partial y_k}{\partial x}) \qquad (2)$$

Where $F_{ok} = F_o.\mu_k$, $\Sigma\mu_k = 1$. Eq. (2) assumes that the littoral transport

rate in each layer is governed by the relationship between each contour line and incident wave direction at breaking point. In the CLC model, therefore, the contour lines do not need to make parallel movement like the shoreline change model, and this makes it possible for the littoral transport to pass the offshore zone of the detached breakwaters. This is because even if the shoreline is perpendicular to the direction of the breaking waves, they are obliquely incident to the offshore contour lines, which makes it possible for the littoral transport to move. From the above, the littoral transport rate in the shoreline change model and the littoral transport obtained by integrating littoral transport rate in each layer in the CLC model are not equal except in the case of parallel contour lines.

μ_k is a coefficient to give the littoral transport rate for each water depth and is calculated using Eg. (3) by giving the depth change of the littoral transport rate.

$$\mu_k = \int_{zk}^{zk+1} \xi(z)dz \,/\, \int_{-hc}^{hr} \xi(z)dz \qquad (3)$$

where z is the vertical distance with reference to the still water level as the reference, h_r wave run-up height and h_c critical depth for sand movement. The continuity equation of the littoral transport is given as follows :

$$\frac{\partial q_k}{\partial x} + h_k \frac{\partial y_k}{\partial t} = 0 \quad ; \quad k = 1 \cdots\cdots n \qquad (4)$$

where h_k (k = 1 .. n) is the characteristic height of beach changes as given by Eq.(5)

$$h_k = Z_k - Z_{k-1} \qquad (5)$$

If the functional form of $\xi(z)$ is given, μ_k is calculated by Eq. (3), and so the contour line change for each depth is calculated by simultaneously solving Eqs.(2) and (4). The depth change in littoral transport rate may be assumed to have such a distribution that it varies between the wave run-up height(h_r) and critical depth for sand movement(h_c), so as to satisfy empirically the field and experimental data.

$$Z^* = Z / H_b \quad , \quad h_c^* = h_c / H_b \qquad (6)$$

When $-h_c \leqq z \leqq h_r$

$$\xi(Z)^* = 2 / h_c^{*3} (h_c^* / 2 - Z^*)(Z^* + h_c^*)^2 \qquad (7)$$

When $z < -h_c$ and $z > h_r$

$$\xi(Z^*) = 0 \qquad (8)$$

In this model stabilization mechanism of beach profile is taken into account as described in detail in Uda・Kawano(1996). If the bottom slope between contours exceeds a critical slope on the foreshore the sea bottom, the local slope is reset by the critical slope and the position of the contour lines is adjusted so as to satisfy the eroded and accreted areas in the profile are equivalent.

In the calculation it is necessary to determine the wave height and breaker angle. There are various methods for predicting wave field. Here the numerical calculation method of the energy balance equation by Karlsson(1969) is used, including the refraction, shoaling and diffraction effects for irregular waves. Wave dissipation effect is calculated using the method of Takayama et al.(1991) and wave breaking was evaluated by Goda's breaker index. Since this study deals with the permeable detached breakwater, wave energy transport is set to be proportional to the square of the wave transmission coefficient of the detached breakwater.

(2) Modeling of Detached Breakwater

Without detached breakwaters, the depth change in littoral transport rate is given by Eqs.(7) and (8). Even when there are detached breakwaters, these equations are applicable if the breaking point is located shoreward of the detached breakwaters, but the dominant sand movement zone is narrowed because the breaker height is decreased. If, on the other hand, the breaking point is off the detached breakwaters, further modeling is required. This is because under such a condition that the breaking point moves off the detached breakwaters, and the cuspate spit has been already developed behind the detached breakwaters. Since the detached breakwaters are permeable, the cuspate spit does not become the tombolo to completely reach the detached breakwaters, leaving seawater surface between the cuspate spit and the detached breakwaters. In this case, the cuspate spit, like the groin, obstructs the longshore sand movement, but sand can still pass in the gap between the cuspate spit and detached breakwaters.

Now, the depth change in littoral transport off the detached breakwaters is calculated by Eqs.(7) and (8) using the breaker height in the offshore zone, and the distribution of littoral transport rate shoreward of the detached breakwaters is calculated by multiplying the littoral transport rate given by these equations by the obstruction rate (ε) of the littoral transport. Since it may be considered that the obstruction rate of the littoral transport is proportional to the cross-sectional shape of the cuspate spit, the following expression is assumed.

$$\varepsilon = 1.0 - \left(\frac{y_l}{y_{d0}}\right)^n \quad (9)$$

Where the offshore distance from the seawall to the detached breakwaters is y_{do} and the distance from the seawall to each contour line (including the contour lines of the land portion) is y_l (see Fig. 8).

If the obstruction rate (ε) of the littoral transport is equal to 1.0, the littoral transport rate passing behind the detached breakwaters is 0, equivalent to that of the impermeable groin. At ε= 0.0, the littoral transport rate passing behind the detached breakwaters is completely the same as that of the natural sandy beach.

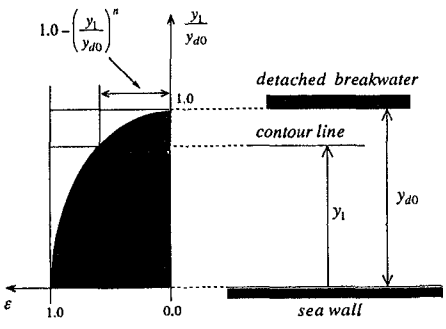

Fig.8 Definition of obstruction rate of littoral transport due to detached breakwater.

(3) Application of Model

In Fig. 3, the extension of the area where the remarkable movement of the sand body was observed is about 4km from the Abe River mouth. As shown in Fig. 2, the Abe River mouth forms a river-mouth delta with a considerably protruded shoreline, and in this area the movement of the sand body is not clear, whereas in the area with almost parallel contour lines on the northeast side of the mouth, remarkable movement is observed. From this reason, the parallel contour lines are simply assumed in this study. But the existence of the detached breakwaters is important for investigating the movement of the sand body, and so due attention must be paid to the modeling of the detached breakwaters. Fig. 9 shows the contour of initial topography. The slope near the shoreline is steep and the offshore is a flat bottom. Along this coastline, seawall and wave-dissipating armour units have been installed and the contour line cannot retreat from the initial position, and therefore the contour line shape given by the initial topography is regarded as the retreat limit. The validity of this assumption will be realized from the fact that in the profile change along the measuring line No. 62 as shown in Fig. 5, the shoreline advanced, but was again eroded and returned to the original concave profile vertically upward. In Fig. 9, 28 detached breakwaters of 80m long are installed at intervals of 40m. Actually the detached breakwaters on the Shizuoka coast have been installed over years, but here the detached breakwaters are installed at the same time to simplify the calculation.

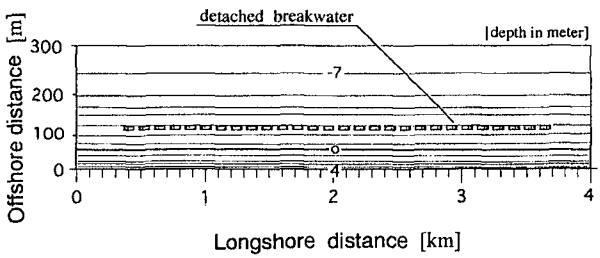

Fig.9 Model beach for movement of sand body.

For the numerical calculation, the finite difference method is used, and the area shown in Fig. 9 is meshed at intervals of 10m. The wave transmission coefficient of the detached breakwaters is set at 0.4.

As to the wave conditions, from the observation results of 1976 to 1991 at the Irozaki Observatory of the Meteorological Agency, 3.0m significant wave with the occurrence rate of 2% is selected as the high wave to give a dominant effect on the topographic change, and the period is set at 9s from the correlation of the wave height/period based on the same observation results. In the calculation, the continuous period of the above mentioned high wave is set at 27 days per year so that the incident energy of the waves per year is approximately equal to the measured value. As to the wave direction, SSE is set based on the predominant wave direction observed at the Mochimune Fishery Harbor located 2.5km southwest of the Abe River mouth. The time step for the topographic change calculation is 10min. As the topography changes, the wave field also changes. The repetitive time interval must be set in consideration of the situation of the topographic change. Here the calculation aims at the prediction of the long-term and relatively mild topographic changes, and so the repetitive time was set at 3 days, sufficiently shorter than the annual order (27 days).

In the calculation, h_c and h_r were set to be 4.0m and 7.0m, and the contour line deformation is predicted at intervals of 1m.

The boundary condition of sediment supply greatly depends on the flood. Due to the flood records since 1980 at a location 4.7km upstream from the river mouth, floods of $1000m^3/s$ or larger in daily average of flood discharge occurred seven times between 1980 and 1993 as shown in Table 2, and especially on September 12, 1982, the flood of the largest discharge $3857m^3/s$ occurred, but thereafter large-scale floods hardly occurred. From this, as a boundary condition, the constant sand supply of $10 \times 10^4 m^3/yr$ was given as the total littoral transport from x=4.0km and distributed to the littoral transport rate for each contour line by Eq.(7). On the other hand, the x=0.0km was set as the passing boundary.

Table 2 Flood discharge of Abe River.

DATE	Daily average of flood discharge $[m^3/s]$	Maximum flood discharge $[m^3/s]$
Aug. 2,1982	1,129	
Aug. 3,1982	1,466	3,857
Sep.12,1982	1,723	
Aug. 2,1983	1,731	2,981
July. 2,1985	1,523	———
Aug.10,1990	1,005	———
Sep. 2,1991	1,396	2,511

In Case 1, the power n (n=1.0) of Eq.(9) is assumed as the obstruction rate of the littoral transport behind the detached breakwaters. In this case, the propagation velocity of the sand body becomes excessive in comparison with the measured value, and in Case 2, the power n=1.6 was used.

In the calculation of the topographic changes around the detached breakwaters using the present model under the above mentioned conditions, the contour lines around the detached breakwaters tend to locally protrude with the elapse of time, and there are some cases in which the condition that the breaker angle of waves is sufficiently small is not satisfied even after the wave refraction. In such a case, in order to enhance the stability of the calculation, even if the reproduction of the local shape of the leading edge of the sand body is somewhat sacrificed, the upper limit is set to be 30° for the angle (θ) between the contour line and the wave crest line at the breaking point.

(4) Results of the Calculation

First the topographic change in Case 1 is shown in Fig. 10. Sand is supplied from x=4.0km and from there sand passes through a group of the detached breakwaters located on the downcoast. Sand clearly moves as the sand body downdriftward, and sand supplied from the river mouth does not show rapid diffusion pattern. Although the mechanism of the sand transport is due to the littoral transport associated with wave breaking, the diffusion of sand is surpressed because of the existence of the detached breakwaters and instead of this, the sand body movement is observed. In this case, the propagation velocity of the leading edge of the sand body is 360m/yr, 56% higher than observed 233m/yr.

It is considered as the cause that the obstruction rate of the littoral transport behind the detached breakwaters is too small(that is, the passing rate of littoral transport is excessive), and in Case 2, therefore, the obstruction rate of the littoral transport behind the detached breakwaters was increased by setting the power n in Eq.(9) as n = 1.6. The results are shown in Fig. 11. The beach changes are similar to those of

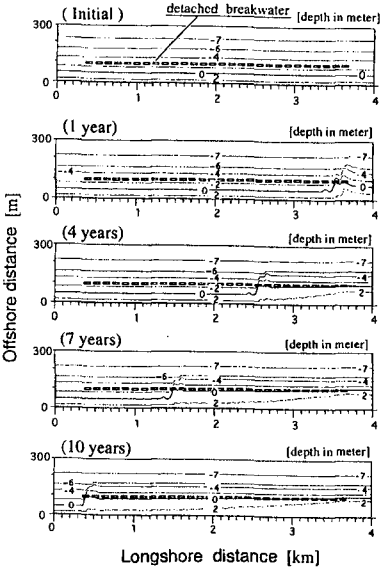

Fig.10 Predicted beach changes (case ①).

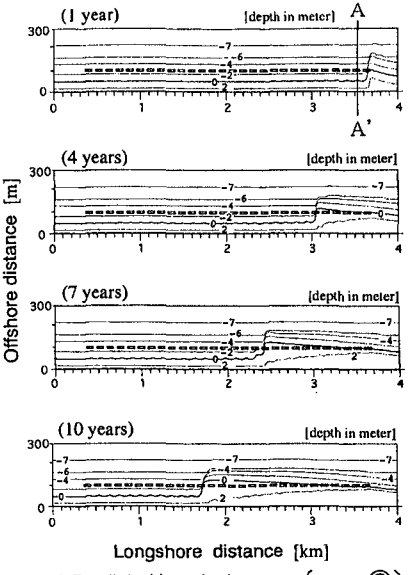

Fig.11 Predicted beach changes (case ②)

Case 1, but the propagation velocity of the leading edge of the sand body is 230m/yr, in agreement with the 233m/yr of the observed result. Since the obstruction rate of the littoral transport shoreward of the detached breakwaters increased, +2m contour line futher advanced.

In the topographic changes shown in Figs. 10 and 11, the profile changes on the updrift side of the littoral transport monotonously with time, and therefore it is sufficient to show the profile change at one section. Fig. 12 shows the profile changes of the section passing at the center of the detached breakwaters shown by A-A' in Fig. 11.

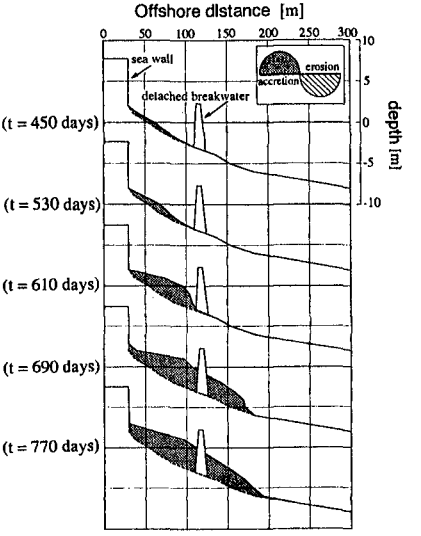

Fig.12 Predicted beach profile changes

It is clearly understood that in the beginning accretion concentrated shoreward of the detached breakwaters, and when the accretion in the zone between the detached breakwater and the seawall becomes full, the accretion advances off the detached breakwaters. As shown in the beach profile after 770 days, the cuspate spit is sufficiently developed, but even in this stage, the littoral drift pass over the foreshore behind the detached breakwaters. The accretion off the detached breakwaters well corresponds to the observed results on the Shizuoka coast shown in Figs. 4 and 5.

IV. DISCUSSION

In this study, the propagation phenomenon of the sand body was discovered through the analysis of the field data of the Shizuoka coast and investigated its occurrence mechanism by means of the CLC model. Occurrence of the sand body can be summarized as follows. First, the littoral transport sand is supplied from the updrift side of the coast provided with detached breakwaters, and when it passes through a group of the detached breakwaters, sand accumulates behind each detached breakwater. When the sand volume accumulated behind the detached breakwater becomes sufficiently large, the sand passes off the detached breakwaters and moves downdriftward, and in the meantime, time lag occurs. As a result, when many detached breakwaters are installed, the propagation phenomenon such as the sand body occurs and looks as if the solitary wave propagates. In comparison with the already clarified propagation velocity of the erosion wave in the eroded area on the Shizuoka coast, the propagation velocity of the sand body is smaller(0.47 to 0.29 times), and this means that the detached breakwaters obstruct it. Presently, the Shimizu coast located northeast of the Shizuoka coast is exposed to severe erosion, but since the velocity of the movement of the sand supplied from the Abe River mouth to the Shimizu coast is greatly reduced, it will take about 30 years for the sand body to move 8.2km from the leading edge of the sand body of the Shizuoka coast to the remarkably eroded point of Shimizu coast (where detached breakwaters are installed as in the case of the Shizuoka coast). This indicates that the countermeasures against erosion on the Shimizu coast must be considered without expecting the sand supply from the upcoast over about 30 years in the future. During this period the sand supply it is required will be minimal, and so to carry out beach nourishment until the sediment reaches the Shimizu coast in order to maintain the sandy beach.

IV. CONCLUSIONS

The main conclusions of this study is summarized as follows.

(1)Observing the beach deformation in the period of 1983 to 1993 on the Shizuoka coast, it was found that the sediment aggregate (sand body) moved downdriftward while deforming. The propagation velocity of the center of gravity of the sand body was 235m/yr, 0.47 to 0.29 times the phase velocity of the erosion wave before the detached breakwaters were installed in the same area.

(2) In this sand body area, the sediment of $10 \times 10^4 m^3/yr$ was accumulated from 1983 to 1993. The sediment supply source of the Shizuoka coast is the Abe River only, and since it is considered that the outflow of sediment beyond the leading edge of the sand body is very small, this accumulated volume is equal to the sand volume supplied from the Abe River into this area. This drift sand volume is about 77% of the estimated sand volume of $13 \times 10^4 m^3/yr$ before the remarkable erosion occurred.

(3)The contour line change model so far limited to the utilization for predicting the topographic changes at the natural sandy beach and around the groin, seawall, and breakwater was extended so that it can be also utilized for predicting the topographic changes around the permeable detached breakwaters installed within the breaker zone. This makes it possible for the contour line change model, so far limited to the application to steep-sloped coasts, to be utilized for predicting

topographic changes around all the structures normally installed on coasts.

(4)By applying this model for reproducing the propagation phenomenon of the sand body observed at the Shizuoka coast, it is found to be attributable to the existence of the detached breakwaters installed along the coastline and the occurrence of floods of the Abe River, the sediment supply source to this coast. That is, when the drift sand flows from the upstream side, accretion develops first shoreward of the detached breakwaters, and when the shore-side area becomes full, accretion develops off detached breakwaters, making it difficult for the drift sand to pass through around the detached breakwaters, and this is the main factor for the propagation phenomenon of the sand body.

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