

# **PART VI**

## **Case Studies**



## CHAPTER 251

### FORMATION OF DYNAMICALLY STABLE SANDY BEACHES ON THE AMANOHASHIDATE COAST BY SAND BYPASSING

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#### Abstract

Due to the construction of fishery harbors up coast, severe beach erosion has taken place on the Amanohashidate Coast of Japan, a typical sand spit, resulting in such a reduction of the sand spit that countermeasures have had to be taken. The sand bypass method recently has been used to stabilize the sandy beaches on this spit. Annual change in the configuration of a sandy beach formed between groins first is considered in relation to erosion countermeasures and the sand volume bypassed. We found that the sandy beaches along the Amanohashidate Coast are being formed with little fluctuation at what approaches the stable condition. On the basis of the theoretical background of the formation of stable sandy beaches (Tsuchiya et al.,1993; Tsuchiya,1994), a satisfactory comparison of the actual and theoretical shoreline configurations was made.

Next, alongshore change in the longshore sediment transport rate was investigated in relation to the sand volume nourished and bypassed. We found that when the sandy beaches formed between groins have nearly reached the stable condition, the relation between the longshore sediment transport rate and wave energy power results in an estimated necessary sand volume to be bypassed of  $5,000\text{m}^3/\text{yr}$ . We conclude that in the case of the Amanohashidate Coast, the use of sand bypassing could well form a series of dynamically stable sandy beaches between groins, the sand volume required for bypassing being only  $5,000\text{m}^3/\text{yr}$ .

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## INTRODUCTION

Results of the most recent survey of the actual state of coastal erosion in Japan show that beach erosion on shorelines forming part of a sand spit has taken place due to the construction of coastal structures that interrupt longshore sediment transport (Uda,1992). Beach erosion also is reported to be actively advancing in many countries of the world (Tsuchiya, 1982). Silvester(1993) has published a geomorphological review that shows that the formation and deformation of sand spits play an important part in the formation and development of barrier beaches. He defines the mode of spit construction and the erosive conditions, and suggests an approach to the control of beach erosion on a sand spit coast.

As seen in Figure 1, the Amanohashidate Coast is a typical sand spit that extends in the direction of the predominant longshore sediment transport in Miyazu Bay.

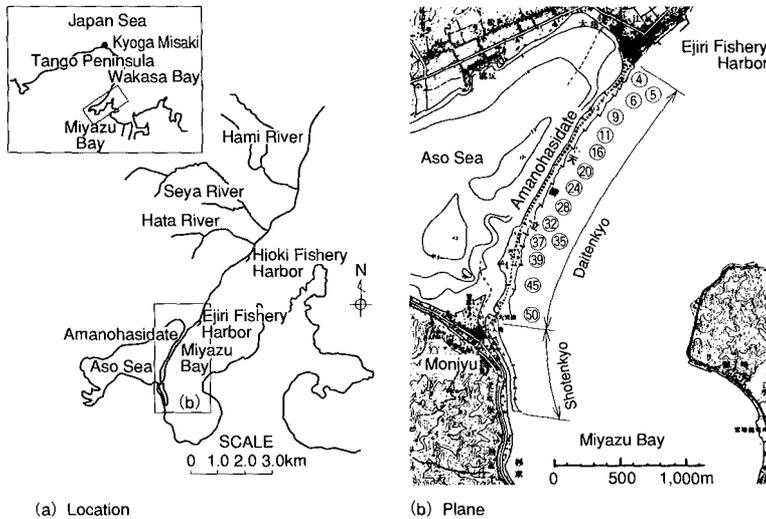


Figure 1. Location and plane figure of the Amanohashidate Coast.

Therefore, if longshore sediment transport is interrupted at an updrift point, beach erosion is inevitable and will take place immediately on the downdrift side of the coast in terms of the continuity of sediment transport. In fact, soon after the construction of breakwaters in both the Ejiri and Hioki fishery harbors upcoast, the natural sandy beaches of Amanohashidate began to be eroded, and groins were erected to protect the shoreline. Recently, beach nourishment and sand bypassing have been applied for the first time in Japan (Yajima,1982; Kuroda,1985). As a result, beautiful sandy beaches have been reformed, as shown in Figure 2. These sandy beaches appear gradually to be approaching dynamic stability. Bypassing the amount of sediment necessary to maintain dynamically stable sandy beaches

therefore may aid in protecting this shoreline, a significant reason for the application of this method.

We here describe the annual change in the shoreline position of sandy beaches formed between groins in relation to changes in the volume of sediment used for beach nourishment and for sand bypassing. The processes by which sandy beaches between groins reach stability are investigated in relation to the theoretical background of the formation of stable sandy beaches reported by Tsuchiya, Chin and Wada(1993) and Tsuchiya(1994) in order to determine the minimum amount of sand to be bypassed.

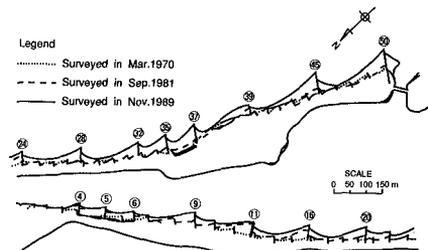


Figure 2. Formation of a series of sandy beaches between groins on the Amanohashidate Coast.

## APPLICATION OF THE SAND BYPASS METHOD

Three types of countermeasures against beach erosion have been taken on this coast: groins, beach nourishment, and sand bypassing. At present, these three measures used in combination prevent beach erosion, and have re-established sandy beaches. Small and large groins first were constructed about 1955 and functioned for about 25 years; but, they did not prove very effective because the sandy beaches continued to erode, and the sand spit has gradually been reduced. From 1979 to 1985 beach nourishment was carried out and resulted in a shoreline advance of about 20m, sand being deposited on the upstream coast of the large groins and transported sand being accreted along the front edge of the groins. Thus, over the Daitenkyo area of the spit (Figure 1), continuity of sand transport has nearly been accomplished (Kyoto Prefecture, 1987). Since 1985, a so-called "conveyer belt" of sand transport (Bascom, 1970), has been formed, which has increased the feasibility of using sand bypassing. After tests, sand bypassing has been done on a large scale. As of 1992, the total volume of sand nourished and bypassed for a 9-year period was about 120,000m<sup>3</sup>.

## REFRACTION CHARACTERISTICS OF WAVES INCIDENT TO SANDY BEACHES

Past wave data recorded for Miyazu Bay, shows there is a relation between the waves in Miyazu Bay and those in the open sea (Kyoga-Misaki). Of the open sea wave characteristics, the wave periods are of very wide range (significant wave

period  $T_{1/3}=5\text{--}12$  sec), and swells are frequent in the monsoon (Kyoto Prefecture, 1987). These waves pass in through the wave window in Miyazu Bay. In terms of this wave window, however, the relation between waves in the open sea and those in the bay has not yet been determined; therefore, the representative waves coming onto the Amanohashidate Coast can not be specified. In terms of wave refraction and the wave window, we first determine the conditions of the waves incident to the coast that control beach change, then using the specified representative waves, we calculate the wave refraction to obtain the breaker characteristics.

### Observation of incident breaking wave rays by aerial photography

As shown in Figure 1(a), the wave window for the Amanohashidate Coast is very narrow; therefore, limited waves come in to the beach. To predict the breaker characteristics along the beach, detailed calculation of wave transformation is necessary, therefore an aerial observation of the incident waves was conducted (Figure 3). The wave rays calculated by the wave ray method and the wave crest lines observed are approximately orthogonal at the breaking points. This indicates that the calculated wave rays are of sufficient accuracy. The observed wave period is nearly equal to 8.0sec, and wave period at Kyoga Misaki, when the photographs were taken, also was 8.0sec. Waves with the direction of  $N48^{\circ}E$  off Wakasa Bay were incident at that time, and they were directly incident because the angle of direction is within the range of the wave window of Miyazu Bay.

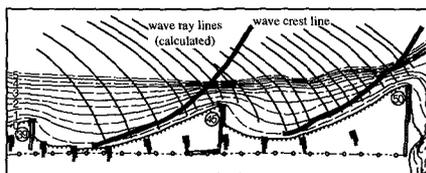


Figure 3. Wave crest lines taken from aerial photographs.

### Calculation of wave transformation

As to the wave conditions in the deep sea off Wakasa Bay, the incident waves are subjected to angles of direction from N to  $N48^{\circ}E$ . For the refraction calculations, taking into account the wave window of Miyazu Bay as well as the plane topography, the wave periods used are: a) 10–12 sec, the periods of relatively long waves coming with the swell into the bay for N to  $N35^{\circ}E$  with the passage of the winter monsoon and b) 6–8 sec, the periods of the wind waves for  $N35^{\circ}E$  to  $N48^{\circ}E$ . Results calculated using the detailed bottom topography of the coast, including Miyazu Bay, show that waves from  $N45^{\circ}E$  to  $N48^{\circ}E$ , which are within the range of the wave window of Miyazu Bay, come directly in; that the most effective are the waves from  $N45^{\circ}E$  to  $N48^{\circ}E$  with a wave period of 8sec and those from  $N40^{\circ}E$  to  $N45^{\circ}E$  with the same wave period; and that they are incident to the beach at nearly the same angle. The estimated breaker angles of the incident waves correlate

well with the breaker heights along the beach for a representative wave height of 1.0m offshore of the Amanohashidate Coast.

**ANNUAL CHANGE IN THE SANDY BEACH CONFIGURATION**

Because sediment movement results in beach change, it is important to understand sediment characteristics, in particular the grain size distribution on the beach. Figure 4 shows the median grain size,  $d_{50}$ , of the shoreline sediments, indicating that on the whole the beaches along this coast consist of fine sediments. The alongshore distribution of grain size can be regarded as almost uniform on the coast in the case of the representative season (winter); but, the grain size ranges from  $d_{50}=0.1\sim 0.2\text{mm}$  for the very fine sand of Daitenkryo beach to  $d_{50}=0.2\sim 0.5\text{mm}$  for the somewhat coarse sand of Shotenkryo beach.

Furthermore, as concerns the sediments in the mouth of the rivers flowing into the area upcoast, which are regarded as the source of littoral sediments, their grain sizes, are somewhat coarser than those on the Amanohashidate Coast. Hence, the source sediment can be said to have been transported downstream by the longshore current, producing a fine grain size that is almost the same as that of the sediments brought to the Amanohashidate Coast by longshore sediment transport.

Groins serve as natural headlands that function to control changes in the sandy beach configuration between groins, thereby approaching the condition of beach stability. Using the definition of stable sandy beaches shown in Figure 5 (Tsuchiya,1991), the annual change in sandy beach configuration is obtained in relation to the annual changes in the sand volume nourished and bypassed. Moreover, the morphological characteristics of stable beaches are obtained. Figures 6 and 7 respectively show the annual changes in shoreline positions and in the sand volume deposited between representative groins.

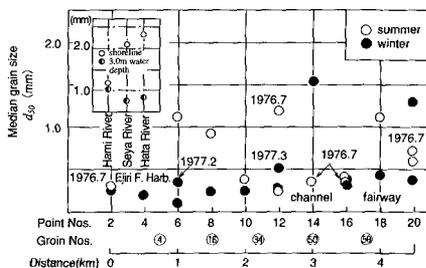


Figure 4. Alongshore distribution of grain size  $d_{50}$  along the shoreline and at river mouths.

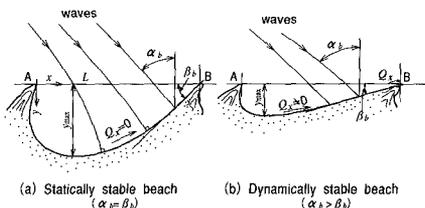


Figure 5. Two kinds of beach form.

Shoreline changes are expressed by the changes in the maximum indentation ratio of the bay ( $y_{max}/L$ ) together with the position. After 1986, little change took place (Figure 6) and the tendency is to approach equilibrium at each headland. In Figure 7, in which the sand volume deposited between groins is plotted as a deviation from the beach formation of 1980~1981, almost the same tendency is shown, although there is some fluctuation. Until 1986, when beach nourishment was actively carried out, the outcome shows large fluctuation. In this case, bottom soundings were made at 10~20m intervals along the shoreline, the level staff method being used for all sections with a water depth shallower than 4.0m.

To show the relationship between the sand volume nourished and deposited in greater detail, the ratio of these values is plotted annually in Figure 8. A ratio of less than 1.0 means that the sand volume deposited is less than that directly nourished, whereas for a ratio of more than 1.0 it is greater. In both cases, with some variation, since 1986 the ratios have been almost constant. The uppermost headland group, Nos.4 and 5 (represented by the star), corresponds to the former case in which almost all the sand nourished is transported as longshore downdrift. That is, under the stationary condition, beaches already have sufficient sand volume, what is called "a feeling of fullness". If an excess volume of sand is supplied to such a beach, the

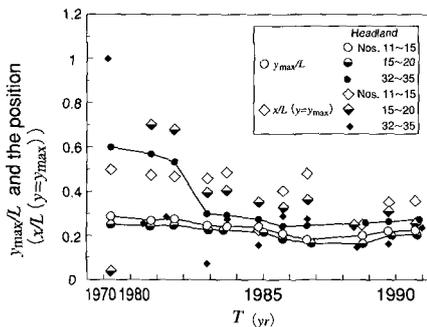


Figure 6. Annual change in the maximum indentation rate and the position.

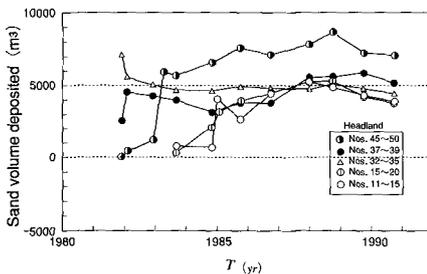


Figure 7. Annual change in the sand volume deposited at groins.

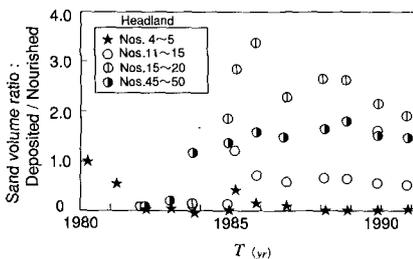


Figure 8. Annual change in the ratio of the sand volume deposited to that nourished.

longshore sand transport rate on the downdrift side of the beach may increase. In the latter case of a ratio of more than 1.0, sand transport coming from the updrift side is trapped between the groins, and the beach is nourished naturally under the function of the headland and the action of natural forces even when a lesser volume of sand is nourished directly. This is distinctly seen on headlands Nos.15 and 20.

Figure 9 shows the relation between  $y_{max}/L$  and the sand volume deposited to that nourished for the sandy beaches between the headlands. Changes in all three elements are shown for the headlands selected (only the sand volumes nourished are shown for the other headlands), the numbers indicating the years when the beach sand was nourished. This figure shows changes in  $y_{max}/L$  and the sand volume deposited on the downdrift side of the beach, due to sand fill on the updrift beach: a) the sand volume nourished on the updrift side intricately related to the increase in the sand volume deposited on the downdrift side, and b) the larger the sand volume deposited on a beach, the lower the indentation rate; i.e., the shoreline position advances.

Changes in indentation,  $b/L$ , averaged spatially are shown in Figure 10. The ratio of  $b/L$  decreases as the sand volume deposited increases and generally the shoreline position advances, whereas the ratio tends to be constant once the volume of sediment exceeds a certain limit. Figure 11 shows the annual changes in the shoreline angle,  $\beta$ , on

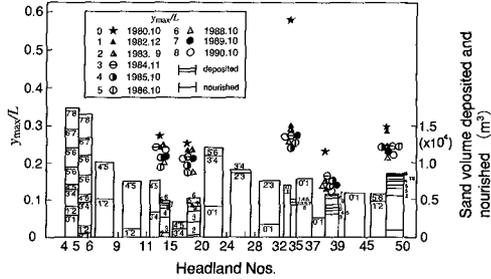


Figure 9. Annual change in the maximum indentation rate and sand volume deposited.

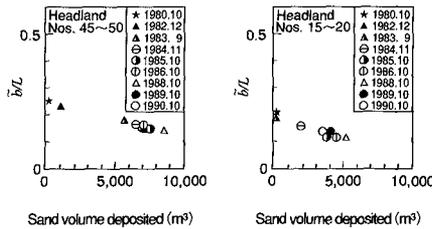


Figure 10. Relation between the mean indentation rate and the sand volume deposited.

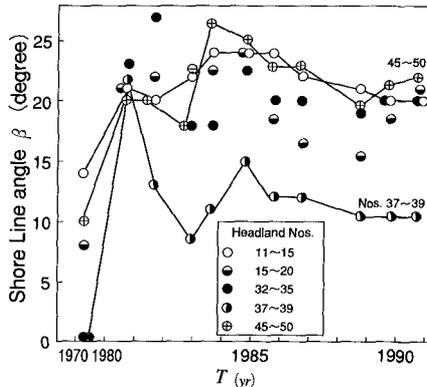


Figure 11. Annual change in the shoreline angle ( $\beta$ ) of the sandy beaches.

the beach immediately on the updrift side of the headland, which depend on the shoreline position and sand volume deposited. Because angle  $\beta$  has remained almost constant since 1986, the beaches have tended to approach the steady state condition with only slight fluctuations.

The most interesting finding here is that there has been no orderly formation of stable sandy beaches from the updrift side. The position of the beaches on the sand spit and the function of the sedimentation between groins, as well as the effects of artificial sand nourishment, may produce a time lag spatially in the formation of stable sandy beaches.

Finally, the maximum indentations  $y_{max}/L$  are compared to the results for morphological characteristics of dynamically stable beaches given in Figure 12. The data representing the relation between  $y_{max}/L$  and shoreline angle  $\beta$  are in good agreement with the lines found by Tsuchiya (1987), further evidence that the sandy beaches between the groins on the Amanohashidate Coast have, to a high degree, already are in dynamically stable conditions.

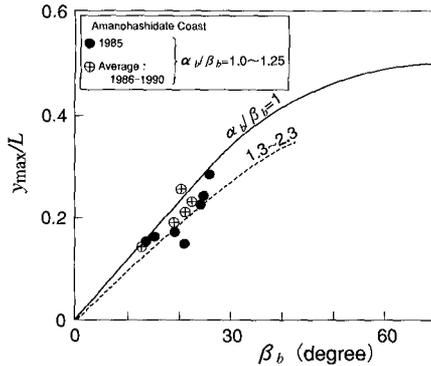


Figure 12. Relation between the maximum indentation rate on and shoreline angle ( $\beta$ ) of sandy beaches.

### SHORELINE CONFIGURATION AND THE FORMATION OF DYNAMICALLY STABLE SANDY BEACHES

On the basis of the results found for annual changes in the plane form of the actual shoreline, the beach process of approaching the dynamically stable condition was considered in terms of the theoretical background of stable sandy beaches (Tsuchiya, Chin and Wada,1992; and Tsuchiya,1994). Figure 13 gives a comparison of the actual and theoretical shoreline configurations (theoretical ones, dotted curve) to show whether the sandy beaches have achieved or are approaching stability. The parameters used for the theoretical calculations were estimated from the representative wave breaker characteristics obtained by calculating the wave transformation and from the actual nearshore configuration characteristics obtained in survey of October 1991. These are shown in Table 1. As

Table 1. Values of incident waves and beach forms.

Symbols headland Nos.	$\alpha_b$ (deg)	$\beta_b$ (deg)	$\alpha_b/\beta_b$	$L$ (m)	$h_b$ (m)	$L/h_b$	$y_{max}/L$	$x/L$	$m$
50	26.4	22.0	1.20	218	1.55	141	0.22	0.30	1/21
39	13.7	13.0	1.05	176	1.44	122	0.14	0.31	1/24
35	25.0	24.0	1.04	84	1.10	76	0.27	0.14	1/20
20	20.8	20.0	1.04	174	1.14	153	0.21	0.26	1/20
15	20.8	20.0	1.04	178	1.07	166	0.21	0.30	1/19

$\alpha_b$  : Incidence angle,  $\beta_b$  : Shoreline angle,  $L$  : Groin space  
 $h_b$  : Breaking water depth,  $y_{max}$  : Maximum indentation distance  
 $x$  : Position where  $y_{max}$  observed,  $m$  : Mean sea bottom slope

indicated by the actual shorelines in Figure 13, the annual sand nourishment and sand bypassing done since 1980, sedimentation between the groins has increased annually, resulting in shoreline advance. In December 1984, the shorelines adjacent to the just updrift sides of the groins reached the tips of the groins. Since then, the shorelines generally have shown an annual advance and have tended to be in the steady state, even though locally there has been some fluctuation.

As to the process of approaching and forming nearly stable beaches, a) the observed shoreline forms are asymptotically approaching the theoretical forms and b) on the whole the two are equivalent, although some differences in local configurations exist because the diffraction effect of the waves due to the presence of the groins was not introduced to the theory. On the basis of all these findings, we conclude that the sandy beaches that presently exist on the Amanohashidate Coast have been steadily approaching the dynamically stable condition.

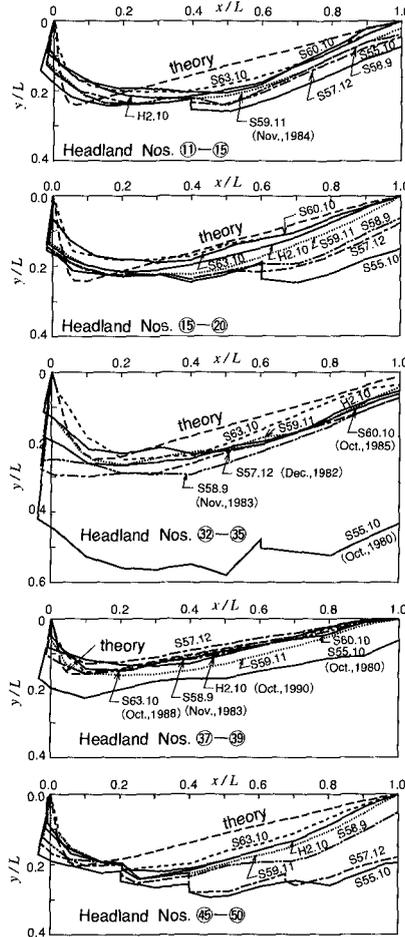


Figure 13. Comparisons between observed shoreline forms of sandy beaches between groins and theoretical ones.

**ESTIMATION OF LONGSHORE SEDIMENT TRANSPORT RATE**

The longshore sediment transport rate,  $Q_x$ , is calculated using the continuity equation for beach change, on the basis of the detailed survey results for beach deformation. Up to 1986 the effect of sand nourishment on the time and spatial fluctuations of  $Q_x$  is large. Results after 1986, which show less fluctuation, were adopted.

Figure 14 shows the alongshore changes in the longshore sediment transport rate under the beach process of approaching a stable sandy beach. The annual sand volume bypassed averages about 5,700m<sup>3</sup>, with little annual fluctuation. There are three types of the alongshore change of  $Q_x$ :  $\partial Q_x/\partial x > 0$ ,  $\partial Q_x/\partial x < 0$ , and a combination of both. The following correspondence exists for these changes, where  $x$  is the coordinate taken to be positive on the downdrift side: first, for periods ② and ③ shown in the figure, there is alongshore change from  $\partial Q_x/\partial x < 0$  to  $\partial Q_x/\partial x > 0$ . In period ② the rate  $Q_x$  decreases toward the downdrift side on the sandy beaches, indicative that on the whole drift sand is deposited on the beaches. On the downdrift groin of No.50, the rate is only 1,000m<sup>3</sup>/yr. In period ③, the rate  $Q_x$  increases on all the beaches, and is 12,000m<sup>3</sup>/yr on No.50. This is because the sand volume deposited during period ② and that bypassed at the beginning of period ③ are both transported as longshore drift sand. In period ④, the regions  $\partial Q_x/\partial x < 0$ ,  $\partial Q_x/\partial x > 0$ , and  $\partial Q_x/\partial x = 0$  appear on the beaches. Note that the fluctuations of  $Q_x$  in alongshore change are greatly reduced as compared to those in periods ② and ③ and, on the average, the rate  $Q_x$  being equilibrated with the sand volume bypassed at any point on the beaches. This indicates that for almost stable beaches even if an unequilibrium occurs in the longshore sediment transport rate, the beaches probably function by themselves, thereby reducing the differences in the rate. That is, a series of groins are considered to serve as headlands that directly control drift sand accretion and erosion in turn and that function organically in the general stabilization of the sandy beaches.

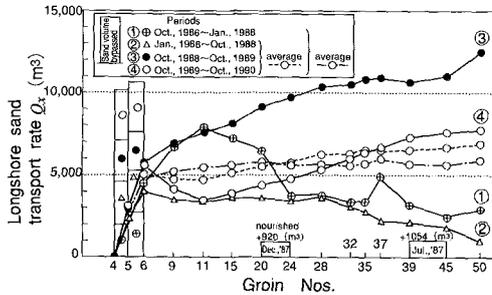


Figure 14. Alongshore change in the longshore sand transport rate.

As the alongshore gradient of the longshore sediment transport rate should be related to the magnitude of the topographical beach changes, the alongshore changes in beach sand volume are shown in Figure 15. Although the magnitude of fluctuation differs according to the groin, in general a longshore sediment transport rate with a range of approximately 10<sup>3</sup>-10<sup>4</sup>m<sup>3</sup>/yr responds to fluctuation in the sand volume between groins with an annual

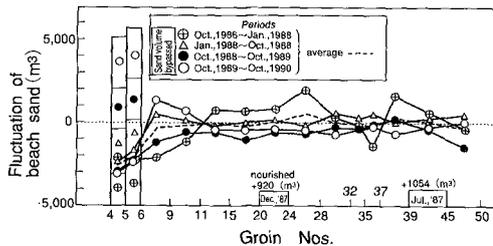


Figure 15. Alongshore change in the beach sand fluctuation rate.

maximum of  $\pm 1,000\text{m}^3$ . Even though such fluctuations are observed, the annual averaged longshore sediment transport rate (indicated by the broken line in Figure 13) is about  $5,300\text{m}^3/\text{yr}$ , and as uniformly plotted alongshore agrees very well with the sand volume bypassed. From this, we assume that at present the sediment transport system in the Daitenkyo area functions very satisfactorily for the formation of dynamically stable beaches.

To establish both only beach stabilization and the applicability of the sand bypass method using groins, it is necessary to determine the longshore sediment transport rate and to recognize the alongshore change in the course of beach erosion under the continuity of sediment transport. The beach process before 1976 should provide useful information. Figure 16 shows the alongshore change of the annually averaged longshore sediment transport rate, as derived by the procedure described previously that is based on change in the beach sand volume surveyed. The drift sand treated here could not, however, necessarily be specified longshore sediment transport because the entire sand volume carried away from the eroding beaches is taken into account; therefore, offshore sediment transport may be included to some extent in the data given in the figure. We estimate that the sediment transport rate has been as much as  $20,000\text{m}^3/\text{yr}$  on the average, even after small groins were constructed; but, once small and large groins were placed in combination, the rate was reduced to approximately  $10,000\text{m}^3/\text{yr}$ . The value of the spatial gradient of the longshore sediment transport rate is positive everywhere, and it is almost constant, whereas its magnitude tends to be reduced, which corresponds to the progress made in the countermeasures taken against beach erosion. This means that in general sandy beaches in the area of concern, continued to erode and be weakened. These facts led to the very important finding that generally sand bypassing decreases the longshore sediment transport rate to about  $5,000\text{m}^3/\text{yr}$  (as stated above) and that sandy beaches become well stabilized through the alongshore balance of the sediment transport rate.

Taking into account that longshore sediment transport depends substantially on the breaker angle  $\alpha_b$ , the facts discussed above suggest the following: the breaker angle formed before the use of sand bypassing was comparatively large because the beaches had been severely eroded and had a poor-looking, saw-tooth like profile; whereas, after sand bypassing the shorelines have advanced, drift sand has accumulated, and the beaches have become dissipative so that sandy beaches have formed well, decreasing the angle  $\alpha_b$ ; i.e., sandy beaches between groins have

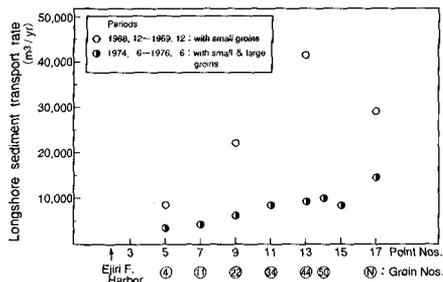


Figure 16. Alongshore change in the longshore sediment transport rate before sand nourishment and bypassing.

oriented their shorelines as parallel to the breaking wave crest as possible, reducing sediment transport. Therefore, in regard to future beach maintenance by means of sand bypassing the following must be considered: Approximately  $5,000\text{m}^3/\text{yr}$  of bypassed sand is considered sufficient to maintain the dynamically stable sandy beaches that presently exist. With regard to appropriate sand volume control, increases and fluctuations in sand drift and beach sand caused by an excess volume of bypassed sand should be avoided. Minimization of the sand volume to be bypassed and fluctuations in the sediment transport rate must also be further considered. To what extent these amounts can be minimized remains to be determined.

## CONCLUSIONS

The main conclusions of our study are

- (1) Sandy beaches that have formed between groins on the Amanohashidate Coast because of the use of sand bypassing have already come very close to being dynamically stable beaches.
- (2) This has been confirmed because in terms of the theoretical background of the formation of stable sandy beaches, the actual shoreline forms surveyed have converged into a steady state with decreasing fluctuations, and the shoreline formation process in general has been asymptotically approaching the theoretical results.
- (3) These phenomena and the relation between the longshore sediment transport rate during the formation of stable sandy beaches and the corresponding magnitude of the sand volume fluctuation, provided appropriate maintenance is not neglected, show that the necessary sand volume to be bypassed is only  $5,000\text{m}^3/\text{yr}$ .
- (4) One criterion of the sand bypassing method therefore, the sand volume bypassed, can be precisely controlled through the formation of dynamically stable sandy beaches.

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