CHAPTER 94

Impact of Offshore Dredging on Beaches along the Genkai Sea, Japan

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ABSTRACT

Offshore dredging has been taking place in the coast of the Genkai Sea, Japan, since the early 1970's, which totaled more than 20 million cubic meters. In order to evaluate the impact of offshore dredging on shorelines as well as the adjacent sea bed, comprehensive coastal engineering studies were carried out over the last four years. The results obtained are not sufficient to establish a direct cause-and-effect relationship between offshore dredging and beach erosion; however, the correlation is sufficient to serve as a warning of a potentially serious problem. Moreover, the dredged holes above 30 meter depth are found to trap the sand from the neighboring bed, and considerable movement of sediment by wave action was observed above 35 meter depth. Thus, offshore mining that would minimize interruption of beach littoral system should be operated below 35 meter depth in the study area.

I. INTRODUCTION

A series of concave beaches separated by headlands forms the coast of the Genkai Sea in the northern part of Kyushu, Japan, as shown in Figure 1. These beaches have been considered to be stable because of the fact that they exist as sandy beaches without much supply of sediment from rivers. Since the early 1970's, owing to the increase in the demand for aggregate and restriction in the mining of gravel from rivers, sea bed at water depth of 15 to 40 meters has been dredged for the extraction of gravel and sand for use as aggregate in concrete. Recently, it was pointed out that beach erosion has been occurring and the cause is thought to be the possible effects of offshore dredging. Due to the possibility of a man-made cause, this erosion problem became an important issue in conserving valuable beaches in the study area and the impact of offshore mining on coastal morphology became public concern.

The objectives of this study are as follows:

(1) to identify historical shoreline changes and to evaluate characteristics of shoreline changes,

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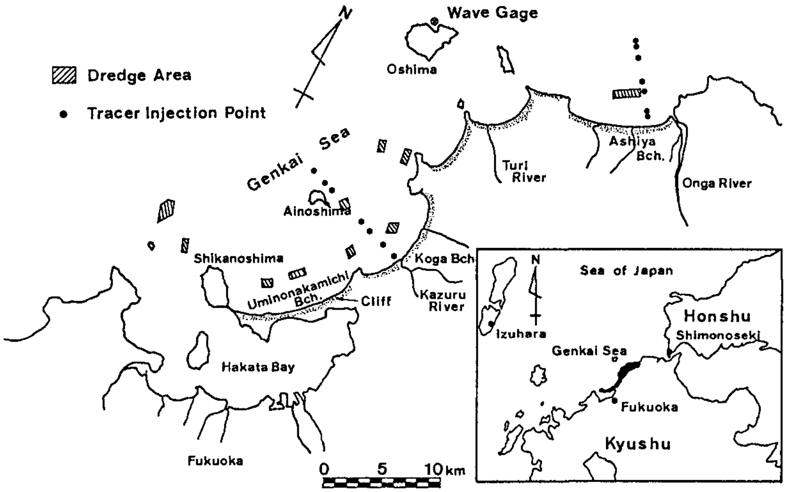

Figure 1 Vicinity Map of the Study Area

(2) to investigate causes of significant beach erosions and accretions through considering wave and climatic characteristics of the study area as well as data pertinent to human activities like offshore dredging and construction of coastal structures,
(3) to assess the link between beach erosion and offshore dredging and the effects of the present offshore dredging activities on the ambient beaches,
(4) to propose guidelines on how offshore mining should be conducted.

II. DATA COLLECTION

Several studies were carried out over four years 1981 to 1985 to obtain pertinent information on morphological changes and offshore dredging effects. They are:

(1) Meteorological surveys including compilation of wind data since 1896 and the number of typhoon attacks.
(2) Compilation of offshore wave data from 1975 to 1984 .
(3) Compilation of allowed volume of sand extraction from the sea bed between 1972 and 1983.
(4) Analysis of aerial photographs to determine historical shoreline changes.
(5) Hydrographic surveys over four years from 1981 to 1985 to obtain profile changes in beach and dredged holes.
(6) Fluorescent tracer studies and sea bed level measurements to acquire data on sediment movement.

III. DESCRIPTION OF THE STUDY AREA

3.1 Description of the Coastal Area

The study area is located in the northern part of Kyushu Island, one of the four main islands forming Japan, and bounded by Onga River to the east and Hakata Bay to the west. One of the major morphological characteristics of the coastline in this area is a series of concave beaches, divided by rocky promontories, resulting from formation of small valleys or basins due to submergence and emergence of land. These beaches stretches from 1 km to 15 km. Because of these headlands, movement of littoral sediment is confined at each concave beach; the supply of sediment from the neighboring beaches is considered to be insignificant.

Major sources of sediment supply in the study area are river and sea cliff. Using annual sediment yield per unit area of drainage basin, obtained from surveys of sediment trapped by reservoirs, and drainage area of each river basin, the total sediment production of each of the rivers was estimated. From this estimation Onga River may at maximum produce about 220,000m^3/year; sediment production of other rivers is considered to be negligible, being less than 10,000m^3/year(1). Sea cliff, another sediment source, is located at the east end of Uminonakamichi Beach, as shown in Figure 1. The cliff is 15 to 20 meters high and stretches about 1.5km along the shoreline.

3.2 Wind and Wave Characteristics

Wind and wave data compiled at Oshima between 1976 and 1980 were used to determine their characteristics. Wind velocity and direction frequencies are shown in Figure 2. The prevailing winds in the study area are from northwest during the winter season and out of the south-southeast during summer months. A dominant direction of strong winds with the velocity of over 10 meters/sec. (hereafter referred to as storm winds) is northwest at any season.

Figure 3 indicates seasonal occurrence frequencies of significant wave height and period. Severe waves with destructive energy occur during winter season. Taking into consideration the direction of storm winds, it is inferred that the prevailing high energy waves in the Genkai Sea are from northwest during winter months.

IV. SHORELINE CHANGES AND THEIR CAUSES

4.1 Historical Shoreline Changes

To quantitatively evaluate long-term shoreline alterations, numerous aerial photographs, taken from 1947 through 1982, were used, together with a digitizer which read positions of the water line on the aerials. After scale and tidal level were corrected, positions of the mean water shoreline were compared at every 50 or 100 meter interval in a consecutive yearly order. Rates of shoreline retreats or advances over three time periods were delineated for each

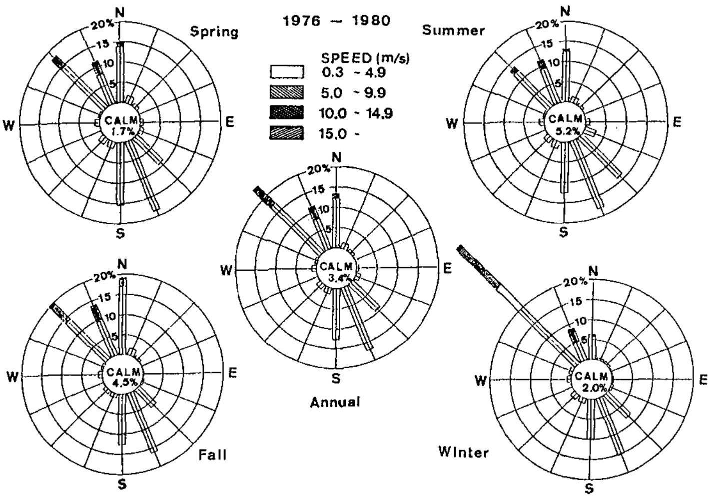

Figure 2 Seasonal Wind Roses

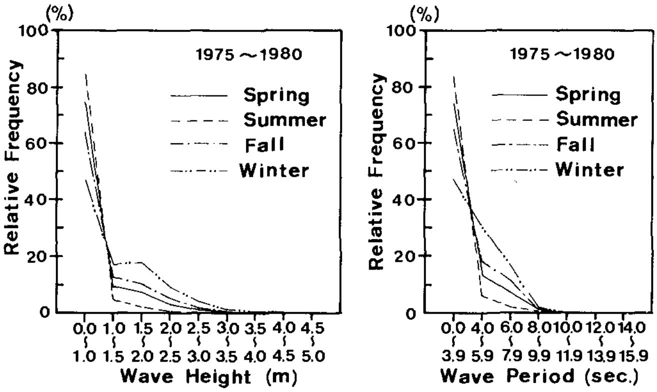

Figure 3 Seasonal Occurrence Frequencies of Significant Wave Heigh and Period

of the concave beaches (called Regions) in Figures 4 and 5. By averaging distances of the shoreline retreats or advances over small portions of each Region (called Areas) which were divided by considerations of spacial distribution patterns of the shoreline change rates plus the location of offshore dredging areas and coastal structures, yearly variations in average shoreline positions were acquired and are shown in Figure 6. Main results drawn from these changes are as follows:

(1) Between 1947 and 1961, a marked beach erosion with an average retreat of 45 meters occurred at the beaches in Region 5, the maximum shoreline recession being 85 meters, which took place in Area 3 of Region 5. For the same period

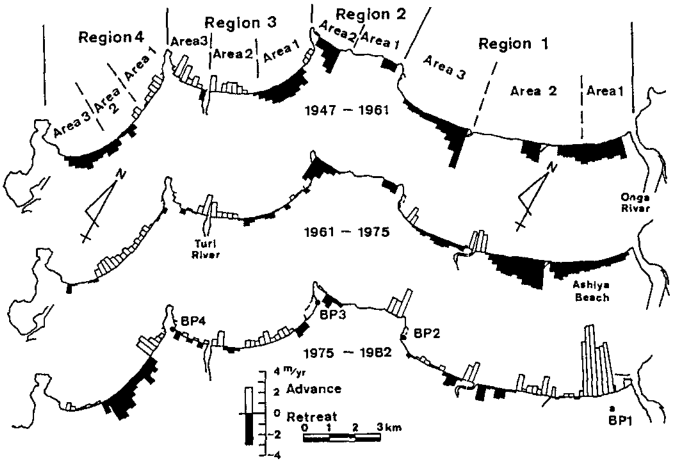

Figure 4 Distribution of Shoreline Change Rates in Regions 1 to 4

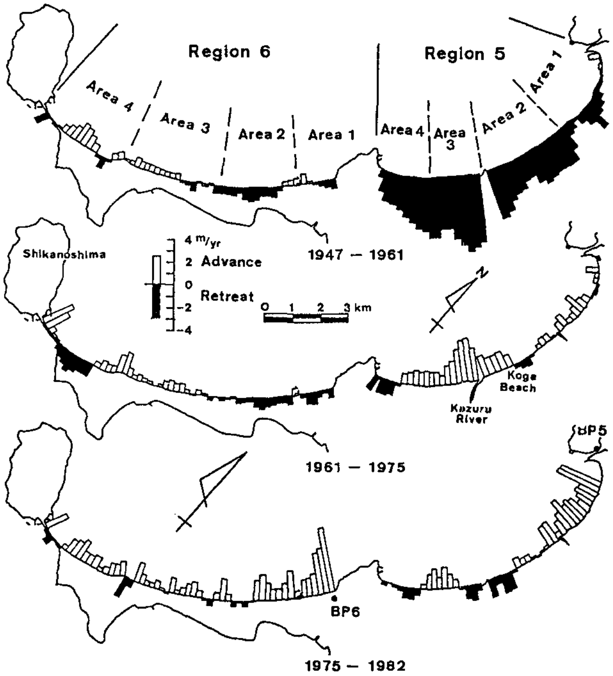

Figure 5 Distribution of Shoreline Change Rates in Regions 5 and 6

other beaches in Regions 1, 2 and 4 also had shoreline retreat ranging from 10 to 30 meters.

(2) Since 1961, most of the beaches have experienced a moderate erosion or stable condition, except for some of the beaches in Region 6 where shoreline receded sharply between 1966 and 1975.

(3) In Region 1, the beaches of Areas 2 and 3 had an erosional trend over 35 years from 1947 to 1982, whereas the beach of Area 1 showed a significant shoreline advance of 38 meters since 1975.

(4) The beaches in Regions 3 and 4, where the curvature of the concave beaches is rather big and an island called Oshima serves as an offshore barrier against the prevailing northwest waves (see Figure 7), indicated small shoreline variations being less than 20 meters over 35 years.

4.2 Causes of Significant Shoreline Changes

Possible causes of the significant shoreline changes identified above, especially beach erosion, are conceived of as follows:

(1) Exceptional intensity of wave impact
(2) Offshore dredging
(3) Construction of coastal structures.

In order to evaluate these factors, we performed extensive wave and weather surveys to determine an offshore wave condition which is regarded as the primary force altering beach configurations, and also collected information on the construction of coastal structures and volumes of the offshore dredgings. Because of the significance of storm-generated winds and typhoons in the overall scheme of coastal processes and erosion, the weather survey consists of two phases: (1) a compilation of data of storm winds with the speed of more than 10 meters/sec. and (2) an investigation of typhoon attacks experienced in the study area. These data were obtained from daily weather reports of the National Weather Service. Wave data measured at the depth of 20 meters offshore of Oshima(see Figure 1) were compiled from 1975 to 1981 for seven years.

Exceptional Intensity of Wave Impact

An attempt was made to correlate yearly fluctuations in the occurrence of both storm winds and severe waves with the trend of the beach erosion. Figure 8 shows occurrence frequencies of onshore storm winds with daily average speed of 5 meters/sec., high waves with significant height of over 3 meters and typhoon attacks which brought onshore storm winds in the study area. A tendency of the storm winds agrees quite well with that of the destructive waves; a remarkably high frequency of the storm winds between 1949 and 1959, thereby suggesting that abnormally strong wave energy may have exerted on the beaches. This period coincides with the occurrence of the severe beach erosion mentioned above.

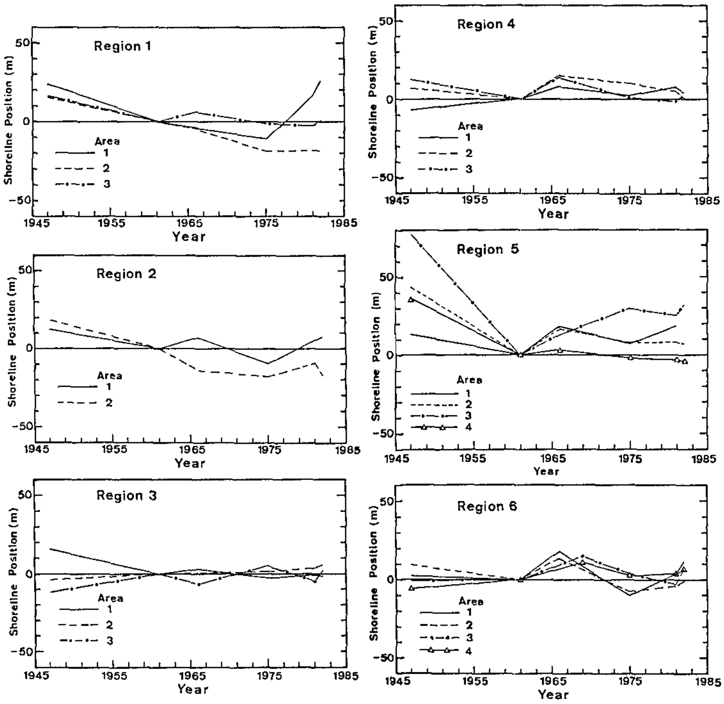

Figure 6 Shoreline Changes for Each Area versus Time

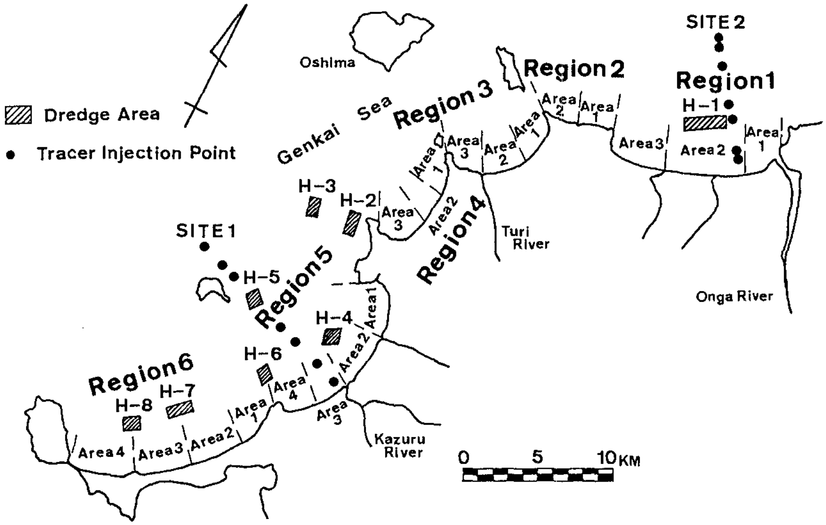

Figure 7 Locations of Areas, Dredging Sites and Fluorescent Tracer Injection Points

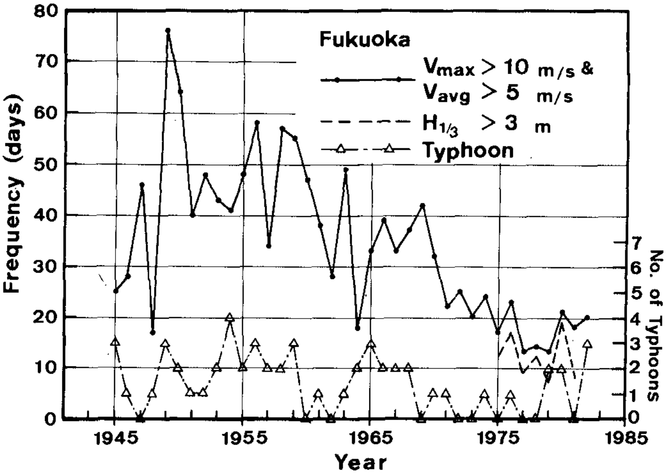

Figure 8 Frequencies of Storm winds, Waves and Typhoons

Thus, this beach erosion would most likely be caused by the exceptional intensity of wave impact.

Offshore Dredging

Annual variations in the dredging volumes were compared with the erosion trends to see if the possible effects of the offshore extraction on the beaches may be evaluated. Location of offshore dredging sites is delineated, in Figure 7, with respect to Areas where yearly shoreline changes were obtained for each Region. There are five Areas, offshore of which gravel and sand have been extracted at the depth of 15 to 20 meters; however, the mining site H-1 was excluded from this analysis because dredging started since 1982 and enough data have not been acquired yet. The average water depth of these four dredged holes are 18 meters for H-4, 25 meters for H-6, 16 meters for both H-7 and H-8.

Figure 9 indicates a relation between annual Varia-

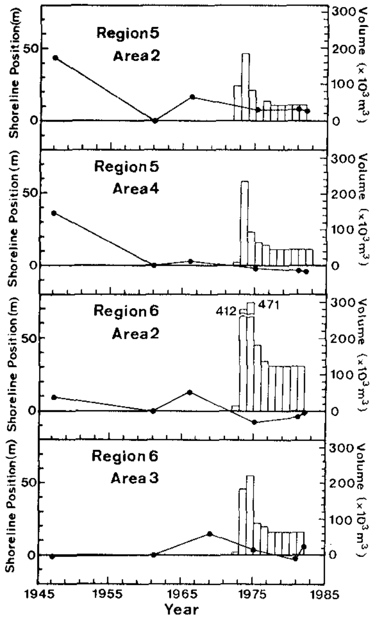

Figure 9 Relation between Shoreline Changes and Dredged Volumes

tions in dredged volumes and shoreline changes. Although the beaches in Region 5 had experienced an erosion trend before the gravel extraction, as seen in Figure 9, the beaches in Region 6 suffered a sharp shoreline recession after the offshore dredging started. Between 1966 and 1975 a shoreline recession rate for Area 2 of Region 6 was one of the severest in the study area over the nine year period, during which more than 0.8 million cubic meters of sand was dredged from the bed at 13 to 20 meters. This result therefore suggests the erosive effect of the dredging on the shorelines.

Coastal Structures

There are no data indicating severe shoreline retreat which may be attributed to the construction of coastal structures. However, drastic recovery from an erosion trend which took place on the beach of Area 1 in Region 1 may be a possible effect of the construction of six detached breakwaters in 1979.

V. ASSESSMENT OF THE PRESENT MINING ACTIVITIES

5.1 Profile Changes at the Dredged Holes

We conducted hydrographic surveys over four years from 1981 to 1985 to investigate profile changes at the dredged holes. In the surveys, an electronic positioning system and a sonic depth finder were used. Figure 10 shows typical beach profiles of four different holes dredged at several water depths. Beach profiles at and around dredge holes situated above the water depth of about 30 meters change substantially by piling up the holes with sediment. Profile changes at the dredged hole H-1 clearly illustrate infilling of the hole from the onshore side. Although profiles at greater depth and far offshore might involve considerable horizontal and vertical errors, changes in beach profiles at 35 to 40 meters seem to be insignificant and dredged holes there remain their shapes. Thus, the dredged trenches above, say, 30 meter depth in the study area may interrupt beach littoral system in that they serve as a trap to littoral sediment that would travel either onshore or alongshore. This depth is about twice as deep as the one obtained by Price, et al.(7) or much greater than the active zone of on-offshore movement which extends to about 10 meters, observed off La Jolla, California, by Inman and Rusnak(4). Although active on-offshore sediment movement in the study area would hardly be considered to extend to 30 meter depth, a considerable infilling of the holes with sand from the ambient bed does occur at that depth, which contributes to interception of the sediment supply to the upper portion of the beach and to steepening of a beach slope in the long run.

5.2 Sediment Movement

Fluorescent tracer experiments and observations of sea

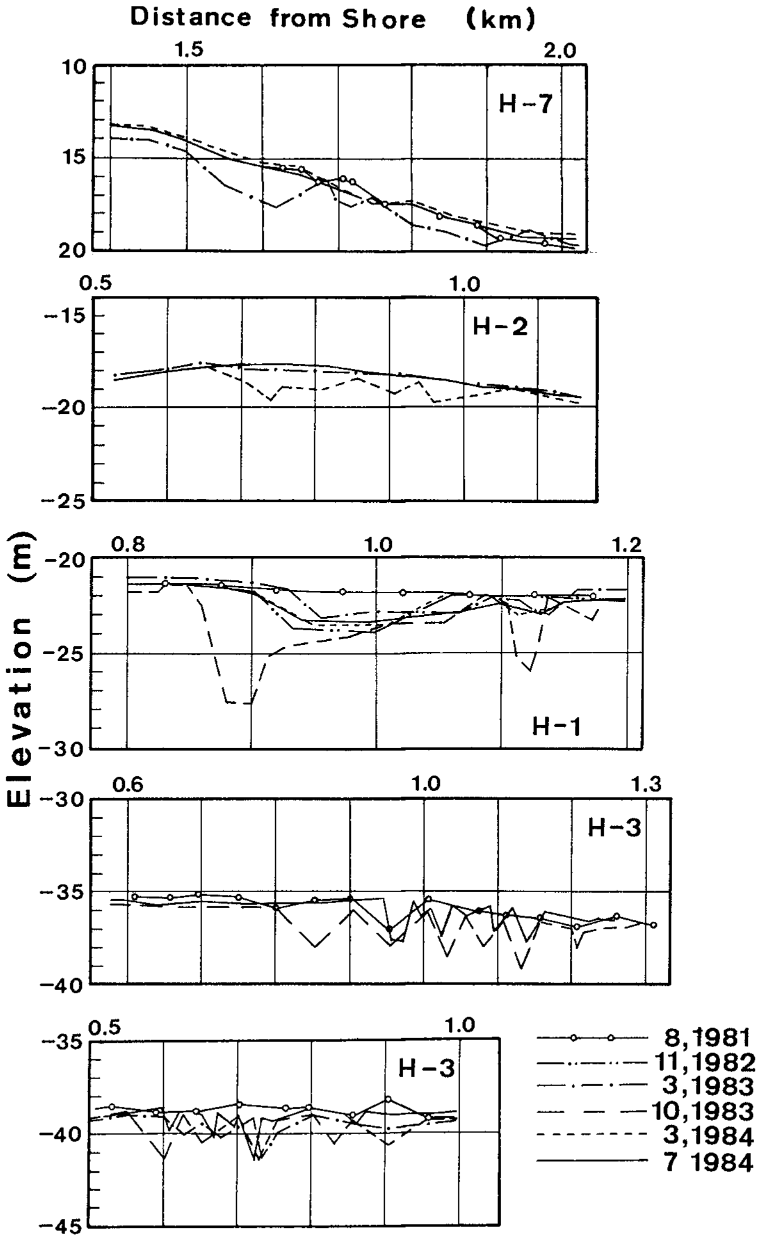

Figure 10 Profile Changes at Dredged Holes

bed levels were carried out to determine critical depth where general movement of sediment may occur. As shown in Figure 7, two locations were chosen for the experiments and fluorescent tracer and a series of graduated rods were placed at every 5 meter depth from the water depth of 10 to 40 meters. Beach profiles and median grain sizes at each 5 meter depth for two sites are shown in Figure 11. We observed tracer movement through taking underwater photographs and measured changes in bed level at the reference rods over three months during the winters of 1984 for SITE 1 and 1985 for SITE 2, the severest season with high waves. Wave data, taken off Oshima during the period of the 1984 measurement, is shown in Figure 12; there are no data for the 1985 measurement due to malfunction of a wave gage.

Figures 13 and 14 show movement of fluorescent tracers and changes in sea bed levels, respectively. Both results indicate that bottom sediment movement above 35 meter depth could be significant, whereas below that depth the movement minimum. This elaborates the result of profile changes at the dredged holes, as mentioned above. At all the observation points were seen sand ripples which form more symmetric shape than asymmetric one, and sea bed levels below 25 meter depth at SITE 1 changes noticeably between 38 and 53 days, during which the highest wave energy was exerted on the bed. These results imply that movement of sediment is more likely activated by wave action rather than unidirectional flow.

There are numerous equations describing sand motion initiation by wave action. It is of great interest for a coastal engineer to know which equations give a representative critical water depth at which sediment movement is considered to be negligible, so that offshore mining at that depth would have minimum adverse effects on the ambient sea bed. The generalized form of expression for critical water depth proposed by many researchers are written as :

$$\frac{H_0}{L_0} = \alpha\left(\frac{d_{50}}{L_0}\right)^m \sinh\frac{2\pi h}{L}.\left(\frac{H_0}{H}\right)$$

where H and L are wave height and length, respectively, h is water depth, d_{50} is median grain diameter, α and m are constant, and subscript 0 indicates offshore condition. Ishihara and Sawaragi(5) proposed α=0.171 and m=0.25 for initial movement; Sato, Ijima and Tanaka(8) suggested α=1.35 and m=1/3 for general movement. Horikawa and Watanabe(3) introduced a more complex expression, based on conditions of bottom surface and boundary layer. In order to determine a critical depth, these three expressions plus recent works on threshold of sediment motion, done by Komar & Miller(6) and Hallermeier(2), were utilized together with the bottom orbital velocity computed from the linear wave theory.

Input parameters for calculation and computed results are shown in Table 1. Wave height and period are those with

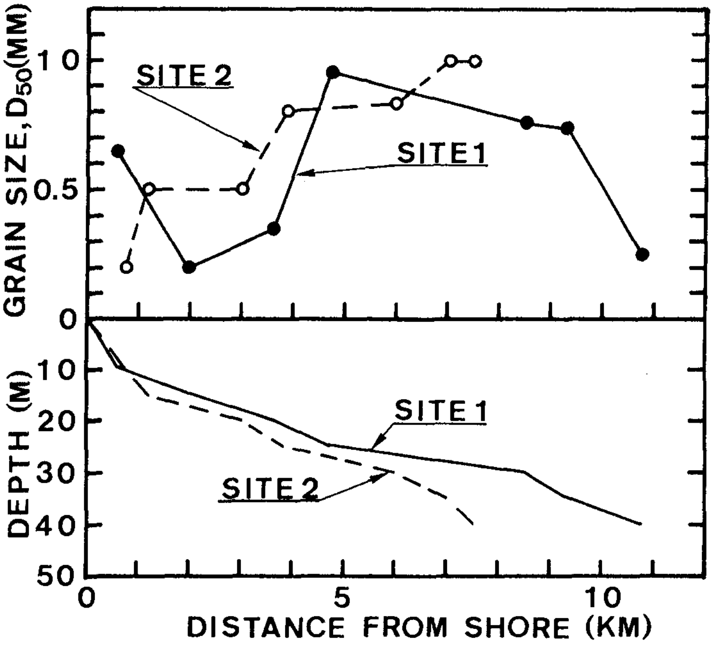

Figure 11 Beach Profiles and Median Grain Size Distribution at SITE 1 and SITE 2

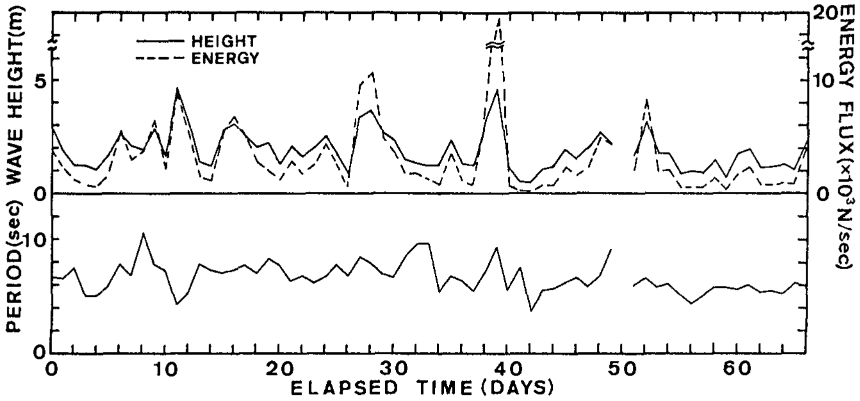

Figure 12 Measured Wave Height, Period and Energy, January 10, 1984 to March 16, 1984

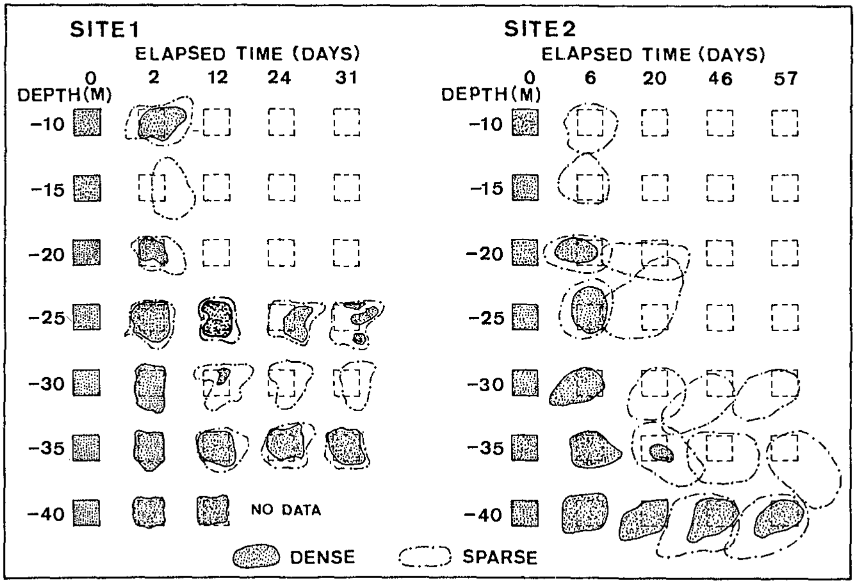

Figure 13 Movement of Fluorescent Tracer at Several Depths

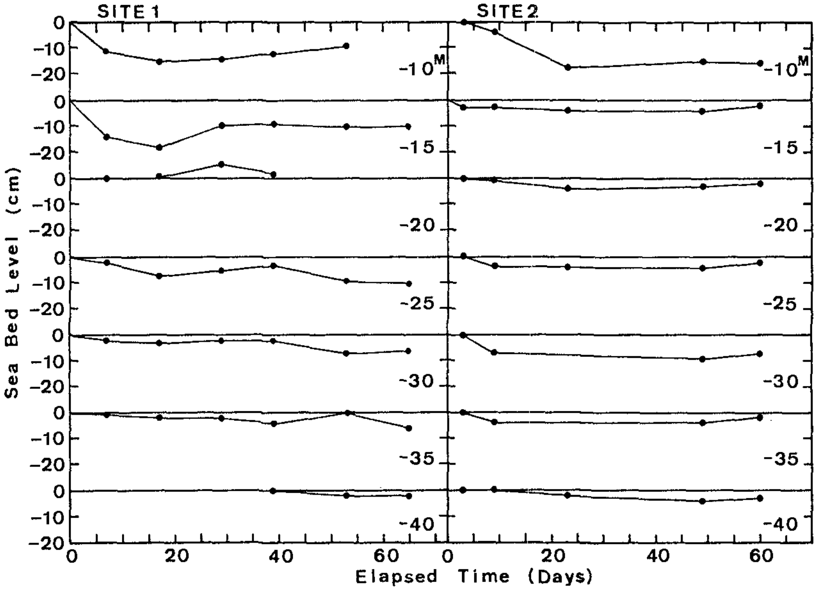

Figure 14 Changes in Sea Bed Levels at SITE 1 and SITE 2

the highest wave energy in Figure 12. The grain diameter was taken as an average value of median sediment grain diameters between 25 and 40 meter depth at SITE 1, as shown in Figure 11. In comparison with the actual measurement indicating a critical depth of 35 to 40 meters, the second and forth values in Table 1 show somewhat smaller and greater depth, respectively. The rest of equations give reasonable estimated depths for this case.

Table 1 Computation of Critical Water Depth

Input Parameters :

Wave Height = 4.58 m, Wave Period = 9.20 sec., d_{50} = 0.58 mm
Specific Weight of Sand = 2.64, Angle of Repose = 45 degree
Kinematic Viscosity = 0.0101 cm^2/sec.

Equation Proposed by	Critical Water Depth(m)
1. Ishihara & Sawaragi	39
2. Sato, Ijima & Tanaka	20
3. Horikawa & Watanabe	37
4. Komar & Miller	49
5. Hallermeier	43

VI. CONCLUSIONS

Although the major cause of the severe beach erosions in the study area would most likely be the abnormally high frequency of destructive wave attacks inferred from the storm-wind data, the offshore dredgings do seem to result in a shoreline recession to some degree. Moreover, dredged holes above the water depth of about 30 meters are found to be refilled with sand which would be mainly transported from the onshore side, thereby interrupting beach littoral system by trapping sand which may travel in the on-offshore or alongshore direction and causing a steeper beach slope in the long run.

The data presented indicates a possible relationship between sand mining and the shoreline changes. Although the available data are not sufficient to establish a direct cause-and-effect relationship between offshore mining and beach instability, the correlation is sufficient to serve as a warning of a potentially serious problem. It is advisable, therefore, that the indiscriminate removal of sand from sea bed be avoided at such water depth that drastic beach profile changes occur. For the study area, it would be above the water depth of 35 meters.

ACKNOWLEDGEMENTS

The authors wish to thank engineers at the Harbor Division, the Prefecture of Fukuoka Department of Civil Engineering, for valuable cooperation and assistance in obtaining pertinent data and for permission to use some of the data. We also appreciated considerable contributions from each member of the Genkai-Hibiki Sea Beach Preservation Advisory Committee chaired by Professor Emeritus T. Ijima, Kyushu University.

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