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PREDICTION OF BEACH EROSION AT MUROZUMI BEACH

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ABSTRACT

Reclamation results generally in beach erosion of a neighbouring coast. Historical changes of shoreline at Murozumi beach, a pocket beach, are first described in accordance with the reclamation. Main causes of beach erosion are then considered by the characteristics of incoming waves over a period of 10 years and of sediment sampled on the present beach plus the consequential effect of reclamation. A method of prediction is proposed for the long-term change and variation of shoreline by the continuity equation of beach change. The long-term beach change of shoreline so estimated agrees well with the results of field survey. It may be concluded, from comparing the results of numerical simulations of beach changes measured before and after reclamation, that the more advances of beach erosion at the coast, the more severe changes of bottom topography and shoreline can be expected.

1. INTRODUCTION

When jetties or vertical seawalls in association with the reclamation near river mouth are constructed, they may upset the natural equilibrium of littoral drift in supply from upcoast and removal downcoast. Consequently, the downcoast shoreline must change its configuration in reaching a new state of equilibrium. These coastal structures thus act as a barrier to the littoral drift, partially or totally intercepting the natural course of sediment movement from river mouth and/or along the shoreline. There exist many examples of this type in Japan, dating back nearly a century.

One of the typical examples, in accordance with the beach processes mentioned, is available at Murozumi beach, as in Fig. 1. This sandy beach, about 3 km in length, has long been treasured because of the scarcity of coastal resort zones in Yamaguchi Prefecture, the western end of Honshu island, Japan. Before reclamation near the mouth of the Shimada river, Murozumi beach was connected with Nijigahama beach, forming a vast pocket beach between the two headlands, namely Zobigasaki and Monzoyama. The material from the Shimada river was the main common source of nearshore sediment for both the beaches. However, reclamation work and construction of Hikari Harbour took place in 1939 at the east side of this river mouth. Immediately following the breakwater construction, which extended 75 m seaward from the original shoreline and seawall installation, the sediment started to accumulate at the west side of the river. Observing the budget of

KEY WORDS: Murozumi beach, Beach erosion, Reclamation, Pocket beach, Shoreline changes

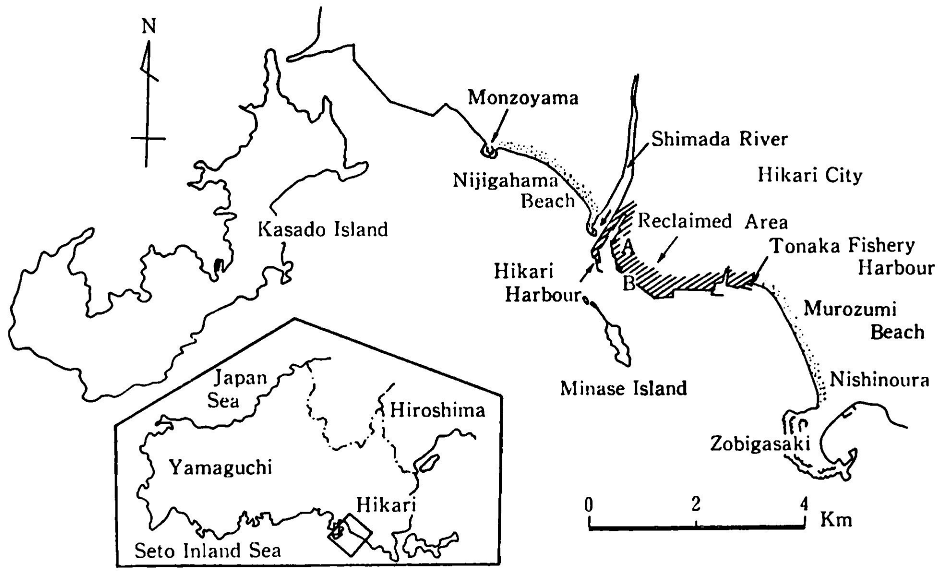


Fig. 1 Location of Murozumi beach.

littoral sediment, Murozumi beach has felt an imbalance without any supply from upcoast. Recently, coastal disasters due to wave overtopping and beach erosion, resulting from stormy waves of typhoon or monsoon, have frequently occurred over its eastern part near Zobigasaki headland. Because the destruction of houses and coastal structures have an immediate visual impact locally, much interest and news media coverage have been focussed on beach erosion. Therefore, it is vitally important in knowing how to predict and control the coastal erosion properly.

In this report, firstly, the hindcasting techniques based on the wind records in the past decade are used to evaluate wave heights, periods, and predominant directions generated by the storms due to the lack of observed wave data. In doing so the wave statistics and their characteristics due to severe storms are investigated. Secondly, the annual or local changes of shoreline configuration and the characteristics of sediment size distribution alongshore are continually surveyed to correlate the prevailing directions of littoral drift and the shoreline in a new quasi-equilibrium. Moreover, from the longshore variations of wave energy flux, in which the effects of wave refraction and diffraction are considered, the changes of shoreline configuration are caluculated by the continuity equation of beach change, in response to the variation of the rate of longshore sediment transport. These results are synthesized to elucidate the beach processes at Murozumi beach where no littoral supply from upcoast (the Shimada river) virtually exists.

2. RECENT BEACH EROSION AND DISASTERS

2.1 Historical Review of Reclamation

The Shimada river, considered as the main source of sediment supply to Murozumi beach and Nijigahama beach, had a large deltaic plain at its river mouth. According to a historical depth sounding as in Fig. 2 [1], it revealed the depths of alluvium once around the river mouth, indicating the river mouth was located at the western side to that of today and has shifted eastward with the repetition of sediment accumulations. The Shimada river, the only river in the hinterland of Murozumi beach, has a hilly watershed (200 m above sea level) with an abundant supply of granite. Before 1938, part of the river mouth delta was utilized for rice fields and the remainder for wasteland or marsh.

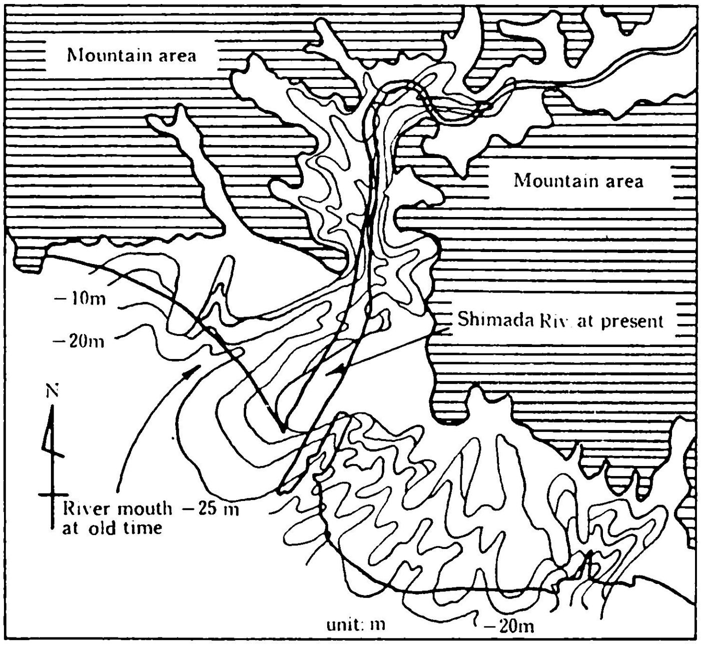


Fig. 2 Depth sounding chart in the vicinity of the mouth of the Shimada river.

An outline of the history of reclamation at Murozumi and Nijigahama beaches, which accompanied with the industrialization of Hikari City, is given as follows. In 1939 the Navy Department constructed the Hikari Naval Arsenal in the southern part of the Shimada river mouth, where the area was about 2.6 million square meter. Although the detailed processes of the construction and reclamation were not known publicly for military reasons, it has been clear that the outline of Hikari Harbour today was established in accordance with the Department's plan. The Hikari Naval Arsenal was demolished after the ending of World War II. In September, 1946, Takeda Pharmaceutical Co. Ltd. established Hikari Factory, and Shin-Nihon Steel Manufacturing Co. Ltd. constructed Hikari Steel Mill in May, 1955 in this area. Further reclamation has been involved in these latter two projects.

Fig. 3 shows the variations of growth and decay of the deltaic plain at the mouth of the Shimada river. Long before any man-made interference, the original shoreline coincided with the contour line about 10 m in height upon viewing the result of geological survey. Because the hinterland was widely covered with erodible weathering granite, the river sediment thus contributed greatly to the seaward development of the river delta. At Murozumi beach two predominant directions of stormy waves have been observed, being the westerly direction in winter monsoon and the southward due to typhoon. There exist two offshore islands, near the mouth of the Shimada river namely Kominasejima and Ominasejima islands. In 1954, they were completely connected with breakwaters, so called as Minasejima island (This means that there is no water resources in the island, in Japanese words). Under these circumstances, a tongue of sediment grew seaward from the original shoreline in the protected lees of these islands. Hence, the river delta had progressively developed and its shape was further deformed in response to the stormy wave conditions. As a result, it can be said from this figure that the sediment was transported from Murozumi beach to the Shimada river mouth in summer and brought back in winter, before reclamation for the Naval Arsenal. This natural movement depended on the seasonal change of prevailing wave directions, whilst a tombolo was formed by diffracted waves behind Minasejima island.

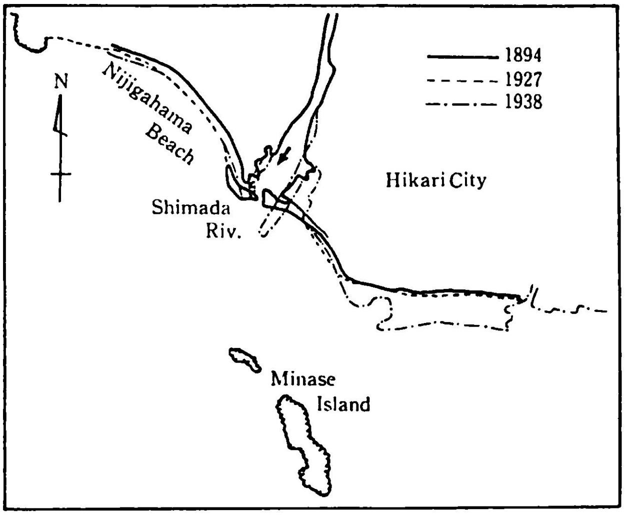


Fig. 3 Historical changes of shoreline before reclamation.

2.2 Changes in Shoreline

It is beneficial to discuss the long-term variation of shoreline with the aid of topographical maps and aerial photographs issued in different times. The shoreline configurations of Murozumi and Nijigahama beaches in the years of 1927, 1963 and 1967 are illustrated in Fig. 4 respectively. It can be found that at the central part of Murozumi beach and the southern part of Nijigahama

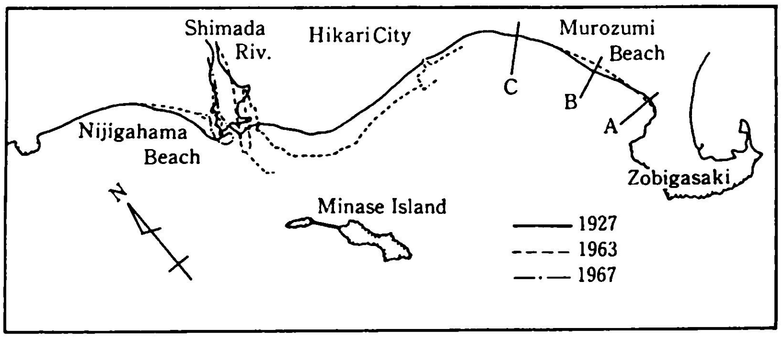


Fig. 4 Comparison of shoreline configurations.

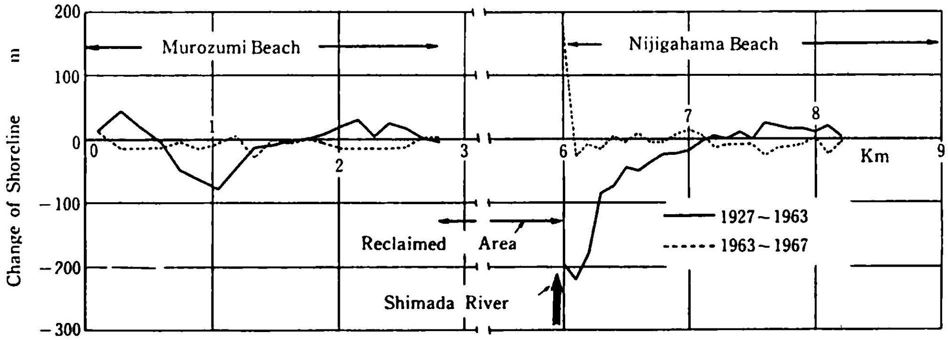


Fig. 5 Changes of shorelines with the distance measured from Zobigasaki headland.

beach close to the Shimada river mouth, the shorelines had remarkably retreated. The rate of advance or retreat of shoreline at Murozumi beach is further depicted in Fig. 5, in which the abscissa denoting the distance from Zobigasaki headland, showing also the case for Nijigahama beach. From this figure, it is recognized that the shoreline near $x=1$ km was eroded about 100 m in 36 years from 1927 to 1963, probably caused by the reclamation. In 1927 the shoreline configuration of this region was somewhat convex seaward, but it eventually became concave in 1963. The result was mainly attributed to a zero supply upcoast from the Shimada river after reclamation in 1939. Subsequently, an apparent tendency of rather uniform shoreline retreat can be observed for the period from 1963 to 1967, and worrying beach erosion occurred at $x=0.5$ km and near Tonaka Fishery Harbour.

Similarly, the retreat of shoreline at Nijigahama beach near the Shimada river can also be detected. An amount of denudation about 200 m was assessed for the period from 1927 to 1963,

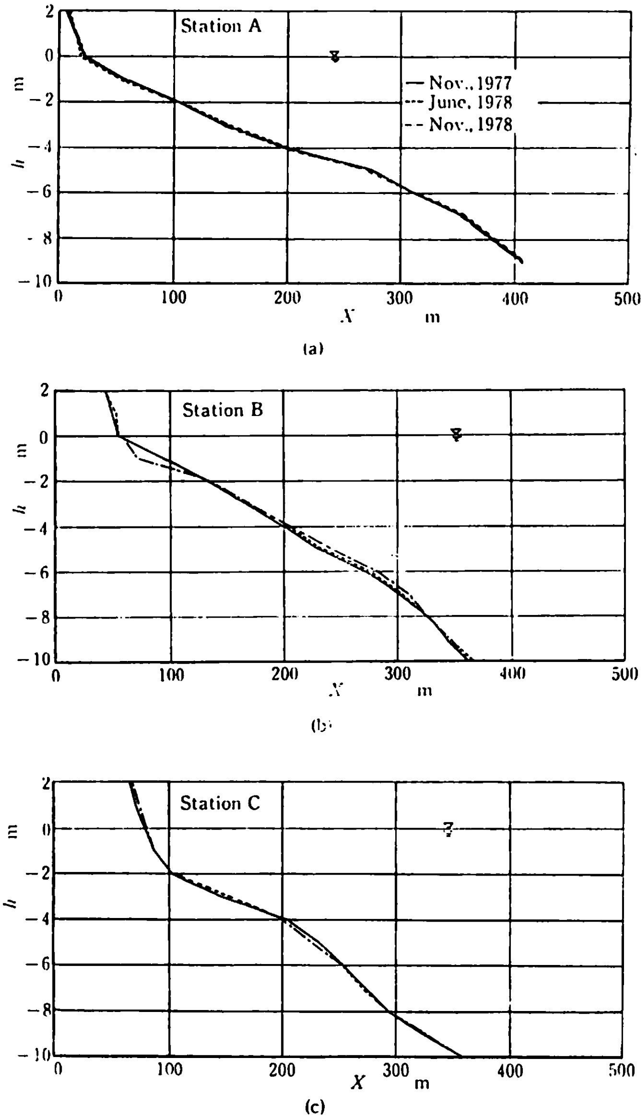


Fig. 6 Comparison of beach profiles at various stations along Murozumi beach (Locations of A, B and C are shown in Fig. 4).

it is probable that dredgings of the river mouth which maintain the performance of Hikari Harbour might affect this. As a matter of fact, the recent shoreline of this area has gradually advanced seaward. It is therefore convinced that the sediment supply from the Shimada river has contributed only to the development of Nijigahama beach.

For the prediction of beach processes, it is important to investigate the characteristics of beach profiles as well as shoreline changes. The hydrographic survey using an echo sounder has been conducted three times, (in Nov., 1977, Jun. and Nov., 1978) at Murozumi beach. The beach profiles at three typical stations along the survey line are demonstrated in Fig. 6, being these stations A, B and C respectively, with x representing the distance seaward from each station. Station A is close to the east end of this coast where a breakwater is now under construction to prevent wave overtopping. Station B corresponds to the region where severe beach erosion once occurred by stormy waves accompanying with typhoon 7818 on 15th Sep., 1978, whilst station C is at a western end near Tonaka Fishery Harbour. Though the period of the depth sounding, being one year only, is too short generally to detect the characteristics of long-term and annual changes of beach profiles, it is noticeable that at station B erosion occurred in the region where water depth less than 2 m with accumulation in the depths of 4–8 m. This is a Nature's defense mechanism. Therefore, the onshore and offshore sediment transport also contributes to the beach processes at Murozumi beach together with longshore sediment transport. It is recognized from this figure that the critical water depth for the threshold of sediment movement is about 8 m.

The erosion-deposition drawings derived from the data of depth soundings are shown in Fig. 7. The rate of beach change is almost less than 0.2 m, so that this value is comparable to the accuracy of depth soundings. Examining qualitatively the result presented, it is obvious that accumulation does occur at the east end of Murozumi beach due to easterly longshore sand transport.

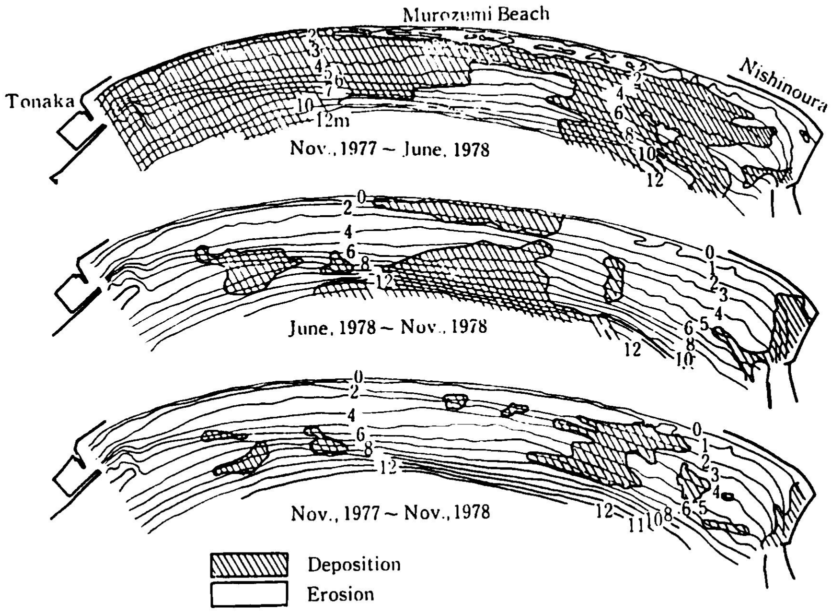


Fig. 7 Areas of erosion and deposition based on the data from hydrographic survey.

2.3 Recent Disasters

Murozumi and Nijigahama beaches facing the Suonada Sea have been the most famous bathing beaches in this district. The sea is usually calm and moderate, and the beaches have seldom suffered from serious coastal disaster. However, since the reclamation in 1939, natural disasters in various forms have become frequent. Some of the recent disasters are described as follows.

The damages due to typhoons in Yamaguchi Prefecture were summarised in Table 1. On 4th August, 1942, the lighthouse at Zobigasaki collapsed and the western part of Hikari City was badly flooded by a storm surge due to Typhoon 4216. The central pressure at the time of landing near Nagasaki Prefecture was recorded at 933 mb. At the Suonada Sea, the storm surge superimposed accidently with high tide. However, more detail information were not available because of the limited number of reports about this typoon. Ruth typhoon in 1951, with a central pressure of 927 mb at landing, caused a storm surge as well as flood hazard along the Shimada river. This typhoon also accompanied with violent wind and heavy rain. The breakwaters of Tonaka Fishery Harbour was broken by stormy waves of the Ruth. Whilst some 30 fishing boats were sunk and other 90 damaged. Though, there have had no serious flood hazard in Hikari City since 1952, but erosion of beach ridge and wave overtopping due to beach erosion frequently occur under stormy wave conditions. Serious beach erosion occurred near station B (mentioned previously) on 15th Sept., 1978 by Typhoon 7818. From the beach profile (as in Fig. 6 (b)) surveyed soon after the typoon, it was probable that an offshore component of sand drift had existed in additional to the longshore component because the beach profile at this station had factually showed erosion near the shoreline and accretion in the water depth range from 4 to 8 m. And it has also been witnessed by residents of Nishinoura that the shoreline has been recessed remarkably since 1975, and their properties have often suffered from damages by large quantities of overtopping splashes in stormy days.

As reported above, it is fair to say that typhoons have resulted in a variety of disasters to these two coasts. Unfortunately, as the natural processes of shoreline retreat are often undetectable though gradual, thus rendering all weak countermeasures ineffective against beach erosion. Because of this, some recent coastal disasters in this area have progressed more seriously.

Table 1 Typhoon damages in Yamaguchi Prefecture.

Name of typhoon	Date	Loss of life (include missing)	Wounded	House razed (include swept away)	House partially destroyed	House flooded
4216	4 Aug., 1942	794	559	2990	9060	42165
5115 (Ruth)	15 Oct., 1951	417	671	1759	2346	32619

3. MAIN CAUSES OF BEACH EROSION

3.1 Waves

In predicting beach changes it is necessary to include all external influences, with waves being the most influential among them all. Hence, engineers have to gather representative information of waves by various means. However, it is difficult in obtaining useful wave data either in short-term or long-term in the field, as the former may not render a typical case whilst the latter has been proven laborious and expensive. Because of these reasons wave forecasting technique is generally adopted to evaluate the characteristics of waves from wind data. In the case of Murozumi beach, a wave forecasting method is employed as no usefull wave data available.

There are three anemometers around this coast, being at Hikari Fire Station, Hikari Factory of Takeda Pharmaceutical Co. Ltd. and Hikari Steel Mill of Shin-Nihon Steel Manufacturing Co. Ltd.. After examining their setting positions and types of instrument, it was decided to use the data from Shin-Nihon Steel Manufactureing Co. Ltd., which were recorded by a cup anemometer set at point A (shown in Fig. 1) from 1953 to 1975.

Annual wind characteristics derived from the data recorded by the above anemometers are shown in Fig. 8. Fig. 9 illustrates the seasonal wind roses with straight line and represents those

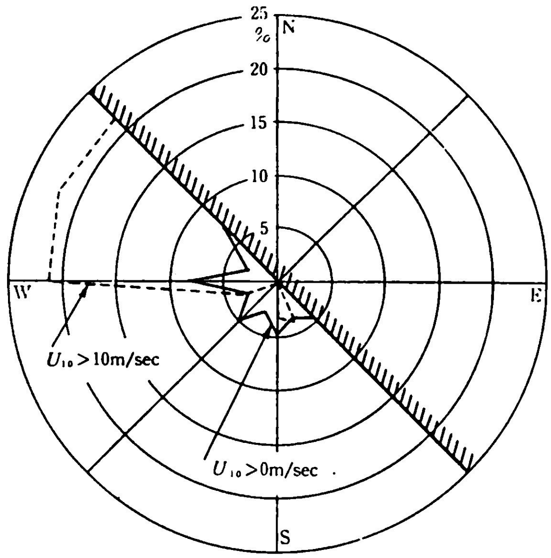


Fig. 8 Annual characteristics of wind roses.

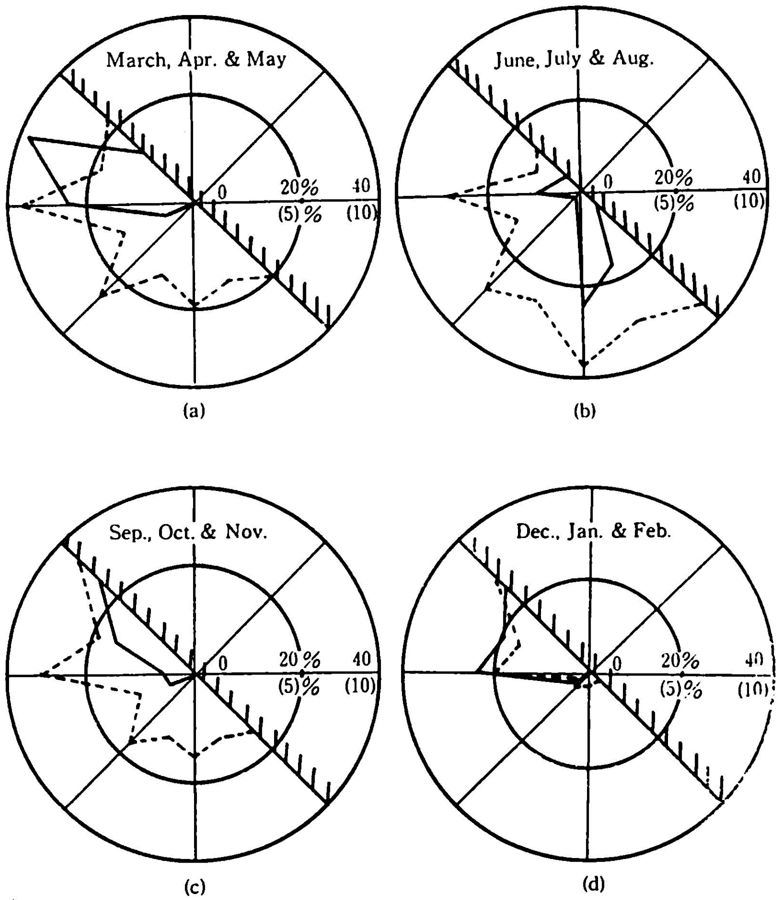


Fig. 9 Seasonal characteristics of wind roses.

from strong winds ($U_{10} \geqq 10$ m/sec) with broken lines. Upon comparing these diagrams it can be recognized that the wind directions W to NW are predominant in the anuual wind roses (Fig. 8). But there exists obviously no specific wind direction in the case of strong winds (Fig. 9), though showing S predominant in summer (June, July & August) as in Fig. 9 (b). It is worth noting that the southerly wind accompanied by typhoon in summer has the same frequencies as other directions in spite of the low frequencies in the annual rose of all winds shown in Fig. 8. In the autumn and winter months (from September to February) the predominant wind directions are NW and W, which are associated with monsoon (seasonal wind), and in spring being the NNW direction caused by 'Taiwan-bōzu' (an abnormal atmospheric depression).

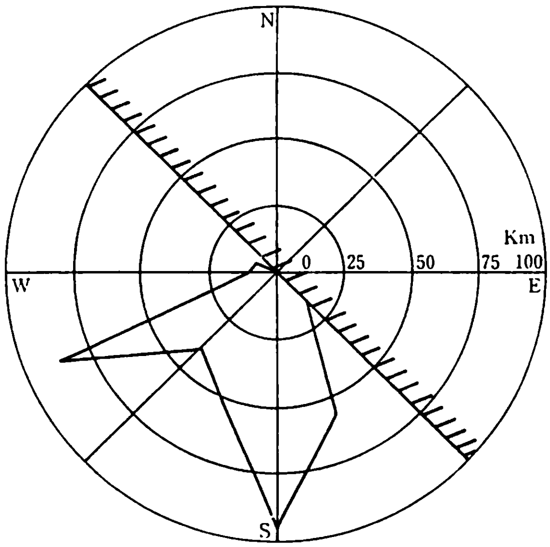


Fig. 10 Maximum fetch in each direction from Murozumi beach.

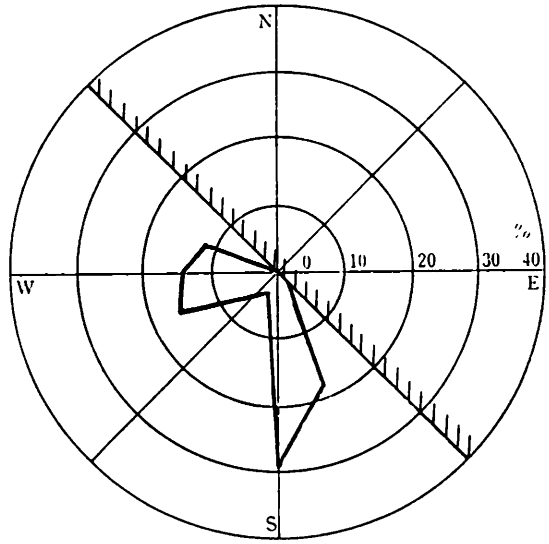


Fig. 11 Directional distribution of wave energy flux in deep water.

To hindcast wave condition, the so-called modified Wilson method and the S.M.B. method are used. Using this method, the wind generation area has to be determined, wherein the mean wind velocity U, fetch F, and duration t are to be evaluated. Fig. 10 shows the maximum fetch in each direction from Murozumi beach. The significant wave height $H_{1/3}$ and period $T_{1/3}$ are determined by the combination of U and F as well as U and t. From these values, the smaller set is selected as the desired wave characteristics. Fig. 11 demonstrates a directional distribution of energy flux in deep water for wave heights greater than 0.1 m, these being forecasted by the movable averaged data of wind directions and mean velocities measured at every 2-hour intervals from 1963 to 1973. The resulting seasonal characteristics of wave energy flux in deep water are depicted in Fig. 12. Two predominant directions of incoming waves in deep water are available, one in the S direction caused by typhoon in summer and autumn, the other in the W direction associated with monsoon in winter and spring, showing also the intensity of the former is larger than that of the latter.

Although long-term wave statistics can be closely related to the annual or long-term beach processes, it is equally important to consider the effect of high waves to beach changes in the short-term. Hence, the characteristics of stormy waves with duration ranging from 10 hours to few days have to be investigated, from the wind data available from 1958 to 1977, including monsoons and extraordinary low air currents in winter plus typhoons in summer.

These calculations have been done under the following assumptions, (1) The hourly changes of wave directions are assumed the same as that of winds, (2) The smaller value of wave height

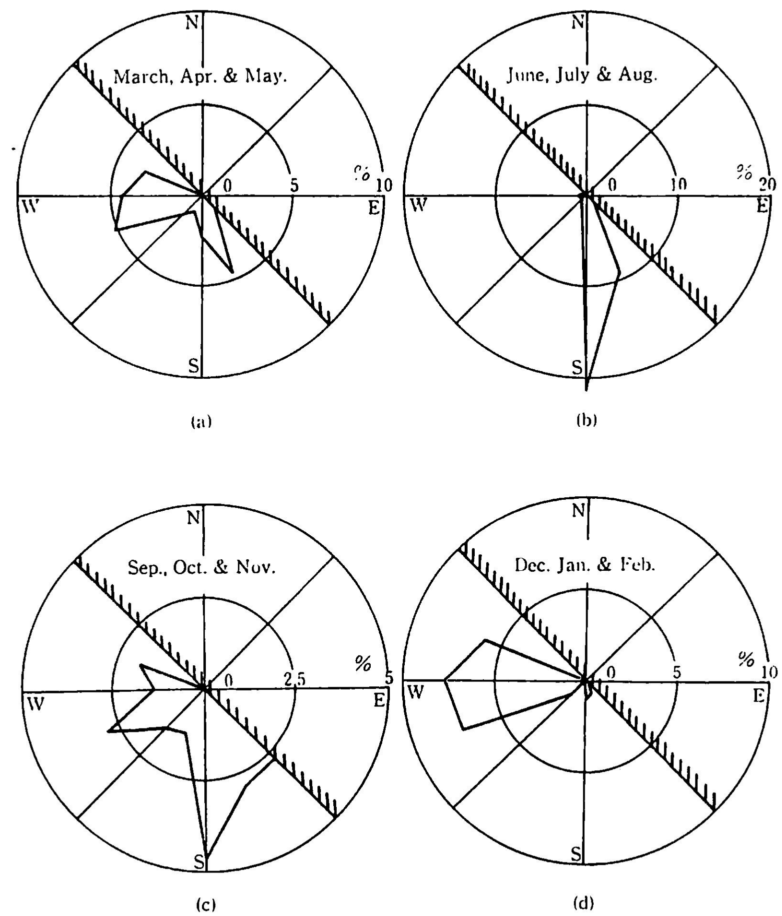
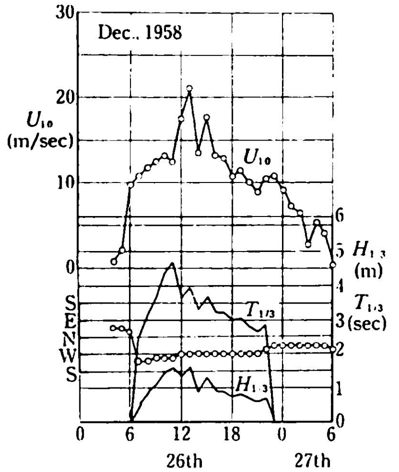
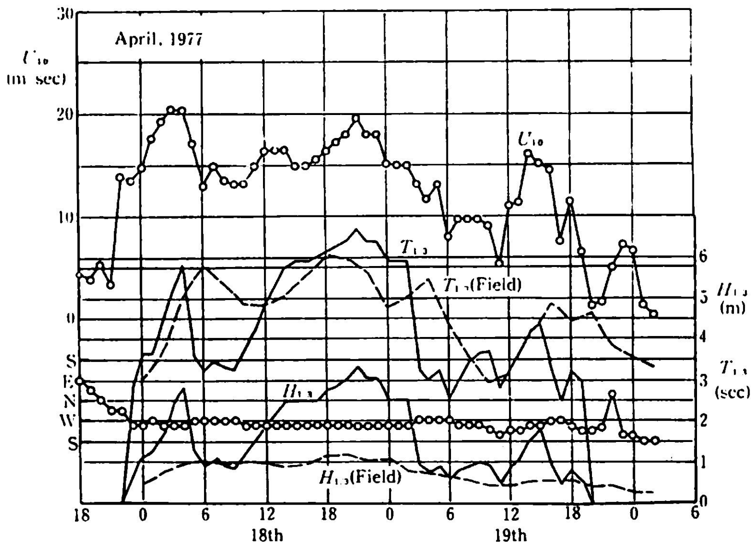


Fig. 12 Seasonal changes of characteristics of wave energy flux roses in deep water.

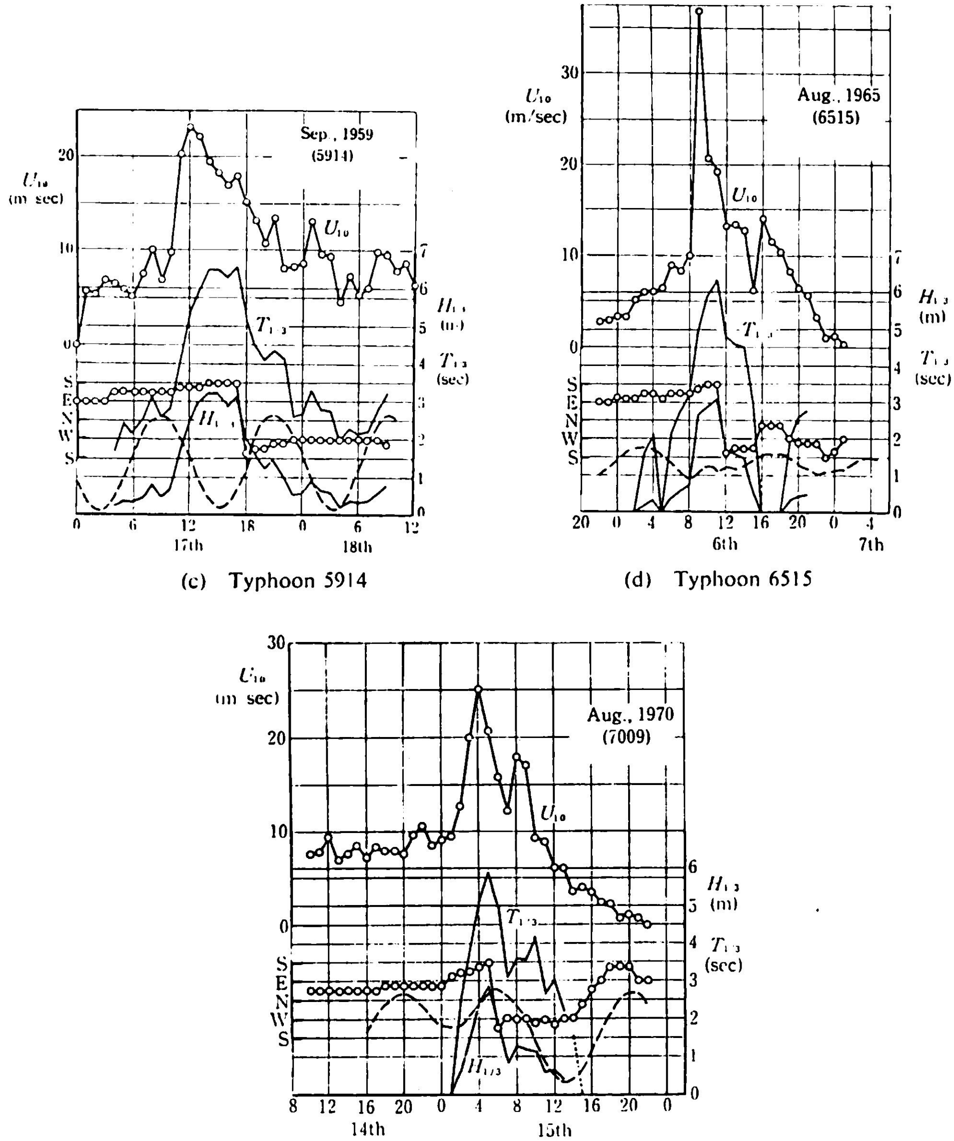
and period from the wave generation in duration-limited and fetch-limited cases is selected as the desired characteristics of waves in deep water based on the S.M.B. method, and (3) The energy of waves is conserved and its hourly change is propotional to the wind velocity for that greater than 5 m/sec. Fig. 13 depicts the wave characteristics as a function of time predicted by the S.M.B. method, using 8 storms selected from 20 years' wind data as mentioned, in which the dotted lines infer the change of tidal level. In these figures, cases (a) and (b) correspond to the cases of monsoons, while (c), (d) and (e) representing the cases from typhoons, with the courses shown in Fig. 14. From Fig. 13 (a) corresponding to monsoon wave, it is observable that significant wave heights of the storms with predominant direction in WSW are greater than those in W. On the other hand, for the cases of typhoon, Fig. 13 (c) to (e), the highest waves approaching southerly occurred when a typhoon passed the western part of Hikari City, whilst the direction of waves changed in the sequence following SE→S→SW→W as the typhoon progressed. However, it is vital to assess the accuracy of the waves so hindcasted as it may be governed by the changeable conditions of wind



(a) Monsoon (1)



(b) Monsoon (2)



(c) Typhoon 5914 (d) Typhoon 6515

(e) Typhoon 7009

Fig. 13 Changes of wave characteristics as a function of time predicted by the S.M.B. method.

fields, resulting from a typhoon or a monsoon. Reasonable good accuracy in the case of monsoon may be expected because of its nearly constant wind fields. Moreover, as the high tidal range is about 2.5 m at Murozumi beach, the effects of tidal level and its associated tidal currents generally cannot be neglected when beach processes are considered. The former is expressed by M.S.L. and C.D.L., which are T.P. (Tokyo Peil) − 1.6 m and +0.2 m respectively. The M.S.L. is used hereafter. The latter is not so strong to contribute to beach change of Murozumi and Nijigahama beaches in comparison with stormy waves [2].

The discussions above are for deep water waves only. Wave transformation in shallow water has to be considered, particularly for the estimation of wave characteristics near the beach. Generally, there exist six kinds of wave transformation, these being (1) Wave shoaling, (2) Wave

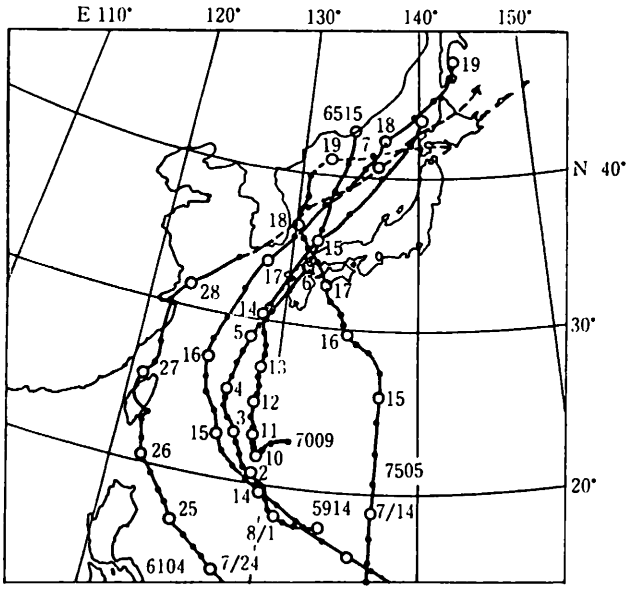


Fig. 14 Courses of typhoons which caused high waves to Murozumi beach during 20 years from 1958 to 1977.

damping due to bottom friction and inner viscosity, (3) Wave refraction, (4) Wave diffraction, (5) Wave reflection, and (6) Wave breaking. Considering only items (1), (3), (4) and (6), characteristics of wave transformation have numerically been calculated by Worthington and Herbich [3]. An improved version of program has been made by Yamaguchi et al. [4].

An outline of the calculation procedure of wave transformation is as follows. The heights and periods of deep water waves are used as the initial conditions, and a criterion of wave breaking originally for solitary wave is assumed as

$$H_b/h_b = 0.78 \tag{1}$$

where, H_b is the breaker height, h_b the breaking water depth. The equation governing wave refraction and wave orthogonal equation are given as

$$d\alpha/dt = \sin\alpha(\partial c/\partial x) - \cos\alpha(\partial c/\partial y) \tag{2}$$

and

$$d^2\beta/dt^2 + p_t d\beta/dt + q_t\beta = 0 \tag{3}$$

respectively, where the variables

$$p_t = -2\{\cos\alpha(\partial c/\partial x) + \sin\alpha(\partial c/\partial y)\} \tag{4}$$

$$q_t = c\{\sin^2\alpha(\partial^2 c/\partial x^2) - 2\sin\alpha\cos\alpha(\partial^2 c/\partial x\partial y) + \cos^2\alpha(\partial^2 c/\partial y^2) \tag{5}$$

$$\beta = b/b_0 = K_r^{-2} \tag{6}$$

in which α is the angle between orthogonals and x-axis, c the wave celerity, b the transverse width between orthogonals measured normal to them, and β the coefficient for the spacing between two adjacent wave orthogonals. The local wave characteristics can thus be obtained by solving these equations numerically with the use of Eq. (7) at every time step.

$$H/H_b=(c_{g0}/c_g)(b_0/b)=K_sK_r \tag{7}$$

where H is the wave height at every calculating point, K_s the shoaling coefficient, K_r the refraction coefficient, and c_g the group velocity, with sufix 0 indicating the conditions at deep water. The wave height distribution derived for a semi-infinite breakwater is used as an initial condition in calculating wave diffraction. To facilitate wave diffraction, bottom topography related to the area of interest is needed. Fig. 15 shows the bottom configuration of Murozumi beach where the depth contours shallower than 15 m are derived from the sounding chart measured in November, 1977, and those deeper ones obtained directly from the hydrographical chart published in September, 1929.

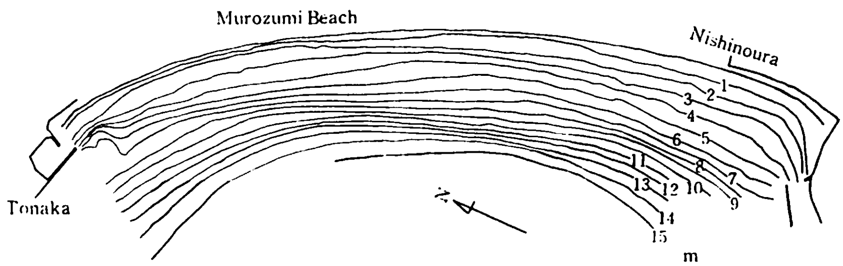
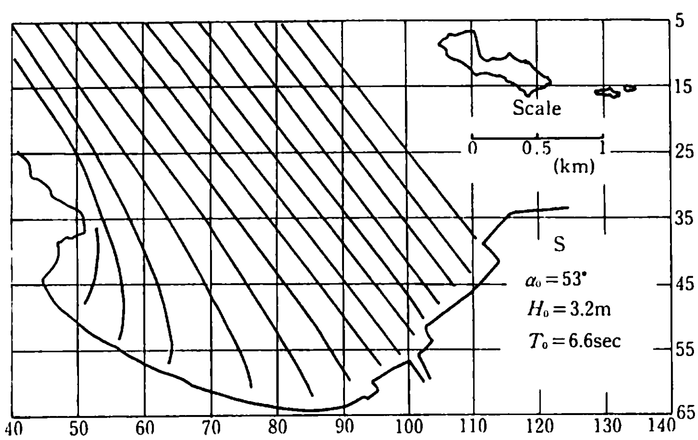
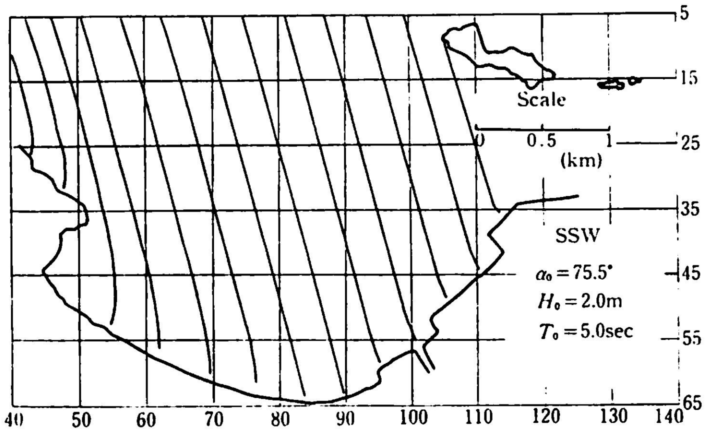


Fig. 15 Bottom configuration of Murozumi beach (under 15 m depth).

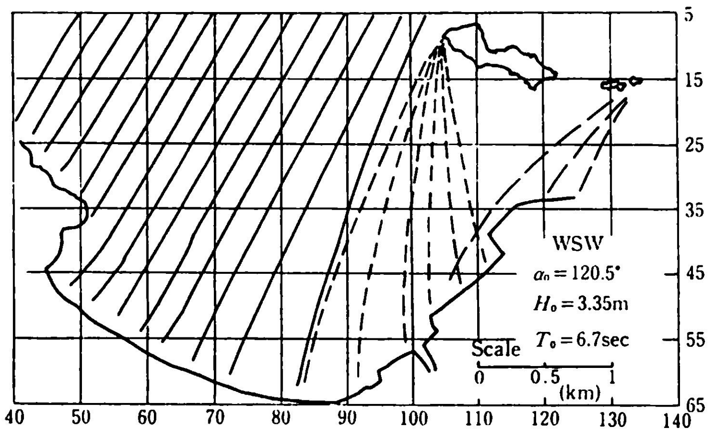
The numerical program covers an area of 8.5×2.4 km of waters in the vicinity of Murozumi beach, with grid spacings at 50 m in both directions. Minasejima island is tacitly assumed as a vertical wall at 15 m water depth for simplifying calculations. Examples of wave refraction and diffraction diagrams are depicted in Fig. 16. Fig. 16 (a) and (b) correspond to the cases of typhoon, whilst Fig. 16 (c) and (d) to that of monsoon respectively. In these figures, solid lines refer to orthogonals of refracted waves, with broken lines indicating those diffracted. It can be summarized from these figures that in the cases of wave directions S and SSW the central and western parts of this coast would directly be attacked by stormy waves from typhoon, whilst in the W direction most part of this coast is in the diffracted zone behind Minasejima island in spite of the highest frequency of incoming waves from this direction. However, in the case of WSW direction, the corresponding fetch is so long that waves with very high amplitude often occur and reach about 80% of this beach.



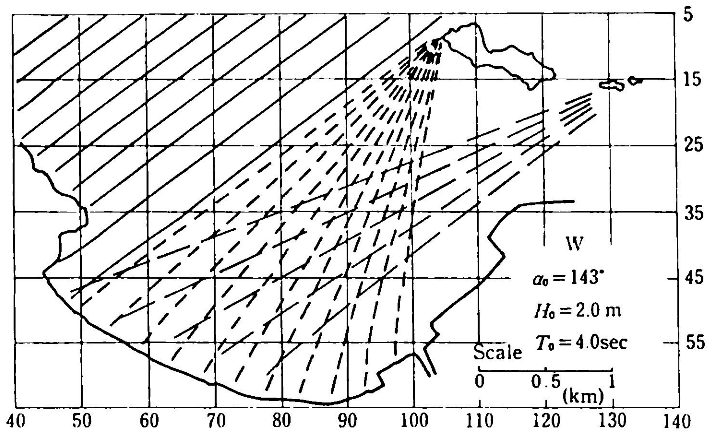
(a) S-direction



(b) SSW-direction



(c) WSW-direction



(d) W-direction

Fig. 16 Examples of wave refraction-diffraction diagrams, representing various directions of wave approaching (Numbers on the co-ordinates show mesh number in calculation).

3.2 Sediments

The Shimada river flows through the mountaineous catchment basin widely covered with weathered granitic rocks. Under these circumstances, river sediments do not contribute particular types of heavy minerals available as tracer materials. Although the systematic variations of sediment size statistics, such as median diameter and standard deviation, can be found from a sieve analysis of sediments. It is still difficult to trace sediment movement to and along beaches in analyzing sediment compositions. In order to identify the dominant directions of longshore sediment transport at Murozumi and Nijigahama beaches, samplings of sediments were carried out on the 17th January, 1979, with distances between sampling points at 50 m and 100 m alongshore on beach respectively. At the Shimada river, six typical sampling points were selected along its center line from the mouth to Kinoshita bridge, at 3 km upstream along the river in Fig. 17. In each sampling, only sediments within a very thin layers near the surface were collected as this might reveal some newly mixing conditions of sediments. In addition, the seasonal changes of dominant wave direction which promote the movement of sediment must be considered, that is to say, for example, the stormy waves in winter come from westerly direction, so the direction of beach sediment transport may coincide with it.

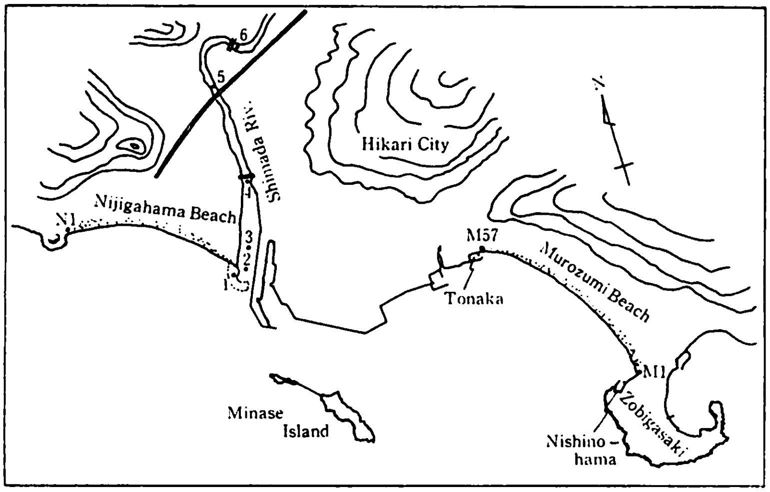
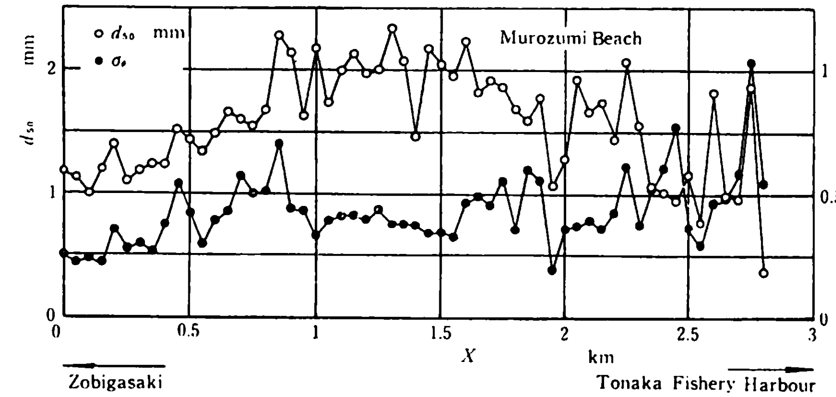


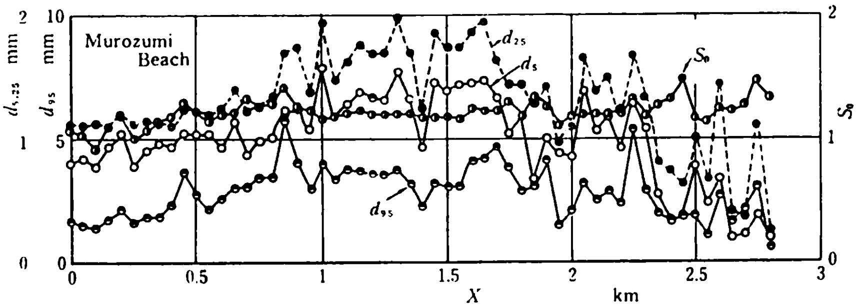
Fig. 17 Location of sampling points of sediments.

3.2.1 *Characteristics of sediments at Murozumi beach*

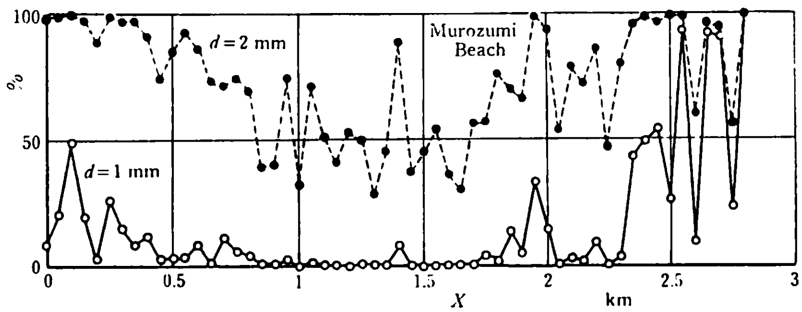
Fig. 18 (a) shows the longshore changes of median diameter d_{50} and also standard deviation σ_{ϕ}. From the aerial distribution of median diameter presented, coarse materials can be found in the range of 0.8 to 1.6 km distance from the east end of Murozumi beach. Further beyond it, the size of median diameter decreases progressively. At the west end in the vicinity of Tonaka Fishery Harbour, no clear tendency can be detected due to complex superposition of incoming waves, reflected waves from the breakwater and diffracted waves in the lee of Minasejima island. A similar results can be obtained upon considering the aerial characteristics of distribution of standard deviation. At the center region of the beach, sediments have well been sorted due to convergence of incoming wave energy, which depends mainly on sea bottom topography. Consequently, it shows smaller standard deviation, hence the sediments are nearly uniform. On the contrary, as the east end of Murozumi beach is protected by a rocky headland (namely Zobigasaki), and the west end is sheltered by Minasejima island, therefore, longshore selective sorting of beach sediments is not so active that the standard deviation is larger in comparison with that in the central region.



(a) Median diameter and standard deviation σ_ϕ



(b) d_5, d_{95} and sorting coefficient S_0



(c) Percent of sediments less 1 mm or 2 mm in diameter

Fig. 18 Longshore distribution of sediment size statistics at Murozumi beach.

The longshore distribution of diameters and sorting coefficient S_0 are depicted in Fig. 18 (b), in which d_5, d_{25} and d_{95} are the diameters of 5, 25 and 95 percentile of sediment samples respectively. Attempts at utilizing the sediment size statistics (d_5, d_{25}, d_{95}, S_0) are successful to support the results mentioned previously, because their longshore patterns are similar to that in Fig. 18 (a).

Moreover, Fig. 18 (c) presents the percentage compositions of sediment diameters less than 1 mm and 2 mm respectively. It is found that the former is below 1 % and the latter is about 50% at the central part of this beach. So, the well sorted but coarse sediments appear in this region, with a general tendency of decreasing sediment size both eastwards and westwards.

The fact that the beach slope of a foreshore increases with sediment size has been demonstrated in several field studies. However, this relationship remains as an empirical one without fuller

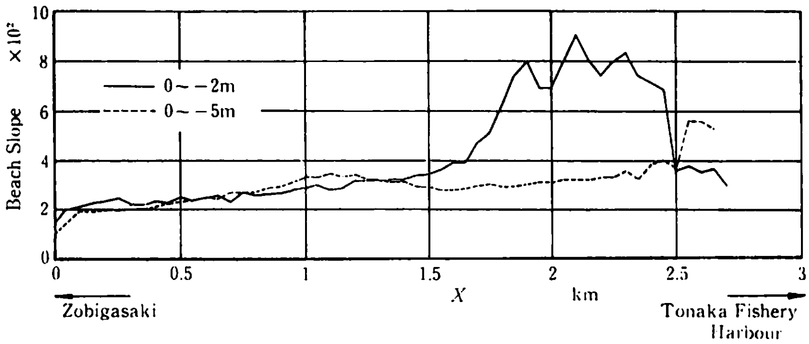


Fig. 19 Local changes of beach slope.

quantitative evidence of the complex relationship between sediment size, beach slope, and characteristics of waves. The changes of beach slopes from shoreline to the contour lines where water depths at 2 m and 5 m respectively are given in Fig. 19, with distances measured from Zobigasaki headland. In the latter case, beach slopes are seen to be as great as 1/25 approximately at Tonaka Fishery Harbour and decrease to about 1/50 at the east end near Zobigasaki. The relationship between beach slope and median diameter of the beach sediments is tentatively given in Fig. 20. Although there exists some scattering of data in this figure, nevertheless, as generally expected, the coarser the sediment is, the steeper the beach slope becomes, particularly for at the central part of Murozumi beach, except the vicinity of its west end.

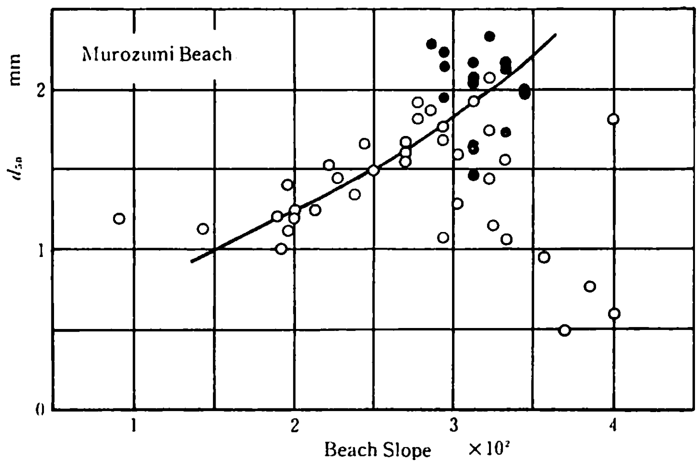


Fig. 20 Beach slope versus median diameter of sediments.
(●; Data in the region of $X>1.5$ km)

Since the reclamation has prevented the supply of river sediment to this coast, some forty years have passed. Now, Murozumi beach appears to be as a pocket beach bounded between Zobigasaki headland and the breakwater for the reclamation, at either end. Under normal wave conditions, it is impossible for beach sediments to be transported out beyond the headland and the breakwater, therefore, this beach has demonstrated a closed system to sediment movement. It is equally difficult for any new sediments to be brought into this beach except for artificial nourishment. In many pocket beaches coarse sediments can be found at the central part, while a gradual decrease in sediment size can be detected at places away from the center. In the vicinity of Zobigasaki rocky headland, the beach slopes are about 1/50 to 1/100 and become milder gradually.

This helps to explain that finer sediments have been accumulated in the sheltered area behind the headland. Thus, Murozumi beach has exemplified the characteristics of a pocket beach.

After synthesizing the characteristics of longshore distribution of sediment size statistics, it is easy to illustrate directions of beach sediment movement schematically in response to the variations of sediment characteristics with distance (given in Fig. 21). Generally, sediments move eastward and westward from the central part of Murozumi beach, which is fully exposed to the stormy waves. In the vicinity of Tonaka Fishery Harbour, the sheltering effect of Minasejima island on the incoming waves are so obvious that complex superposition between diffracted and reflected waves (from the breakwaters) would govern the directions of beach sediment movement. Therefore, the direction of sediment transport changes locally and temporally. The data on which sediment sampling was made would inevitably affects the conclusion. Stormy waves generated by typhoons in summer or autumn often arrive from south or southwest direction and would be capable of moving the sediments westward. On the contrary, large westerly waves would cause a progressive shift of beach sediments eastward.

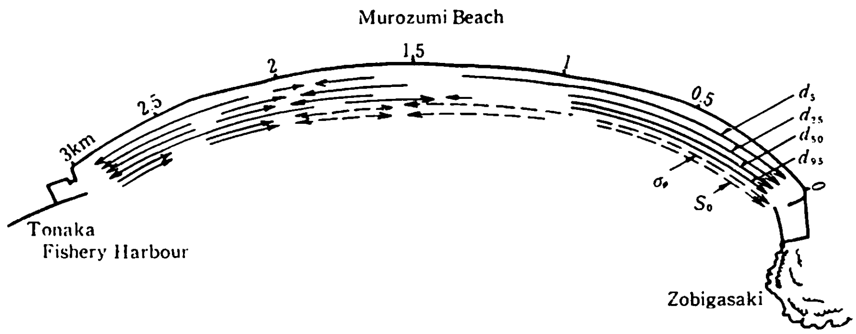
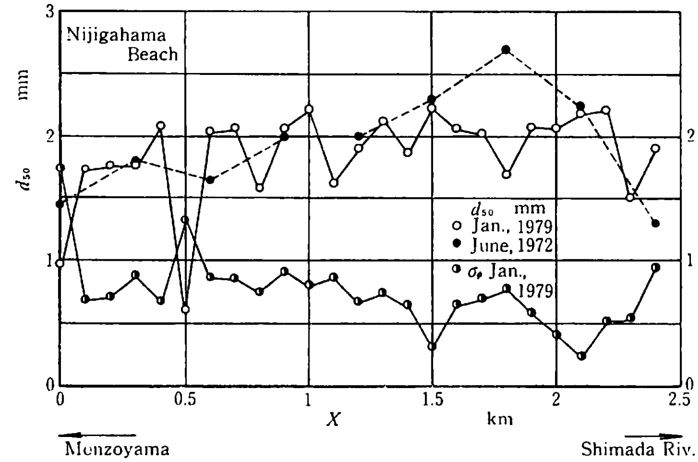


Fig. 21 Schematic diagram of directions of longshore sediment transport.
(——; Clearly estimated direction of sediment movement, ----; Somewhat doubtful, but possible direction of sediment movement)

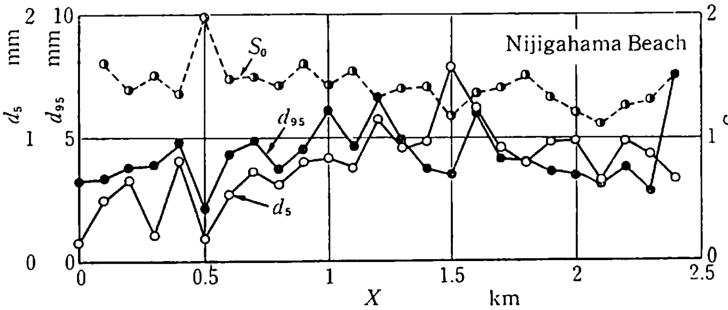
3.2.2 *Characteristics of sediments at Nijigahama beach*

After the reclamation, the river sediments have continuously accumulated at the west side of the river mouth. At the east side, dredging of sediments have frequently been carried out to maintain cargo handling at Hikari Harbour. With the development of river delta, accretion results in the vicinity of the river mouth, hence, the shoreline of Nijigahama beach at this region has consistently advanced seawards.

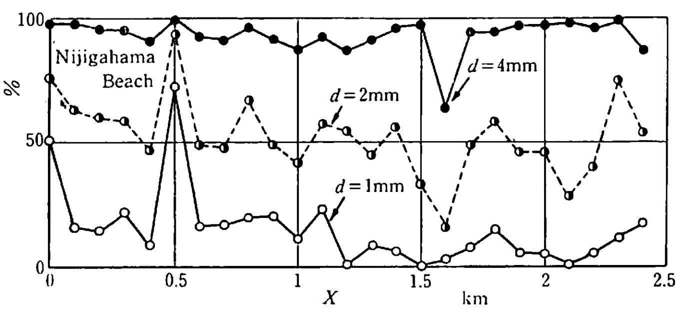
Fig. 22 (a) shows the longshore changes of median diameter and standard deviation at Nijigahama beach. In this figure, the information on median diameters obtained in June, 1972 is sufficient in justifying a general discussion. It was found that the westward sediment movement can be accounted for the decrease in sediment size to the west end of this beach, namely Monzoyama headland. This tendency has been confirmed by the data obtained in January, 1979. Neighbouring to the river mouth, this tendency is not very clear. This may well be attributed to the sheltering effect of Minasejima island on the incoming waves, as well as to the interaction of flood discharge from the Shimada river with currents alongshore. A longshore change of d_5, d_{95} and S_0 with distance measured from Monzoyama headland is given in Fig. 22 (b), showing various peak positions for these diameters. This might have been resulted from the longshore selective sorting in accordance with the variations of characteristics of waves and currents. The information revealed in Fig. 22 (c) can also be helpful to identify the tendency of characteristics of sediment movement. Upon comparing with the central part of Murozumi beach, the east end of Nijigahama beach has seldom been exposed directly to the southern stormy waves from typhoons due to the existence of Minasejima island. The sorting process of sediments is thus not completely developed in the vicinity of the Shimada river.



(a) Median diameter d_{50} and standard deviation σ_ϕ



(b) d_5, d_{95} and sorting coefficient S_0



(c) Percent of sediments less 1 mm, 2 mm or 4 mm in diameter

Fig. 22 Longshore distribution of sediment size statistics at Nijigahama beach.

4. PREDICTION OF BEACH CHANGES

As a matter of fact, the position of shoreline often fluctuates in response to the ever changeable wave actions and likely pressure from human populations in the hinterland. Tsuchiya [5] has cited this potential conflict from a view point of the time history in developing a community. Allowing the Nature to work on a beach alone without man-made interferences, it would have taken decades or even a geological time scale in reaching a permanent stable beach. In fact, this state of final equilibrium has existed ubiquitously long before the human settlement along a coastal plain and particularly near an estuary.

As the progress of human activities has later extended to the mountainous catchment area of mild-slope as well as further out into the sea from the beach, there developments have affected the quantity of sediment supply to the beach and also interrupt the natural course of sediment movement. Unfortunately, these 'aggressive' activities have often accomplished without fuller consideration of their consequential influence nor producing any appropriate preventive countermeasures to the downcoast, thus causing beach erosion problems of all degrees.

As illustrated in Fig. 23, beach changes consist both of long-term change and short-term variations, including seasonal changes. The former presents the trend of annual change of beach erosion or accretion over years or decades. However, in most cases the beach concerned does not always show clear tendencies in a short period of time, even in a state of temporally dynamic equilibrium. On the contrary, the frequency of abnormal changes may substantiate the trend of beach change. Hence, each of the abnormal changes, resulted from an abrupt work of stormy waves in severe typhoon etc., has certain characteristics to match with the long-term beach change. Nevertheless, the seasonal or abnormal change should not be envisaged as a permanent form, as they fluctuate tremendously.

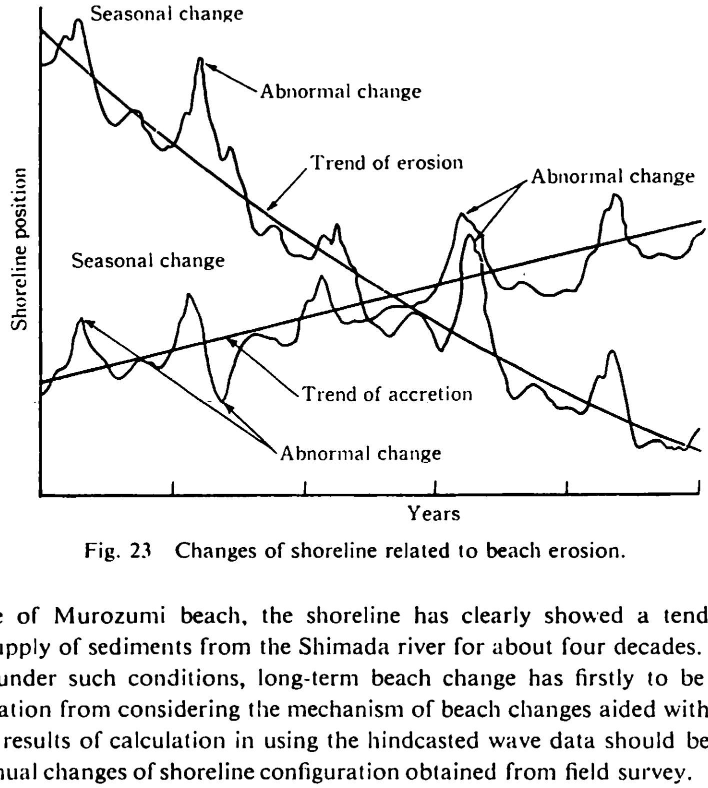


Fig. 23 Changes of shoreline related to beach erosion.

In the case of Murozumi beach, the shoreline has clearly showed a tendency of retreat because of no supply of sediments from the Shimada river for about four decades. To predict the beach changes under such conditions, long-term beach change has firstly to be investigated by numerical simulation from considering the mechanism of beach changes aided with the bathymetry available. The results of calculation in using the hindcasted wave data should be compared with the averaged annual changes of shoreline configuration obtained from field survey. Through above discussion, the general process of beach erosion after reclamation can be made clear. Secondly, variations of beach changes are obtained from the study of hourly change of longshore wave energy flux and its deviation. The convergence of wave rays due to wave refraction and the directional change of longshore wave energy flux are also discussed to clarify the process of beach erosion.

4.1 Outline of Mechanism of Beach Change

The basic governing equations to beach changes are the continuity equation of sediments and

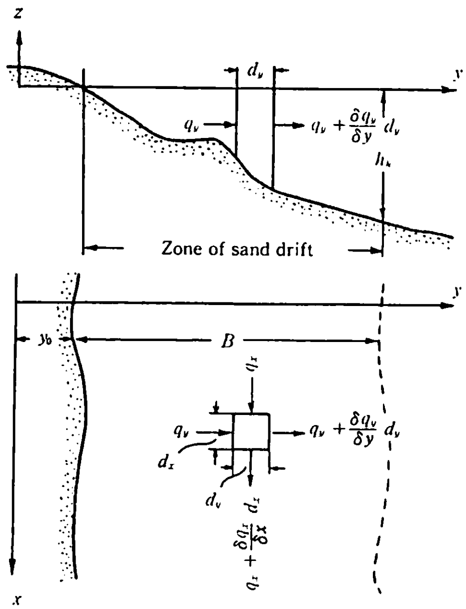


Fig. 24 Co-ordinate system used for predicting shoreline changes [6].

appropriate formulations of sediment transport. To make clear the mechanism of beach change, analytical methods have been attempted to solve these equations together with a set of initial and boundary conditions. An outline of this approach (by Iwagaki [6]) is briefly given in this section. Using the co-ordinate systems shown in Fig. 24, the continuity equation of beach change in both the x- and y- directions, for a small column element, is given as

$$\frac{\partial h}{\partial t}-\frac{1}{(1-\lambda)}\left(\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}\right)=0 \tag{8}$$

in which h is the water depth, q_x and q_y the rates of sediment transport per unit width in the longshore and offshore directions respectively, t the time and λ the correction factor for the pore space of beach sediment (approximately 0.4 for most beach deposits). In general, the onshore and offshore sediment transport associated with changes of beach profile is important. If long-term beach changes only are considered, as might be resulted from the local variation of longshore sediment transport, the seasonal beach change might then be neglected thus $q_y=0$. Integrating Eq. (8) with respect to y and introducing variables B, the width of littoral zone, and h_k the water depth at the offshore limit of this zone, a basic equation of beach change was firstly obtained by Iwagaki for the one-dimensional model, and modified by Tsuchiya [7] as,

$$\frac{h_k}{B}\frac{\partial y_0}{\partial t}=\frac{\partial \bar{h}}{\partial t}-\frac{h_k}{B}\left(1-\frac{\bar{h}}{h_k}\right)\frac{\partial B}{\partial t}-\frac{1}{(1-\lambda)B}\frac{\partial Q_x}{\partial x}+\frac{1}{B^2}Q_R(t)\delta(x-x_0) \tag{9}$$

in which $\bar{h}$ is the mean water depth over the littoral zone, Q_x the total rate of longshore sediment transport, and $\delta(x-x_0)$ the delta function defined by Dirac for sediment source from a river or cliff erosion at $x=x_0$. Eq. (9) states explicitly that there exist four factors in considering beach changes, these being, 1) Change of beach profile in terms of $\partial\bar{h}/\partial t$, 2) Time variation of the width of littoral zone B, 3) Non-uniformity of the rate of longshore sediment transport $\partial Q_x/\partial x$, and 4) Change of the sediment source from a river in terms of $Q_R(t)\delta(x-x_0)$. In the case of long-term beach change it may be adequate for practical purposes to consider only the third and the fourth items.

Under the assumption that the rate of longshore sediment transport is directly proportional to the longshore component of wave energy flux, Q_x may be given as,

$$Q_x = K(Ec_g)_b \sin 2\alpha_b = KP_l \tag{10}$$

in which $(Ec_g)_b$ is the wave energy flux evaluated at the breaking point, α_b the incident angle of breaking wave measured between its crest and the shoreline, and K a dimensionless empirical coefficient which is evaluated as 0.11 (m-sec unit) by Komar [8].

Therefore, when beach changes (or, more specifically to shoreline position) are examined based on these equations, it is possible to derive a mathematical solution under the general expressions of $\bar{h}$, h_k and B, which might be given as functions of wave parameters and sediment characteristics. However, even with the simplest boundary conditions, it renders a very complex partial differential equation whose solution is very difficult to be obtained except by numerical method using a computer. Fortunately, under long-term wave statistics and without river sediment source, Eq. (9) implies that the rate of shoreline change is simply related to the sediment transport alongshore. Fig. 25 illustrates schematically the mechanism of long-term beach change by Iwagaki [6]. For a positive $\partial Q_x/\partial x$, the quantity of sand being transported increases in the longshore direction (the x-direction), thus rendering $\partial y_0/\partial t$ negative. This simple relation infers that the shoreline must be retreated. On the contrary, if $\partial Q_x/\partial x$ is negative, then $\partial y_0/\partial t$ becomes positive thus suggesting an advanced shoreline.

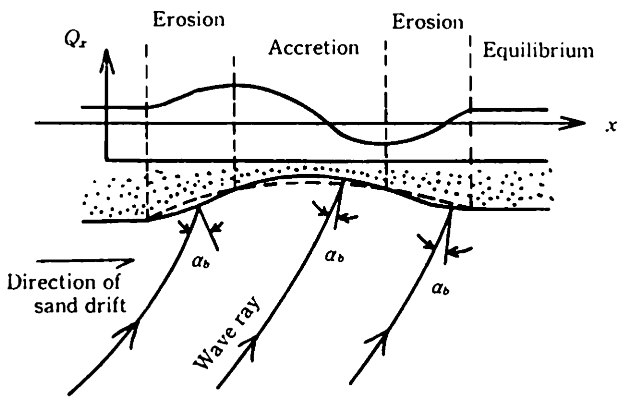


Fig. 25 Schematic diagram of beach changes [6].

In the case of Murozumi beach, there has been no additional sediments being supplied to the beach since the reclamation in 1939 in the vicinity of the Shimada river mouth and elsewhere. Moreover, it is reasonable that the long-term (in this case about 10 years) characteristics of wave conditions, as shown in Fig. 11 previously, has not changed drasticaly but constantly remained. Using the hindcasted wave data, the numerical approach is capable of predicting the long-term beach change. However, some localized coastal disasters, such as erosion of beach ridge and overtopping, should receive further attention as wave energy might have concentrated at these positions due to wave refraction or even from reflection. Unfortunately, the one-dimensional model currently used can not handle this localized problem with success.

4.2 Long-Term Beach Change

Studies undertaken to predict long-term beach change at Murozumi beach involved investigations at two stages as follows.

Stage 1: Study of long-term beach change before relcamation, utilizing historical maps and sounding charts, dating back to September, 1929.

Stage II: Analysis of long-term beach change after reclamation. The sea bottom topography of depth less than 15 m was drawn from depth sounding charts made in November, 1977. Region deeper than 15 m is assumed the same as in Stage I, because the critical water depth ($h_k = 8$ m) off this beach is smaller than this boundary depth (at 15 m).

Longshore wave energy flux computed from the hindcasted wave data is available to predict the long-term beach change. The averaged annual wave energy flux for Stage II is shown in Fig. 26, in which the abscissa is the distance from Zobigasaki headland and the ordinate being the longshore wave energy flux A averaged over 200 m seaward from the shoreline (4 meshes) and its derivative B with respect to x. Positive value of longshore wave energy flux (P_l in Eq. (10)) indicates westward direction (see Fig. 1 for location of this coast). It is found that the longshore wave energy flux changes sign at the point $x = 500$ to 600 m from the east end and gradually increases its magnitude till reaching a maximum at $x = 2.5$ km. At the very west end near Tonaka Fishery Harbour, accuracy in calculating P_l, the longshore wave energy flux $(Ec_g)_b \sin 2\alpha_b$, is doubtful due to the sudden changes of depth contours and complex boundaries from breakwaters

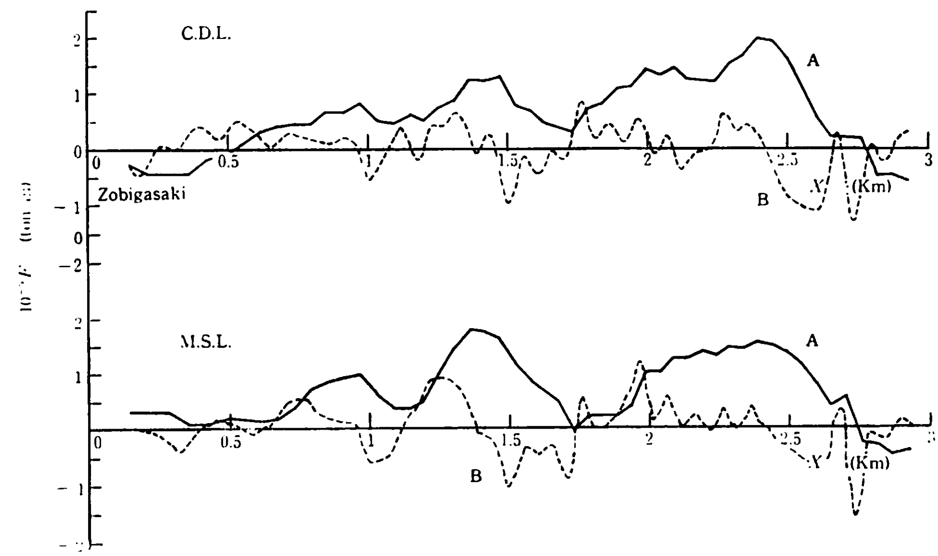


Fig. 26 Averaged annual longshore wave energy flux after reclamation (Stage II).

and harbour lay out. Moreover, Fig. 27 depicts the averaged annual longshore wave evergy flux in each predominant wave direction as determined in 3. It is observable that the longshore wave energy flux associated with the southerly stormy waves generated by typhoon is much larger than that from any other directions. Therefore, the distribution pattern of the total longshore wave energy flux is overwhelmingly governed by the former. Nevertheless, the adverse influences of waves approaching from the W or WSW directions on the total longshore wave energy flux should also be noted for region in the vicinity of Zobigasaki headland. Westerly waves can pass through narrow strait between Minasejima island and the mainland, and finally arrive at the eastern part of Murozumi beach directly. Waves from the WSW direction which may be generated in winter (monsoon) or summer (typhoon) would reach the east coast outside the shadow zone of Minasejima island. Inspecting the distribution characteristics of longshore wave energy flux presented has revealed the following facts. Firstly, in the vicinity of Zobigasaki headland, longshore wave energy flux progressively increases eastwards, thus resulting in a tendency of sediment accumulation on its foot. On the other hand, the sign change (or direction) of longshore wave energy flux at the point $x = 500$ to 600 m from the headland may cause severe beach erosion. In fact, at region

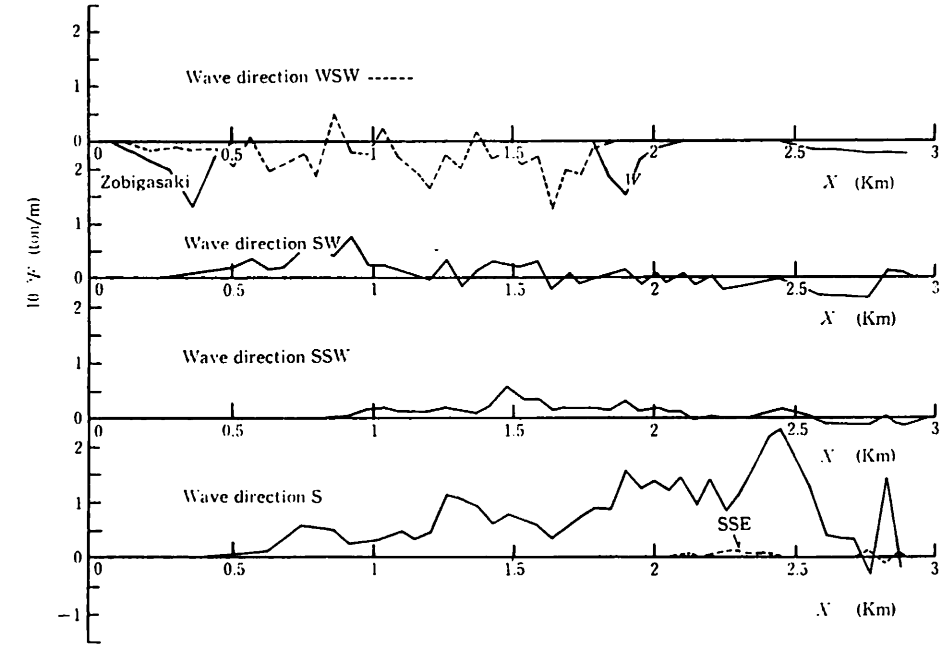


Fig. 27 Contributions of longshore wave energy flux in each predominant wave direction to the total one.

for x between 500 m and 1.5 km the trend of erosion has already been found. At further west for x greater than 1.5 km accretion and erosion have occurred alternatively. It is found that these qualitative characteristics coincide with the observed pattern of long-term retreat and advance of the shoreline.

The longshore wave energy flux for Stage I (before reclamation) is presented in Fig. 28, showing zero value at both ends of Murozumi beach. At that time, sediment from the Shimada river could be supplied to Murozumi beach. This is equivalent to the case in which no net sediment transport across these boundaries in the long-term, a case of dynamic balance. Furthermore, in comparison with Fig. 26, absolute value of longshore wave energy flux and its variation are so small throughout the beach that it had generally been accumulative before reclamation. In 1927, there was a cusp-shaped shoreline growing seaward in the protected lee of Minasejima island as a tombolo. The

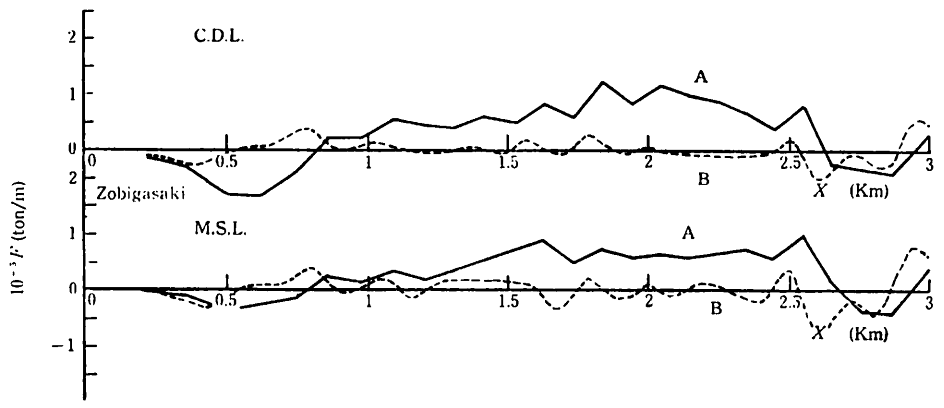


Fig. 28 Averaged annual longshore wave energy flux before relcamation (Stage I).

prevailing drifts near the river mouth were from east to west in typhoon and reversed in winter. In accordance with the wave directions, sediments from the Shimada river were conveyed to the Murozumi beach along the tombolo in winter and carried back to the peak of tombolo as longshore sediment transport. Through this reversible process, the tombolo had developed and maintained till reclamation began. From the view point of long-term beach processes, it may be concluded that Murozumi beach was more stable in the early 1930's than that at the present time, though the tendency of shoreline retreat had existed at the region for x between 0.4 and 1.5 km from Zobigasaki headland. This also qualitatively confirms the results from the analysis of geological survey as shown in Fig. 5, and the westward direction of longshore wave energy flux in the vicinity of Tonaka Fishery Harbour justifies the development of a tombolo because it corresponds to the progressive advance of shoreline.

Fig. 29 compares the results of numerical simulation based on the one-dimensional model with the averaged annual shoreline changes observed, with broken lines representing the moving averaged value over every 200 m consecutively alongshore. To simplify the numerical simulation, it is assumed that there is no sediment transport across both headlands. It is found that the long-term beach change can fairly be predicted by the one-dimensional numerical model, even if the method is restricted to a single-sloped beach profile to be independent with time and prohibits the sediment supply from outer regions. In Stage I, sediment supply from the Shimada river had existed long before reclamation and depth contour lines are believed to have roughly been drawn,

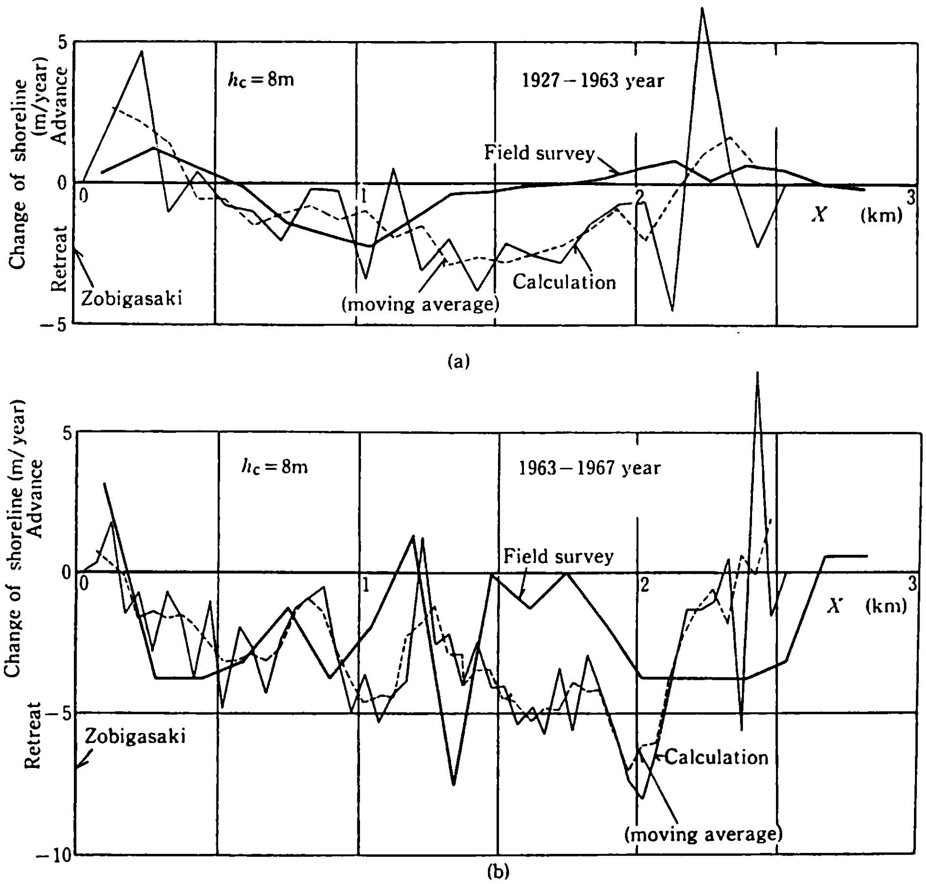


Fig. 29 Comparison on shoreline changes between results of numerical simulation and field survey.

therefore, the discrepancy between the results of field survey and that from numerical simulation is noticeable to some extent.

It may be also concluded that the current approach, with one-dimensional models, can make clear reasonably and reliably the long-term beach change at Murozumi beach. Since the natural sediment transport system, river sediment supply from the river mouth to downcoast without any obstacles, has been interrupted by the constructions of breakwaters in accompany with reclamation, the beach erosion has occurred at downcoast except behind the shadow region of Minasejima island, the western part of Murozumi beach. Recently, the rate of shoreline retreat has accelerated at an eastern part ($x=0.5$ to 0.7 km from Zobigasaki headland) and the west at $x=2$ to 2.5 km. This tendency is due to no sediment supply from the Shimada river plus large longshore wave energy flux and its variation after reclamation.

Generally speaking, the process of beach erosion occurs through the following two steps. Firstly, beach slope becomes steeper due to a decrease of onshore sediment transport and secondly shoreline retreats rapidly from a direct attack of stormy waves obliquely on beaches. Meanwhile, increases of longshore sediment transport rate would promote further denudation beyond that have been created by the process just mentioned. From this point of view, it seems that shoreline retreat between 1 to 2 km distance from Zobigasaki headland has been developed by the increase of longshore sediment transport, as the beach slopes are relatively mild and essentially constant. And, at the far west end offshore sediment transport becomes active besides the tranpsort alongshore. In spite of not accurately knowing sediment loss from the beach, yet the process of beach erosion may still be described within a satisfactory extent. In other words, as the west end (in the vicinity of Tonaka Fishery Harbour) was located at the foot of a tombolo before the reclamation, thus the beach slope would inevitably be steeper as compared with other regions of the beach as shown in Fig. 29. In addition, large areas of relatively deep water stretch out offshore from Minasejima island. Therefore, sediment transported along the beach is likely to be carried out to deeper waters by offshore sediment transport. This process seems to be substantial for the beach erosion at Murozumi beach. Consequently, as the beach erosion advances at a coast due to interception of downdrift sediment movement from the river, the beach slope gradually become steep. Through these processes, the wave rays tend to concentrate on some particular region and shoreline retreat is further accerelated.

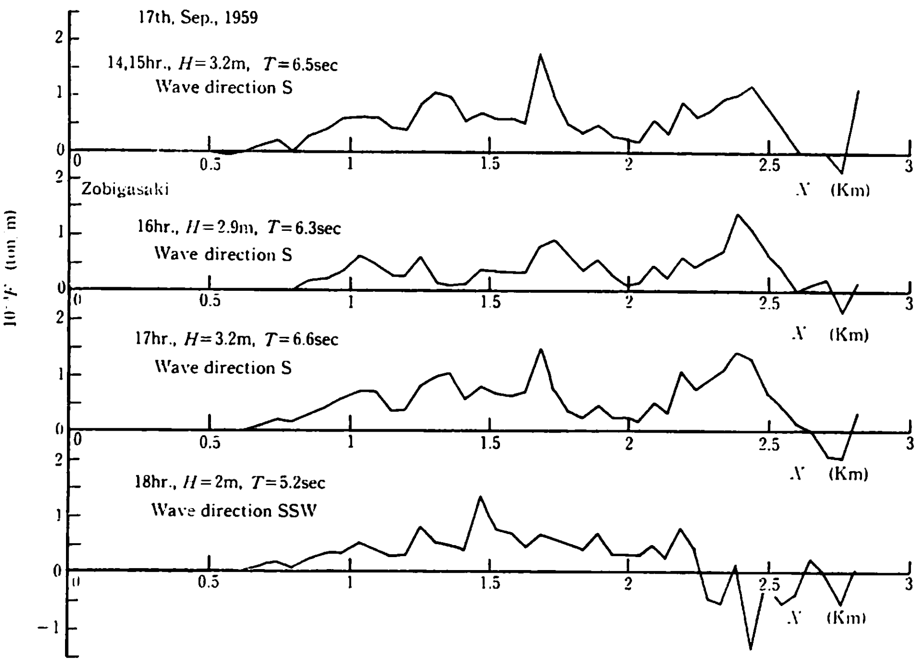
4.3 Variations of Beach Changes

As already discussed, predominant directions of stormy waves attacking Murozumi beach are generally S and WSW. The former corresponds to waves associated with typhoons and the latter from monsoons in winter and abnormal atmospheric depression so called "Taiwan bōzu" plus typhoons. In the case of typhoon, wind directions depend on its course, hence the absolute value of longshore wave energy flux and its direction inevitably change with time. On the other hand, the direction of high waves in accompany with northwestern monsoons in winter reasonably remains unchanged, regardless of the time.

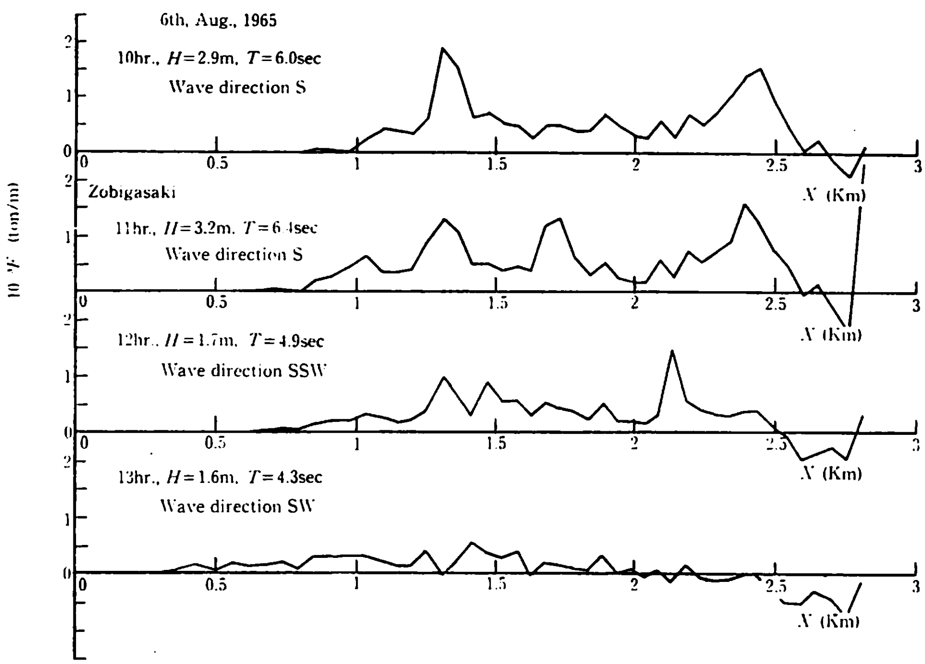
Sediment movements vigorously occur when longshore currents suddenly change direction or rapidly increase their strength. Consequently the budget of beach sediments are stirred up because in most cases the system of sediment transport is not reversible. Moreover, the average width of Murozumi beach at the present is less than 10 m on high tide due to the worsening of beach erosion after reclamation. Therefore, other coastal disasters such as beach ridge erosion and wave overtopping have frequently occurred as resulted from the convergence of refracted wave rays. Of course, the long-term beach change is an integrated sum of short-term variations over some decades of time. Following a fuller demonstration on the hourly changes of longshore wave energy flux associated with the typhoon, monsoon and abnormal atmospheric depression, short-term beach changes will be discussed.

4.3.1 *Variation of longshore wave energy flux*

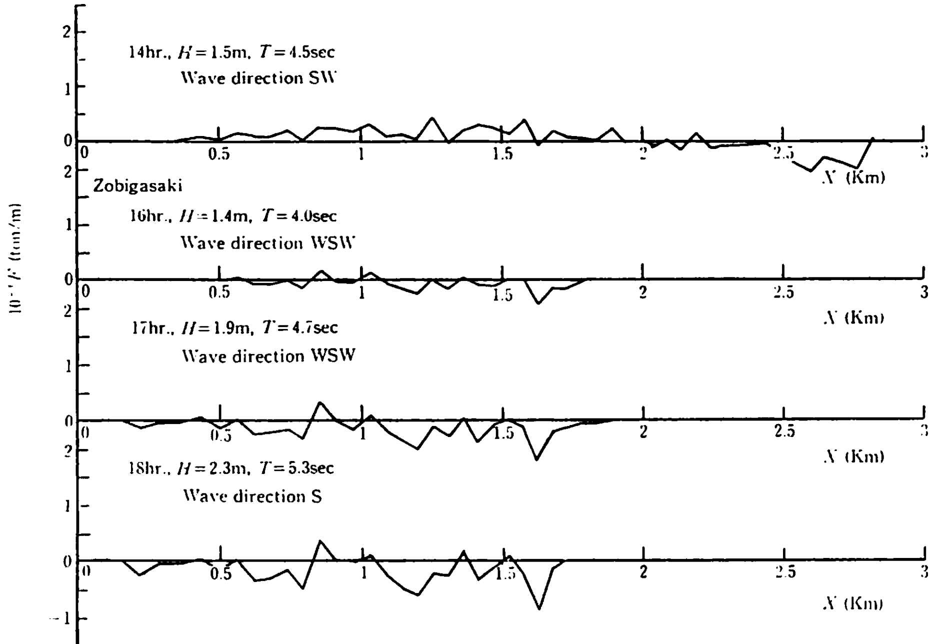
Fig. 30 (a) shows the hourly changes of longshore wave energy flux associated with Typhoon



(a) Typhoon 5914

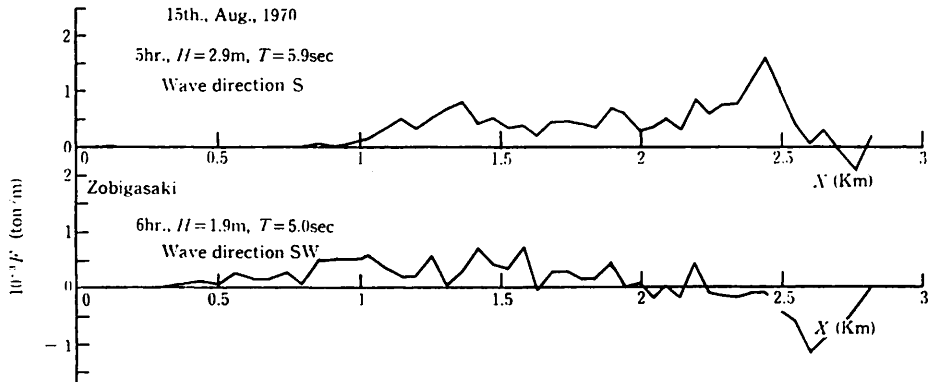


(b-1)



(b-2)

(b) Typhoon 6515



(c) Typhoon 7009

Fig. 30 The hourly changes of longshore wave energy flux associated with typhoons.

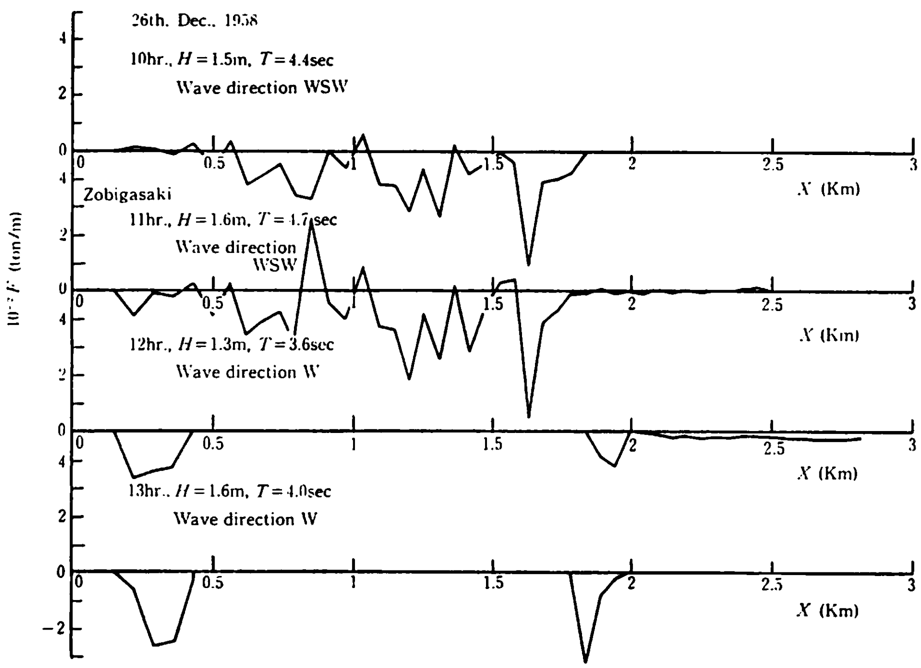
5914, generated by incoming waves within four consecutive hours from 14: 00 to 18: 00 on the 17th September, 1959. As stated previously in Fig. 14, this typhoon moved northwards from the west off Nagasaki Prefecture in Kyushu island, through Tsushima strait to the Japan Sea. In accordance with the typhoon course, a wide fan of wind directions was observed at Murozumi, from SE to S and finally W. Attempts in classifying the hourly variation of wave energy flux arriving at this coast have startlingly revealed the interesting behavior of beach. Firstly waves coming from the SE and SSE directions were all trapped by Minasejima island, thus, failing to reach Murozumi beach. At 14: 00, waves intruding from S generated the westerly energy flux with two positive peaks located respectively at the point of about 1.7 and 2.4 km from Zobigasaki headland. Meanwhile, the value of energy flux decreased to zero at the both ends. This may imply that there was no longshore sediment transport across these boundaries. This distribution pattern of longshore energy flux had continued for 3 hours. The waves directed from SSW at 18: 00, and in turn, longshore currents were resulted for between $x=2.3$ km west from Zobigasaki and the west end of it. Finally at 19: 00, the wave direction shifted to SW. Since both the wave height and period became smaller at this stage and hereafter, the absolute value of longshore wave energy flux rendered insignificant.

A similar kind of investigation is applied to Typhoon 6515 as depicted in Fig. 30 (b). This typhoon landed in the vicinity of Kumamoto City located in Kyushu island and again to Yamaguchi Prefecture after passing the Suonada Sea, Seto Inland sea. As its path was so close to Murozumi beach (see Fig. 14) that highly disastrous waves had attacked the beach. Waves with changeable directions had produced a series of fluctuating longshore effects and was similar to that of Typhoon 5914. Just before leaving Murozumi beach at 17: 00 on 6th August, 1965, the direction of waves altered from S to WSW. Easterly wave energy flux (negative sign) might be observed within beach from Zobigasaki headland, to $x=1.7$ km westward. Although waves from the WSW direction had lasted at least for two hours (from 16: 00), but as the duration time available in this direction was too short to generate large waves, thus, yielding only relatively small longshore energy flux.

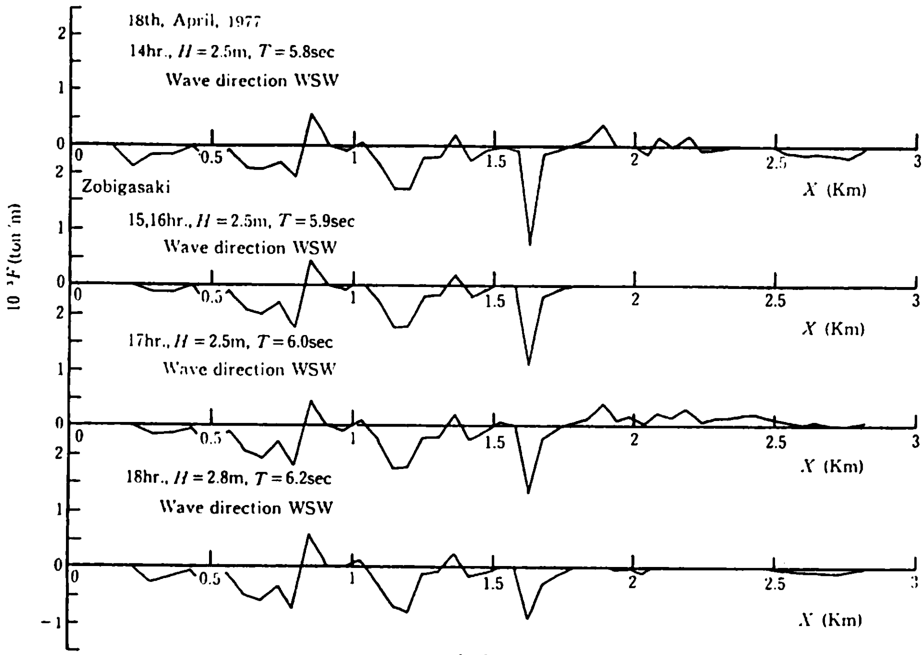
In spite of the small values resulted, this phenomenon can be regarded as a recovery process to the sediment transported.

Fig. 30 (c) presents the influences from Typhoon 7009. Although at 4: 00 on the 15th August, 1970, waves with 2.5 m hight and 5.1 sec period came from the SSE direction, the condition of sea surface off Murozumi beach was fairly calm as being sheltered behind Minasejima island. But at 5: 00 the wave direction changed to S, so high waves suddenly impinged upon Murozumi beach. About one hour later, the wave direction became SW and easterly longshore wave energy flux could be seen.

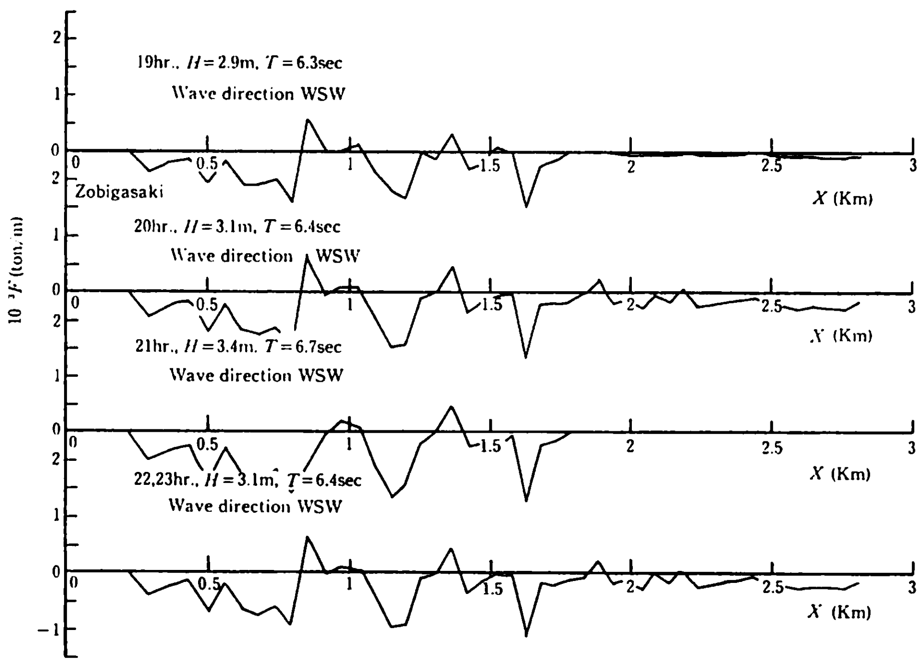
The hourly changes of longshore energy flux, as in Fig. 31 (a), indicate the generation, development and decay of waves associated with a storm in winter monsoon. Though the directions of waves changed slightly from the WSW to W, the distribution patterns of longshore energy flux were totally different from each other. As mentioned previously, westerly waves are often inter-



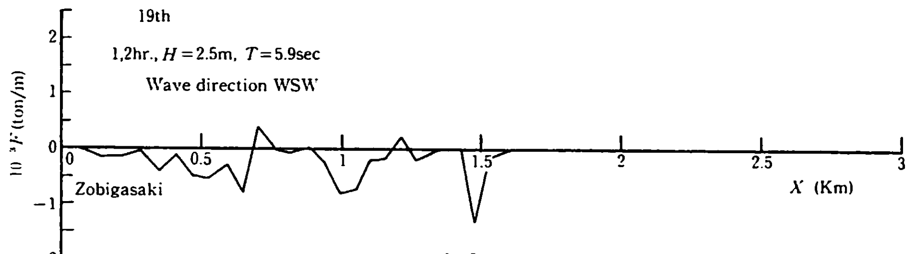
(a) Monsoon


18th, April, 1977
14hr., H = 2.5m, T = 5.8sec
Wave direction WSW
Zobigasaki
15,16hr., H = 2.5m, T = 5.9sec
Wave direction WSW
17hr., H = 2.5m, T = 6.0sec
Wave direction WSW
18hr., H = 2.8m, T = 6.2sec
Wave direction WSW
X (Km)
10⁻³F (ton/m)

(b-1)


19hr., H = 2.9m, T = 6.3sec
Wave direction WSW
Zobigasaki
20hr., H = 3.1m, T = 6.4sec
Wave direction WSW
21hr., H = 3.4m, T = 6.7sec
Wave direction WSW
22,23hr., H = 3.1m, T = 6.4sec
Wave direction WSW
X (Km)
10⁻³F (ton/m)

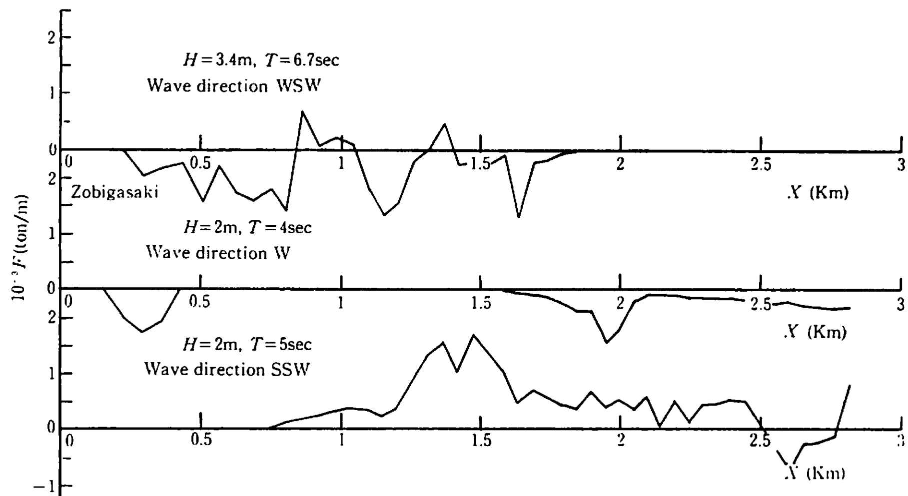
(b-2)



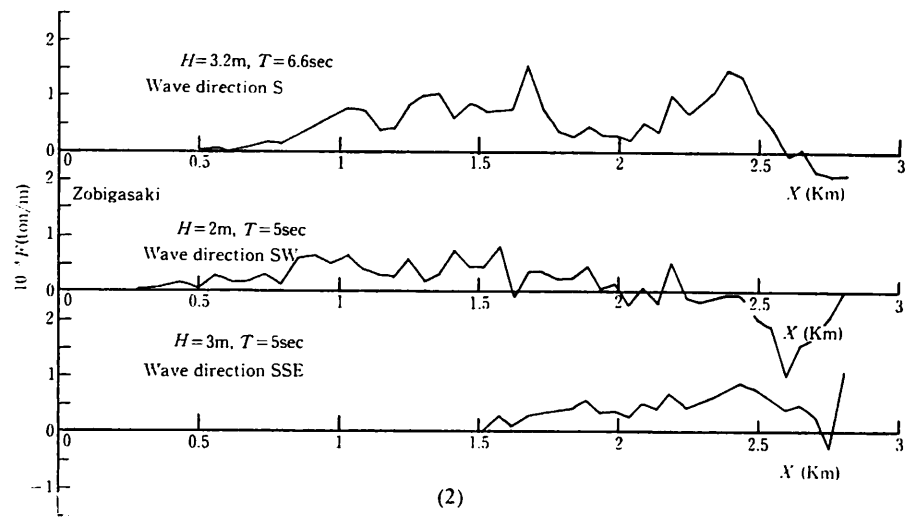
(b-3)

(b) Abnormal atmospheric depression

Fig. 31 Changes of longshore wave energy flux due to monsoon and abnormal atmospheric depression.



(1)



(2)

Fig. 32 Distributions of longshore wave energy flux derived from the likely maximum wave in each approaching direction.

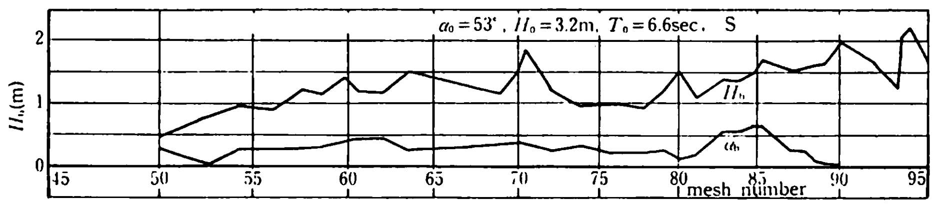
cepted by Minasejima island before arriving at Murozumi beach, except for the waves passing through the narrow strait between the island and the mainland. These waves generated the easterly longshore energy flux which carried sediment to Zobigasaki headland, showing also two sharp peaks of energy flux due to the convergence of wave rays at $x=0.8$ and 1.6 km from Zobigasaki headland.

When an abnormal atmospheric depression moved through the Japan Sea in spring, longshore wave energy flux associated with it is illustrated in Fig. 31 (b). High waves might continuously attack the beach for more than 12 hours, transporting a large amount of sediment eastward to and near Zobigasaki headland.

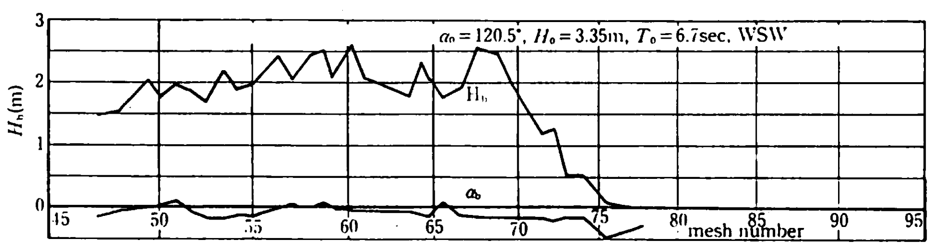
4.3.2 *Short-term beach variations*

Waves incoming from the S and WSW directions effectively dominate the rate of beach changes as can be inferred from the longshore distribution of wave energy flux in Fig. 32. In spite of their relatively lower frequency, stormy waves from the W, SSW and SW directions also influence the beach sands to some extent, particularly to the beach in the vicinity of Zobigasaki headland, at the central and the western parts of Murozumi beach respectively.

Due effect from the southern waves on beach change is firstly discussed. When a typhoon proceeds northeastwards near Murozumi beach, the wave direction associated with it shifts from SSE to S. As proposed early in Eq. (9), rapid changes of critical water depth with the time affect beach changes through the first and second terms on the right hand side of it. The tendency of change can not clearly be found for the beach within $x=1$ and 2 km west from Zobigasaki headland. But further west from it, longshore energy flux progressively increases till at 2.4 km. Examples on the convergence of wave rays (or the concentration of wave energy) can be observed from Fig. 33. Under these circumstances, offshore sediment transport becomes important because the beach slope near the west end is very steep in comparison with that at the eastern part. Thus, it is reasonable to interpret the loss of beach sediment from this process.



(a)



(b)

Fig. 33 Distributions of wave height and wave direction at breaking point along Murozumi beach.

Secondly, waves from the WSW direction cause eastward longshore energy flux near the region at $x=0.8$ km west from Zobigasaki headland. Therefore, sediment accumulation occurs herein due mainly to the waves from WSW, being independently justified by depth sounding. On the contrary, the shoreline near Zobigasaki has gradually been retarded, with a result that the distance between the foot of seawalls and the shoreline is about 5 m or less at high tide. As a matter of fact, a seawall can protect only its immediate hinterland but not the beach sand in front of it, because wave reflection from seawalls inevitably promotes offshore transport. Therefore, depth contour lines of less than 5 m have gradually stretched seawards. And, sediment movement around Zobigasaki headland tends to be one-way transport towards the relatively deeper sea bed with an uneven rocky bottom. The process in lossing sediments may well coincide with that at Shirarahama beach, a typical pocket beach [9]. Moreover, wave rays from the WSW direction converge at some particular points within the stretch of beach between 1 and 2 km west from Zobigasaki headland, thus easily eroding beach ridge by wave runup.

These results can also be confirmed from the analysis of sediment sorting alongshore (see Fig. 18). The directions with which sediment movement occurs within the stretch of Murozumi beach are given as follows.

(i) For beaches within 1 km distance from Tonaka Fisherly Harbour, westward sediment movement results from southern waves.

(ii) To the central region, the beach is influenced by waves from the S and WSW directions alternatively, being reversible in direction within the course of typhoon. Therefore, no net tendency can clearly be concluded in respect to sediment movement.

(iii) In the vicinity of Zobigasaki headland, waves from the WSW direction that generate the easterly energy flux govern the sediment movement.

Fig. 34 illustrates the longshore wave energy flux derived from waves in the S and WSW directions respectively during Stage I (before reclamation) as reported previously. The absolute value and its variation of energy flux were rather small in comparison with that in Stage II as depicted in Figs. 30 and 31. Thus, it can be concluded that Murozumi beach had reasonably been accumulative before reclamation. At that time, westward longshore energy flux can often be generated for the beach 1 to 2 km distance from Zobigasaki by not only waves from the S direction but also those from WSW. Under these situations, they contribute to the development of a tombolo near the mouth of the Shimada river.

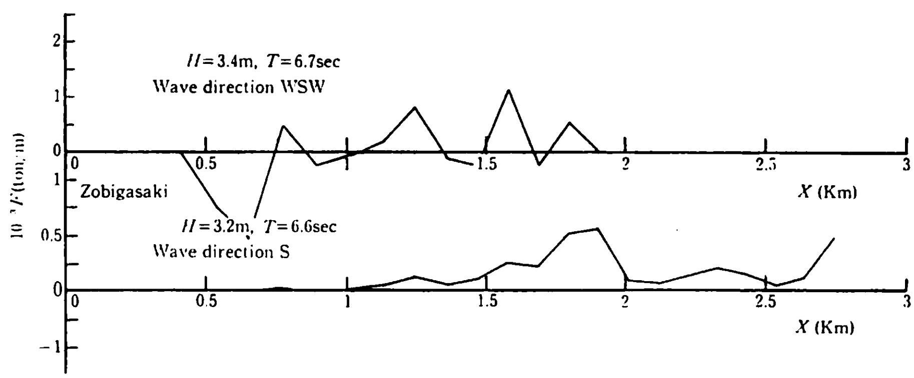


Fig. 34 Distributions of longshore wave energy flux derived from condition within Stage I.

The above discussions on beach changes at Murozumi beach, proven independently with field survey, are analytically promoted by assuming the rate of longshore sediment transport to be directly proportional to the longshore energy flux. It is believed that more complete investigations can be achieved if the rate of onshore and offshore sediment transport can be integrated with a simulation model of beach changes. However, the present approach, as it is so employed with the one-dimensional model has provided sufficiently reliable estimation for predicting beach changes at Murozumi beach.

5. CONCLUSIONS

As beach sediments originally from the river mouth move alongshore to an adjacent beach under oblique wave actions, the drift may be intercepted or forced to change its existing course by man-made structures, such as breakwaters and seawalls in accordance with reclamation. From the historical review, field survey, numerical simulation and discussions presented for Murozumi beach, the following conclusions are arrived.

1) Murozumi beach has shown a clear trend of beach erosion after reclamation in 1939. The approach, an one-dimensional simulation model currently used, can fairly interpret the long-term beach change at Murozumi beach. This is mainly due to the accuracy of wave data hindcasted with the wind record for about ten years. The results of calculation can be justified by field survey and sediment size statistics.

2) The process of beach change after reclamation is generally explained as follows. Owing to no supply of sediments from updrift coast, the shoreline recession has accelerated at some region in accompanying with the steepening of beach slope. Through this physical process, the tendency is amplified by the concentration of wave energy, in turn, resulting in irregular change of bottom topography. The repetitive nature of this sequence has inevitably occurred, thus promoting severe beach erosion.

Since the reclamation commenced operating, Murozumi beach has consequently demonstrated the very nature of a pocket beach, having no input of sediments. Recently, the rate of shoreline retreat is rapidly increased. Therefore, some appropriate management practices such as maintenance with protective control works and with artificial beach nourishment should be beneficial to the long-term usage of Murozumi beach.

ACKNOWLEDGEMENT

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