

CHAPTER 244

EROSION CONTROL BY CONSIDERING LARGE SCALE COASTAL BEHAVIOR

Yoshito Tsuchiya¹, M. ASCE, Takao Yamashita² and Tatsuhisa Izumi³

Abstract

Due to the construction of Naoetsu harbor, severe beach erosion has taken place on the Joetsu-Ogata coast facing the Japan Sea. To establish a principal methodology for beach stabilization, large scale coastal behavior first is investigated by constructing a long-term shoreline change model in which the representative monsoon wave is introduced. Comparison of hindcast and actual long-term shoreline change shows that the proposed model can predict long-term shoreline change. Shoreline change after the construction of Naoetsu harbor also was predicted under the condition that natural sandy beaches had been retained. Results show that shoreline retreat is severe near the harbor and extends to the central part of the coast. To determine the most suitable location for headlands to be used for stabilizing the coast, long-term shoreline changes were calculated under the condition that a headland is given at several locations. We conclude that in principle when the boundary condition for shoreline change by headland is given near the Shinbori River, a sandy beach tends to have stable large scale coastal behavior during long-term shoreline change. We propose a principal methodology for beach stabilization, part of which is being used in current construction.

INTRODUCTION

When planning erosion control works for sandy beaches, investigation of their coastal behavior from the long-term and large-scale view points is extremely important. Local and temporal measures alter sandy beaches, sometimes destroying them. This is what coastal engineers have learned from their experiences during the past several decades in Japan. Many attempts have been made to control beach erosion throughout the world, but in the long term none have succeeded in stabilizing sandy beaches that are being eroded. Almost all the common countermeasures are of little use for stabilization as they cause beach profiles

¹Professor Emeritus, Kyoto University & Professor, Meijo University, Tenpaku-ku, Nagoya 467, Japan

²Instructor, Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto 611, Japan

³Director, Niigata Port Construction Bureau, Niigata Prefecture, Niigata 950, Japan

gradually to become steep. This study treats beach erosion control on the Joetsu-Ogata coast, facing the Japan Sea, to show a principal methodology for sandy beach stabilization in which the large scale behavior of a sandy beach under continuous development is considered (Tsuchiya, Yamashita, Izumi and Tottori, 1993).

In 1967, the Disaster Prevention Research Institute, Kyoto University established a wave observatory on this coast for the investigation of the beach erosion mechanism and its control. A T-shaped observation pier that extends 260m offshore was constructed. The coast (shown in Figure 1) is a slightly concave sandy beach about 25 km long and is bounded by the Gotsu and Yoneyamazaki headlands respectively on its west and east ends. It has been an erosive beach since the construction of Naoetsu Harbor on the right side of the mouth of the Seki River in 1961. The history of the construction of coastal structures is shown briefly in the figure, and shoreline changes measured on aerial photographs also are shown. Severe beach erosion began

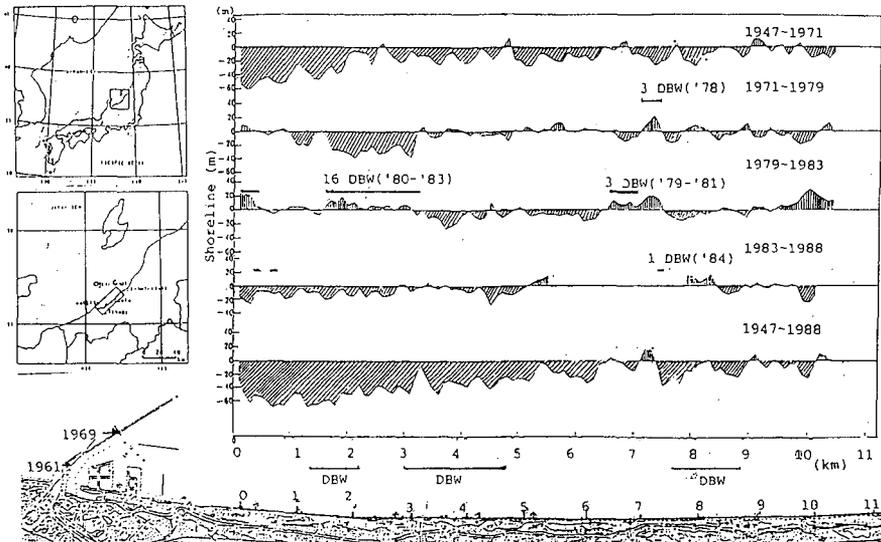


Figure 1. Location of the Joetsu-Ogata coast and the history of the construction of coastal structures in relation to shoreline change.

near the east end of the harbor due to the lack of longshore sediment transport and has propagated eastward in relation to the extension of the breakwaters in the harbor. The countermeasures taken have been sea dikes with armor blocks, offshore breakwaters and, recently, mild-slope revetments. Beach erosion has continued to take place, resulting in steep beach profiles, and little can be expected of these countermeasures in terms of beach stabilization.

The erosive process along this coast is investigated in terms of large scale coastal behavior. A long-term shoreline change prediction model is established by introducing the representative monsoon wave and qualifying the alongshore distribution of the longshore sediment transport rate. The hindcast result is compared with actual shoreline change from 1910 to 1961, before beach erosion took place. Calculations of wave and nearshore current fields are used to estimate the alongshore distribution of longshore sediment transport in relation to the extending breakwaters. The rates of longshore sediment transport are compared with those estimated from bottom topography changes. Numerical predictions of long-term shoreline change show the most suitable locations for the headlands to be constructed for beach

stabilization of large scale coastal behavior. Based on these findings, as well as on the theoretical background of the formation of stable sandy beaches, we propose a principal methodology for beach stabilization in relation to change in longshore sediment transport rates.

HINDCAST OF SHORELINE CHANGE BEFORE CONSTRUCTION OF NAOETSU HARBOR

Bottom topography for the computational domain

The oldest shoreline recorded by the Geographical Survey of Japan is shown in a topographical map issued in 1910. The biggest coastal structure in the area, at present, Naoetsu Harbor, was constructed in 1961. The coast, at least before 1961, probably behaved naturally, having had no artificial impact on it. Hindcasting the shoreline changes for the period 1910 to 1961 (before harbor construction), should provide important information about such natural external forces that act on long-term beach change as storm wave conditions and the magnitude of sediment input from rivers. The bottom topography for the computational domain was reproduced by connecting two maps, a marine chart and a topographical map issued in 1910, on the assumption that beach topography shallower than a 20m water depth can be replaced by the equilibrium beach profile proposed by Dean (1981);

$$h = Ay^{2/3} \quad (1)$$

where h is the water depth, y the distance taken offshore from the shoreline, and A the model constant which may be related to the beach sediment diameter. The bottom topography for the computational domain was obtained. The model constant varies alongshore. Nearly the same tendency for the alongshore distributions and maximum exists for both the model constant and sediment diameter near the observation pier.

The long-term shoreline change prediction model

(1) Shoreline change prediction model A one-line shoreline change prediction model can be used. An outline of the model we used (Yamashita, Tsuchiya, Matsuyama & Suzuki, 1990) is explained. The equation of continuity for shoreline change is given by

$$\frac{\partial y_0}{\partial t} + \frac{1}{(1-\lambda)} \frac{\partial Q_x}{\partial x} = \frac{Q_R(t)}{h_c B} \delta(x-x_0) \quad (2)$$

where y_0 is the shoreline change from the datum line, t the time, x the alongshore distance from the origin, h_c the critical depth for beach change, λ the porosity of beach sediment, Q_x the total rate of longshore sediment transport, B the width of the river mouth, and $Q_R(t)$ the sediment input from the river as the beach sediment source. Practically, the CERC formula for the total rate of longshore sediment transport can be used;

$$Q_x = \frac{a\rho g^2}{64\pi} H_0^2 T K_R^2 \sin 2\alpha_{BS} \quad (\text{m}^3/\text{yr}) \quad (3)$$

where H_0 is the deep water wave height, T the wave period, α_{BS} the breaker angle to the shoreline, K_R the refraction coefficient, ρ the density of water, g the gravitational acceleration, and $a = 1.26 \times 10^7$ an empirical constant that may be changeable in relation to sediment properties but is assumed to be constant in this

shoreline change prediction. Introduction of the geometrical relation in shoreline change and combing (3) and (2) yields

$$\left. \begin{aligned} \frac{\partial Q_x}{\partial t} &= \frac{\partial Q_x / \partial \alpha_{BS}}{(1 - \lambda) \{1 + (\partial y_0 / \partial x)^2\}} h_k \frac{\partial^2 Q_x}{\partial x^2} + A_R \\ A_R &= \frac{\partial}{\partial x} \left[\frac{Q_R(t)}{h_k B} \delta(x - x_0) \right] \end{aligned} \right\} \quad (4)$$

where α_{BD} is the breaker angle to the initial shoreline. This diffusion type equation can be solved under the given initial shoreline and boundary conditions by an implicit method to obtain the total rate of longshore sediment transport Q_x . By its use shoreline change can be obtained by solving (2). In practice, when boundary conditions are given at both ends where no longshore sediment transport exists, forward and backward differentials must be applied alternatively to solve this equation numerically.

(2) The representative waves and their transformation In long-term shoreline change prediction two methods have been used to estimate the most effective wave or the representative wave in shoreline change: a time series of waves to be obtained by long-term wave data, and a certain representative wave for shoreline change. In the second method, in practice the single representative wave is estimated by use of the annual total rate of wave power proportional to the longshore sediment transport rate which can be evaluated by long-term wave data. As the representative wave condition has been evaluated from the annual total rate of wave power under deep water wave conditions, relatively small waves have been estimated. It is questionable whether such waves actually cause shoreline change. In this paper, therefore, in relation to the monsoon wave sequences in the Japan Sea, we assume the representative waves shown in Table 1 where the 1st, 2nd and 3rd waves

Table 1. Representative waves proposed in relation to monsoon wave sequences and their properties.

Representative Waves	Wave Direction	Wave Period in sec	Wave Height in m
1st	NW5°W	6	2
2nd	NW	7	3
3rd	NW 10°N	8	2

respectively correspond to the monsoon wave sequences, generating and developing wind wave stages, and decaying swell stage.

At Naoetsu Harbor, wave observation has been carried out over a long period. From the collected data the annual averaged duration of waves higher than 2 m in terms of significant wave height was evaluated as 264 hr/yr. We assume that monsoon waves with a duration of 24 hr strike the coast 11 times a year. A representative monsoon wave is defined as a sequence of three successive representative waves each having a duration of 8 hr.

Using three representative waves, we could calculate their transformation. In the wave refraction diagrams shown in Figure 2(b) small black points indicate the breaking points. The breaker angles are so small that accurate calculation is needed to evaluate them. Figure 3 shows the alongshore distributions of breaker height and

and angle for the three representative waves, the dotted lines indicating smoothed breaker heights. Breaker height varies remarkably alongshore around the Gotsu headland, Naoetsu Harbor (the Seki River), and the Kakizaki River, in particular for the second representative wave. This is because of wave refraction by the local bottom topography. Note, however, that no remarkable alongshore variations

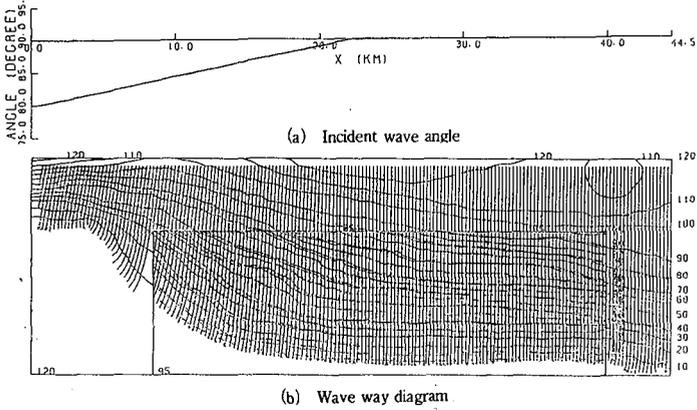
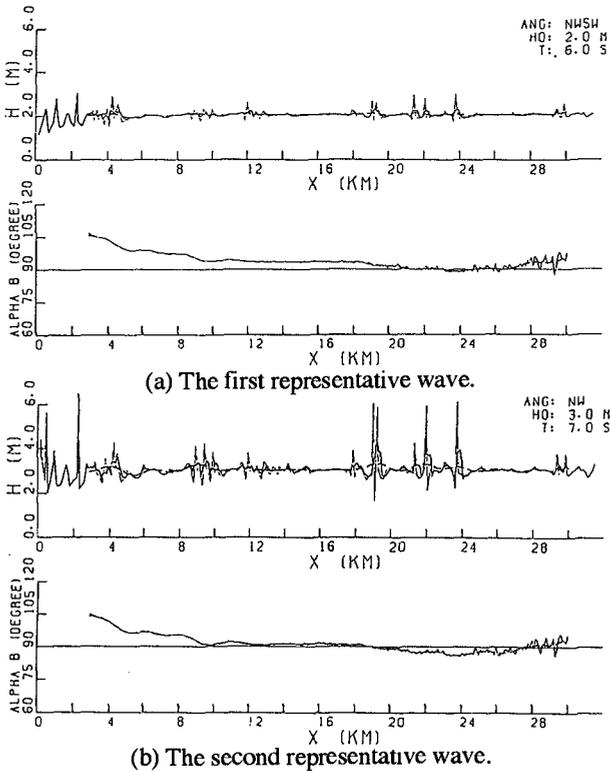
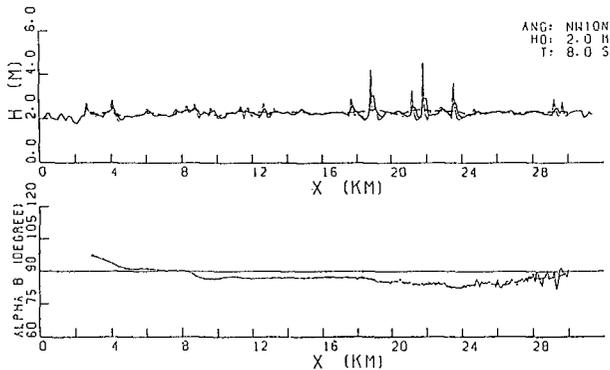


Figure 2. Wave ray diagrams and incident angle of the representative wave.





(c) The third representative wave.

Figure 3. Alongshore distributions of breaker height and angle for three representative waves.

take place, but there is a distinct change in breaker angle that is positive in the east direction west of the center of the coast but negative east of the center. This tendency is a direct reflection of longshore sediment transport along the coast, resulting in the formation of a coast bounded by the Gotsu and Yoneyamazaki headlands in relation to the sediment sources from the Seki and Kakizaki Rivers.

(3) The boundary conditions As stated earlier, the two main sediment sources are the Seki and Kakizaki rivers. The rates of sediment input from these rivers have been estimated, but it is not known what rate contributes to the sediment source. When sediment sources are given as point sources, a sharp river delta may develop which may not contribute to long-term shoreline change because the sediment input from the rivers is due to flooding in summer, whereas in the other seasons, sediment deposited near the rivers' mouths is transported by waves both as longshore and offshore sediment transport. In long-term shoreline prediction, the period of flooding that results in sediment input from the rivers actually is very short compared with shoreline evolution. Therefore we here have estimated the incident wave angle by changing the incident wave angle in deep water along the coast so that long-term shoreline changes could be calculated under the third representative wave condition, in which the wave height and wave period are 0.7 m and 8 sec, until we could successfully hindcast the actual shoreline on the Joetsu-Ogata coast. The final estimate of the incident wave angle is shown in Figure 2(a), the upper part showing the estimated incident wave angle and the lower part its wave ray diagram. As shown in Figure 1, an island (Sado Island) lies several tens of kilometers offshore. Waves are formed due to wave dispersion and diffraction by this island.

This may result in the change in the incident wave angle as discussed above. In the long-term shoreline change prediction, the boundary conditions are

1) At the Gotsu headland on a rocky shore, no longshore sediment transport is assumed to occur. Actually, a small sea cliff has supplied a small amount of sediment to the coast, but currently no sediment input is assumed.

2) At the Yoneyamazaki headland on a rocky shore bounded by small sandy beaches an offshore bottom topography composed of fine sand is assumed where there is longshore sediment transport.

3) As previously stated, the Seki and Kakizaki Rivers discharge at the coast, providing the sediment sources. Their annual sediment rates respectively are assumed to be 10,000 to 100,000 m³/yr and 5,000 m³/yr.

Based on these boundary conditions for shoreline change, long-term shoreline

change is hindcast in two steps:

- 1) First step: No sediment sources from the rivers are assumed. No longshore sediment transport is assumed at the Gotsu headland, but is assumed around the Yoneyamazaki headland.
- 2) Second step: The sediment sources from the rivers are added to the first step to evaluate the effect of the rivers on shoreline change.

Hindcast long-term shoreline change and the representative monsoon wave

The shoreline changes hindcast are compared with those measured in 1910 and 1961 when there was a natural sandy beach along the coast before construction of Naoetsu Harbor. On the basis of the results of this comparison we propose the representative monsoon wave for the long-term shoreline change prediction model.

(1) **In the case of the first step** Using three representative waves, we hindcast long-term shoreline changes for 51 years. Figures 4, 5 and 6 show the respective shoreline changes hindcast by the first, second and third representative waves, the changes being shown for intervals of 10 years. In these figures, the upper part shows the alongshore distribution of the longshore sediment transport rate, the direction of

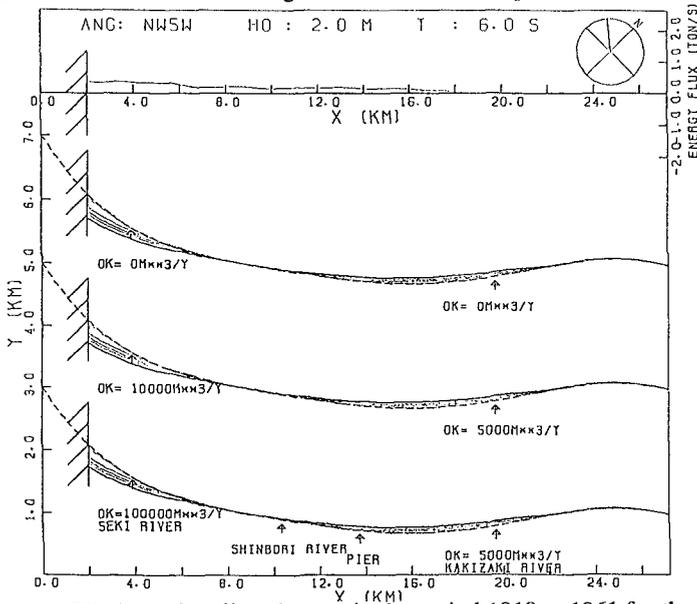


Figure 4. Hindcast shoreline changes in the period 1910 to 1961 for the first representative wave.

which is taken as positive in the easterly direction. The three respective lower parts indicate shoreline changes in the first and second steps, the sediment sources being given. In the cases of the first and second representative waves, the shoreline retreats near the Gotsu headland, whereas accretion takes place along the central part of the coast and little change occurs near the Yoneyamazaki headland. In contrast, in the case of the third representative wave, shoreline accretion takes place near the Gotsu headland and the central part of the shoreline due to westerly longshore sediment transport. Figure 7 shows the alongshore distributions of the longshore sediment

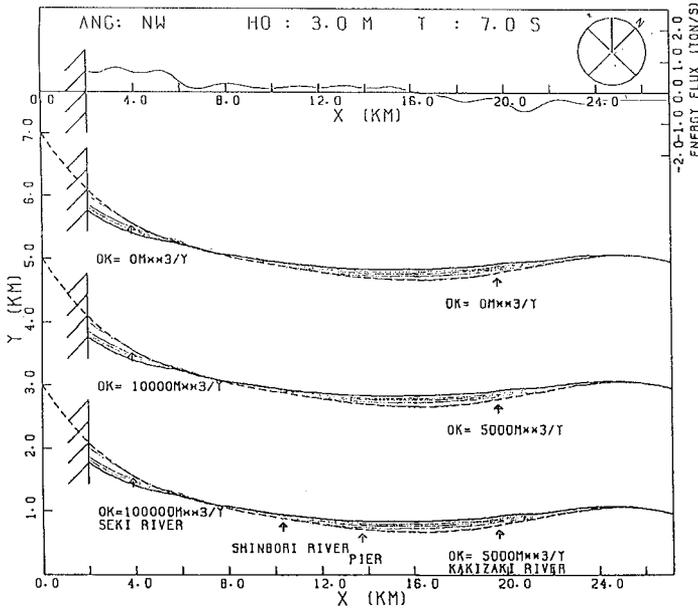


Figure 5. Hindcast shoreline changes in the period 1910 to 1961 for the second representative wave.

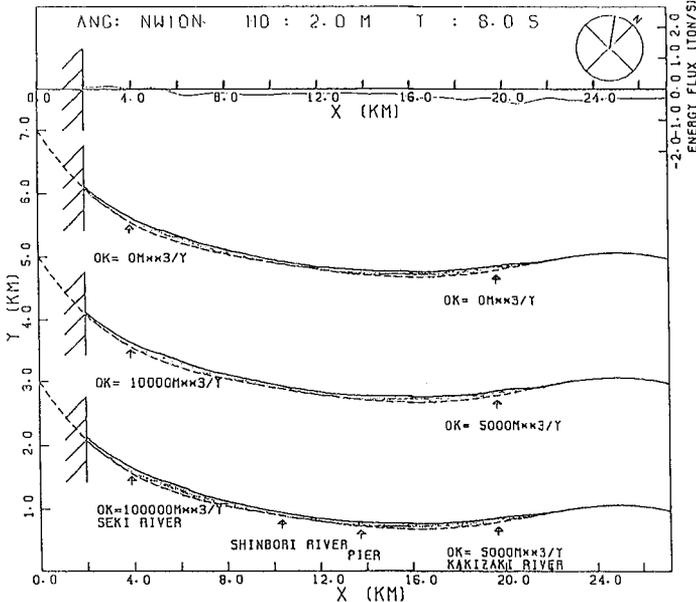


Figure 6. Hindcast shoreline changes in the period between 1910 to 1961 for the third representative wave.

transport rates for the initial shoreline condition and the three representative waves,

in which the dotted curve indicates the annual averaged rate of longshore sediment transport. This varies alongshore in relation to variations in breaker height (Figure 3), but shows the same tendency for alongshore distribution as the breaker angle shown in Figure 3. The first and second representative waves show the same tendency, but the third differs.

(2) In the case of the second step In Figures 4, 5 and 6, the shoreline changes predicted for the second step are shown. In these predictions, the sediment sources

are 1) 10,000 m³/yr and 5,000 m³/yr; 2) 100,000 m³/yr and 5,000 m³/yr. The sediment sources influence shoreline accretion in the central part of the coast and tend to decrease shoreline retreat near the Gotsu headland. For shoreline change, the alongshore changes in longshore sediment transport rate are given in Figure 7. This shows that the alongshore distributions change slightly near the river mouths, but here was remarkably little influence on shoreline changes by the sediment sources for period of about half a century.

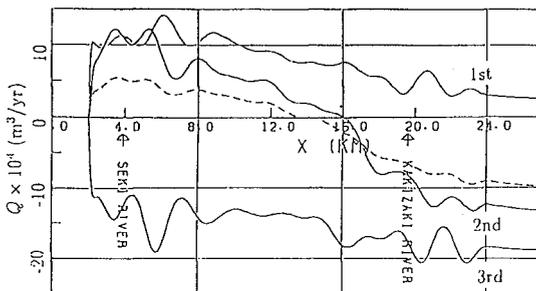
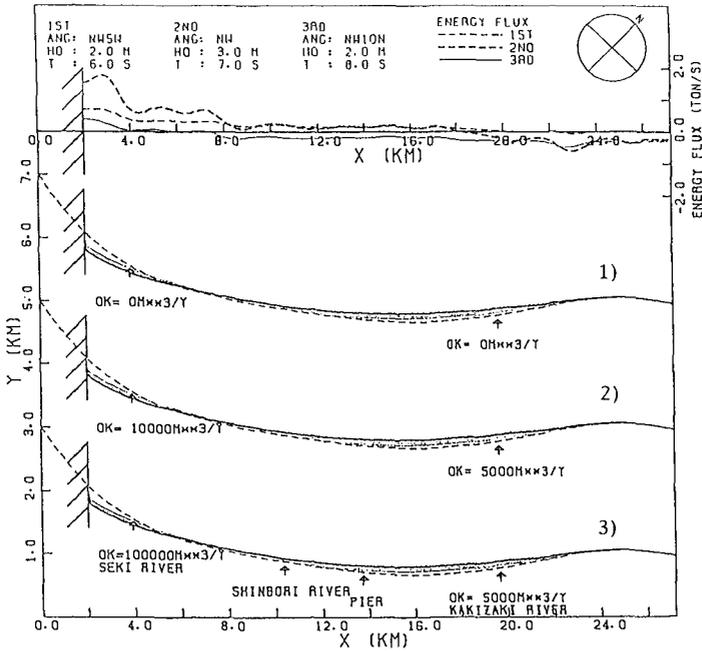


Figure 7. Alongshore distributions of longshore sediment transport rates for the three representative waves and the annual averaged one when the sediment sources are 100,000 m³/yr and 5,000 m³/yr.

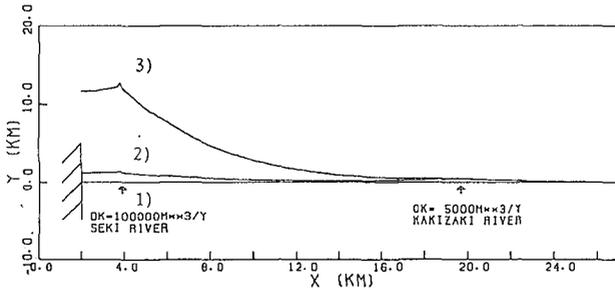
(3) The representative monsoon wave and predicted long-term shoreline change

As to the sequence of wind waves and swells generated by a monsoon, we have assumed that the representative monsoon wave is composed of first, second, and third representative waves each with a duration of 8 hours and that these repeat 11 times a year. Using the representative monsoon wave, we hindcast the change in the initial 1910 shoreline for 51 years, and compared it with the actual recorded shoreline change. In Figure 8 (a) the upper most part shows the alongshore distributions of the longshore sediment transport rates produced by the representative waves, and the lower three parts respectively indicate the comparison under the given conditions that 1) no sediment sources are given, 2) 10,000 m³/yr and 5,000 m³/yr are given from the rivers, and 3) 100,000 m³/yr and 5,000 m³/yr are given. Figure 8 (b) shows the detailed expression of shoreline changes produced by the sediment sources. The alongshore distribution of longshore sediment transport by the representative monsoon wave is shown by the dotted curve in Figure 7. The annual averaged total rate of longshore sediment transport reaches a maximum near Naetsu Harbor and amounts to about 50,000 m³/yr; nearly equal to the value estimated from the bottom topography change. In the alongshore distribution, it is positive and decreases gradually in the easterly direction on the central part of the coast, but changes to the westerly direction along the east part. This tendency demonstrates that the central part of the coast is depositional in long-term beach evolution and that easterly and westerly longshore sediment transport exists in relation to the breaker angle of the incident waves. The offshore bottom topography measured in the central part also is depositional.

From this comparison, we conclude that the long-term shoreline change calculated shows some shoreline retreat near the Gotsu headland and shoreline accretion along the central part of the coast, but it is in good agreement with the actual long-term shoreline change over 51 years. We therefore conclude that our proposed long-term



(a) Long-term shoreline changes hindcast for 51 years.



(b) Detailed expression of shoreline change under the given sediment sources.

Figure 8. Comparison of long-term shoreline changes hindcast by the representative monsoon wave with actual shoreline change from 1910 to 1961.

shoreline prediction model, in which the representative monsoon wave is introduced, is applicable for future long-term shoreline change prediction as large scale coastal behavior.

PREDICTION OF SHORELINE CHANGE AFTER CONSTRUCTION OF NAOETSU HARBOR

Changes in the sedimentation system and longshore sediment transport rates

(1) Calculation of the wave and nearshore current fields As stated previously, Naoetsu Harbor was developed in 1961 with extending western breakwaters. Its

construction has changed the sedimentation system, resulting in severe beach erosion the area of which has expanded easterly in relation to the extension of the breakwaters. To establish a principal methodology for beach stabilization, we predicted changes in wave and nearshore current fields numerically in order to evaluate changes in the longshore sediment transport and shoreline along the coast. In considering large scale coastal behavior, long-term shoreline change along the

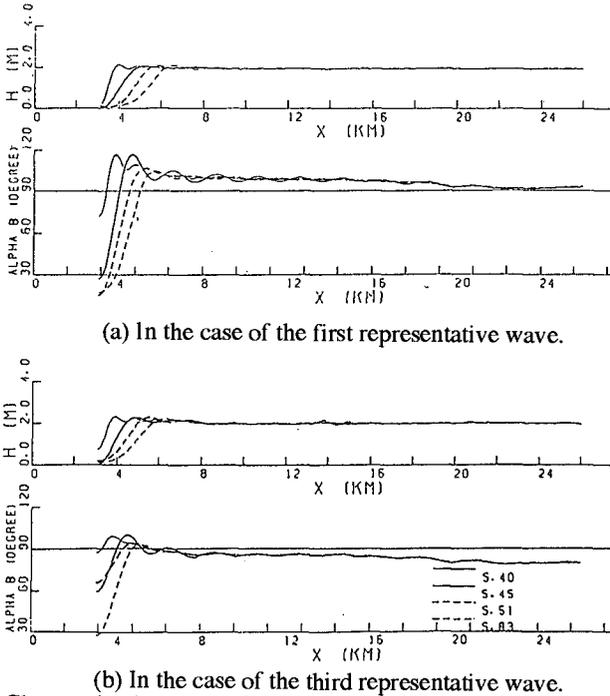


Figure 9. Changes in alongshore distributions of breaker height and angle in relation to the extension of western breakwaters in Naoetsu Harbor.

coast is predicted on the assumption that sandy beaches have remained when shoreline retreat has taken place. Various numerical simulation models of waves and nearshore currents have been proposed in terms of the so-called mild-slope equation and nearshore current equations. In relation to the extension of the western breakwaters, we calculated changes in the wave and nearshore current fields due to the construction of these breakwaters using a numerical model (Yamashita, Tsuchiya, Matsuyama & Suzuki, 1990).

(2) Changes in the wave and nearshore current fields Figure 9 shows changes in the alongshore distribution of breaker height and angle after the construction of Naoetsu harbor, S. 40, S. 45, S. 51 and S. 63 respectively indicating 1965, 1970, 1976 and 1988. The wave and nearshore fields have changed in the area where breakwater influence is marked. In the nearshore current field, some circulation has formed within the area, resulting in the westerly movement of longshore sediment (For more detail consideration, see Tsuchiya, Yamashita, Izumi and Tottori, 1993).

(3) Alongshore distributions of longshore sediment transport rates Using the wave characteristics for 1988, we calculated the alongshore distribution of longshore

sediment transport rates by (3), as shown in Figure 10 where the solid curves marked 1st, 2nd and 3rd were reduced by the first, second and third representative waves, and the dotted curve indicates the annual averaged total rate of longshore sediment transport. The total rate of transport is reduced near the harbor due to the effect of the break-

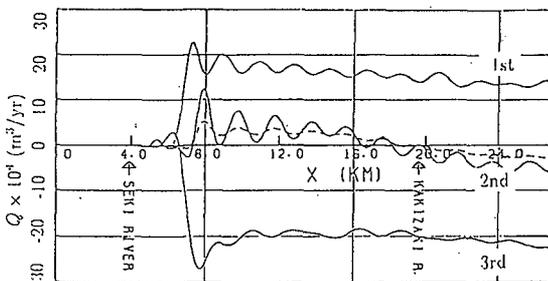


Figure 10. Alongshore distributions of longshore sediment transport rates for three representative waves and the annual averaged one after the construction of Naoetsu Harbor.

waters. A comparison of this figure with Figures 7 and 10 shows that longshore sediment transport has been reduced in the area near the harbor and that its direction is positive along the part of the coast west of the central area, but negative in the eastern part. Note that the location in which the direction of the annual averaged longshore sediment transport changes from easterly to westerly has become more easterly. We therefore conclude that construction of the large harbor has changed the sedimentation system and affected large coastal behavior.

The mechanism of beach erosion and long-term shoreline change prediction

As previously shown, the alongshore distribution of the longshore sediment transport rate has changed after the western breakwaters were built. It is of prime importance for the principal methodology of beach stabilization to show how this influences long-term shoreline change as large scale coastal behavior. In the numerical prediction of long-term shoreline change, we assume that natural sandy beaches have remained even after shoreline retreat has taken place.

Using the long-term shoreline change prediction model and the representative monsoon wave, we predicted numerically the shoreline change from 1961 for one hundred years, under the boundary conditions that at Naoetsu Harbor no longshore sediment is given and that longshore sediment transport exists at the Yoneyamazaki headland. Figure 11 shows the predicted shoreline change along the coast, the dotted curve indicating the initial shoreline, and the solid curves shoreline change at

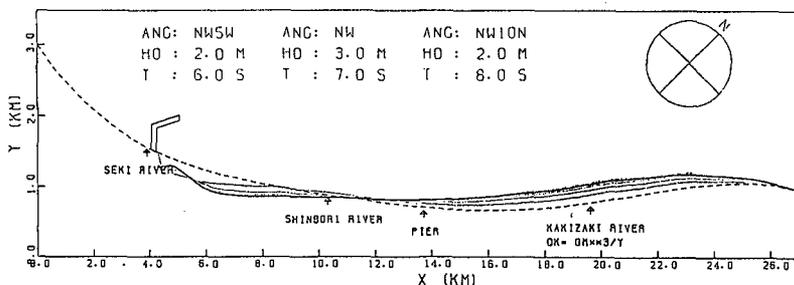


Figure 11. Long-term shoreline change predicted for 100 years after the construction (1961) of Naoetsu Harbor.

intervals of 20 years. The prediction includes the influence of building the west breakwater shown in Figure 9. Due to the direct effect of the breakwater, severe shoreline retreat takes place down the coast from the harbor. A cusped foreland is formed inside the harbor due to changes in the wave and nearshore current fields. In contrast, in the central part near the Kakizaki River shoreline accretion takes place. This long-term shoreline change should be considered as one type of large scale coastal behavior for a coast bounded by two headlands. It should be mentioned that the depositional area is wider than the eroded area due to the westerly longshore sediment transport passing the Yoneyamazaki headland. If the total amount of longshore sediment transport from the headland is assumed to be reduced, the accretional area may become narrower. Note, however, that this tendency for shoreline accretion corresponds to the present bottom topography change. Actually, the various countermeasures have been taken along this coast have resulted in the retardation of shoreline retreat, but produced a steep beach profile.

THE METHODOLOGY FOR BEACH STABILIZATION

Long-term shoreline change with boundary conditions

On the basis that long-term shoreline change is large scale coastal behavior, a principal methodology for beach stabilization must be established because a large coastal construction, Naetsu Harbor, has created a man-made boundary condition that is so effective for shoreline change that we must look for a methodology for stabilizing the whole coast.

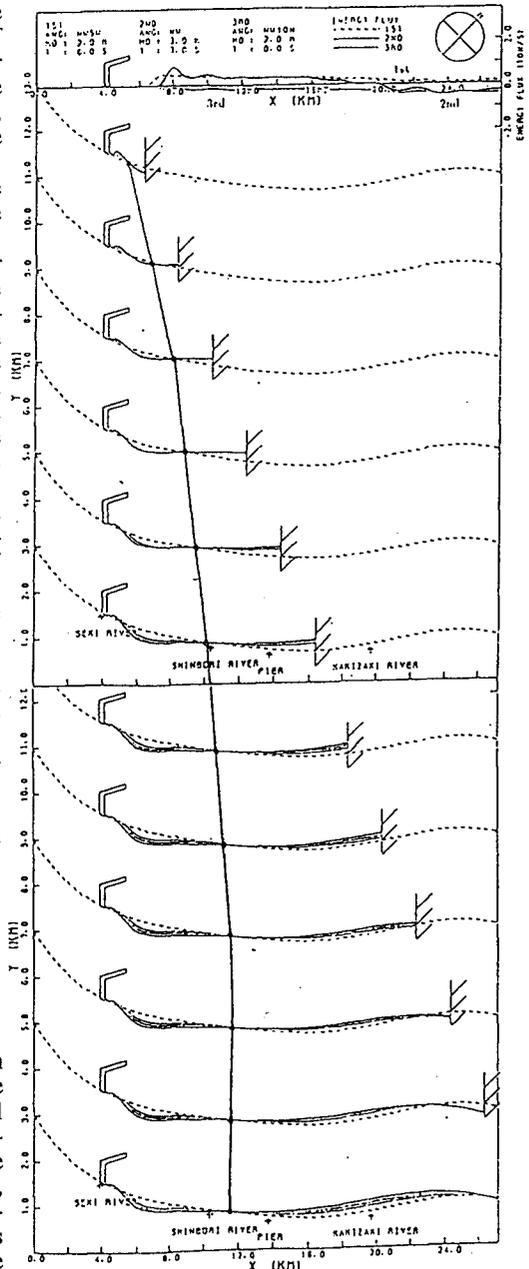


Figure 12. One-hundred years of shoreline evolution with change in the location of the boundary condition.

Therefore, we predict long-term shoreline change for another condition that counters the man-made boundary condition of the breakwater. The new boundary condition is given at a location where longshore sediment transport is completely stopped, but no wave diffraction is introduced. As previously, we predicted the shoreline changes shown in Figure 12 where the upper and lower figures are the cases for the boundary conditions located 2 to 12km and 14 to 24km from the Gotsu headland. In this figure, the solid curves show the shoreline change for one hundred years at intervals of 20 years. Shoreline change is subject to the location of the boundary condition, but the nodal point for shoreline change clearly exists near the Shinbori drainage river and remains at the same location with change in the position of the boundary condition. This is a most important factor in shoreline change as large scale coastal behavior for stabilization of the coast against the man-made boundary condition.

A principal methodology for beach stabilization

Generally, beach erosion takes place locally due to various causes of erosion, but it is more pervasive down coast. When countermeasures were taken to prevent further erosion at that location, more severe erosion took place down coast. To stabilize the coast against erosion, we must therefore first consider what will happen along the entire coastal area due to erosion as large coastal behavior. Second, we must investigate whether the coast can be stabilized by some boundary conditions for beach change. Once a possible boundary condition for stabilizing the coast in the large coastal behavior, based on the theoretical background of the formation of stable sandy beaches (Tsuchiya, Chin and Wada, 1993, and Tsuchiya, 1994) is found, a principal methodology for beach stabilization can be established.

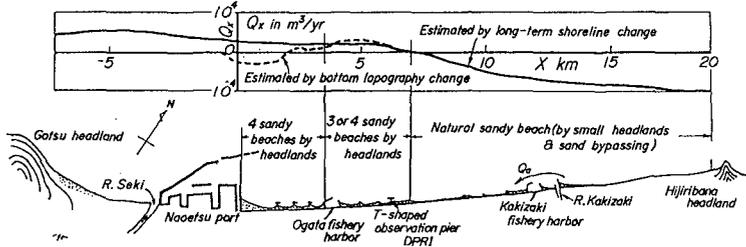


Figure 13. The methodology for beach stabilization proposed for the Joetsu-Ogata coast where two west headlands are under construction.

As stated, there is the possibility of stabilizing the coast against beach erosion by constructing a boundary condition for shoreline change at the nodal point for shoreline change. However, how this boundary condition is to be constructed must be considered. We can not construct a mathematical headland that has no wave diffraction and deflection. It must be a headland that reflects natural headlands or small islands that produce as little wave diffraction and deflection as possible. Therefore, when a headland is constructed, another boundary condition is needed to compensate for its direct influence in order to stabilize the down coast for making stable sandy beaches form. Based on the boundary condition found from viewing long-term shoreline change as large scale coastal behavior, we propose the methodology for beach stabilization shown in Figure 13, in which the upper part shows the alongshore distribution of the longshore sediment transport rate estimated by numerical calculation (solid curve) and from the bottom topography change (dotted curve). The lower part shows the proposed series of headlands used as boundary conditions for shoreline change. It should be noted that the direction of the longshore sediment transport rate has changed from easterly to westerly due to

changes in the wave and nearshore current fields (Tsuchiya, Yamashita, Izumi and Murakami, 1994). These two west headlands shown in the figure are now under construction.

CONCLUSION

In establishing a methodology for beach stabilization, two principal roles must be taken into account: 1) Beach erosion must be considered over the entire coastal area as large scale coastal behavior and possible measures for stabilizing the coast from erosion found. 2) Based on the theoretical background of the formation of stable sandy beaches, a principal methodology for beach stabilization must be established. Beach erosion on the Joetsu-Ogata coast and its stabilization have been investigated in terms of these roles. The main conclusions are

(1) By introducing the representative monsoon wave, a prediction model for long-term shoreline change could be proposed using the so-called one-line model. This model was applied to hindcast long-term shoreline change on the Joetsu-Ogata coast, which is bounded by two headlands, for the 51 years before the construction of Naoetsu Harbor. The results agree well with the actual shoreline changes that are part of the large scale coastal behavior.

(2) On the assumptions that a natural sandy beach has remained during shoreline evolution and that the direct influence of building a harbor breakwater is introduced, we predicted long-term shoreline change for 100 years after the construction of the harbor. Severe shoreline retreat takes place along the west part of the coast, but shoreline accretion occurs along the east part. This tendency is very similar to the current bottom topography change.

(3) We have also predicted long-term shoreline changes with a given boundary condition for shoreline change. We found the most suitable location for the boundary condition to be the nodal point for shoreline change. Based on the large scale shoreline change and the theoretical background of the formation of stable sandy beaches, a principal methodology for beach stabilization has been proposed that uses a series of headlands.

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