MORPHOLOGY VARIABILITY IN THE VICINITY OF COASTAL STRUCTURES

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The morphology variability is carried out in this study by using the historical bathymetry data. Two study areas in which the vicinity of coastal structures are selected and make a comparative study, Sendai Port and Yuriage Port. Both are located in the Sendai Coast, northeast of Japan, with the similar incoming wave condition from SE and ESE direction. Sediment is trapped in front of Breakwater at Yuriage Port; on the contrary, the severe erosion occurs in the updrift side of Sendai Port. Consequently, these phenomena should be clarified by study on morphology variability. To overcome these aspects, it needs to analyze a long-term series data set and investigate the characteristics of morphological variability in order to well understand for the perspective of coastal management.

Keywords: morphology; EOF; coastal structure

INTRODUCTION

In recent years, the number of coastal morphology areas dramatically changed has been rapidly increased in Japan caused by the development of coastal harbors. The coastal works in early year in Japan were principally concerned with this development in order to maintain the routes for transportation. Correspondingly, coastal protection structures have been constructed to against the effect of wave and sediment transport.

The causes of beach change can be classified into several categories. The most frequent cause is the obstruction of littoral drift by coastal structures. It was found that the mainly cause of beach erosion of Futtsu-Misaki cuspate spit; located at the mouth of Tokyo Bay; is due to lack of sand from the southern coast caused by obstruction of littoral drift at Shitazu fishery harbor (Uda and Kanda 1998). In case of Kashiwazaki Port, Niigata Prefecture, a large amount of sand accumulated in the shelter zone of the breakwater, causing severe beach erosion on the Arahama coast adjacent to this port (Uda and Noguchi 1993). It is found that wave reflection from the breakwater caused remarkable changing in the longshore sediment transport (Tanaka 1983). Moreover, it resulted in the river mouth morphology evolution (Tanaka and Srivihok 2004) and also shoreline change in the area vicinity of Sendai Port (Kang and Tanaka 2005).

Consequently, the identification and analysis of trends in coastal morphologic processes and features are of great importance in the planning and design of coastal engineering efforts and of long-range management. The planning and design of coastal engineering projects and the long term management of coastal areas require a basic knowledge of the likely morphologic variations that can be expected to occur during the lifetime of the project. Thus, before planning and designing, some study of the environmental and morphologic features of the coastline to be engineered, and its relation to adjacent coastlines, should be given detailed attention.

To overcome these aspects, we should understand the variation of topographic change then investigations have to be done. It needs to analyze a long-term series data set and investigate the characteristics of morphological variability in order to well understand for the perspective of coastal management.

STUDY AREAS

There are two study areas included in this study, Sendai Port and Yuriage Port. Both are located in the sandy beach close to Sendai city in Miyagi prefecture, northeast of Japan, as can be seen from Fig. 1. Sendai Port located in the north end of sandy coast, northward of Yuriage Port about 15 km. The sandy beach is aligned between these 2 sites.

The most prevailing incoming wave in Sendai Bay is from ESE and SE direction (Tanaka and Takahashi 1995). The incoming wave directions bring about the moving longshore current and sediment transport from south to north direction for overall area. Moreover, there is the breakwater at Sendai Port located around 2 km apart in the north which is possible to generate the reflected wave and drive the longshore sediment to the opposite direction, north to south direction, which can influence to

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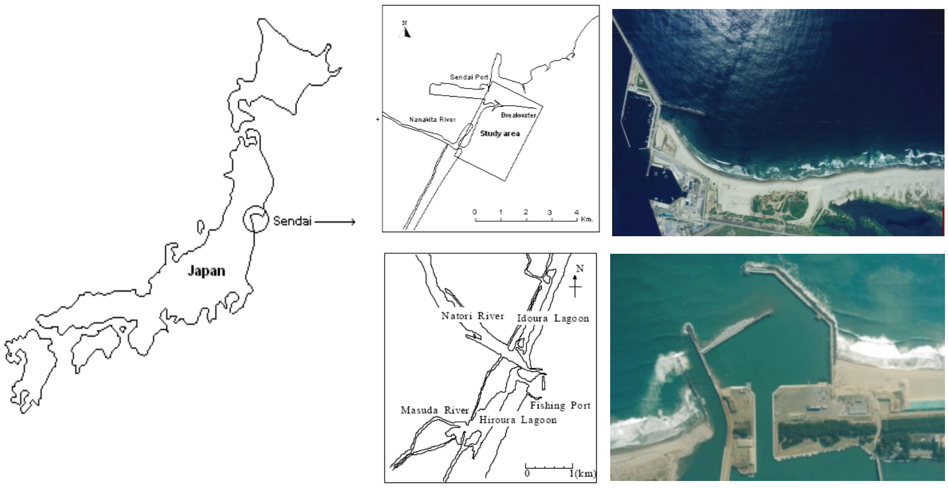

Figure 1. Study areas

the sediment transport in this area. The mean diameter of bottom material was about 0.4-0.5 mm. in the inshore zone and 0.2 mm. in the offshore zone (Tanaka 1977).

Morphology change in Sendai Coast has been done by some researchers by using aerial photos and survey data since severe erosion around the updrift side area after construction of breakwater at Sendai Port in 1968. When the south breakwater reached to more than 400 m in 1970, the beach of in the updrift area has become to be eroded. It was reported that the influence of wave reflection from breakwater at Sendai Port caused severe erosion in the updrift side (Tanaka 1977).

It was found that wave reflection from the breakwater caused remarkable changed in the longshore sediment transport (Tanaka 1983) and result in shoreline retreated since the construction (Uda 1990). The depth of closure along Sendai Coast is much deeper than the one in others (Tanaka et al. 1995). Furthermore, it was reported also the movement of sand split at Nanakita River Mouth (Srivihok 2005) and also shoreline change in the area vicinity (Kang 2006)(Ritphring 2006).

PRELIMINARY ANALYSES

The morphology variability is carried out in this study by using the historical bathymetry data. Two study areas in which the vicinity of coastal structures are selected and make a comparative study, Sendai Port and Yuriage Port. Both are located in the Sendai Coast with the similar incoming wave condition from SE and ESE direction. Sediment is trapped in front of Breakwater at Yuriage Port; on the contrary, the severe erosion occur in the updrift side of Sendai Port. Consequently, these phenomena should be clarified by study on morphology variability.

From the preliminary analyses, it can be clearly seen that the erosion in front of breakwater at Sendai Port started as soon as the construction had finished. Bottom elevation has eroded trend with the maximum rate -0.3 m/year throughout area in long term as well as the retreat of shoreline as shown in Fig. 2. The most severe erosion occurs around 500 m in the southern part of structure with the maximum rate 300m during 1967-1998. Beach slope around Sendai Port become steeper after the construction which can be seen the depth contours shift close to others and move onshore. As the result of morphology change, the estimated depth of closure in this area has changed in the recent year. During 1967-1978, 1978-1988 and 1988-1998, it can be computed the depth of closure as 7.4 m, 9 m and 12 m respectively.

At Yuriage Port, the phenomena which can be observed are vice versa comparing with Sendai Port. Sediment is obstructed in front of the structure with rate 65,000 m^3/year result in the advancement of shoreline with the maximum rate 5-6 m/year as shown in Fig. 3. The positive trend of bottom elevation can be seen clearly particularly in the nearby area close to the tip of breakwater with rate 0.5m/year approximately. In long term, most of the depth contours subject to move offshore with some fluctuation owing to the short term variation.

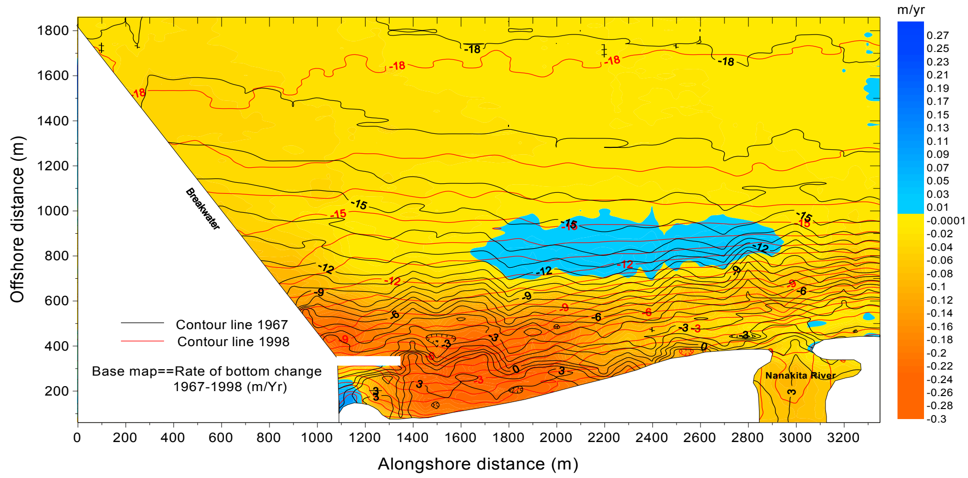

Figure 2. Morphological change at Sendai Port

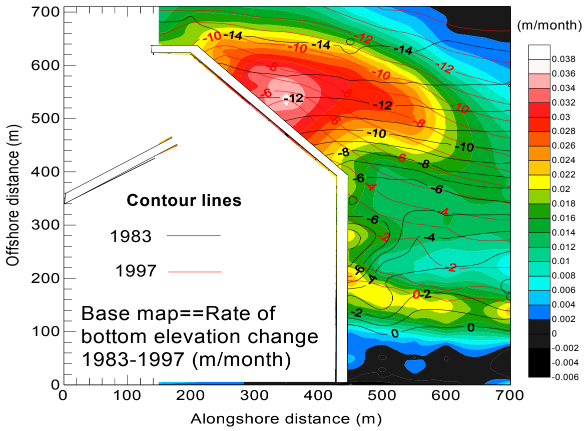

Figure 3. Morphological change at Yuriage Port

EOF ANALYSIS

All obvious phenomena which are found in Sendai and Yuriage Port are vice versa based on these preliminary studies. The application of statistic tool, EOF method, is used to clarify in the second step. This technique is used to derive the dominant patterns of variability from a statistical field. The objective of the analysis is to separate the temporal and spatial dependence of the data so that it can be generated as a linear combination of corresponding function of time and space. These functions then objectively represent the variation of the beach configuration in terms of distance and in terms of temporal changes in topographic over the period of study.

EOF analysis was originally applied in coastal morphology in the middle of the 1970s to investigate variations in the beach profile shape in space and time (Winant et al. 1975). It was found that most of the variation in the profile configuration is accounted for the first tree eigenfunctions which corresponded to the mean beach, bar berm and terrace function. After these pioneering studies, EOF analysis has become a commonly applied technique in morphological research to investigate beach response over time scales of several years. It was proposed a new model to analyze beach profile changes due to longshore and on-offshore sand transports (Hashimoto and Uda 1979). This technique was used for the analysis of position of shoreline on Sendai Coast (Tanaka and Mori 2001). It can be related the first and second components with longshore and cross-shore sediment transport respectively.

Prior to EOF analysis, mean values for each position is calculated and used to subtract with the survey data. The topographic change can be expressed in terms of superposition of eigenfunction as in Eq.1:

$$H'(x,y,t) = \sum_{n=1}^{n_x} C_n(t) e_n(x,y) \quad (1)$$

Where $H'(x,y,t) = H(x,y,t) - \overline{H}(x,y)$; $\overline{H}(x,y)$: average depth from historical data; n_x denotes the number of survey data, and $C_n(t)$ and $e_n(x,y)$ are the temporal and spatial eigen functions, respectively. The temporal eigen functions, $C_n(t)$, show how the amplitude of each EOF varies with time. The spatial eigen functions, $e_n(x,y)$, stand for the spatial structures *(x,y)* of the major factors that can account for the temporal variations of water depth *H'(x,y,t)*.

EOF analysis is applied to the same bathymetry data which used in the preliminary analysis. The contribution ratio, temporal and spatial eigenfunction is computed. The opposite temporal trend can be notice at Sendai Port comparing with Yuriage Port which corresponds to the preliminary analysis as well. Although these patterns of eigenfunction do not necessarily have any physical meaning, it is found that the dominant mode are in fact related to physical mechanisms such as the construction of breakwater and sand dumping. Furthermore, this pattern corresponds with rate of bottom elevation change in both Sendai and Yuriage Port.

By fitting a regression line between the temporal eigenfunction and the corresponding time series of longshore component of wave energy flux at the breaking point, the quite good relationship can be clearly noticed in both Sendai and Yuriage Port in Fig.4. It is explored by considering the correlation between the 1st temporal eigenfunction, $C_1(t)$, and corresponding time series of longshore component of wave energy flux at the breaking point which can be calculated by using wave ray method in collaboration with wave breaking formula (Goda 1975). The component of energy flux (P_ℓ) is given by Eq.2 (U.S. Army Corps of Engineers 1977):

$$P_\ell = \overline{P} \cos\alpha \sin\alpha = \frac{\rho g}{8} H^2 C_g \sin\alpha \cos\alpha \quad (2)$$

while ($\overline{P}$) stands for the energy flux per unit length of wave crest or equivalent, C_g is group celerity, H is wave height at breaking line and α is wave direction at breaking line.

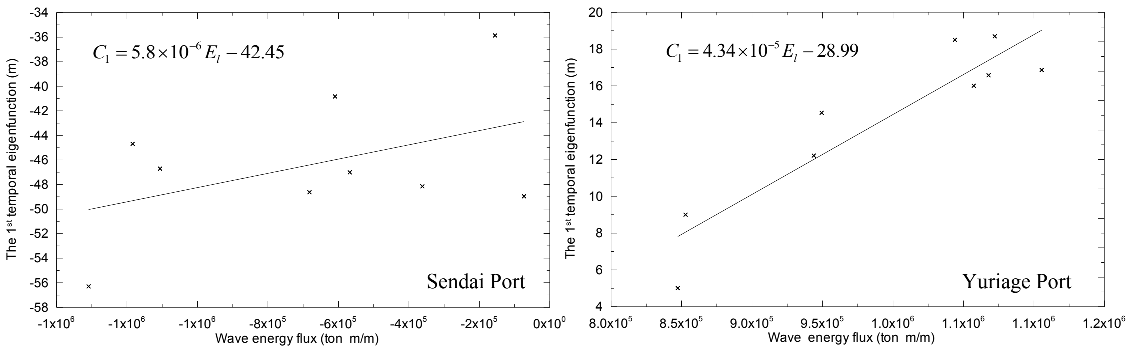

Figure 4. The relationship between the 1st temporal eigenfunction and longshore component of wave energy flux

SEDIMENT TRANSPORT

The analysis based on morphology data and statistic tool that mentioned above can clarify the coastal process in these two areas. Moreover, the simulation of wave and sediment transport is done in order to understand the response of morphology to the external force. When wave train propagates from deep water into shallow region, its height changes due to shoaling, refraction, diffraction, reflection, and breaking. These processes in wave transformation are extremely important in the field of coastal engineering.

The way to compute wave transformation in this study uses numerical model which consists of two parts. The first of which is a wave transformation model based on the wave ray method in collaboration with Goda's wave breaking principle. The second part of this model is a sediment transport rate computation which is typically presented in term of wave condition at breaking line proposed by the U.S. Army Corps of Engineers (CERC) in 1977.

The most prevailing incoming wave is from ESE or SE direction which can drive the longshore current and sediment transport from south to north throughout area. However, the breakwater which located at Sendai Port is possible to generate the reflected wave and bring about the longshore sediment transport to the opposite direction, north to south. Therefore, the longshore sediment transport rate computation is separated into two parts including sediment transport induced by incident and reflected wave

From Fig.5, the net longshore sediment transport rate in the updrift side of Sendai Port is 35,000 m^3/year (southward) which is strongly influenced by the wave reflection from breakwater. It can be seen in that almost none of sediment transport move southward in case of Yuriage Port. The net longshore sediment transport rate which move northward is 50,000 m^3/year which correspond to the preliminary analysis as well.

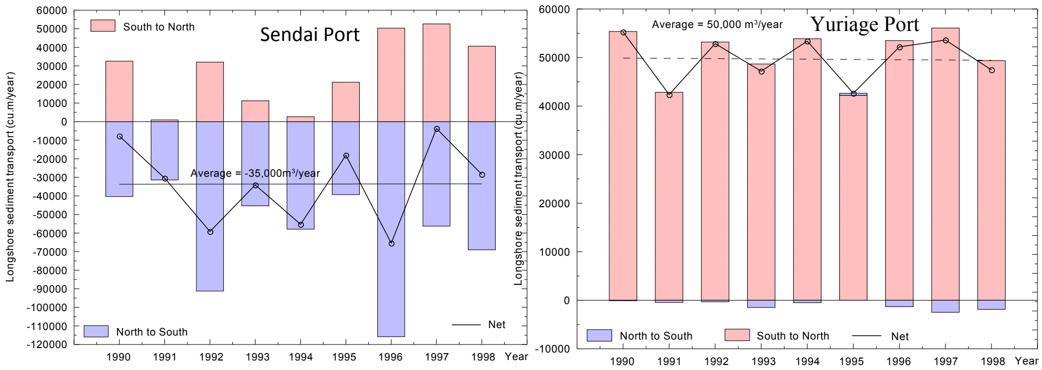

Figure 5. Longshore sediment transport

The alignment of these two structures against with the wave angle is strongly affected to the generating of reflected wave which bring about southward sediment transport. The layout of breakwater at Yuriage Port is more parallel to the angle of wave. When wave from the same direction strike to the structure, the reflected direction are different In Sendai Port, the angle which is ranged between 105-130 degree can produce the significant amount of southward longshore sediment transport, but cannot notice in case of Yuriage since the reflected wave has no significant effect to the sediment movement in this area.

HYPOTHETICAL CASES

From the comparative study, it can be noted that wave angle is strongly affected to the generating of reflected wave which bring about southward sediment transport. In this section, the hypothetical case study are set and simulated with the same process as the existing condition. Five study cases are divided by varying the angle of structure at Sendai Port without changing the length as shown in Fig. 6.

Case 1 and 3 are set the alignment of breakwater more parallel to the wave angle whereas case 2 and 4 are set more oblique compare to the existing condition. Table inside shows the angle of breakwater to the average shore direction in five cases.

The amount of longshore sediment transport in five cases shows in Fig.7. Even though it can be seen some fluctuation during a year, the yearly longshore sediment transport rate clearly show the relationship between the angle and the amount of sediment. In case of breakwater has more parallel alignment to the wave angle, the amount of longshore sediment transport which generated by reflected wave is less. While the oblique layout produce more amount of the alongshore sediment transport.

The differences of the alignment angle even less can be significantly affected to wave reflection at the structure. In the existing condition, wave reflects from breakwater and strike to the beach in the updrift area that may result in the erosion problem in this area as shown in Fig. 2. Although there is more amount of longshore sediment transport in case 4, wave reflect and run across to the area next to Nanakita River Mouth. Meanwhile the parallel alignment in case 3 induces the reflected wave drive outside the area of interest.

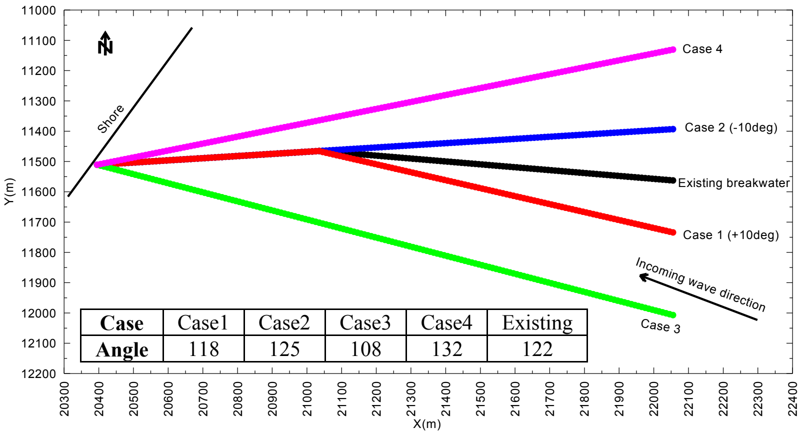

Figure 6. The alignment of structure in hypothetical study cases

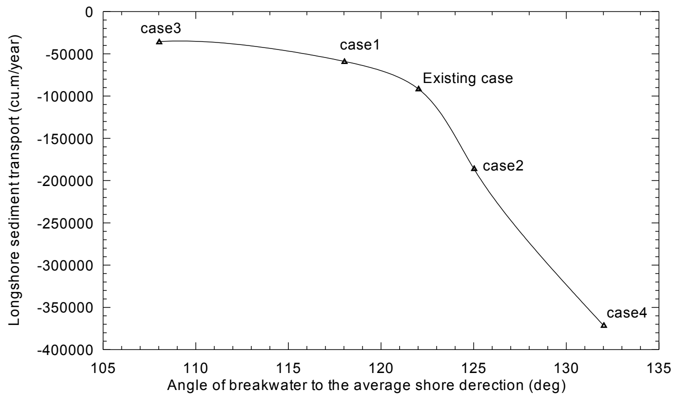

Figure 7. The alignment of structure in hypothetical study cases

These hypothetical study cases are simulated based on the wave condition in 1990 and 1992 with varying 5 angles of structure alignment. It can be noticed obviously that the angle between wave and the alignment of coastal structure significantly effect on the movement of alongshore sediment to the opposite direction. Consequently, it may result in the erosion in the updrift side of coastal structure.

CONCLUSIONS

The morphology variability is carried out in this study by using the historical bathymetry data. Two study areas in which the vicinity of coastal structures are selected and make a comparative study, Sendai Port and Yuriage Port, northeast of Japan. Sediment is trapped in front of Breakwater at Yuriage Port; on the contrary, the severe erosion occurs in the updrift side of Sendai Port.

It can be clearly seen that the erosion in front of breakwater at Sendai Port started as soon as the construction had finished. Bottom elevation has eroded trend with the maximum rate -0.3 m/year throughout area in long term as well as the retreat of shoreline. The most severe erosion occurs around 500 m in the southern part of structure with the maximum rate 300m during 1967-1998. At Yuriage Port, the phenomena which can be observed are vice versa comparing with Sendai Port. Sediment is obstructed in front of the structure with rate 65,000 m^3/year result in the advancement of shoreline with the maximum rate 5-6 m/year.

By fitting a regression line between the temporal eigenfunction produced by EOF technique and the corresponding time series of longshore component of wave energy flux at the breaking point, the quite good relationship can be clearly noticed in both Sendai and Yuriage Port. It is implied that the 1st temporal eigenfunction stand for the morphological evolution which is influenced by the longshore sediment transport.

It can confirm that the angle between wave and the alignment of coastal structure significantly effect on the movement of alongshore sediment to the opposite direction. Consequently, it may result in the erosion in the updrift side of coastal structure. Moreover, the length of structure also affects the occurrence of reflected wave; on the other hand, the longer structure will block and reflect wave much more than the shorter one. Breakwater at Sendai Port is three times of the length at Yuriage Port results in the more occurrence of reflected wave which possible to generate the more southward longshore sediment transport.

The identification and analysis of trends in coastal morphologic processes and features are of great importance in the planning and design of coastal engineering efforts and of long-range management. The planning and design of coastal engineering projects and the long term management of coastal areas require a basic knowledge of the likely morphologic variations that can be expected to occur during the lifetime of the project. Thus, before planning and designing, some study of the environmental and morphologic features of the coastline to be engineered, and its relation to adjacent coastlines, should be given detailed attention.

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