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INFLUENCE OF MORPHOLOGICAL CHANGE ON WATER LEVEL RISE AT THE SHIRIBETSU RIVER MOUTH

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SYNOPSIS

Distinct water level rise above tidal elevation was observed at the Shiribetsu River mouth located in Hokkaido, Japan during the period from October to March every year. It was found that the magnitude of water level rise increased in winter with the development of sand spit at the river mouth. In order to establish a relationship between water level rise and sand spit length at the river entrance, oblique photographs were taken from a small mountain almost every week, and were effectively utilized in the present analysis.

INTRODUCTION

Precise prediction of water level at a river mouth has practical applications for flood inundation modeling in the vicinity of a river mouth. The water level in a river entrance is influenced by several external forces, such as river discharge, tidal motion and wave action. However, very little attention has been paid to the effect of waves. In recent years, several field observations of wave set-up at a river mouth have been reported by Hanslow and Nielsen (3), Hanslow et al. (4), Santoso et al. (6), Tanaka and Shuto (8) and Tanaka et al. (9). From their results, it can be concluded that the height of wave set-up shows distinct dependence on the morphology at a river entrance. However, a quantitative relationship between the magnitude of wave set-up height and river morphology has not yet been thoroughly clarified. One of the reasons for this is the inconsistency of data acquisition interval of water level and river mouth morphology, that is, data accumulation of river mouth topography at a short interval is very rare in general, whereas field data of water level variation in a river mouth can now be easily obtained using an automated water level measuring system. Thus, even though we have sufficient data sets of wave set-up at a river entrance, it is quite difficult to correlate them with river mouth morphology due to the lack of corresponding field surveying data of river mouth topography.

In the present study, the water level rise at the entrance of Shiribetsu River was investigated, where oblique photographs were taken almost every week for these twenty years from the top of a mountain nearby. Thus, instead of surveyed shoreline data of the river mouth, oblique photographs were utilized to investigate the quantitative relationship between the wave set-up height and river mouth morphology.

STUDY AREA

The Shiribetsu River is located in the western part of Hokkaido, Japan and pours into Japan Sea as seen in Photo 1. In the preset study, field data around the Shiribetsu River mouth were measured and analyzed. The catchments area and the length of the river are 1640km^2 and 126km respectively. The left side of river mouth was bounded by a jetty as shown in Photo 1, while the right hand side used to be connected to sandy coast with the length of 2.1km. In 1999, another jetty was been constructed on the right side to prevent longshore sediment intrusion into the mouth. However, field data analyzed herein are limited to those obtained before the construction of the right jetty.

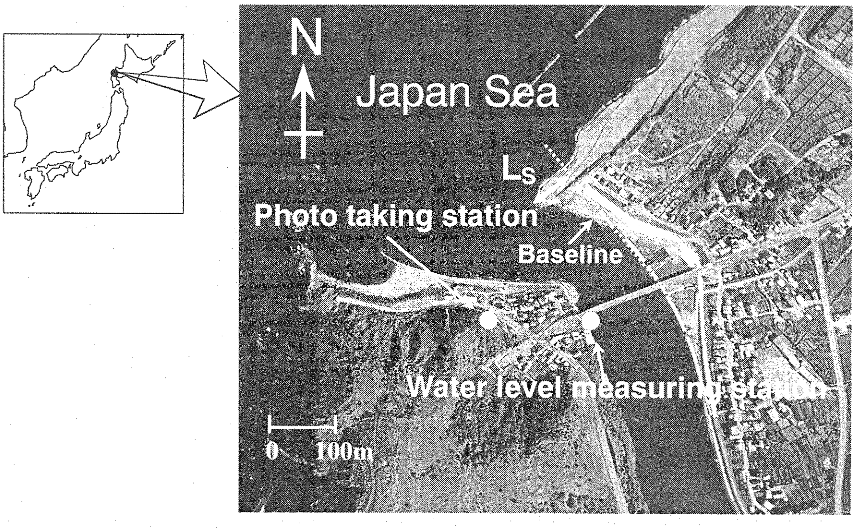


Photo 1 Location map and aerial photograph of the Shiribetsu River mouth

DATA COLLECTION

For the purpose of the present study, the following hydraulic characteristics were collected. First, hourly water levels at the river mouth were obtained. The water level measuring station is close to the bridge in Photo 1 and is 300 m upstream from the river mouth. The fresh water discharge of the Shiribetsu River was measured hourly at the Nakoma discharge measuring station 14.2km upstream from the river mouth. Tidal level was measured at Setana Port, which is about 60 km from the river mouth towards the southwestern direction. The wave height observation point is 3.6km offshore from Setana Port with 52.9m depth. The tidal level and the significant wave height variations were measured at two-hour intervals. Thus, these data sets were interpolated to fit other data measured with one-hour interval. The data from January 1991 to December 1998 were used in this study.

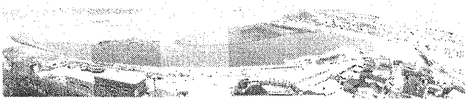
Oblique photographs were taken once every week for twenty years from the top of a small mountain of 26m height near the river mouth, as shown in Photo 1. On the other hand, there are several surveyed data of shorelines around the river mouth. Thus, at first, the correlation between the coordinates in the oblique photograph, (ξ,ζ) and the corresponding coordinates in the surveyed shoreline data, (x,y) on the same date or the nearest date was examined. Using the transformation method from (ξ,ζ) to (x,y) thus obtained, all of other oblique photographs without corresponding surveying data can be converted to a two-dimensional plane coordinate system.

RESULTS AND DISCUSSIONS

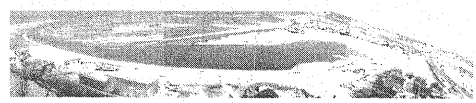
Seasonal Change in River Mouth Morphology

A typical example of seasonal change in river mouth morphology at the Shiribetsu River is shown in Photo 2. Photo 2(a) and Photo 2(b) show a fully developed stage of the sand spit on the right side of the river mouth, due to predominant waves in winter. During spring, the amount of river discharge increases due to snow melting in the mountainous area at the upstream region, which causes flushing of the sand spit as seen in Photo 2(c) and Photo 2(d). Since the wave action is not so predominant during summer as compared with winter, the growth of the sand spit is not so notable. Furthermore, typhoons sometimes hit this area and cause considerable increase of river discharge. The front during rainy season called "Ezo-tsuyu" is another cause of increase of the discharge. These help to keeps the river mouth open in summer (Photo 2(e) and Photo 2(f)). Photo 2(g) shows the early stage of sand spit development, and the sand spit finally reaches the fully developed stage in Photo 2(h).

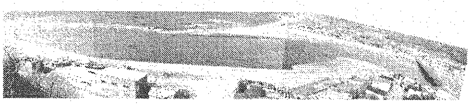
The length of the sand spit, L_s, obtained from the oblique photographs is plotted in Fig. 1, where the length is defined in terms of the baseline given in Photo 1. The following seasonal variation of sand spit can be observed every year in Fig. 1: (1) gradual development of sand spit in autumn and winter, (2) its decline in spring due to increase of river discharge caused by snow melting and (3) no growth of sand spit length due to floods caused by typhoons and "Ezo-tsuyu" during summer. Such annual variation of sand spit development with distinct periodicity has not been reported elsewhere in Japan (Sawamoto and Shuto (7), Inamura and Tanaka (5)).



(a) January 11, 1996



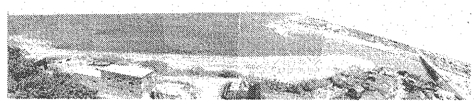
(b) February 13, 1996



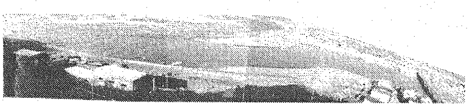
(c) April 12, 1996

(d) May 15, 1996

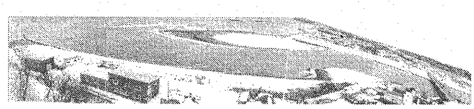
(e) July 16, 1996



(f) August 20, 1996



(g) November 8, 1996



(h) December 10, 1996

Photo 2 Seasonal migration of sand spit in 1996

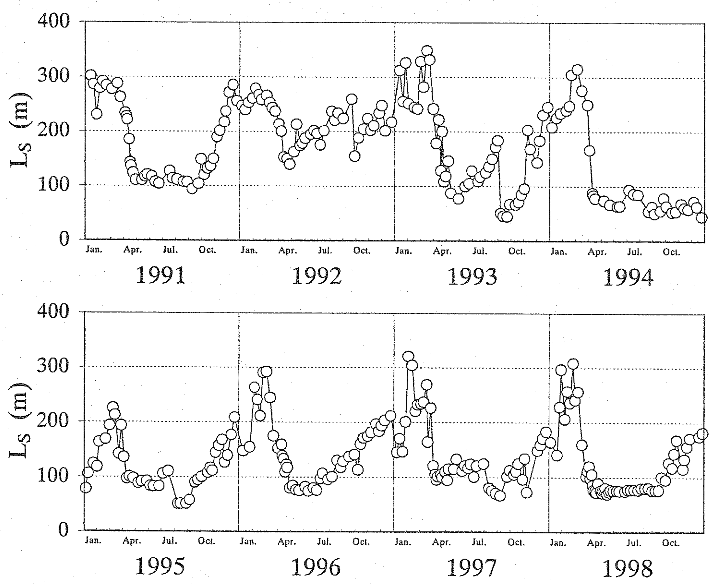


Fig. 1 Variation of sand spit length from 1991 through 1998

Water Level Variation at The Mouth

The monthly average of the water level rise $\Delta\eta$, the significant wave height H_0 and the fresh water discharge Q are plotted for 1996 data in Fig. 2. The bar denotes an averaged value over one month. The fresh water discharge is almost constant, about $50m^3/s$, except in April, May and June. As aforementioned, the increase of discharge in spring is caused by snow melting in the mountainous region in the upstream area. However, the increase of discharge in spring does not cause distinct water level rise at the river entrance. In contrast, the variation of monthly averaged water level rise in the year shows quite similar behavior to the wave height. This finding suggests that the water level rise at the Shiribetsu River mouth is considerably influenced by wave motion, that is, wave set-up induced by wave breaking. It was confirmed that the monthly averaged water level in the mouth observed in other years also shows similar behavior to Fig. 2.

A more detailed inspection of hydraulic characteristics can be explained based on hourly data. In Fig. 3, Typical examples of water level variations for two periods at the Shiribetsu River mouth are depicted, in which η_{RM} and η_T denote water level at the river mouth and tidal level, respectively. In Fig. 3(a), a flood occurred at the beginning of the month, resulting in slight water level rise in the mouth above the sea level. The maximum of fresh water discharge was about $600m^3/s$ on May 2, 1998. Immediately after this flood event, the difference $\Delta\eta$ becomes smaller in accordance with the reduction of discharge. After the flood, the wave height is always almost less than 1m, and it is evident that the wave height has no correlation with $\Delta\eta$.

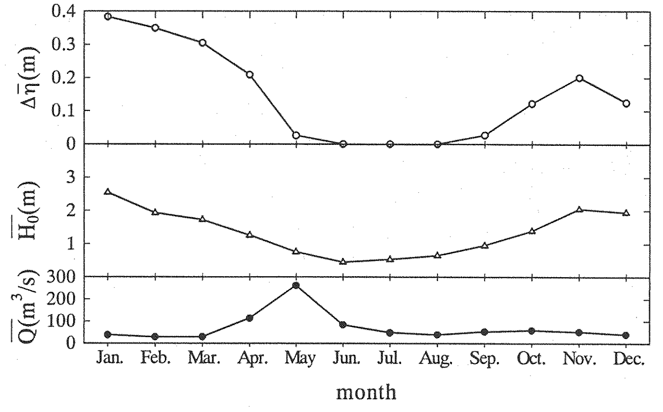
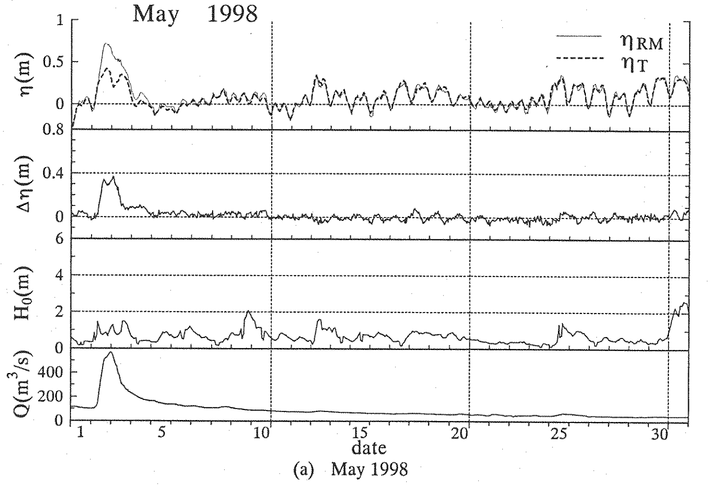
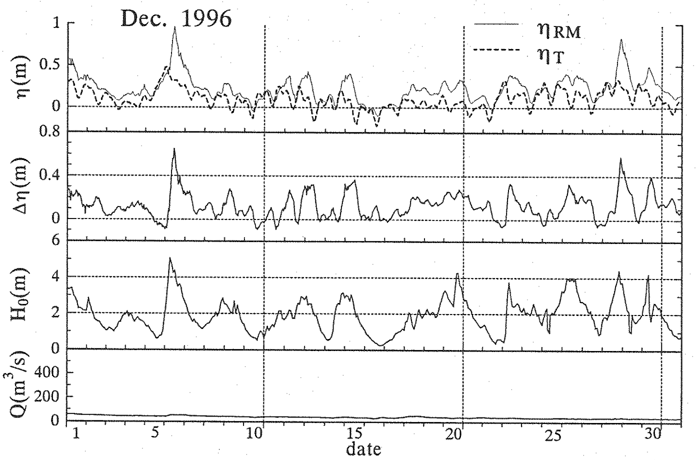


Fig. 2 Monthly averaged water level, wave height and discharge in 1996



(a) May 1998

Fig. 3 Time variation of water level, wave height and river discharge



(b) December 1996

Fig. 3 (continued) Time variation of water level, wave height and river discharge

The field data observed in winter is plotted in Fig. 3(b). In contrast to the results observed in May 1998 (Fig. 3(a)), the water level in the mouth η_{RM} is distinctly different from tidal variation η_T, which is always higher than the tidal elevation. During the whole of this month, the superelevation of water level at the river mouth shows a very close correlation with the wave height, but there is no relationship with the fresh water discharge in the river. Thus, it can be concluded again that the water level rise shown in Fig. 3(b) is induced by wave set-up.

Relationship Between Morphological Change and Wave Set-Up Height

Wave set-up height data are collected from all the data set spanning from January 1991 to December 1998. In the present study, wave set-up height data was selected when the significant wave height was higher than 2m and fresh water discharge was smaller than 200m^3/s. The number of selected wave set-up data reached 159 cases during the whole period of the present investigation.

The relationship between dimensionless wave set-up height and the sand spit length is shown in Fig.4. The ratio $\Delta\eta/H_0$ shows seasonal variation from 0.0 to 0.16. The maximum value is somewhat smaller than that observed on a sloping beach (Goda (1), Guza and Thornton (2)) and is similar magnitude to Tanaka et al.'s (9) measurements in a river entrance.

It should be here noted that the annual variation of dimensionless wave set-up height is very similar to that of sand spit length. The reason for this can be explained as follows. According to previous studies on wave set-up height at a river entrance, the height is closely related water depth at the mouth (Hanslow et al. (4) and Tanaka et al. (9)). For example, Hanslow et al. (4) proposed the following expression correlating set-up height on a sloping beach, $\Delta\eta_{SB}$, and that in a river mouth $\Delta\eta_{RM}$.

$$\Delta\eta_{RM} = \frac{\Delta\eta_{SB}}{1+\dfrac{a h_{RM}}{H_0}} \tag{1}$$

where a the constant and h_{RM} the depth of a river mouth. If we assume $\Delta\eta_{SB} = bH_0$ (b: constant) for simplicity (Guza and Thornton (2)) and substitute it into Eq.(1), we obtain the following expression.

$$\frac{\Delta\eta_{RM}}{H_0} = \frac{b}{1+\dfrac{a h_{RM}}{H_0}} \tag{2}$$

From Eq. 2, it can be concluded that wave set-up height decreases with the increase of the water depth at a river entrance. Based on field data at the Nanakita River mouth, Japan, Tanaka et al. (9) also showed that wave set-up in a river mouth is smaller than that on an ordinary sloping beach. At the Shiribetsu River mouth, detailed surveyed data of water depth are not available; however, it is plausible that the sand spit length and the river mouth depth are inversely correlated. Thus, it can be concluded the increase of $\Delta\eta/H_0$ during autumn and winter in Fig. 4 is evidence of sediment deposit around the river mouth and a subsequent decrease of water depth at the river entrance.

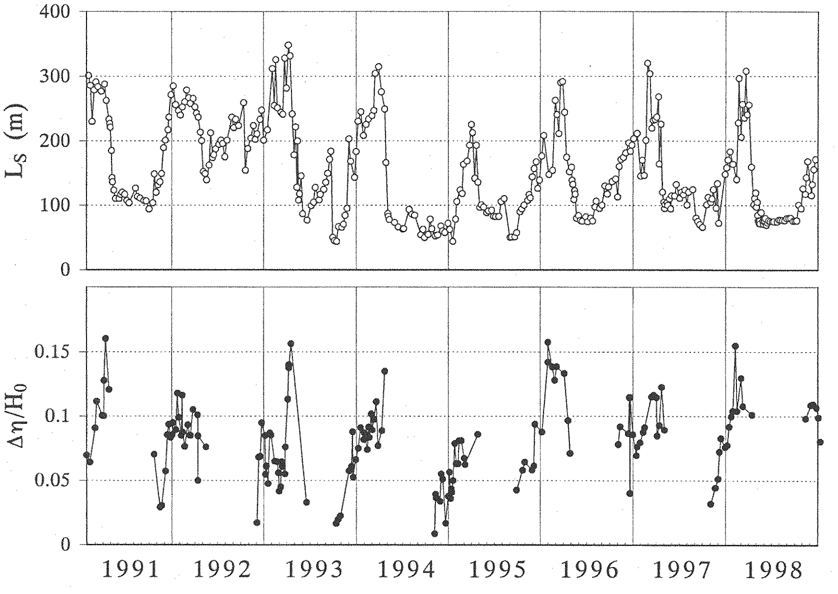


Fig. 4 Relationship between dimensionless wave set-up height and sand spit length

CONCLUSIONS

The following conclusions of the present study were obtained by analyzing the water level variation at the Shiribetsu River mouth in Hokkaido, Japan.

(1) The superelevation of the water level above tidal elevation can be observed in the Shiribetsu River mouth during winter. The magnitude of water level rise shows a very close correlation with the wave height. It can therefore be concluded that this superelevation is induced by wave set-up caused by wave breaking in front of the river mouth.

(2) Oblique photographs of the river mouth taken every week are utilized to obtain time variation of sand spit length at the Shiribetsu River mouth. It was found that the sand spit shows distinct seasonal variation throughout the year.

(3) Dimensionless wave set-up height $\Delta\eta/H_0$ has a very close relationship with the length of sand spit.

ACKNOWLEDGEMENTS

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APPENDIX – NOTATION

The following symbols are used in this paper:

a	= constant in Eq. 1;
b	= constant in Eq. 2;
h_{RM}	= water depth at the river mouth;
H_0	= deep water wave height;
Ls	= length of sand spit;
Q	= river discharge;
x, y	= plane coordinates;
$\Delta\eta$	= η_{RT}-η_{T};
η_{RT}	= water level in the river mouth;
η_{T}	= tidal level; and
ξ, ζ	= coordinate system in an oblique photograph.

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