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ACCURACY OF AN ESTIMATION METHOD OF WATER DEPTH AT A RIVER MOUTH USING WATER LEVEL VARIATIONS

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Abstract: It is observed that the water level variation inside and outside the Natori River mouth shows distinct difference after the formation of sand spit at the mouth, although the difference is not so remarkable after flushing of the spit during a flood. Using a simple model for an inlet-bay system, an estimation method is proposed to calculate water depth at the throat section of the river mouth from measured water level variation. Detailed investigation is carried out for the accuracy of the estimation method.

Key words: River mouth, Water depth estimation, Natori River, Tidal variation

1. INTRODUCTION

Development of sand spit at a river mouth is a significant concern for river authorities in connection with backwater effect during a flood. Due to that reason, it is important to grasp the change in river mouth topography at a river mouth caused by combined effect of river flow, tidal current and waves. In order to obtain topography data in a river mouth, however, it consumes a lot of time and budget in general, especially in an immersed area. If it is possible to estimate underwater topography in river mouth from water level data, it will be remarkably effective for the maintenance of a river entrance, because water level measurement is much cheaper and easier as compared with ordinary field surveying of river mouth morphology.

In the present study, an estimation method of water depth at a river entrance is proposed and applied to hypothetical data from a numerical model to validate the estimation method. Furthermore, the estimation method is applied to field observation data. For this purpose, detailed field measurement data of water level variation at the Natori River mouth, Japan is used (Watanabe, et al., 2002).

2. ESTIMATION METHOD OF WATER DEPTH AT A RIVER MOUTH

Schematic explanation for the assumption in the present estimation method is shown in Fig.1. Since the model will be applied to Natori River in Japan (see Fig.6), two jetties are drawn in this figure. The corresponding governing equations are given by Eqs.(1) and (2), equations of motion and continuity, respectively (Keulegan, 1967).

$$\eta_o - \eta_R = (K_{en} + K_{ex} + \frac{2gn^2 L}{R^{4/3}})\frac{|U|U}{2g} \tag{1}$$

$$U = \frac{A_R}{A_C}\frac{d\eta_R}{dt} \tag{2}$$

where η_O is the tidal elevation, η_R is the water level in the river mouth, R is the hydraulic radius, U is the velocity, and A_c is the cross-sectional area of the river mouth. The definition of other quantities can be found in Fig.1 and Table 1.

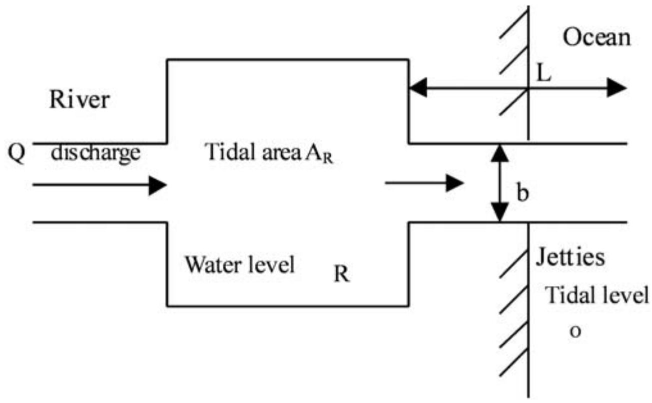

Fig. 1 Schematic explanation for river mouth modeling

Here, the shape of river mouth cross-section is assumed to be rectangular. Field observation inside and outside of a river mouth enables us to obtain time-variation of η_O and η_R. Furthermore, morphological surveying gives us L and A_R for the area of our interest, both of which can be regarded as unchanged quantities. As for K_{en}, K_{ex} and n, commonly accepted values have already been available as listed in Table 1. Thus, it is now possible to calculate the water depth h, contained in R and A_c in Eqs.(1) and (2), using measured water level variation inside and outside of a river mouth.

3. APPLICATIN TO MODEL DATA

3.1 GENERATION OF Hypothetical Data

In order to compensate field data, a numerical model explained above has been employed to generate water level variation at a river mouth. The calculation condition is summarized in Table 1, considering the real condition at the Natori River mouth. Using Runge-Kutter method, time-variation of water level in a mouth can easily been obtained, and is used later as a model data.

Accuracy of measured water level is up to **mm** or **cm** in general, whereas hypothetical data obtained by a computer can be quite accurate, much more than observed data. Therefore, the effect of significant figure on estimated result is investigated. Furthermore, it should be noted that the first derivative is included in the governing equation, Eq.(2), and the accuracy in the calculation of first derivative is dependent on the interval of water elevation data. Thus, second investigation is performed for the effect of interval of water level data.

Table 1 Calculation condition

notation	definition	value
A_R	tidal area (m^2)	1,730,000
L	channel length (m)	522
B	channel width (m)	86
h	water depth (m)	3.1
a_o	tidal amplitude (m)	0.74
T	tidal period (s)	43,200 or 86,160
K_{en}	entrance loss coefficient	0.3
K_{ex}	exit loss coefficient	1.0
n	Manning's coefficient of roughness	0.035

3.2 EFFECT OF SIGNIFICANT FIGURE

At first, the effect of significant figure of measured data on estimated results is examined. The interval of the water variation data is 5 min in this analysis. Fig. 2 shows the result for semi-diurnal tidal data, while Fig.3 is for diurnal tidal variation. In each figure, η_O and η_R indicate hypothetical water level variation, and estimation of water depth is made for three different accuracy of water level data, i.e., single precision, rounded off to **mm** and to **cm**. From Fig.2, it is seen that the data rounded off to cm yields considerable error, whereas **mm** data gives satisfactory estimation for water depth *h*.

Comparing the estimated results for semi-diurnal and diurnal tides, it is observed that the estimation for the latter is worse. O'Brien and Dean (1972) indicated that when tidal period is shorter, the phase difference between tide and water level becomes larger. In the present estimation method, the water level difference inside and outside the mouth is utilized, and, thus, the bigger the water level difference is, the higher the accuracy in the estimation becomes. This is the reason why the estimation for semi-diurnal tide shown in Fig.2 is better as compared with Fig.3.

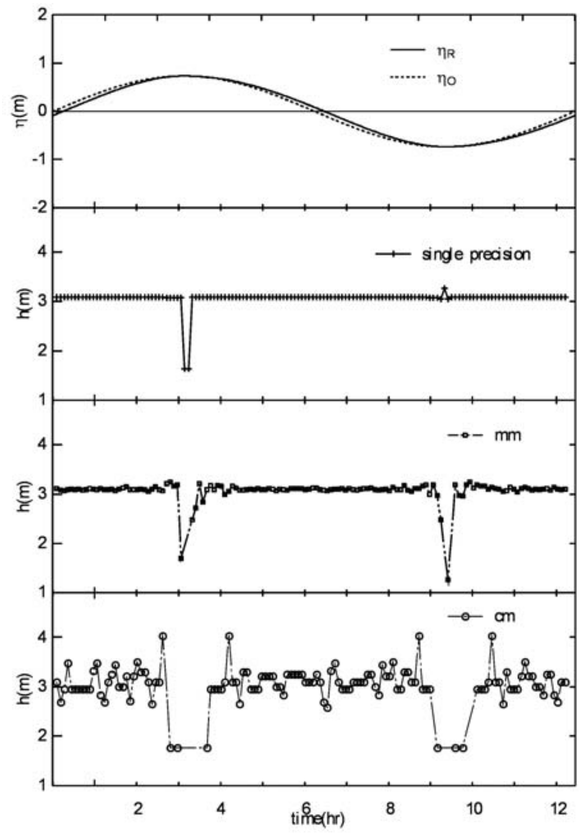

Fig. 2 Effect of significant figure (semi-diurnal tide)

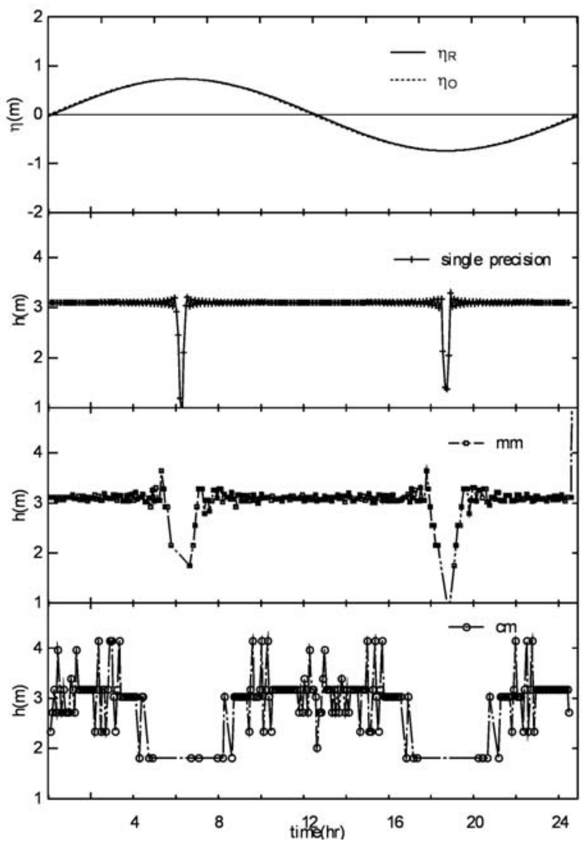

Fig. 3 Effect of significant figure (diurnal tide)

3.3 EFFECT OF DATA INTERVAL

Next, the effect of interval of water level data on estimation accuracy is investigated. Fig. 4 and Fig. 5 shows the results for semi-diurnal and diurnal tides, respectively.

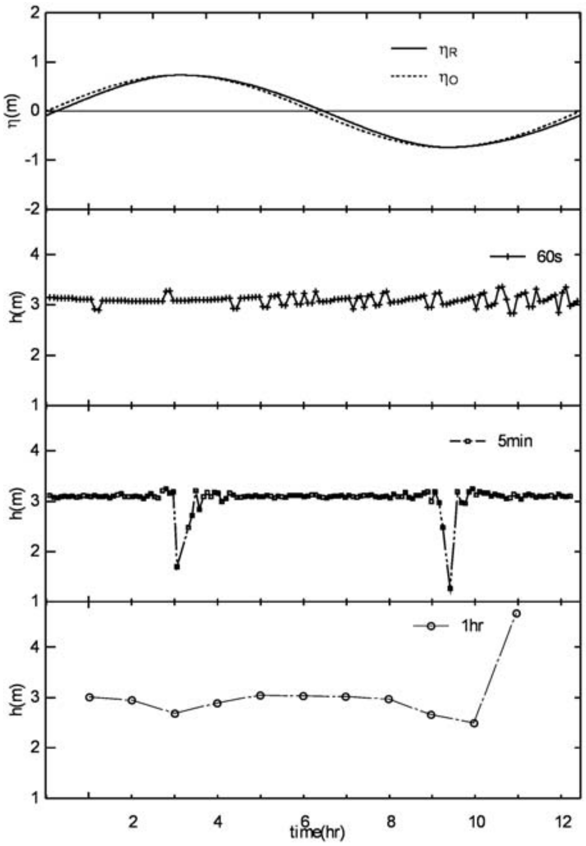

Fig. 4 Effect of data interval (semi-diurnal tide)

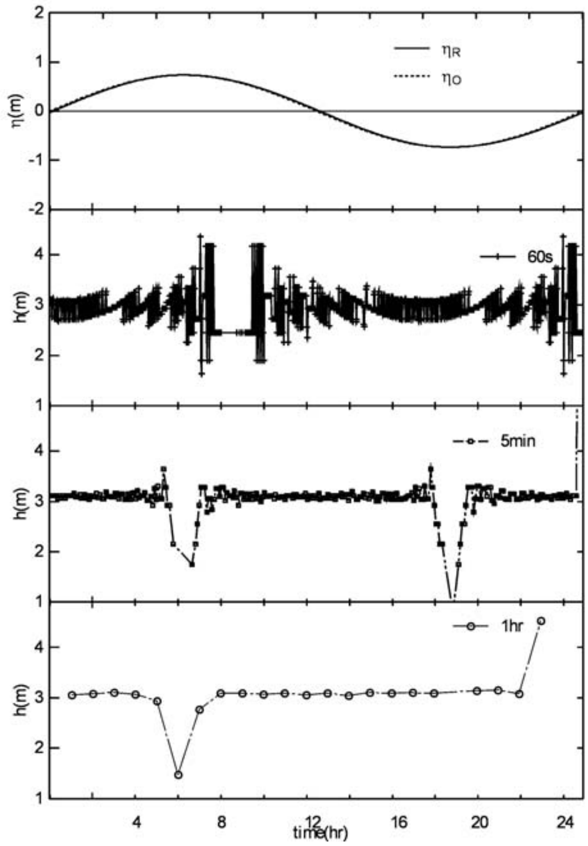

Fig. 5 Effect of data interval (diurnal tide)

The data rounded off to **mm** are used here. In Fig.4, it is seen that the accuracy is not sufficient when the difference between tide and water level is almost zero. Except these periods, the estimation method gives good results.

The estimation for diurnal tide is comparably worse, as seen in Fig.5. This result is consistent with that observed in Fig. 2 and Fig. 3.

3.4 EVALUATION OF ERROR

To make more quantitative evaluation of the estimation accuracy, *Root Mean Squared Error* (*RMSE*) and the average of the estimated water depth h_{mean} are used. The definition of *RMSE* is given by Eq.(3).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(h_{(cal)i} - h_{(real)})^2}{N}} \tag{3}$$

where the subscript *cal* and *real* means calculated and real values, respectively, and *N* is the number of estimated water depth.

Tables 2 and 3 show h_{mean} and *RMSE* for each case. From Table 2, it can be concluded that the estimation with the water level data rounded off to **mm** yields sufficient accuracy. As explained above, the estimation for longer tidal variation is less accurate, due to smaller difference of water levels inside and outside the river mouth.

4. APPLICATION TO NATORI RIVER MOUTH

4.1 STUDY AREA AND WATER LEVEL MEASUREMENT

A map around the study area is shown in Fig.6. The Natori River has catchment area of 938.9km^2, with the length of 55.0 km. The Natori River originates near the border between

Yamagata and Miyagi Prefectures, Japan and pours to the Pacific Ocean. The River mouth jetties have slight curvature toward the north, which causes erosion on the right side bottom due to spiral flow. There are Idoura Lagoon and Hiroura Lagoon on the right-hand and left-hand sides of the mouth, respectively, which indicates extreme migration of the opening in the past due to predominant longshore sediment movement.

In the downstream area of Natori River, there has been flood damage four times in the past fifteen years. In order to reduce the damage in this area due to floods, an embankment was constructed near the River mouth in 2001, to separate the main channel from the tributary, Masuda River. After the completion of the construction, abrupt change in river mouth morphology has been observed, as reported by Watanabe et al. (2003).

Table 2 h_{mean} and *RMSE* (semi-diurnal tide)

Significant figure / Δt		Single precision	mm	cm
60s	h_{mean}(m)	3.11	3.11	3.53
	RMSE (m)	0.54	0.58	1.06
5min	h_{mean}(m)	3.06	3.10	3.04
	RMSE(m)	0.18	0.40	0.39
60min	h_{mean}(m)	3.17	3.17	2.90
	RMSE(m)	0.43	0.42	0.31

Table 3 h_{mean} and *RMSE* (diurnal tide)

Significant figure / Δt		Single precision	mm	cm
60s	h_{mean}(m)	2.95	3.01	3.80
	RMSE(m)	0.25	0.36	0.91
5min	h_{mean}(m)	3.06	3.07	3.01
	RMSE(m)	0.26	0.33	0.54
60min	h_{mean}(m)	3.03	3.07	2.89
	RMSE(m)	0.23	0.47	0.44

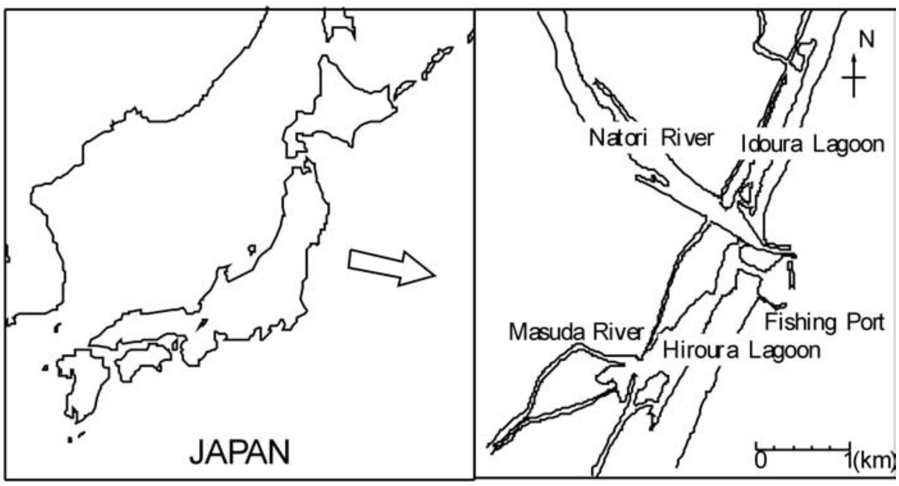

Fig. 6 Map of study area

Water level gauges were installed inside and outside of the Natori River mouth. Fig. 7 shows the measured water level variation in January 2002. Time-interval of water level observation is 1 min, which is much smaller than that of ordinary measurements.

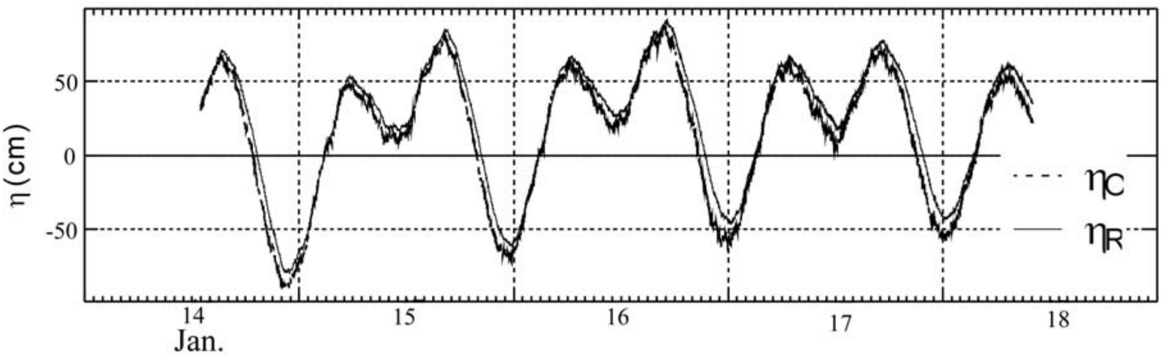

Fig. 7 Measured water level at the Natori River mouth

4.2 RESULT AND DISCUSSIONS

It is observed in Fig.7 that the measured water level, especially tidal data, is accompanied with fluctuations with higher frequency. Since use of law data with the fluctuation yielded unrealistic results for water depth, smoothed data is used in the analysis hereafter.

The result of estimation is shown in Fig.8, along with the water level variation after smoothing. When the difference of water levels is small, the estimation result diverges to infinity, as mentioned above. Except these periods, however, estimated value for the water depth h is almost constant. Averaging over the period excluding unrealistic estimations, we obtain h=2.53m, whereas average of the measured water depth is h=3.1m, with minimum depth h=2.77m between the jetties. Thus, fairly good agreement can be seen between the field measurement and the estimation by the present method.

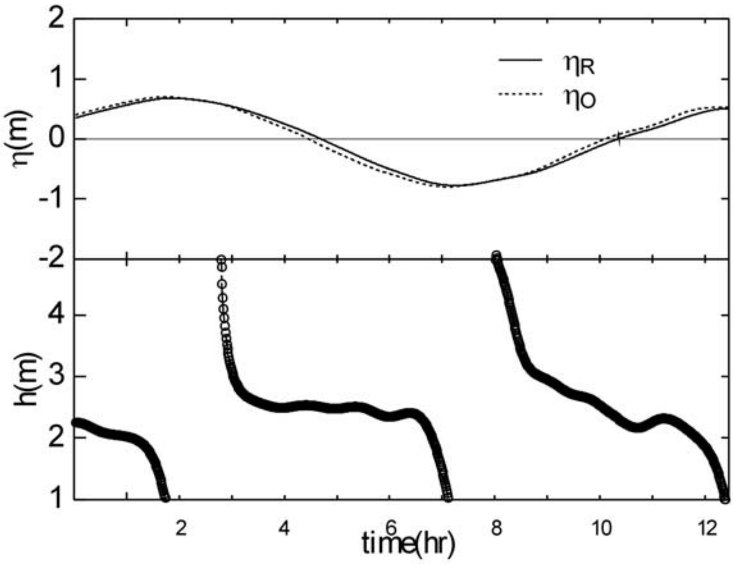

Fig. 8 Estimation of water depth for Natori River

5. CONCLUSIONS

An estimation method is developed for estimating river mouth depth. Before applying to a real river mouth, applicability of the estimation method is examined for hypothetical data generated by a numerical model for an inlet-bay system. It is concluded that the method gives satisfactory estimation. However, it should be noted that the estimation method is significantly influenced by both significant figure and measurement interval of water level data.

Secondly, the method is applied to the Natori River mouth, Japan. It is confirmed that the estimation method yields fairy good result for the water depth at throat section of the river mouth.

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