II −69 INVESTIGATION OF WATER FLOW PROPERTIES INSIDE NAGATSURA-URA LAGOON

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1. INTRODUCTION

A natural semi-enclosed water area is usually used for aquaculture because of its calm flow condition. However, the water quality of some such areas continues to decrease due to the increase of the cultivation, which exceeds the self-purification capacity of pollution load. It is very important for environmental conservation to understand each characteristic of the region because each semi-closed water area is unique and various in its form. Therefore, it is necessary to carry out field observation to evaluate the characteristic of the each water areas.

Nagatsura-ura Lagon, located in the northeastern part of Miyagi Prefecture, is a brackish water body connected with the sea area through a small channel of tidal inlet. The cultivation of oyster has been done actively for 50 years using the calm feature of the water body. Unfortunately, the death of oyster happened in recent years due to anoxic water in bottom layer.

It has already known that physical characteristic, including flow field, takes major part in determining the water quality. Biological and chemical information are greatly influenced by both spatial and time variation of flow characteristic. However, flow behaviors inside the lagoon have not been well understood. This study is an attempt to get more information concerning the flow condition inside the lagoon.

2. STUDY AREA AND FIELD OBSERVATION

Location of the study area, Nagatsura-ura lagoon, is about 60 km to the North East from the City of Sendai, and in the vicinity of river mouth of the Kitakami river. It has an area of 1.41 km^2, a perimeter of 8 km, and a tidal inlet with a length of 1.7 km and a maximum depth of 2 m, which connects the lagoon with the sea. The outline of geographical features is shown in Fig. 1.

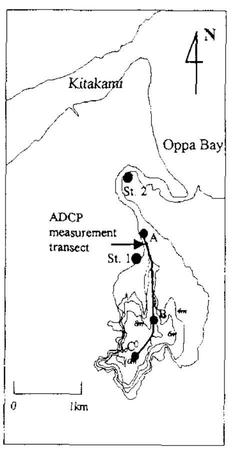

Fig.1 Lay out of the study area

In the bottom part of the lagoon, there happened lack of oxygen condition during summer season (Tanaka et al., 2004). Accordingly, an observation was conducted from July 21 to August 15, 2003. At the time of flood tide within the observation period (July 28th and 29th), ADCP (Acoustic Doppler Current Profiler, a product made by RDI) was used to measure velocity profile along a measurement transect as shown in Fig. 1. Water temperature and salinity were measured at the lagoon inlet (location A) whereas water temperature, salinity, and DO were measured at the inner part of the lagoon (location B). However, this paper is restricted to discuss the flow characteristic of the lagoon. Discussion on water quality characteristic based on the observation can be found in a paper published by previous investigator (Okajima et al., 2004). In addition, automatic measurement devices have already been installed in station 1 and station 2 to measure water level since the year of 2002.

3. RESULTS AND DISCUSSIONS

Previous investigation (Okajima et al., 2004) shows that there is a flow water intrusion happened in the middle layer of the lagoon as it is shown in Fig. 2. Furthermore, it has been shown that such kind of intrusion happens when salinity of incoming flow has intermediate value of salinity stratification, thus causing density stratification, in the lagoon (Tanaka et al, 2004).

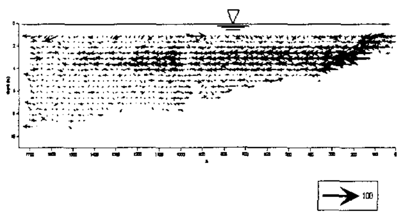

Fig.2 Middle layer intrusion of N-S velocity

The vertical distribution of velocity of the middle layer intrusion has its maximum value around the depth of 3 to 4 m, which is located around the center-line of the distribution, and decreases as it goes further into the lagoon. This characteristic is similar to that of the jet theory. In order to know better about the velocity distribution of the inflowing water flow, it is reasonable to make a comparison with turbulent two-dimensional jet theory (Schlichting,1979):

$$u = \frac{\sqrt{3}}{2}\sqrt{\frac{K\sigma}{x}}\left(1-\tanh^2\eta\right) \quad (1)$$

$$v = \frac{\sqrt{3}}{4}\sqrt{\frac{K}{x\sigma}}\left\{2\eta\left(1-\tanh^2\eta\right)-\tanh\eta\right\} \quad (2)$$

where $J = \frac{4}{3}\rho U_s^{\,2}\, s/\sigma$, $K = J/\rho$, $\eta = \sigma\, y/x$, U_s : center-line velocity at a fixed characteristic distance s, σ: empirical constant (=7.67), ρ : density, u and v : x and y velocity component respectively.

Four vertical distributions of north-south (N-S) velocity are selected at distances of 1007.66 m, 1065.37 m, 1187.77 m, and 1251.57 m measured from the starting point of ADCP measurement transect on 28th July, 2004, at a time of flood tide. These distributions are then compared with the theoretical curve of jet theory as shown in Fig. 3. The horizontal axis is the N-S velocity u normalized by the maximum value u_{max} of its vertical distribution. The vertical axis is depth location of the N-S velocity y normalized by depth location of $0.5u_{max}$ that is denoted by a function $y(0.5u_{max})$ calculated from Eq. 1 after substituting u with $0.5u_{max}$. In this figure, the south-velocity has positive value due to normalizing process. The figure shows good agreement between measurement and the theoretical jet curve except at the bottom part of the curve.

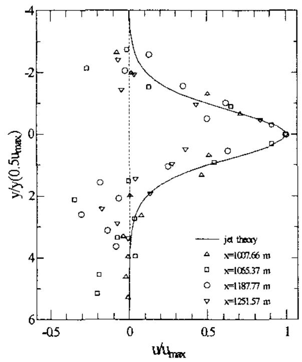

Fig.3 Vertical distribution of N-S velocity and the jet theory

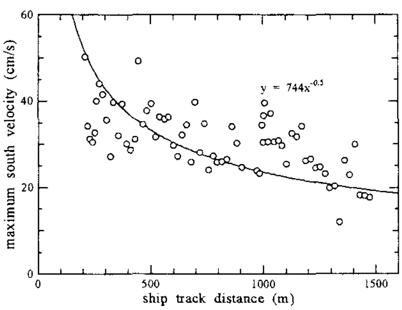

Fig.4 Maximum of vertical distribution of N-S velocity

Fig. 4 shows the maximum values of vertical distribution of north-south velocity along the ADCP transect after eliminating some`differently behaved points. The jet theory states that the decrease of center-line velocity is in proportion to $x^{-0.5}$ where x is the distance from the point of discharge. The least square fitting is used to fit the jet theory with the observed value of the maximum velocity. In this figure, the south-velocity is denoted by positive value to show clearly the gradient of its decreasing value. The comparison shows that the measurement does not well agree to the jet theory especially near the inlet and inner part of the lagoon.

The upper part of Fig. 5 shows water level variation in which the full line denotes that of inside the lagoon while the broken line denotes that of outside the lagoon. The water level inside the lagoon can not be lowered as compared to that of outside the lagoon due to the existence of the tidal channel. This means that the existence of the tidal channel reduces the amount of water volume exchange in the lagoon. The bottom part of Fig. 5 shows time-variation of discharge that passes through cross section of the lagoon inlet. The line with circles shows the computation based on the time-variation of water level: $Q_\eta = A_L\, d\eta/dt$, where A_L: the area of the lagoon, η: the water level, and t: the time, whereas triangle marks show the computation based on the average flow velocity passing the cross section of the lagoon inlet: $Q_u = A_{inlet} u_{inlet}$, where A_{inlet}: cross-sectional area of the inlet, u_{inlet}: cross-sectional averaged flow velocity of the inlet. A comparison of both the two discharge computations shows identical patterns, though the computation based on the flow velocity shows fluctuation that needs further smoothing by comparing to other cross sections. The comparison confirms the computation of the tidal prism that should be based on the water level variation in the lagoon.

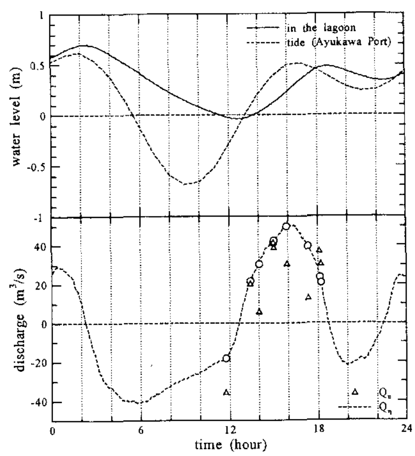

Fig.5 Time-variation of discharge

4. SUMMARY

The vertical distribution of velocity of the middle layer intrusion is appropriately represented by the turbulent jet theory profile except at the bottom part of the curve. However, the decrease of center-line velocities along measurement transect does not fully follow that of the jet theory especially near the inlet and inner part of the lagoon. The comparison of the two method of discharge computation confirms the computation of the tidal prism that should be based on the water level variation in the lagoon

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