II－79

SIMULATION OF TURBIDITY IN NAGATSURA-URA LAGOON

Tohoku University　Graduate Student　○ Purwanto Bekti Santoso
Tohoku University　Fellow Member　Hitoshi TANAKA
PENTA-OCEAN Const. Co.Ltd　Research Engineer　Susumu KANAYAMA
Ishinomaki SENSHU Univ.　Professor　Mitsuru TAKASAKI
Tohoku University　Research Associate　Hiroto YAMAJI

1. INTRODUCTION

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

High turbid water that sometime reaches the lagoon is one of the causes of environmental impact to the lagoon area. Human activities in watershed of the Kitakami River, the nearby river, contribute to increasing of suspended sediment concentration level in the river. High turbid water flows along the Kitakami River following high precipitation happened on the river catchment area. The resulted runoff brings sediment to the river resulting in higher turbidity. Turbid water may content high nutrient concentration that can influence ecosystem in the lagoon. Knowledge of spreading of fine suspended particles is necessary to understand whether the influence of turbid water to oyster growth is in acceptable level or not.

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 connected to the sea by a tidal inlet with a length of 1.7 km and a maximum depth of 2 m. The outline of geographical features is shown in Fig. 1.

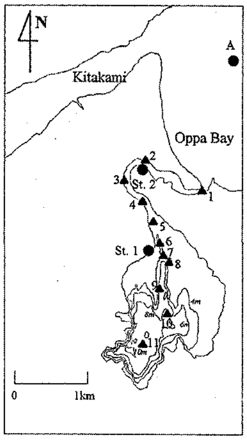

Fig.1 Lay out of the study area

Equipment used for measurement of turbidity is AAQ 1183, a product made by ALEC Electronics Co. Ltd., that measures turbidity using back-scattering light type method. The unit of measurement is FTU (Formazin Turbidity Unit) since it employs formazin as the calibration standard. Measurements were carried out in summer 2005, 08/15-16 and 09/26-27, at the time of flood tide on each measurement day. Location of measurement is along the tidal channel (point 1 – point 5) and in the lagoon (point 6 – 11), which denoted by filled triangle in Fig. 1. Salinity and temperature were measured in point 5 and point 11. In addition, automatic measurement devices have been installed in St. 1 and St. 2 to measure water level since the year of 2002.

In 2001, a field observation was carried out to measure suspended solid concentration and its related settling velocity by deploying sediment traps. For the current study purpose, settling velocity measured in location A is used for calculation. The suspended particles must be fine enough to be able to travel over a distance from the mouth of the Kitakami River to the lagoon. The smallest value of 3.24E-05 m/s is chosen for simulation (see Table 1.).

Table 1. Settling velocity and its measurement time

Measurement time	Settling velocity	
	m/d	m/s
2001/08/25-26	2.8	3.24E-05
2001/08/26-27	3.2	3.70E-05
2001/08/27-30	8.1	9.38E-05
2001/09/14-15	3.8	4.40E-05
2001/09/15-16	16.8	1.94E-04

3. RESULTS AND DISCUSSIONS

(1) Numerical Modeling

The hydrodynamic model adopted here is the one based on the hydrostatic pressure approximation and the boussinesq approximation, and fixed layer divisions in vertical discretization. This model basically follows the procedure introduced by Sato et al. (1993) with addition of baroclinic term to take into account the effect of density gradient. The procedure itself inherently contains capability of wetting and drying procedure with negligible expense on computational time as previously shown by Casulli and Cheng (1992). A set of governing equations is required to compute four unknowns, three velocity components and water level. The momentum equations are

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}$$
$$=-g\frac{\partial \eta}{\partial x}-\frac{g}{\rho_0}\frac{\partial}{\partial x}\int_z^{\eta}\rho' dz+v_h\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(v_v\frac{\partial u}{\partial z}\right) \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}$$
$$=-g\frac{\partial \eta}{\partial y}-\frac{g}{\rho_0}\frac{\partial}{\partial y}\int_z^{\eta}\rho' dz+v_h\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(v_v\frac{\partial v}{\partial z}\right) \quad (2)$$

and the continuity equation is

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (3)$$

Here, (u,v,w) is flow velocity in the direction of (x,y,z). η is the height of free water surface, g is the gravity, ρ_0 is a constant reference density, $\rho'(x,y,z,t)$ is the local variation from the reference density, ν_h and ν_v are the eddy viscosity coefficients in horizontal and vertical respectively. Calculation of η is based on depth integration of equation (3) with kinematic boundary condition at the free surface to obtain

$$\frac{\partial \eta}{\partial t}+\frac{\partial}{\partial x}\left[\int_{-H}^{\eta} u dz\right]+\frac{\partial}{\partial y}\left[\int_{-H}^{\eta} v dz\right]=0 \qquad (4)$$

where H is depth of bottom boundary measured from undisturbed free water surface. The resulting velocity field is then coupled with the conservation equation of fine solids concentration C as follows:

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+(w-w_0)\frac{\partial C}{\partial z}$$
$$=\frac{\partial}{\partial x}\left(\nu_{hc}\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu_{hc}\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(\nu_{vc}\frac{\partial C}{\partial z}\right) \qquad (5)$$

where w_0 is settling velocity of suspended particles; ν_{hc} and ν_{vc} are horizontal and vertical diffusion coefficients respectively. The concentration is calculated by using semi-implicit difference scheme, which is implicit in vertical and explicit in horizontal direction. As calculation is done over short period, i.e. 1.5 hours that is the time needed to make measurement from point 1 to point 11, and the resulted current not fast enough to erode bottom deposit, no bottom sediment pick up is considered in this study.

(2) Calculation condition

Calculation is done over 72 x-grids and 148 y-grids in which both directions have uniform mesh size of $\Delta x = \Delta y =$ 20 m. In vertical, the domain is divided into 20 layers. A total of 1 m thickness, 0.3 m added to 0.7 m of tidal fluctuation, is set at the first layer, whereas 0.25 m of thickness is specified to 2-13th layers and the rest of layers are set to 1 m of thickness. Since there is no water level data in Oppa Bay, tide level data at Ayukawa Port, located 30 km to the south from the study area, provided by Japan Meteorological Agency is used as open boundary condition. Temperature and salinity data measured at point 5 are uniformly set along the channel up to open sea boundary. Similarly, turbidity of 14 FTU is specified in the same location. Turbidity data obtained from measurement conducted on 2005/08/16 is selected for the simulation because of its highest turbidity among other measurement data. Turbidity along the tidal channel can be considered as uniformly distributed because of strong mixture in the channel. Model is allowed to "spin up" for 24 hours, which correspond to 2 tidal cycles, to obtain field current before the turbidity is specified at that location. Initial condition is set to 2 FTU for turbidity, while temperature and salinity are specified from measurement. Drag coefficient of 0.007, which corresponds to Manning coefficient of 0.025, is used for bottom stress calculation.

(3) Calculation result

Verification of resulted density current profile is not shown here since it can be found elsewhere (Purwanto et al., 2005). Fig. 2 shows measured and calculated water level in the lagoon, along with water level at Ayukawa Port. Simulation shows lagoon's water level characteristic, i.e. it cannot be lowered due to the existence of shallow tidal channel. Discrepancies shown in the figure contributes to open boundary water level that is estimated from Ayukawa Port instead of using measured value at boundary. Furthermore, bathymetry uncertainty and geometry reproduction of the channel used for the simulation give further discrepancies.

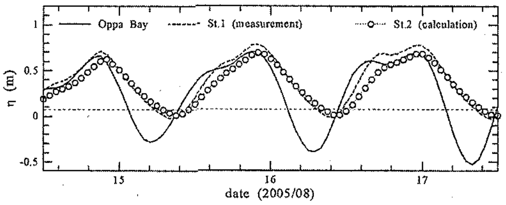

Fig.2 Measured and calculated water level

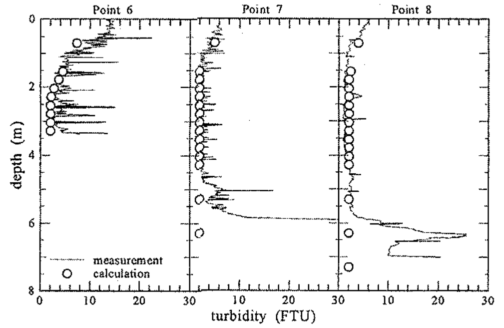

Fig.3 Measured and calculated turbidity

Fig. 3 shows comparison of measured and calculated turbidity. Since the simulation is done over short period, it cannot appropriately simulate high turbidity in bottom of point 7 and point 8, which results from settling of suspended particles of previous flooding. However, turbidity profiles near the water surface can be captured. This comparison confirms that most suspended particles in the lagoon originate from the Kitakami River.

4. SUMMARY

Simulation of turbidity in Nagatsura-ura Lagoon had been carried out. Given that settling velocity used in the simulation is obtained from measurement near the mouth of the Kitakami River, turbidity profiles resulted from the simulation confirm that most suspended particles in the lagoon originate from the river.

ACKNOWLEDGMENT

The authors express their thanks to Kitakami River Lower Research Office, the Ministry of Land, Infrastructure and Transportation, for providing the settling velocity data.

REFERENCES

1. Casulli, V., and Cheng, R. T.: Semi-Implicit Finite Difference Methods for Three-Dimensional Shallow Water Flow, Int. Jour. for Numerical Methods in Fluids, 15, pp. 629-648, 1992.
2. Purwanto Bekti Santoso, Kanesato, M., Kanayama, S., Tanaka, H., Takasaki, M. and Yamaji, H.: Flow characteristics in Nagatsura-Ura Lagoon, Proceedings of Coastal Eng. JSCE., Vol.52, pp. 871-875, 2005. (in Japanese)
3. Sato,K. et al.: Efficient calculation method of 3-D tidal current, Proceedings of Coastal Eng. JSCE., Vol.40, pp.221-225. 1993. (in Japanese)