A three dimensional numerical model of tide and tidal current in the bay of Cheonsu in Korea

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ABSTRACT

The purpose of this study is to find tide and tidal current variation by three dimensional numerical model of tide and tidal current in the bay of Cheonsu in Korea. On the basis of the observed data on water temperature and salinity data and wind data of summer(July) in the bay of Cheonsu in Korea, water circulation in the bay of Cheonsu is investigated with use of a robust diagnostic numerical model, including wind-driven current, density-driven current,and tide-induced residual current. The calculated co-range and co-tidal charts of M_2 tide are similar to the observed ones. The residual flow pattern at the surface layer during summer formed clockwise circulation in the front coastal the dike of the Sosan A zone(Ganwor island) and Taeju island. The residual flow pattern at the 15m layer during formed clockwise circulation in the front Taeju island. The residual flow pattern at the surface layer formed anti-clockwise circulation in the upper Sangmok and Naepasu island.

1.Introduction

Bay of Cheonsu is located between 126° 30′ E~126°50′ E and 36°35′ N at the western coast of the Korean Peninsula. In summer NNE wind prevails over the bay with an average speed of about 2.2 *m*/sec(Report of Taechon harber development work). There are many small islands including extensive areas of semi-diurnally flooded and dewatered tidal flats. Bay of Chednsu has a range of 6.39m spring tide. The maximum tidal current speed between Taeju island Hongsong coastal is about 0.9m/sec and 0.8m/sec in ordinary spring tide. Recently, the degree of ocean environmental pollution in the Cheonsu bay serious because polluted escapage from gate drainage of the Sosan dike. It is obvious that residual flow plays an important role in the long term material transport process in the Cheonsu bay. But there has been no study on the residual flow in the Cheonsu bay. In this study a robust diagnostic three-dimensional numerical model is applied to simulate the residual current field, including wind-driven current, density-driven current , and tide-induced residual current in the Cheonsu bay. The result of this study can be used for pollution prediction of Cheonsu bay.

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2. Field Observation

The field observations of tide and tidal current in the Cheonsu bay were carried out by the Fisheries Science Institute in Kunsan University(July 1997). The observed data of water temperature and salinity data of summer(July) in the bay of Cheonsu at 2 levels from 1989 to 1994 are obtained from National Fisheries Research and Development Agency, Republic of Korea. Wind fields are use Meteorological Agency of Korea(Report of Taechon harber development work). The observed co-range(full line) and co-tidal(broken line) of M_2 tidal constituent are shown in Fig.1(R.D.C.Korea,1988). The amplitude of tide is 208cm at the Oe island.

3. Numerical Model of tide and tidal current in the bay of Cheonsu

A three dimensional numerical model of tide and tidal current in the bay of Cheonsu based on the 3-D Saint-Vernant equation system(Nihoul and Jamart,1987) is used to simulate the propagation of tidal wave as well as to consider the tidal currents and tidal-induced residual flow in the bay.

It is common in tidal models to make some simplifying approximations in the equations of fluid motion. The fluid is assumed to be incompressible. The vertical momentum equation can be approximated by the hydrostatic pressure equation, that is a hydrostatic approximation. With these assumptions, using conventional notation, horizontal momentum equations on the cartesian co-ordinate are as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{3.1}$$

$$\frac{\partial u}{\partial t}+\frac{\partial (uu)}{\partial x}+\frac{\partial (uv)}{\partial y}+\frac{\partial (uw)}{\partial z}-\Omega v=$$

$$-g\frac{\partial \zeta}{\partial x}+A_h\frac{\partial^2 u}{\partial x^2}+A_h\frac{\partial^2 u}{\partial y^2}+\frac{\partial}{\partial z}\left(A_v\frac{\partial u}{\partial z}\right) \tag{3.2}$$

$$\frac{\partial v}{\partial t}+\frac{\partial (vu)}{\partial x}+\frac{\partial (vv)}{\partial y}+\frac{\partial (vw)}{\partial z}-\Omega u=$$

$$-g\frac{\partial \zeta}{\partial y}+A_h\frac{\partial^2 v}{\partial x^2}+A_h\frac{\partial^2 v}{\partial y^2}+\frac{\partial}{\partial z}\left(A_v\frac{\partial v}{\partial z}\right) \tag{3.3}$$

Here, x, y, z is a Cartesian coordinate with the z axis pointing vertically upwards and xy-plane being the undisturbed position of the water surface. u, v, w are x, y, z velocity components,respectively. Ω,Coriolis parameter, the gravitational acceralation, and A_v , A_h horizontal and vertical $g(=980cm$ sec^{-2})eddy viscosities, respectively.

There are boundary condition at the sea surface $z=0$,at the bottom $z=-h$, and at the lateral boundaries. They are

$$z=0 \quad : \quad \frac{\partial \zeta}{\partial t}+u\frac{\partial \zeta}{\partial x}+v\frac{\partial \zeta}{\partial y}-w=0 \tag{3.4}$$

$$\rho A_v\frac{\partial u}{\partial x}=0\ , \quad \rho A_v\frac{\partial u}{\partial z}=0 \tag{3.5}$$

$$z=-h \quad : u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}+w=0 \tag{3.6}$$

$$\rho A_v\frac{\partial u}{\partial z}=\tau_x^b, \quad \rho A_v\frac{\partial v}{\partial z}=\tau_y^b \tag{3.7}$$

At the solid boundary: The velocity component normal to this boundary is suppressed:

$$V_n = 0, \quad (\vec{n} \text{ is the unit outward vector}) \tag{3.8}$$

At the open boundary: The sea water level is prefixed on the basis of observation results: $\zeta = f(x, y, t)$ (3.9)

The vertical viscosity A_v, according to the Prantl's mixing lengh theory , is taken as

$$\begin{aligned} A_v &= A_{v0} + l^2\sqrt{(\partial u/\partial z)^2 + (\partial v/\partial z)^2}, \\ l &= k_0(z+h+z_0)[1-(z+h)/h] \end{aligned} \tag{3.10}$$

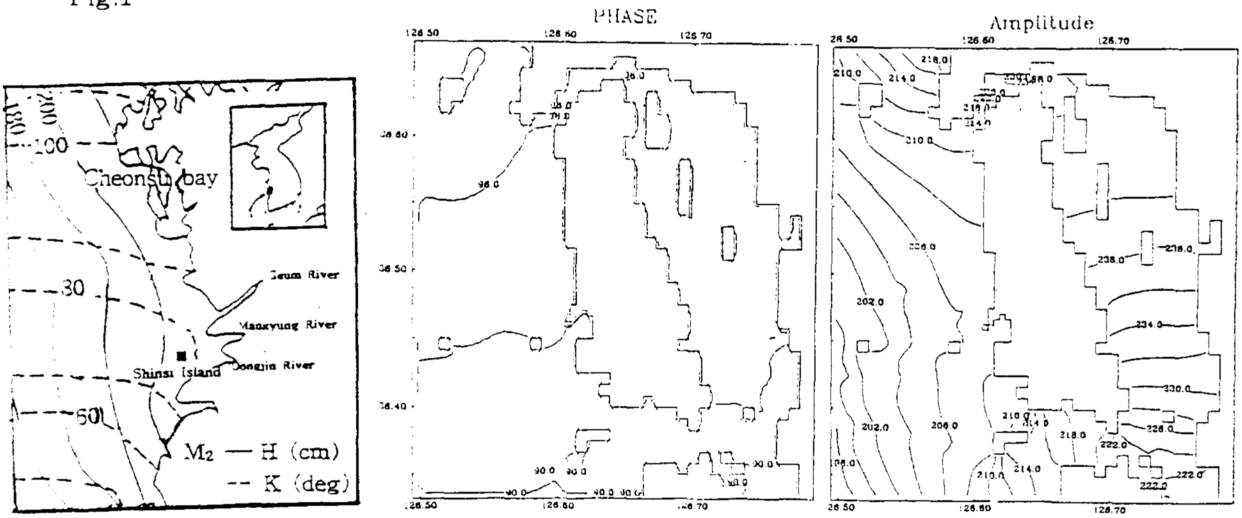
where, x_o(=0.4) is the Karman constant : z_o(=10cm) is the sea bed roughness length: A_{vo} is a small number to prevent the case of dividing by zero during the calculation. The components of bottom friction stress (τ_x^b, τ_y^b) are got the following form:

$$(\tau_x^b, \tau_y^b) = \beta\sqrt{(u^2+v^2)}\,(uv) \tag{3.12}$$

where, β is the botton friction coefficient. The boundary condition along the open boundary is

$$\zeta = \zeta_o \sin\left(\frac{2\pi}{T}t - P\right) \tag{3.13}$$

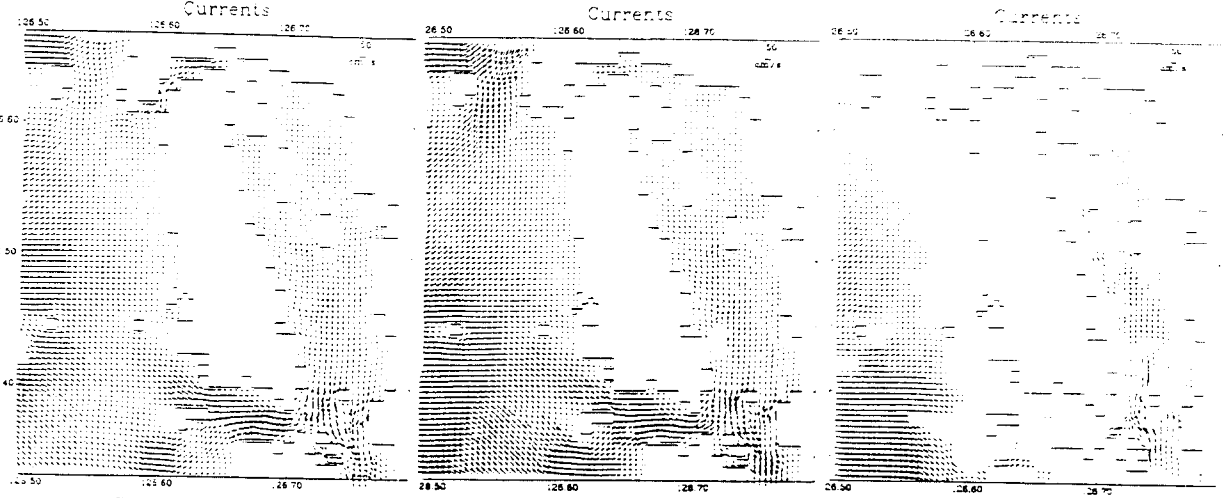
where, ζ_o and F are the amplitude and phase along the open boundary, respectively, T($= 12^h\ 25^m$) the tidal period of M_2 constituent, t the time. In order to solve velocity components and sea water level, the finite difference method is applied. Firstly, the depth averaged velocity components and sea water levels are determined. In this computation an alternative direction implicit(ADI) Scheme is employed. The calculated co-range and co-tidal charts of M_2 tide are shown in Fig.1



The observed co-range(full line) and co-tidal(broken line) of M_2 The calculated co-range charts of M_2 The calculated co-tidal charts of M_2

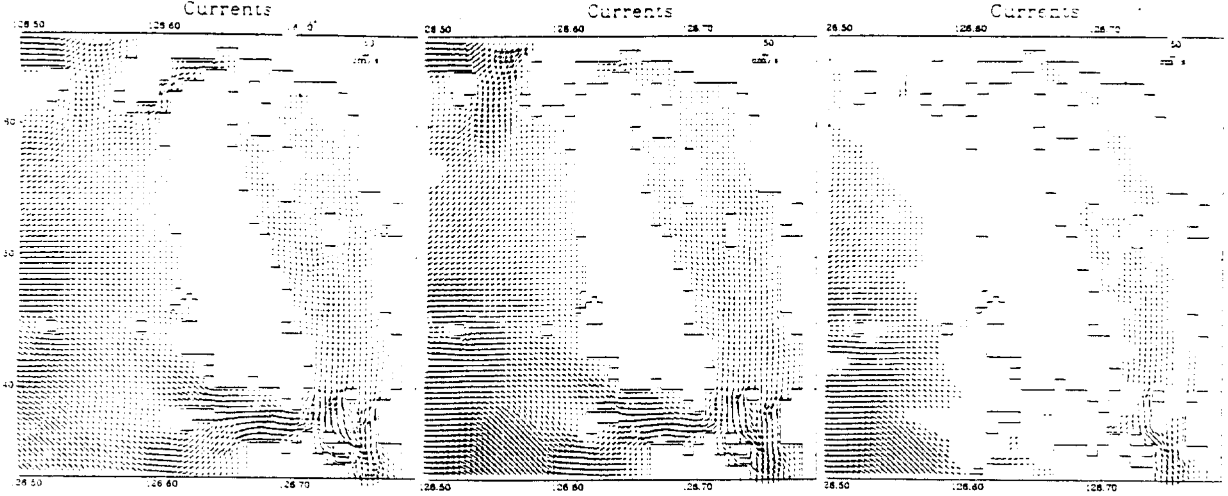
Fig.1 The co-range and co-tidal charts of M_2 tide.

The flow patterns of tidal current at the time of maximum flood and maximum ebb in the Cheonsu bay coastal region area are shown in Fig.2.3.



flow patterns of surface flow patterns of 5m layer flow patterns of 15m layer

Fig.2 The calculated flow patterns of tidal current after 3 time



flow patterns of surface flow patterns of 5m layer flow patterns of 15m layer

Fig.3 The calculated flow patterns of tidal current after 9 time

4. Numerical model of the residual flow

Seasonal variation of the residual flow in the Cheonsu bay is investigated with use of a robust diagnostic numerical model. Water circulations were calculated diagnostically from the observed data of water temperature and salinity data of summer(July) in the bay of Cheonsu from 1989 to 1994(National Fisheries Research and Development Agency,Republic of Korea). Wind datas of summer(2.2 m sec $^{-1}$) are use Meteorological Agency of Korea(Report of Taechon harber development work).

The model basin is divided horizontally into $0.5km \times 0.5km$ grid. Using conventional notation, the governing equations on the cartesian co-ordinate are as follows(Yanagi and Takahashi, 1993):

$$\frac{\partial u}{\partial t}+(u \cdot \nabla_h)u+w\frac{\partial u}{\partial z}+fx \times u= -\frac{1}{\rho_o}\nabla_h p+A_h\nabla_h^2 u+A_v\frac{\partial^2 u}{\partial z^2}+T_s \tag{4.1}$$

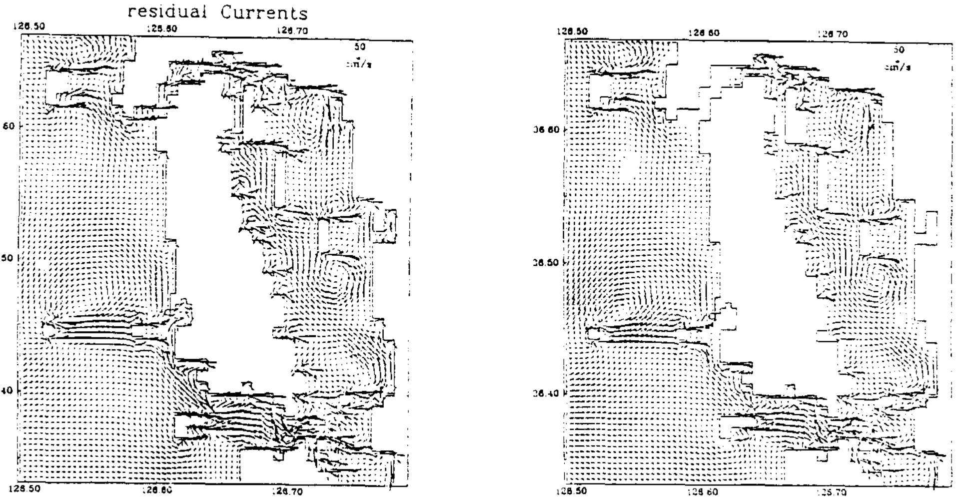
$$\frac{\partial p}{\partial z}=-\rho g \tag{4.2}$$

$$\nabla_h u+\frac{\partial w}{\partial z}=0 \tag{4.3}$$

$$\frac{\partial T}{\partial t}+(u \cdot \nabla_h)T+w\frac{\partial T}{\partial z}=K_h\nabla_h^2 T+K_v\frac{\partial^2 T}{\partial z^2}+\gamma(T^* - T) \tag{4.4}$$

$$\frac{\partial S}{\partial t}+(u \cdot \nabla_h)S+w\frac{\partial S}{\partial z}=K_h\nabla_h^2 S+K_v\frac{\partial^2 S}{\partial z^2}+\gamma(S^* - S) \tag{4.5}$$

where, u is the horizontal velocity vector, w the upward velocity, f the Coriolis parameter, x the locally vertical unit vector, $g(=980cm\ \mathrm{sec}^{-2})$ the gravitational acceralation, ∇_h the horizontal gradient operator, t the time, p the pressure, ρ the density, ρ_0 the reference density, T water temperature and S salinity. The density ρ is calculated from T and S with use of the usual nonlinear state equation(Wadachi, 1987). The last terms in Eqs.(4.4) and (4.5) are called γ terms which were introduced by Sarmiento and Bryan(1982) to prevent calculated values T and S deviating greatly from observed values T^* and S^*. The degree of modification is represented by γ .

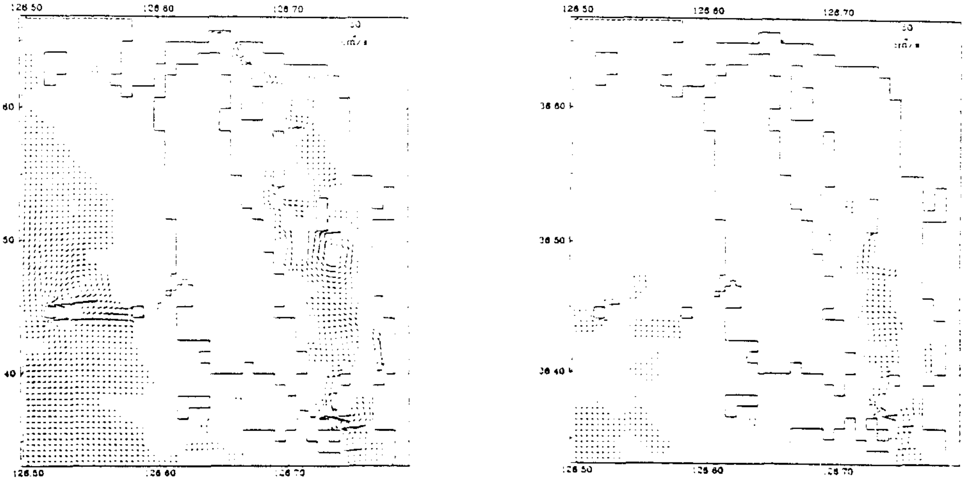


flow patterns of surface

flow patterns of 5m layer

Fig.4 The calculated residual flow pattern

For a small γ, the model is near to be independent of the observed data and approaches a prognostic model. For a large γ, the model is restricted by the observed data and approaches a purely diagnostic model(Fujio and Imasato, 1991). A_v and K_v are the vertical eddy viscosity and diffusivity, respectively. A_h and K_h are the horizontal eddy viscosity and diffusivity, respectively.



flow patterns of 15m layer

flow patterns of 20m layer

Fig.4 The calculated residual flow pattern

5.Conclusion

The calculated co-range and co-tidal charts of M_2 tide are similar to the observed ones. The residual flow pattern at the surface layer during summer formed clockwise circulation in the front coastal the dike of the Sosan A zone(Ganwor island) and Taeju island. The residual flow pattern at the 15m layer during formed clockwise circulation in the front Taeju island. The residual flow pattern at the surface layer formed anti-clockwise circulation in the upper Sangmok and Naepasu island.

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