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Weihai bay tidal current field analysis

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ABSTRACT

To provide a scientific and effective basis for Weihai Bay oil spill simulation research, the paper adopts plane two-dimension numerical model to study the tidal current field. The unstructured triangular grid is used to split the computational domain, and the standard Galerkin finite element method is adopted to horizontally discrete space. As for time, the explicit upwind difference format discrete momentum equation and the transport equation are adopted to analyze and forecast the Weihai Bay tidal field. The tidal field distribution and flow rate verification results at different measure points indicate that the mathematical model and boundary setting is proper and well reflects the tidal feature of the research area and its nearby waters and is applicable to the Weihai Bay oil spill simulation research.

KEYWORDS

Plane two-dimension numerical model;
Unstructured triangular grid;
Galerkin;
Explicit upwind difference format;
Tidal current field.

INTRODUCTION

In order to objectively evaluate the pollution conditions in ports, docks, loading and unloading terminals as well as the units engaged in such activities as ship repair and manufacturing, salvage and ship dismantling, etc, and thus to improve their pollution prevention capability and to better protect the marine environment, the Administrative Regulations of Controlling Marine Environment Pollution from Ships promulgated by China states that ports, docks, loading and unloading terminals as well as the units engaged in such activities as ship repair and manufacturing, salvage and ship dismantling, etc, should set up safety operation and pollution prevention management system, comply with the related national rules and standards about ship pollution prevention and marine environment protection, be equipped with the relevant pollution prevention facilities and equipments and get the approval of maritime administration authorities.

Accurate and scientific tidal current field analysis and forecast is the basis for assessment of ship pollution risk and pollution prevention ability. Currently, relatively few studies focus on the movement law of Weihai Bay's tidal current field. Wang Lvqing (2011)'s research points out that under the double influence of M2 amphidromic point outside of Chengshan Cape in Rongcheng of Shandong Province and K1 amphidromic point located in the middle part of Bohai Sea Gulf, the tidal current field at Weihai Bay is very complicated. With the presence of strong winds, the tidal current field in Weihai Bay significantly changes. Adopting the numerical model, Wang Lvqing made research on the influence of E wind and W wind on

Weihai Bay current field and figured out the tidal current flow rate and direction and its change law under the influence of strong wind. Unfortunately, there is no research on the main flow direction of flood tide and ebb tide.

Whether the tidal current field analysis and prediction is scientific and accurate or not depends on the adoption of proper mathematical model and boundary setting. The present study adopts the plane two-dimension numerical model for the study of the engineering water tidal current field, the unstructured triangular grid for computational domain[1-3], the standard Galerkin finite element method for horizontal space discrete[5-7], and the explicit upwind difference scheme using discrete momentum equation and the transport equation[8,9]. Thus the analysis and prediction obtained can better reflect the tidal feature of the study area and its nearby waters, which is of significant reference to the assessment of ship pollution risk and pollution prevention capability of the study area.

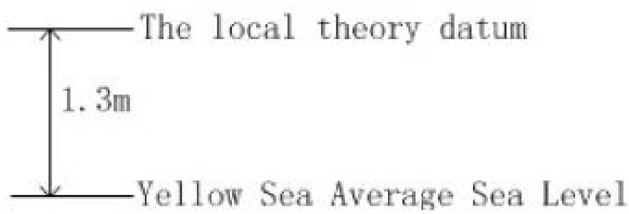

Figure 1 : The relation between the local theoretical depth datum and the Yellow Sea average sea level

NATURAL CONDITION OF WEIHAI BAY

Meteorological conditions

The highest, lowest and average temperature (°C) of each month in Weihai is shown in TABLE 1.

The general wind condition of Weihai is: WNW~N winds are prevalent in Winter, and the total frequency of the 4 directions is up to 58%, and the frequency of NNW is 23%, which is the maximum. While SSE~SSW winds are prevalent in Summer, and the total frequency of the 4 directions is up to 48%, and the frequency of SSW is 19%, which is the maximum. And for the whole year, WNW~NNW winds are usually experienced, and the total frequency of the 3 directions is up to 32%; and then the SSE~SSW winds, the total frequency of which is 22%.

Marine hydrological conditions

Tide

The tide of Weihai Bay waters is irregularly semidiurnal. For the tidal datum, see figure 1. The relation difference between the local theoretical datum and that of the Yellow Sea average sea level is 1.3 meters. The tide level eigenvalue (starting from the theoretical depth datum) is shown in TABLE 2.

Current

Weihai Bay and its nearby waters are under the control of the M2 rotary tidal wave system situated east of chengshantou, Rongcheng, Shandong Province, in addition to other natural environmental limitations. These lead to the reciprocating motion of the tide essentially parallel to the coastline. In the meanwhile, as the area is also close to the Chengshantou semidiurnal amphidromic point, the tidal range is small and the flow rate is not big. Based on the measured data, the calculated tidal nature of the waters belongs to the irregular semidiurnal.

TABLE 1 : The highest, lowest and annual average temperature (□) of each month in Weihai

month	1	2	3	4	5	6	7	8	9	10	11	12	year
Annual average	-1.5	-0.4	4.1	10.3	16.6	20.8	23.9	24.6	20.9	15.3	8.3	1.5	12.1
highest	13.6	19.6	23.4	29.6	35.0	38.4	35.9	36.8	32.4	30.4	23.3	17.4	38.4
lowest	-13.8	-13.2	-8.6	-5.7	2.8	9.3	14.4	15.3	7.5	7.5	-7.9	-11.3	-13.8

TABLE 2 : The tidal characteristics of Weihai Bay and its near waters

Historical highest tide level	Historical lowest tide level	Mean high tide	Mean lowtide	Mean sealevel	Mean tidal range
3.34m	-0.88m	1.90m	0.55m	1.30m	1.35m

The current in Weihai Bay is slow, the underlying flow rate is about 5cm/s, and the maximum rate is about 10cm/s. While in the Bay, the maximum surface flow rate is 50cm/s, which appears off the Jinxianding Morro.

The measured flow rate off a shipyard project waters is about 40cm/s, which is greater than that inside the Weihai Bay, and the flow is E-SE; The measured ebb tide flow rate is 35cm/S, W~NW. For the other parts, the flow rate is about 10cm/s, SE.

Wave

Based on the statistical analysis of historical data, the most frequent wave direction is E near a shipyard project in the waters, and the frequency is 43%, while for the second frequent wave, the wave height is about 2.2 m, and the annual mean wave height is about 0.3m. The waves show significant seasonal variation, see figure 2.

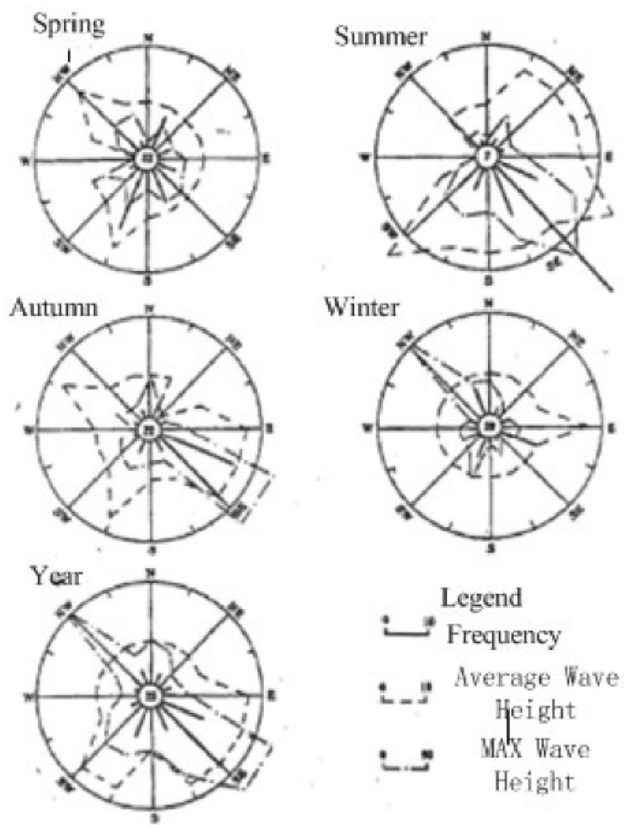

Figure 2 : Wave height and frequency variation near a shipyard project

In spring, the frequent wave is E with a frequency of 39%, the strong wave is ESE, and the maximum height is 1.8m; In summer, the frequent wave is E with a frequency of 37%, and the strong wave is E with a maximum height of 3.1m; In autumn, the frequent wave is E with a frequency of 36%, and the strong wave is also E with a maximum height of 3.1m; In winter, the frequent wave is E with a frequency of 60%, and the strong wave is also E with a maximum height of 1.8m. Due to the influence of topography, E wave is prevalent while the strong wave is easterly in all seasons. All the year round, the wave is the strongest in autumn, while the weakest in summer.

Topography

Weihai Zaobu Bay waters belong to the Ludong hilly areas, which is situated in the central part of the Jiaobei Palaeohigh. The offshore terrestrial height above sea level is 200-300m.

PREDICTION MODEL

In this paper, the plane two-dimension numerical model is adopted to study the tidal field movement of the project waters.

The model control equation

(a) The mass conservation equation:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial}{\partial x}(hu)+\frac{\partial}{\partial y}(hv)=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial u}{\partial x}\right)-\frac{\partial}{\partial y}\left(\varepsilon_x\frac{\partial u}{\partial y}\right)-fv+\frac{gu\sqrt{u^2+v^2}}{{C_Z}^2H}=-g\frac{\partial \zeta}{\partial x} \tag{2}$$

(b) The momentum equation:

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}-\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial v}{\partial x}\right)-\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial v}{\partial y}\right)+fu+\frac{gv\sqrt{u^2+v^2}}{{C_Z}^2H}=-g\frac{\partial \zeta}{\partial y} \tag{3}$$

While in equation 2 and 3: ζ indicates the water level; h represents static depth; H represents the total depth, H=h+ζ ; u and v represents the average vertical velocity in x-axis and y-aix respectively; g represents gravitational acceleration; f is the Coriolis force parameter ($f = 2\omega sin\varphi$, φ is the geographic latitude for the calculated waters); CZ is the Chezy Coefficient, $C_z = \frac{1}{n}H^{\frac{1}{6}}$,n is the Manning Coefficient; ε_x、ε_y and represents horizontal eddy viscosity coefficient in x and y axis respectively.

The boundary conditions

To solve the initial boundary value problem in equation 1, 2, and 3, the appropriate initial and boundary conditions should be offered.

(a) Initial conditions:

In this paper, the initial flow rate and initial tide level is taken as 0.

$$U(x,y,t_0) = U_0(x,y) \quad (4)$$

$$V(x,y) = V_0(x,y) \quad (5)$$

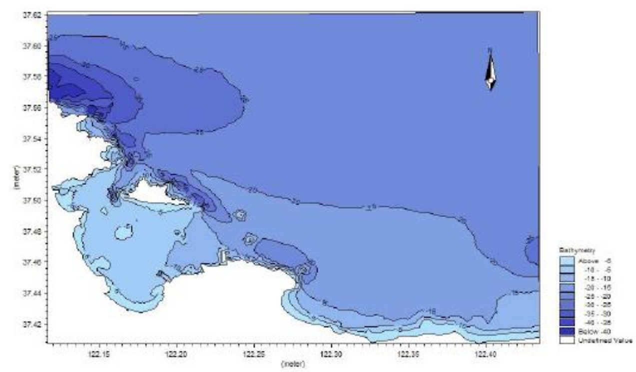

Figure 3 : Depths in the simulated computational domain

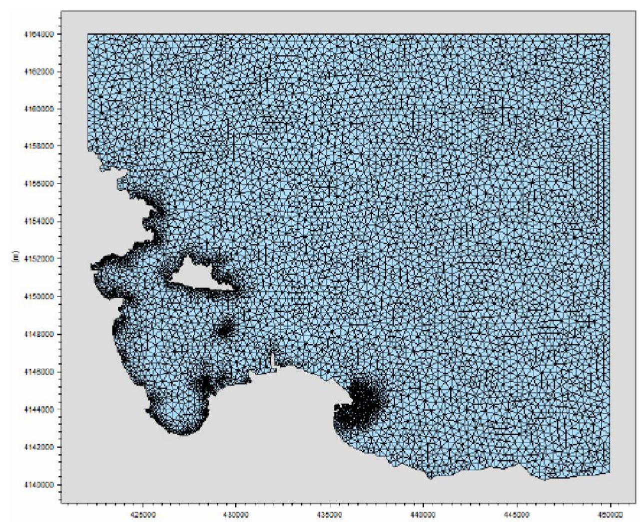

Figure 4 : The computational domain grid

$$\zeta(x,y,t)|_{t=0} = \zeta(x,y) = \zeta_0 \quad (6)$$

(b) Open boundary conditions:

There are three boundaries in the calculated area, that is, the W, N, and E boundary, where the water level ζ can be obtained by using the tide level forecasting methods:

$$\zeta = A_0 + \sum_{i=1}^{4} H_i F_i \cos[\sigma_{it} t - (v_0 + u)_i + g_i] \quad (7)$$

While in equation 7, A0 is the average sea level, Fi,(v0+u)i represents the astronomical element, and Hi and gi represent the harmonic constants. Four partial tides are chosen as harmonic constants, including two daily tides (O1, K1), and two semidiurnal tides (M2, S2).

(c) Closed boundary conditions:

In the calculate area, the boundary where the land mass and water meets is set as a closed boundary condition and the water particle normal velocity is set as 0.

COMPUTATIONAL DOMAIN AND GRID SETTINGS

The unstructured triangular grid split computational domain is adopted, and the standard Galerkin finite element method is used for horizontal space discrete. As for time, the explicit upwind difference format discrete momentum equations and the transport equations are used.

Computational domain

The scope of the computational domain based on mathematical model is shown in figure 3. The range of coordinates is 37.41°~ 37.62°N, 122.12°~ 122.43°E. The unstructured triangular grid is adopted, and the simulated grid distribution of the computational domain is shown in figure 4. To get a clear understanding of tide and current condition of the waters, the area near the shipyard project is under a local encryption. The whole simulated area consists of 13236 nodes and 20157 triangular units, the minimum space step length is about 50m.

Water depth and shore boundary

The water depth and shore boundary is taken from the chart from Weihai port to Shidao port (chart scale 1:120000, No. 12110), which is produced by the Assurance Department of Navy of the Chinese People's Liberation Army.

Water boundary input of large sea area

Open boundary: The value of four major tidal harmonic constants M2, S2, K1 and O1 are input to make calculation.

$$\zeta = \sum_{i=1}^{N} \{ H_i \cos[\sigma_i t - G_i] \} \quad (8)$$

Here, σi represents the angular velocity of No.i partial tides (here four partial tides are taken: M20S20O1 and K1); Hi and Gi are harmonic constants, which are the amplitude and epoch of partial tide.

Closed boundary: using the shoreline as a closed boundary.

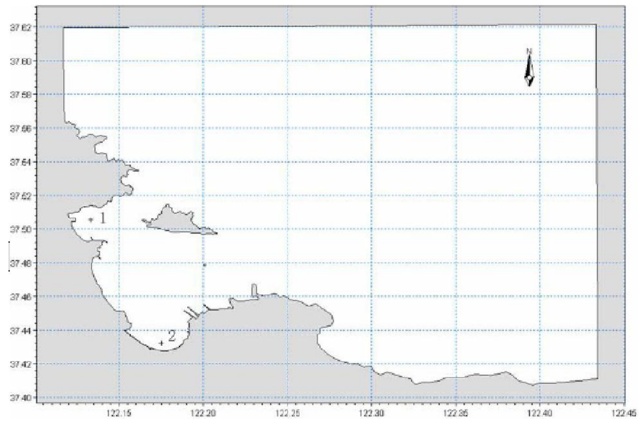

Figure 5 : Tide level verification points

Calculation of the time step and bed roughness

When calculating the time step, the model makes adjustment according to CFL condition to ensure its stable calculation and the minimum time step is 0.3s. The bed roughness is controlled by Manning Coefficient, and the Manning Coefficient n is taken as 0.3~0.45 m1/3/s.

The horizontal eddy viscosity coefficient

The sub-scale grid effect Smagorinsky (1963) formula is considered to be used to calculate the horizontal eddy viscosity coefficient, which is expressed as follows:

$$A = c_s^{\,2} l^2 \sqrt{2S_{ij}S_{ij}} \qquad (9)$$

Wherein: cs is the constant, l is the characteristic mixing length, by $S_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$, (i, j=1,2)can be calculated.

TIDAL NUMERICAL MODEL AND ITS VALIDATION

The tide level, current velocity and flow direction of the calculated domain are compared with the real measured data to verify the numerical model. For the verification of tide level, two tide points are set up; while for the verification of current, two tide points set up in the year 2007 are adopted.

Tide level verification

As shown in figure 5, the location of the two tide level verification points is: Point N0.1(122°08.000'E,37°30.333'N), Point No.2(122°10.500'E,37°25.917'N). The tide level value of point No.1 is analyzed and forecast by applying the constants of M2, S2, K1, O1 of the point, while the tide level value of point No.2 is the real measured value.

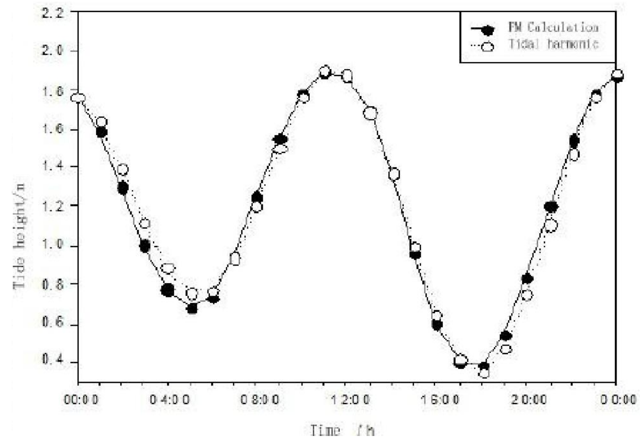

Figure 6 : Spring tide level verification at point No.1

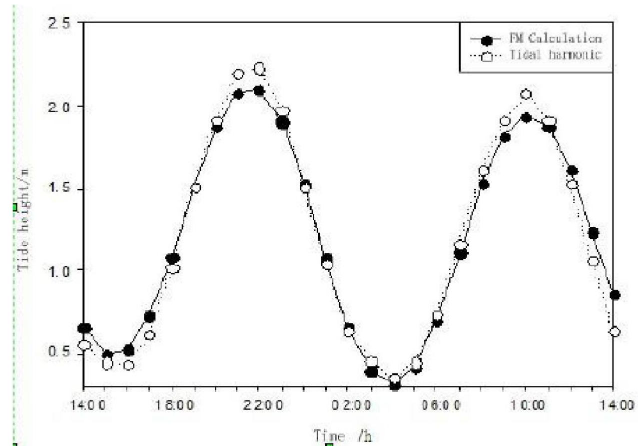

Figure 7 : Spring tide level verification at point No. 2

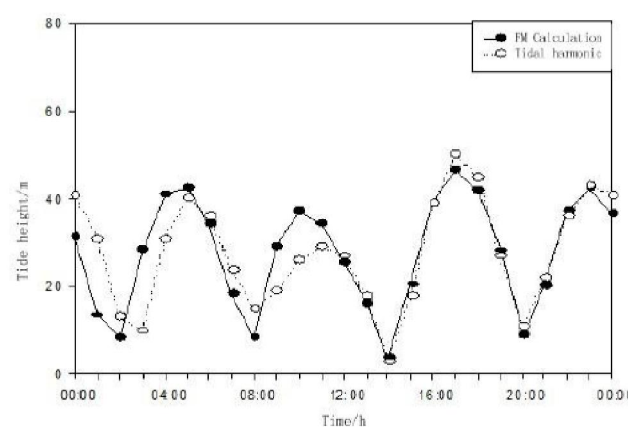

Figure 8 : Spring tide current velocity verification at point No.3

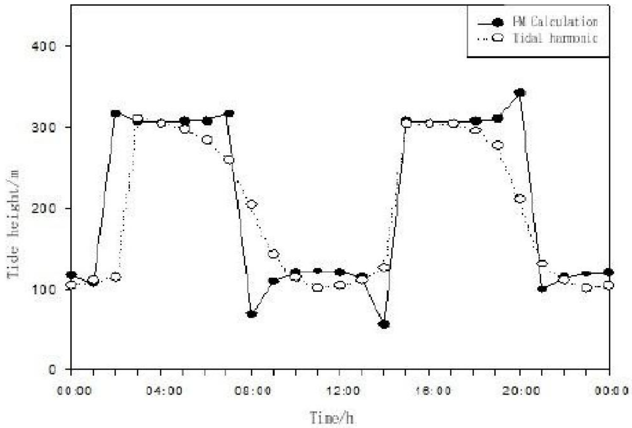

Figure 9 : Spring tide current flow direction verification at point No.3

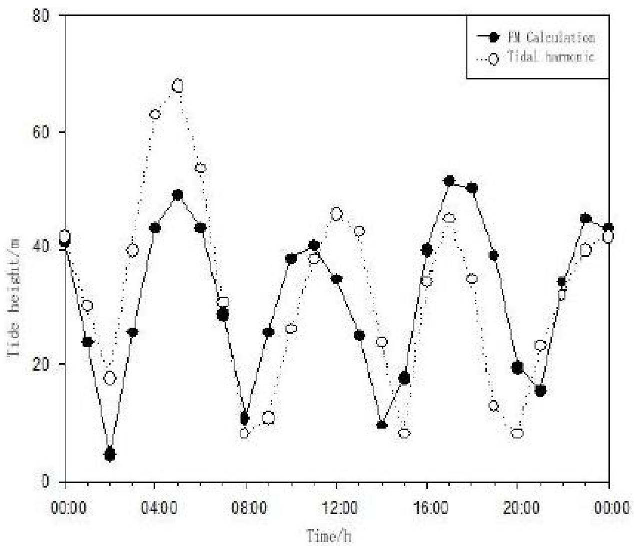

Figure 10 : Spring tide current velocity verification at point No.4

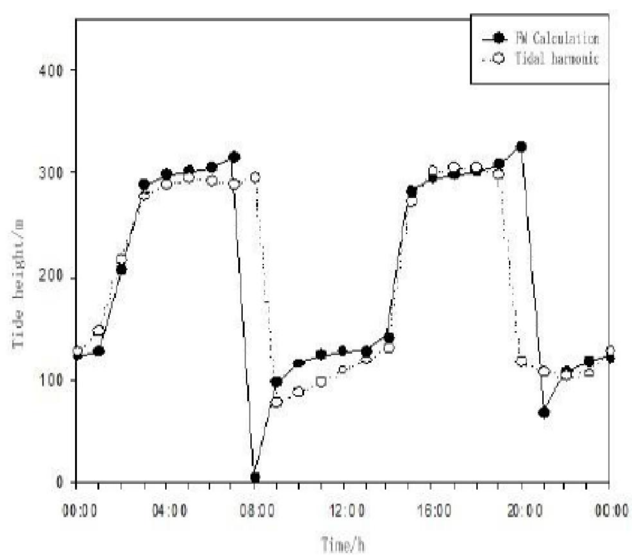

Figure 11 : Spring tide current flow direction verification at point No.4

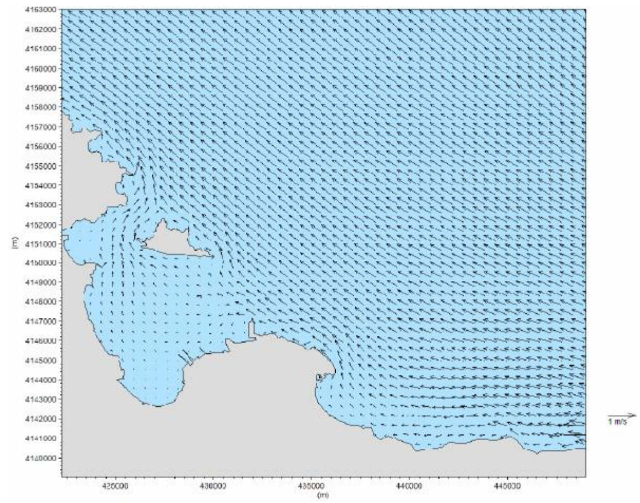

Figure 12 : Current flow direction verification at point No.4 (when tide is rising)

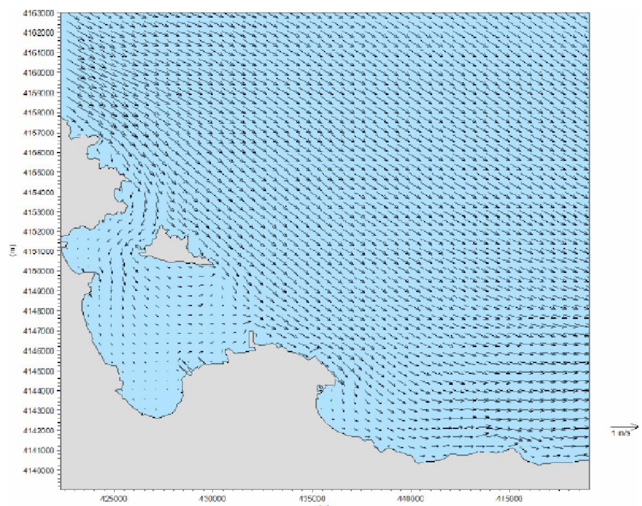

Figure 13 : Tidal current field calculation(when tide is falling)

In figure 6, the tide level verification result of spring tide at point No.1 is given, from September 22, 2010 to September 23, 2010. And in figure 7, the tide level verification result of spring tide at point No.2 is given, from October 26, 2007 to October 27, 2007.

Seen from figure 6 and figure 7, the tide in this area is of irregular semidiurnal type. That is, one daily tide consists of two complete flood tides and two ebb tides processes, and the phenomenon of inequality between high water level and low water level is apparent. Both the real measured data and the simulated calculation results illustrate this. At point No.1, the forecast spring tide level is in good agreement with the calculated one; while at point No.2, the real measured tide level is in general agreement with the calculated one, though the later is slightly less than the former, which indicates that the simulated result can meet the accuracy requirements of the project.

Current verification

The locations of two current verification points are: Point N0.3(122°16.200'E,37°34.000'N), Point No.4(122°21.300'E,37°31.350'N). Figure 8-10 show the current velocity and flow direction verification result at point No. 3 and No.4 from 1400 hour, October 25, 2010 to 1400 hour, October 26, 2010 respectively. From the comparison with the result of the year 2007, one can see that the result of current velocity and flow direction value is in good agreement with the real measured data.

Analysis of current calculation results

Figure 12 gives the whole calculation area's software simulated field vector when the tide rises, while figure 13 gives the software simulated field vector when the tide falls. From figure 12 and figure 13, one can see that:

(A)The flow directions for both flood and ebb tide outside of Weihai

Bay are mainly WNW~ESE, WNW~NW for rising tide and ESE~SE for falling tide.

(B) The flow directions of rising and falling tides inside the Weihai

Bays vary with the formation of coast line. When the tide rises, the currents flow through the southern entrance into the Bay and run out of the Weihai Bay through the Northern entrance in a clock-wise way. While when the tide falls, the current runs through the Northern entrance to the Bay and runs out of the Bay through the Southern entrance in a counter-clockwise way. The flow velocity in the Southern and Northern entrances is great.

CONCLUSION

The tidal field distribution and the verification result of flow rate at different measured points show that, the mathematical models and boundary settings established are reasonable and can better reflect the tide feature of the research area and its nearby waters. They can meet the requirements of Ship Environment Pollution Risk Assessment Technical Regulations (trial) and is applicable to Weihai Bay oil spill simulation research.

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