

The application of ship oil spill risk prediction in Dongying emergency capacity planning

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Abstract. This study combines the hydrodynamic prediction model MIKE21 and the oil spill model OILMAP. Using the hydrodynamic prediction model to provide the accurate tidal current field for oil spill model, we apply oil particle tracing method and stochastic simulation method to predict and evaluate the risk of oil spill in the planned port area. The numerical simulation results show that the current and the wind will directly affect the range and trajectory of the oil film. Once the oil spill accident happens, the area with probability greater than 70% is about 191.5km², which is mainly affected by 5km within two sides of port. Through risk prediction and assessment, we can provide necessary support for the regional emergency forces.

1. Introduction

With the development of the port and the increase of transportation business, the accidents of marine oil spill frequently occur at sea. According to statistics, from 1976 to 2000, the number of ship oil spill accident is 2353 cases. In China, the total spill amount to about 30000 tons^[1]. In accordance with the requirements of the development of the port, it is also necessary to build the emergency capacity of the port area in order to adapt to the corresponding level of risk. In order to improve the risk response capability and emergency management level of Dongying's sea area, we need to analyze the characteristics of sea area and build emergency capacity planning, but the emergency capability planning is inseparable from the prediction and assessment of ship's oil spill risk. According to the situation and demand of Dongying's emergency capability, we use the stochastic module of oil spill to predict the risk of oil spill under typical wind and flow conditions, and provide strong technical support for emergency planning and construction.

2. Simulation method

Prediction of oil spill risk is one of the key technologies for oil spill trajectory analysis, oil spill pollution and oil spill control. Countries such as Europe, America and Japan have studied it since 1960s and developed software for forecasting oil spill successively, and the OILMAP software of the ASA company is a widely used commercial software^[2]. However, the software has generalizability in dealing with the current coastline, water depth, offshore boundary and hydrodynamic parameters, resulting in a certain deviation of hydrodynamic field for oil spill calculation.



In this paper, the MIKE21 model is applied to predict the hydrodynamic field of the study area. And the simulation results are applied to OILMAP by data processing, so as to achieve the accuracy and reliability of the hydrodynamic prediction and the prediction results of the oil spill model.

2.1 governing equation

The governing equations are 2D flow continuity equation^[3] and motion equation.

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t} \quad (1.1)$$

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left(\frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left(\frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial x} + \frac{gp\sqrt{p^2+q^2}}{C^2 \cdot h^2} - \quad (1.2)$$

$$\frac{1}{\rho_w} \left[\frac{\partial}{\partial x} (h\tau_{xx}) + \frac{\partial}{\partial y} (h\tau_{xy}) \right] - \Omega_y - fVV_x + \frac{h}{\rho_w} \frac{\partial}{\partial x} (P_\alpha) = 0$$

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y} \left(\frac{q^2}{h} \right) + \frac{\partial}{\partial x} \left(\frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial y} + \frac{gq\sqrt{p^2+q^2}}{C^2 \cdot h^2} - \quad (1.3)$$

$$\frac{1}{\rho_w} \left[\frac{\partial}{\partial y} (h\tau_{yy}) + \frac{\partial}{\partial x} (h\tau_{xy}) \right] + \Omega_x - fVV_y + \frac{h}{\rho_w} \frac{\partial}{\partial y} (P_\alpha) = 0$$

In which $h(x, y, t)$ -surface elevation; $d(x, y, t)$ -depth(m); $p, q(x, y, t)$ -flux; $C(x, y)$ -Chezy(m^{1/2}/s); $f(V)$ -wind friction; γ_α^2 -wind stress; $\Omega(x, y)$ -coriolis parameter(s-1); $\tau_{xx}, \tau_{xy}, \tau_{yy}$ -shear stress.

2.2 oil spill model

The oil spill model is based on the Lagrange particle tracking method, considering the particle movement model caused by wind and flow, physical dispersion and Stokes scattering.

$$X = X_0 + (U + \alpha W_{10} \cos A + r \cos B) \Delta t \quad (1.4)$$

$$Y = Y_0 + (U + \alpha W_{10} \sin A + r \sin B) \Delta t \quad (1.5)$$

In which, X_0, Y_0 -initial coordinates of a particle (m); W_{10} -wind speed (m/s); A -Wind direction; α -Correction coefficient; r - random coefficient, $r = R \cdot E$, R - random number between 0 ~ 1, E -diffusion coefficient.

The OILMAP model can simulate a series of processes such as drift, weathering, diffusion, dissolution and shoreline adsorption of oil products, which can predict the oil film drift trajectory and the leakage of oil products^[4]. The simulation program is shown in Figure 1.

3. Model and Parameter Selection

3.1 Calculation area and grid division

From Fig.2, it shows that study area include the Laizhou Bay and the southern coast of Bohai Bay, The north-South span is 171km, and the East-West span is 248km, and the area of simulation area is about 15237km².

Computation adopts structured grid mesh of horizontal coordinates, mesh space is 250m, Model uses a horizontal grid consisting of 671300 elements, which the number of participate computing is 371800.

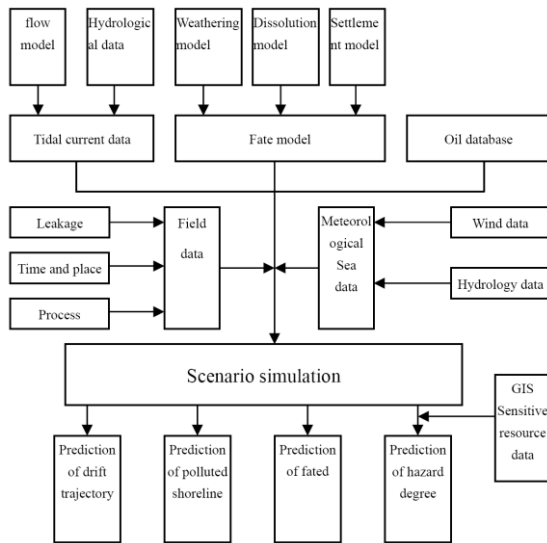


Fig.1 Simulation process

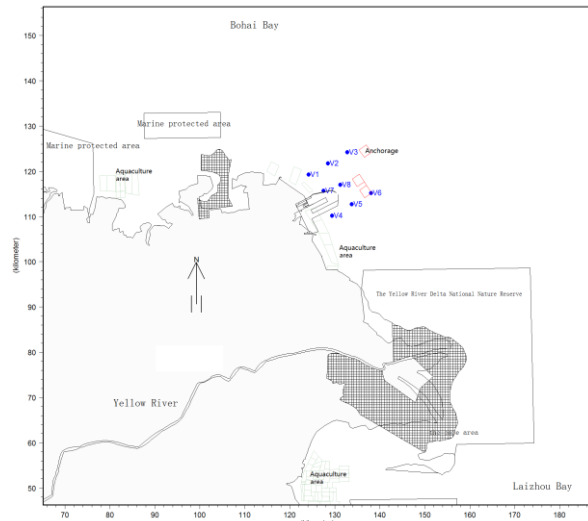


Fig.2 Research Domain and Verification

3.2 Parameter Selection

The open boundary is controlled by water level, and the data is provided by the tidal wave model in Bohai. and the coefficient is shown in table 1.

Tab.1 Selected coefficient by using mathematical model

coefficient	Mesh space Dx/Dy	Time step	Eddy viscosity	Resistance	Flood and Dry	coriolis f	water densityp
Values	250m	30s	0.02	52m ² /s	0.2m	$2\omega \cdot \sin(30.5^\circ) s^{-1}$	1020kg/m ³

4. Verification and result analysis

4.1 Validation of elevation and current

There are three sections, and 3 tidal stations are set on each section, with a total of 9 tidal stations. in the paper, the verification results of V3 and V6 stations are given(As shown in Fig.3 to fig.4).

It can be seen from the results that the tidal current belongs to the normal semidiurnal tide^[5], and the trend of sports performance of reciprocating flow, the flood tide to NW, the ebb tide to SW. In all figures, the points represent the observed data and the solid lines represent the computed values, which conform to “Technical Regulation of Modelling for Tidal Current and Sediment on Coast and Estuary”^[6].

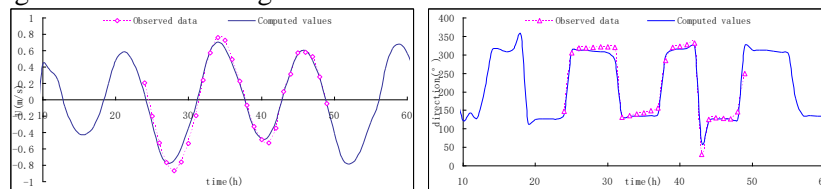


Fig.3 V3 station velocity magnitude and direction

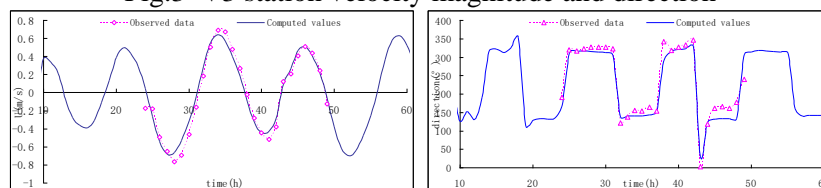


Fig.4 V6 station velocity magnitude and direction

4.2 Characteristics of flow field

Using MIKE21 software to predict the power flow field, the results are shown in Fig.5 to fig.8:

(1) The study area is located at the boundary between the Laizhou Bay and the Bohai Bay^[5,7], The flow velocity is larger in the sea area.

(2) In the outer sea, the maximum velocity at flood tide can reach 0.8m/s, the maximum velocity at ebb tide can reach 0.9m/s.

(3) The tidal current flows along the coastline before the port planning is implemented.

(4) After the implementation of the port area planning, the tidal current is affected by the port area, bypassing the breakwater to flow, but the flow velocity in the harbor basin is obviously decreasing.

(5) The port planning will have a certain impact on the trend of the near shore, but it has little effect on the sea.

5. Analysis of the effect of oil spill

5.1 Analysis of source of pollution

According to the future port area planning and ship form analysis, the most likely source of risk is the 50 thousand ton oil tanker, which is calculated according to a cargo compartment overflow, and the oil spill volume is 2200t.

The accident point is usually selected at the entrance, anchorage and channel position. In this paper, a typical pollution accident is analyzed by planning the accident at the entrance.

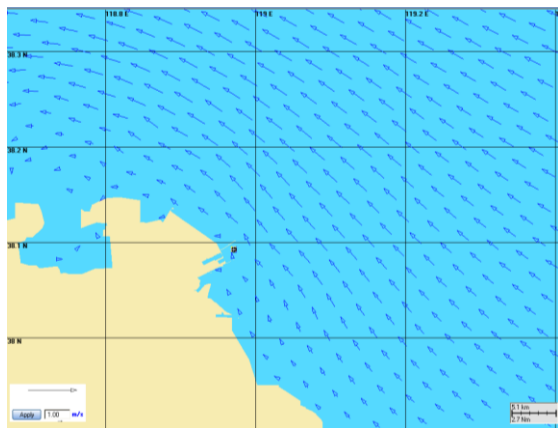


Fig.5 Flow filed at flood tide at pre planning

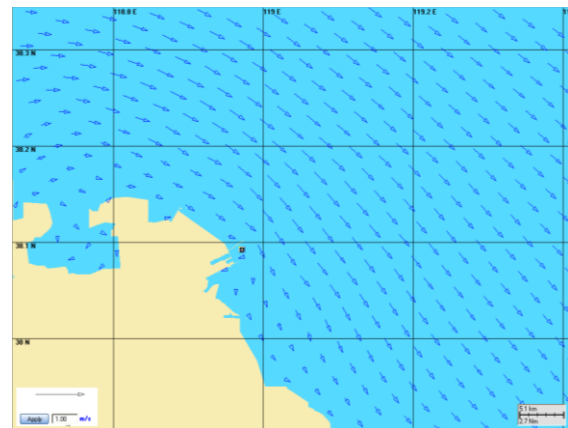


Fig.6 Flow filed at ebb tide at pre planning

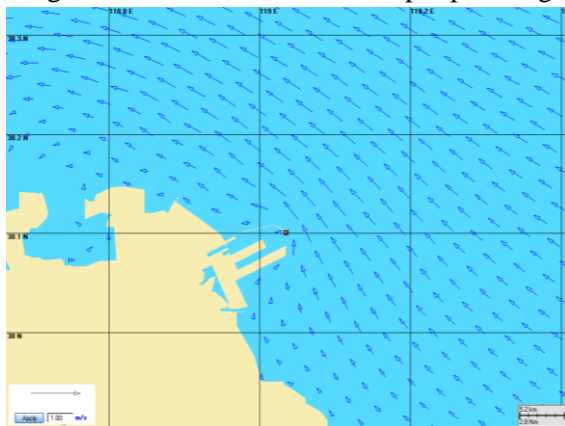


Fig.7 Flow filed at flood tide after planning

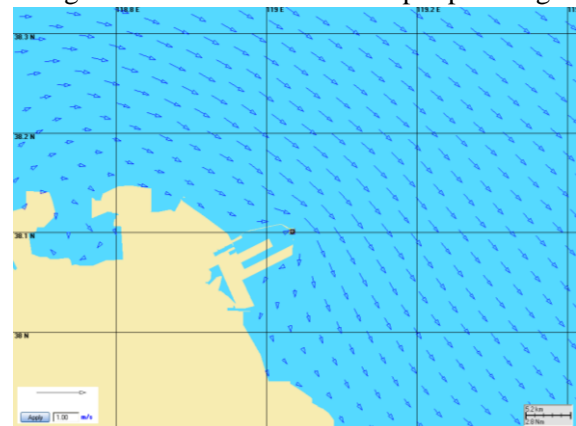


Fig.8 Flow filed at ebb tide after planning

5.2 Pollution accident prediction

The Lagrange oil particle tracking method is used to predict the drift trajectory and the influence range of the oil film. Results show in Fig.9 to fig.11.

(1) Under the condition of E wind, the oil film will drift westward and drift to the Nearshore Area under the action of tidal current and wind. It will reach the shore in 24 hours. During the whole process, the oil film will not directly affect the current area and protected area in the north.

(2) In the ebb tide, the oil film in the South under the action of tidal current and wind drift, arrived in the south breakwater in 19 hours, will not affect the environment sensitive target.

(3) Under the adverse wind NW wind, the oil film drifted south-east, and entered the the Yellow River delta marine reserve 18 hours later, which had a continuous impact on the protected area. The continuous impact time was 49 hours. In this process, the oil sweeping area was about 226.5km², and the drift distance was 62km.

Tab.2 Sea-swept area of oil spill

time	Annual leading wind E		Adverse wind NW
	flood tide	ebb tide	ebb tide
h	affected area (km ²)	affected area (km ²)	affected area (km ²)
0	0	0	0
1	0.6	0.6	0.4
2	1.2	1.8	1.4
3	2.2	2.5	2.8
4	3.2	3.1	5
5	3.8	3.5	6.9
6	4.8	3.5	8.7
7	6.0	3.5	10.2
8	6.2	3.1	11.6
9	6.3	2.5	12.5
10	5.7	1.9	13.2
...
71	0.0	0.0	66.2
72	0.0	0.0	68.1

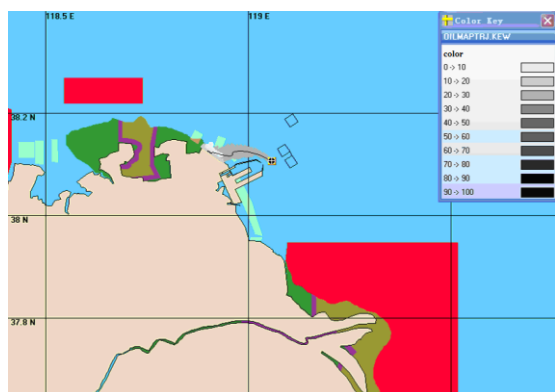


Fig.9 Trace and range of oil spill pollution when leading wind E and flood tide

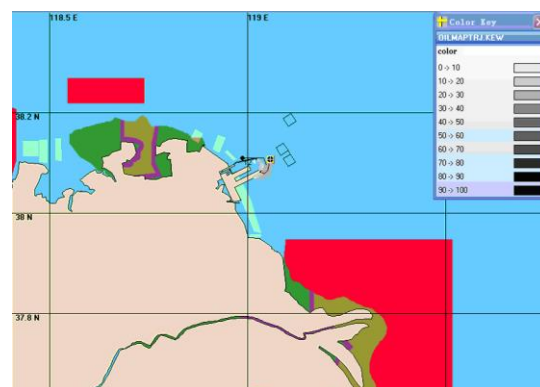


Fig.10 Trace and range of oil spill pollution when leading wind E and ebb tide

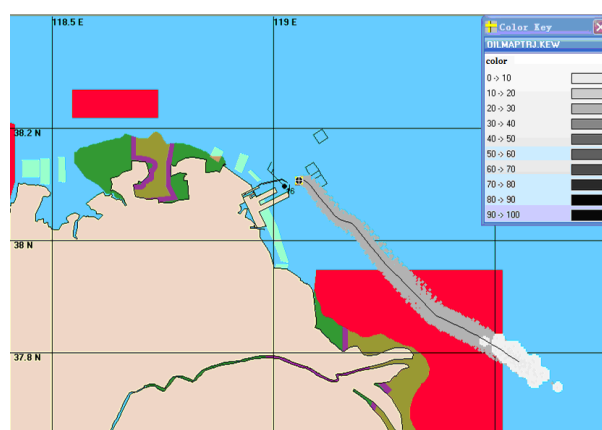


Fig.11 Trace and range of oil spill pollution when leading Adverse wind NW and flood tide

5.3 Study on the probability of pollution

The flow field and wind field data in the past 3 years were selected for prediction, and the simulation time was 96 hours. Obtaining the probability distribution and the fastest arrival time of oil film pollution after oil spill accident were obtained. The results show that:

- (1) The probability of oil spill over the 5km range on both sides of the channel is more than 70%
- (2) In the Yellow River Delta National Nature Reserve on the north side of Dongying port, the probability of oil spill is not more than 10%.
- (3) Once the oil spill accident happens, the area with probability greater than 70% is about 191.5km², which is mainly affected by 5km within two sides of port.
- (4) Once the oil spill accident happens, the 24km coastline may be contaminated with oil spill.
- (5) The fastest time for the oil film to reach the aquaculture area is 1~2 hours, and the fastest time to reach the National Nature Reserve in the Yellow River delta is 4 hours.

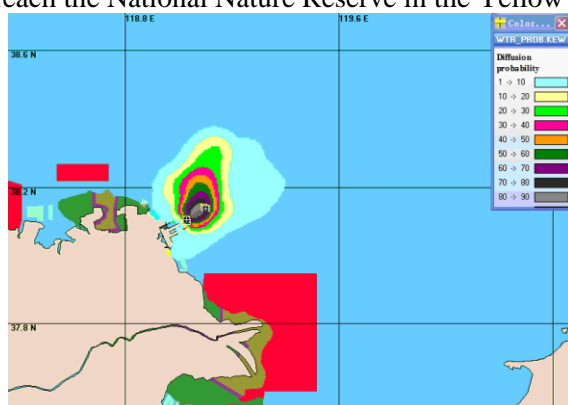


Fig.12 Influence probability of oil film

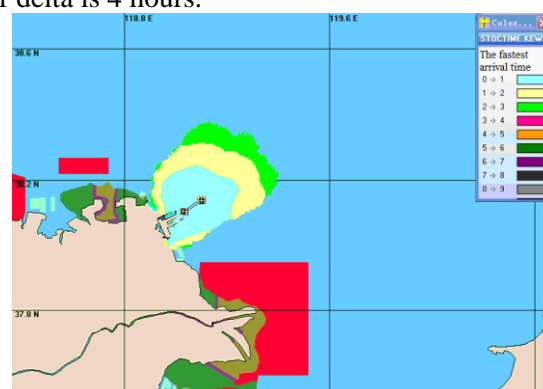


Fig.13 The fastest arrival time of oil film

Through risk prediction and assessment, we can understand the impact of oil spill random events, the probability of impact and the fastest time of oil film arrival, so as to identify high-risk areas, and provide necessary support for the regional emergency forces.

6. Conclusions

This study combines the hydrodynamic prediction model MIKE21 and the oil spill model OILMAP. Using the hydrodynamic prediction model to provide the accurate tidal current field for oil spill model, we apply oil particle tracing method and stochastic simulation method to predict and evaluate the risk of oil spill in the planned port area. Research shows:

(1) The port planning will have a certain impact on the trend of the near shore, but it has little effect on the sea.

(2) Under the adverse wind NW wind, the oil film drifted south-east, and entered the the Yellow River delta marine reserve 18 hours later, which had a continuous impact on the protected area.

(3) Once the oil spill accident happens, the area with probability greater than 70% is about 191.5km², which is mainly affected by 5km within two sides of port.

(4) The fastest time for the oil film to reach the aquaculture area is 1~2 hours, and the fastest time to reach the National Nature Reserve in the Yellow River delta is 4 hours.

Through risk prediction and assessment, we can provide necessary support for the regional emergency forces.

Acknowledgements

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