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Numerical simulation of oil spill pollution in the sea of Huanghua port

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Abstract. It applies hydrodynamic Model MIKE21 HD to complete simulation the characteristics of Bohai Bay,and the tidal level and current are verified with observed data in Huanghua Sea area. In this study, A oil spill model in channel of huanghua harbour was established based on the tidal current field, and keep track of Oil spill trajectory using Lagrange method. The numerical simulation results reveal that the oil sweep range and trajectory of spill oil is mainly affected by the current,in addition,the Oil spill trajectory changes affected by wind friction. under the action of wind spilled oil will drift to the environment sensitive target quickly.

1. Introduction

According to statistics, from 1974 to 2004, the global total of 9266 cases of ship oil spill accident, there are 442 cases which the leakage is more than 700 tons. In China, from 1976 to 2000, the number of ship oil spill accident is 2353 cases, the total spill amount to about 30000 tons[1]. Oil spill accidents not only generated huge clean-up costs, but also brought huge damage to the marine environment and safety of navigation. So when we develop the port, we need research and analysis the probability of ship oil spill accident, influence scope of oil film and the emergency response time. So that it can better guide port management, more detailed and targeted to establish port accident prevention measures, reduce the risk of oil spill accidents, and it has positive significance for the protection of the marine environment.

The channel length of Huanghua port is about 58.8km, channel terminal is located in the Bohai Bay -18.3m, while south and north coastal area of port is the fishing areas, so we need analysis the oil spill to protect environment.

In this paper, using MIKE21 HD and MIKE21/3 SA module[2] to study on current field and oil spill risk.

2. The content and method of research

2.1 Governing Equations

The governing equations are 2D flow continuity equation[4] and motion equation.

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

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2\cdot h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}(h\tau_{xx})+\frac{\partial}{\partial y}(h\tau_{xy})\right]-\Omega_q-fVV_x+\frac{h}{\rho_w}\frac{\partial}{\partial x}(P_\alpha)=0 \tag{1.2}$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{gq\sqrt{p^2+q^2}}{C^2\cdot h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial y}(h\tau_{yy})+\frac{\partial}{\partial x}(h\tau_{xy})\right]+\Omega_p-fVV_y+\frac{h}{\rho_w}\frac{\partial}{\partial y}(P_\alpha)=0 \tag{1.3}$$

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

MIKE21/ 3 SA module bases on the Eulerian-Lagrange system, model based on flow field, and considering the oil film as a series of oil particles, calculating the drift and diffusion trajectory of oil particle.Equation reads:

$$X = X_0 + (U + \alpha W_{10} \cos A + r \cos B)\Delta t \qquad (1.4) \qquad Y = Y_0 + (U + \alpha W_{10} \sin A + r \sin B)\Delta t \qquad (1.5)$$

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.

3. Model and Parameter Selection

3.1 Calculation area and grid division

From Fig.1, it shows that study area include the Bohai Bay, north to Caofeidian, South to the old Yellow River mouth, East to the area which water depth is 26 meters, covered the Tianjin port, Huanghua port, comprehensive port area of Huanghua port, and the area of simulation area is about 9142km^2.

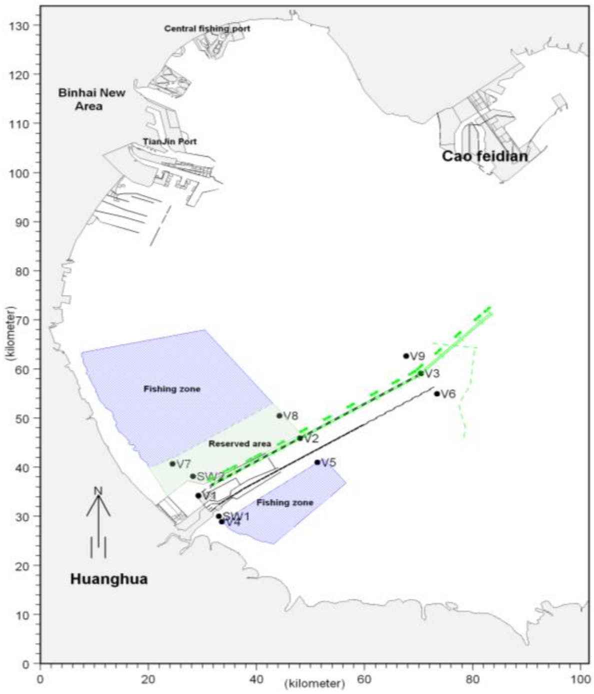

Fig. 1 Research Domain and Verification

Computation adopts structured grid mesh of horizontal coordinates, mesh space is 50m, Model uses a horizontal grid consisting of 5199200 elements, which the number of participate computing is 3485381.

3.2 Parameter Selection

The open boundary uses water level control, which is provided by the Bohai ocean tide model. Other 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 densityρ
Values	20m	10s	0.02	50m^2/s	0.3m	2ω*sin（30.5°）s^{-1}	1020kg/m^3

4. Hydrodynamic model calibration and Analysis

4.1 Results of elevation and current

In paper, the observed hydrological data are used to calibrate this model, which time from May of 2011 to June. There are two stations SW1, SW2 to verify tidal elevation, and the current is verified at station V2. The computation domain and observed station distribution are show in Fig.1.

Fig.2 shows the verification results of tidal elevation, and Fig.3 is the velocity calibration plots, in which the flow direction is measured in degrees clockwise from the north. 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"[3].

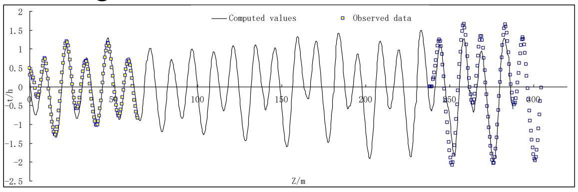

Fig.2 Verification of elevation process of SW2

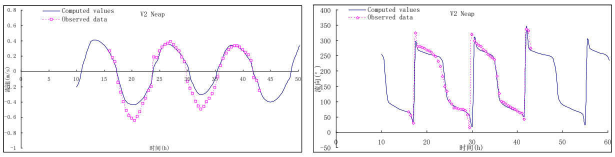

Fig.3 V2 velocity magnitude and direction of neap tide

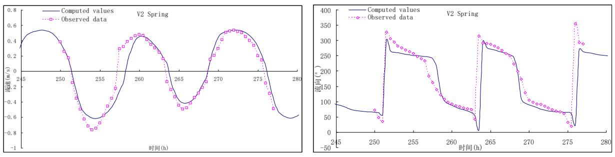

Fig.4 V2 velocity magnitude and direction of spring tide

4.2 Characteristics of Current

In the process of the oil drift, tide is the main driving force, thus improving the accuracy of tide field is important condition for simulating oil spill accidents.

Fig.5~6 show the flood and ebb tide in this study area, from the plot, we can see the direction of flood tidal current is NW and WNW, the direction of ebb tidal current is SE and ESE[5-6], paralleled to the channel in the rectilinear current movement. The maximum flow velocity can reach 0.6m/s in Flood stage, average velocity in ebb stage is 0.17 ~ 0.44m/s.

Due to the cover of comprehensive port breakwater, the flow velocity is smaller in internal port, the maximum flow velocity is 0.2m/s in flood stage, and 0.34 m/s in ebb stage.

While at the port entrance, due to the cross section decrease, the velocity is relatively large, according to simulation, the maximum flow rate can reach 0.73m/s, appeared in the ebb stage.

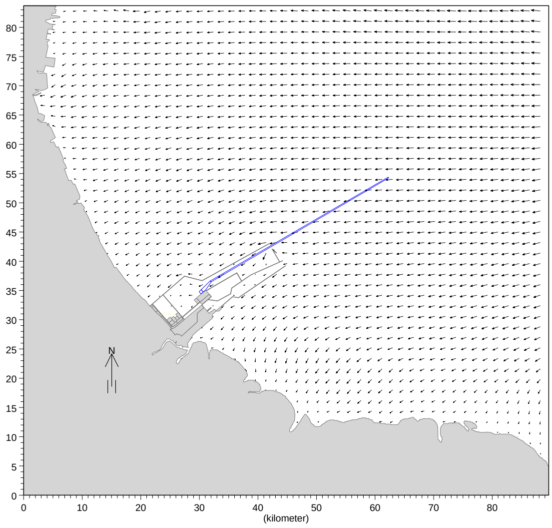

Fig.5 Flow filed at flood tide

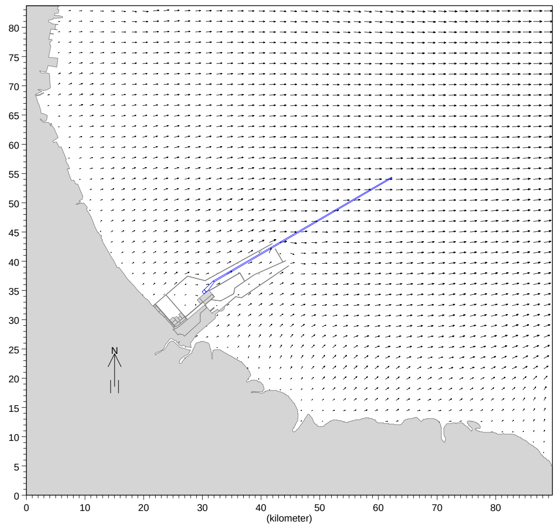

Fig.6 Flow filed at ebb tide

5 Research of Oil Spill Pollution

5.1 Simulation conditions screening

In the channel construction period, construction of the ships are increased in channel region, when the collision of construction ships, oil will leak. According to the requirements of construction ship operating efficiency, The amount of ship carrying oil to the number of 10 days usage, estimated that fuel capacity of $5000m^3$ drag suction dredger is about 574 tons.

During the operating period, the waterway mainly for transport ships, according to the ship design standards, the ship can carry about 20000 tons of fuel oil, and single class loading capacity is about 2000 tons.

So in this paper, the spilled quantity select 2000 tons in simulation, the oil is fuel oil, and density is 0.94~0.98. oil spill site have 6 points, which in the channel turning.

5.2 Pollution analysis

Fig.7 and Fig.9 gives the process of oil spill at S1-S6 when on wind and flood tide, Fig.8 and Fig.10 is the process when no wind and at ebb tide. From the four plots we can see,

(1) at s1 position, due to oil spill is located in the harbor, the oil is drifting in harbor, not directly affecting foreign sea.

(2) at port entrance s2 position, because the flow condition is complex, the oil film can spread quickly. In ebb stage, oil film will drift to the southeast direction, it arrive the edge of fishing zone in 6 hours later, the maximum distance of oil film drift about 11.8km, sweeping area is $13.35km^2$. In flood stage, oil film is carried by the flood tide, drifting from harbor entrance into internal port, due to the flow velocity is larger at harbor entrance, so the oil film will spread quickly, and drift to port shoreline.

Tab.2 Sea-swept area of oil spill

Position/Tide	tidal flood	tidal ebb	tidal flood	tidal ebb	tidal flood	tidal ebb
	S1#		S2#		S3#	
6h sweeping area(km^2)	10.61	8.91	14.11	13.35	8.51	10.36
Drift distance(km)	8.6	7.6	7.5	11.8	10.55	13.8
Position/Tide	S4#		S5#		S6#	
6h sweeping area(km^2)	9.32	14.6	9.9	15.9	10.47	12.8
Drift distance(km)	12.1	15.8	13	15.9	14.3	15.6

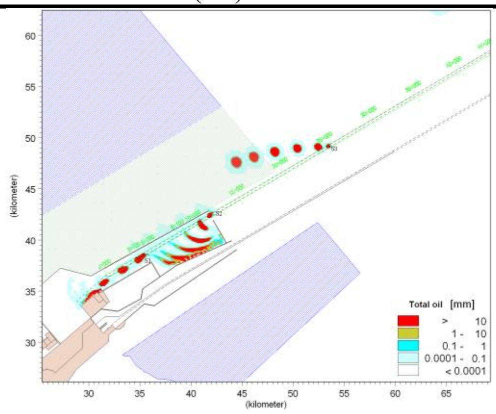

Fig.7 Oil trajectory when no wind and flood tide at S1～S3

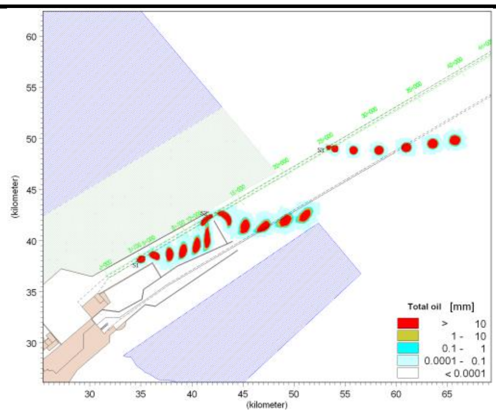

Fig.8 Oil trajectory when no wind and ebb tide at S1～S3

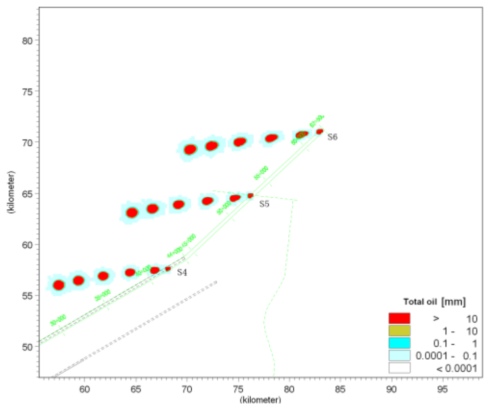

Fig.9 Oil trajectory when no wind and flood tide at S4～S6

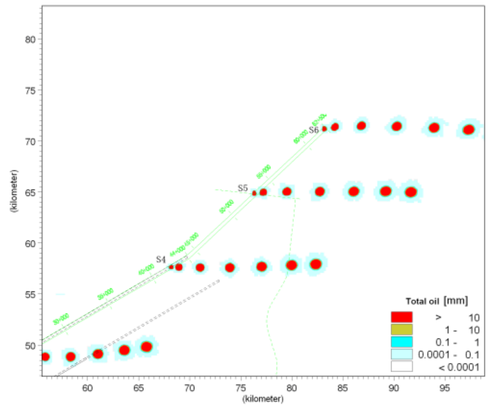

Fig.10 Oil trajectory when no wind and ebb tide at S4～S6

(3) when the oil spill accident happened at outside of the port, because the flow conditions is single, the topography is smooth, so oil film drift along with the flow direction, and the trajectory is rule. It will drift to the W direction at flood stage.

(4)Due to the environmental sensitive targets distributed on both sides of Huanghua port, according to all oil spill track, we can find when the oil spill accident happened at port entrance, the accidents has the greatest influence on sensitive target, and when the oil film diffusing, it will be difficult to control.

Fig. 11 shows oil spill trajectory at S4 position under the adverse wind conditions E, (From Huanghua weather station in 2010, the wind speed is 4.6m/s), In this simulation, we track the oil film trajectory by using the Lagrange method, and the wind friction coefficient is 0.02.

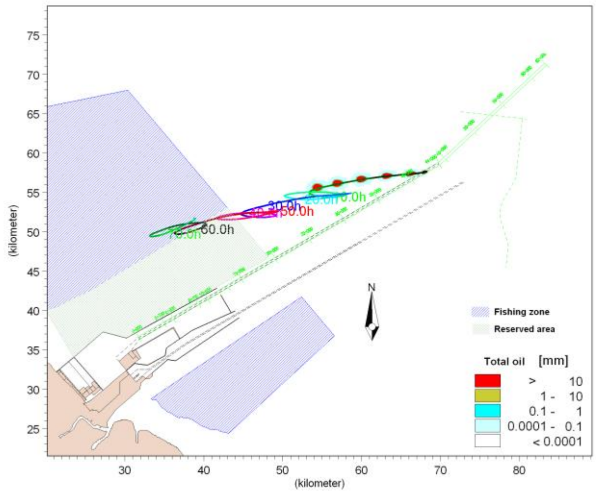

Fig.11 Oil spill trajectory when flood tide at S4

Through the study found that, under the tidal currents and wind, oil film will drift quickly, and after 55 hours later, which can arrive on the fishing zone locating at the west side of Huanghua prot. We can see, if we do not something when oil spill accident happening, the oil film will have a direct impact on the water environment protection target.

6. Summary

This study is basing on hydrodynamic and oil spill analysis module, model can precisely simulate the water dynamic condition and the process of the oil film drift about Huanghua channel. The results of the model tests show that,

1. The weeping range and trajectory of oil film is mainly affected by the flow after oil spill accident occurs, and the wind viscous effect will also affect the trajectory of the oil film, adverse wind conditions may accelerate the drift velocity of the oil film, shorten the influence time of the sensitive target.

2. when the oil spill accident happened at inside of the port, the sweeping area will locate in port interior. While at port entrance, the oil film can spread quickly to the sensitive target.

3. when the oil spill accident happened at outside of the port, oil film drift along with flow direction , and the trajectory is rule.

4. In the management of port, we should adopt the scientific method to establish the corresponding contingency plans and measures, to ensure the rationality of the emergency plan and feasibility of the measures.

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