Analysis on the impact of ship oil spill pollution on marine environmental risk

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Abstract—In this study, Zhanjiang port is taken as a typical sea area to study the influence of oil film on marine environment under the joint action of current and wind. In the simulation process, the final destination of the oil film after evaporation, emulsification, dissolution and sedimentation is considered. After the oil spill accident, the probability of oil spill in the range of 1 ~ 5km to the west of the leakage location is more than 70%; in dongtoushan Island, the probability of being affected by the oil spill can reach more than 40%; the probability of being affected by the oil spill in the marine reserve of Techeng island is more than 20%; the probability of the impact of oil spill on the restricted red line area of Mangrove in Nanshan island is less than 10%. In the sea area affected by oil spill, its marine life and ecology will also be affected.

1.INTRODUCTION
With the development of Zhanjiang port industry, the number of vessels in Zhanjiang port increased from 18008 in 2009 to 36565 in 2018[1], and the risk accidents caused by accidents also increased. Therefore, it is necessary to analyze the impact of oil spill on marine environment and the impact of oil film on marine ecology.

According to the requirements of technical guidelines for environmental risk assessment of oil spill on water, the spatial scope of risk assessment of water transportation engineering construction project is the space scope that may be affected by the oil spill accident. Therefore, the object of this study is Zhanjiang port, and the research content is the ship leakage accident in the port. The purpose of the study is to analyze the impact of the leakage accident on the marine environment and ecology Ring.

2.TECHNIQUES AND METHODS
Firstly, Mike21 is used to study the hydrodynamic forces in Zhanjiang port, and then oil map is used to study the drift and diffusion of oil spill, and its impact on marine ecological environment is analyzed.

2.1.Governing Equations
The governing equations are 2D flow continuity equation[2-3] and motion equation:

\[
\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t}
\]
\[
\frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left( \frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left( \frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial x} + \frac{gh \sqrt{\rho^2 + q^2}}{C^2} \cdot \frac{h}{h^2} = 0
\]
\[
\frac{1}{\rho_\infty} \left[ \frac{\partial}{\partial x} (hr_{x_{1}}) + \frac{\partial}{\partial y} (hr_{y_{1}}) \right] - \Omega_x - fV_y + \frac{h}{\rho_\infty} \frac{\partial}{\partial x} (P_x) = 0
\]
\[
\frac{\partial q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{pq}{h} \right) + \frac{\partial}{\partial y} \left( \frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial y} + \frac{gh \sqrt{\rho^2 + q^2}}{C^2} \cdot \frac{h}{h^2} = 0
\]
\[
\frac{1}{\rho_\infty} \left[ \frac{\partial}{\partial y} (hr_{y_{1}}) + \frac{\partial}{\partial x} (hr_{x_{1}}) \right] + \Omega_y - fV_x + \frac{h}{\rho_\infty} \frac{\partial}{\partial y} (P_y) = 0
\]

In which, \( h(x, y, t) \) - surface elevation; \( d(x, y, t) \) - depth(m); \( p, q(x,y,t) \) - flux; \( C(x,y) \) - Chezy(m1/2/s); \( f(V) \) - wind friction; \( \alpha \) - wind stress; \( \Omega(x,y) \) - coriolis parameter (s-1); \( \tau_{xx}, \tau_{yy}, \tau_{xy} \) - shear stress.

2.2. Oil spill model
MIKE21/3SA 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:

\[
X = X_0 + (U + aW_{10} \cos A + r \cos B) \Delta t
\]
\[
Y = Y_0 + (U + aW_{10} \sin A + r \sin B) \Delta t
\]

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

3. THE STUDY AREA

3.1. Calculation domain setting and mesh generation
The calculation domain of the large model includes Zhanjiang Bay and the sea area 25km east-west, 75KM east-west and 84km north-south, as shown in figure1. The whole simulation area is composed of 8447 nodes and 9724 triangular elements. The minimum space step is about 40m.

Fig.1 Calculation scope and mesh generation diagram

3.2. Model water boundary setting
Open boundary: a total of 92 points are set on the open boundary for control. Four main tidal components M2, S2, O1 and K1 extracted from Mike21 global model are used for calculation.
\[ \zeta = \sum_{i=1}^{N} \left\{ f_i H_i \cos\left[ \sigma_i t + (V_{oi} + V_i) - G_i \right] \right\} \]

Here, \( f_i \) is the intersection factors and angular velocity of the i tidal component (\( M_2, S_2, O_1 \) and \( K_1 \) are taken here)[4]; \( H_i \) and \( G_i \) are harmonic constants, which are amplitude and delay angle of the component respectively; \( V_{oi} + V_i \) is the amplitude of the component.

### 3.3 Oil spill scenario setting

It is assumed that a ship leakage accident occurs at the wharf front, and the leakage amount is 1000 tons. The drift and diffusion processes of oil film are predicted under the conditions of normal summer and winter winds[5].

#### Table 1. Scenario combination of wharf front leakage accident

| Leak location scale | Wind condition | Wind speed m/s | Tidal current |
|--------------------|----------------|----------------|---------------|
| Wharf apron 1000 tons | Summer wind ESE | 3.6 | flood |
|                     | Winter wind N | 3.6 | ebb |

### 4. Oil spill prediction results

#### 4.1 Oil spill prediction results under typical scenarios

When the oil spill accident occurs in the front water area of the wharf, the oil film drift track and sweeping range under the action of summer monsoon and winter wind are shown in Fig. 2 ~ Fig. 3.

It can be seen from the calculation that, no matter in the combination of summer monsoon and winter monsoon, once the oil spill accident occurs, the oil film will basically drift in Zhanjiang Bay, and the oil film will reach the surrounding shoreline, and the oil film will not affect the sea area outside Zhanjiang port.

When the oil spill occurs in the high tide stage, the oil film will drift to the northwest directly under the action of wind and current, and reach the shore after 6 hours. In this process, the oil film will not have a direct impact on the surrounding environment sensitive targets.

When the oil spill occurs at ebb tide stage, the oil film begins to drift to the East under the influence of wind and current, and then drifts to the southeast along the main channel. After 8 hours, some oil film will arrive at the coastline of the East Island in the south. Then, under the combined action of wind and current, the oil film will gradually drift into the Bay and reach the shore after 51 hours. In this process, the oil film will not affect the island brigade on the north side of the project Tourism and entertainment area, Xiashan Techeng Island Marine Ecological Nature Reserve restricted red line area and the ecological red line area outside Zhanjiang Bay have a direct impact.

#### Table 2. Oil spill risk prediction and analysis table

| scene | Tidal current | Time after accident (h) | Diffusion area (km^2) | Impact on environmental objectives |
|-------|---------------|-------------------------|----------------------|-----------------------------------|
| Summer wind | flood | 1 | 1.6 | The oil film reaches the shore after 6 hours |
|         |       | 6 | 0.7 | |
| Summer wind | flood | 1 | 2.5 | The oil film will affect the shoreline of dongtoushan island in 27 hours |
|         |       | 6 | 18.7 | |
|         |       | 12 | 2.5 | |
4.2 Simulation statistics and analysis of oil spill impact in random scenario

In this project, oil spill accident occurred at the wharf front of the project. The probability of oil spill influence within 1-5km to the west of the leakage location is more than 70%, the impact probability of oil spill in dongtoushan island is more than 40%, the probability of oil spill in Techeng Island Marine Reserve is more than 20%, and the probability of oil spill influence in Nansan Island mangrove restricted mangrove zone is less than 10%.

It can be seen from the distribution chart of the fastest arrival time of oil film on the sea surface, under the most unfavorable wind and current, the fastest time for oil film to arrive at Techeng Island Marine Reserve and dongtoushan island is 6 hours, while the fastest time to reach the mangrove restricted red line area of Nansan Island and the protection target in the sea off the mouth is more than 1 day.

| Probability (%) | Area affected (km²) | Time (d) | Affected area within the fastest time of arrival (km²) |
|-----------------|---------------------|----------|-----------------------------------------------------|
| 10–20           | 41.6                | 0–0.25   | 51.9                                                |
| 20–30           | 4.2                 | 0.25–0.5 | 19.2                                                |
| 30–40           | 2.6                 | 0.5–1    | 0.1                                                 |
| 40–50           | 3.2                 |          |                                                     |
| 50–60           | 7.8                 |          |                                                     |
| 60–70           | 7.7                 |          |                                                     |
| 70–80           | 3.2                 |          |                                                     |
| 80–90           | 0.6                 |          |                                                     |
| 90–100          | 0.3                 |          |                                                     |
4.3. Impact on marine ecology

After the oil spill accident, the crude oil entering the marine environment will form emulsified water droplets under the action of waves and tidal currents, which will directly harm the early development of fish and shrimp[6-7]. According to the living shrimp experiment of Yellow Sea Fisheries Research Institute, when the oil concentration is lower than 3.2mg/l, the metamorphosis rate of nauplii is basically consistent with that of artificial breeding; but when the oil concentration is more than 10mg/l, the metamorphosis rate of nauplii is obviously increased due to the influence of oil pollution. When the concentration is lower than 0.1mg/l, the survival rate and metamorphosis rate of the flea larvae have no obvious influence; when the concentration reaches 1.0gm/l, the flea can not survive; when the concentration is higher than 3.2mg/l, the larva can die within 48h.

The impact of oil spill on fish is multifaceted. First of all, oil will cause changes in fish feeding patterns, migration routes, population reproduction or individual imbalance. In different stages of fish development, the degree of impact is different, and the most harmful to fish in early development stage. The toxic effects of oil pollution on early developing fish are mainly manifested in slowing down embryonic development, affecting hatching, reducing physiological functions and leading to death. According to Linden's research, the anesthetic effect of soluble aromatic hydrocarbons in crude oil leads to the weakening of fish embryo vitality and low metabolism. When the embryo develops to membrane breaking, the body shape of newly hatched larvae is distorted due to lack of energy. In addition, fishing areas and fishing operations will be greatly affected during the oil spill drift. In order to avoid oil pollution, the adult fish fled the fishing ground, and the fishing ground was destroyed, which led to the reduction of fish catches.
5. CONCLUSION
Taking Zhanjiang port as an example, through the hydrodynamic prediction software Mike21 and oil spill analysis software oilmap, taking the fuel oil leakage of typical Wharf in Zhanjiang port as an example, this paper analyzes the oil film drift and diffusion trajectory after the fuel oil leakage into the sea, and analyzes the impact of the oil film on the marine environment and ecology.

According to the requirements of technical guidelines for environmental risk assessment of oil spill on water, the oil film drift process under the conditions of summer wind and winter wind is calculated respectively, and the stochastic process of oil spill at wharf front is simulated. The specific conclusions are as follows:

(1) When the oil leakage occurs at the wharf front, the oil film will drift quickly under the action of wind and diffuse along the direction of wind;

(2) No matter in the combination of summer monsoon and winter monsoon, once the oil spill accident occurs, the oil film will basically drift in Zhanjiang Bay, and the oil film will reach the surrounding shoreline;

(3) The probability of being affected by oil spill within 1-5km to the west of the leakage location is more than 70%; that of dongtoushan island is more than 40%; and that of Techeng Island Marine Reserve is more than 20%.

(4) Under the most unfavorable wind and current, the fastest time for oil film to arrive at Techeng Island Marine Reserve and dongtoushan island is 6 hours after the oil spill accident occurred at the wharf front.

(5) During the oil spill drift, fishing areas and fishing operations will be greatly affected. In order to avoid oil pollution, the adult fish fled the fishing ground, and the fishing ground was destroyed, which led to the reduction of fish catches.

Therefore, in order to protect the water quality, it is necessary to strengthen the management and reasonable allocation to avoid the occurrence of oil spill accidents. When the ship is berthing, oil boom should be set around the ship to prevent the possible leakage risk accident from affecting the surrounding water environment.

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