

Risk Countermeasures for Jiangyin Waters of Yangtze River Based on Oilmap Model

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Abstract. The common calculation methods for vessel fuel oil leakage were summarized. By analysing the fuel carrying capacity of non-tanker vessels statistically and regressively, the relationship between fuel carrying capacity and gross tonnage was worked out. The possible leakage from vessel of 10,000 gross tonnage was estimated based on the result. By using a numerical simulation method, the trajectory and polluting range of the vessel oil spill was simulated in Jiangyin waters of Yangtze River downstream, and different wind direction and tidal current conditions were considered in the simulation scenarios. The prevention and emergency response measures were proposed according to the simulated result.

1. Introduction

With the development of waterborne transport, the frequency of oil spill accidents increase with the rising demand for petroleum [1]. Oil spill accidents not only affect the economic development along the Yangtze River, but also destroy the coastal water ecosystems. There are two main types for vessel oil spill: operational spill and accidental spill. The main research is focused on accidental spills, such as crude oil spilled into the sea caused by collisions, grounding, exposure to rocks or oil spill pollution resulted from cargo oil loading and unloading operations [2].

In Jiangyin waters of the Yangtze River, the drifting trajectory of fuel oil spilled was simulated, and the influence of different environmental conditions on pollution degree was also studied. Based on the simulated result, the prevention and emergency response measures were proposed.

2. Leakage estimating

The amount of leaked oil is an important parameter for conducting numerical simulation of the trajectory. In practical usage, the methods for determining the amount of leaked oil can be classified to three kinds.

2.1 Formula calculation

This method is mostly used for scientific research and contingency plan making before the happening of accidents. The Bernoulli equation can be used to establish a formula for calculating the leakage of a continuous leakage source through a small hole, as seen in equation (1) [3]:

$$Q=C_dA\rho\sqrt{2gh+\frac{(P-P_0)}{\rho}} \quad (1)$$

Where, Q is the liquid leakage flow, in kg/s; C_d is the leakage coefficient, usually 0.6-0.65; A is the leakage area, in m^2 ; ρ is the leakage liquid density, in kg/m^3 ; P is the medium pressure in the container, in Pa, P_0 is the environmental pressure, in Pa; g is the acceleration of gravity, $9.8m/s^2$; h is the height of the liquid level above the leak, in m.

2.2 Empirical estimation

This method is mostly used for on-site estimation. After vessel oil spill accident occurs, the experts at the accident site can use remote sensing or artificial observation to estimate the diffusion area, drift thickness and density of pollutants, and provide reference for emergency response guidance and accident investigation [4].

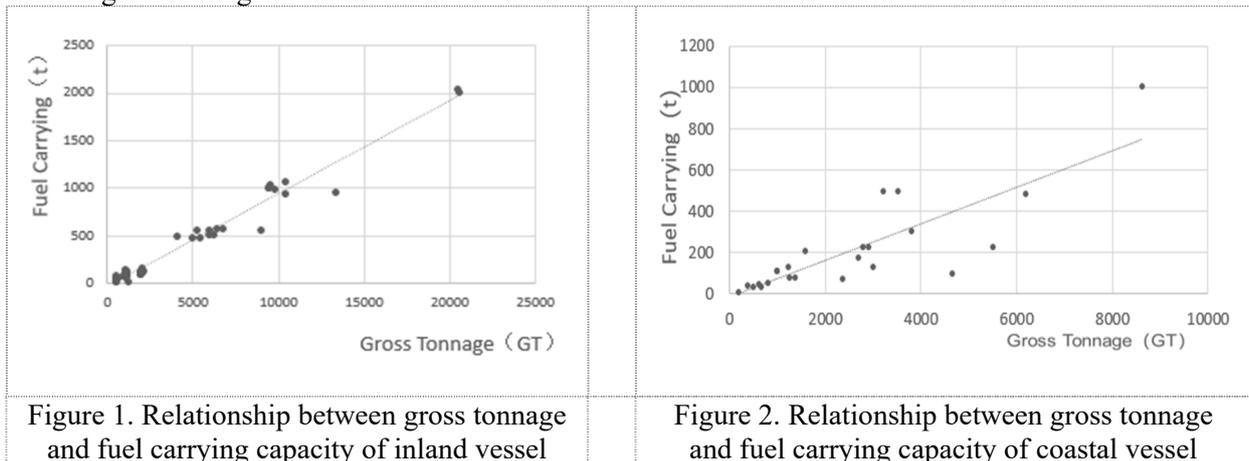
2.3 Statistical analysis

This method is based on the statistics of a large amount of data, using Matlab or other tools to find out the interrelationships among various factors. To analyse the actual fuel oil amount carried by vessels, the statistics on the fuel carrying capacity of non-tanker vessels navigating in inland and coastal waters were collected. Here is the results:

2.3.1 vessels navigating in inland waters. The paper presents a statistical analysis of the fuel carrying capacity and gross tonnage of 50 vessels with a capacity of 500-20000 GT navigating in inland river, as shown in Figure 1. The results show that the fuel carrying capacity F is approximately linear with the gross tonnage GT , as seen in equation (2):

$$F=0.0971GT-27.864 \quad (2)$$

Where, F is the fuel carrying capacity, the unit is tons; GT is the total tonnage of the ship, the unit is gross tonnage.



2.3.2 vessels navigating in coastal waters. The statistical analysis of the fuel carrying capacity and the gross tonnage of 25 vessels carrying 100-10,000 GT vessels navigating in coastal area shows that the fuel carrying capacity F is approximately linear with the gross tonnage GT , seen in Figure 2. The relationship can be expressed by equation (3). The meanings of F and GT are the same as above.

Statistical analysis is used to estimate the amount of leaked oil. It is assumed that a 10,000-GT non-tanker vessels navigating in inland waters had a leakage accident. In general, there are six fuel tanks on vessel, assuming that all the fuel oil had leaked out from one of the tanks. The total fuel carrying

capacity of the vessel calculated using equation (2) is about 943 tons. The amount of leaked oil is 157 tons, so the simulated amount is about 160 tons.

3. Oil spill consequence estimating

3.1 Numerical simulation methods

Oilmap is an oil spill drifting trajectory and weathering model developed by Applied Science Association. The principle is based on the Lagrangian particle tracking algorithm. The particle movement due to wind, tide, physical dispersion, and Stokes scattering was considered. The model simulates a series of processes such as drift, weathering, diffusion, dissolution, and shoreline adsorption of oil spill to predict the trajectory and the fate of the oil and evaluate the risk degree [5]. The particle drift rate is calculated by Formula (3) [6]:

$$\vec{U}_{oil} = \vec{U}_w + \vec{U}_t + \vec{U}_r + \alpha \vec{U}_e + \beta \vec{U}_p \quad (3)$$

Where, \vec{U}_w is the speed component due to the action of wind and wave, in m/s; \vec{U}_t is the speed component due to the action of water current, in m/s; \vec{U}_r is the speed component due to the action of the residual currents (e.g. density flow), in m/s; \vec{U}_e is the speed component due to action of Ekman flow, in m/s; \vec{U}_p is the speed component due to action of squirt flow, in m/s; α is 0 for floating particles and 1 for underwater particles; β is 0 for non-squirt spill and 1 for squirt spill.

The results of the oil weathering process were calculated by the Oilmap fate model. The weathering process includes extension, evaporation, water carrying, emulsion, and shoreline adsorption. The calculation process adheres to the Law of Mass Conservation and covers the oil spill that exist on the water surface, in water bodies and sediments, in atmosphere, those adsorbed on shorelines, and those manually contained and removed.

3.2 Simulated parameters setting

The Huangtian Port of the Jiangyin waters was selected as simulated point, the Jiangyin fortress forest park at about five kilometers downstream of the leakage point was selected as sensitive point.

The Huangtian Port is dominated by southeast wind in summer and northeast wind in winter, followed by northwest wind. The annual average wind speed is 3.8m/s. On the basis of the statistical results of the frequency of flow rates at the Datong Station of the Yangtze River since 2003, the upstream multi-year average flow (28,500 m³/s) was selected as the runoff parameter. According to the statistical data of the tide stations in the Yangtze River Estuary from January 1996 to December 2009, the tide range (2.5m) was selected for simulation.

Risk factors include visibility, wind, runoff, cargo traffic and tide [7]. Combined with the above analysis, the wind conditions and tide changes in the open water were selected as variables of the simulation. 4 kinds of simulated scenarios are shown in Table 1.

Table 1 Simulated parameters

scenario	runoff (m ³ /s)	tidal range (m)	amount of leaked oil (t)	tide	wind direction
scenario 1	28500	2.5	160	high tide	SE
scenario 2	28500	2.5	160	low tide	SE
scenario 3	28500	2.5	160	high tide	NE
scenario 4	28500	2.5	160	low tide	NE

3.3 Simulated results and analysis

According to the simulated results, it can be seen that in scenarios 1 and 2, the oil spill drifts to the opposite side of the sensitive point under the combined effect of wind and tide after the accident happens, then the pollutant gradually spreads to the downstream as time passes. Therefore, scenarios 1 and 2 will not contaminate the sensitive area. In scenarios 3 and 4, the oil spill drifts along the river bank that is on the same side of the sensitive point, arrives to the sensitive point after 5 and 1 hours respectively, traverses and leaves the sensitive area after 7 and 2 hours. Comparing the shoreline absorption results (Figure 3) after 6 hours of oil spill leakage under each scenario, it can be found that the wind plays a leading role in the drift of oil spill compared with the effect of the action of tide current.

The shoreline adsorption rate after 6 hours of oil spill leakage under various scenarios was calculated, which was shown in Table 2. The degree of shoreline adsorption in scenario 4 is much smaller than that of other scenarios. Combined with the oil spill weathering curves (Figure 4) to analyse, this may be because only a small proportion of oil spill spread along the river bank in scenario 4.

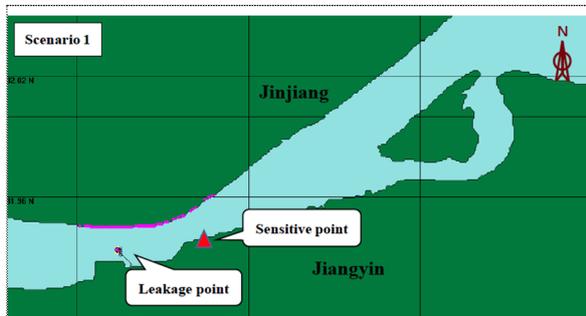


Figure 3(a). Simulated results after 6 hours of spillage (scenario 1)

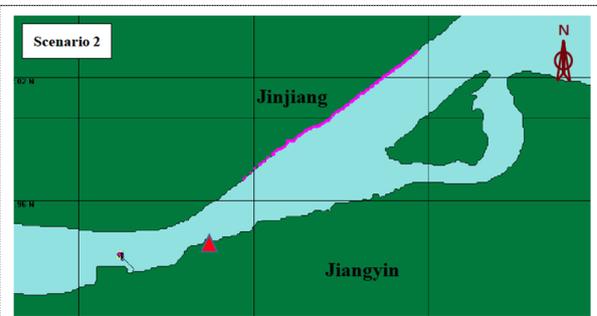


Figure 3(b). Simulated results after 6 hours of spillage (scenario 2)

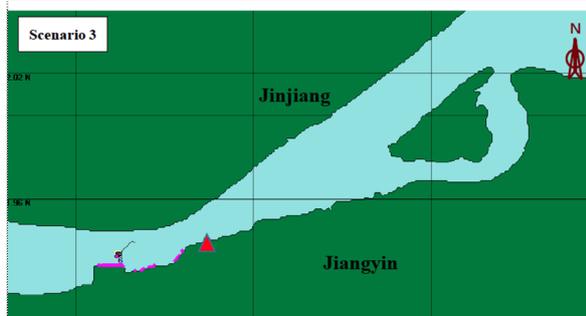


Figure 3(c). Simulated results after 6 hours of spillage (scenario 3)

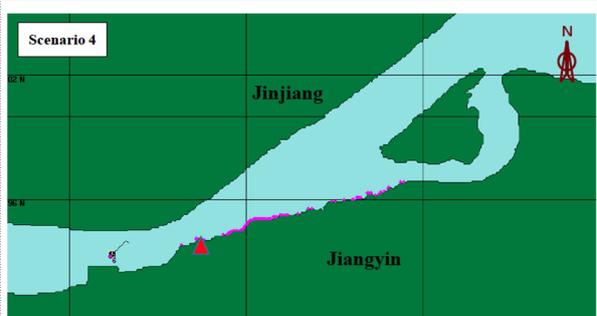


Figure 3(d). Simulated results after 6 hours of spillage (scenario 4)

Table 2 Comparison of the shoreline absorption rate of oil spill

scenario	shoreline adsorption rate
scenario 1	64.4%
scenario 2	98.1%
scenario 3	96.9%
scenario 4	29.4%

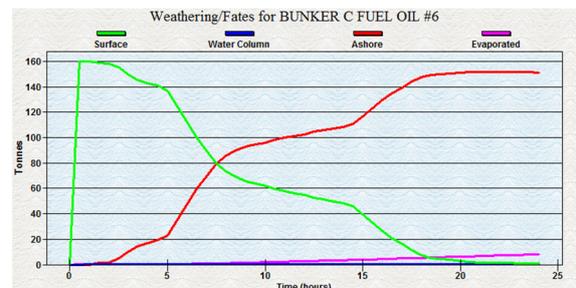


Figure 4. Weathering/fates for oil spill(scenario 4)

4. Risk countermeasures

In response to the above-mentioned results of numerical simulation, the countermeasures for mitigating the consequences of accidents from three aspects like emergency response time, emergency measures and individual protection was proposed:

4.1 Emergency response time

The emergency response time determines the effectiveness of the emergency response to a large extent. The shorter the time for emergency personnel and equipment reaches the accident site, the smaller the degree of pollution damage will be. After receiving the alert, the emergency personnel should formulate emergency strategies in terms of the accident situation as soon as possible, and take corresponding emergency measures referring to the time when the oil spill reaches the sensitive point.

4.2 Emergency measures

The emergency disposal of oil spill accident can be divided into surveillance and monitoring, containment and diversion, mechanical recovery, and decentralized adsorption. It is recommended to set up detection and alarm devices for pivotal beacons, important ports and vessels in the inland river, and provide comprehensive monitoring with aerial surveys and satellite telemetry. Containment and diversion is the main way to protect sensitive resources. The type of boom, the location and the time of deployment need to be determined in conjunction with the trajectory and fate of the oil spill.

4.3 Individual protection

In emergency response actions for oil pollution accidents, on-site operations and ambulance staff should give priority to personal safety and take appropriate measures to prevent oil spill from causing fire and explosion resulting in an accident escalation. It is recommended that emergency person wear self-contained positive pressure respirator and protective fire clothing. The emergency vessels should quickly evacuate the crew of the accident vessels and person of the contaminated area to safe area, measure the concentration of oil in the air near the leakage point to prevent secondary hazard such as acute poisoning, fire and explosion at the same time.

5. Conclusion

The common methods for calculating the amount of fuel oil in ship accident were concluded. By using the statistical analysis, the most likely amount of leaked oil of a 10,000 GT non-tanker vessel was calculated. Oilmap was used to propose countermeasures to mitigate the consequences of accidents from the aspects of risk prevention and control. The research results can provide a scientific decision-making reference for the risk prevention and control of vessel fuel leakage accident in the downstream of the Yangtze River.

Acknowledge

The article is based on the related research of the National Science and Technology Support Project “Dangerous Goods Ship Transportation Safety Control and Emergency Technology” (2015BAG20B03) and the Support Research Project of China Waterborne Transport Research Institute—Study on establishing of national scientific research platform of oil spill emergency (WTI61708).

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