Study on the oil spill risk of 10,000 dwt multi-purpose wharf in the Chengao harbor area, Sandu bay, Ningde city

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Abstract. With the rapid development of marine industry, oil spill accidents occur frequently, which have a great impact on the ecology and economy. The research on oil spill risk has become the focus. In this paper, taking Sandu bay, Ningde city as an example, a comprehensive oil spill risk study is carried out based on the method of probability statistics, risk matrix and numerical simulation, and relevant suggestions are put forward for the prevention and treatment of oil spill accidents.

1. Introduction
Sandu bay is a strategic hub in Fujian province, which connecting the south China sea, the North Sea and the Taiwan strait. Its main channel can meet the one-way navigation of 300,000-ton oil vessels. And it has six operating areas. Among them Chengao harbor area is one of the key development operating areas of Ningde port in the near and medium term [1]. In recent years, the number of vessels entering and leaving Ningde port area has increased year after year. In 2017, the total number of oil vessels was 410. It is estimated that the oil and oil product throughput of Fuzhou port will reach 36 million tons by 2035. With the increasing throughput, it brings more economic opportunities to the port, but also means more severe environmental risks. Especially the oil spill accident and its far-reaching impact cannot be ignored. In recent years, there have been several oil spills in Ningde sea area. For example, on November 7, 2010, the engineering ship, “Xiang Loudi 78” which belongs to Loudi City Xiangzhong Shipping Co. Ltd touch the Niu Reef during sea trial in the surrounding area of Fuding City, Qingyu Island. The leakage of about 2 tons of diesel oil into the sea resulted in the pollution of water cage, oyster and laver culture and the surrounding ecological environment in the waters near Qingyu Island. The total loss is up to millions of yuan, which identified a major maritime traffic accident. On May 20, 2011, the steel scrap ship "Yihai 723", belongs to Fujian Port and Shipping Co. Ltd caused a serious oil spill pollution accident in the process of dismantling and lifting machinery bilge at the foreshore of port.

There are such environmentally sensitive areas as Guanjingyang large yellow croaker breeding reserve, Sandu tourism and entertainment area, agricultural and fishery environmental protection and utilization area in Sandu bay area. With the construction of port area, especially the development and construction of oil products wharf and deep-water channel, according to relevant studies [2-5], Xu wenbin et al. believed that the potential risk of oil spill would seriously threaten the surrounding environmental resources such as germplasm resources of large yellow croaker [6].

Once the Marine oil spill accident happens, it will cause serious environmental pollution and great economic loss, which should be given enough attention. So it should be given enough attention. In the
existing studies on the risk of marine oil spill, Zheng shifeng [7] evaluated the risk of vessel oil spill accident in Xiamen sea area through the method of risk matrix and numerical simulation; Ding wangping [8] calculated the oil spill probability through the method of probability prediction, so as to optimize the configuration of oil spill emergency equipment for large ships. At present, many achievements have been made in the risk of oil spill, but the research on Sandu bay which have many environmentally sensitive areas is still not comprehensive and in-depth.

This paper based on the relevant data of Chengao harbor area, Sandu bay, Ningde city and The codes for marine environmental risk assessment by ship analyzing the causes and influencing factors of the accident. Adopts the methods of probability prediction, risk matrix and numerical simulation to study and analyze the risk of oil spill accident, and puts forward relevant suggestions on reducing the accident frequency and reducing harm of the accident.

2. Accident profile and probability prediction
The ship oil spill accident can be divided into operation oil spill accident and marine peril oil spill accident [9]. Operation oil spill accidents are mainly caused by equipment failure, illegal discharge and other reasons. It usually happens in the port. Marine peril oil spill accident is mainly caused by ship collision, grounding, hull damage, fire, explosion, and so on. Most of these accidents occurred in the channel and anchorage, with a large oil spill.

As for the channel and anchorage, the width of the channel between the tributary channel and the main channel is inconsistent at this port. At the same time, there are few navigational aids. If the position of the ship is improper or the timing of turning is not good, it may cause the ship to run out of the channel and strand. The secondary channel is close to the roundabout area of the nearby wharf, Jigong mountain anchorage and Qingshan anchorage. Without properly operation, navigation ships and berthing ships in the channel may be disturbed, and collision accidents will probably occur. In addition, the approach channel of the project is a natural waterway, and the surrounding area of the channel is a traditional tidal flat breeding area. The entry and exit of aquiculture vessels and the encroachment of aquiculture waters on channel are both easy to cause accidents.

As for the wharf in the port, improper berthing operation or strong wind and other bad weather, are easy to cause ships to touch the port, and cause the leakage of cargo.

Therefore, as the Table 1 shows, according to The codes for marine environmental risk assessment by ship, and based on the above discussion, it can be considered that the most risky factor is the channel or anchorage and wharf.

|                | Channel or Anchorage | Wharf | Ship | Cargo |
|----------------|----------------------|-------|------|-------|
| Management     | ▲                    | ▲     | ▼    | ▼     |
| Weather        | ▲                    | △     | △    | △     |
| Hydrology      | ▲                    | △     | △    | △     |
| Personnel      | ▲                    | △     | △    | △     |

▲: Greatest risk factor; △: Risk factor; ▼: Less risky factors

The reasonable prediction of oil spill accident at sea can effectively reduce the loss caused by the accident if actions are taken in time when the accident occurs. Therefore, we use probability statistics method to predict the frequency and pollution of operation accidents and maritime peril accidents respectively.

In the aspect of the frequency of accidents, the number and scale of berths, cargo throughput, environmental management system and other factors of the project were considered. It can be predicted that the frequency of operation oil spill accidents is 5-10 years/incident. According to The codes for marine environmental risk assessment by ship and the marine peril oil spill accident data of Fuzhou, the prediction probability formula is as follows:
\[ P = \frac{N_1}{N_2} \times \text{Number of vessels of this project} \times k \]  
(1)

In the equation:
- \( P \) — Probability of marine peril accidents
- \( N_1 \) — Number of ship traffic accidents in N year
- \( N_2 \) — Number of ships entering and leaving ports in N year
- \( k \) — Probability of pollution accident caused by marine peril accident

From 2007 to 2011, there are 51,528 vessels entered and left Ningde port, and 29 of them were involved in oil spill accidents. The total number of vessels entering and leaving the port is about 140. According to the above equation, the probability of maritime peril accidents is \( 3.15 \times 10^{-3} \) per year.

In the aspect of the amount of pollution, according to Table 2 of *The codes for marine environmental risk assessment by ship*, the amount of operational oil spill accidents of different tonnage of wharfs is as follows:

**Table 2.** The amount of oil spill quantity corresponding to different tonnage of wharf.

| Tonnage of oil wharf | 1000 | 5000 | 10000 | 50000 | 100000 | 150000 | 250000 | 300000 |
|----------------------|------|------|-------|-------|--------|--------|--------|--------|
| Oil spill quantity (t)| 17   | 21   | 42    | 60    | 125    | 175    | 225    | 261    |

The tonnage at the port is 10,000 tons. It can be seen from table 2 that the amount of oil spill of operation accident is about 42 tons. As for marine peril oil spill accident, according to *The codes for marine environmental risk assessment by ship*, according to the loading capacity of the main ship type, the overflow capacity of the most likely marine peril accident is predicted according to the oil leakage of about one oil tank or fuel tank. Combined with *Technical guidelines for environmental risk assessment of water spill (JT/t1143-2017)*, according to the calculation of 80% oil loading rate, it is determined that the most likely oil spill is 93.6 tons.

3. Numerical simulation of oil spill

A large number of serious oil spill accidents may occur during the operation of the port. A tide current model can be established to reasonably predict the trajectory of oil spill diffusion. In this way the planning and arrangement of cleaning equipment and power can be more reasonable, and the emergency plan for accidents can be put forward more specifically, and the cleaning power can be dispatched more reasonably and efficiently after the accident.

In the process of oil spill simulation in this port, the water flow control equations can be expressed in Euler form and Lagrange form, and the non-structural finite volume difference scheme proposed by Casulli and Zanolli is used for numerical dispersion. At the same time, the oil spill model adopts the Euler-Lagrangian theoretical system to simulate various processes of oil film such as the expansion in water body, dissolution under the action of water flow and wind field, dispersion (entrainment), turbulent diffusion, evaporation and emulsification. The drifting position and thickness of oil film with time can be given by the model. And the model adopts the oil particle method, which is widely used in the world to simulate the drift track and concentration distribution of oil film.

Based on the prediction of risk factors and the property of the accident in the previous article, it can be assumed that the amount of oil spill of operation accident is 42t in the dock area and the amount of oil spill of marine peril accident is 93.6t in the corner of channel, and the specific location is shown in Figure 1.

The direction of the unfavourable wind at the port is southwest. At the same time, the port is close to the northwest of Pacific Ocean, and the northwest Pacific Ocean is the most active area of tropical cyclone activity in the world [10]. Summer is the frequent season of Typhoon, and the wind direction of Ningde port is dominated by the southwest wind [11]. Therefore, SW is selected as the wind direction.
direction to simulate the oil film diffusion range in different periods of high tide and low tide in the two regions.

![Figure 1](image1.png)

**Figure 1.** The location of the simulated accident.

### 3.1. The wharf area

The oil film range of different periods in the port area is shown in the figures 2 and 3 as below:

![Figure 2](image2.png)

**Figure 2.** High tide lasted 24 hours, 48 hours of oil film sweep the sea area.

![Figure 3](image3.png)

**Figure 3.** Low tide lasted 24 hours, 48 hours of oil film sweep the sea area.
From the simulation, it can be seen that after the oil spill occurred at the beginning of the rising tide the oil film first drifted to the south bank of Sandu island in the periods of rising tide with the SW wind. In the 12th to 15th hour, part of the oil film gradually invaded into Sandu tourist recreation area, and presented a long strip distribution. At the 24th hour, the oil film was stretched again, and the center of the oil film drifted to the south side of Qingshan island and the north side of Jigong mountain. At the 48th hour, the oil film developed and diffused as shown in Figure 2 (b).

After the oil spill occurred in the early ebb tide, the oil film first drifted to southward with the ebb tide, and it could reach the outside of the Jingshui agricultural area within 6 hours. At the 12th hour, the oil film arrived at the east side of Qingshan island. It was located in the center of Guanjingyang, and it posed a serious threat to the local aquaculture area. At the 24th hour, the center of oil film approached the Changyao island. Then, at the 48th hour, the oil film further drifted and diffused as shown in Figure 3(b).

### 3.2. The channel area
The oil film range of different periods in the channel area is shown in the figures 4 and 5 as below:

![Figure 4](image.png)  
**Figure 4.** High tide lasted 24 hours, 48 hours of oil film sweep the sea area.

![Figure 5](image.png)  
**Figure 5.** Low tide lasted 24 hours, 48 hours of oil film sweep the sea area.

It can be seen from the simulation that the oil film drifts to the northeast in the early rising period of about 6-9 hours. At the 12th hour, the oil film returned to form a long strip, which had a span of about 4km. And then it gathered in Guan Cuaocheng port area. At the 24th hour, the oil film continued
to expand and was still concentrated in the front sea area of Guan Cuocheng port area. At the 48th hour it developed to expand as shown in Figure 4(b).

At the beginning of the ebb tide in the channel area, the oil film drifted to the southward and the left of the Dongchong corner. About the 15th hour, the oil film was further extended to the Guanjingyang and the sea area outside the Dongchong corner. At the 24th hour, the oil film was widely distributed in the waters around the shipping area of Dongchong port. At the 48th hour, the development of oil spill as shown in Figure 5(b).

Generally speaking, the environmental sensitive areas which may be affected by oil spill are Guanjingyang large yellow croaker breeding area, Sandu tourist recreation area and Jingshui agriculture and fisheries area. According to the simulation results, in the wharf area, during rising tide period the oil spill invaded Sandu tourist protection area at the 11th hour. And it invaded Gujing ocean protection area at the 12th hour. During the ebb tide period, the oil spill invaded Gujing ocean protection area at the 2nd hour. And it invaded Jingshui agriculture and fishery area at the 6th hour. In the channel area, the oil spill invaded the Guanjingyang yellow croaker protection area at the 2nd hour of high tide. During the ebb tide, the oil spill invaded the Guanjingyang yellow croaker protection area at the 2nd hour.

4. Risk matrix analysis
In order to put forward a more objective and reasonable evaluation of oil spill risk, the acceptable level of risk can be described by risk matrix. In the risk matrix, the abscissa represents the accident consequences and the ordinate represents the accident frequency. According to The technical guidelines for environmental risk assessment of offshore oil spills, the risk probability and hazardous consequences of accidents can be classified, as shown in Figure 6 and 7. Therefore, the operation oil spill and maritime peril accident in port are both in the low risk range.

| Accident probability (years/incident) | Oil spill quantity (t) | Low risk area | Medium risk area | High risk area |
|---------------------------------------|-----------------------|--------------|------------------|---------------|
| <1                                    | <10                   |              |                  |               |
| 1-5                                   | 10-5                  | ★            |                  |               |
| 5-10                                  | >50                   |              |                  |               |

**Figure 6.** Risk analysis matrix of operation oil spill accident.

| Accident probability (years/incident) | Oil spill quantity (t) | Low risk area | Medium risk area |
|---------------------------------------|-----------------------|--------------|------------------|
| <1                                    | <50                   |              |                  |
| 1-10                                  | 50-100                |              |                  |
| 10-50                                 | 100-500               |              |                  |
| 50-100                                | 500-1000              |              |                  |
| 100-1000                              | 1000-10000            |              |                  |
| >1000                                  | >10000                |              |                  |

**Figure 7.** Risk analysis matrix of marine peril oil spill accident.

Notes: ★represents the most likely risk range.
The oil spill accident may bring serious harm to the nearby marine industrial areas, such as Guanjingyang yellow croaker breeding area, Sandu tourist recreation area and Guanjing agriculture and fisheries area. So even the risk of oil spill accidents is low, it is still necessary to develop a series of prevention measures for the port.

5. **Advice on risk prevention and accident management**

In view of the risk of oil spill that still exists in the port, combine with *The guidelines for assessment the emergency capacity of coastal pollution accidents by ships*, the following three suggestions are put forward in order to reduce the probability of the accident and quickly control the situation after the accident.

First, daily management can be strengthened and standardized to reduce the probability of accidents such as ship navigation management, ship berthing operation management, ship loading fuel management and so on. Specific can include the following points:
- To strengthen the training and education of seaman, improve operational skills and safety awareness;
- To urge ships entering and leaving the port to strengthen the risk control of navigation and berthing;
- Strengthen coordination with adjacent berths;
- Strengthen the training and education of the practitioners, improve the operational skills and professional quality, standardize the dock management;
- Formulate safety and pollution prevention and management system, establish maintenance and update system of equipment and facilities.

Secondly, anti-pollution emergency equipment, such as oil fence, oil absorption felt, oil collectors, etc. can be equipped to meet the pollution prevention and emergency of port.

Finally, the reasonable and effective environmental emergency plan, clarified personnel allocation and arrangement of emergency response, and regular drills can be made to improve the ability to prevent environmental emergencies.

Above preventive measures can more effectively prevent the occurrence of sudden environmental pollution accidents. And we can carry out activities such as emergency rescue, environmental monitoring, personnel evacuation, cleaning and purification, pollution tracking and information notification quickly and effectively after the accident. So the accident loss and social harm can be reduced to the minimum degree.

6. **Summary**

In this paper, the methods of the probability statistics, the risk matrix and the numerical simulation were used to supplement the study on the oil spill risk of 10,000 dwt wharf in the Chengao harbour area, Sandu bay. The following conclusions can be drawn from the analysis of this paper:

1. At port, the probability of operation accidents is predicted to be 5-10 years/incident, and the probability of marine peril accidents is predicted to be $3.15 \times 10^3$/year. The most likely oil spill quantity: operation accident 42 tons; marine peril accident 93.6 tons.

2. There is a high probability of oil spill in the wharf and the channel area. The unfavorable wind direction, SW is used as the simulated condition. It can be known from the simulation results; the oil spill can invade the Guanjingyang protected area after 2 hours during ebb tide in the wharf area. And it takes 2 hours for oil spill to invade the Guanjingyang protected area during both rising and ebb tide in the channel area.

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References

[1] Zheng J P 2015 Exploration on the development potential of direct economic hinterland of Sandu port area China Ports 2015(1) 40-2

[2] Lin Y B and Zou W 2013 Practice analysis and countermeasure of environmental risk assessment on oil spills in Yangpu Bonded Port Area Environ. Sci. Manag. 2013(01) 185-92

[3] Liu C P, Shen Y B and Din S P 2012 Marine environmental risk assessment of port engineering Port Waterway Engin. 2012(5) 68-73

[4] Li T and Xie Z Y 2013 Study and application of Oil Spill Trajectory Model Environ. Sci. Manag. 2013(07) 60-5

[5] Xu W B 2011 Forecast to marine oil spilling impact of Futai docklands in Fuzhou Port J. Fujian Fisheries 2011(2) 44-9

[6] Xu W B and Mo H R 2014 Analysis and prediction of influence of oil spill risk on Pseudosciaena Crocea Protection Zone at Sanduao crude oil terminal Coastal Engin. 2014(4) 71-82

[7] Zheng S F 2013 Risk assessment and emergency countermeasures of oil spill accident in Xiamen sea area (Shanghai: Shanghai Pujiang Education Publishing House)

[8] Din W P 2015 Study on the optimal allocation of oil spill emergency equipment for large ships in the region (Ningbo: Ningbo University)

[9] Gao Z B 2014 Oil spill pollution risk analysis in port based on oil spill simulation (Qingdao: Ocean University of China)

[10] Yang Y 2009 Report after typhoon in the northwest Pacific (Shanghai: Shanghai Jiaotong University)

[11] Zeng J Y, Gao C H, Ye D Y and Wang J P 2017 Wind distribution characteristics and the selection of forecast indicator station in the northeast coastal islands of Fujian Marine Forecasts 2017(4) 42-51