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Risk analysis and emergency countermeasures for oil pollution in main channel of South to North Water Transfer Project

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Abstract: The total length of the main channel of the South-to-North Water Transfer Project is 1432 kilometers. There are nearly 1,000 supporting mechanical and electrical equipment along the channel gate station. At the same time, there are more than 1,000 main roads with channel crossing roads along the route. Oil spills may occur due to various reasons such as equipment leakage or traffic accidents. Entering the channel directly causes pollution of water quality. The pollution of water quality will directly endanger the health of human beings. Therefore, it is essential to quickly and efficiently remove oil pollutants from the water supply channels. This paper analyzes the basic characteristics of the Middle Route Project of South-to-North Water Transfer, and the risk sources of sudden oil pollution, and the common degreasing devices such as oil booms, oil absorbing pads, and oil removal devices based on steel structure pontoons in the main trunk The applicability was analyzed. The results show that the traditional oil-absorbing felt, oil boom and other degreasing devices have poor applicability in the middle line, which can not meet the requirements of the mid-line water quality and channel flow rate, and the adaptability to the channel engineering characteristics is also insufficient. The degreasing device based on the steel structure pontoon can adapt to the current situation of the midline, and has good effects in preventing the oil film from escaping and splashing. Therefore, in general, the degreasing device based on the steel structure pontoon is suitable for the midline burst oil. Effective measures and means of pollution accidents

1 Overview

Sudden oil pollution accident refers to water pollution accident caused by oil spill into water body due to accidental or improper operation during the production, storage, transportation and use of crude oil, fuel oil and various oil products.[1]

Sudden oil pollution usually occurs in oceans, lakes and rivers. There are two main ways to cause pollution of shipping oil in the sea: the first is the normal operation of operational oil discharge, which mainly includes bilge water in the engine room, ballast water in the cargo hold of the oil tanker and washing water; the second is oil spills caused by accidents, such as marine accidents (stranding, collision, explosion, fire, etc.)[2]. The impact of oil pollution on lake ecosystem is manifold, including COD, BOD, total P, total N and other water quality indicators seriously exceeding the standard, intensified lake water eutrophication, and significant change of the species, density and spatial distribution of benthic macroinvertebrates, zooplankton and phytoplankton[3]. The river has a large volume of water and a rapid flow. When oil pollution occurs, the oil mass will spread rapidly, expanding the scope of pollution and increasing the difficulty of disposal[4].

Sudden oil pollution is extremely harmful and difficult to be treated. Once the oil enters the water body, it will rapidly drift along with the water flow. If the oil is not blocked or stopped in time, the damage and pollution caused by the oil will constantly expand. Therefore, the key of oil water pollution disposal lies in three links: 1) how to control pollution diffusion quickly and effectively; 2) how to collect pollutants, that is, to remove oil; 3) how to separate oil and water.

2 Risk analysis on oil pollution in main channel of the middle route of South to North Water Transfer Project

The middle route of South-to-North Water Transfer Project, as a major infrastructure facility to alleviate the water resource crisis in Beijing, Tianjin and north China, can increase water supply by 6.4 billion cubic meters for urban living and industrial production and another 3 billion cubic meters for agriculture for cities along the route of Beijing, Tianjin, Henan and Hebei. This project will greatly improve the ecological environment and investment environment in water supply areas and promote economic development in central China. The water transfer route of the middle route of South-to-North Water Transfer Project is shown in figure 1.

2.1 Overview of the middle route of South-to-North Water Transfer Project

2.1.1 Overview of the engineering situation of the middle route of South-to-North Water Transfer Project

The main channel of the middle route of South-to-North Water Transfer Project has the following basic characteristics:

(1) Long water transfer route The total length of the main channel of the South-to-North Water Transfer Project is 1432 kilometers, of which the channel is 1,277 km long, divided into 8 sections. The length between the starting point of the channel and the middle branch of North Juma River is 1,196.505 km, using open channel for water transfer. The Beijing section is 80.052 km long, using PCCP pipe and culvert for water transfer . The Beijing-Tianjin water diversion branch is 155 km long, using culvert to transport water.

(2) Large water transfer scale The annual average water diversion volume of the first stage project of the middle route is 9.5 billion cubic meters, with the volume scale of main control points of the main channel being: 350 m^3/s of designed volume and 420 m^3/s of increased volume for Taocha channel; 265 m^3/s of designed volume and 320 m^3/s of increased volume for the Yellow River-crossing project; 50 m^3/s of designed volume and 60 m^3/s of increased volume for North Juma River; and 50 m^3/s of designed volume and 60 m^3/s of increased volume for the main channel of Tianjin.

(3) A large number of architecture There are more than 1,750 architecture of all kinds within the construction area, including164 river-channel crossing structure (including the Yellow River-crossing project); 463 drainage structure on the left bank; 136 channel-channel crossing structure; 41 railway crossing structure; 736 road bridge crossing channels; 97 diversion stations; 64 regulating gates; 54 water release gates; 61 water control gates; 9 water tunnels; and 1 pumping house.

(4) Strict water quality requirement Water transfer of the middle main route aims to meet the needs of daily life and production water usage for residents in water-scarce areas. Therefore, the water supply quality shall reach the Category II standard of China’s standard of surface water quality (GB3838-2002). The water quality reaching the water-receiving areas must reach Category III standard or higher of the standard of surface water quality.

2.1.2 Overview of the water running situation of the middle route of South-to-North Water Transfer Project

Since its completion on December 12, 2014 as of June 17, 2018, the water volume of the first diversion from Taocha Channel has reached 15 billion cubic meters, benefiting 19 large and medium-sized cities along the route including Beijing, Tianjin, Shijiazhuang, Zhengzhou, etc. More than 53.1 million people living in the north are able to use water transferred from the south. Among those people benefiting from this project, there are 11 million people in Beijing, 9 million in Tianjin, 15.1 million in Heibei and 18 million in Henan. Currently, it is responsible for more than 70% and 100% of the urban water supply in Beijing and Tianjin respectively, and it has effectively alleviated the water resource stress in cities along the route and improved the water ecological environment. The benefit brought by the middle route of South-to-North Water Transfer Project is shown in Figure 2.

For more than three years since the completion of the project of the middle route of South-to-North Water Transfer, the water supply safety coefficient of water-receiving provinces and cities along the route including Beijing, Tianjin, Hebei and Henan has been effectively increased, and the water quality has been significantly improved.

In Beijing, the city's per capita water resource has been increased from 100 cubic meters to 150 cubic meters, and the water supply safety coefficient in the central urban area has been raised from 1.0 to 1.2. In tianjin, the South-to-North Water Transfer Project once became a lifeline, with the residents of 14 administrative districts using the water from the south, and the water supply guarantee rate has been greatly increased with the single "Luan River" source changed to a dual source guarantee. In Hebei, more than 4 million people bid farewell to high-fluorine water and bitter saltwater. In Henan, the water supply range covers more than 10 cities, including Nanyang, Luohe, Pingdingshan, Xuchang, Zhengzhou, Jiaozuo, Xinxiang, Hebi and Puyang.

Figure 1 water conveyance route for the middle route of South to North Water Transfer Project

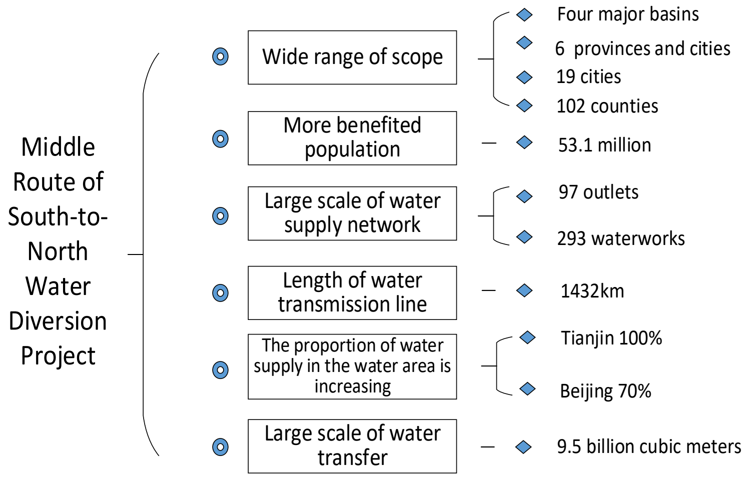

Figure 2 Benefits of the middle route of the south to North Water Transfer Project

2.2 Risk source analysis on oil pollution in the middle route of South to North Water Transfer Project

The oil risk sources of the main channel of the middle route of South to North Water Transfer Project mainly include the following aspects:

1. Hydraulic equipment failure at the gates may lead to oil leakage into the channel

The main sources of oil risk in the main channel of the middle route include hydraulic oil and lubricants for gate opening and closing machines such as regulating gates and diversion gates, and thermal oil ice-melting equipment. Nearly 1,000 mechanical and electrical equipment are set up along the main channel of the middle route of South-to-North Water Transfer Project. In the process of operation and maintenance of the project for more than one year, it is found that oil leakage occurs in some electromechanical equipment which enters the channel directly causing water pollution. According to the data reported, the hydraulic oil of a single opening and closing machine of a gate is 500L and the oil of a single ice-melting facility is 600L. The total number of gate opening and closing machines of the main channel is 469, and there are 19 sets of thermal oil ice-melting equipment, which makes the total oil storage 245,900 L or so. In July 2015, the emergency monitoring results of the oil leakage accident of the repair of the opening and closing machine of the regulating gate of the Tuan River water channel show that 30 L hydraulic oil leakage flowed to the channel, causing impact on the channel by expanding the influenced distance to 12 km (where the oil peak still reached 1 mg/L, while class II standard is 0.05 mg/L) and that the influence lasted for more than 7 hours. It is evident that the hydraulic oil of opening and closing machines and ice-meting oil can pose threat to the water quality of the channel.

2. Oil pollution in the channel caused by damage and leakage of fuel tanks of vehicles passing over the channel-crossing bridge

There are a total of 1,238 bridges along the main channel, with roads and channels crossing with each other. After the completion of the main route water supply project, it is inevitable for enterprises along the route to transport raw materials, by-products or products across the channels, such as diesel, gasoline, ethanol and other chemical liquids[5]. There are potential risks of leakage due to various reasons such as traffic accidents. Once a traffic accident occurs, hazardous chemicals may enter the main channel, affecting its water quality.

Since the official completion of the project, there has been occurrence of sudden water pollution accidents in the middle route of the main channel. For example, at about 8:30 on September 8, 2015 at the upstream 50m on the left bank, a mini truck of the security system construction unit slid into the channel accidentally. Above the channel is the North Bridge of Nanfu Mountain (stake mark: 1124+267) in the main channel under the administration of West Heishan Office. During the process of salvaging the vehicle, some diesel leaked into the channel (Figure 3).

Figure 3 Scene of sudden water pollution accident on September 8, 2015

3.Oil leakage was caused by a sudden traffic accident on a road under operation and maintainance

There is relatively standard management on the hazardous goods transported on railways. As for hazardous chemicals and dangerous goods transported through highways, even though the state has relevant regulations, it has always been an important source of emergencies in road transportation due to its characteristics of dispersibility, convenience and flexibility. For the main channel of the middle route of South-to-North Water Transfer Project, although the probability for transport vehicles to have traffic accidents when passing across the channel-crossing bridge and trigger dangerous leakage, explosion and capsizing is relatively low, once accidents occur, dangerous goods will directly enter the main channel bringing catastrophic damage to the water quality due to such unpredictable emergencies. Therefore, water pollution accidents caused by traffic accidents will be the biggest potential risk source for the water quality protection of the main channel.

3 Countermeasures for sudden oil pollution in main channel of the middle route of South to North Water Transfer Project

3.1 Overview of disposal of traditional oil pollution

The current disposal device for oil pollution mainly concentrated in the disposal of oil spill in the sea, while less research has been carried out on the disposal device for oil spill in rivers. He Jing[6] briefly introduces the process of disposing diesel pollution using physical recycling method and analyzes the role of powder activated carbon automatic dosing device in treating oil pollution, which serve as reference and basis for dealing with similar pollution accidents.

Qi Peishi et al.[7]explored the adsorption speed and absorption rate of cotton, linen and hemp fibers to the floating oil on water surface and the effect of river water temperature on the absorbability of the material. The research results show that the three kinds of fiber have their absorption capacity to diesel going from strong to weak to be cotton > linen > hemp. Compared with the widely used polypropylene non-woven in oil spill treatment (the oil absorption capacity is about 10 to 16 times of its own weight), they have similar oil absorption capacity. In addition, these fibers are easily accessible and can be used as oil spill treatment materials to respond to sudden oil spill accidents in city rivers.

Zhang Chengyi and others[8] carried out a research on the effection depth of solid floater oil containment boom under under the water flow action and the oil containment performance of it under the joint action of waves through a model test. The results show that with the flow rate being 0.5 kn, the height of oil containment boom (vertical direction) will be inclined a little, wiht the inclination degree being α = 10 °; for physical objects with a height of 0.9 m, it can sink in static water as deep as 0.5175 m, while its effective depth is 0. 5103 m under the action of water flow of 0.5 kn. The overflow oil can be successfully enclosed under the wave height of 1.2m and has good oil containment performance.

Liu Xian et al.[9] analyzed four typical problems in the application of the oil boom in oil spill in rapids: escaped oil spill, leaked oil spill, splashed oil spill, and oil boom instability. In the study, four corresponding oil boom measures were discussed, including placing the oil boom and the water flow in certain angle, making oil boom moving at a certain speed relative to the water flow, adopting the rapid diverter system, setting up oil booms based on a multistage overlapping principle, optimizing oil boom choices, and setting up ropes at the top and bottom of the oil boom,It provides a reference for the prevention and treatment of oil spill pollution in rapids.

3.2 Screening of and applicability analysis on the oil pollution disposal device in the main channel of the middle route

The water in the main channel of the middle route of South-to-North Water Transfer Project is used for drinking. Pollution of the water quality will directly endanger human health. Therefore, it is of vital importance to remove the oil pollutant in the main channel.

The removal methods of oil slick include chemical method, biological treatment method and physical method, etc.[10] As the water transferred from the south to the north is for drinking, it is not suitable to have the water be treated with chemical method. The biological technology method[11] requires a long period and is not suitable for use in the process of water transfer through channels. And due to the small thickness and large scale of the oil slick on the river surface, it is difficult to remove the oil slick using direct suction method. At the same time, the gates cannot be closed for treatment, so it would be reasonable to use physical method for treatment in the river channel of South-to-North Water Transfer Project.

Physical method is a method of removing oil pollutant from water surface by means of mechanical devices. The main devices used in physical method include oil containment boom, skimmer, adsorption materials, etc.[12] This paper will discuss the applicability of these devices in the disposal of oil pollutant in the middle route engineering channel of South-to-North Water Transfer Project, and analyze the characteristics of existing disposal devices of the middle route.

3.2.1 Analysis on the applicability of oil containment boom in the main channel of the middle route

Oil containment boom is generally composed of floating body (also known as floater), screen body (or skirt body) and counterweight (Figure 4). The floating body mainly plays the role of buoyancy, which makes the oil containment boom float on the water. The skirt body forms a barrier under the water to prevent oil from flowing from below, and the counterweight is hung below the skirt body to maintain vertical balance[8].

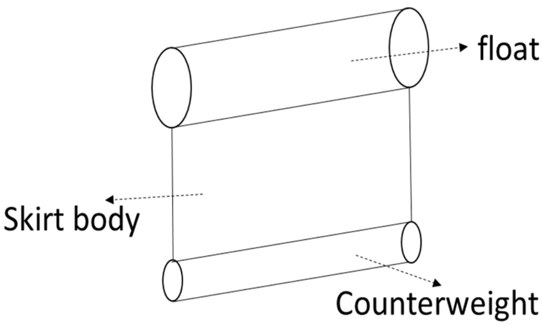

Figure 4 The general structure of the oil booms

Figure 5 Failure of oil booms

The most important property of oil containment boom is that it can control the oil spill and guide the oil spill track. At the same time, it should have some flexibility to adapt to the movement under the action of waves and maintain stability to meet certain oil retention ability[13]. When the water flow velocity is greater than 1knot (0.5m/s), all oil booms will fail no matter how deep they are. This limiting factor causes the drag speed of oil booms to be within the range of 0.5-1knot (0.25-0.5m/s)[14].

As for river oil spill, the oil booms may roll over due to the fast water flow, resulting in failed containment control. Shi Ning et al.[15] and Wei Fang et al.[16] successfully simulated the near-failure velocities of low-viscosity oil and high-viscosity oil when using traditional oil booms by adopting the Fluent numerical simulation method, and compared the results with previous calculation results, as shown in the table. It can be seen that the critical failure velocity is about 0.25m/s when an oil boom is used. The design of the oil boom structure mainly takes into account the tide and wind wave characteristics of the marine environment, while little attention is paid to the rapid conditions of inland rivers. Therefore, it is necessary to study a new type of oil boom structure based on the characteristics of the water area of the inland rapids, so as to prevent containment failure of oil booms in the water area of rapids.

The middle route velocity is 0.8 1.2 m/s, far more than its critical flow velocity, and the cross section of the middle route channel shows that it is a trapezoidal channel. Therefore, when using oil boom device, oil can easily "slip” from both sides of the device, and due to the large velocity of the middle route, under the impact of the water flow, the oil pollutant may submerge the oil boom, resulting in failure of the oil boom (as shown in Figure 5). The oil removal effect is affected. Therefore, it is not feasible to set up oil containment boom to deal with oil pollution in the main channel of the middle route of South-North Water Transfer Project.

3.2.2 Analysis on the applicability of oil absorbing pad in the main channel of the middle route

Oil absorbing pad (also known as oil absorbing hair pad) is a form of oil absorbing cotton. Like oil absorbing cotton, oil absorbing pad is made of inert polypropylene fiber through non-spinning process. It has strong hydrophobic and hydrophilic properties and can effectively absorb and retain liquids[17](Figure 6). The oil adsorption products to remove oil spill are mostly packaged by oil absorbing pad in thread sewing or hot sealing. The surface of oil absorbing pad can bear some weight after activation treatment to increase its strength, but it itself brings strong adsorption performance to keep oil spill at the internal obstacles of the pad, thereby reducing oil absorption efficiency and increasing oil absorption time.

The arrangement of oil absorbing pad shall be appropriate so as to make full use of it. When the oil absorption capacity of the oil absorbing pad is full, it should be pulled out of the water as soon as possible to avoid staying in the water for a period of time unnecessary. When using oil absorbing pad, oil dispersant should not be used at the same time, so as not to reduce the oil absorption capacity of oil absorption pad. According to the amount of oil spill, sea conditions and meteorology situation, and flow rate and flow direction, oil absorbing pad should be put into use and recovered in a timely manner.

Once oil absorbing pad is put into oil adsorption use, .

most of the oil will stay in the interior of the pad and thus reducing the recycling and utilization rate of the pad, resulting in waste of a large number of petroleum products and oil absorbing pad materials. Moreover, oil absorbing pad absorbs water and oil at the same time, which greatly reduces oil absorption efficiency and is relatively expensive and the pad cannot be recycled and reused

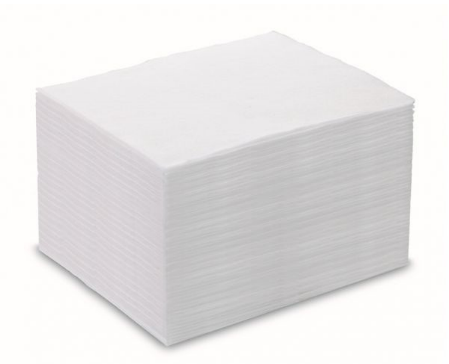

Figure 6 Oil absorbing pads

Figure 7 Coiling of Oil absorbing pads

The main factors influencing the use of oil absorbing pads are its own characteristics and environmental factors, such as temperature, wind speed, tide and flow rate[18]. For the middle route project of South-to-North Water Transfer Project, the flow rate of the main channel is relatively large (the flow rate is about 0.8-1.2m/s), and the oil absorbing pads placed in front of the oil booms is easy to be rolled under the impact of water flow (Figure 7), which affects the oil absorption effect. Therefore, the oil absorbing pad device is not applicable for the treatment of oil pollution in the middle route of the main channel.

3.2.3 Analysis on the applicability of oil containment device based on the steel-structured floating bridge in the main channel of the middle route

The river channel of the South-to-North Water Transfer Project is relatively wide, usually ranging from 25 to 60 meters, and the depth ranges from 8 to 10m. Therefore, to carry out oil containment work on the surface of the river, fixed mechanism of bridge piers cannot be adopted, while floating mechanism should be used. In buoy floating mechanism, a PVC board is fixed in the front of and under each buoy. The length of the board is the same as the length of the buoy, which is 1 m. The two parallel buoys are connected with each other by a circle link. Fixed above the buoy is a wooden-board walkway of a width of 1.5m, on both sides of which there are railings. Each buoy is connected to the next buoy by a stainless steel link, which guarantees that the adjacent two buoys can move freely in the water under the action of water flow.

The bridge and river banks shall be set at 60 degree angle. In this way, the board will be set at 60 degree angle to the river banks. When there is oil in the river, the oil will gather at one side of the river bank as a result of the combined effect of the water and the board. In the upper part of three different areas where the oil gather together, an oil detector will be equipped. In addition, a pump connected to the oil treatment tank will be set in the oil gathering area. When any two of the three oil detectors detect oil pollutants and give an alarm signal, the program will automatically start the pumping device. And then the pump will start pumping, taking water contaminated by oil into the oil treatment tank for processing. When all three oil detectors fail to detect oil, the pump stops working.

The oil containment device based on the steel-structured floating bridge has been installed in front of the regulating gate (pile number: 1197+669) in North Juma River (Figure 8). It is mainly in use when there is a small amount of oil floating on the water surface to intercept and remove the oil slick. When there is a large amount of oil slick, the rotary oil collector or vacuum oil collector can be put into use after the oil containment device is used to intercept the oil, so as to speed up the processing speed. When there is a large amount of oil slick in the main channel, while using the oil containment device to intercept the oil, the working state of the water release gates of North Juma River culvert should be adjusted and the flap door should be opened to discharge the oil slick on the surface.

Figure 8 site map of the channel

This device can not only adapt to the high flow rate situation of the main channel of the middle route, but also efficiently and quickly intercept oil, reduce the amount of channel water oil caused by sudden accidents, reduce the degree of water pollution, ensure water quality and safety, and ensure the safety of production and living for urban residents along the bank, which is of great significance to people's wellbeing.

4 Conclusion

The middle route project of South-to-North Water Transfer Project is a strategic infrastructure project which fundamentally solves the problem of water shortage in north China. The middle route project of South-to-North Water Transfer Project is a remarkable large-scale inter-basin water transfer project. It is of significant meaning in terms of adjusting the layout of water resources in our country, optimizing water resources allocation, alleviating the water shortage situation in north China, and ensuring sustainable economic and social development. The disposal device of the middle route of this infrastructure project is in urgent need of further research and development. This paper introduces the general situation of South-to-North Water Transfer Project, summarizes possible risk sources of sudden oil pollution, traditional devices commonly used such as oil containment booms and oil absorbent felt in emergent oil pollution treatment cases, as well as the oil removal devices currently in use for middle route project, and analyzes the applicability of these devices in the main channel of the middle route. The results show that traditional oil removal devices are not adaptable to the engineering characteristics of the main channel of the middle route and its water flow feature, while the oil containment device based on floating bridge can better adapt to the site conditions such as high velocity, and has great value in the main channel of the middle route.

However, the oil containment device based on floating bridge needs further improvement:

(1) This device has a significant effect on the disposal of oil slick, but it does not take into account other soluble oil, such as oil, etc., so the above situation needs to be taken into consideration to increase and improve the disposal methods.

(2) This device is less arranged along the main channel of the middle route, and it is inconvenient to move the device. Moreover, there is little storage along the route. When there is no floating bridge to be served as soon as possible near the location of pollution, it is extremely difficult for emergency response. Therefore, it is suggested to carry out analysis and survey of the channel-crossing bridge, scientifically arrange the protective section, and at the same time, make improvement in terms of portability and fast assembly of the device.

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