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Research on Water Environment Protection Technology During the Construction Period of Bridges in Shenzhen-Zhongshan Link

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Abstract. During the construction period of sea-crossing bridge, pile foundation construction and other operations are easy to cause marine water environment pollution. In order to enhance the green development level of the cross-river (sea) channel project, this paper selects the Shenzhen-Zhongshan Link, a typical cross-sea traffic cluster project, as the research object. And introduces water environmental protection technologies such as bored pile with steel casing, cofferdam formed by locking steel pipe pile, cofferdam formed by geotech-bag, and whole trestle across the sea. The variation characteristics of suspended solids, oil, inorganic nitrogen, inorganic phosphorus and heavy metal concentrations with respect to time and space in the whole sea area of the bridge project were systematically analyzed, to explore the influence of bridge construction on water quality of the whole sea area. Further verify the application effect of the water environmental protection technologies, and provide reference for similar bridge green construction and water environment protection research in the future.

Keywords. Shenzhen-Zhongshan Link, bridge, construction period, water environment protection, variation characteristics of water quality

1. Introduction

The Shenzhen-Zhongshan cross-river link (hereinafter referred to as the Shen-Zhong Link) is located in the core area of the Guangdong-Hong Kong-Macao Greater Bay Area. It is a world-class cross-sea cluster project integrating bridge, island, tunnel and underwater interconnection. The project has a large scale, complex construction conditions and high comprehensive technical difficulties. It crosses many sensitive points such as Lingding channel, Hengmen east channel, artificial reef, Wanqingsha marine reserve and white dolphin reserve. Thus it has extremely high ecological protection requirements.

The Bridge in the Shen-Zhong Link started at the intersection of Zhongshan Port Town and Xinlong Interchange of Zhongjiang Expressway, and ended at the western artificial island. The total length is about 17 km, including the main bridge

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Lingdingyang Bridge (main span 1666 m three-span floating system sea suspension bridge) and Zhongshan Bridge (main span 580 m semi-floating structure system cable-stayed bridge). The main bridge project was started in April 2018. The construction work of bridge pile foundation and anchorage island cofferdam is mainly concentrated in 2019~2020. The sediment content of the project area is four times that of the Zhuhai-Hong Kong-Macao Bridge. The construction of bridge pile foundation and anchorage island cofferdam will cause environmental impacts such as dredging disturbance and water pollution to the underwater environment, and will also affect the marine ecological environment of Wanqingsha Marine Protected Area, Pearl River Estuary Chinese White Dolphin Protected Area and Qi'ao Island Marine Protected Area. Therefore, advanced environmental protection technology and construction technology should be adopted to maximize the protection of the marine environment.

At present, there are some research reports on the technology, measures and application effect of water environment protection during the construction period of offshore bridge engineering. For example, the construction of offshore bridge in Shacheng Bay cross-sea highway channel project adopts steel pipe pile, steel trestle bridge, rotary drilling, bored pile construction and other technical methods, which successfully protect the water environment around Shacheng Bay [1]. During the construction period of Zhuhai-Hongkong-Macao Bridge, measures such as bridge pile cap, land prefabrication of piers columns and ship's sewage oil and water recycling were adopted to make it less impact on seawater quality, and effectively protect the habitat environment of Chinese white dolphins [2-3]. However, there is no report on the water environmental protection technology adopted during the construction period and the impact on the water quality of the sea area for the Shen-Zhong Link Cross-sea Bridge Project, which is more difficult to construct and has a number of innovative technologies.

Therefore, this paper summarizes the water environment protection technology applied during the construction period of the super project Shen-Zhong Sea-Crossing Bridge. By analyzing the water quality of the sea area during the main construction period from 2018 to 2020, the impact of the project on the water environment of the sea area is evaluated, which provides technical reference for the green construction of the follow-up sea-crossing bridge project and the development of marine water environment protection.

2. Water Environmental Protection Technology

During the construction of the bridge, the construction of the pier and the deep-sea anchorage have an impact on the marine environment. In addition, the operation of the construction ship and the artificial activities of the offshore construction platform will also have a certain impact on the marine environment. In this regard, the project proposes four technologies, such as bored pile with steel casing, cofferdam formed by locking steel pipe pile, cofferdam formed by geotech-bag, and whole trestle across the sea, to solve the marine water environment pollution problems caused by bridge pile foundation, east and west anchorage island cofferdam construction and offshore construction.

2.1. Bored Pile with Steel Casing [4]

In order to protect the marine environment, the pile foundation construction of the bridges in Shen-Zhong Link adopts the bored pile with steel casing technology, as shown in figure 1. The process such as drilling and pouring concrete are all carried out in the steel casing, which can prevent the loss of drilling mud and the impact of the cleaning process on the hydrodynamics, topography, seawater quality, and tidal flat organisms in the sea area.

On the drilling platform, the rotary drilling rig uses a slag hopper to clean up the drilling slag. The mud is only used for the wall protection and the amount is small. The mud can be recycled after being treated by the filtration and purification system. The generated drilling slag is collected by the slag collecting box, and transported to the designated place by flatbed truck or mud boat for unified treatment to avoid seawater pollution. After the construction is completed, the steel casing and the drilling platform are completely removed to reduce the footprint of the sea area.

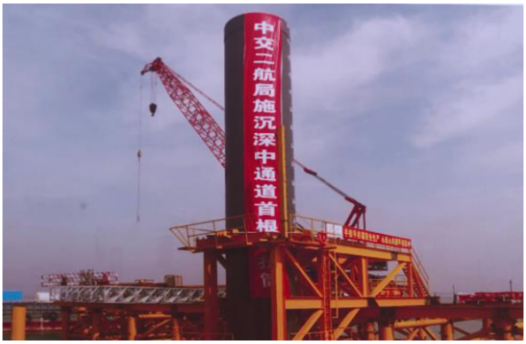

Figure 1. The first steel sheath of the east tower. (Photograph: Shen-Zhong Link Management Center, China.)

2.2. Cofferdam Formed by Locking Steel Pipe Pile [4]

The Lingdingyang Bridge of the Shen-Zhong Link is a ground-anchored suspension bridge with a main span of 1666m. The east and the west anchorage are the world's first large-scale marine anchorages. Among them, the water depth of the east anchorage area is 3 to 5 meters, and the maximum flow rate is 1.7 m/s. The stratum contains deep soft silt and fine sand layer. According to the hydrological and geological conditions of the location of the east anchorage, it is finally determined that the combination cofferdam island building scheme, “locking steel pipe pile, I-shaped sheet pile and parallel steel wire lock”, is adopted for the construction of the connecting wall foundation of the east anchorage ground, as shown in figure 2. The diameter of the island is 150m. The steel pipe piles pass through the silt layer, and the medium sand layer is used as the bearing layer. The steel pipe piles and the I-shaped sheet piles are connected by locks. The locks are made of C-shaped steel pipes and welded to the steel pipe piles. In the construction process, the construction guiding and positioning device of self-developed hydraulic clamp “riding type” is used to realize the alternating and rapid sinking of the locking steel pipe pile and the I-shaped sheet pile. And the construction accuracy of the steel pipe pile meets the requirements. The cofferdam can be accurately closed at one time, forming a cofferdam structure with relatively stable structure and strong antityphoon ability. This technology uses a small amount of steel, sand and stone, which can effectively reduce the amount of foundation soil excavation, and has the advantages of high construction efficiency, small environmental impact, and easy removal after construction. On this basis, the water construction environment is converted into land construction through backfilling on the island, which effectively solves the environmental protection problem of offshore deep-water anchorage construction.

Figure 2. Island-building cofferdam closure of deep-sea anchorage. (Photograph: Shen-Zhong Link Management Center, China.)

2.3. Cofferdam Formed by Geotech-bag [4]

The west anchorage of Lingdingyang Bridge in Shen-Zhong Link is 210 meters long and 150 meters wide, with a total of 26,000 m^2. The water level and water depth at the project area are 3-4 meters. According to the actual needs of the west anchorage construction, to solve the problem of land occupation for construction machinery and materials, it is necessary to set up a steel platform for the offshore concrete distribution center. In order to implement the construction concept of energy saving, emission reduction, quality and efficiency improvement, it is considered to build the concrete distribution center on the west anchorage foundation construction island. In order to minimize the island building area, save construction costs, and reduce the amount of dredging, the original circular island building was changed to an oval shape. In order to solve the problem of shallow water level in the project area and difficult dismantling of temporary facilities in the later stage, the construction unit put forward a new island construction scheme of cofferdam formed by geotech-bag, which is “offshore DCM pile treatment water deep soft foundation, wave resistant sand bag filling molding, blowing fill coarse sand island and island compaction sand pile”, as shown in figure 3.

First, the advanced offshore deep cement mixing pile (DCM) is used to treat the weak foundation. Compared with the traditional method, the construction cost of DCM is lower and the impact on the offshore environment and aquaculture industry is smaller. After laying a layer of geotechnical reinforcement material to further improve the overall stability of the silt layer. Two-stage anti-wave sandbags are filled on the foundation that meets the bearing capacity, that is, the water filling and land filling construction are carried out in sequence to form the weir body island wall.

The island building scheme has the characteristics of high construction efficiency, easy removal of the cofferdam after completion, little disturbance to the sea area, and reduction of temporary land occupation. It is helpful for follow-up research work and engineering application.

Figure 3. Island cofferdam with west anchor. (Photograph: Shen-Zhong Link Management Center, China.)

2.4. Whole Trestle across the Sea

Due to the complex construction environment of offshore bridges in typhoon areas, it has brought great challenges to construction safety and efficiency. In the process of pile foundation construction, in order to facilitate the construction personnel to carry out their work and reduce the oil consumption and oil pollution caused by the operating ship as a construction platform, after the comparison and selection of multiple schemes, the scheme of steel trestle and drilling platform is finally adopted for pile foundation construction of bridge in Shen-Zhong Link. As is shown in the figure 4, through constructing offshore trestle bridges and drilling platforms on both sides of the bridge and connecting them to each pier in turn, a transportation channel between the water and land production areas was established. The offshore construction was changed to onshore construction. The trestle has enough load bearing and working space, which can place construction equipment and materials such as drilling rigs and steel bars, and ensure the smooth passage of tank trucks, automobile pumps or cranes.

The whole trestle construction process can solved the problem of working platform for offshore bridge construction in typhoon areas, which provides a stable and safe working surface for pile foundation construction. In addition, it improves construction efficiency, effectively reduces seawater disturbance and oil pollution caused by ship transportation and protecting the marine environment. It provides a good reference for the construction of large-scale offshore steel trestle bridges and steel platforms of the same type in the future.

Figure 4. Trestle and platform along west approach bridge. (Photograph: Shen-Zhong Link Management Center, China.)

3. Analysis of Seawater Quality during Bridge Construction Period

3.1. Water Quality Analysis Method

In order to explore the impact on the sea water quality during the construction period of bridge in the Shen-Zhong Link, a total of 15 water quality survey stations were set up in the sea area near the bridge, as shown in figure 5. Among them, the monitoring stations Z1~Z2 were near the Zhongshan Bridge, Z3~Z7 were near the non-navigable hole bridge in the shoal area, Z6~Z9 were near the non-navigable hole bridge in the west flood discharge area, Z8~Z13 were near the Lingdingyang Bridge, and Z12~Z15 were near the non-navigable hole bridge in the east flood discharge area.

The temperature of Guangdong Province is between 27 to 33 °C in fall, which is representative of the typical temperature throughout the year. Therefore, this study selected the water quality indicators in fall from 2018 to 2020 for analysis [5]. The water quality indicators are oil, suspended solids (SS), ammonia nitrogen, nitrate, nitrite, inorganic nitrogen (IN), inorganic phosphorus (IP), heavy metal Cu, Pb, Zn, Cd, Cr, Hg, and As.

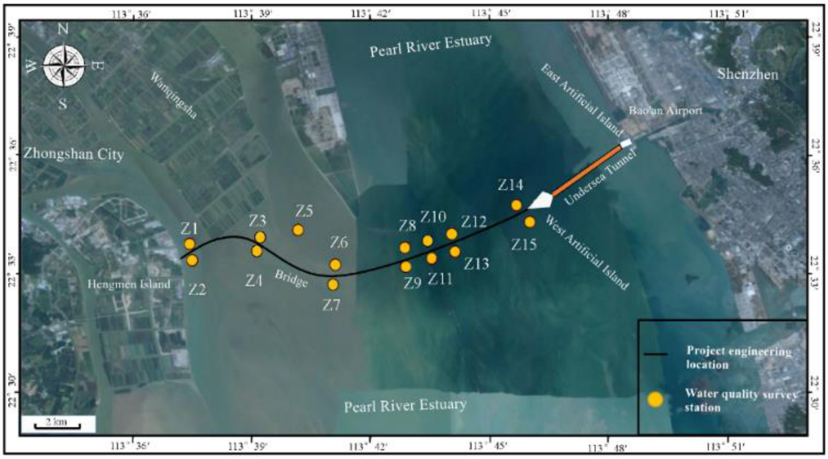

Figure 5. Distribution map of marine environment monitoring stations in the sea area near the bridge of the Shen-Zhong Link.

3.2. Analysis of Water Quality Change Pattern with Respect to Time and Space in Bridge Sea Areas

3.2.1. Analysis of Pollutant Concentration Change Pattern with Respect to Time

In order to explore the impact of different construction periods on the water quality of the bridge in Shen-Zhong Link, the changes of oil, SS, IN and IP concentrations in the bridge sea area from 2018 to 2020 were selected for comparative analysis. The results are shown in table 1 below. Excessive concentration of oil pollutants will seriously damage the marine ecosystem and cause irreversible marine environmental pollution. Therefore, marine oil pollution has become a hot issue of human concern. During the construction of the project, the oily sewage generated from the construction ships was collected and disposed of on the shore. Therefore, the construction of the project basically had no effect on the concentration of oil in the sea area.

The concentration of SS in seawater is one of the indicators to measure the quality of the water environment. The sediment produced during the construction process is mixed with seawater to form a water mass with high suspended mud content, resulting in a substantial increase in SS in the seawater and affecting the photosynthesis of phytoplankton. Decreasing its biomass and destroying the structure of marine biological communities are the most common pollution problems faced by offshore construction operations. As can be seen in table 2, the concentration of SS in seawater gradually decreased from 15 mg/L (Class II standard) in 2018 to 7.57 mg/L (Class I standard) in 2020, and the foundation construction of the project is mainly concentrated in 2019 and 2020. It shows that the construction such as bridge pile foundation, anchor island cofferdam and so on have little disturbance to seawater, and the above-mentioned advanced water environmental protection technologies have good application effects.

Excessive concentrations of nitrogen and phosphorus in seawater will cause eutrophication of water bodies, massive reproduction of plankton, and affect the marine ecological balance. It can be seen from table 1 that the concentration of IN was in a state exceeding the standard during the construction period. According to the monitoring results of seawater quality in the Pearl River Estuary sea area in the *2017 Guangdong Provincial Ecological and Environmental Status Bulletin* [6], it was found that the sea area had been seriously polluted by IN and IP. A large amount of human-generated wastewater containing high concentrations of ammonium salts was discharged into the sea along the coast after treatment, resulting in excessive nitrogen and phosphorus concentrations in the Pearl River Estuary sea area. Therefore, the influence of bridge construction on nitrogen and phosphorus concentration in sea area needs to be further studied.

Table 1. Annual changes of oil, SS, IN and IP concentrations (average of Z1-Z15) in the bridge sea area in fall from 2018 to 2020. (Unit: mg/L)

Time	oil	SS	IN	IP
Fall 2018	0.01138	15.10	0.34	0.05
Fall 2019	0.02204	13.30	1.48	0.00
Fall 2020	0.01505	7.57	0.61	0.02

Marine organisms have a great ability to accumulate heavy metals. Once the heavy metal concentration exceeds the standard, it will accumulate in the organism, and then enter the human body through the food chain, causing a series of diseases. Therefore, this paper explored the effect of bridge engineering on the concentration of heavy metals in the sea area during the construction period. The results are shown in table 2. The Cu concentration accumulated to 0.00566 mg/L (Class II standard) in 2019, and then recovered to 0.00137 mg/L (Class I standard) in 2020. The Hg concentration decreased from the Class I standard in 2018 to the Class II standard in 2020. And the concentrations of other heavy metals meet Class I standards. It indicates that the excavation of the geology may have partially released minerals from the seabed sediments. In addition, materials such as steel casings used in construction may be harmful to seawater. Heavy metal concentration has a certain effect, but overall, the effect is minimal. It shows that the construction materials used in the construction process of this project are environmentally friendly. And the construction technology has little disturbance to the geological layer, which is beneficial to the protection of the marine environment.

In general, the concentration of oil, SS and heavy metal all met the requirements of the *Marine functional zoning of Guangdong Province*.

Table 2. Annual changes of heavy metal concentrations (average of Z1-Z15) in the bridge sea area in fall from 2018 to 2020. (Unit: mg/L)

Time	Cu	Pb	Zn	Cd	Cr	Hg	As
Fall 2018	0.00205	0	0.00875	0.00001	0.00113	0.00007	0.00125
Fall 2019	0.00566	0.00025	0.01721	0.00001	0.00097	0.00011	0.00141
Fall 2020	0.00137	0.00017	0.00967	0	0.00048	0.00011	0.00999

3.2.2. Analysis of Pollutant Concentration Change Pattern with Respect to Space

In order to further analyze the influence of each construction site on seawater quality, the monitoring station was taken as the abscissa to analyze the concentration changes of pollutants at different monitoring stations, as shown in figures 6 and 7. Figure 6 shows the change of nitrogen and phosphorus concentration in the bridge sea area with the monitoring station in fall from 2018 to 2020. It can be seen that the concentration of IP in the entire sea area has increased significantly at the monitoring station Z5, and the rest of the monitoring stations have reached the Class II standard of *Sea Water Quality Standard* (GB 3097-1997). After investigation and analysis, it is known that the domestic sewage produced by the construction ships of this project will be uniformly collected and treated on shore. The Z5 closed to the Nansha New Area, and the domestic sewage discharged along the coast might be the reason for the increase of IP concentration at Z5. The results showed that the bridge construction had no effect on the concentration of IP.

The concentration of IN in the whole sea area exceeded the standard, but tended to be stable along the line. The concentration of IN at monitoring stations Z10-Z11 increased slightly, which was about 0.1 mg/L higher than that at monitoring stations Z8-Z9. It might be that the domestic sewage with high ammonia nitrogen generated from the living area on the cable tower construction work platform in the middle of Lingdingyang Bridge reached the target after treatment and entered the sea body, where it would be further oxidized to nitrate in a more stable structure form. As a result, the nitrate content increases, resulting in an increase in the IN concentration. However, the effect on the sea nitrogen concentration was small. The discharge of residential sewage along the coast was the main reason for the excessive nitrogen concentration in the whole sea area.

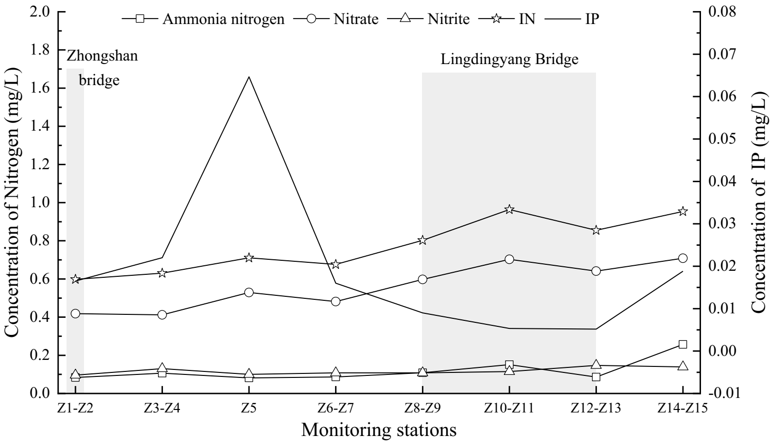

Figure 6. Changes of nitrogen and IP concentration in the bridge sea area with the monitoring station in fall from 2018 to 2020.

Figure 7 shows the variation of SS, oil and Cu concentrations in the bridge sea area with the monitoring station. It can be seen from the figure that the construction of Lingdingyang Bridge would cause an increase in the concentration of Cu and SS in the sea area. But the increase was very small and the concentration was always maintained at the Class II standard of *Sea Water Quality Standard* (GB 3097-1997). It showed that the construction technology adopted during the construction period was beneficial to the protection of the water environment.

In addition, the oil concentration increased greatly at the monitoring stations Z3-Z4, while the monitoring stations near Zhongshan Bridge and Lingdingyang Bridge were at lower concentrations. It indicated that the vessels used in the construction of the main bridge had little effect on the oil concentration in the sea area.

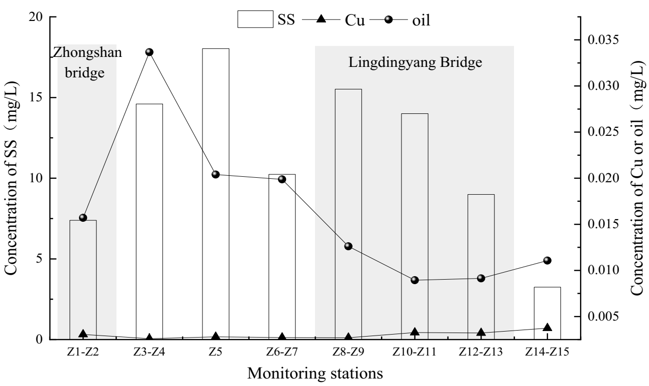

Figure 7. Changes of SS, oil and Cu concentration in the bridge sea area with the monitoring station in fall from 2018 to 2020.

4. Conclusion

The bridge in the Shen-Zhong Link has a special geographical location and passes through many sensitive points of water environment. In view of its extremely high water quality requirements in the sea area, this paper proposes four advanced water environmental protection technologies, namely bored pile with steel casing, cofferdam formed by locking steel pipe pile, cofferdam formed by geotech-bag, and whole trestle across the sea. By analyzing the water quality of the sea areas along the construction line, it had little effect on the concentration of nitrogen and phosphorus in the sea area during the bridge construction process. And the concentrations of SS, oil and heavy metals all met the requirements of the *Marine functional zoning of Guangdong Province*. The application effect of the four technologies is further verified, which has the advantages of small construction disturbance, good water environmental protection effect, and small marine benthic environment disturbance. It fully demonstrates the ecological and environmental protection concept in the construction process of Chinese super engineering, and provides reference for the green construction of Bridges in China.

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