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Engineering Effect Test and Inspection of the Evolution of the Seabed Level near the Artificial Island of the Hong Kong-Zhuhai-Macao Bridge

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Abstract. The Hong Kong-Zhuhai-Macao Bridge is located at the mouth of Lingdingyang Bay. The east and west artificial islands are on both sides of the Lingdingyang Dahao Deep Channel. The waters of the artificial islands are deep and rapid, and the currents impact the artificial islands frontally, which is likely to cause major changes and adjustments in the underwater topography near the artificial islands, eventually forming a new pattern of the local beach evolution centred on the artificial islands. In the engineering design stage of the bridge, the Lingdingyang two-dimensional tidal current and sediment mathematical model was used to simulate the underwater topography near the artificial island of the Hong Kong-Zhuhai-Macao Bridge based on the verification of the measured basic data. The simulated results show that the impact of the artificial island on the water and sand environment of the Lingdingyang waters is concentrated in the waters of 5 km upstream and downstream of the artificial island. The results of the erosion and deposition changes of the underwater topography before and after the construction of the artificial island from 2009 to 2019 show that the trend of the seabed erosion and deposition changes caused by the construction of the artificial island is basically consistent with the prediction results of the mathematical model, which provides good evidence for the applicability of the mathematical model.

Keywords. Hong Kong-Zhuhai-Macao Bridge, artificial island, engineering effect, mathematical model, model verification

1. Introduction

The Hong Kong-Zhuhai-Macao Bridge, spanning Lingdingyang Bay of the Pearl River Estuary, is a large cross-sea passage linking the Hong Kong Special Administrative Region, Zhuhai City in Guangdong Province and Macao Special Administrative Region. The bridge cross Lingdingyang Bay in the way of "bridge-island-tunnel". Two large artificial islands in the east and west where the main navigation area is located are the main part of the project. The seabed of LingDingYang over the past century has always maintained a "three beaches and two channnels" distribution pattern, and

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construction of large artificial island in the LingDingYang Bay will change the local hydrodynamic conditions and impact the underwater topography nearby, a new pattern of the underwater beaches and grooves will form under the long-term effects of tides, waves, and other power. The Lingding Channel, as an important seaward channel of Guangzhou Port, passes through the waters between the east and west artificial islands. Whether the construction of large artificial islands will have an impact on the water and sediment environment and the change of scouring and silting of the Lingding channel after forming a new local underwater beaches and grooves pattern is of great significance to the future development. Therefore, it is necessary to study the influence of large artificial island project on the evolution of beaches and grooves.

A large number of studies have been carried out on the prediction of the impact of artificial islands in the sea on the surrounding environment [1-7]. The islands changed the distribution of underwater topography and the hydro-dynamic structure, thus has an impact on the geomorphic evolution of surrounding areas. Mathematical model is widely used to predict the impact of artificial islands [2-5,8]. For example, Sheng Tianhang et al. [3] used a two-dimensional numerical model to simulate the flow field after the construction of an artificial island in the estuary of Tanghe, Qinhuangdao, and showed that the artificial island was conducive to sediment erosion, along with river dredging. Li Songzhe [2] studied the balance relationship between the layout pattern of artificial islands and the evolution of shoals in Hongtang Bay of Hainan Province by using numerical models of tidal current and wave. He Jie et al. [8] used a two-dimensional numerical model to explore the influence of the construction of artificial islands in the Hong Kong-Zhuhai-Macao Bridge Project on the dynamics of the Pearl River Estuary, and predicted the sediment back deposition in the foundation trench of the immersed tube tunnel and the changes in hydrodynamic conditions at the joint of the tunnel and the eastern artificial island. To check and compare the results of topographic evolution predicted at the design stage by tracking the actual impact effect of artificial island project will be very meaningful for the results predicted by the model can rarely be directly compared with the actual effect after construction.

In the design stage, this article uses a two-dimensional tidal current and suspended sediment mathematical model to explore the influence of the artificial island of HZMB on the shoal and through evolution around the project. In the verify process of model backsilting, the backsilting process of artificial trussed trough is well verified and the evolution trend of shoal and trough around artificial island is predicted. Ten years after the completion of the artificial island, the monitoring results of underwater terrain nearby have been used to explore the engineering effect of artificial island in Hong kong-Zhuhai-Macao bridge on the evolution of underwater shoal and through, and verify the prediction accuracy and applicability of the mathematical model using in the for the bridge's engineering design stage through comparing the artificial island engineering design stage to predict the terrain and construction after the measured terrain differences.

2. Overview of the Bridge Project

The two large east and west artificial islands of the HZMB are located on both sides of the Dahao Deep Channel in Lingdingyang, realizing the bridge and tunnel structure transformation. The two artificial islands were built in 2009, sharing the same shape of pebbles, as shown in the green part in figure 1. The west artificial island is east-west, while the east artificial island which big head side points to the bridge, and small head side points to the tunnel, is arranged diagonally along the pile numbers at both ends. Both upstream surface length of the two islands is 100m.West island, which area is 93688 m^2, shapes slightly drum with a 180m big head size and 100m small head size on the downstream direction, while East Island shapes slightly flat, has 225m long big head and 115 m small head along the water direction, which area is 102462 m^2, slightly larger than the previous. The distance between the two artificial islands is 5573 m, and the protection for shore wall of the artificial islands is set as 1:2 slope, and three anti-collision piers are arranged at a certain distance from the shore at the tunnel-side end of the east and west artificial islands.

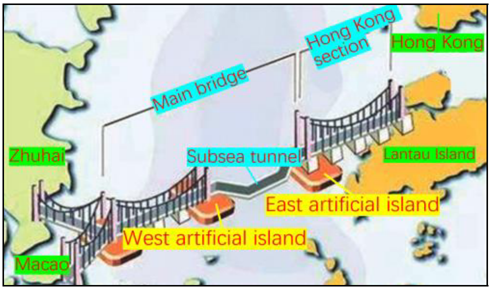
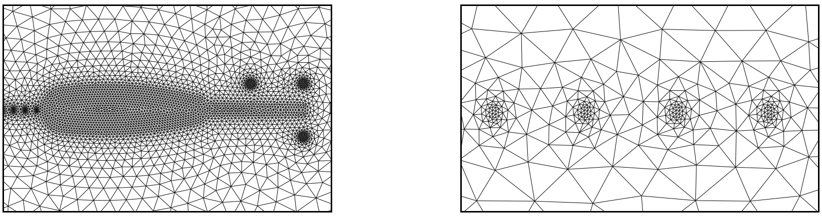


Figure 1. Schematic diagram of the east and west artificial islands.

3. Two-dimensional Mathematical Model of Tidal Current and Suspended Sediment

The study water area is large and open, with a much larger plane scale than the vertical scale, thus the vertical physical process can be ignored and the plane two-dimensional model can be used.



(a)The west artificial island (b) Bridge piers in non-navigable areas

Figure 2. Divided grids of artificial island and piers.

The computational domain of the mathematical model starts from Humenmen in the north and reaches 5 km south of Dawanshan Island in the south. The western boundary ends at Battery Hill in Zhuhai and the eastern boundary ends at Kap Shui Mun in Hong Kong. The spatial scale of the model is 51 km from east to west, 108 km from south to north, and the controlled area is 3 877 km^2. There are more than 100,000 triangular units in the computational domain. For the waters of Wailingdingyang with wide water surface, large-scale grid division is adopted, and the main channel waters and waters near artificial islands are grid encrypted. In order to improve the accuracy of numerical simulation of hydrodynamic changes before and after the project, the bridge pier and artificial island are also divided into grids. Under the current conditions, all grids are divided into the model calculation, and the side walls of the bridge pier and artificial island are treated as solid boundaries (see figure 2 for the splitting effect).

4. Analysis of Scouring and Silting Prediction Results in Artificial Island Waters

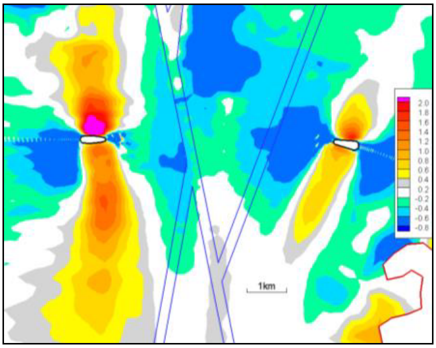


Figure 3. Scour and siltation rate of bed surface of the artificial island water area one year after the build of the artificial island ("-" means scouring, "+" means silting, unit: m/a).

Figure 3 shows the numerical simulation results of sea-bed scour and silting changes one year after the implementation of the artificial island project that fusiform silting bodies are formed upstream and downstream of the islands. After comparing the distribution patterns of two siltation bodies, it can be seen that the impact of the artificial island on the water and sediment environment of the Lingdingyang Waters is concentrated in the waters 5 km upstream and downstream of the two islands, showing the scouring at both ends of the artificial island and the formation of zonal siltation bodies centered on the island. The zonal siltation in the south of the island are longer and larger in scope, while those in the north are smaller. The size of the siltation has a certain relationship with the reflux range in the north and south of the artificial islands. The thickness of the siltation body on the north side of the artificial island is larger than that on the south side, and the maximum siltation strength is more than 2.0 m/a. Compared with the east and west artificial islands, the size and intensity of the silts formed on the north and south of the west island are larger than those on the east island. The zonal silts have no effects on the navigation area of Lingding channel, Tonggu channel and Rongshutou channel. Different degrees of scour occurred on both sides of the artificial islands due to the effect of jet flow, leading to larger scouring range on the west side of the western island and the two sides of the east island, where scour intensity was more than 0.80 m/a. The water bunching effect of the two artificial islands enhanced the tidal current dynamics in the navigable area, therefore, Part of the Tonggu Channel (west line) was scoured, and the siltation of the channel through a section of the main navigable area of the Lingding channel showed a decreasing trend.

The design scheme calculated by the model takes the anti-collision piers at both ends of the artificial island, but not the slope protection around the artificial islands and the protection tank at the joint of the island and tunnel into consideration. In the actual construction process, the anti-collision piers were cancelled, the slope protection and the protection tank were increased. Thus there are some differences between the actual scouring and silting around the artificial islands and those predicted by the model, but the general trend of the scouring and silting of Lingdingyang is basically the same.

5. Measured Sedimentation Rate in the Waters around Artificial Island after Engineering

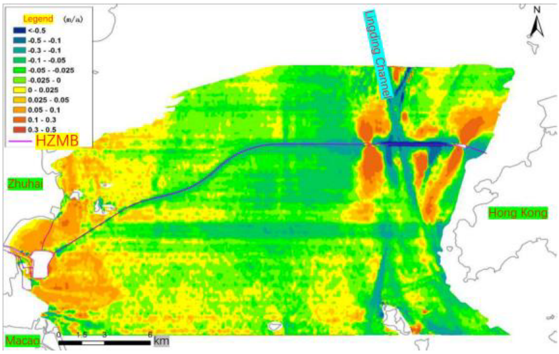


Figure 4. Scour and siltation rate of bed surface in the project waters from 2009 to 2019.

The artificial island project was completed in 2009, and underwater topographic surveys were conducted in the nearby waters in 2019. According to the distribution of the measured annual average scour and silt rate of underwater terrain from 2009 to 2019 (figure 4), it can be seen that along the bridge, the scour and silt changes of underwater terrain generated by the artificial islands and tunnel areas are relatively obvious. Due to the incomplete backfilling of the foundation trench after the completion of the tunnel immersed tubes, the depth of water along the tunnel has increased greatly. The west artificial island forms a north-south siltation zone centered on the island, of which the length is 5.2 km and 4.5 km, respectively on the south and north sides. The maximum width of the siltation body is 1.5 km in the east-west direction, and the siltation rate of the maximum siltation thickness area is about 0.3 m/a. The east artificial island also forms a siltation body centered on the island, while the siltation belts on the south and north sides are in NNE-SSW direction, with lengths of 5.5km and 4.2km respectively, and the maximum width is slightly smaller than that of the west artificial island. The siltation area formed by the two artificial islands is mainly generated by the blocking effect of the islands on the tidal current. The direction of the siltation zone is consistent with the tidal current movement direction of the waters where the islands are located, which agree with the distribution pattern of the artificial islands' siltation predicted by the mathematical model. In the initial stage of artificial island construction, its engineering effect on the surrounding seabed was relatively large, but with the gradual adaptation of the water-sediment dynamic environment and beach-trough pattern around the project, the scour/silt rate of the underwater terrain generated by the project gradually decreased with the time [4]. From 2009 to 2019, the measured annual average siltation rate of the artificial island is about 0.3 m/a, and the numerical model predicted that the maximum siltation rate would be 2.0 m/a one year after the construction of the project, which will gradually decrease with time. In general, the prediction results of the mathematical model are consistent with the actual results both in terms and amplitude of the siltation, which provides good evidence for the simulation accuracy and applicability of the mathematical model adopted in the engineering design stage.

6. Conclusion

In this paper, a two-dimensional numerical model of tidal current suspended sediment is used to simulate the scouring and silting influence of the artificial islands of the Hong Kong-Zhuhai-Macao Bridge on the topography of the surrounding waters. Before the islands' construction, the model is well verified by water and sediment data and measured topographic data of trial excavation. On this basis, the evolution of topographic scouring and silting after the construction of artificial island is predicted, which provides relevant basis for the construction decision. Through using measured underwater topography scouring and silting change data before and after 10 years of project construction to test and verify the predicted results calculated by the mathematical model used in design phase, the trend of seabed erosion and deposition caused by artificial island construction is basically consistent with the prediction results, which provides good proof for the simulation accuracy and applicability of the mathematical model used in the engineering design stage and the application for the prediction of water and sediment movement and the evolution of underwater beach trough in similar cross-sea channel projects.

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