The Hydrodynamic Division of Lingdingyang Estuary and its Application in the Impact Analysis of Large Water-Related Projects

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Abstract. The dynamic environment of lingdingyang estuary is very complex due to the confluence of runoff and tide as well as the different characteristics of each entrance. Meanwhile, human activities are intensive. Taking the large bridge project of the Pearl River Estuary--Shenzhen-Zhongshan Bridge Project as an example, this paper divides the waters of Lingdingyang estuary where the project is located into tidal channel area, shoal area and two west flood discharge areas based on the differences of hydrodynamic and environmental characteristics. Combined with the one and two-dimensional tidal current model of estuary and delta, the paper discusses the dynamic response of different dynamic characteristic areas to the engineering construction, and carries out the construction scheme optimization and hydrodynamic influence demonstration. The project impact analysis based on dynamic zoning proposed in this paper not only rationally evaluates the hydrodynamic environmental impact of large water-related projects of Lingdingyang, but also is of great significance to the balance of protection and development of Lingdingyang Estuary.

1. Introduction

Estuaries are the areas where land and sea meet. They have rich resources, convenient transportation and dense cities, which have been the key areas of sustained human development since ancient times. Therefore, they are of great scientific research value and practical guiding significance to evaluate and analyze the impact of the construction of major water-related projects in estuary [1-2].

The river-crossing channel from Shenzhen to Zhongshan (short as Shenzhen-Zhongshan Bridge) project is a large scale project spanning the crest of the Lingdingyang Estuary. The construction of the project will increase the flow resistance along the project line and reduce the over-water section, which will have a certain impact on the hydrodynamic environment of the surrounding waters, and further affect the material transport and long-term evolution of the estuary [3-4]. The scientific demonstration of the influence that the construction has on the dynamics of Lingdingyang Estuary is of great significance to further optimize the construction scheme, rationally evaluate the impact of project construction on water dynamics, and balance the protection and development of Lingdingyang Estuary. It is also of great reference value for the demonstration of other estuary projects.
2. Overview and Hydrodynamic Characteristics of Lingdingyang Estuary

Lingdingyang is the largest bell-shaped estuarine bay of the Pearl River Estuary. Its crest is at Humen and its waist is in the line of Neilingding Island, Qi’ao Island and Chiwan. Its mouth is outside Macao and Dahao Island. The mouth of the bay is about 65km wide and 60km deep, and the water area is about 2110km². It is connected with the South China Sea at the lower level. At the upper level, it is connected with the complex river network of the delta via the east four entrances of the Pearl River Estuary, namely Humen, Jiaomen, Hongqimen and Hengmen. Of the four entrances, Humen is a type of tidal estuary, and the others are type of runoff estuary.

The northwest region of Lingdingyang is obviously controlled by runoff dynamics, while the estuary under Humen is mainly controlled by tidal dynamics, which is far stronger than runoff dynamics. Under the shape of different dynamics of flood tides, the riverbed topography of Lingdingyang has typical characteristics of three beaches and two channels (i.e., east beach, middle beach, west beach, east channel and west channel). East and west channels are respectively Fanshi channel and Lingding channel.

The hydrodynamic environment of Lingdingyang is complex under the influence of the comprehensive action of tidal force, wind wave and current, as well as the riverbed topography and shoreline boundary. Its prominent hydrodynamic characteristics are mainly shown in the following aspects [5-6]:

- The flow and sediment not only exchange in the bay, but also are redistributed to the estuary waters after entering the river network through the entrance.
- There is an intersection angle between the runoff and the tidal current, and there are transverse branches of the runoff dynamics in flood season. The main channel in the dry season has a strong power, which restricts the eastward expansion of the west runoff and forms a dynamic balance zone.
- The dynamic characteristics in the estuary compound beach and channel are different. The space-time difference of the runoff and the tidal current control power is great.
- Estuarine ebb and flow are asynchronous, thus produce large-scale planar circulation.

3. Brief Introduction of Shenzhen-Zhongshan Bridge Project

The Shenzhen-Zhongshan Bridge project starts from the East artificial island on the east side of Shenzhen, goes through the Dachan channel, airport branch channel and Fanshi channel with 6,845m super-long tunnel. It sets up the West artificial island in the middle beach to realize the transformation of tunnel and bridge, and crosses the Lingding channel and Hengmen east channel with 1,660 and 580m large span bridges respectively, and ends at Zhongshan Ma’an Island in the west. Shenzhen Airport, Wanqingsha (reserved, adjacent to Nansha) and Hengmen are set up on the whole line and are interconnected, which contain various structural forms of bridges, islands and tunnels. The structure is complex, with a total length of about 24 km, and the length of crossing the Lingdingyang Estuary is about 22.4 km. The layout of the engineering scheme is shown in Figure 1.
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Figure 1. The Shenzhen-Zhongshan Bridge project scheme and the dynamic zoning scheme of the estuary where the project is located (unit: m, Yang et al., 2018)

4. Engineering scheme optimization and hydrodynamic impact analysis based on dynamic zoning

4.1 Dynamic zoning of Lingdingyang
The Shenzhen-Zhongshan Bridge project spans the entire bay crest of Lingdingyang Bay, with a river crossing route of 22.4km. In addition to the east and west main channel, it also cross the Dachan channel, airport branch channel, Longxue south channel and Hengmen east channel. In order to minimize the disturbance of engineering construction to the hydrodynamic environment of Lingdingyang, in the early stage of engineering construction, the route selection and structural optimization are mainly carried out centering on reducing the water-resistance ratio of engineering structures and reducing the angle between structures and the vertical line of water flow. In the demonstration of the hydrodynamic influence of the recommended scheme, the change of tidal level, flow pattern and tidal volume before and after the project construction is mainly calculated and analyzed.

However, if the whole project and the estuary section it crosses are demonstrated and analyzed as a whole without distinction, especially in the early optimization stage of the project, it is not only inefficient, but not well targeted, for three reasons: 1) Different entrances of the upstream of Lingdingyang bay bear different tasks of flood discharge and tide holding; 2) The dynamic environment and underwater topography of different waters in lingdingyang Estuary differ greatly; 3) Different types of structures in different engineering sections of Shenzhen-Zhongshan Bridge lead to significant differences in water-blocking effects. Aiming at this situation, the project is divided into a tidal channel area, 2 west discharge area (cross extension of the east side of Hengmen island and extension of Jiaomen) and a beach area (mainly west beach section) according to the different diameter tidal power of engineering waters (open sea tidal channel to the east and delta main discharge to the west), as shown in Figure 1. On the basis of the dynamic zoning, the project scheme optimization and hydrodynamic influence analysis of the scheme are carried out.

4.2 Optimization of Engineering Scheme Based on Dynamic Zoning
According to the results of the dynamic zoning of the water area of the project, the Shenzhen-Zhongshan Bridge project extends from east to west across the tidal channel area, the west flood discharge area 1, the shoal area and the west flood discharge area 2. The one and two-dimensional joint solution dynamic flow dynamic mathematical model is adopted to simulate each engineering design scheme under typical hydrological conditions and carry out targeted scheme optimization within each dynamic zone. The specific optimization process is as follows:
Inside the tidal channel: the length of the western artificial island is reduced from the original 700m to 625m. The side of the island bridge and the two anchorages are changed from the original ladder structure to vertical structure.

West flood discharge area 1: the span of non-navigation hole is changed from 70m to 110m; the downstream position is shifted to the south, and the pier angle is adjusted to reduce the angle between the pier and the water flow.

West flood discharge area 2: the main east span of Hengmen was changed from 480m to 580m, the shape of the piers was changed from double pier to single pier. The span of non-navigation hole and the spacing between the main span piers are changed from 70m to 110m.

Shoal area: the caps are buried in the riverbed, distance between the piers is changed from 50m to 70m.

After the above optimization, the effective water resistance ratio of the tidal channel area where the project is located has been controlled to less than 10%, and the engineering water resistance ratio of the west flood discharge area 1 and west flood discharge area 2 are about 4.90% and 4.95% respectively, which can basically guarantee the demand for flood discharge at the estuary.

4.3 Hydrodynamic Impact Analysis Based on Dynamic Zoning

Combined with the one and two-dimensional tidal current model of estuary and delta [4], the dynamic response of different dynamic characteristic areas to the engineering construction were discussed.

4.3.1 Influence on Tide Level

The scope of influence of the project construction on the tidal level is mainly located in the waters of Lingdingyang, east four entrances and part of its upstream netted waters. The upstream high water level is lowered, the low water level is raised, the tidal range is reduced, and the dynamics is weakened. The downstream high water level is raised, the lower water level is lowered, and the tidal range is slightly increased. The trend is contrary to the upstream, which is consistent with the conclusions of other scholars [3].

Taking the "2005.6" flood hydrological combination as an example, the change of tidal level in the upper and lower reaches of the entrance control station and the west artificial island is shown in Figure 2. In the control station of east four entrances, the tidal level variation of Dahu station was relatively large, ranging from -0.03 to 0.04m. The tidal range of the other three stations was basically below 0.03m. The tidal range of each station at the entrances decreased by 0.02~0.04m, and the range was higher in the east and lower in the west. The maximum change of tide level was around 0.06m, appearing in the upstream of the west artificial island, reflecting the main water-blocking effect of the west artificial island.

![Figure 2. Tidal changes in the main waters near the project (Yang et al., 2018, blue line: tidal level before the construction; purple line: tidal level after the construction; orange line: Tidal range (after-before))](image-url)
4.3.2 Effects on flow patterns

Within each dynamic zone, the impact of engineering scheme on water flow pattern is as follows:

Within the tidal channel: the western artificial island has the greatest influence on the flow pattern and tidal current environment. At both rising and falling tides, a reflux zone about 450~670m long and 300~650m wide would obviously form on the dorsal water side of the west artificial island. The partial flow of anchor and pier was weakened and the current was deflected. The flow potential in the main tank was enhanced and the flow direction had little change. The change of water flow pattern of the west artificial island at ebb tide is shown in Figure 3.

The west flood discharge area: the flow pattern variation mainly concentrated on the upper and lower waters of the piers. The flow potential in the main tank was enhanced under the action of diversion.

Shallow shoal area: the water was shallow, the flow current was weak, and the flow pattern was in disorder. Under the action of water resistance of the project, the ebb tide deflected to the south obviously, and the maximum deflection was about 30°; the south rising tide of the project is deflected to the northwest, showing an upward trend along the bridge line, the north side of the project is part of the tidal current into the northeast Jiaomen extension of the tidal current.

4.3.3 Effect on volume in flood discharge area and tidal channel area

Further comparing the changes of tidal volume in the flood discharge area and tidal channel area before and after the construction of the project, and making statistics of the changes of tidal volume in the sections near each dynamic zone, the data is shown in Table 1. It can be seen that since the main water-blocking structures such as the west artificial island and anchors are arranged in the tidal channel waters, at the ebb tide of flood, the tidal volume reduction in the tidal channel is the most obvious, and the impact of engineering construction is relatively concentrated in the tidal channel, which is also related to the incised Humen riverbed and the increase of the ratio of subdivided flood discharge in Humen river bed in recent years. During low water tide, due to the water-blocking effect of the west anchor at the downstream exit of Jiaomen, the relative tidal volume variation near the west flood discharge area 1 was the largest, followed by the tidal channel area.

On the whole, under the action of water resistance of the project, the tidal volume of the section of Lingdingyang where the project is located decreased, and its influence amplitude was lower in the west than in the east.

Figure 3. A comparative map of rapids in the waters around the west artificial island before and after the construction
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Table 1. Variation of tidal volumes within dynamic zones.

|                      | west flood discharge area 1 | west flood discharge area 2 | tidal channel area |
|----------------------|-----------------------------|----------------------------|-------------------|
| Ebb volume in flood discharge | -0.03%                      | -0.23%                     | -0.68%            |
| Flood volume in low flow         | -3.46%                      | -1.08%                     | -1.72%            |

5. Discussion
The east-west direction of the Shenzhen-Zhongshan Bridge Project crosses the top section of the Lingdingyang Estuary. In the demonstration and analysis of the impact of engineering construction on hydrodynamic environment, the strength difference of tidal dynamics along the project is the most prominent in the whole hydrodynamic environment. Therefore, in this study, the dynamic characteristics of tidal dynamics are mainly combined to implement dynamic zoning. As a matter of fact, estuary dynamics are complex with many influencing factors, and their outstanding dynamic characteristics are also different in different research areas with different objects. For example, at the top of the estuary, the wavy sand lifting in the large area at the west bank should be considered in the study of sediment transport. In the outlet waters of Modao Entrance of the Pearl River Estuary, the wave dynamics is more prominent than other waters because it faces the South China Sea.

On the other hand, human activities in the Pearl River Estuary are not only frequent but also multiform and diverse. In addition to the bridge engineering mentioned in this study, there are also port and wharf construction, channel excavation, shoreline regulation, and river sand mining, etc. Different types of human activities have different impacts on water dynamics, material transport, and long-term evolution. For example, compared with bridge engineering, the impact of port and wharf construction on hydrodynamics and material transport is more localized. Therefore, the basis of dynamic zoning is not unique, and it should be chosen flexibly according to the characteristics of water area and research objects.

6. Conclusion
The hydrodynamics of Lingdingyang Estuary are complex and human activities are frequent. How to rationally demonstrate the impact of major water-related projects is a hot issue in the protection and development of estuaries. Taking the Shenzhen-Zhongshan Bridge Project as an example, this paper divides it into different dynamic areas based on the difference of tidal dynamics in the water area of the project, and then carries out targeted scheme optimization and impact analysis to get the following conclusions:

- The dynamic zoning of engineering water area is actually a process to clarify the primary and secondary relations in complex dynamic environment based on demand. Based on the dynamic zoning, it is very effective to improve the optimization efficiency of engineering construction scheme.
- The development of dynamic zoning also helps to enhance the coherence of the impact demonstration of engineering construction plans, and to conduct a deep analysis of the water area of major concern.
- Among the four dynamic zones in the water area of the Shenzhen-Zhongshan Bridge Project, the impact of engineering construction on the hydrodynamic environment is mainly concentrated in the tidal channel area and the two west flood discharge areas, which is the largest in the tidal channel in the west artificial island, and the smallest in the shoal area. In the tidal channel and flood discharge area, the implementation of the project will cause the dynamics of ebb and flow to be further concentrated in the main channel, and the influence of the project construction on the hydrodynamic force is mainly concentrated in the waters near
the project line, which has little influence on the overall pattern of the beach and channel of Lingdingyang Estuary.

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