Study on projects of bending shoal-cutting regulation for tidal river

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Abstract: By taking bending shoal-cutting of Water Conservancy park in Lingjiang as a case, the change of flow pattern in the curved channel before and after the shoal-cutting project is analyzed by numerical simulation, and application effect is analyzed. By analyzing the tidal level data of the engineering reach, the appropriate barrier clearance elevation is determined. The relationship between water level variation and different range of shoal-cutting is established, and the suitable range of shoal-cutting is recommended. It has an important reference for the management of bend in tidal river.

1. Introduction

It is extremely disadvantageous for flood control because of water blocking of bend shoal and concave bank scouring[1-2]. The method of retreating dike and shoal-cutting is commonly used in expand flood carrying capacity of river [3-5]. Generally, after shoal-cutting, the depth of the bend is increased, and the cross-section of the bend is enlarged. The sharp bend effect has been effectively improved to reduce the flood control risk of concave bank, and the "bottleneck" problem of flood discharge has been solved, the flood control benefit is obvious. Due to the limitation of upstream and downstream river conditions, It is not that the larger the range of shoal-cutting is, the better. The proper range and elevation of shoal-cutting can reduce the sediment siltation and maximize the benefits of shoal-cutting.

2. Summary

Jiaolong River is the largest river in Taizhou, which is the third-largest river system in Zhejiang Province, the river length is 209km. Lingjiang River starts from Sanjiang village in Linhai City, goes down to Sanjiangkou in Huangyan district, and then flows into Jiaolong River after merging with Yongning river. Lingjiang River is a tidal river, the length is 46km, and the area is 1054.4km², the natural drop is 1.6m and the average slop is 0.04‰. The riverbed gradually widens from upstream to downstream, with the width of 200-1400m.

In 2019, the super typhoon "Lekima" landed in Taizhou, and a historic flood occurred in Jiaolong River basin, which caused great pressure on water conservancy and flood control facilities in Linhai City. The length of river between Linhai Ximen and Datiangang is about 8.2km, the water level drop is 4.05m, and the average hydraulic gradient is 0.5‰. The Water Conservancy park is located in the tidal reach, and the river channel is narrow with sharp bend. In addition, bridges, mountains and reefs have serious water resistance, and the river resistance is significantly greater than that of the upstream and downstream reaches. Therefore, shoal-cutting regulation project is implemented.

Based on the analysis of measured hydrological and topographic data and 2D numerical simulation,
the scheme of shoal-cutting is determined. First of all, through the analysis of the tide level data of the engineering reach over the years, the barrier clearance elevation is determined, and 2D numerical simulation model is established to simulate and verify the flood routing of super typhoon "Lekima". This paper focuses on solving the problem of flood plain flow generalization, analyzes the flow pattern change of bend in different shoal-cutting schemes, and determines the shoal-cutting scheme from the flow pattern change, river regime stability and flood control benefits.

3. Research method

3.1 Model introduction

The 2D numerical simulation model adopts the finite volume model based on triangular mesh. The model has the advantages of flexible grid layout, convenient local encryption and strong applicability. It has been successfully applied to the reclamation and flood control and drainage engineering research and has achieved some results.

\[
\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = 0
\]

\[
\frac{\partial hu}{\partial x} + \frac{\partial}{\partial x} \left( hu^2 + \frac{1}{2} gh^2 \right) + \frac{\partial}{\partial y} (huv) = -gh \left( \frac{\partial z}{\partial x} + u \frac{\partial u}{\partial x} + \frac{v^2}{C_f h} \right) + fhu + W_x + \frac{\partial}{\partial y} \left( he, \frac{\partial u}{\partial y} \right) + \frac{\partial}{\partial y} \left( he, \frac{\partial u}{\partial y} \right)
\]

\[
\frac{\partial hv}{\partial x} + \frac{\partial}{\partial x} \left( hv^2 + \frac{1}{2} gh^2 \right) + \frac{\partial}{\partial y} (huv) = -gh \left( \frac{\partial z}{\partial x} + u \frac{\partial u}{\partial x} + \frac{v^2}{C_f h} \right) + fhu + W_y + \frac{\partial}{\partial y} \left( he, \frac{\partial v}{\partial x} \right) + \frac{\partial}{\partial y} \left( he, \frac{\partial v}{\partial y} \right)
\]

Where \( Z_0 \) is river bed elevation (m); \( u, v \) are mean velocity in vertical in x and y directions (m/s); \( h \) is water depth (m); \( g \) is gravity acceleration, 9.81m²/s; \( f \) is Coriolis force parameter \( (f=2\omega \sin \phi, \phi \) is latitude, and \( \omega \) is earth rotation speed \); \( C_f \) is Xie Cai coefficient, and \( n \) is roughness coefficient; \( \varepsilon_x, \varepsilon_y \) are eddy diffusion coefficients in X and Y directions respectively; \( W_x, W_y \) are wind stress components in X and Y directions; X and y are rectangular coordinates; \( t \) is time.

3.2 Modeling

The total length of the model is about 58km. The upper boundary is located in Sanjiang village of Lingjiang River and the lower boundary is set in Haimen. Shoal and houses are considered in the model generalization, as shown in Figure 2. The measured topographic data in 2016 is used for the model. The upper boundary adopts the flow boundary, and the downstream adopts the tidal level boundary control. The time step of the model is \( \Delta t = 6s \). The calculated regional roughness is affected by many factors, which is a very important parameter in numerical calculation. It is related to water depth, bed shape and other factors. After debugging, the roughness of main channel is \( n=0.009 \sim 0.032 \), and that of shoal is 0.05.
3.3 Model validation

The measured data of typhoon "Lekima" in 2019 is selected. The verification results are shown in Table 1. The water level errors are all within 0.15m, and the accuracy meets the requirements.

| Point               | Measurement | Numerical simulation | Difference |
|---------------------|-------------|----------------------|------------|
| Chaotianmen         | 10.85       | 10.93                | 0.08       |
| Xingshanmen         | 9.48        | 9.51                 | 0.03       |
| Lingjiang No.1 Bridge | 9.33       | 9.46                 | 0.13       |
| Linhai Bridge       | 8.8         | 8.7                  | -0.10      |
| Lingjiang No.2 Bridge | 7.68       | 7.64                 | -0.04      |
| Datiangang          | 6.69        | 6.75                 | 0.06       |
| Miaolonggang        | 6.1         | 6.15                 | 0.05       |

4. Analysis of shoal-cutting schemes

In addition to the effect of different shoal-cutting range, the sediment deposition caused by the tide after shoal-cutting should be considered in the bend shoal-cutting of tidal river. Therefore, it is very important to determine the barrier clearance elevation within the range of shoal-cutting to improve the benefits of shoal-cutting.

4.1 Analysis on water level of Engineering reach

In order to analyze the barrier clearance elevation, the high tide level of Ximen hydrological station near the project river section from 1991 to 2018 is statistically analyzed. The high tide level of each frequency is shown in Table 2.

| Frequency | 1% | 2% | 5%  | 10% |
|-----------|----|----|-----|-----|
| Water level | 4.6 | 4.5 | 4.3 | 4.1 |

It shows that 99% of water level of Ximen hydrological station is within 4.6m, 98% of water level is within 4.5m, 95% of water level is is within 4.3m, and 90% water level is within 4.1m.
The water level difference between Water Conservancy park and Ximen hydrological station is about 20cm in case of spring tide. Therefore, it is considered that 98% of water level in the Water Conservancy park is within 4.3m, and there is no sediment deposition above this elevation. This elevation can be used as the barrier clearance elevation for the Water Conservancy park.

4.2 Scheme arrangement

Four shoal-cutting schemes of Water Conservancy park are considered, including full cutting scheme, 2/3 cutting scheme, 1/2 cutting scheme and 1/3 cutting scheme. The length of full shoal-cutting scheme is about 1.6km, starts at about 230m away from Linhai bridge and ends at Baita park. The elevation of shoal-cutting is -1m. The layout of different shoal-cutting schemes is shown in Figure 3.

4.3 Analysis of the effect of shoal-cutting

(1) Flow field analysis

The flow field under the condition of small discharge (flood flow 5000m³/s encountering the average tide level of the Haimen) is selected for analysis, and the rationality of shoal-cutting schemes is analyzed. Figure 4 ~ figure 8 show the distribution of river flow field.

![Figure 3. Scheme arrangement](image3)

![Figure 4. Distribution of current river flow field](image4)

![Figure 5. River flow field distribution of full shoal-cutting scheme](image5)

![Figure 6. River flow field distribution of 2/3 shoal-cutting scheme](image6)
The flow field distribution shows that, under the current river condition, the Water Conservancy park is at the bend, the deep groove is located on the right bank, the flow direction is basically parallel to both shorelines. With the continuous expansion of shoal-cutting, the downstream flow of Linhai bridge gradually deviates to the left, and the velocity on the opposite side gradually decreases. For the full shoal-cutting scheme, the main stream area is concentrated on the left bank. The cross-sectional velocity is larger on the left bank and smaller on the right bank. The velocity is less than 0.5m/s within 120m from the opposite bank, and there is a typical recirculation region and the length is about 300m, which makes the river regime change greatly and easy to cause siltation. For the 1/2 shoal-cutting scheme, although the range of shoal-cutting is small, the flow conforms to the river regime in good condition.

(2) Analysis of flood level

In order to analyze the effect of shoal-cutting, the flood level along the river is calculated under the condition that the upstream flood discharge is 13600m³/s and encountering the average tidal level of Haimen. The results are shown in Table 3.

| scheme             | Ximen | Wangjiangmen | Zhenningmen | The No.1 Lingjiang bridge | Linhai bridge |
|--------------------|-------|--------------|-------------|---------------------------|--------------|
| 1/3 shoal-cutting  | -0.17 | -0.18        | -0.24       | -0.25                     | -0.28        |
| 1/2 shoal-cutting  | -0.23 | -0.24        | -0.32       | -0.34                     | -0.38        |
| 2/3 shoal-cutting  | -0.24 | -0.26        | -0.35       | -0.37                     | -0.42        |
| Full shoal-cutting | -0.26 | -0.28        | -0.39       | -0.41                     | -0.45        |

For the full shoal-cutting scheme, the water level from Ximen to Linhai bridge reduces by 0.26 ~ 0.45m, and reduces obviously near the Water Conservancy park; for the 2/3 shoal-cutting scheme, the water level at Ximen reduces by 0.24m, and 0.42m at Linhai bridge. for the 1/2 shoal-cutting scheme, the water level at Ximen reduces by 0.23m, and 0.38m at Linhai bridge, the effect is nearly 90% of full shoal-cutting scheme; the water level at Ximen is reduced by 0.17m and 0.28m at Linhai bridge under the 1/3 shoal-cutting scheme. It shows that, the “bottleneck” effect of the river near the Water Conservancy park is gradually reduced with the continuous expansion of the shoal-cutting area, and the section of Linhai bridge gradually becomes new bottleneck.
5. Conclusion
The project is located in the upstream of Jiaojiang River, which is affected by tide, the hydrodynamic condition is complex. Based on the statistical analysis of the high tide level over the years, the barrier clearance elevation is determined as 4.3m. It is not that the larger the range of shoal-cutting is, the better. For the 1/2 shoal-cutting scheme, although the range of shoal-cutting is reduced, the flow conforms to the river regime in good condition, and the flood control benefit reaches nearly 90% of the full shoal-cutting scheme, the effect of shoal-cutting is obvious.

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